OP 2230

SECOND REVISION

WORKMANSHIP AND DESIGN PRACTICES FOR ELECTRONIC EQUIPMENT

This publication supersedes OP 2230 (First Revision) dated 22 April 1959.

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FOREWORD

Ordnance Pamphlet 2230 has been prepared as a guide for the design and construction of military electrical and electronic equipment. Information contained herein should not be construed as a specification, but as a guide in designing for reliable performance and ease of manufacture, inspection, operation, maintenance, and repair of equipments.

This publication is intended primarily for engineers and technicians who must translate circuit designs or breadboard models into a product design, and those who must manufacture or inspect the final products in accordance with the applicable detail performance specifications.

Because of the great variety of electronic equipments and the many factors which influence individual design considerations, only recommended basic practices of general application are included.

Comments for the improvement of this publication are invited. Recommended additions, corrections, or deletions should be addressed to the Bureau of Naval Weapons, RREN-4, Department of the Navy, Washington 25, D.C.

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Chapter I

PERSONNEL PROTECTION

1.0 GENERAL

Design of any equipment must embody features to protect personnel from electrical and mechanical hazards; also, from those dangers which may arise from fire, elevated operating temperatures, and toxic fumes.

There are various methods of incorporating adequate safeguards for personnel, many of these methods being implicit in routine design procedures. However, certain procedures, design practices, and related information are of such importance as to warrant special attention.

1.1 DESIGN OBJECTIVES

In the design, attention must be given to the protection of both operating and maintenance personnel. Personnel aboard ship are frequently required to operate and maintain equipment on an inherently unstable deck.

Operating personnel must not be exposed to any mechanical or electrical hazards, nor should operation of the equipment necessitate any unusual precautions; in particular, all parts accessible during normal operations should be reliably grounded.

Maximum safeguards must be provided inside the equipment to protect maintenance personnel working on energized circuits.

1.1.1 Operating Personnel

Operating personnel must be safeguarded from dangerous voltages, excessive temperatures, and mechanical hazards which may cause physical injury during either normal operation or malfunctioning of the equipment.

Design must minimize the possibility of operator's clothing becoming caught or entangled in the equipment. Handles and knobs should be so arranged that clothing will not catch; corners should be rounded; and potentials greater than 70 volts must be physically shielded or removed by the action of interlock switches.

Some of these precautions are particularly important. In military service it may become necessary for the operator to rapidly manipulate or abandon the equipment. There is also the ever-present possibility that despite safety regulations, operating personnel may attempt to service equipment in a non-approved manner.

1.1.2 Maintenance Personnel

Safeguarding the maintenance man is more difficult; tests and repairs must often be made with much of the apparatus exposed. It may be necessary to short out interlock switches and to remove covers which shield high voltages or moving machinery.

Every effort should be made in the design to protect maintenance personnel against contact with dangerous voltages in unexpected places. Controls for adjustment and points of access for lubrication should be located away from high voltage and moving parts. Danger signs imprinted next to dangerous parts or on protective covers should be used to alert maintenance personnel.

1.2 ELECTRIC SHOCK

Potentials exceeding 70 volts are considered to be possible electric shock hazards. Research reveals that most deaths result from contact with the relatively low potentials ranging from 70 to 500 volts, although under extraordinary circumstances, even lower potentials can cause injury.

Many severe injuries are caused not by electric shock directly, but by the reflex action and consequent body impact with nearby objects.

Some contact with electric potentials can be expected where maintenance personnel are by the very nature of their duties exposed to live terminals. Both shocks and burns, however, can be minimized by greater care in design, and by a better understanding of electrical characteristics.

Three factors determine the severity of electric shock: (1) Quantity of current flowing through the body: (2) Path of current through the body, and (3) Duration of time current flows through the body.

The most important variable is current. Amperage depends not only on voltage, but also on resistance of the circuit through the body, which in turn depends on whether points of contact are wet or dry. In cases on record, potentials below 10 volts have proved fatal when points of contact have pierced the skin.

Sufficient current passing through any part of the body will cause severe burns and hemorrhages. However, relatively small currents can cause death if the path includes the heart or lungs. Electric burns are usually of two types, those produced by heat of the arc which occurs when the body touches a high-voltage circuit, and those caused by passage of electric current through skin and tissue.

1.3 PREVENTION OF ELECTRIC SHOCK

1.3.1 Warnings

Warning signs marked "CAUTION-HIGH VOLTAGE," or "CAUTION ____ VOLTS," should be placed in prominent positions on safety covers, access doors, and inside equipment wherever danger may be encountered. These signs should be so durable, easily read and so placed that dust or other foreign deposits will not in time obscure the warnings. However, since signs are not physical barriers, they should be relied upon only if no other method of protection is feasible.

1.3.2 Fusing

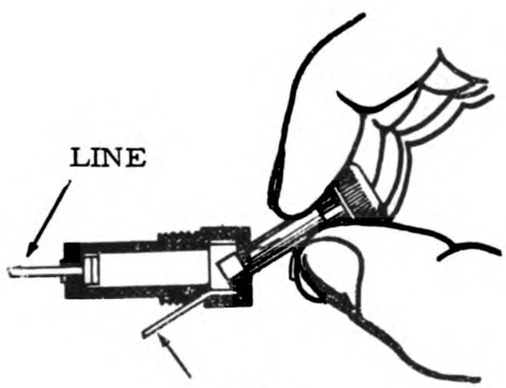
All leads from the primary service lines should be protected by fuses. Fusing of circuits should be such that rupture or removal of a fuse will not cause

Current Values (Milliamperes)	Effects
0 - 1	Perception
1 - 4	Surprise
4 - 21	Reflex action
21 - 40	Muscular inhibition
40 - up	Respiratory block

PROBABLE EFFECTS OF SHOCK

malfunction or damage to other elements in the circuit.

Fuses should be connected to the load side of the main power switch. Holders for branch-line fuses should be such that when correctly wired, fuses can be changed without the hazard of accidental shock. At least one of the fuse-holder connections should be normally inaccessible to bodily contact, and this terminal should be connected to the supply; the accessible terminal should be connected to the load. The following illustration shows the correct manner of wiring the instrument type of fuse holder to prevent accidental contact with the energized terminal.



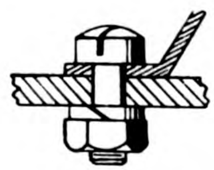
FUZE HOLDER WIRING

Provisions for storage of spare fuses should be made at an accessible location.

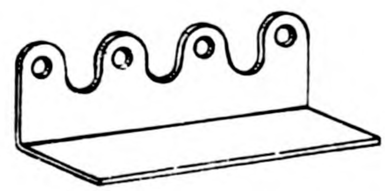
1.3.3 Grounding

Various grounding techniques are used to protect personnel from dangerous voltages in equipment. All enclosures, exposed parts, and chassis should be maintained at ground potential.

Specifications for the reduction of electrical noise interference should be consulted to determine the maximum permissible resistance of a grounding system. Reliable grounding systems should be incorporated in all electronic equipment. Enclosures and chassis should not be used as electric conductors to complete a circuit because of possible inter-circuit interference.



BOLTED LUG

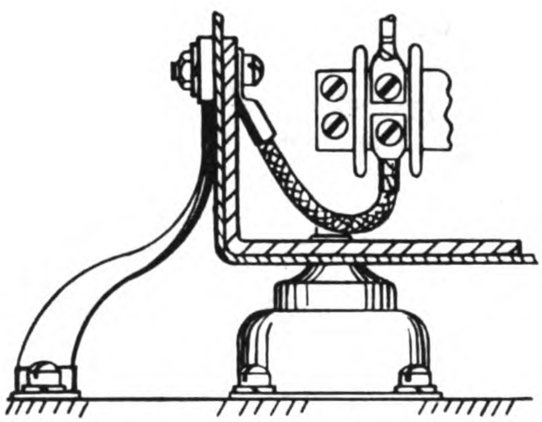


SPOT WELDED LUG

A terminal spot welded to the chassis provides a reliable ground connector. For aluminum chassis where welding is not feasible, a terminal properly secured by a machine screw, lockwasher, and nut is satisfactory.

A grounding lug should not be included as part of a "pile-up" that includes any material subject to cold-flow. The machine screw used should be of sufficient size so that eventual relaxation will not result in a poor connection. A lockwasher is necessary to maintain a secure connection. All nonconductive finishes of the contacting surfaces should be removed prior to inserting the screw. In no event should riveted elements be used for grounding since these cannot be depended upon for reliable electrical connections.

The common ground of each chassis should connect to a through-bolt, mounted on the enclosure and clearly marked "ENCLOSURE GROUND," which in turn should connect to an external, safety ground strap.



CABINET GROUNDING SYSTEM

For best design, the external ground conductor should be fabricated from suitably plated, flexible copper strap, capable of carrying at least twice the current required for the equipment.

Electronic test equipment must be furnished with a grounding pigtail at the end of the line cord. Signal generators, vacuum tube voltmeters, amplifiers, oscilloscopes, and tube testers are among the devices so equipped. These leads are to be used for safety grounding purposes. Thus, in the event that a fault inside the portable instrument should connect a dangerous voltage to the metal housing, the dangerous current is bypassed to ground without endangering the operator.

The power supply lines aboard ship are not grounded. For such purposes as reducing of interference, these leads may be bypassed through capacitors to ground, but the total current, including leakage, which the capacitor is likely to permit, must not exceed 5 milliamperes.

1.3.4 Power Lines

Designers are often inclined to confine their safety considerations to high-voltage apparatus. However, it is important that considerable attention be devoted to the hazards of power lines. Fires, severe shocks, and serious burns are known to result from personnel contacting, short-circuiting, or grounding the incoming lines.

1.3.5 Main Power Switch

Each equipment should be furnished with a clearly labeled main power switch which will remove all power from the equipment by opening all leads from the primary power service connections.

Main power switches should be equipped with safety devices that afford protection against possible heavy arcing. Barriers which shield fuses and conducting metal parts, and devices that prevent opening the switch box with the switch closed, should be provided as protection for personnel. Switches incorporating such safeguards are standardized, commercially obtainable equipment.

1.3.6 Panel-Mounted Parts

Panel-mounted parts, especially jacks, are occasionally employed in power circuits for the insertion of meters, output lines, test apparatus, and other supplementary equipment. Such items should be connected to the grounded leg of the monitored circuit, rather than in the ungrounded, high-voltage line.

VOLTAGE RANGE	SUITABLE PROTECTIVE MEASURES
70 - 350 volts	Interlocks alone
350 - 500 volts	Barriers and interlocks
- 500 volts and up	Enclosures, warnings, and interlocks

1.3.7 Parts Safety

Electric parts and circuits should be designed to minimize arcing in switches, relays, and other make-or-break apparatus. Fast-action switches are usually employed. Switches used in dc circuits employ magnetic arc blowouts and capacitors across the contacts.

Only explosion-proof switching devices should be employed where there is any possibility that equipment will be operated in an atmosphere of explosive gas or vapor. The design of explosion-proof equipment is covered by military specifications.

Protective devices should be incorporated in the design for all parts carrying hazardous voltages. Wherever possible, such components should be mounted beneath the chassis. Ventilation requirements must always be considered.

When it is impracticable to mount parts below the chassis and thus reduce the hazard to maintenance personnel when replacing above-chassis parts, protective housings having ventilating holes or louvers should be provided. If housings cannot be used, exposed terminals of the parts should be oriented away from the direction of easy contact. These expedients lessen the possibility of accidental shock and arcing.

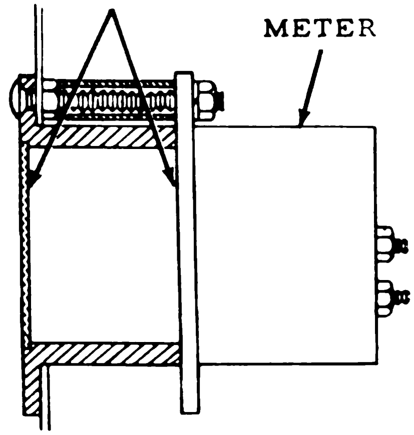
1.3.8 Shields and Guards

Safety enclosure covers should be anchored by means of screws or screwdriver-operated locks and should be plainly marked by warnings.

Hinged covers, doors, and withdrawable chassis should be counter-balanced or provided with other means to retain them in their open position, thus preventing accidental closing due to ship movement.

Terminal boards carrying hazardous voltages above 500 volts should be protected by means of a cover provided with holes for the insertion of test probes. Terminal numbers should be plainly marked on the external side of the cover. With this arrangement, it is possible to check circuits that are energized.

High-voltage meters should be recessed and two shatter-proof windows used.



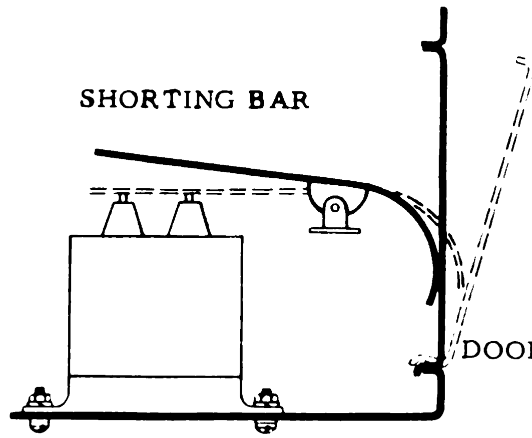
HIGH VOLTAGE PANEL METER

Housings, cabinets, or covers may require perforations to provide air circulation. The area of a perforation should be limited to that of a 1/2-inch square or round hole. High-voltage components within should be set back far enough to prevent accidental contact. If this cannot be done, the size of the openings should be reduced.

Where access to rotating or oscillating parts is required for servicing, it may be desirable to equip the protective covers or housings with safety switches or interlocks.

1.3.9 Discharging Devices

Since high-grade filter capacitors can store lethal charges over relatively long periods of time, adequate discharging devices must be incorporated in all medium- and high-voltage power supplies. Such devices should be used wherever the time constant of capacitors and associated circuitry exceeds 5 seconds; they should be positive acting, reliable, and should be automatically actuated whenever the enclosure is opened.



SHORTING BAR ACTUATION

Shorting bars should be actuated either by mechanical release or by an electrical solenoid when the cover is opened.

Good insurance is provided by the automatic charge-draining action of a bleeder resistor, permanently connected across the output terminals of a dc power supply. Although bleeder current is an added load on the power supply, the system should be designed to carry this slightly additional load. Bleeder resistance should be the lowest value, without presenting excessive loading, through which the capacitors can discharge quickly after the power is switched off.

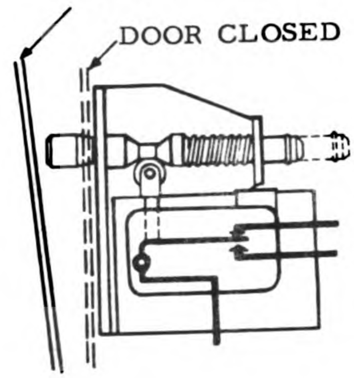
However, in circuits where large high-voltage capacitors must be operated without adequate bleeding; as in high-voltage radar apparatus, capacitors must be discharged by automatic devices as described previously. For high-voltage capacitors, discharging devices should be equipped with large resistors rated at 200 watts, 10,000 ohms, to limit discharge current and the possibility of damage.

1.3.10 Interlocks

Interlock switches are used to remove power during maintenance and repair operations. Each cover and door providing access to potentials greater than 70 volts should be equipped with interlocks. Some interlock systems function also to ground capacitors, as described in 1.3.9, when the enclosure is opened.

An interlock switch is ordinarily wired in series with one of the primary service leads to the power supply unit. It is usually actuated by the movable access cover; thus breaking the circuit when the enclosure is entered. Where more than one interlock switch is used, they are wired in series. Thus, one switch may be installed on the access door of an operating subassembly; another, on the dust cover of the power supply.

The selection of a type of interlock switch must be based upon its reliable operation. The so-called self-aligning switch appears most reliable, but in actual usage the type shown, although it contains moving parts, has proven most satisfactory.



DOOR INTERLOCK SWITCH

Since electronic equipment must often be serviced with the power on, a switch enabling maintenance personnel to bypass the interlock system should be mounted inside the equipment. The switch should be so located that reclosing of the access door or cover automatically restores interlock protection. Also to be provided are a panel-mounted visual indicator, such as a neon lamp, and a suitable nameplate to warn personnel when interlock protection is removed.

A "Battle-Short" switch or terminals for connection of an external switch should also be provided to render all interlocks inoperative. It differs from the switch used to bypass the interlock system for maintenance purposes in that the panel-mounted or remotely controlled "Battle-Short" switch is designated for emergency use only. The circuit consists of a single switch, wired in parallel with the interlock system. Closing the "Battle-Short" switch places a short circuit across all interlock switches, thus assuring incoming power regardless of accidental opening of interlock switches.

1.4 MECHANICAL AND OTHER HAZARDS

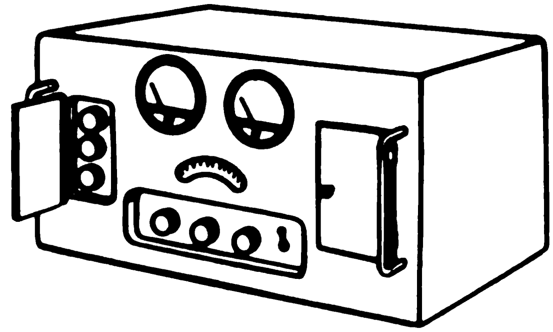
To minimize the possibility of physical injury, all enclosure edges and corners should be rounded to maximum practical radii. This is especially important for front-top edges, front-side edges, and enclosure, door, and panel corners.

Thin edges should be avoided and chassis construction should be such that the chassis may be carried without danger of cutting the hands on the edges.

To prevent hazardous protrusions on panel surfaces, flathead screws should be used wherever sufficient panel thickness is available; otherwise, panhead screws should be used.

All accessible surfaces should be smooth. Surfaces that cannot be reasonably machined to a smooth finish should be covered or coated to prevent the possibility of skin abrasion. Small projections, in areas where the rapid removal of plug-in units may cause injury to the hands, must not be left uncovered.

Recessed mountings are recommended for small projecting parts such as toggle switches and small knobs located on front panels.



RECESSED CONTROLS

Care should be taken when designing equipment to prevent personnel from accidentally contacting rotating or oscillating parts such as gears, couplings, levers, cams, latches, or heavy solenoid equipment. Moving parts should be enclosed or shielded by protective guards wherever possible. Where such protection is not possible, warning signs must be furnished.

The cathode-ray tube is a special hazard in view of the high voltages that must be applied and the physical damage that may result from implosion. If the tube is accidentally nicked or scratched, resultant implosion may not occur until days later.

The face of such a tube must be safeguarded by a shatterproof glass or heavy plastic shield firmly attached to the panel. Signs warning personnel that the neck of the tube is easily broken and must be handled with caution should be posted inside the equipment.

In their normal installed positions, chassis should be securely retained in enclosures. Stops should be provided on chassis slides to prevent inadvertent removal. Provision for firmly holding the chassis handles while releasing the equipment from the cabinet should also be incorporated. In the tilt-up position, a secure latch should support the equipment firmly despite conditions of shock, vibration, or inclination.

Suitable handles or similar provisions should be furnished for removing chassis from enclosures. Bails or other suitable means should be provided to protect parts when the chassis is removed and inverted for servicing. These serve also to protect the hands as the chassis is placed on the service bench.

Where access is provided to rotating, oscillating, or any other hazardous mechanisms, the cover or apparatus should bear a warning such as:

CAUTION - KEEP CLEAR OF
ROTATING PARTS

All reasonable precautions should be taken to minimize fire, high temperature, and toxic hazards. In particular, any capacitors, inductors, or motors involving fire hazards should be enclosed by a noncombustible material having minimum openings. As stated previously, elevated operating temperatures, and ventilation requirements are primary considerations in personnel protection. Since many equipments are installed in confined spaces, materials that may produce toxic fumes must not be employed. Finished equipment should be carefully checked for verification of protective features in the design.

Chapter 2

OPERATION AND MAINTENANCE

2.0 GENERAL

Equipment for military use must be designed to facilitate operation and maintenance, and thus decrease "down-time" and minimize over-all manpower and training costs. Realistically designed operating features simplify control of the equipment, and well-planned maintenance features permit faults to be rapidly located and defective parts to be easily repaired or replaced.

2.1 OPERATIONAL FEATURES

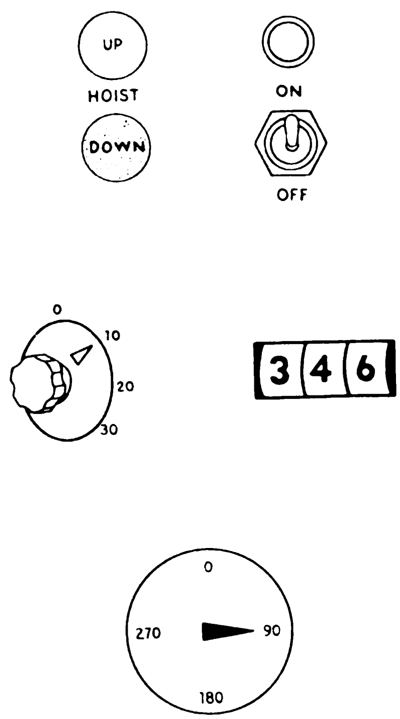
The following general recommendations are presented as an aid in the selection of operational devices. Specific applications sometimes require exceptions to these rules, however, and it may be wise to consult the human-engineering specialist when in doubt.

2.1.1 Visual Indicators

For a few discrete conditions (qualitative), use an indicator which presents large differences in position, brightness or color. The use of two or more variables is recommended, such as color and position, as in the traffic light.

For precise numerical values (quantitative) with no need for interpolation between numbers or for rate or directional information, use a counter. A scale indicator, however, is more efficient when such values are to be "set into" the equipment.

For numerical value plus orientation (check reading) in time, space, magnitude, or rate, use a scalar type of indicator. Avoid multiple pointers on a single pivot when possible. One pointer plus and adjacent counter is best when scale expansion is necessary.



VISUAL INDICATORS

Once the type of indicator has been chosen, and the amount and accuracy of the information to be displayed have been determined, then it is necessary to consider the factors which contribute to the legibility of the indicator. The size of detail, form of numerals and pointers, and illumination all affect the efficiency with which an operator uses the visual display.

CHECKLIST FOR A GOOD INDICTTOR

CAN THE INSTRUMENT BE READ QUICKLY IN THE MANNER REQUIRED (THAT IS, QUANTITATIVE, QUALITATIVE, OR CHECK READING)?

CAN THE INSTRUMENT BE READ ACCURATELY WITHIN THE NEEDS OF THE OPERATOR (PREFERABLY NO MORE ACCURATELY)?

IS THE INSTRUMENT DESIGN FREE OF FEATURES WHICH MIGHT PRODUCE AMBIGUITY OR INVITE GROSS READING ERRORS?

ARE THE CHANGES IN INDICATION EASY TO CHECK?

IS THE INFORMATION PRESENTED IN THE MOST MEANINGFUL FORM REQUIRING THE MINIMUM OF MENTAL TRANSLATION TO OTHER UNITS?

IS THE RELATIONSHIP OF THE REQUIRED CONTROL MOVEMENTS NATURAL TO THE EXPECTED INSTRUMENT MOVEMENT?

IS THE INFORMATION PERTINENT WITH RELATION TO THE NEED?

IS THE INSTRUMENT DISTINGUISHABLE FROM OTHER INSTRUMENTS?

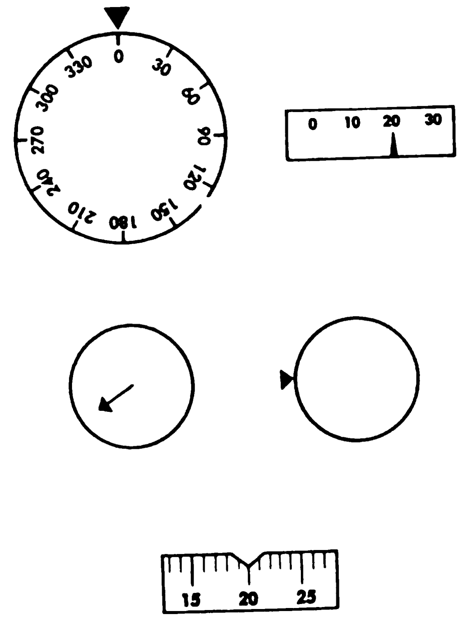
WILL THE OPERATOR BE AWARE OF AN INOPERATIVE CONDITION?

IS ILLUMINATION SATISFACTORY UNDER ALL CONDITIONS OF EXPECTED OPERATION?

2.1.1.1 Scalar Indicators. Dials and scales provide qualitative as well as quantitative information. Dials provide greater scale length in less space than straight-line scales. The straight-line scale, however, is not as apt to confuse the observer as to the direction of numerical increase.

Moving pointers with fixed scales are generally preferred to fixed-pointer and moving-scale design for both dial and straight-line scales. The fixed-pointer type, however, may be used satisfactorily for setting-in operations such as match the pointer operations.

An open window with fixed pointer is slightly better than an entirely exposed scale when reading accuracy alone is the criterion of choice.



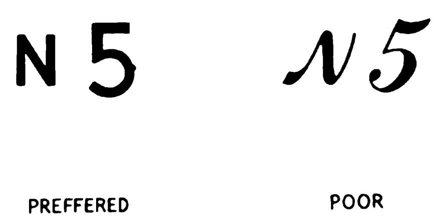
SCALAR INDICATORS

2.1.1.2 Design of Numerals, Letters, and Graduations. In general, the larger the size of letters and numerals the less we have to worry about background and illumination.

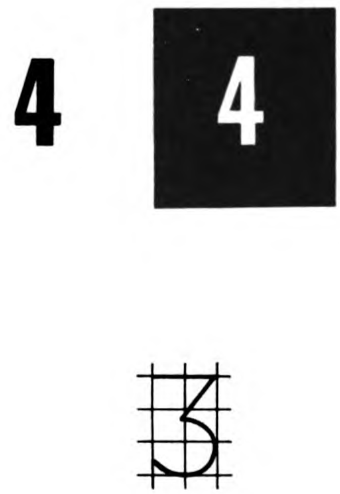
Capital letters are recommended for most panel labels although upper- and lower-case letters are suggested for extended instructional material.

All labels should be normally oriented so that they can be read from left to right. Special cases of vertical orientation are permissible when the label is generally ignored and confusion might arise if it were adjacent to more critical labels.

For panel use, the design of letters and numerals should be without flourishes. Such details are confusing, especially under threshold illumination conditions. The critical details of the figures should be simple but prominent. Diagonal portions of the characters should be as near 45 degrees as possible and such characteristic features as openings and breaks should be readily apparent.



PANEL LABEL DESIGN



LETTERING TECHNIQUES

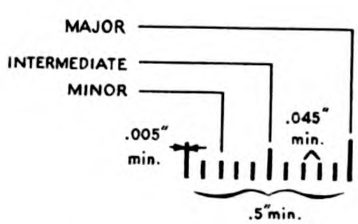
The stroke width of black characters on white background should be about one-sixth of the character height. Stroke width of white figures on black background should be about one-seventh to one-eighth of the character height; the narrower stroke is necessary since the light figure tends to spread or irradiate.

The height-to-width ratio of the normal character should be about three to two. Although there are exceptions to this rule, a close approximation to this ratio is recommended, especially for panel and scale design.

CHARACTER HEIGHT FOR GENERAL DIAL AND PANEL DESIGN

VIEWING DISTANCE (feet)	CHARACTER HEIGHT (inches)
2/3 or less	0.09
2/3 to 3	0.17

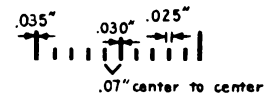
Minimum space between characters, one stroke width; between words, one character width.



SCALE GRADUATIONS

Scale graduations should be limited in number by the accuracy required. Furthermore the smallest readable division should never be finer than the probable error in the metering apparatus. A minimum of 0.5 inch is recommended for the distance between "major" graduations. These figures are for the normal reading distances, 13 to 28 inches. The minimum graduation dimension shown in the illustration is for 28-inch viewing distance.

The number of graduation marks between numbered points should not exceed nine. Optimum dimensions on a dial are shown.



SCALE MARK DIMENSIONS

For ease in reading, figures should be oriented according to the type of scale or dial used.

Orient figures vertically on dials which have a fixed scale and moving pointer.

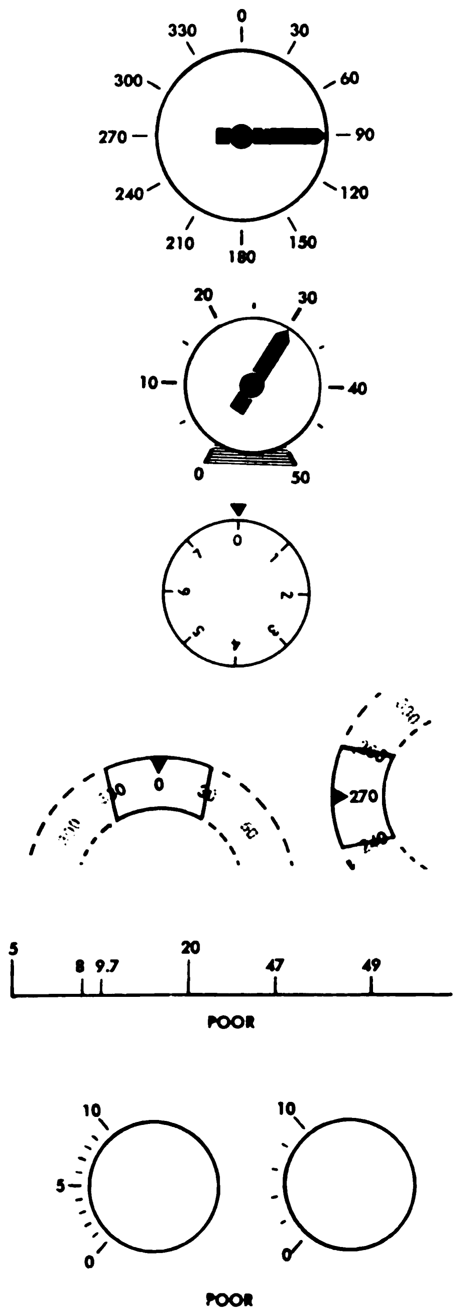
When the scale is of finite length, there should be a scale break between the end and the beginning of the scale. The break should be equal to a major scale division.

Orient figures radially on dials which have a fixed pointer and moving scale. When possible, orient the index at the 12-o'clock position.

When the figures of a dial move past an open window, they should be oriented so that they appear vertically at the window opening. Two or more figures should appear in the window simultaneously.

Numbers should appear to increase in a clockwise direction, left to right, or bottom to top. Avoid the use of irregular scales whenever possible. Some machine and slide-rule type scales are considered as exceptions to this rule.

When two or more similar scales appear on the same panel, they should have compatible numerical progression and scale organization.



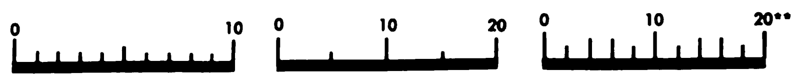
INDICATOR SCALE DESIGN

RECOMMENDED NUMERICAL PROGRESSION

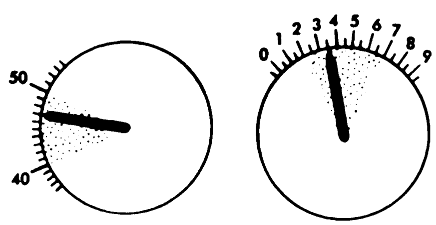
GOOD					FAIR					POOR			
1	2	3	4	5	2	4	6	8	10	3	6	9	12*
5	10	15	20	25	20	40	60	80	100	4	8	12	16
10	20	30	40	50						2.5	4	5	7.5

* Except for bearing dials where cardinal directions are standard orienting points or where operating doctrine specifies conditions of time scales, or turn rates.

RECOMMENDED SCALE BREAKDOWN

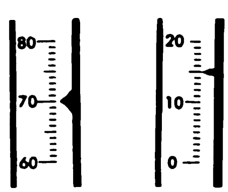


** Studies of this design showed less variability in time when setting-in than did usual dial markings.



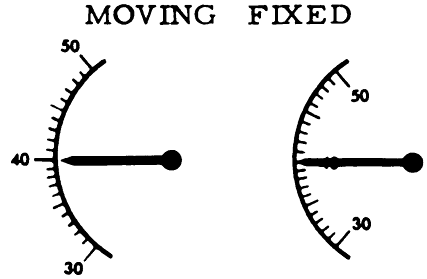
SCALE ORIENTATION

Whenever possible, orient a dial scale so that the critical range to be read will appear as left to right or bottom to top, to avoid confusion as to direction of increase. This is especially important for check-reading instruments. For multirevolution dials, orient zero at the 12-o'clock position.



MOVING FIXED

MOVING FIXED



POINTER AND SCALE RELATIONSHIP

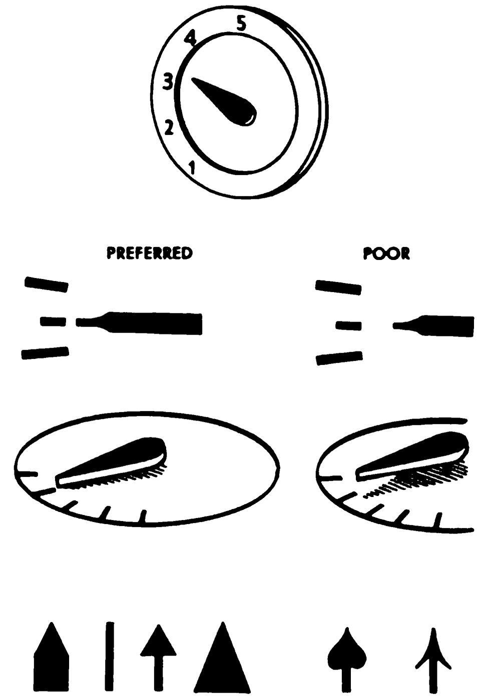
Pointers and scale graduations should be oriented so that the pointer, either moving or fixed, is close to the index and yet does not cover the number.

When the dial diameter must be too small for adequate pointer and graduation design, it is possible to utilize bezel or panel space for engraving the numbers. (This method should be used only when gross pointer position is all that is needed). The pointer tip should be the same width as the smallest graduation.

The pointer should be designed so that there is a minimum distance between tip and graduation - 1/16 inch maximum.

The pointer should be mounted so that visual parallax is minimized. This can generally be achieved by placing the pointer close to the dial scale. The pointer should be painted the same color as numbers and graduations when possible.

When reciprocal readings are necessary, the two ends of the pointer must be identifiable. Simplicity in pointer-tip design is important for reading speed and accuracy.



DIAL AND POINTER DESIGN

CHECKLIST FOR DIAL AND SCALE DESIGN

HAS MAXIMUM SIMPLICITY COMMENSURATE WITH INFORMATIONAL REQUIREMENTS BEEN MAINTAINED?

CAN THE DIAL OR SCALE BE INTERPRETED (NO SPECIAL COMPUTATIONS OR MULTIPLIERS REQUIRED)?

HAS MAXIMUM CONTRAST BETWEEN FIGURES AND BACKGROUND AS RELATED TO EXPECTED ILLUMINATION BEEN PROVIDED?

HAS OPTIMAL DIAL SIZE BASED ON BEST FIGURE AND GRADUATION SIZE AND SPACING BEEN USED?

HAS AN APPROPRIATE NUMERICAL PROGRESSION (OPTIMUM NUMBER PROGRESSION; SCALE BREAKDOWN; RELATIONSHIP BETWEEN NUMERICAL INCREASE, POINTER MOVEMENT, AND RELATED CONTROL MANIPULATION BEEN USED)?

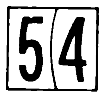
2.1.1.3 Design of Counters. In designing or selecting a counter, strive to provide a device which is easy to read. The style, size, and figure-to-background contrasts of the numerals on the counter drum must be chosen with care. In general, the design rules for numbers and letters given in 2.1.1.2 are good. In addition, however, counter displays present several specific problems of their own.

The height-to-width ratio of numerals for counter displays should be one to one, rather than three to two as recommended for dials and scales. This factor is important since the curved surface of the counter drum plus the movement of the display make it difficult to recognize the critical portions of the numeral, the top and bottom.

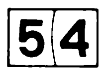
Whenever practicable, the numbers should "snap" into place to eliminate blurring.

Numbers should not follow each other faster than about two per second if the observer is expected to read the numbers consecutively. An upward movement of the counter drum should indicate a numerical increase. Although this is not critical in reading the number out, it is quite important when a manual control is used to set the numerical value into the device.

Avoid large horizontal spacing between number drums. Large spaces between counter drums make it especially difficult to read large numbers.



POOR



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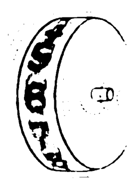

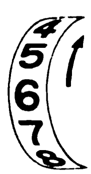

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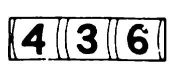


POOR

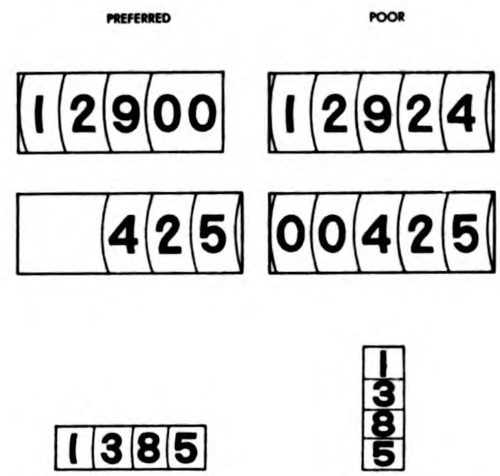
COUNTER DESIGN

When last digits have little value, as in large values of range or altitude, they should be replaced with stationary zeros. Similar treatment is recommended for preceding digits which are seldom used; in this case, however, the space should be blanked out completely during the time when no numerical value is to appear.

Counters should be mounted as close to the panel surface as possible to provide maximum viewing angle and minimum shadow effects from ambient lighting. Counters should be oriented so that they may be read from left to right.

2.1.1.4 Indicator and Warning Lights. Brightness factors are of utmost concern in light displays. Lights which must attract immediate attention should be at least twice as bright as the immediate background. The background should be dark in contrast to the light and should be in a dull finish. When the major panel area is light in color, it is possible to improve the effectiveness of the light display by painting the immediate area a dark matte finish. The addition of a matte-black panel around a signal light improves the effectiveness of even an outdoor signal. Control of indicator-light brightness should be provided when the range of ambient illumination varies. This control is especially important when dark adaptation is necessary.

Printed information on pilot and warning lights should be designed to fit the job at hand. Black printing on the bright background of the pilot light allows a maximum of brightness and is ideal for a warning signal, whereas a perforated mask between the bulb and the filter emits less glare for the dark-adapted eye.



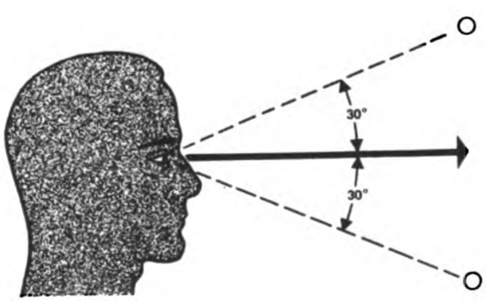
NUMERAL PLACEMENT

LIGHT TO BACKGROUND CONTRAST

WARNING AND PILOT LIGHT IDENTIFICATION

Pilot lights need not be large to be effective since the brightness and color are more important variables. Colors for pilot or warning lights should be chosen with care. For general usage, colors to be used on the same panel should be widely separated in spectral wave length. The color red should be preserved for danger signals when possible. Avoid using similar colors, such as red with orange or purple with blue. Approved red, blue, and green are recommended for panel displays when erroneous interpretation, by an observer deficient in the ability to distinguish colors, might be dangerous.

Lights of varying size, color, brightness, and grouping provide an effective means for presenting simple, discrete information. Critical lights should be isolated from less important lights whenever possible. Simplicity is important in using light displays. Too many lights or too many colors tend to confuse a panel layout.



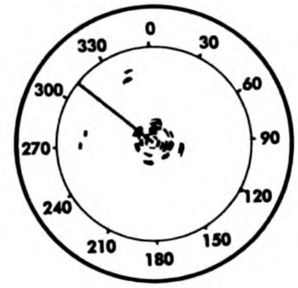
Mounting of warning lights and other visual displays within 30 degrees of the normal visual axis is recommended when the operator must attend to other tasks. A central warning light may be used to direct an operator's attention to another panel. Flashing lights are useful in getting attention when they provide flash rates of 3 to 10 per second and each flash duration is of the order of at least 0.05 second.

2.1.1.5 Cathode-Ray Tube Displays. Electronic displays are usually presented on cathode-ray tubes in rectangular or polar co-ordinate form. Display considerations that affect operator performance are presented as follows:

Size - When plotting or simultaneous viewing by several operators is not important, there is no significant advantage between large or small tubes. More time is required to scan the whole scope of an extremely large tube, but such a tube will allow use of a more adequate grid overlay and thus improve accuracy. Scopes of 5- to 7-inch diameter are quite adequate when plotting is not required.

Shape - The bezel or frame around a CRT display should conform to the general configuration of the type of presentation - round for a Plan-Position Indicator (PPI) or rectangular for an A-scan.

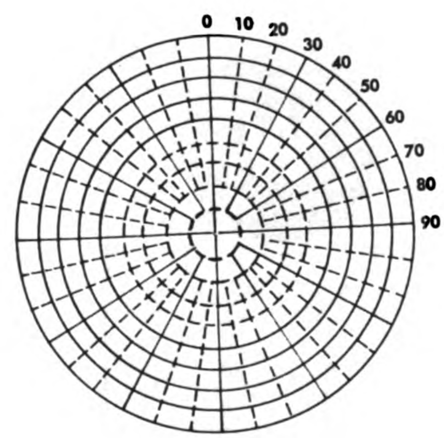
Mounting Position - CRT's should be mounted so that the visual axis of the operator is perpendicular to the face of the tube at its center. Recommendations for various operator positions and tube mounting angles may be found in 2.1.3. Normal viewing distance is 14 to 18 inches.



PPI BEARING SCALE

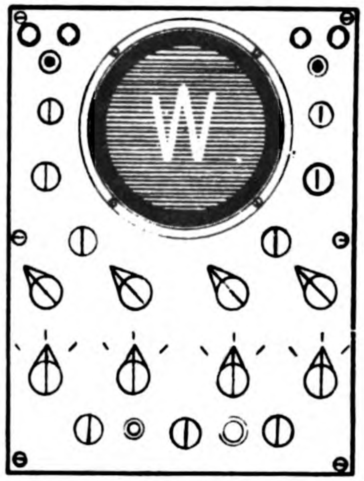
Cursors - Electronic cursors which are continuously printed are superior to mechanical cursors from the operators point of view, since parallax can be eliminated and accuracy improved. The addition of a scale is essential for bearing accuracy; the addition of a counter which presents the exact numerical values found by the cursor manipulation improves accuracy still more. When bearing accuracies of 5 degeres or more may be tolerated, there is no real need for the cursor since the operator can interpolate bearing position to that degree of accuracy.

Grids - Accuracy of interpolating target position is improved by adding grid markings. The more accurate the reading requirements, the more elaborate the grid structure should be. To minimize the confusion caused by many fine grid lines, it is important to increase scope size. The size compromise cannot be predicted, but certain design suggestions can be made.

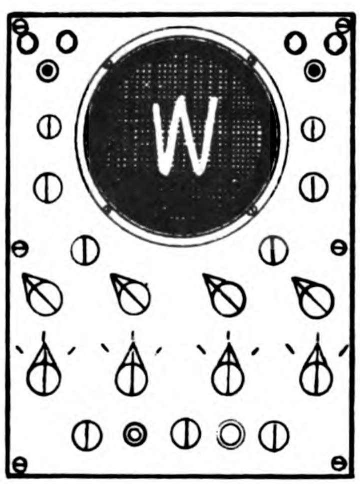


PPI GRID SYSTEM

Range Rings - The minimum spacing between range rings on a polar display should be of the order of 1 degree 36 minutes visual angle subtended at the eye, or about

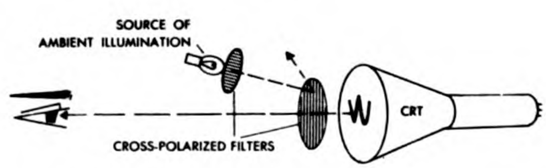


1/2 inch at 18-inch viewing distance. For bearing, a solid line for each 30 degrees and dotted lines for each 10 degrees are recommended for maximum accuracy. If more than four range rings are necessary to cover the scale it is wise to divide the rings into subgroups by making half of them dotted and half solid lines. Use of separate colors per subgroups is also satisfactory. Range rings may also be designed to act as unnumbered bearing aids on very large grid systems (30-inch diameter or larger).



CRT CONTRAST RATIOS

Illumination - Brightness contrasts between signal and background and between target and "noise" vary to such a degree that exact optimum levels cannot be stated. Contrast ratios may be improved by minimizing background brightness and surface reflections. By proper filtering, the trace to background ratio can be maximized. A cross- polarization filter technique has proven quite adequate. The technique utilizes a polarized light over the scope face. With this technique it is not necessary to work in completely darkened rooms. Scope hoods are recommended for a single operator when ambient illumination cannot be adequately controlled.



REDUCTION OF BACKGROUND BRIGHTNESS BY USE OF CROSS-POLARIZED FILTERS

2.1.1.6 Combined Indicators. The combination of different types of visual displays within one instrument or of several instruments into an array or group should be governed by the following principles:

Combine only those forms of information which bear a common relationship.

Keep the common factor of interpretation (fixed and moving parts, scale values, etc.) the same.

Do not confuse the operator with unnecessary information.

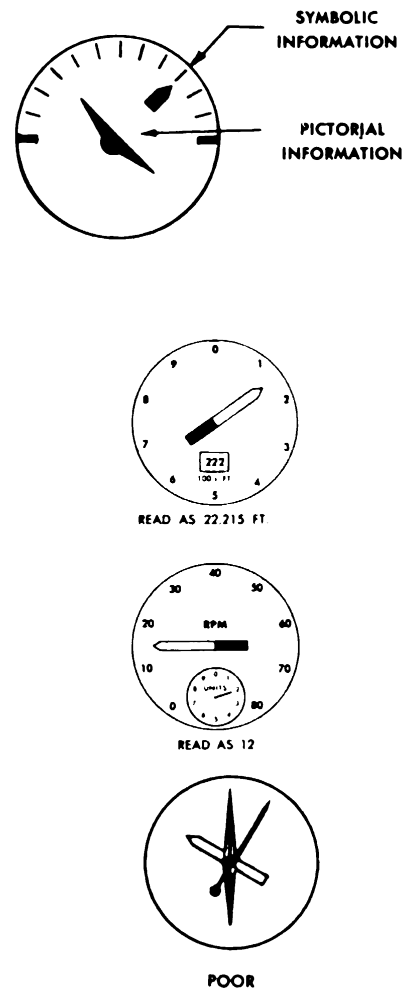
Combining on one dial more than one item of information saves the operator time which would be taken in locating parts of a total picture.

Scale range may be increased by combining pointers and counters. The total range may be increased by extension (pointer plus counter) or the range may be given with more precision (pointer plus sub-dial and pointer).

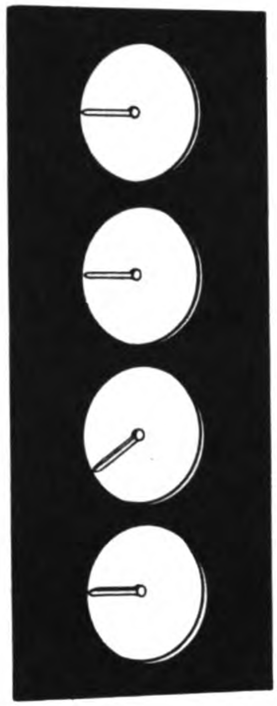
Note that this type of scale expansion is to be used only when some qualitative information relative to rate or normal operating range is needed. The counter is best when only quantitative information is needed.

Do not use multiple-pointer displays with more than two pointers.

With two pointers on the same dial face proper orientation will make check reading easier, however, avoid unrelated information combinations such as azimuth and grid current.



COMBINED DISPLAY ON
A SINGLE DIAL



When the number of sources of information becomes too great and are apt to complicate one instrument, it is wise to combine several simple instruments into an array. Such arrays of instruments will allow the rapid check-reading of a large number of instruments in a minimum of time if the pointer positions for the normal operating conditions are arranged at the 9- or 12-o'clock position. The slight deviation of any one of the instrument pointers from this symmetrical pattern of pointers is easily and quickly located during even a cursory scan.

CHECKLIST FOR SINGLE OR MULTIPLE INSTRUMENTS COMBINED ON ONE DISPLAY

HAS THE BEST SCALE AND DIAL FACE DESIGN BEEN USED?

ARE ALL THE SCALE VALUES AND THEIR RESPECTIVE GRADUATION CONSISTENT IN THE DIRECTION OF INCREASE OR DECREASE?

HAS THE SAME NUMERICAL SCALE PROGRESSION PRINCIPLE BEEN USED ON ALL SCALES OF THE COMBINED DISPLAY?

HAS THE SAME PICTORIAL RELATIONSHIP BEEN USED FOR ALL INSTRUMENTS ON THE SAME PANEL?

HAS THE NORMAL VISUAL AXIS OF THE OPERATOR BEEN CONSIDERED SO THAT PARALLAX WILL NOT BE A PROBLEM?

ARE ALL PARTS OF THE INSTRUMENT OR INSTRUMENTS ILLUMINATED EQUALLY WELL AND ARE DIMMERS PROVIDED FOR COMBINED DISPLAYS WHERE DARK ADAPTATION REQUIREMENTS CALL FOR SELECTIVELY LOWERING THE ILLUMINATION OF SPECIFIC PORTIONS OF A DISPLAY?

2.1.2 Controls

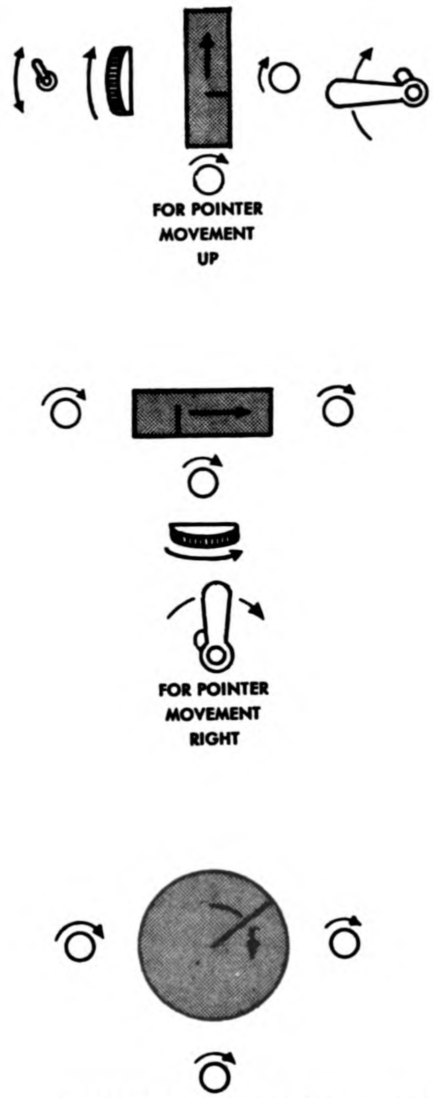
In the design or selection of control devices it is important to consider two basic factors: (1) the compatibility between the movement and location of the control device and of the elements to be controlled; and (2) the physiological and anatomical efficiency with which the operator can utilize the control and display.

2.1.2.1 Compatibility. There are certain accepted relationships between control and display that should be provided so that movement errors will be at a minimum.

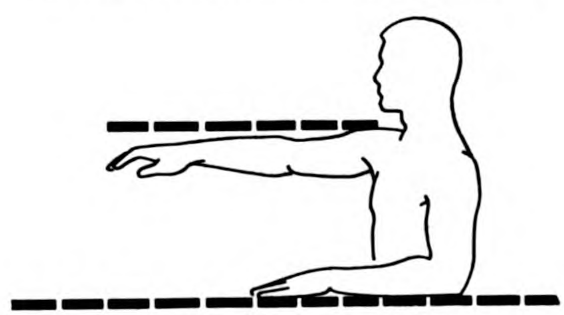
Whenever possible, control movements and location should be parallel to the axis of the display motion they affect. Various control motions for a given display are illustrated.

Controls should be oriented to fit normal habit-pattern reflexes. An operator will normally move his control so as to center deviations or reduce errors presented by the visual display.

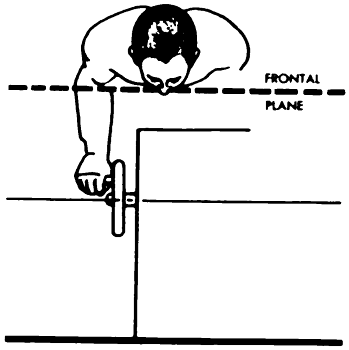
2.1.2.2 Physiological Efficiency (Location of Controls). To reduce fatigue controls which must be used most often should be placed somewhere between elbow and shoulder height. Locations forward and slightly below shoulder height are found most easily when "blind" reaching is required.



DIRECTIONAL COMPATIBILITY



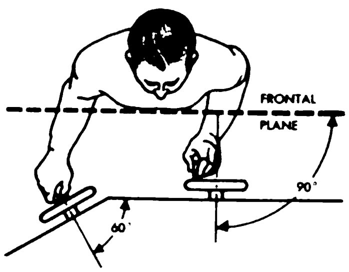
CONTROL PLACEMENT



Mounting eigher side of center is superior to mounting in the center of the operator's position.

Cranks which require extreme torque should be mounted so that the turning axis is parallel to the frontal plane of the body.

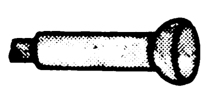
Crank-type controls which are to be turned rapidly should be mounted so that the turning axis lies within a range from perpendicular to about 60 degrees off the frontal plane of the body.



Controls which must be operated from a fixed operator's position, such as that of an aircraft pilot secured by means of shoulder harness, should be within an arc of 28 inches measured from the individuals shoulder position.

2.1.2.3 Size of Controls. Control dimensions should take into consideration the normal hand-grasp limitations.

Adjustment knobs for instrument-type equipments should, when possible, be limited in diameter to 2 inches or less for most convenient hand grasp.



OPTIMUM CRANK HANDLE SHAPE

Handles for cranks should be about 1-1/2 inches in length by 1/2 inch in diameter for operations requiring fast wrist and finger movements, 3-3/4 inches in length by 1 inch in diameter for operations requiring arm movement of heavy loads.

For high-speed cranking, the diameter can vary from 3 to 9 inches, with 4-1/2 inches recommended for general use.

Wheel and crank diameters depend upon the mounting position and torque to be expected as well as the speed of turning required. The table below shows the optimum diameters for several mounting conditions and torque conditions.

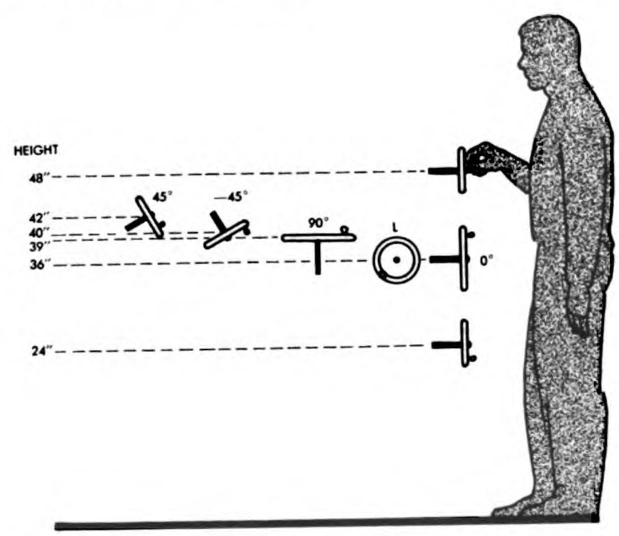
OPTIMUM CONTROL DIAMETERS *

HEIGHT (in.)	POSITION (deg.) **	TYPE ***	SIZE Handwheel (W), Diameter in Inches; Crank (C), Radius in Inches — AT TORQUE OF 0 in. lb	40 in. lb	90 in. lb
24	0	W	3-6	10	16
36	0	W	3-8	10-16	16
	L	W	3-6	10	10
	0	C	1½-4½	4½-7½	4½-7½
39	90	W	3-10	10-16	16
	90	C	2½-4½	4½-7½	4½-7½
40	−45	W	3-6	6-16	10-16
	−45	C	2½-7½	4½-7½	4½-7½
42	45	W	3-6	10	10-16
	45	C	2½-4½	2½-4½	4½
48	0	W	3-6	8-16	10-16
	0	C	2½-4½	4½	4½-7½

* These data were based on setting the control device in only one revolution. The author infers that for less than 90-degree turn, handwheels would be more effective than cranks.

** Angle in degrees from horizontal

*** Code: W - Handwheel, C - Crank



2.1.2.4 Force Limitations. The human operator should not be expected to perform at maximum capacity for any great length of time, so it is wise to leave a safety factor in force required.

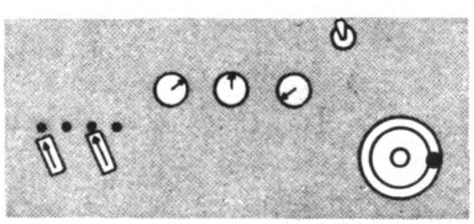
A maximum force of 8 to 16 ounces is recommended for small toggle switches.

A maximum torque of 2 inch-pounds is suggested for rotating knobs.

A load of 2 to 5 pounds is suggested for smooth operation of small, high-speed cranks.

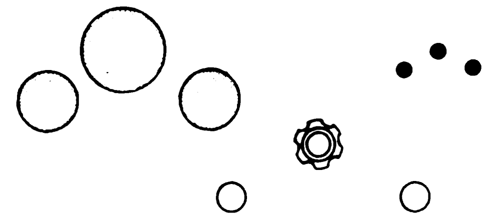
Hand levers of the gearshift type should not require more than 30 pounds of applied force.

2.1.2.5 Coding. Coding techniques such as location, shape, size and color are useful in the layout of control panels from the standpoint of reducing operator error in the selection of the correct control.

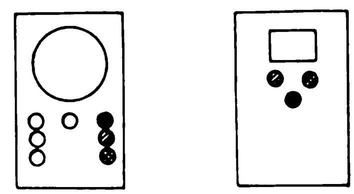


Location or position coding provides spacing or positioning of controls in groups far enough apart to establish a position habit pattern. An operator soon establishes a code for himself; the more definite spacings we give him, the sooner he establishes accurate habit patterns.

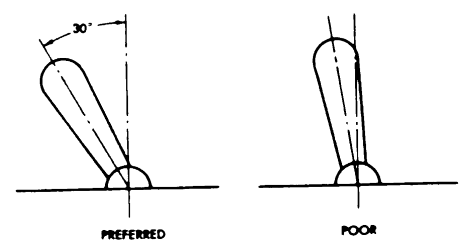
Shape coding is useful to augment location coding under black-out conditions. It is more useful with lever-type controls such as toggle switches, rotary detented switches, and joysticks, because the shape will not interfere with the manipulation of this type of control. Shape coding is not generally recommended, however, for electronic types of control knobs since manipulation is often hampered and recognition is difficult when the knob is inverted. Some shape variability may be had from selected commercial designs.



Size coding provides tactual cues of size which may be used to identify gross categories of control functions and enhance location habits acquired initially through position coding.

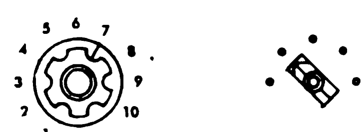


Color coding establishes relationships from one equipment to another. Since all colors are not equally distinguishable and are variously affected by lower light levels, it is important to select colors that are recognizable under the expected illumination conditions.



2.1.2.6 Selection and Use of Standard Devices. Select toggle switches which provide a visual cue as to the switch position; 30 degrees either side of the center position is satisfactory. Mount toggle switches so that the ON position is always forward, up, or to the right as the operator looks at the switch.

Use small knobs (approximately 1 inch in length) for non-critical adjustments such as volume, focus, and dimmers. Use larger knobs (approximately 2 inches in diameter) for more critical adjustments such as tuning or frequency selection.

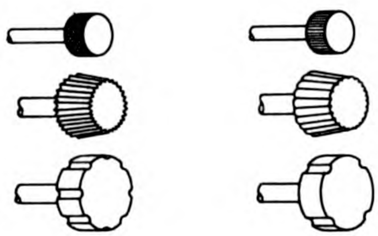


USE ROUND KNOBS FOR CONTINUOUS TURN

BAR KNOB FOR STEPWISE TURN

Use bar or pointer-shaped controls exclusively for switching functions which have mechanical detents to aid positioning. Size is not important as long as there is sufficient gripping surface.

When using two controls on a concentric shaft arrangement, use the larger for vernier adjustment so that the scale spread will be maximized.



PREFERRED POOR

Knobs which are less than 3/4 inch in depth should be knurled rather than serrated to provide adequate gripping surface. For knobs with a depth greater than 3/4 inch, serrations are adequate but should be chosen with care. Serrations should be chosen which give the best gripping characteristics, that is, point contacts rather than round ones, and evenly spaced serration rather than uneven or widely spaced ones.

Select skirt designs which allow an engraved index to be seen in spite of the fingers. Special skirts should be fabricated for edge-lighted panels used under blackout conditions. A transparent pointer which allows light to come through should be used with a back-lighted panel.

PREFERRED POOR

Push buttons should not require extreme pressure for actuation (maximum, 31 pounds). The contact should be definite, that is, the finger should feel a "click." There should be sufficient finger contact area so that the pressure is not irritating. The push button or buttons should be mounted, possibly by recessing, as shown, so that they cannot be accidentally tripped. Proper illumination should be provided when there is a possibility of pressing the wrong button.

2.1.3 Console Design and Panel Layout

The layout and design of instrument panels with suitable packaging into a well human-engineered unit are, at best, a compromise. It is important to approach each design in such a manner that the best compromises are made. As in the design of any piece of hardware, it is of utmost improtance to have answers to certain technical aspects of the problem in hand before starting to work on the actual layout. The engineer must know the answers to the following questions if he wishes to incorporate good human-engineering principles into his finished panel or console.

Armed with answers to these questions, the engineer is ready to acquaint himself with the human-engineering rules for panels and consoles.

CHECKLIST FOR CONSOLE DESIGN AND PANEL LAYOUT

WHAT LIMITATIONS ARE FIXED BY SPECIFICATION OR BY ULTIMATE SPACE FACTORS IN THE INSTALLATION AREA?

WHAT VISUAL DISPLAYS ARE NECESSARY? WHAT SIZE MUST THEY BE? WHICH OF THESE MUST BE ACCESSIBLE TO THE OPERATOR DURING OPERATION AND WHICH ACCESSIBLE ONLY TO THE MAINTENANCE MAN?

WHAT CONTROLS ARE NECESSARY? WHAT SIZE? WHICH MUST BE ACCESSIBLE TO THE OPERATOR; TO THE MAINTENANCE MAN?

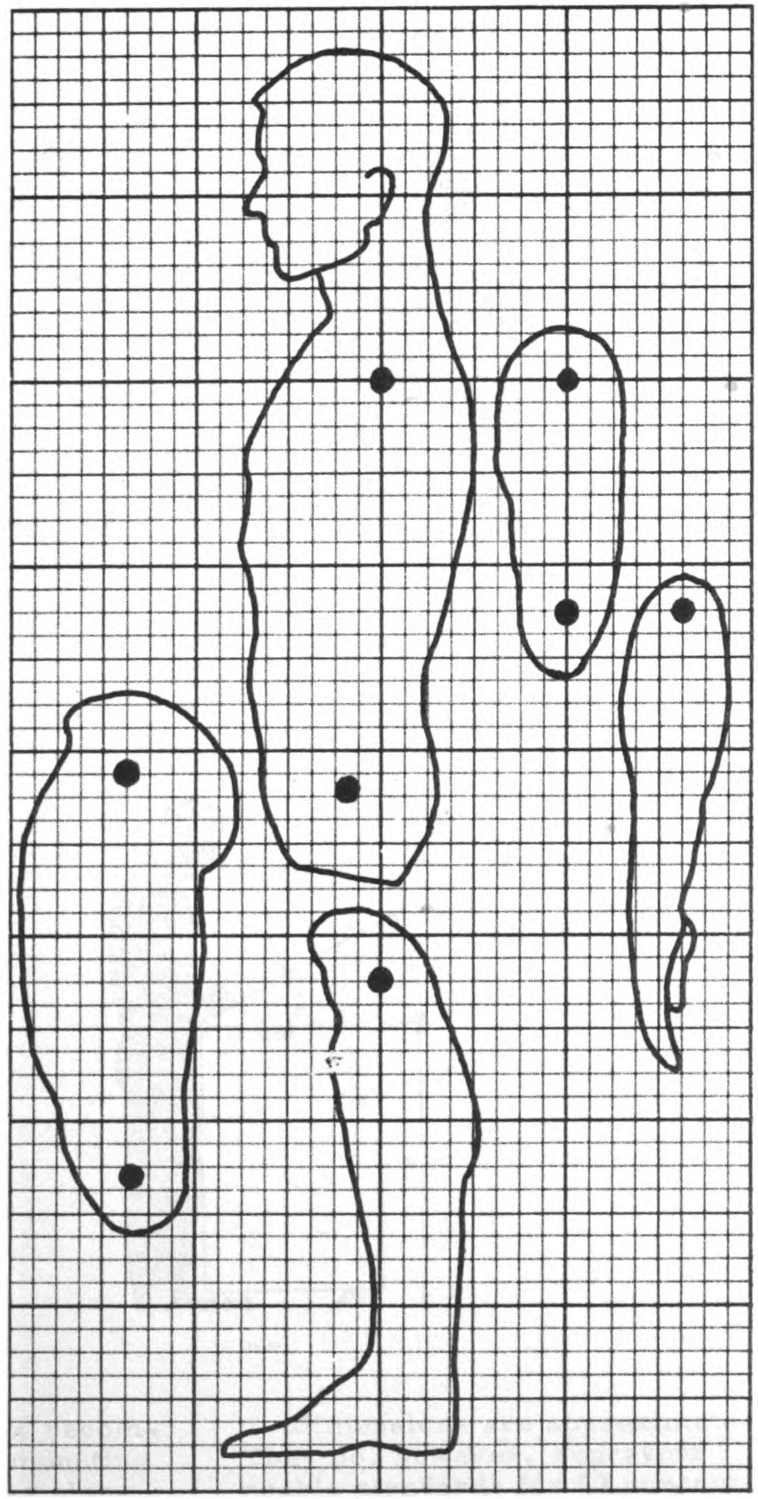
WHAT AUDITORY DISPLAYS AND WHAT MEANS OF COMMUNICATION BETWEEN OPERATORS ARE NECESSARY?

WHAT OPERATING CONDITIONS ARE EXPECTED - ILLUMINATION, NOISE ENVIRONMENT, TEMPERATURE, VIBRATION, PITCH AND ROLL?

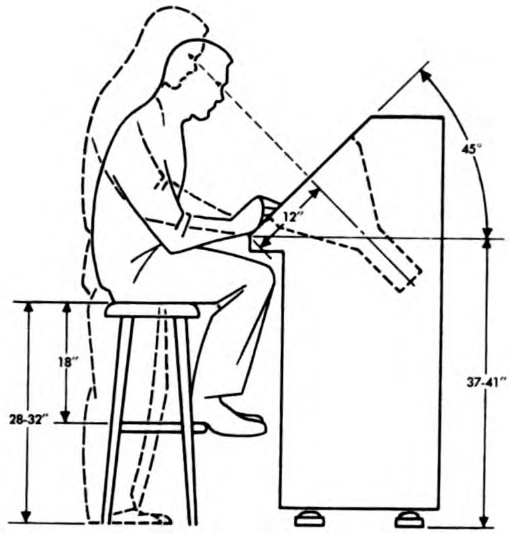
WHAT OPERATOR CONDITIONS ARE EXPECTED - ONE OR MORE OPERATORS, CONTINUOUS OR INTERMITTENT OPERATION, OPERATOR'S POSITION, STATIC OR DYNAMIC?

WHAT MAINTENANCE FACILITIES ARE REQUIRED DURING OR BETWEEN OPERATIONS?

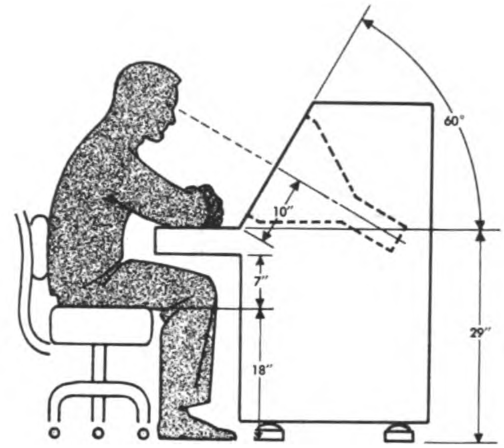
At this point it is suggested that a mock-up be constructed. The mock-up need not be elaborate but it should be accurately scaled. A miniature mock-up is recommended because it is easier to handle and may be all that is required to solve the problem, thus saving the expense and time consumed in the construction of a full-scale mock-up. The sheet following provides a 1/8 scale layout for use with mock-ups. The scale model may be made from materials such as cardboard, solid wood pieces, or erector-type building blocks. This model will be found to be quite helpful even when used in connection with engineering drawings. It is suggested that these manikins be reproduced in 1/8-inch thick clear plastic and that the joints be flush-riveted. Stiff cardboard may be used in lieu of plastic.



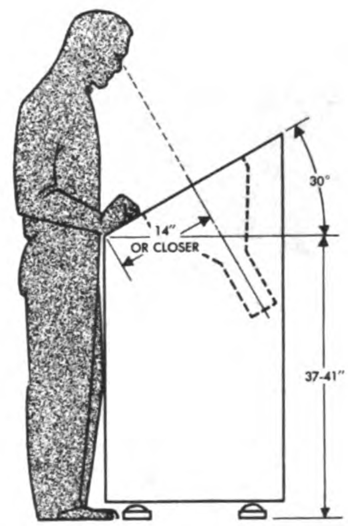
UNASSEMBLED 1/8 INCH = 1 INCH



SIT-STAND



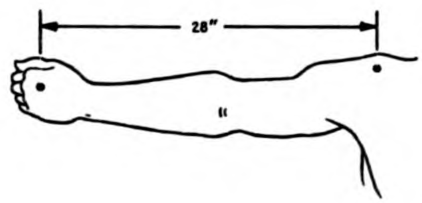
SIT



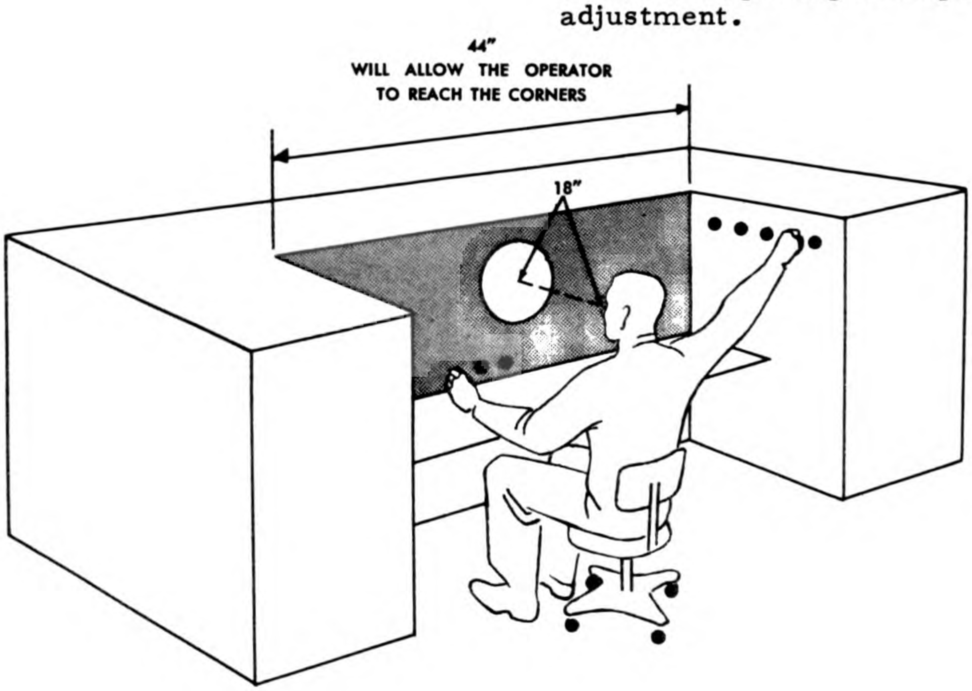
STAND

The illustrations show recommendations for angular mounting of visual displays such as plan-position indicators (PPI).

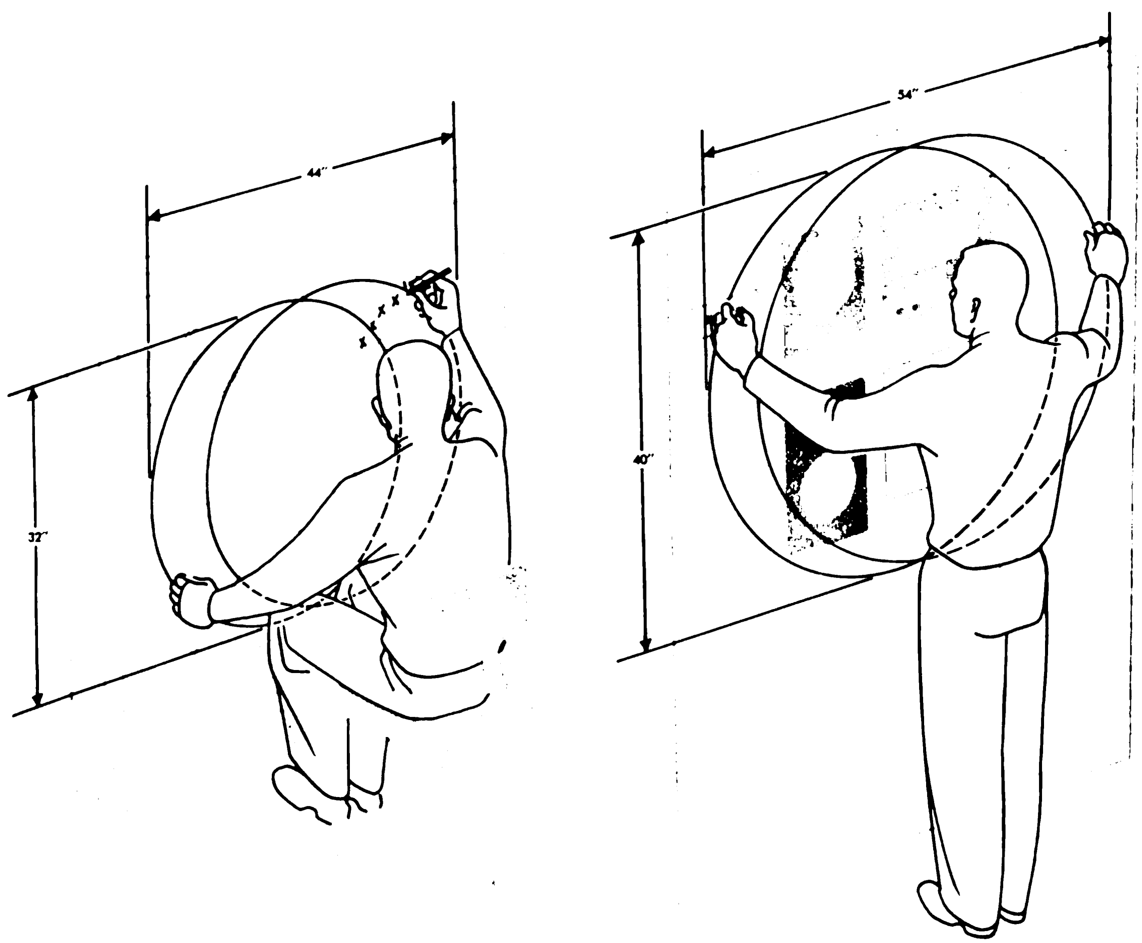
Dimensions are approximate. They do, however, represent usable standards for 90 percent of the male population.



The size of an instrument panel depends primarily upon the normal arm reach of the human operator. In general, convenient arm reach is about 28 inches from the respective shoulder pivot point. This rule cannot be hard and fast for the obvious reason that in most situations the operator has freedom to bend his body and thus extend the useful reaching distance. A word of caution, however, is that he cannot be expected to bend two directions at once, so do not take advantage of his flexibility unless it is clearly necessary. Further, he will tire quickly if his arm is in the extended position for a prolonged time period as shown. Controls in this position should be either switches or controls requiring infrequent adjustment.



Convenience limits for placement of controls on horizontal 60-degree, and 30-degree console panels are shown in the illustrations on the preceeding page. A visual display may limit the flexibility of the operator's position or special apparatus may restrict his flexibility for reasons of safety. Convenience limits may be established to restrict necessary arm reach when the operator is restricted to a more or less static position.



Arm reach from static sitting and standing positions are shown, when the operator is at a normal viewing distance (18 to 28 inches) from the control panel. These are not maximum reaches, but do take into consideration some normal bending of the operator's body.

<table>
<tr><td>A

PPI Scope
PPI Controls

Focus
Intensity
Range Cursor
Video gain</td><td>B

Speaker

Audio control
Output meter
Freq. selector</td></tr>
<tr><td colspan="2">C

Communications Receiver

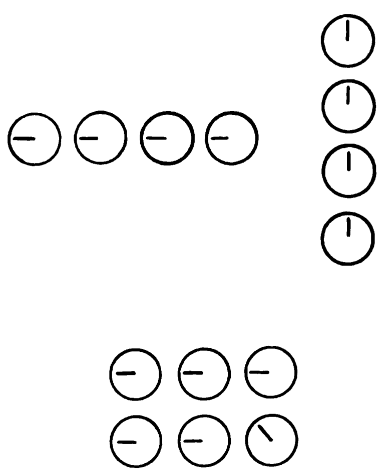
Tuning dial
RF gain control
Audio gain control
Selectivity control</td></tr>
<tr><td>D

Intercom. Cont.

Phone jacks
Station selector
Volume control</td><td>E

Navigation Instr.

Compass
Course indicator</td></tr>
</table>

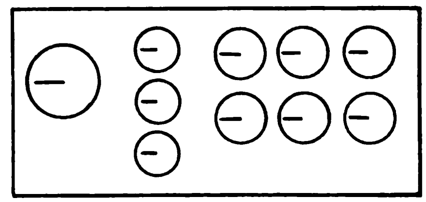


Once a rough idea of the form and size factors of the panel or console have been decided upon, it is then necessary to organize the components that are to be placed on the panels. The components will undoubtedly vie for optimum positions and compromises will have to be made. A suggested method for arriving at the best compromise and organizations, first, itemize all components by related groups.

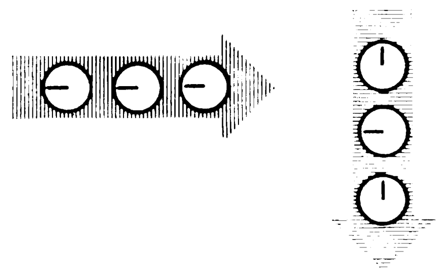
Next prepare cardboard "cutouts" of each separate item. These "cutouts" should be drawn to scale and should represent the interior dimension of such items as dial face or control knob, and the interior dimension of the physical structure of the control mechanism that will limit the proximity of adjacent items. These cutouts can now be placed in the proposed panel area and moved about until you have arrived at the best organization and fit. It is much more economical to find out that you do not have room in this manner than to build a finished package that must be modified later. The following group procedures should be used as a guide in organizing panel components.

2.1.3.1 Grouping Procedures For Panel Layout (Check-Reading Dials). For a single group of five or fewer check-reading dials in a horizontal row, normal operating position of the pointers should be located at the 9-o'clock position; for the vertical groups, orient the pointers to the 12-o'clock position.

For groups of six or more, use rows or columns rather than extending a single row; long rows or columns impose undesirable scanning movements upon the operator.



For several groups on the same panel, use a consistent pointer position regardless of the above recommendations.

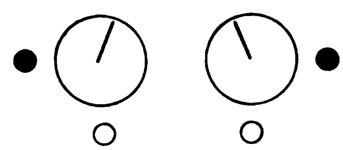


Linear gauges or meters should follow the same general rules as specified for dials.

The positions of specific dials which are grouped together should be determined by the sequence in which they are to be read, that is, the operator should be able to read in order of sequence from left to right or from the top of the panel to the bottom.

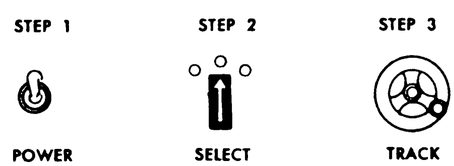
Controls should be placed:

Close to the display which they affect, when possible.



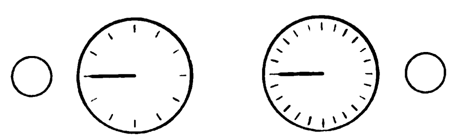
Below or to the left for left-hand operation; below or to the right for right-hand operation.

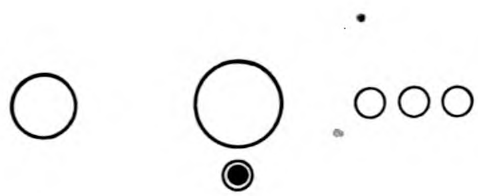
Sequentially with respect to the expected order of operation.



At the optimum position for manipulation of the control which is to be used most frequently.

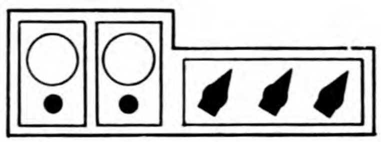
So that there is an equitable distribution of work load between right and left hands; right hand operation should be reserved for operations requiring the finest adjustment.



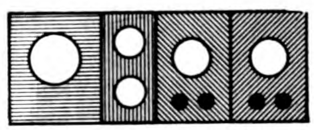


Control-display organization should be such that visual displays occupy central areas and controls occupy peripheral areas so that hand movements do not obstruct the view of visual indicators.

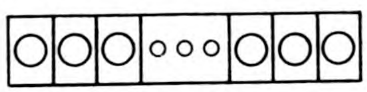
Area or group identification is quite important in complex layouts. It may be accomplished satisfactorily in several ways as follows:



Adequate spacing of display or control groups; horizontal separations are preferred to vertical separations.

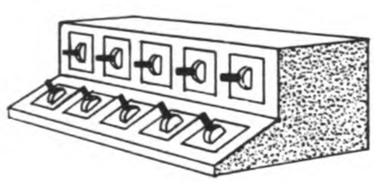


Marked outlines around each group.

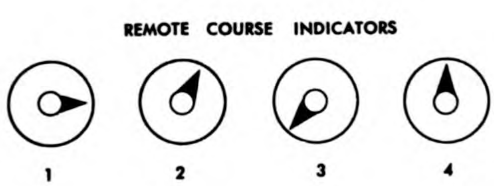


Area color patterning.

Symmetry.



Differential place of mounting.



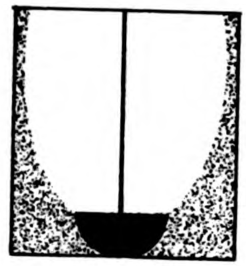
Label consistently either above or below for a specific category, that is, group title above, as shown; individual labels below or centered. Lable in terms of what is measured (rpm), not by the name of the instrument (tachometer). Company trade names should not appear on the face of a dial.

Space saving may be accomplished by overlapping partially hidden dials.

2.1.4 Lighting Applications

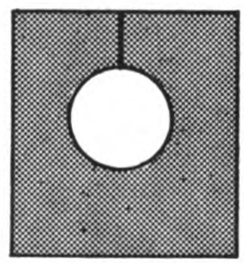
Certain human-operator tasks involve the need for maintaining the eye at an optimum dark-adaptation level and yet allowing for adequate visibility of instrument markings on a panel or console. Unfortunately, the optimum level of dark adaptation is not possible with even the minimum amount of instrument illumination, but is possible to reach a satisfactory compromise with a minimum amount of "red light" of the proper wavelengths.

DIRECT



INDIRECT

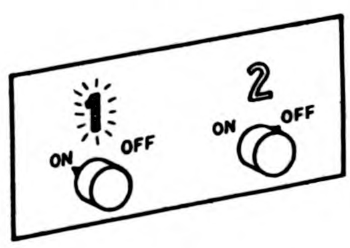
Other special tasks require reduced ambient illumination for optimum visibility, but the required level of dark adaptation is not so stringent. The sonar or radar operator, for instance, needs a rather low level of ambient illumination in order to operate his scope satisfactorily, while other operators in the same area may need to write or move about and must have sufficient light to accomplish their own tasks. This condition we have chosen to call "dimout" since actual blackout is not necessary even for the scope operators.



DIFFUSED

GENERAL ILLUMINATION

For blackout conditions (night lookouts, ship's bridge) use illumination at wavelengths above 600 millicrons. Incandescent light passing through filters conforming to Federal Standard No. 3, Identification Red, meets this requirement.



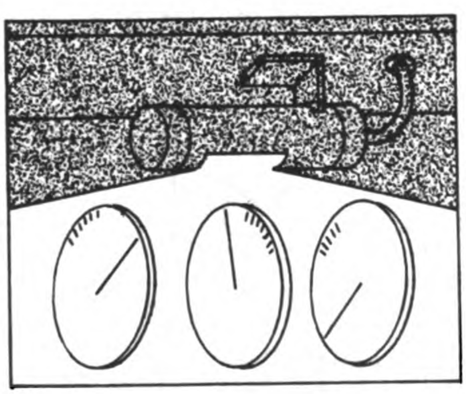
BACKLIGHTING

RED-LIGHTING LEVELS FOR DARK ADAPTATION

AREA	LIGHT	LEVEL (foot candle)
Control Rooms	Illumination on working areas	0.01-0.4
	Illumination on black and white dials, figures, name plates	0.03-0.10
	Brightness of instrument faces (white portion)	0.02-0.08
	Brightness of indicator lights (not to exceed 1 square inch area)	0.10-1.00
Ready Areas; crew's mess, wardrooms	Illumination at table-top height	0.50-2.00
	Brightness of any area in the visual field not to exceed	2.00

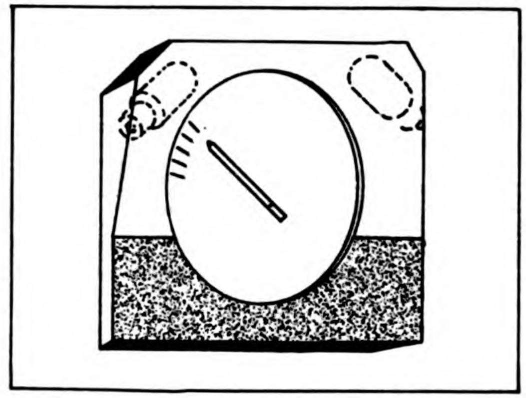
For dim-out conditions (communications rooms employing radar, sonar, or other scope reading tasks; aircraft control towers) use red illumination and/or very low-level white illumination. The upper limit for reflected ambient light should be no more than two foot candles.

The use of optimum materials and techniques has progressed quite rapidly in recent years and is, of course, still under development. The following suggestions are, therefore, not to be construed as the ultimate, but rather the best that can be recommended to date.



2.1.4.1 Floodlighting. Red or white light for floodlighting may be furnished by small fixtures on approximately 8-inch centers above the panel to throw an even illumination over the whole area. The operator can change the light from white to filtered red as needed, by rotating the sleeve of the lamp housing. Experiments have shown that such floodlighting at control centers in conjunction with individual instrument lighting is superior to either type of lighting alone.

Individual ring lighting may be provided satisfactorily by housing two miniature lamps under a hinged shield which protects the operator from direct glare.



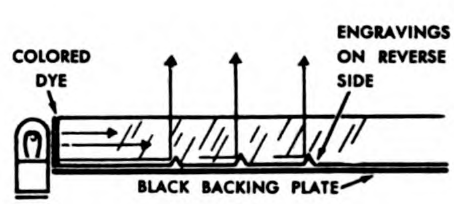
A stand-out fixture provides maximum compactness for individual instrument illumination.

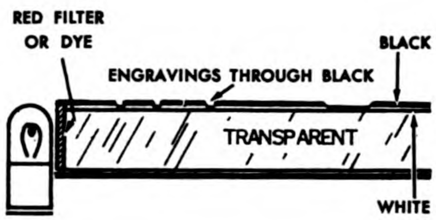
The following precaution should be exercised. Floodlighting casts shadows. Keep instrument faces flush with the panel; orient sources so that shadows do not interfere with other instruments; diffuse the light with appropriate filter materials.

2.1.4.2 Transillumination. Transillumination is an indirect type of illumination utilizing edge and backlighting techniques on clear, fluorescent, or sandwich-type plastic materials.

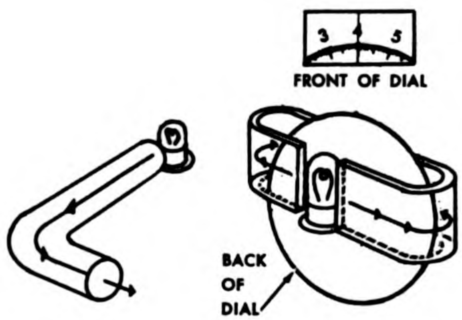
Clear plastics such as Plexiglas or Lucite possess excellent light-transmitting characteristics which can be used to advantage in instrument lighting problems.

Figures may be engraved on the reverse side of clear plastic and edgelighted for dials, pointers, and nameplates. Maximum contrast for reading may be achieved by backing up the display with a back panel. Illumination may be in any desired color by dyeing the edges of the plastic.

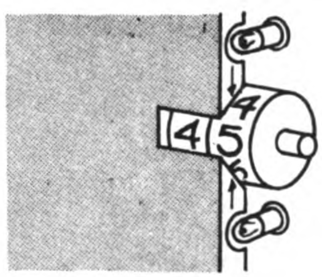




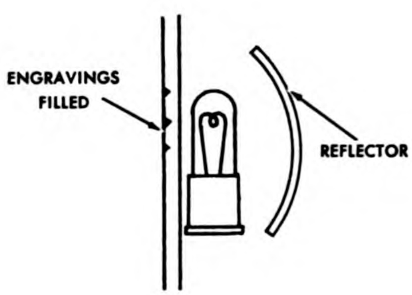
Excellent blackout displays may be made with a sandwiched fabrication of clear plastic plus a white layer of translucent paint or vinyl topped with an opaque black paint or vinyl. Illuminated with red light, this type of display, when engraved properly, will serve for daytime use (the figure will appear white on a black background) as well as for nighttime use (the figures will appear red on a black background). Similar results may be accomplished with a silk-screen process.



Light piping may be accomplished by bending clear Lucite. Such devices may serve to pipe light to hard-to-reach pilot indicators or may be used to illuminate a lubber line or index in front of a moving-scale dial. In the latter use, a single light illuminates the translucent dial as well as the inscribed index.

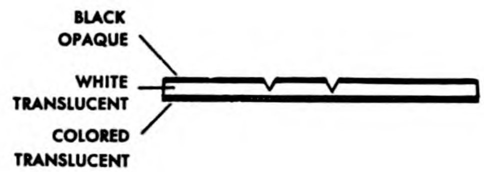


Counter illumination is possible with clear-plastic edgelighting techniques. The plastic panel edges should be roughened to diffuse the light.

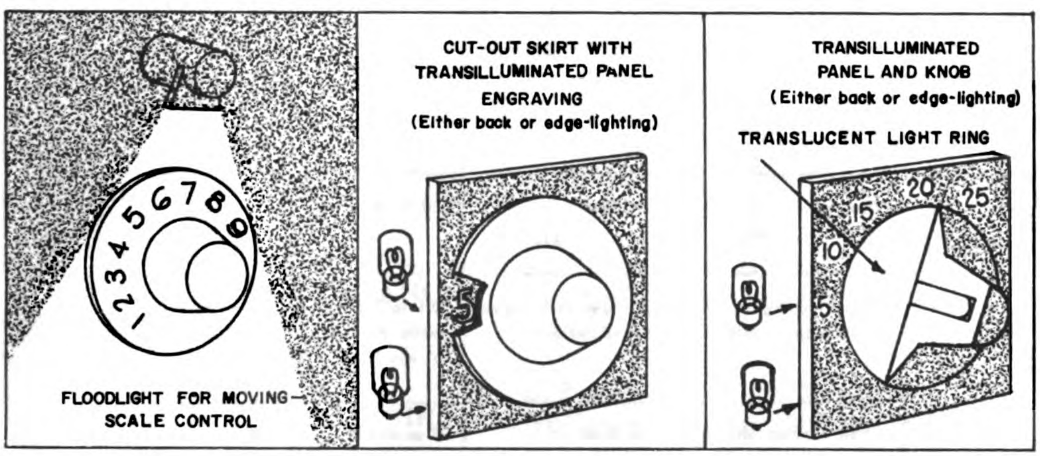


Translucent plastics in various colors may be used for backlighting purposes. Figures should be engraved on the front surfaces and filled with an opaque paint, preferably black, for best results. Even illumination requires that the lamp be placed very close to the surface of the plastic for best results; a reflector behind the lamp helps. The brightness drops off rapidly within a very short distance from the light source. This type of material is not recommended for large displays but rather for individual nameplates with a minimum number of figures.

Laminated sandwich-type plastics combine translucent with opaque characteristics and are treated somewhat the same as the clear sandwich. The major difference is that backlighting rather than edgelighting is necessary. The same problems of even illumination are found here as were mentioned in the foregoing paragraph. These displays are more satisfactory for small nameplates than for large area displays. Engravings appear white in daylight and red at night.



SPECIAL TECHNIQUES FOR ILLUMINATION OF PANEL CONTROLS



GENERAL RECOMMENDATIONS FOR INSTRUMENT AND CONSOLE LIGHTING

CONDITION OF USE	RECOMMENDED SYSTEM	BRIGHTNESS OF MARKINGS (foot Lamberts)	BRIGHTNESS ADJUSTMENT
Instrument lighting, dark adaptation critical	Red flood, indirect, or both, with operator choice	0.02 to 0.1	Continuous through range
Instrument lighting, dark adaptation not critical	Red or low-color-temperature white; flood, indirect, or both, with operator choice	0.02 to 1.0	Continuous through range
Instrument lighting, no dark adaptation required	White flood	1 to 20	May be fixed
Control console lighting, dark adaptation required	Red edgelighting, additional optional red or white flood desirable, with operator choice	0.02 to 1.0	Continuous through range
Control console lighting, dark adaptation not required	White flood	1 to 20	May be fixed
Possible exposure to bright flashes	White flood	10 to 20	Fixed
Chart reading, dark adaptation required	Flood, operator's choice of red or white	0.1 to 1.0 on white portions of chart	Continuous through range
Chart reading, dark adaptation not required	White flood	5 or above	May be fixed

Acknowledgement

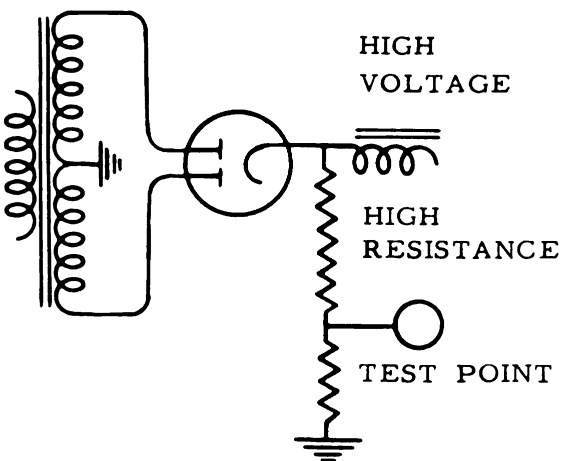
The foregoing material on Operational Features was obtained from Human Engineering Guide by Wesley Woodson, University of California Press.

2.2 MAINTENANCE FEATURES

Good design can greatly reduce the time and skill required for maintenance. Provision must be made for testing, adjusting, and repairing of equipment, in keeping with its size and complexity.

2.2.1 Testing

2.2.1.1 Test Points. The selection of test points must be carefully made based upon circuit functions and conditions. A critical examination of the equipment block diagram and schematic is necessary. Major test points should be provided with suitable terminals, readily accessible. A turrett terminal, properly designed is satisfactory. Terminals on tube sockets and other inaccessible points are not satisfactory. Where critical circuits, or high voltages are involved a simple isolating arrangement may be used.



ISOLATION OF TEST POINTS

A terminal board containing key test points and located above-chassis is desirable. No disassembly should be required to use test points. A multipoint selector switch is practical in some applications.

2.2.1.2 Failure Indicators. Fuses should be supplied with neon indicators to indicate failure. In complex equipment where functions are sectionalized, all sections, where applicable, should be provided with additional fuses.

Panel meters are an excellent means of indicating failure. A sufficient but minimum number to monitor all critical functions should be provided. In some applications, meter scales may be colored to indicate the normal operating range. Where equipment is to be automatically protected, high and low limit alarm contacts on the meter are useful. "Push-to-read" buttons or rotary multiple contact switches enable several points to be monitored with a single meter.

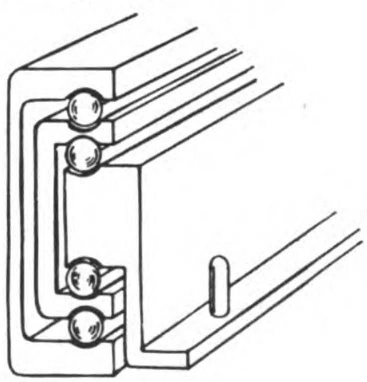
Monitoring oscilloscopes and similar apparatus may be used where waveform, in addition to magnitude, must be critically monitored. Suitable switching arrangement can extend the usefulness of a single oscilloscope. In many cases, where a cathode-ray tube is provided for operation, switching arrangements can be made to adapt the tube for maintenance purposes.

2.2.1.3 Built-In Testers. Built-in test facilities are more desirable than portable test equipment in achieving rapid servicing. These facilities should provide for over-all performance checks and circuit isolation. For example, in a radar apparatus, means should be provided to continuously monitor the power into the antenna; a built-in noise generator coupled to the receiver imput would quickly check its performance.

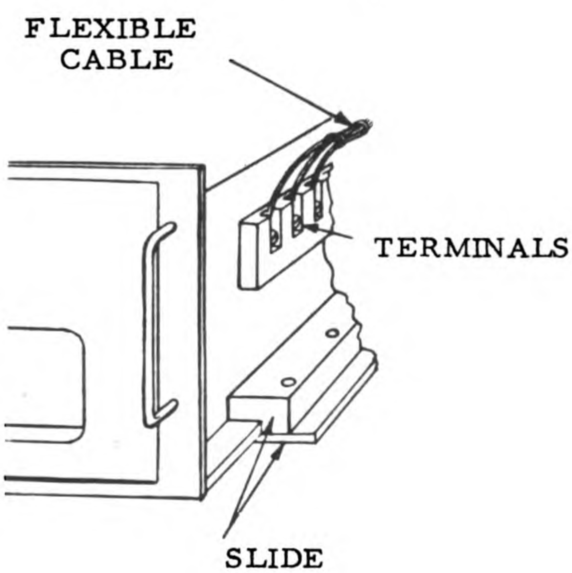
2.2.1.4 Test Equipment. There are many standard test equipments available for maintenance purposes. The design of systems should be such that special test equipment is not required. This can sometimes be accomplished during circuit development by making proper provisions to adapt the circuit to be measured to the test equipment characteristics. Use of built-in adapters is a simple solution.

2.2.2 Assembly Slides

2.2.2.1 Types. Where equipment is complex and of unitized construction, chassis slides, runners, and tilting mechanisms are usually required.

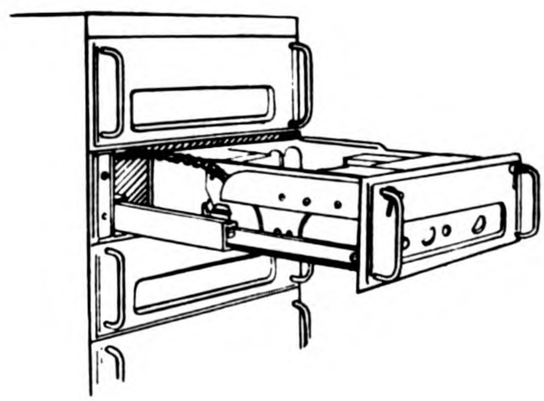


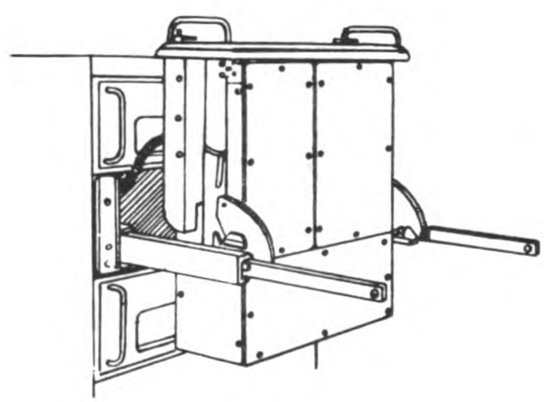
ROLLER SLIDE



Continuous operation of such equipment under severe environmental conditions requires that rapid servicing be possible. Withdrawal must be toward the front of the equipment, and provisions should be incorporated to prevent damage to any rear-connected cabling.

Position locking of the chassis in operating position is required. A stop must be provided to limit the extent of withdrawal. Additional provisions for positioning during maintenance, such as devices for tilting and turning must be made accident proof.





AN APPROVED ARRANGEMENT

Some expedients which can be used in conjunction with these arrangements are counter-balancing springs, adequate detents, and over-center locking linkages.

Complete release and removal of the chassis must require another manual releasing operation.

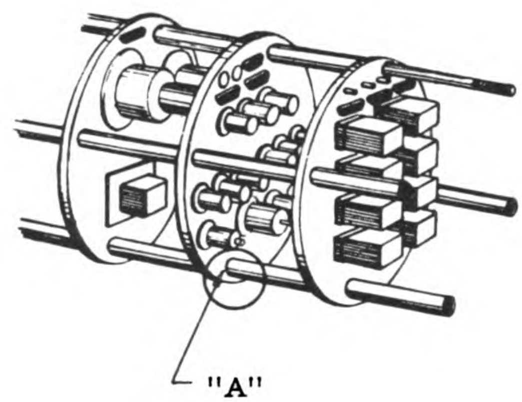
2.2.2.2 Permanent Links. Where interconnecting cables are permanently wired at one end to a terminal board, adequate preparation and location of the cable must be considered. Cables should be suitably sheathed with flexible plastic sleeving and anchored to the chassis. Storage space and an obstruction-free path prevent chafing when the chassis is moved. The cable must be long enough to permit disconnection with the chassis withdrawn. Strain on individual wires must be avoided by proper lacing, and strain-relieving clips or clamping devices.

2.2.2.3 Auxiliary Links. Where the chassis is of the "plug-in" type, similar to a module, an auxiliary "link-connecting" cable with mating plugs may be supplied for maintenance purposes. This method allows rapid removal of equipment for testing.

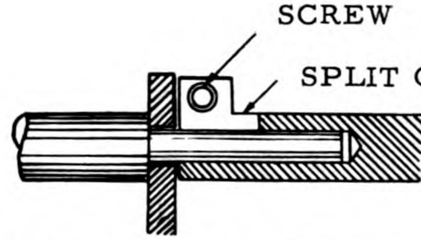
2.2.3 Replacing Subassemblies. All essential subassemblies should be mounted, when practicable, so that they may be removed as a unit. This applies to mechanical as well as to electrical and electronic units. Riveting, welding, and other permanent methods of fastening must be avoided. "Pile-ups" of assemblies that necessitate a chain of removals should be avoided. The need for special tools should be minimized, but, if necessary, such tools must be supplied with the equipment.

Free access to parts in large equipment requires adequate doors, covers, and openings.

Replacement of any part should be possible from the front of the equipment.



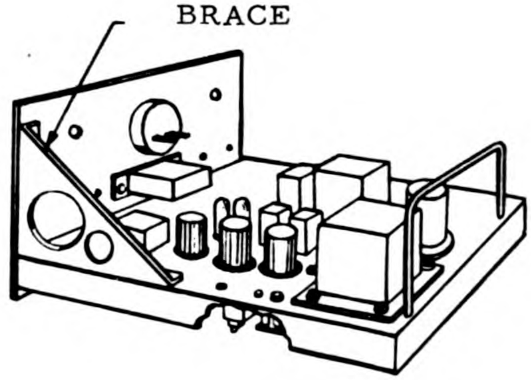
DIFFICULT TO DISASSEMBLE



SCHEMATIC ASSEMBLY AT "A" TO FACILITATE DISASSEMBLY

2.2.4 Replacing Parts

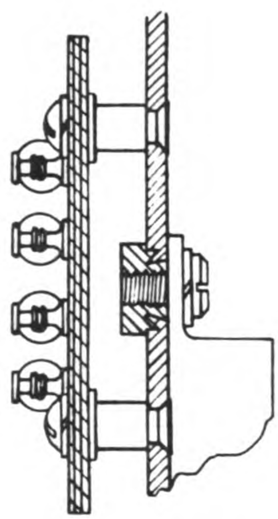
2.2.4.1 Accessibility. Any feature that leads to better accessibility should be a prime consideration of design.



PARTS ACCESSIBLE

Ease of replacement and maintenance should take precedence over manufacturing simplifaction. The type of enclosure required to meet the environmental conditions imposed should be constantly kept in mind when designing for accessibility.

All component mounting areas should be utilized uniformly to prevent the crowding that may result from the inefficient use of space.



APPROVED MOUNTING

This provides increased accessibility to fastenings and leads. Ample clearance must be provided for installation and the securing of screws and nuts.

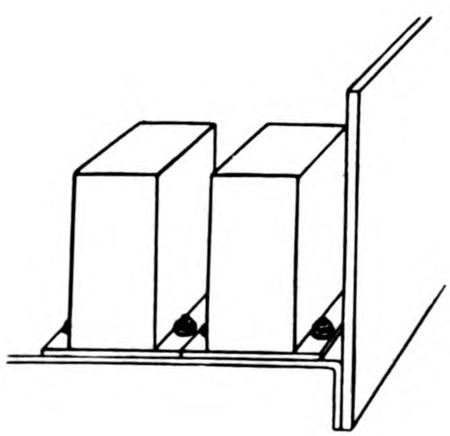
Component fasteners should not be located under cabling and apparatus. Permanently secured bolts and fasteners should be used wherever possible.

Finger room for starting nuts and screws must be provided. Nuts must not be located close to a barrier such that a spinner or socket wrench cannot be used to properly engage them.

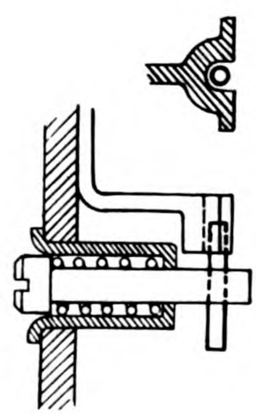
Clearance holes for screws must be large enough and located suitably to allow for variations in component mounting holes.

Small screws, nuts, washers, pins, clamps, springs, and similar hardware are difficult to handle. For facility in assembly, the largest practical size of screws, nuts, washers, and clamps should be employed. Inaccessible fasteners should be avoided.

2.2.4.2 Removal Method. A single chassis panel and cabinet combination usually requires captive screws or quick-locking fasteners as the panel attachment element.



INACCESSIBLE FASTENERS



QUICK LOCKING FASTENER

Where the chassis is provided with a bottom plate, quick-locking fasteners permit rapid access. It is desirable to supply sturdy mechanical devices on the chassis such that the unit may be placed in any position for servicing without damage to components.

Sectionalized construction offers considerable advantages in ease of maintenance. Minor repairs can be made with the equipment in position or single units can be removed and carried to the service bench for repairs. For easy maintenance, the depth of equipment is usually limited. Cables, terminals, receptacles, and similar connections should be easily accessible.

Large and heavy parts must be located so that their replacement is possible. Heavy power transformers or rotating equipment should be located in the lower sections.

Accessibility of cabinet-rack enclosures and consoles made of sheet metal is usually somewhat reduced because size of the access opening is limited in area by the bracing requirements. The rear surface of many equipments, particularly where depth is considerable, is located against walls. The use of slides and drawers is especially important in this type of equipment.

Where waterproofing and splashproofing are required, access plates are held against gasket seals by means of captive screws or the equivalent. Removable doors with suitable clamp-lock handles, offset hinges, gaskets, and similar attachments are required to provide ready access for minor servicing.

Hinged doors should be provided with position retainers to prevent accidental closing when equipment is installed aboard ship or in a moving vehicle.

2.2.4.3 Tools. Equipment should be designed to minimize the need for special maintenance tools. Tools not ordinarily commercially available should be considered "special."

It is good practice to forward a list of special tools to the agency concerned for approval. Those items deemed necessary may be mounted in the equipment or located in a separate container.

2.2.4.4 Wiring and Slack. Cabling technique in the vicinity of terminals should be planned carefully for ease of parts replacement. Enough slack should be provided for each lead to permit at least one replacement. Cable ends well "fanned out" are required to prevent errors in connections and permit rapid installation.

Chapter 3

ASSEMBLY DESIGN

3.0 GENERAL

The following material is intended for use by the designer when formulating a general plan and layout for an assembly and should aid in solving specific problems relating to assembly design. A plan and layout involve the arrangement of all the parts and a preliminary conception of the structural form which will include a consideration of all factors. The final design is usually a compromise in which these factors are satisfactorily adjusted to meet performance requirements.

The table of contents of this publication is helpful as a checklist for the design of an assembly. Before attempting a layout, a review of all subjects would be of assistance. As the layout and general plan progress, and as problems arise, reference to specific subjects can be made through the index.

A tabulation of all the requirements stated in the equipment specification is helpful. In addition, a study of all other referenced specifications should be made. Often these specifications yield enough information to establish a plan for an assembly design.

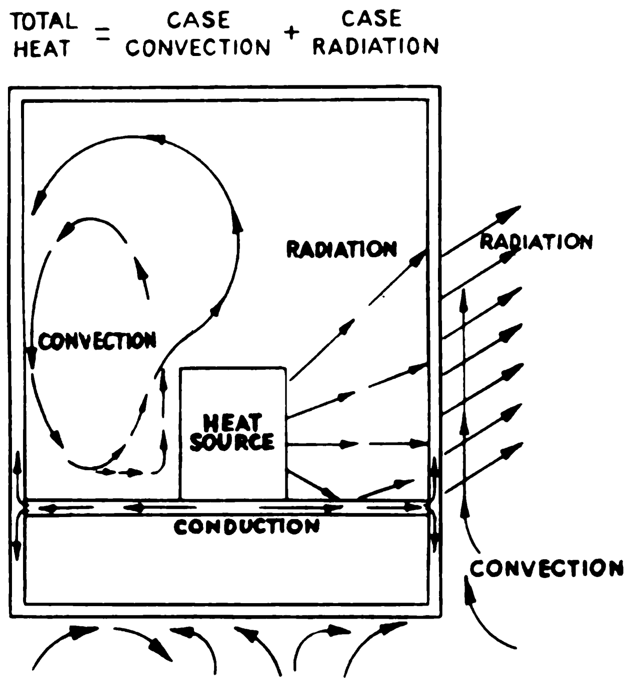
3.1 HEAT TRANSFER

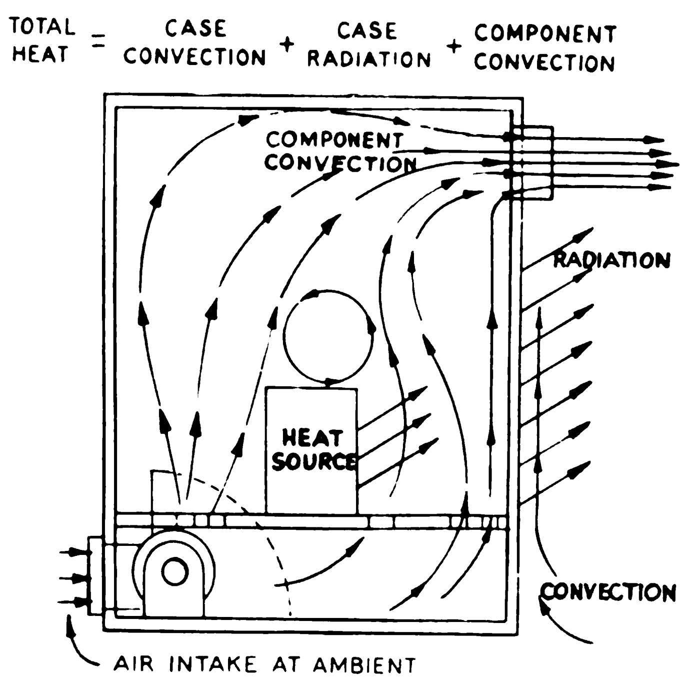
The reliable performance of electronic equipment is greatly influenced by operating and ambient temperatures. Military equipment is subjected to temperature conditions which vary widely, Individual equipment specifications may call out one of several operating and nonoperating temperature ranges. High temperature operating limits vary from 50°C to 65°C. Low temperature operating limits vary from 0° to -55°C. Nonoperating limits are usually -62°C to 85°C. Nonoperating limits are significant in that equipment shall not be damaged nor shall the operational performance be degraded when restored to operating temperatures.

Each + 75°C source of heat should be carefully examined in order to eliminate excesses. For example, high efficiency rectifiers and inductors should be utilized and power supplies should not be overdesigned or overloaded. Heat-sensitive parts should be separated from heat-generating elements.

Insulation life is materially affected by temperature. Chemical reaction rate, plasticizer migration, and softening increase in direct proportion to the temperature, resulting in a degradation of materials and decreased operating life.

Heat removal may be divided into three phases: removal of heat from the source, transfer of heat along a thermal bus to a sink, and dissipation at the ultimate sink. The heat transferred in each phase is a combination of conduction, radiation, and convection.





As illustrated, all three types of heat transfer may occur at the same time, and it is recommended that each type be considered in any particular case.

A discussion of each of the fundamental types of heat transfer is given as follows.

Heat Transfer by Radiation.- Radiation is a surface phenomenom. Surfaces emit and absorb radiant energy in various degrees, depending on the nature of the surface.

The rate of heat transfer is expressed as follows:

$$H_r = \epsilon \times 3.7 \, (T_o^4 - T_a^4) \times 10^{-11}$$

where H_r is the heat radiated in watts per square inch, ϵ is the absorption coefficient of the receiving surface; T_o the absolute temperature of the emitting surface in degrees Kelvin; and T_a the absolute temperature of the absorbing surface in degrees Kelvin.

Average values of radiation (and absorption) coefficients are presented in the table below.

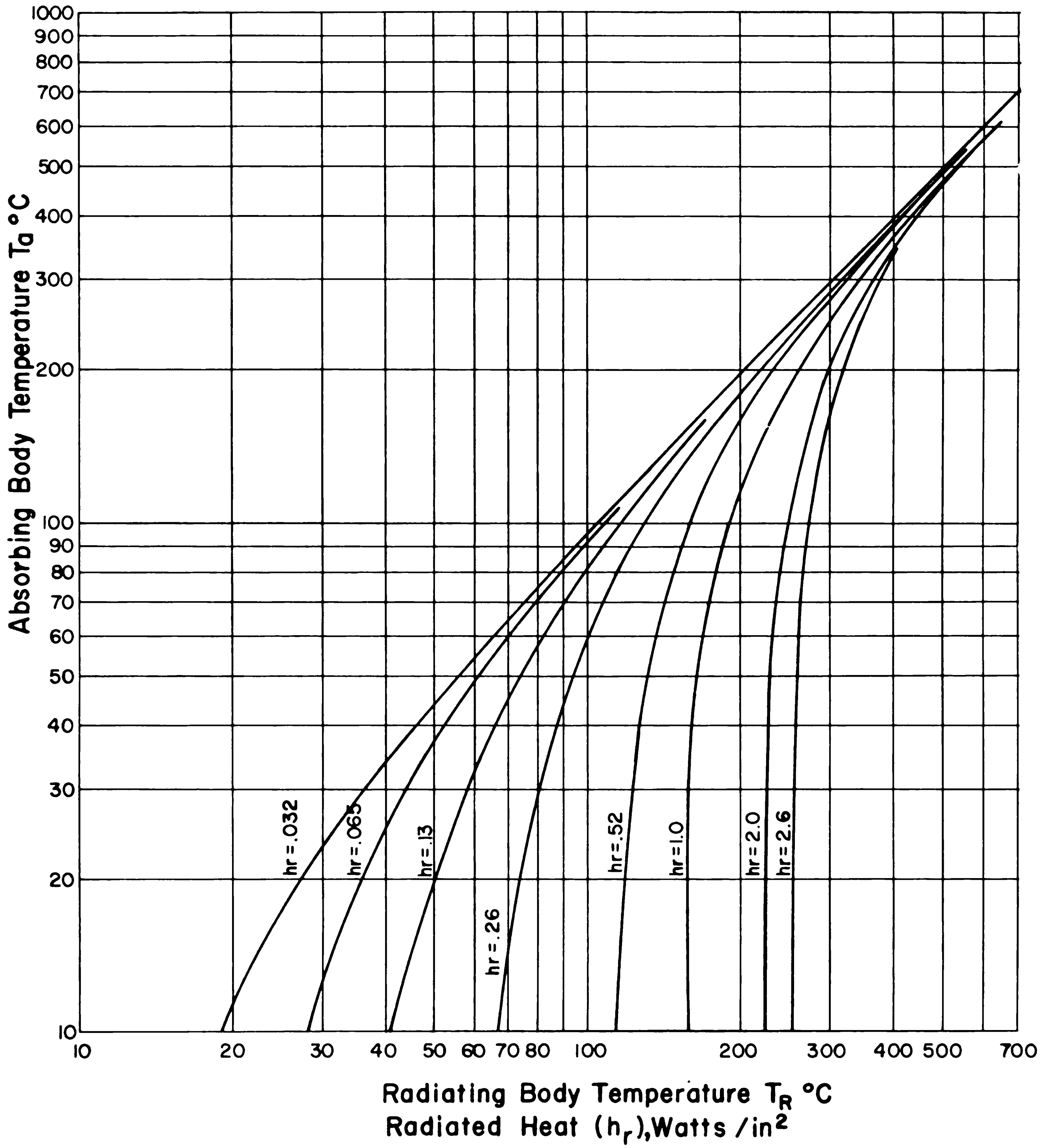
*Average Values of Radiation (and Absorption) Coefficients

Material	Radiant-Energy Coefficient
Black body	1.0
Lampblack	0.95
Asbestos board	0.93
Steel, oxidized	0.79
Copper, oxidized	0.72
Lead, oxidized	0.63
Cast iron, oxidized	0.62
Cast iron, bright	0.22
Brass, oxidized	0.60
Brass, polished	0.10
Nickel, oxidized	0.42
Zinc, oxidized	0.11
Silver, polished	0.03
Aluminum, polished	0.04
Aluminum, oxidized	0.11

*Data obtained from Standard Handbook for Electrical Engineers, Eight Edition, McGraw-Hill Company.

As illustrated, radiation coefficients vary from 1.0 for a black body to 0.03 for a polished silver. Surface finish is quite significant. Low emissivity is synonymous with high reflectivity

The rate of heat transfer by radiation, H_r in watts/inch can also be determined graphically from the curves which follow. All curves have been plotted for ϵ equal one. If the value of ϵ is less than one, multiply the radiated heat obtained from the curves by ϵ .


Absorbing Body Temperature Ta °C
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
100
200
300
400
500
700
hr=.032
hr=.065
hr=.13
hr=.26
hr=.52
hr=1.0
hr=2.0
hr=2.6
Radiating Body Temperature T_R °C
Radiated Heat (h_r), Watts /in²

Heat Transfer by Conduction.- Heat transfer by conduction can take place in all three states of matter, i.e., solids, liquids, and gases. The amount of heat that flows through any body by conduction depends upon the time of flow, the area through which it flows, the temperature gradient, and the type of material. The rate of heat transfer by conduction is expressed by the following relation:

$$H_c = k\,At\,\frac{\Delta T}{L}$$

where H_c is the rate of heat transfer by conduction in watts/square inch; k is the thermal conductivity in watts/(in^2-sec.-^{o}C/in) when H_c is measured in watts/square inch; A the area of the cross section of the path of heat measured at right angles to the direction of flow of heat in square inches; t the time the flow continues in seconds; and $\Delta T/L$ the temperature gradient. The symbol ΔT is the difference in temperature in degrees Centigrade between two parallel surfaces a distance L, in inches, apart.

There is a noticeable difference in the thermal conductivities of various materials. Gases have low conductivities. Liquids also are generally poor conductors. The conductivities of solids vary over a wide range, from the very low values for asbestos fiber or brick to the relatively high values for most metals.

An illustration of the range of thermal conductivity of various metals is presented in the plot of Temperature Drop vs. Heat Transfer by Conduction.

The rate of heat transfer by conduction can also be obtained graphically from these curves. All curves are plotted for A=1 in^2, t=1 sec, L=1 in. For other values of A and t, multiply H_c obtained from the curve by the desired value. For other values of L, divide H_c obtained from the curve by the new value of L.

To determine the rate of heat transfer by conduction of a material not illustrated by these curves, multiply the ratio of thermal conductivity of the desired material to the thermal conductivity of any material illustrated by the amount of heat transfer by conduction.

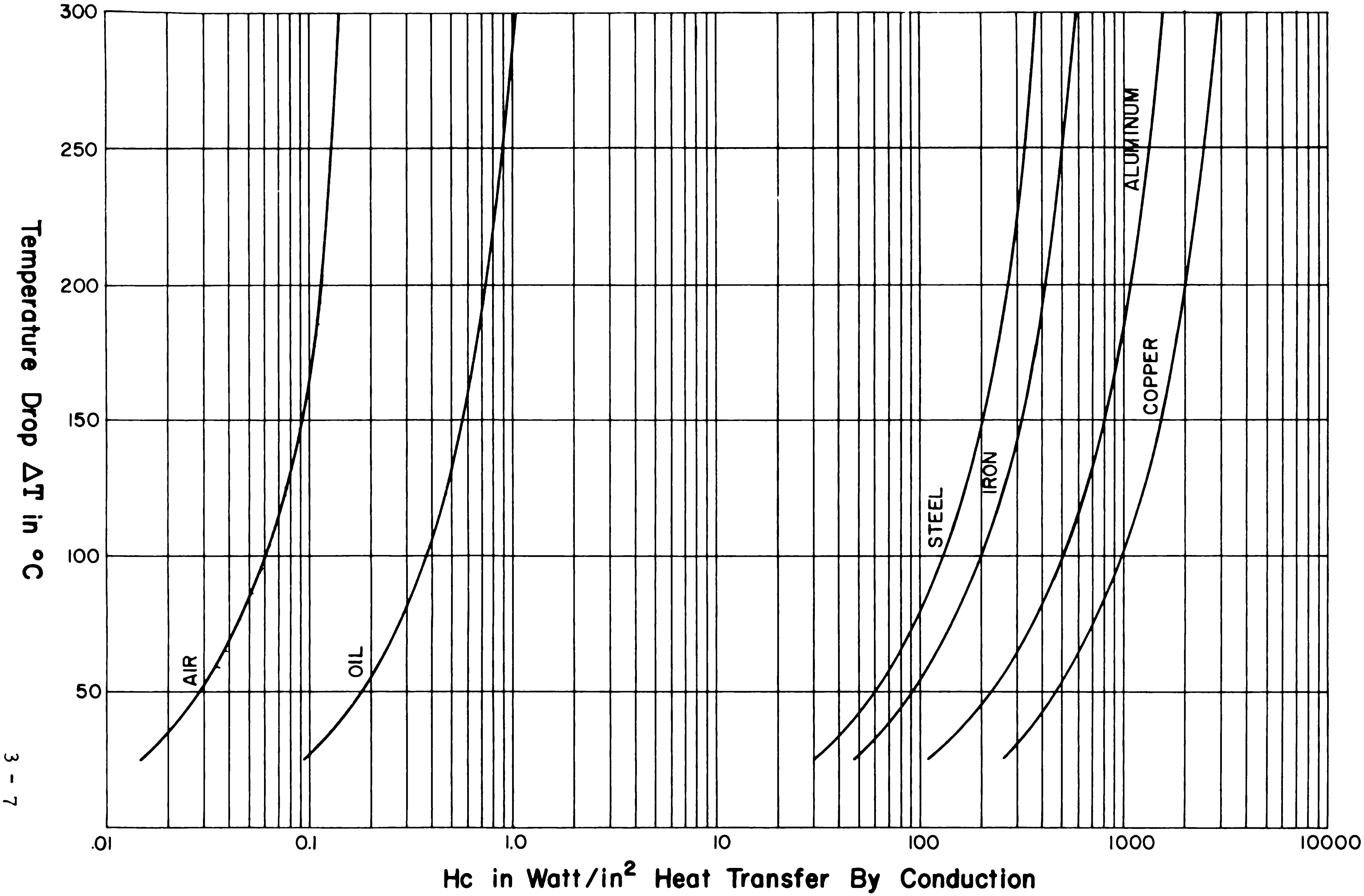
Example: Find the rate of heat transfer of silver for a temperature differential of 150^{o}C.

k for silver = 10.3 watts/(in^2-sec. - ^{o}C/in)
k for copper = 9.75 watts/(in^2-sec. - ^{o}C/in)

Ratio of $\frac{k_{Ag}}{k_{Cu}} = \frac{10.3}{9.75} = 1.054$

From the plot:

H_c for copper for ΔT = 150^{o}C is 1030 watts/in^2
H_c for silver for ΔT = 150^{o}C is 1030 x 1.054 or 1085 watts/in^2


300
250
200
150
100
50
Temperature Drop ΔT in °C
.01
0.1
1.0
10
100
1000
10000
Hc in Watt/in² Heat Transfer By Conduction
AIR
OIL
STEEL
IRON
ALUMINUM
COPPER

Heat Transfer by Convection.- Natural convection is the transfer of heat to or from a surface by the movement of a fluid when this movement is caused solely by a difference in fluid density.

Heat transfer by natural convection in free air is expressed by the following equations:

$H_{cv} = 11.70\ (\Delta T)\ 1.25 \times 10^{-4}$ from a vertical surface*

$H_{cu} = 15.80\ (\Delta T)\ 1.25 \times 10^{-4}$ from a horizontal surface facing upward*

$H_{cd} = 8.20\ (\Delta T)\ 1.25 \times 10^{-4}$ from a horizontal surface facing downward*

In all cases H_c is in watts/square inch and ΔT is the temperature differential in degrees Centigrade.

The first equation listed above applies to a vertical plane more than 12 inches in height. For height less than 12 inches multiply the coefficients by the appropriate constant listed below:

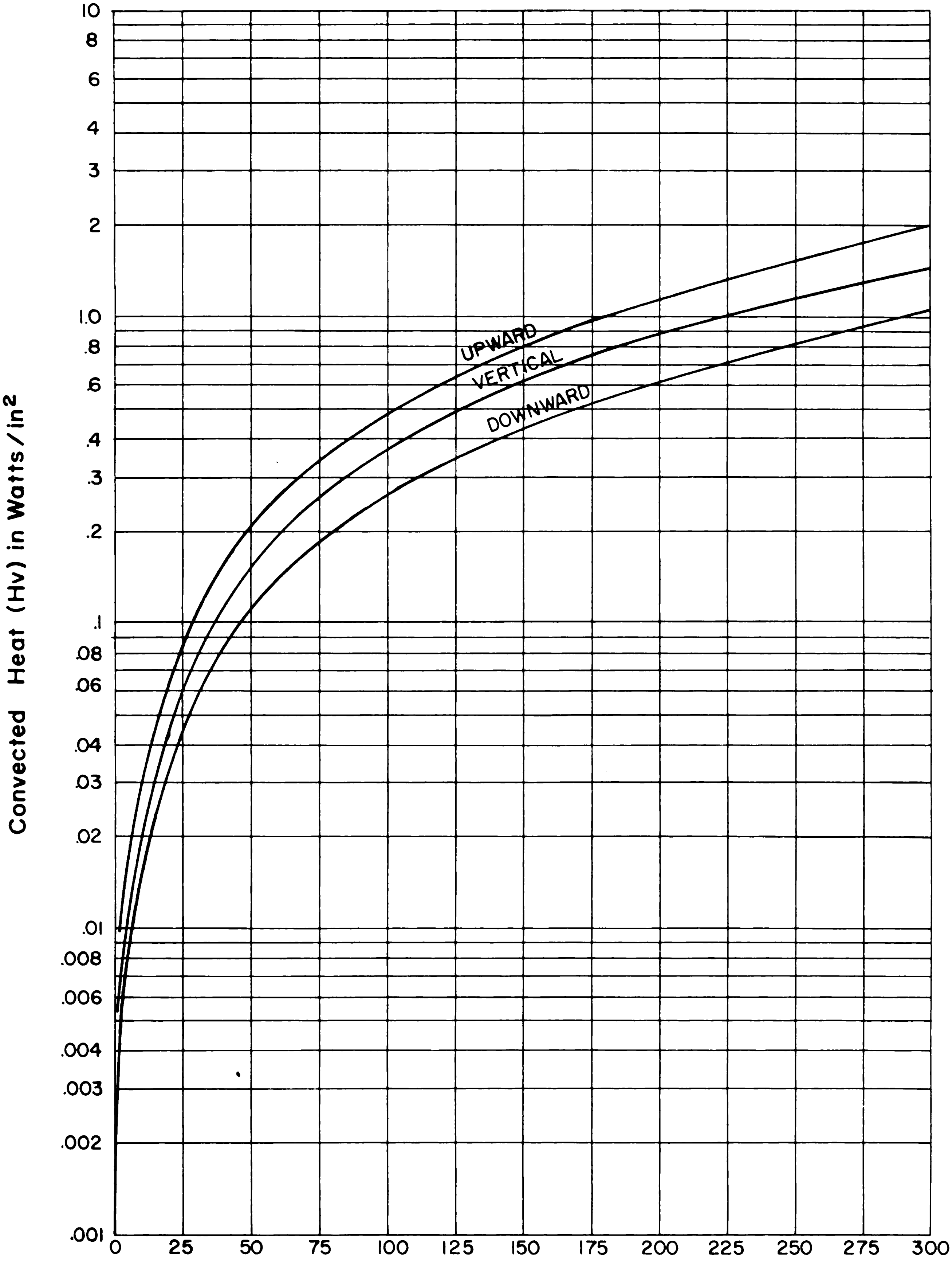
Height in Inches*	Constant
8	1.35
6	1.53
4	1.76
2	2.70

*Obtained from Standard Handbook for Electrical Engineers, Eighth Edition, McGraw-Hill Book Co.

Heat transfer by natural convection is presented graphically in the following curves. As illustrated by these curves, the rate of heat transfer by natural convection from a horizontal surface facing upward is about 35 percent greater, and the rate from a horizontal surface facing downward is about 30 percent less than from a vertical surface.

The amount of heat transfer by convection can be increased by inducing a draft over the surface. This is known as heat transfer by forced convection.

In summary, the total heat transfer of a body is the sum of conduction, radiation, and convection in watts/square inch.



Rate Of Heat Transfer By Convection In Free Air (Hv)

3.1.1 Parts

For parts using Class A insulation (magnet wire insulation rated at 105°C) the maximum temperature should not appreciably exceed 105°C. At 130°C, service life expectancy is reduced from 10 years to as little as 6 months. High quality solid impregnation, oil sealing, and Class B insulation permit higher temperature operation. Class H insulation provides long life at 200°C. All classes are described in the specifications for insulation.

Oriented grain or tape wound core materials are desirable to reduce core losses. Enclosed, potted transformers provide a larger heat-dissipating surface area and improved thermal conductivity between the windings and case.

When such cases are bolted to a good thermal sink, substantial amounts of heat can be dissipated.

Inductors should, if possible, be located near a cabinet corner or other metallic thermal sink.

Composition resistors operating at full rating are materially affected at 105°C ambient. Their resistance values may change appreciably.

A 2-watt size resistor may permanently increase in resistance by 40%; a 1-watt size, 7%; and a 1/2-watt size, 5%. If environmental temperatures are high, resistors should be derated in accordance with tables established in the applicable specifications. A minimum derating of 50% is normal. Composition resistors used in bridge-balancing networks, feed-back loops, and similar circuits must be located in comparatively cool areas.

Wire-wound, deposited-carbon, boro-carbon, palladium, and other resistors are designed for high temperature applications. Since most heat lost by resistors operated at full ratings is by radiation, they should not be located adjacent to heat sensitive apparatus.

Bleeder resistors should be located adjacent to cabinet or chassis surfaces that provide good thermal sinks. Wire-wound, metal-encased types can be attached directly to outer chassis walls. Leakage resistance of paper capacitors decreases approximately 50% for each 10°C rise in temperature. This is of especial significance in coupling applications.

Paper filter capacitors are often incorrectly located near heat-producing elements. If properly derated and selected, they may be operated at comparatively high temperatures up to approximately 125°C. Direct radiation from electron tubes must be avoided.

Mica and glass dielectrics are reasonably stable at 105°C. However, the plastic cases, when used, are subject to deterioration at temperatures above 120°C.

At temperatures exceeding 85°C, barium titanate capacitors are subject to appreciable capacitance and resistance variations. If used as frequency-controlling elements or calibrated reactances, they must be mounted in a protected location of minimum temperature variations.

Tantalum electrolytic capacitors of the foil type are satisfactory at temperatures up to 85°C; the sintered-anode type with some voltage derating up to 200°C.

Aluminum electrolytic capacitors of the better grades are subject to reduced life and decreased capacitance if temperatures are in excess of 85°C. Such capacitors, when used, should be bolted to a suitable thermal sink or otherwise protected.

Electron tubes are the chief source of heat in equipment. Seventy-five to 85 percent is due to plate dissipation. As glass envelopes have been progressively reduced in size, heat dissipation has increased from roughly 1 watt per square inch to more than 3 watts per square inch for some subminiature electron tubes. Glass temperatures in high ambients (70° to 100°C) can easily exceed manufacturers ratings and thereby decrease tube life and reliability. Most tubes are rated by the manufacturer for a maximum bulb temperature of 200°C.

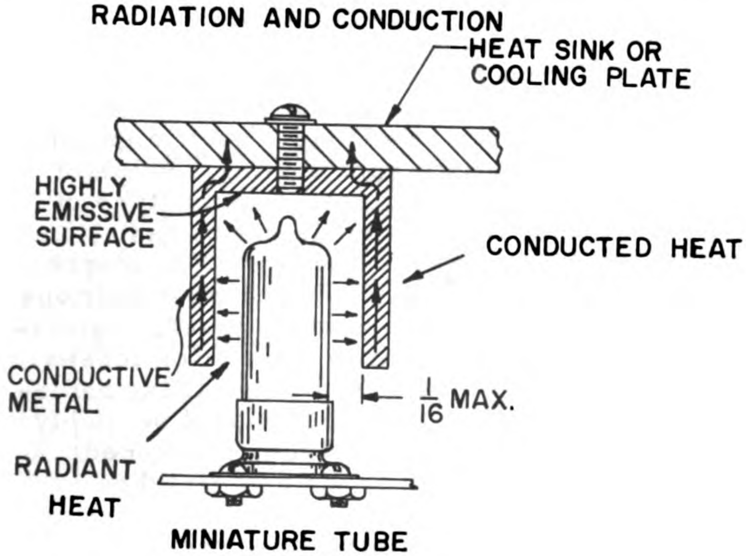
In subminiature applications, bulb temperatures above 200°C may reduce tube life to less than 1000 hours. Causes are: vaporization of cathode materials; evolution of gas from "getters" and glass, resulting in increased positive ion bombardment of the cathode; and aggravated electrolytic deterioration of glass at the seals. Grid current is affected by the foregoing factors, and this tends to circuit instability.

There are many methods for heat control; some of these considerations are given below.

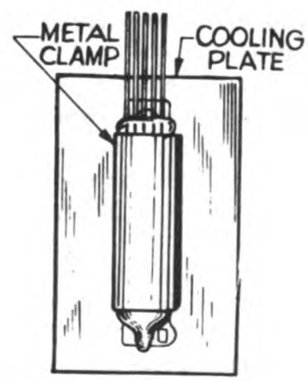
Loosely fitted tube shields increase bulb temperatures. Where electrostatic shielding is unnecessary, shields may be replaced with a "top-hat" retainer.

Shields should be made highly emissive and thermally conductive to the chassis. Highly polished shields are poor radiators. Heavy, rough, oxidized-copper shields with vent holes should be used for best heat conduction, convection, and radiation.

A high temperature source of heat, such as a tube, may dissipate energy by conduction into a large surface area-lower temperature sink. Large cross-sectional area and short paths are necessary for effective heat transfer.



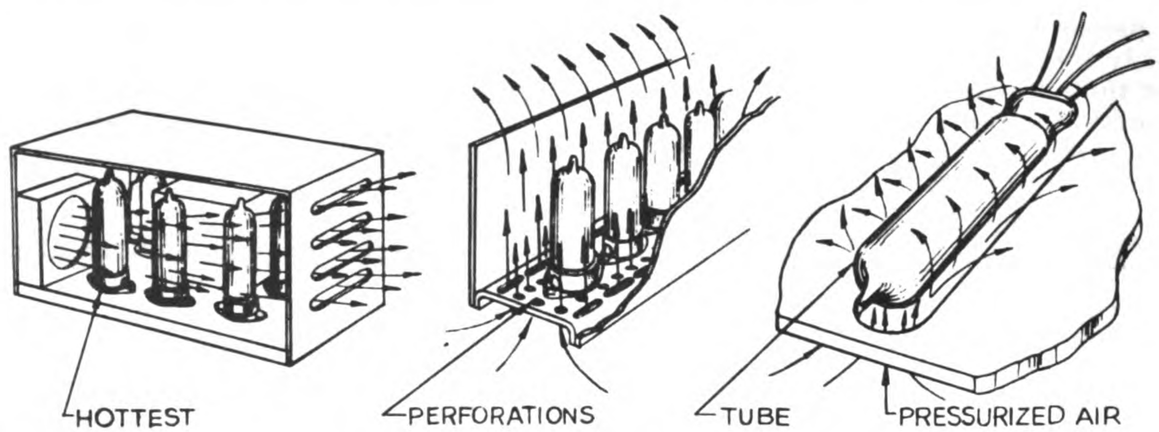
MINIATURE TUBE



SUB MINIATURE TUBE

Mechanical joints should be close fitting to provide a maximum of metal-to-metal contact. In some instances, silicone greases have been effectively utilized to improve joint conductivity.

Cooling by means of convection normally accounts for half of the heat losses. It has been found that for free convection, the coefficient of transfer increases directly with the temperature differential. Thus, for high ambients where the temperature differential is relatively small, free convection will afford relatively little cooling.



CROSS-FLOW COOLING GOOD

INDUCED AIR FLOW FAIR

TURBULENT AIR FLOW FOR EXTREME "HOT SPOTS" GOOD

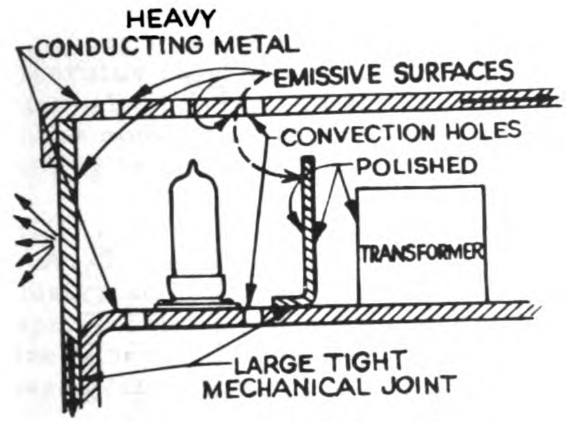
To provide sufficient cooling in high ambients, forced convection must be used. In the transfer of heat by forced convection the velocity of the fluid is the main factor to consider. This effect of velocity and the flexibility of its control together with the penetrating property of gases provide an effective means of heat transfer in many cases. Three methods of an effective means of heat control can be achieved by means of forced convection. Each of these methods are discussed individually in the paragraphs that follow.

High transfer coefficients can be attained by forcing cool air over the hottest part of the heat sink.

Where the characteristics of the air flow change from laminar to turbulent, the transfer coefficients increase sharply. Such air flow should be directed through slits or orifices to the desired areas for efficient cooling.

Radiation plays an important role in cooling tubes at high temperatures. The type of glass used for electron tubes has a coefficient of emissivity approaching a value of 1.0. With a glass temperature of 200°C, the coefficient of radiation is almost independent of ambients up to 75°C. Under these conditions, radiation dissipation losses materially exceed free convection losses.

To most efficiently utilize radiation, the heat sink should be highly emissive. Oxidized, blackened, roughened, or wrinkle finishes provide good emissivity. Practically all oxide paints, irrespective of color, have an emissivity of 0.05 to 0.2 and may be used to shield a component if temperatures are not high.



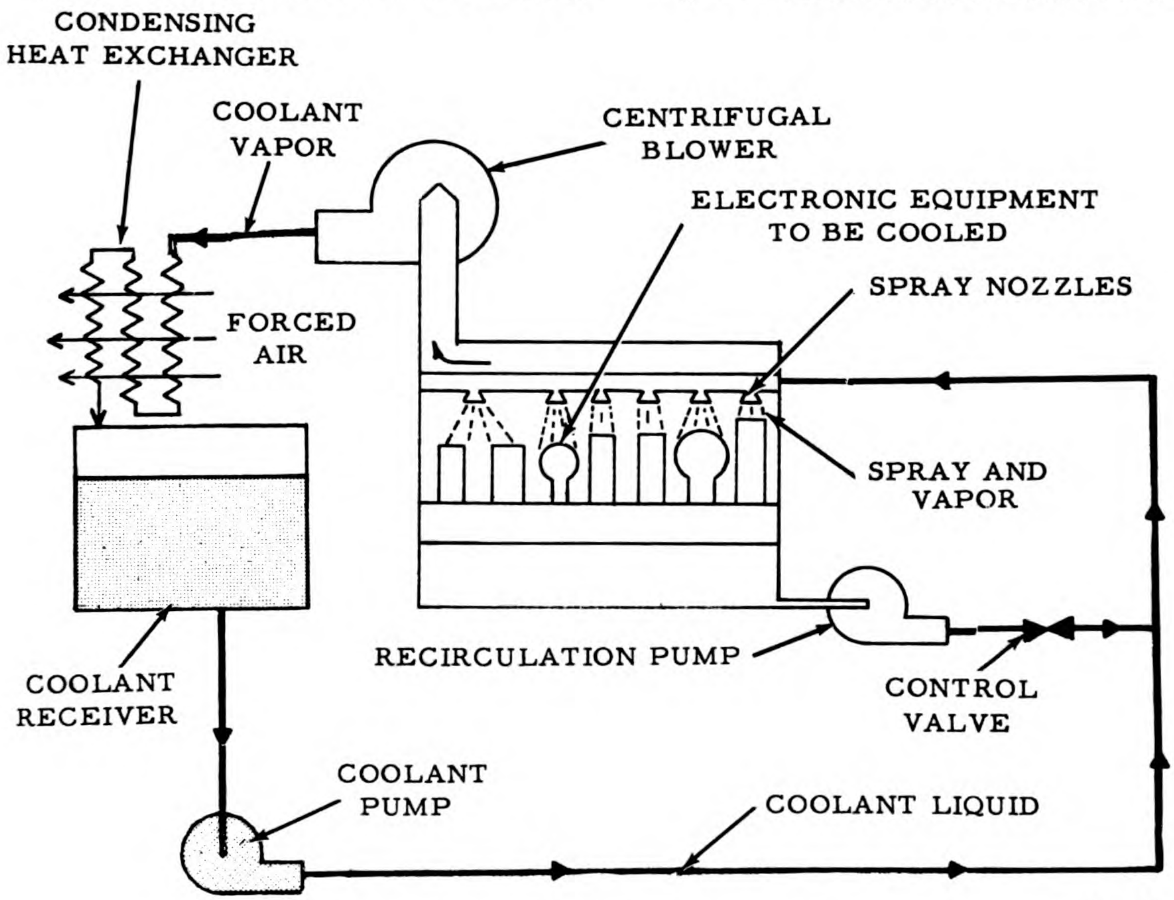
UTILIZING EMISSIVITY AND CONDUCTIVITY

Cooling of electronic parts and equipment which must operate with high heat concentrations may be very effectively accomplished by liquid or vaporization cooling. Vaporization cooling, shown in the accompanying illustration, is the most effective of the various methods in current use.

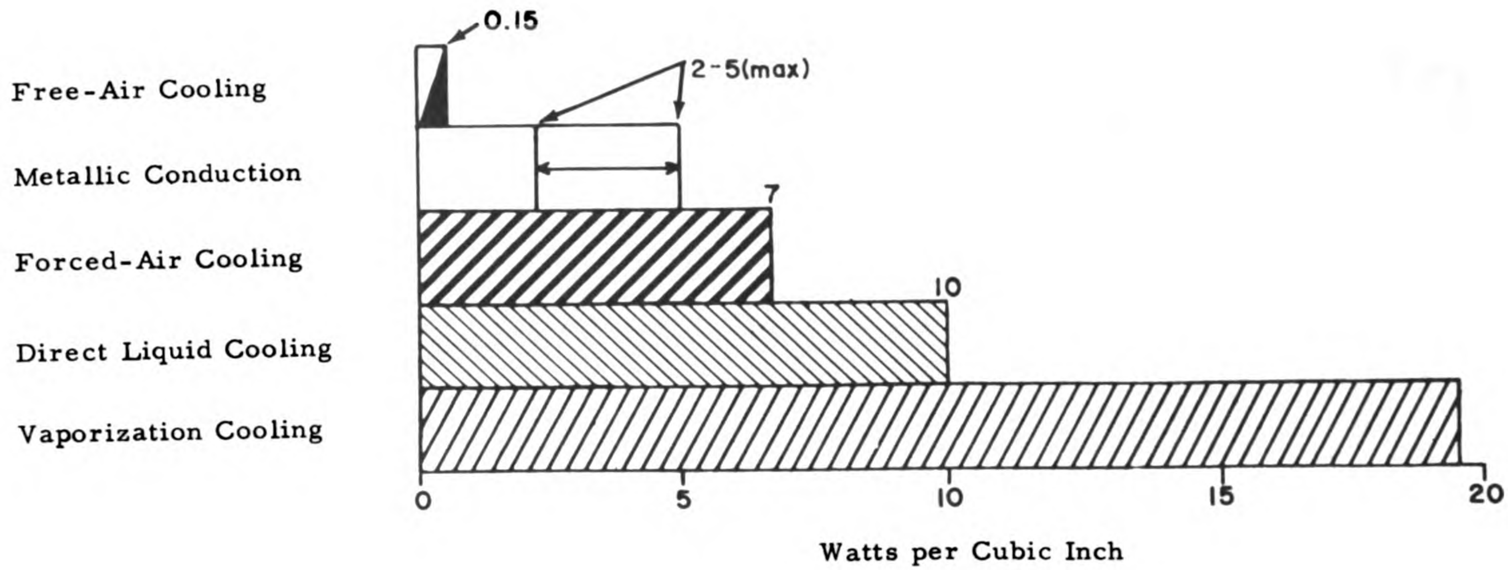
Liquid or vaporization cooling, however, is restricted to circuits which can function satisfactorily despite the increased stray capacitance and electrical losses resulting from the use of liquids. The liquid coolant selected must be chemically and electrically compatible with the electronic parts and the case.

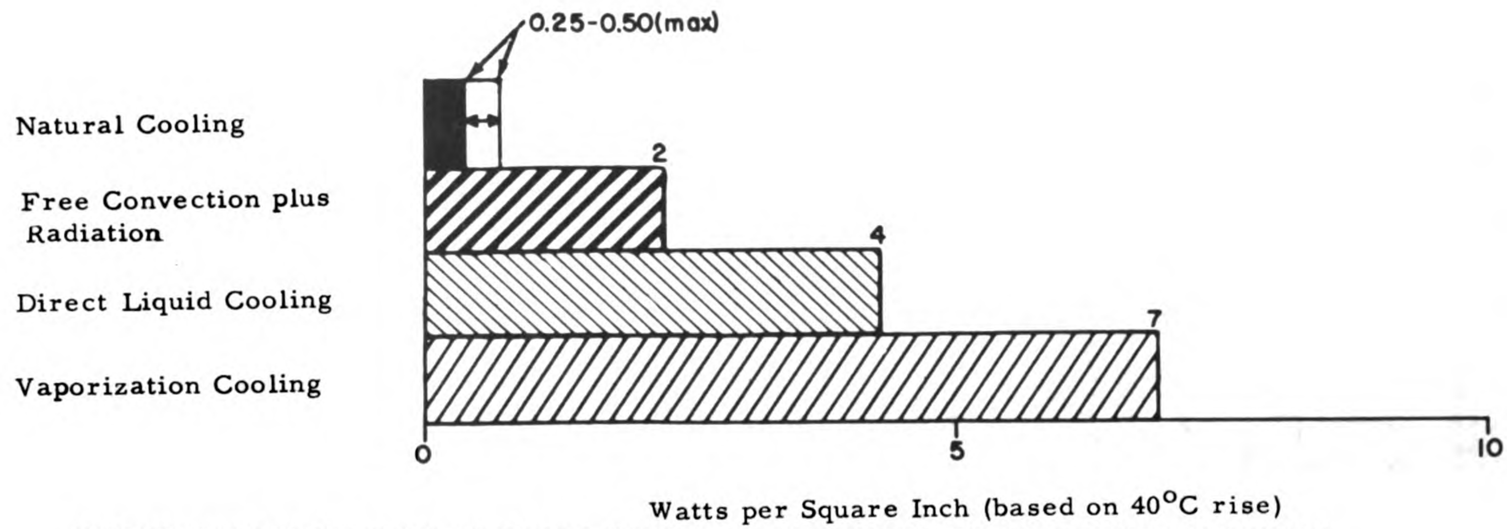
The first chart on the following page gives a comparison between the amount of heat which may be effectively removed from a sealed unit by vaporization cooling, direct liquid cooling, forced-air cooling, metallic conduction, and free-air cooling.

The second chart on the following page gives a comparison between the amount of heat which may be removed from an external surface by vaporization cooling, direct liquid cooling, free convection plus radiation, and natural cooling.



VAPORIZATION (SPRAY) COOLING





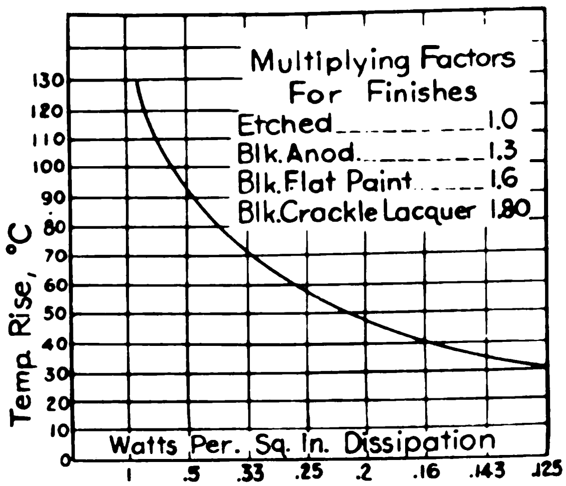
COMPARISON OF THE AMOUNT OF HEAT REMOVED BY VARIOUS METHODS OF COOLING

3.1.2 Cases and Cabinets

Cases and cabinets enclosing apparatus must dissipate all internally generated heat except where convection or forced-air cooling is utilized.

3.1.2.1 Convection Cooling

A. Natural Convection Cooling. Illustrated here is a curve showing experimentally measured, combined convection and radiation losses from a typical cabinet.



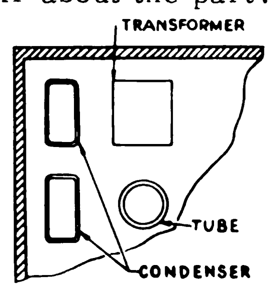
MEASURED HEAT TRANSFER OF ETCHED ALUMINUM CASE

For design purposes, basic transfer coefficients can be used to estimate the amount of heat transferred from a case containing heat dissipating components. This lengthy procedure for evaluating reasonably compact assemblies is to assume that internal air will be heated directly or indirectly by heat dissipating components to a temperature approximately 20% above that of the cabinet. Cabinet temperature rise can then be approximated from the preceding curve. Internal heat-generating components will be found to rise in temperature as indicated by curves for radiation, convection and conduction.

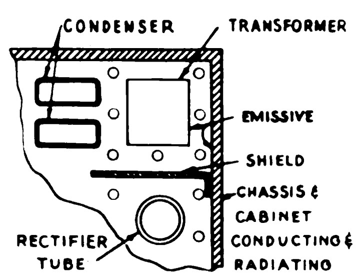
Openings such as louvers do not significantly improve cabinet cooling unless quite large and so designed that they present little or no resistance to air flow. Parts raised to a temperature of 105°C in a 50°C ambient (complete air circulation) tend to be cooled for the greater part by radiation and tend to nullify casual circulatory cooling.

Localized overheating should be avoided in the layout of components. Heat generating elements are usually located near cabinet walls, which when properly treated, serve as good sinks. Components are cooled appreciably by conduction if surfaces are separated by less than 1/16 inch.

There are instances where a combination of cooling devices is desirable for a temperature-critical part. As an example, a part heated only by an 80°C cabinet internal temperature can be effectively cooled toward a 50°C external ambient by installing radiation shielding and circulating 50°C air about the part.



TUBE AND TRANSFORMER HEAT IS CONFINED MARGINAL LAYOUT

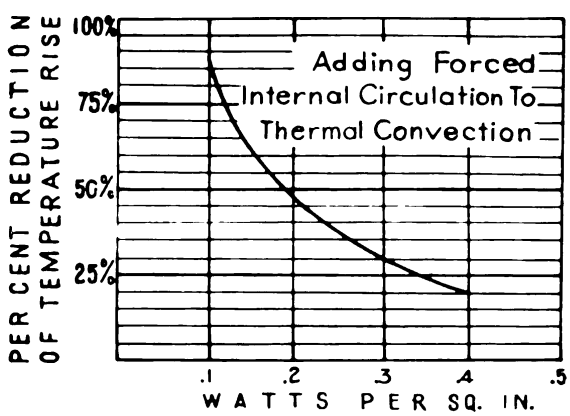


UTILIZING CABINET TO DIRECTLY DISSIPATE HEAT GOOD

Electron tubes are usually operated at temperatures below maximum ratings permitted for the glass, and should be located near cabinet walls if possible.

Adjacent apparatus may be protected by reflective shields to project heat into cabinet walls providing a rise in bulb temperature is permissible. A highly conductive material should be used as a shield to increase its effectiveness. It is good practice to make all internal cabinet, chassis, and component parts both emissive and conductive except those which require isolation from heat.

B. Internal Convection. Since heat dissipation within a case is not generally uniform, forced internal-air cooling may be required to eliminate "hot spots". The average temperature of case walls thus becomes somewhat lower, and more uniform. This type of cooling is recommended where moisture and dust conditions are severe.

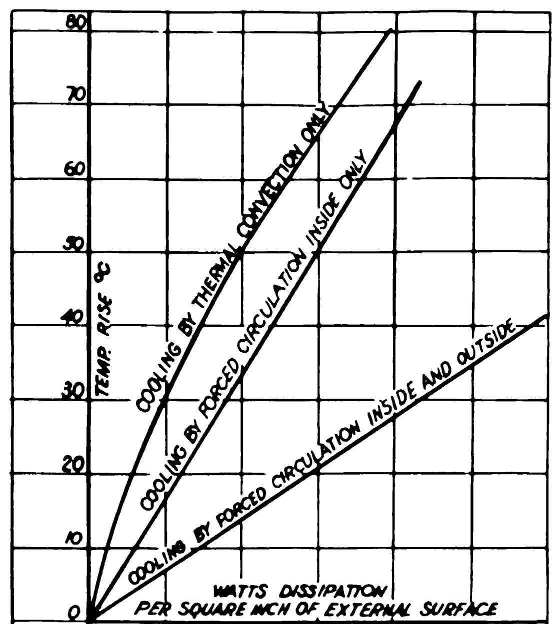


TEMP. RISE IMPROVEMENT TEST

Blower motor heat losses should be less than 25% of the total heat losses and can be as low as 10% in an efficient system.

To be effective, air velocities should be high at hot spots; otherwise, radiation transfer will predominate when temperatures exceed approximately 120°C. For general circulatory cooling, clear lines of air flow at large volume and low velocity are desirable.

C. Internal-External Forced Convection. Forced air cooling provides two benefits: lowered cabinet temperature serves as a more efficient radiation sink, and internal air temperature is reduced to nearly equipment ambient. Since it is moving at a greater velocity, it effects a higher temperature differential, thereby increasing convection transfer coefficients. Forced-air cooling is particularly desirable where normal radiation and convection paths are unavoidably restricted.

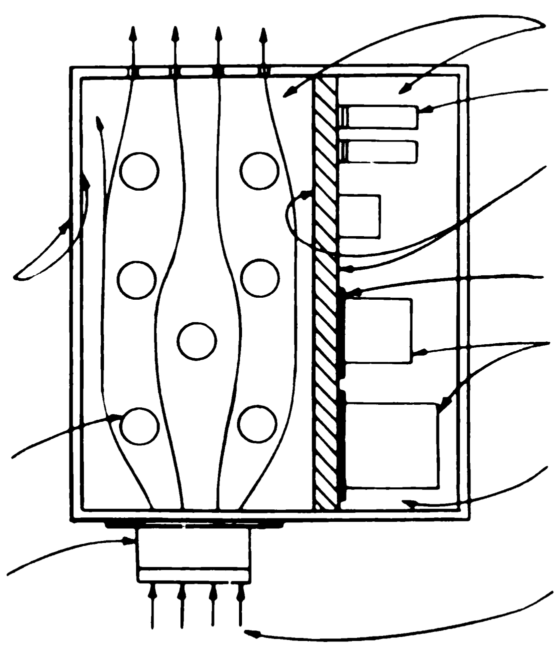


COOLING OF CLOSED CONTAINERS

Forced-air cooling will extract approximately 1 watt for each 1-1/2 cubic feet of air flow per minute per °C difference between input and output air temperatures. This should be considered as the minimum air flow necessary.

Baffles, channels, and similar air-control devices should be designed to cool hot spots without unduly impeding air flow. Free air-flow design results in more temperature reduction for a given blower. The air flow around unheated objects is wasted and therefore the flow should be concentrated across surfaces to be cooled.

Dust, water, and overcooling require attention. Air entrances should be fitted with dust filters which can be easily replaced. When louvers or other openings are used, precautions must be exercised to maintain the degree of enclosure required by specifications. The degree of overcooling relative to environmental conditions may be controlled by installing thermostatically controlled blowers or other devices.



FORCED IN-OUT AIR COOLING OF POWER SUPPLY

3.1.3 Liquid Filling and Potting.

Oils used in liquid-filled cases are excellent distributors of heat, and reduce hot spots to a minimum. Good thermal contact is provided by the fluid at all points. The thermal conductivity of such oils is about four times that of air. Oils should be temperature stable and must be compatible with the other materials with which they come in contact.

Miniaturized assemblies, enclosed in silicone oil-filled, hermetically sealed cases have found application. Difficulty of servicing such units is more than compensated for by added life and dependability.

Solid potting compounds or encasements are good thermal conductors. The number of possible applications is limited by the loss of convection cooling and problems of surface contact.

However, if the thermal buss is made short, and a good sink is available, solid-potting methods can be used to advantage.

For a more complete treatment on the subject of heat transfer, it is recommended that Bureau of Ships publication, A GUIDE MANUAL OF COOLING METHODS FOR ELECTRONIC EQUIPMENT (Contract No. NObsr-49228), be consulted.

3.2 SHOCK, VIBRATION AND INCLINATION

Military equipment must be designed for reliable operation in normal service and under combat conditions despite conditions of shock, vibration, and inclination. Reliable operation is most vital during combat when the environment may be most severe. Shock forces from gunfire and other sources then becomes a normal operating condition. Ideally, Naval equipment should be designed to withstand any action which a floating ship can endure short of complete destruction. A ship should be able to fight as long as it floats. To this end, tests which simulate shipboard conditions are conducted.

3.2.1 Shock Loads

The duration and magnitude of shock at the point of attachment of the equipment depend on a number of factors, such as equipment location, size, shape, rigidity, and flexibility. Shock loads can vary from approximately 15 to 1000 g's for durations varying from approximately 0.0002 to 0.005 seconds. The maximum shock load to be withstood by the equipment is usually stated in the equipment specifications.

Shock loads from an underwater explosion at the hull of a ship may range as high as 1000 g's while at the upper deck, the shock may be attenuated through the ship's structure to a value of 100 g's. Gun blast loads in the area adjacent to guns is appreciable. Shock loads are lower in the superstructure where most antennas are located. However, displacements may be very high. For a given shock load, the displacement of equipment is inversely proportional to its mass.

In addition to extreme service conditions, shock and vibration imposed upon equipment while being transported can be severe. Equipment may be accidentally dropped 5 feet from a truck to a concrete floor, or to a ship's deck. Equipment is usually packed and crated to absorb the shock of handling, but if uncrated, it may be subjected to shock loads as great at 1000 g's, momentary peak. In some cases the equipment housing should be designed to absorb some of this shock.

If dropped by parachute, apparatus will experience a shock equivalent to a free fall of 12 to 15 feet.

3.2.2 Vibration

Vibration aboard ship is relatively not severe and is of low amplitude in the frequency range of 5 to 23 cycles per second. Ship vibrations can be continuous for long periods, and hence, equipment must be isolated to prevent damage due to mechanical fatigue. Shipborne equipment is tested through the 5 to 23 cycle per second range for response to vibration. If an assembly has a natural resonant frequency of less than 5 cycles per second, it is also tested at this lower frequency. The amplitude for this test is

0.036 inches. The normal maximum force due to vibration aboard ship is approximately 5 g's. The design must be sufficiently reliable to provide equipment which will not fail when subjected to vibration without vibration isolators. This is a reasonable assumption, because within the frequency range of vibration, amplification of vibration by a factor of two or even three will generally appear. Should the mounting system have resonance at low frequencies, the amplitude of displacement during shock may be unacceptable. If resonance occurs at high frequencies, the mounting system must necessarily be relatively rigid, and vibration isolation is sacrificed.

3.2.3 Inclination

Equipment should not shift, twist, or malfunction when inclined. Equipment for naval use is usually required to operate when tilted to an angle as great as 45° from the vertical. Pendulous or shifting masses are therefore unacceptable. During testing, equipment may be held stationary at any intermediate angle or may be caused to oscillate at a frequency of 5 to 7 cycles per minute up to 45° from normal in any plane.

3.2.4 General Practice

Present design practice for shipborne equipment is to provide shock-resilent mounting systems having a natural frequency in the range of 25 to 30 cycles per second. In this range, properly designed systems provide absorption for the major portion of the shock energy. They also maintain their resonant frequency above the highest principal frequency of vibration encountered aboard ship.

A mounting system having a natural frequency of less than 25 cycles per second can be employed if damping devices are used to limit deflection. However, there must be no discontinuity in the rate of damping, since this would give rise to increments of decelerative shock. Although a self-damping type system greatly attenuates shock and vibration, a more complicated and larger mechanism is required.

Components, such as motors and generators, which can produce vibration, should be isolated from other equipment, but only when the frequency and amplitude of their vibration are harmful to other components.

Some items are sufficiently rugged or flexible enough to withstand shock loads without shock mounts. These items should be rigidly secured. The application of resilient mounts in these cases can prove harmful, should they introduce resonant frequencies of vibration in the operating range, or fail to provide sufficient clearance for deflection.

Metal supports which deform under high shock loads are sometimes used in place of conventional resilient mounts. These are flexible enough to attenuate ordinary shock loads, but under severe loads, absorb the shock energy by bending. The disadvantage of this type of mount is that it becomes permanently deformed and must be straightened. Due to this feature, they are not frequently used for electronic equipment. The advantages are the small size for heavy equipment and very low amplification, if any, of vibration. Protection of equipment during transit and storage is provided by proper packaging and by the mounts of the assembly. Exterior caution signs cannot be relied upon to protect equipment from rough handling.

3.2.5 General Design

To avoid amplification of vibratory motion, the natural frequency of an assembly should be either higher or lower than any exciting frequency. To avoid excessive sensitivity to vibration, natural frequencies of any element of the completed structure should be at least twice the frequency of the completed structure or of the exciting frequency, whichever is higher. For this reason, resiliently mounted elements within an equipment should be avoided when the equipment as a whole is mounted on resilient mounts; otherwise, the danger of cascaded amplification exists.

Shock absorbers and dampers are employed to absorb a certain proportion, (at least 50%) of the energy in a shock load. Shock mounts are usually made stiffer than vibration mounts in order to absorb the energy of shock loads without undue deflection, and do not usually aid in damping high- or low-frequency vibrations. Vibration mounts are more flexible and permit considerable deflection under static load. A shock absorber may be combined with a vibration damper if sufficient flexibility and space for deflection are included.

Ideally, for transient shock loads, the force of a shock should be absorbed (damped) without oscillation when the equipment is displaced from its equilibrium position. This is known as critical damping. For steady-state vibration, maximum isolation and minimum damping are desirable unless the frequency of vibration is near the natural frequency of the mounted unit. In such cases, some damping is necessary to limit amplification of the vibration amplitude at resonance and to reduce transmission of energy at all other frequencies to a practical value. For unknown conditions where the natural frequency of the apparatus and the vibratory frequency may at times coincide, and where shock loads may also be encountered, the damping factor is usually 19% of the critical value. This value has produced good results for shipboard installations.

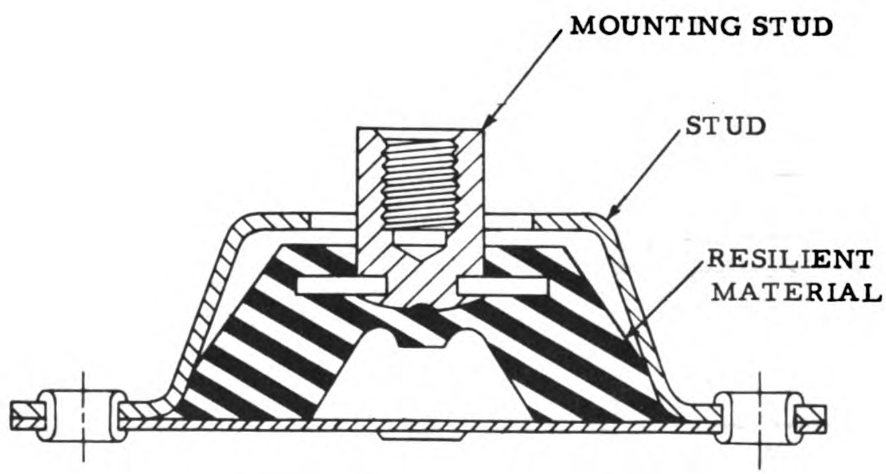
There are two types of dampers used, namely, viscous dampers and friction dampers.

Upon application of a shock load, the viscous damper expends shock energy in the form of work performed to displace fluid or air. Viscous damping is inherent in the vibration of solid panels because of air resistance, and may take many forms. Of these, the hydraulic shock absorber is the most common. Viscous dampers are most effective for absorbing shocks of large amplitudes at low to medium frequencies.

Friction damping is used effectively for all types of shock loads and low- to medium-frequency vibrations. Such dampers usually attenuate the shock transmitted to the equipment more effectively than do viscous dampers. Internal friction damping is a fundamental property of all substances, being especially high for rubber and other non-metallic materials.

The common rubber shock mount, or vibration isolator, is extensively used since it offers some inherent damping due to the internal friction of the rubber. Other types of commercially available mounts are enhanced by added viscous or friction damping in addition to the natural damping characteristics of the rubber.

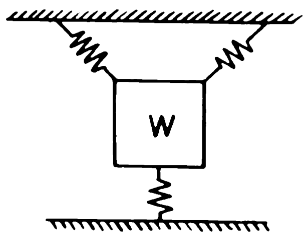
Resilient mounts must be designed to absorb forces in any plane of disturbance. For best design, shock, vibration, and combination mounts should suspend equipment at or near the center of gravity, so that the lines of all forces pass through the plane of the mounting. Many equipments are supported at the bottom and at or near the top. Mounts at or near the top are usually known as stabilizers. The height of an assembly supported only at the base should not exceed the shortest base dimension. Heavy parts should be mounted on or near the base; more fragile parts toward the interior of the assembly where the shock is attenuated. Space about an equipment assembly must be adequate for maximum anticipated deflection. Failure of the resilient element's mounts should not permit any element to become free to move sufficiently to immobilize the equipment.



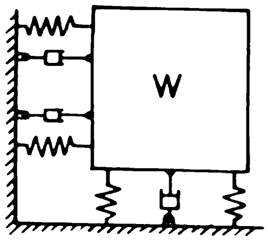
SHELL RETAINS MOUNTING STUD IF RESILIENT ELEMENT FAILS

3.2.6 Resilient Mountings

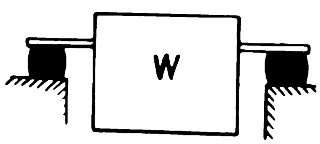
The following figures illustrate various designs of resilient mounts used for protection of electronic equipment. A brief description is given opposite each figure along with advantages and disadvantages associated with specific applications.



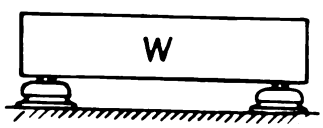
Assembly suspended by springs. Provides maximum isolation. Space factor high. Requires minimum damping.



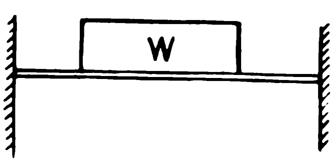
Assembly supported by springs. Well-isolated. Good vibration damping and shock absorption with separate damping devices.



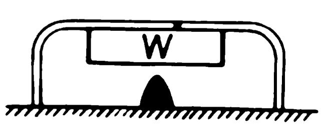
Assembly supported by rubber mounts near center of gravity. Well-isolated. Good vibration damping.



Rubber mounts combine vibration, damping, shock resistance; limit deflection.



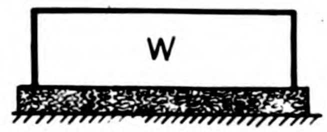
Flexible beam permits only one or two angular degrees of freedom.



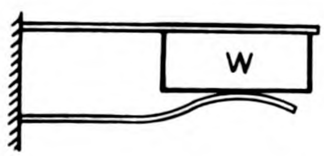
Flexible beam support with gradually stiffening rubber snubber which limits vertical deflection resulting from shock force.

Assembly protected by surrounding soft, resilient material. Depending on thickness of material, absorbs sound, high-frequency vibration and shock loads.

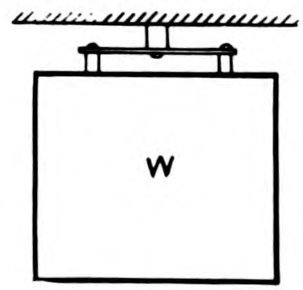
Resilient pad furnishes characteristics of resilient mount. Similar to above.



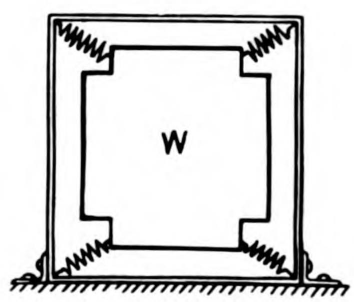
Assembly mounted on flat spring, suspended partially by loose friction spring to dampen vibration and dissipate shock loads.



Deforming support will bend under high shock loads. Isolated from vibrations due to low, natural frequency. Used for special applications.



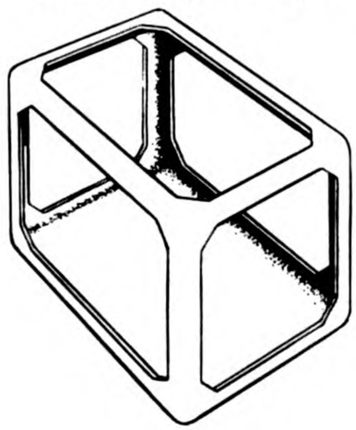
Rigidly mounted outer case protects and holds resiliently mounted interior framework; reduces shock mounted weight to minimum; affords good handling protection.



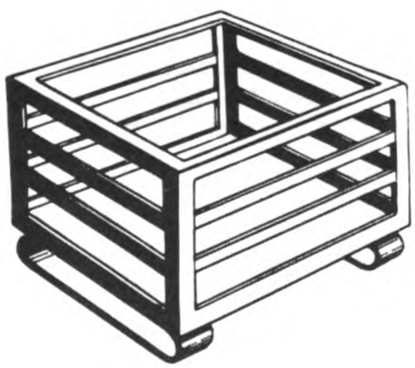
3.2.7 Resilient Structures

Structures should be able to absorb energy which is not absorbed by mounts. Rolled, forged, and extruded metal is extensively used for structural purposes since this material is comparatively tough, yet ductile enough to yield under load without rupture. The use of cast metals or other brittle metals should be avoided. Stress concentrations should also be avoided, particularly between rigid and flexible members. Fasteners are especially vulnerable because of concentrated stresses, and should, therefore, be designed with care. A structure whose members are stressed in flexture is capable of absorbing higher shock loads than one in which members are loaded in tension and compression only.

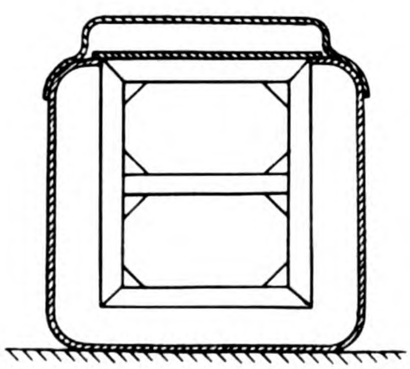
Several resilient structures are shown in the figures which follow. A brief description, and advantages and disadvantages of application are also presented.



All-welded frame. Flexibility or rigidity depends on width of flanges. Strength is equal in all directions. High cost.



Frame with non-rigid braces. Bending stresses distributed throughout welded or riveted members. Resilient base absorbs some shock and vibration.



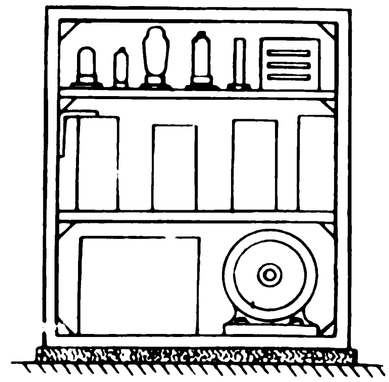
Rigid frame enclosed in sheet metal box. Box absorbs much of shock and vibration, also protects frame from atmosphere and handling.

3.2.8 Component Mounting

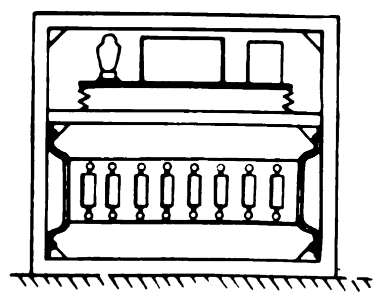
The location and method of mounting components must be considered in designing equipment to withstand shock and vibration.

Design techniques that may be employed to reduce the possibility of damage resulting from shock and vibration are illustrated below.

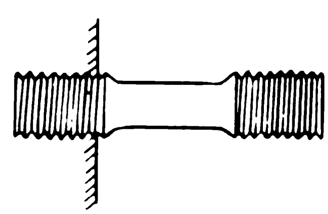
Heavy assemblies mounted near base. Light, weaker units mounted at top and interior where shock loads are least severe.



Component resiliently mounted on rigid framework. Adequate space between components for deflection.

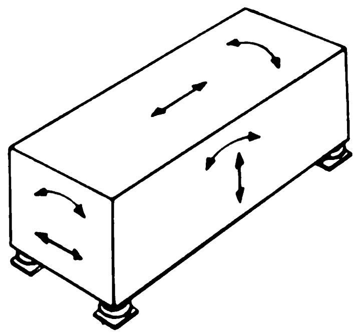


Bolt with undercut shank used for mounting components and assemblies. More resilience. Less stress concentration at threads.



3.2.9 Modes of Vibration

There are six principal modes of vibration for every structure. As illustrated below, three of these are translational and three are rotational. A well-designed, shock-mounted assembly is free to vibrate in all modes at nearly equal frequencies.



MODES OF VIBRATION

3.2.10 Workmanship

Many well-designed electronic assemblies for military use have failed when subjected to shock, vibration, and inclination simply because of poor workmanship or inadequate control of production processes.

Hand operations require considerable care. Since fastening operations are frequently performed by unskilled workers using hand tools, there is apt to be a great variance in the quality of work. An improperly tightened screw cannot properly perform its function. Rivets, improperly driven and seated, often work loose when subjected to vibration and shock. Welded joints, characterized by burned, weakened metal adjacent to the joint, lack of fusion, or improper amounts of weld metal, tend to cause stress concentrations or weakness at the joint.

Machine operations can also cause mechanical defects. Metal may be over-stressed or ruptured in the process of forming. Machine tool marks or notches may cause stress concentrations and consequent failure of a highly stressed part. All cast parts, and especially sand castings, are subject to innumerable variables.

Conversely, automatic production processes, when coupled with adequate visual and mechanical inspection, tend to result in products of more uniform quality than hand-working operations. Manufacturing processes in which an element of automatic control is involved, include sheet-metal die stamping, automatic screw machine operations, machine riveting, use of torque wrenches, and automatic welding.

3.3 SUBASSEMBLIES

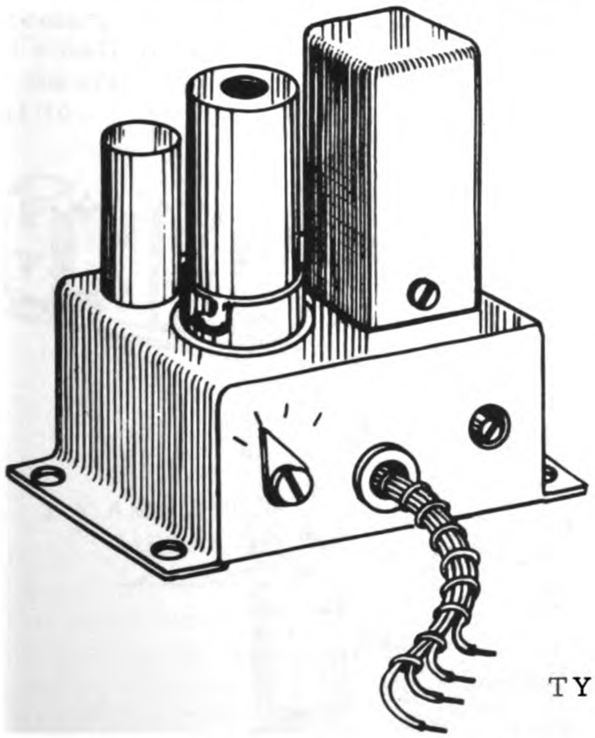
Experience shows that so-called "scrambled" parts and wiring layouts are unsatisfactory for ease of maintenance required in Military equipment. It is often desirable to sectionalize assemblies into a number of easily replaceable units, with parts and wiring arranged to permit maximum accessibility.

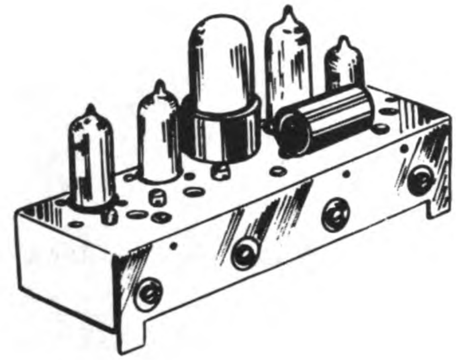
Examples of types of circuits readily susceptible to unitization are power supplies, i-f strips, oscillators, tuners, relay assemblies, and servo and gyro units. Each unit should include all components required to perform a definite function such as amplifying, rectifying, pulse shaping, frequency controlling, or frequency generating.

The additional manufacturing cost that may be introduced as a consequence of unitization, when weighed against the added servicing facility, is justified when it is considered that maintenance costs often greatly exceed the original cost of the equipment. The size of the over-all equipment can be reduced because of the increase in permissible density with ease of maintenance afforded by unitization techniques.

3.3.1 Types

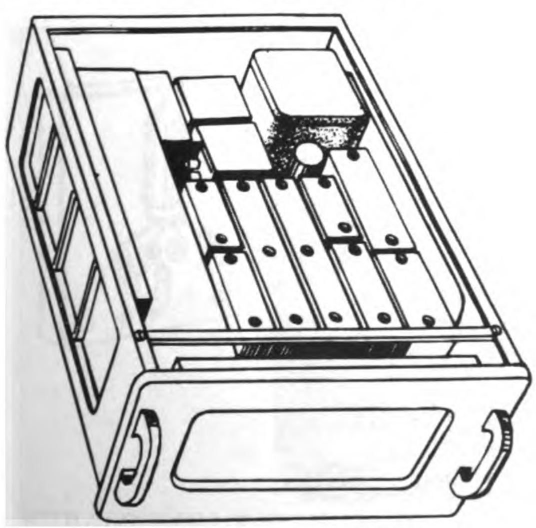
The folded sheet metal type of chassis is most widely used, since it provides excellent rigidity with a minimum of metal and is readily fabricated. Large parts are usually mounted on top of the chassis, while wiring and small parts are mounted underneath. The depth and size of chassis may be easily specified to meet particular space requirements. Two typical subassemblies are shown below.

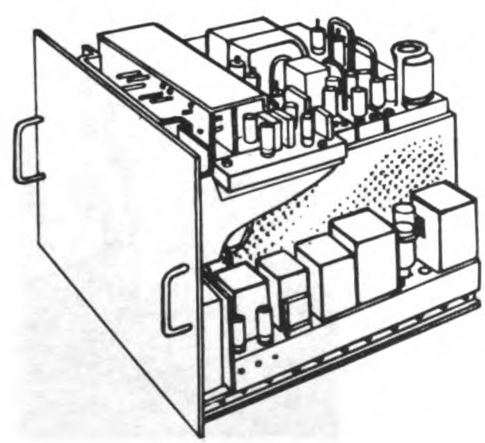




TYPICAL SUBASSEMBLIES

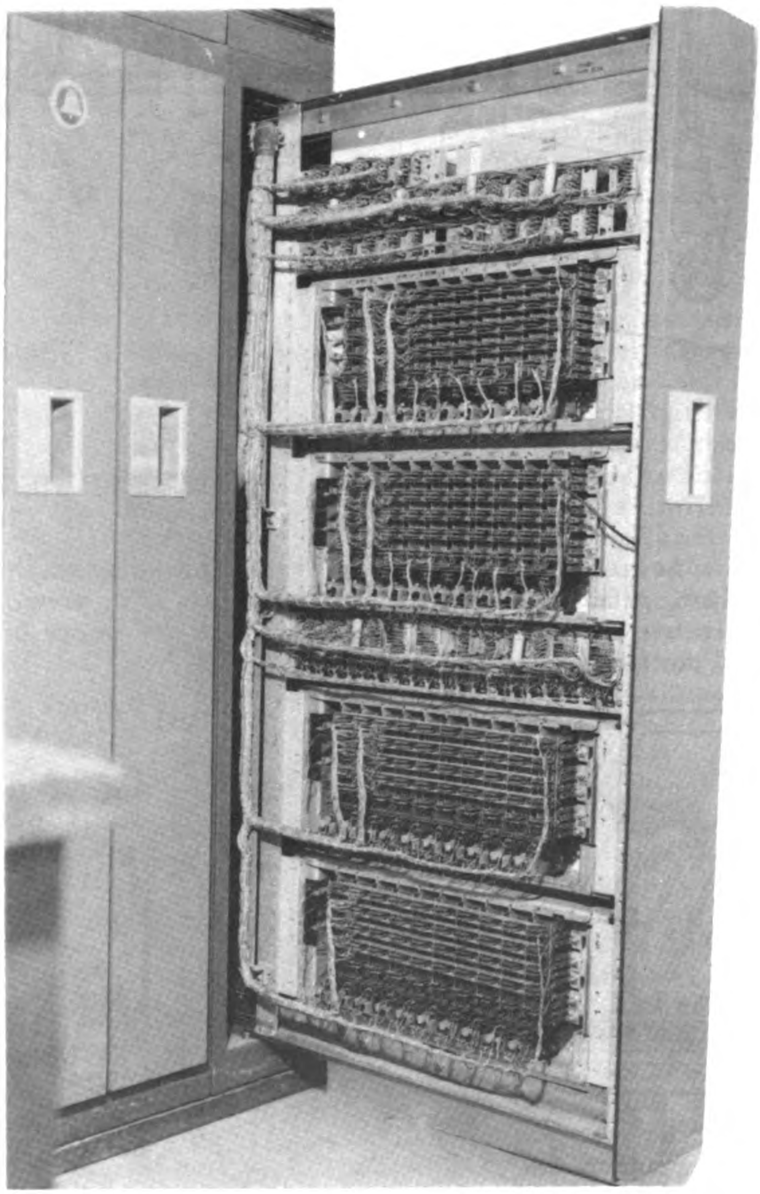
Rack-panel arrangements, similar to those shown below, offer a proven means of sectionalizing equipment. Subassemblies and parts are fastened directly to the front panel or to a framework which extends to the depth of the rack.





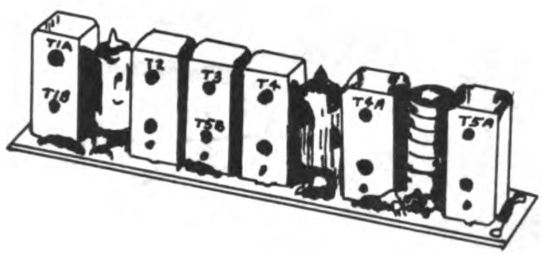
RACK PANEL
SUBASSEMBLIES APPLIED IN MILITARY EQUIPMENT

The accompanying illustration shows the use of the drawer-type construction for mounting subassemblies. In this case, the individual subassemblies are component mounting boards. Printed wiring boards can be installed in the same way. This method makes efficient use of available space and at the same time permits ready accessibility of subassemblies. If this method is used, however, a lock-in arrangement must be provided to prevent "pop-out" of the subassemblies under vibration or shock. Locking bars over each row of boards may be used for this purpose.

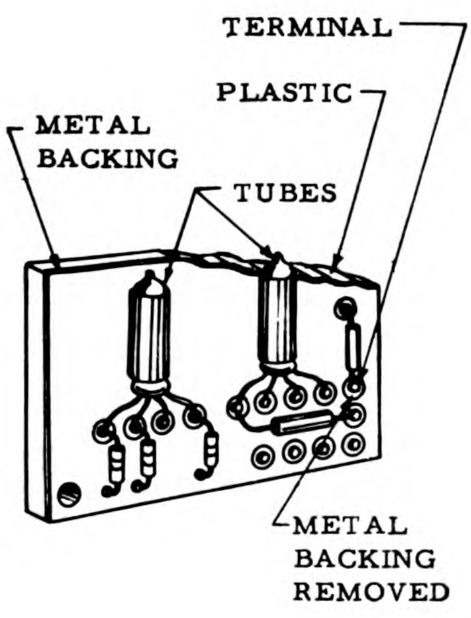


DRAWER-TYPE CONSTRUCTION

Mounting boards and strips are widely used in small subassemblies. Of particular value are metal plastic laminates used as a mounting for subminiature tubes and small components in very high-frequency units. The metal backing provides effective shielding when grounded Circuitry is laid out in segments, and small areas of metal removed for insertion of terminals into the plastic.

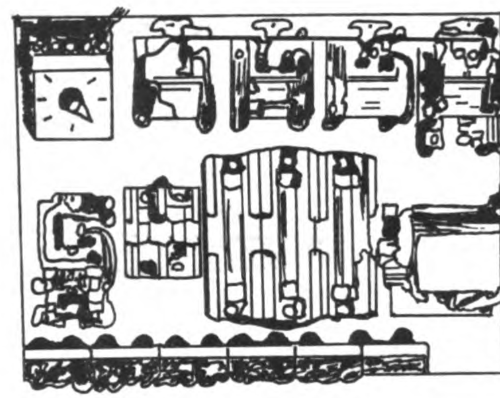


I-F AMPLIFIER UTILIZING METAL-PLASTIC LAMINATE BASE



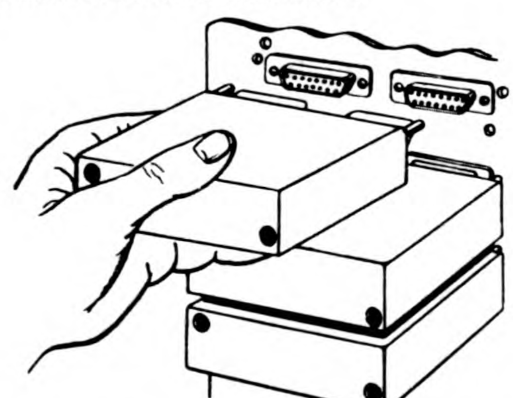
SUBASSEMBLY UTILIZING MINIATURE COMPONENTS

Larger subassemblies are usually mounted on metallic or thick laminated plates, and are generally used where a vertical mounting of the unit is required. Typical applications include control, fuse, relay, indicator, and terminal assemblies.



MOUNTING LARGE SUBASSEMBLIES

A sectionalized unit may consist of a subassembly encased by a small shell and fitted with plug-in connectors. Miniaturized units are adaptable to a wide variety of applications such as multivibrators, cathode followers, af, rf, servo amplifiers, filters and transistorized circuits.

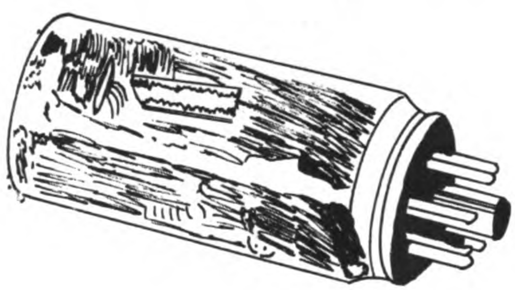


MINIATURIZED, PLUG-IN UNITS

Enclosures may be either enclosed or ventilated. If heat dissipation is critical, a readily removed, perforated-metal enclosure can be used.

Sealed units can be filled with oil or resin. In some applications, casting resin has been used without a case and results have proved satisfactory. Resins having properties suitable for casting are commeri ially available. Desirable properties are complete polymerization, good adhesion, limited shrinkage, low water absorption, and a degree of flexibility. Consideration must be given to the provision of adequate heat transfer through the resin.

Hermetically sealed units filled with an inert gas or dry air are adaptable to some parts and modules.



HERMETICALLY SEALED UNIT

3.3.2 Connectors

The following items merit special consideration in plug-in design:

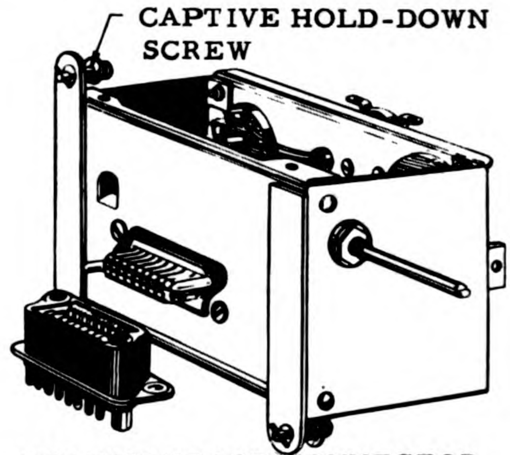
a. A single multiterminal connector simplifies alignment and mating problems.

b. Exposed pins located in the extractable unit should be recessed to prevent physical or electrical damage that might otherwise result from possible misalignment.

c. Piloting devices and hold-down clamps should be designed to avoid undue stressing of the connector body. Some "floating" of contacts is desirable.

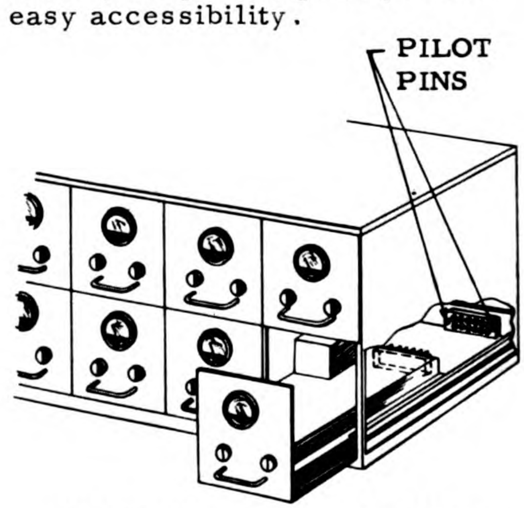
d. A minimum of 10 percent or two excess terminals, whichever number is the larger, should be provided as spares.

e. Extreme care must be exercised when soldering the smaller multiwire connectors, since the tubular pins are not fitted with means for making a mechanically secure joint prior to soldering.



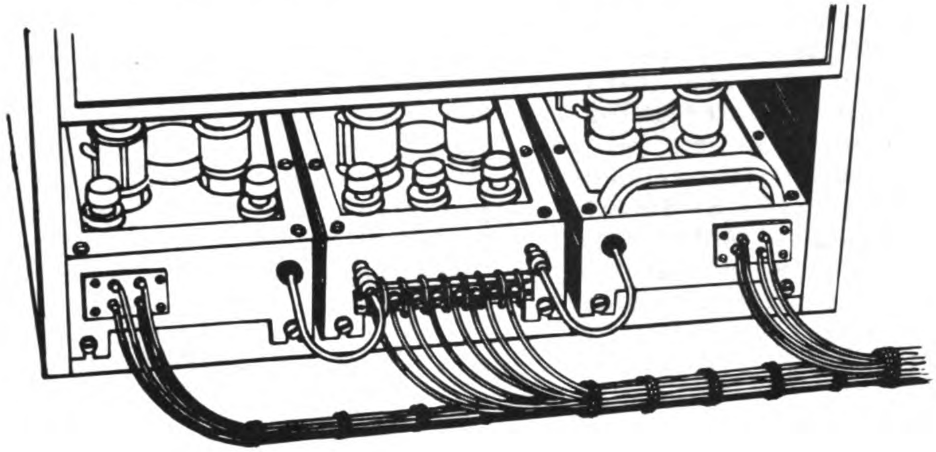
MULTICONTACT CONNECTOR USED IN PLUG-IN ARRANGEMENT

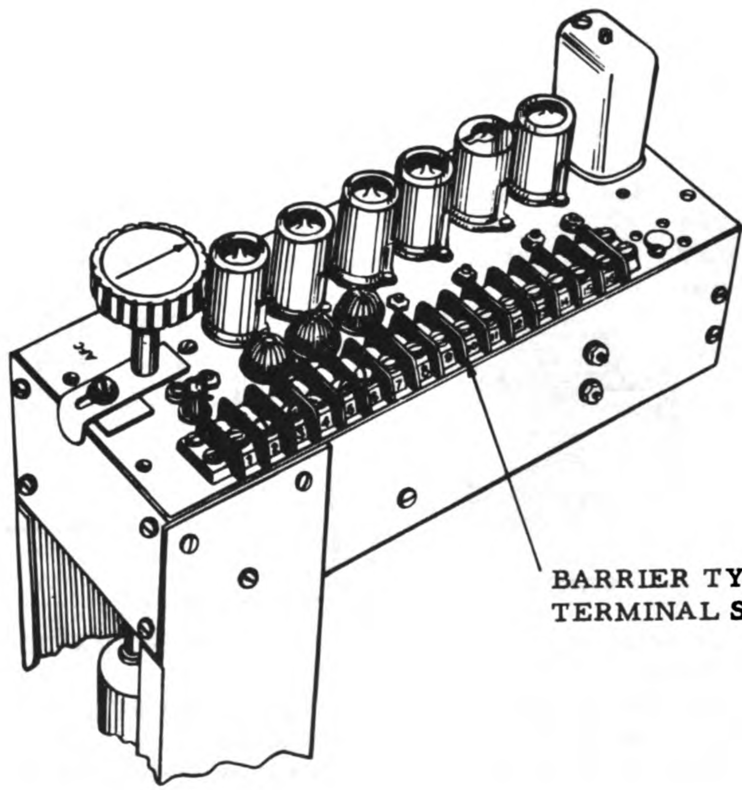
Rack and panel construction is usually characterized by the location of connectors and terminals at the rear of each subassembly. Where accessibility is limited, it is desirable to employ quick release connectors and doors that are clearly large enough to permit easy accessibility.



DRAWER CONSTRUCTION UTILIZING PLUG-IN ARRANGEMENT

Terminal strips of the barrier type can be used, if sufficient access room is provided for making connections and for the additional cable length required for easy withdrawal.

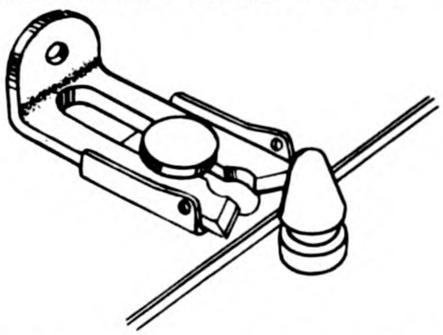




3.3.3 Clamping and Supporting

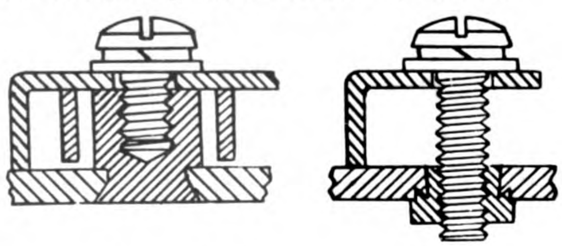
Techniques for clamping and supporting units on flat, sheet-metal chassis vary, according to particular circumstances.

Mounting projections such as lugs, brackets, and folds are used where space permits. Material for projections must not be brittle or of low impact strength. If threaded fasteners cannot be easily or quickly disassembled, bolted tie rods, slide fasteners, knurled nuts, and latches may be employed. Captive types of fasteners are recommended.



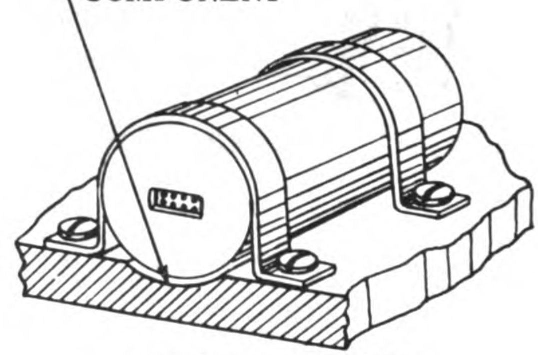
CAPTIVE TYPE FASTENER

Through-holes in the body can be used if the subassembly is comparatively light and close grouping is desired. Members strong enough to withstand full tension of the mounting bolt should be used.



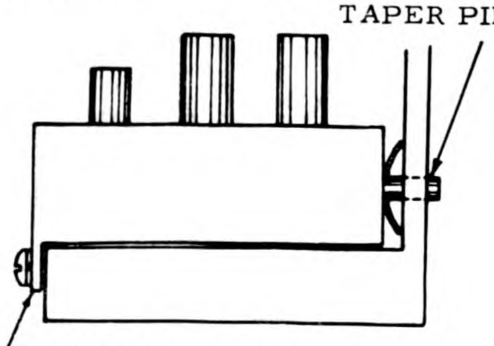
For heavy loads or accurate alignment, through-studs attached to the unit and projecting through the chassis form a satisfactory mounting.

Straps, clamps, retaining rings, framebrackets, and similar items are used where structural strength or the profile of the unit is of such shape that customary fastening methods are not applicable. Considerable care must be exercised in designing straps and clamps to avoid localized stresses which can cause loosening under shock. A locating recess or projection will prevent lateral slippage.



STRAP MOUNTING

Where one end of a unit is inaccessible, a piloting-pin type of retainer may be used at that end. The pin should be tapered to fit snugly in its socket, to prevent any motion during vibration.



3.4 ENCLOSURES

The primary purpose of enclosures is to protect internal apparatus from external elements.

Enclosures vary widely in their shape and construction according to the type of service desired.

A proposed design of the enclosure, based upon a detailed study of the equipment specification, should be submitted to the bureau or agency concerned.

The type, or degree, of enclosure may be specified as "protected," "splashproof," "fogproof," "watertight," "submersible," or "gunblastproof". Accordingly, one or more of the following tests to verify conformance must be conducted on the final design. Military standards are available which specify testing procedures for enclosures and define degrees of enclosure.

a. Hose test; water or spray is directed toward the equipment from a hose adjusted at various angles for prescribed periods of time.

b. Submergence test; water pressure and duration of test are specified according to the required degree of enclosure.

c. Gunblast test; the enclosure is located near a test gun when fired.

d. Shock, vibration, and inclination tests.

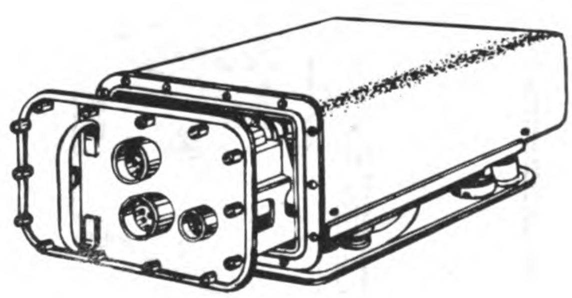
Enclosures must be designed to withstand severe temperature, and corrosion conditions. For below-deck use, enclosures are usually lighter and more compact, but must be "fogproof." More open, or "protected," construction may be used for fire-control equipment, and carefully designed to be "watertight," and structurally rugged. Submersible equipment, in particular, should be corrosion proof and obviously pressure tight.

Enclosures should not show any light from within; dial and indicator lights are excepted. The design of these should be in accordance with practices recommended in 2.1.

Limiting dimensions are specified by the design activity to insure that limits of available military installation space are not exceeded.

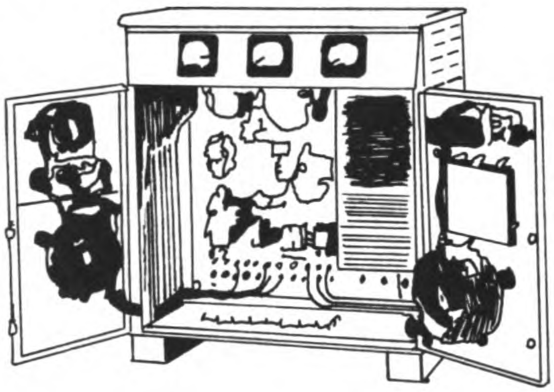
3.4.1 Types

Sheet metal enclosures are preferable to cast enclosures because of advantages in weight and size. The height rather than the depth or width should be extended because of limited deck or floor space. Good practice for many applications is to mount apparatus on a framework-panel structure which can be inserted into the enclosure. If gasketing is required, the front of the enclosure should be flanged to provide strength and a seating area for the gaskets. Chassis runners should be securely fastened to enclosure inner walls. Corners and edges must be rounded for personnel protection.



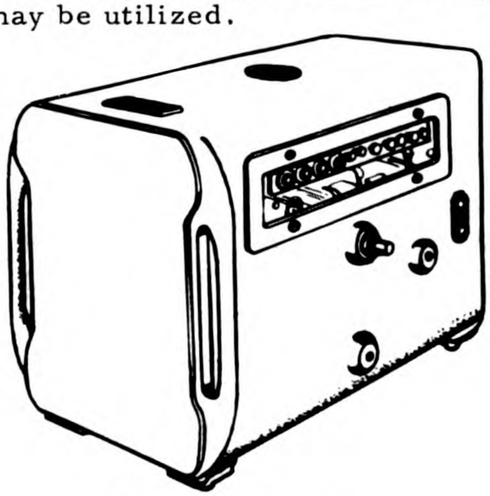
SHEET METAL ENCLOSURE

Internal framing is omitted in small welded consoles where loads are well distributed. Sheet material of reasonable thickness usually can provide sufficient rigidity for mounting doors, slides, and covers. Slides and other retractable devices assure accessibility.



WELDED CONSOLE

Cast enclosures are readily adaptable to sealing. Materials such as cast iron and ordinary die castings that are weak and brittle cannot be used. Cast steel and certain specified aluminum alloys may be utilized.



CAST ENCLOSURE

Large enclosures, designed to carry heavy loads, are made of an all-welded, heavy sheet construction. Sufficient framing and bracing are incorporated to support internal apparatus, and to improve over-all structural rigidity. Where the enclosure is located above deck, adequate safety factors for protection against the elements must be provided.

This applies also to mountings, doors, hinges, windows, cable entries, gaskets, seals, protective finishes, and similar considerations. High-strength aluminum alloys of certain classes are preferred construction materials; other materials being employed when greater strength is required.

Sectionalizing is necessary where the size of a single-unit enclosure precludes passage through access doors and openings as a single unit.

3.5 CLIMATIC PROTECTION

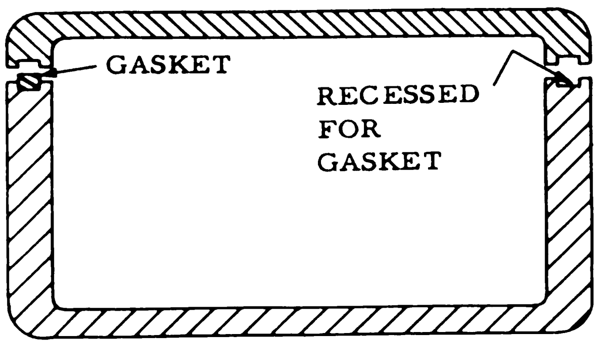
Equipment must be protected from severe climatic conditions, such as extremes of temperature and humidity, direct water damage, ice, wind, and dust. Ability of equipment to withstand these conditions is a basic design consideration. Experience demonstrates that a high percentage of equipment failures in the field are directly attributable to one or more of these climatic conditions.

3.5.1 Humidity

Equipment is usually required to be able to withstand relative humidities up to 95% during periods of continuous or intermittent operation. Simultaneous temperature variations can result in the condensation of moisture throughout the equipment.

Enclosures, housings, castings, and welds capable of functioning under external hydrostatic pressures of 600 pounds per square inch are frequently required. If enclosures are required to dissipate less than 1/10 of a watt per square inch of external surface, ventilating louvers and fan openings are not effective and should be omitted.

Particular attention should be paid to the application of gaskets, rubber-like covers, O-rings, and similar seals. In a gasket, the hydrostatic pressure must be built up along a continuous line. If exposed to pressure, gaskets should be constrained to prevent any lateral flow of material.



The seepage of humid air into equipment enclosures, and condensation caused by subsequent temperature drops, will result in unreliable equipment operation. This is especially likely to occur in a tropical atmosphere. This action can be minimized only by incorporating effective sealing. Where such sealing is impractical, consideration should be given to standby heaters that may be used to prevent moisture condensation on vital parts.

Failures caused by condensation can be classified as:

- Electrical leakage
- Arc-over
- Electrolytic corrosion
- Swelling of nonmetallic material.

The effects of leakage can be minimized by employing low-impedance circuits wherever possible. High-impedance circuits such as grid, automatic sensitivity control, and automatic frequency control, must be well-isolated from other voltages.

To maintain a high impedance, considered here to be greater than 1 megohm, nonhygroscopic materials such as silicone-glass laminates are used. Other materials, ranging from Teflon to the best grades of phenolic are applicable for somewhat lower impedances. Linen, cotton, and wood flour are specifically unsatisfactory for use as plastic fillers. Glass, mica, and similar fillers are satisfactory; however, an additional water-repellent coating should be applied to the surfaces.

Water repellent varnishes can be used where suited to the particular design; as for example, on connectors and tube sockets where spacings are marginal. Encapsulation with repellent greases or their equivalent may be used for sealing out water if this will not unduly interfere with servicing operations or accumulate foreign material.

Barriers are also useful to minimize leakage or to increase critical spacings.

Arc-over resulting from condensation or surface leakage can result in permanent damage should material become carbonized in the process. Materials selected for insulation should, therefore, be particularly resistant to carbonization. Glazed ceramics, Teflon, glass-filled silicone, and glass-bonded mica are suitable.

Unglazed ceramics should not be used. Arc-through can be avoided by using materials that are not water absorbent and are sufficiently thick to maintain adequately low voltage gradients.

Under certain circumstances, condensation may activate strong chemicals present to a varying extent in insulating materials, waxes, paints, fluxes, and platings. This will result in electrical leakage or, in the case of metals, produce electrolytic corrosion. Inductors, transformers, relay coils, meters and other solenoid-controlled devices, when exposed to corrosion products will deteriorate rapidly. All such items should be hermetically sealed or encapsulated. Mechanical connections are particularly liable to corrosion and failure since recesses may serve as pockets for fluids. Lubricants containing rust-inhibiting additives should be used to retard corrosion of mechanisms.

Moisture absorbed by organic materials can cause harmful swelling and warping and, therefore, should not be used where accurate mechanical positioning is required. Where vacuum impregnation of material is required, varnish rather than wax should be used as the impregnant.

3.5.2 Temperature

Care must be taken in locating temperature-critical materials. Many plastics, varnishes, oils, adhesives, and other materials deteriorate at high temperatures. Loss of the plasticizer is accompanied by brittleness and shrinkage and oils tend to oxidize and form varnishes. Consequently, these materials must have life-temperature ratings at least equal to that anticipated for the equipment.

Sunlight causes organic materials, sensitive to heat and ultra violet light, to deteriorate. Vinyl-jacketed rf cables having polyethylene dielectrics are unsatisfactory for continuous outdoor exposure because of temperature-plasticity effects that cause the inner conductor to move off center. Corrosion of the outer braid may also occur because of humidity.

Where equipments may be exposed to or operated in intense sunlight, the 65°C ambient temperature stipulated in some specifications may be exceeded on the exposed surface. Also, equipment may be stored in areas at very high ambient temperatures. This requires particular care in choosing impregnants, waxes, encapsulating compounds, and plastics.

Manually operated controls should be fitted with nonmetallic knobs which have a low heat transfer coefficient.

Mechanical failures are often directly attributable to temperature changes. Bearings and shafts may seize at high temperatures because of thermal expansion and lack of effective lubrication. Large aluminum or magnesium sections are particularly susceptible to dimensional changes, since their thermal coefficient of expansion is relatively high, twice that of steel. Where aluminim is used in a hydraulic seal, its size should be limited if O-rings of small cross section are used.

The starting torque of small induction motors is often marginal, and at low temperatures, reduced starting torque coupled with increased bearing friction may prevent the motor from starting under load.

Cold test failures are caused principally by frost formation, jelling of oils and greases, and brittleness in materials. Improper test methods also result in failures. Where severe internal frost is encountered, covers, doors, windows, or heat insulating devices may be used to control condensation and freezing. Excessive internal moisture can be minimized by improving enclosure sealing or heat insulation. Water-repellent coatings are useful on some insulators.

Oils and greases of the ordinary petroleum types become extremely viscous at low temperatures and their lubrication effectiveness is materially reduced. A congealed lubricant impedes proper flow into bearing surfaces and may greatly increase the starting torque.

Lubricants having special cold-test properties are described in specifications and other publications.

Wherever a lubricated bearing is clearly necessary, suitable impregnated, sintered bearings should be considered. Solid lubricants may be applicable. Best practice is to avoid lubrication provisions unless clearly needed to prevent corrosion or premature wear. Instruction plates affixed to the equipment should note any special lubrication requirements.

Many plastic materials become brittle at extremely low temperatures and break easily when subjected to undue stresses. This occurs also to an appreciable extent in various types of metal. Polyethylene dielectrics, widely used in coaxial cable, crack readily at -60°C if appreciable flexure is encountered.

3.5.3 Wind, Ice, and Dust

Equipment such as antennas, towers, and beacons, which must be exposed to weather, should be designed to withstand wind velocities up to 100 miles per hour, keeping in mind that effective surface areas and weight may be increased by ice. Resilient structures may be driven at natural frequencies by gusts of wind and thus be subjected to appreciably magnified loads. Under certain steady-wind conditions, continuous vibratory motion is induced on horizontally oriented center-supported rods. These factors, together with any inclination considerations, suggest that ample design safety factors must be employed. Screens, grids, or perforated surfaces having a small projected area are helpful in reducing wind loads.

Attention should be given in the design to permit ice removal without damage to the equipment. De-icing by means of electrical heating has proved successful for antennas and feed lines.

Dust filters should be used in equipment utilizing forced-air cooling. They should be readily replaceable, easily cleaned, and flush mounted. With a maximum air velocity of approximately 600 feet per minute, the pressure drop across the filter should not exceed 0.105 inch water gage where the filter is loaded with 0.021 pounds of dirt per square foot of face area. Dirt used for testing consists of 48% lint, 43% fly ash, and 9% lampblack. Impregnated glass wool, 1 inch thick, is usually a satisfactory element.

3.6 RADIO FREQUENCY INTERFERENCE

Because simultaneous operation at one location of many types of equipment is necessary, it is imperative that undesired electrical radiations or electrical noise conduction of each unit be an absolute minimum to prevent interference.

Since the range of frequencies involved is wide (.014 mc to 1000 mc), the reduction of interference is often complex and difficult. Following is a brief discussion of the problems which are encountered and their possible solutions.

By proper design, the generation and propagation of interference can be greatly reduced. Experience has shown that the noise intensity which can be tolerated is dependent upon the operating frequency of equipment. These limits, and the methods for their measurement, are described in pertinent specifications.

Interference can be classified as either radiated or conducted. In many cases, it is found that a combination of both exists. Suppression of undesired radiations requires:

a. Elimination of favorable conditions for generation.

b. Dissipation of generated noise.

Two requirements are basic: lead lengths must be kept as short as possible and the best possible grounding system must be uitlized. These requirements can often be met concurrently. When the physical location of parts requires leads of appreciable length, they should be as large as practical. If shielded, the shielding should be grounded; the number of grounding points or location of the single optimum ground location will depend upon the circuit involved and is usually determined by trial and error.

3.6.1 Radiated Noise

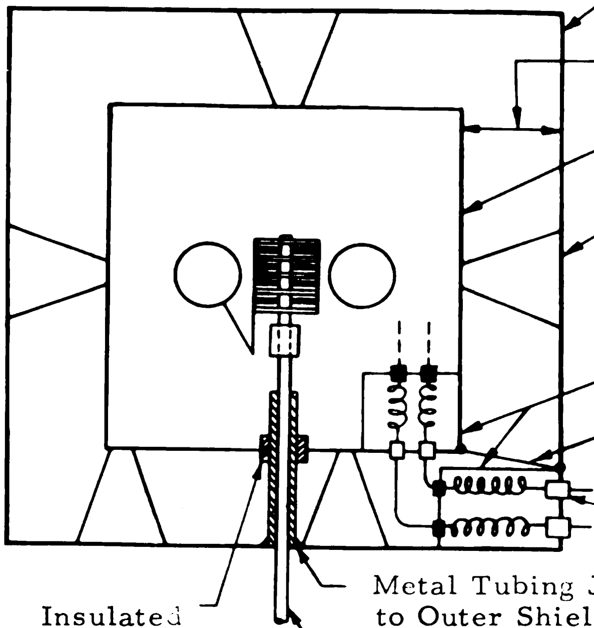
Shielding of radiating circuits is accomplished with copper or aluminum enclosures. A rule-of-thumb, which experience has shown to be surprisingly accurate, is that joints of rf shielding must be virtually watertight. Double walls of shielding are sometimes used. Necessary apertures should be no larger than required by capacity to ground considerations. Whenever practical, interconnection of rf units should be made by low-impedance coaxial cable, which can be 100% shielded. In addition to the harmonics of the desired frequency, spurious frequencies may be generated at any point in the frequency spectrum by rectifying action of poor connections.

Supply leads entering shielded enclosures must be well-filtered and the filter itself enclosed in a compartment which is essentially a part of the main enclosure. All ground leads should be returned to a common point. Double-shielded enclosures should be connected together at one point only, and additional filtering placed in the supply leads between enclosures.

3.6.2 Conducted Noise

This term is usually applied to interference which is generated within equipment and conducted along interconnecting cables. When only the power lines are involved, filters are required in each side of the line. Their configuration will depend upon the frequency range over which suppression is desired. A simple filter may be adequate if proper suppression has been provided within the equipment.

A typical two-section filter is illustrated.



Some of the most prolific sources of noise and their remedies are listed below:

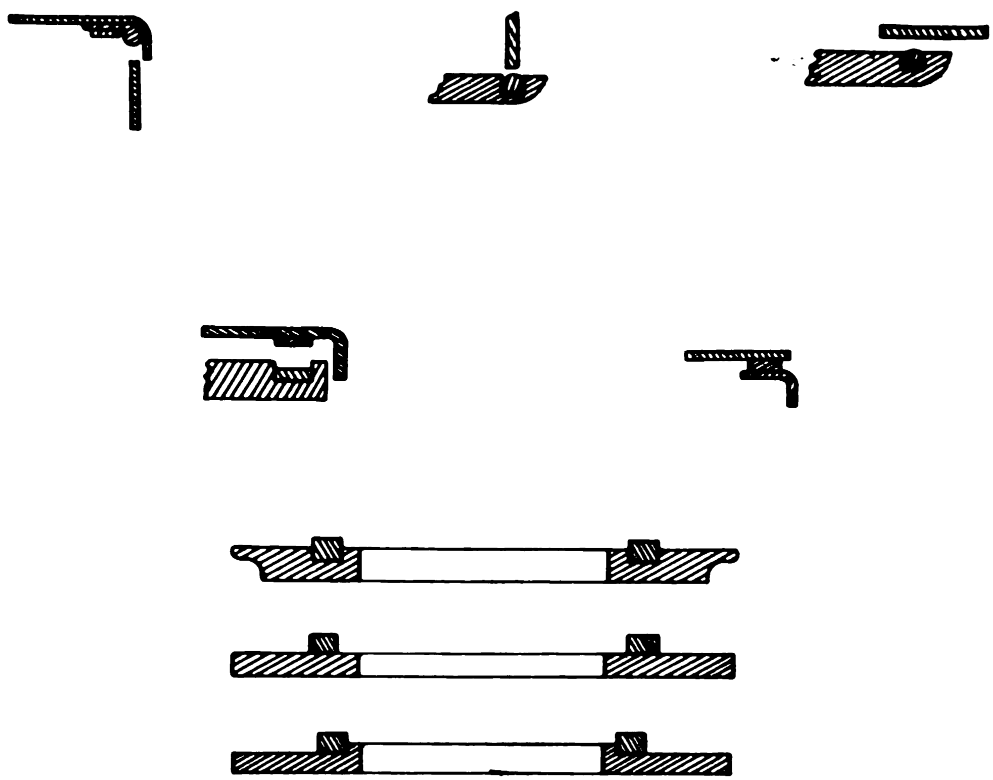
Cause	Cure
1. Arcing of contacts.	a. R-C fitter across contacts. b. Copper oxide rectifiers across contacts where circuit function permits.
2. Commutator/Brush arcing.	a. R-C circuits across contacts. b. Use of capacity only, but in the form of highly effective feed-through configuration. c. L-C filters in output leads in IR drop can be tolerated.
3. Gas-discharge tubes, mercury-vapor rectifiers.	a. Rf chokes in plate and grid leads. b. Close-fitting shield. c. Electrostatically shielded power transformer, center tapped to ground on the equipment side.

3.6.3 Types of Shields

Shielding of cathode-ray tubes from interference presents a special problem. Sometimes multiple shields are required to provide adequate protection. Laminates of magnetic and high-conductivity materials may be used for the multiple shielding.

3.6.3.1 Wire Meshes. When design requirements, such as forced-air cooling, preclude the use of a solid shield, a wire mesh is permissible and is fairly effective. The mesh size is determined by the attenuation desired and the frequency of the interfering source; the higher the frequency, the finer the mesh required. The contact between the mesh and its mounting must not permit leakage of energy.

3.6.3.2 Metal Gaskets. Metal gaskets of special design are effective around doors and other apertures. Typical gaskets are made of knotted wire mesh. Where both shielding and sealing are required, the wire mesh gasket is combined with a suitable sealing material. Various applications of wire mesh gaskets are illustrated below.



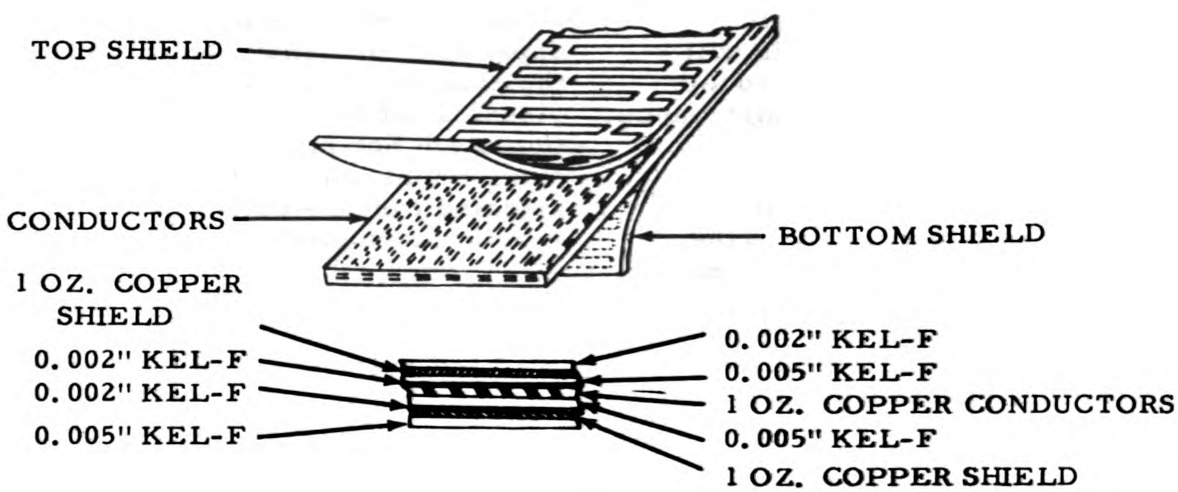
WIRE MESH GASKETS

3.6.3.3 Reduction of Conducted RF Interference. Observance of the following rules will help to minimize conducted rf interference:

a. Assure that soldered connections are sound.
b. Do not lay out conductors carrying interfering currents and conductors sensitive to interference pickup in parallel unless they are shielded. If it is necessary for unshielded wires to cross, cross them as nearly as possible at right angles.

3.6.3.4 Shielding of Printed Harnesses. Printed harnesses may be shielded by the following methods:

a. Solid shields. A solid shielding material may be laminated to both sides of the insulated cable, if flexibility is not important. If the cable can come in contact with other parts, the exposed surface of the shield should be insulated.
b. Striated shields. Striated shielding should be used on both sides of the insulated cable if flexibility is desired. The construction of a cable with striated shielding is shown below.
c. Shielding adjacent conductors. Sufficient shielding may be obtained in some cases by grounding conductors adjacent to the signal-carrying conductor.



FLEXIBLE CABLE
WITH STRIATED SHIELDING

3.7 AUTOMATIC PROCESSES

Due to the increasing complexity of electronic equipment, a reduction in weight and size has become mandatory. Along with reduction in weight and size, reliability has also become a major problem. To improve reliability, it has become necessary to develop new fabrication techniques for producing electronic circuits. Conventional methods whereby individual parts are manually assembled and wired on a chassis no longer provide the reliability and quantity of production required. In many cases, it is difficult for human hands to handle some of the miniature parts, components, and assemblies.

Automatic production techniques are needed for electronic equipments regardless of size. Important advantages are greater uniformity and reliability, smaller weight and size, and reduced cost. The ultimate goal is increased reliability and cost reduction which will make complete expendability of small subassemblies practical. This will eliminate repairs as well as reduce costly and time-consuming maintenance.

3.7.1 Prefabricated Circuits

By fabricating the electrical conductor as an integral part of the base-plate the need for wiring parts into the desired circuit is reduced to a minimum or is completely eliminated. In certain techniques of prefabrication, condenser plates, coil turns, and resistors are made a part of the conductor. In the cases where completely automatic fabrication is possible, the attachment of tubes and connectors is all that is necessary to finish the assembly or subassembly.

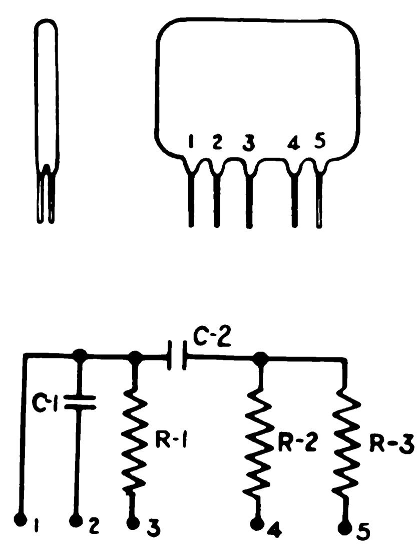
Some of the automatic processes used for printed circuits are:

a. Silver fired conductors
b. Stencil-etched circuits
c. Pressed silver powder
d. Stamped conductors
e. Sprayed-copper conductors
f. Silver-ink printing
g. Photo-etched conductors
h. Silk screening

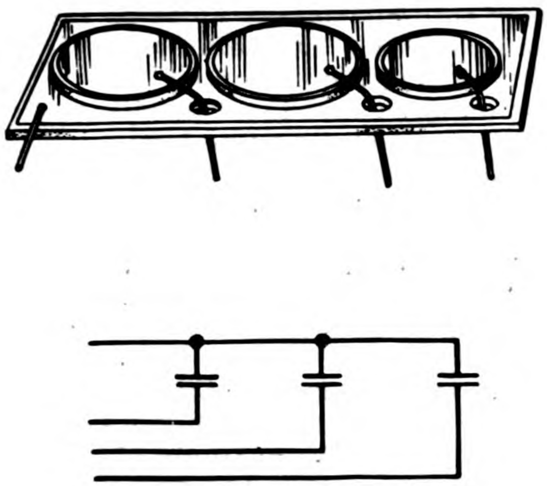
3.7.1.1 Silver Fired Conductors.

Silver fired printed circuits usually consist of R-C networks and find wide application at audio, video, and vhf frequencies. Some applications are interstage coupling, decoupling filters, integrating and phase-shifting networks, multi-vibrator and slipping circuits, and arc and audio networks. As an example, the complete circuitry and sockets for a three-stage, subminiature, audio amplifier have been fabricated on a ceramic plate occupying a space of only 1 by 1-1/2 by 1/2 inches.

A widely used printed circuit consists of a plate on which combinations of resistive and capacitive elements, as well as the conductors, are fired on glass, steatite, or barium titanate. For high-frequency applications above 40 mc, spiraled pancake coils are readily fabricated.



SILVER FIRED CONDUCTOR

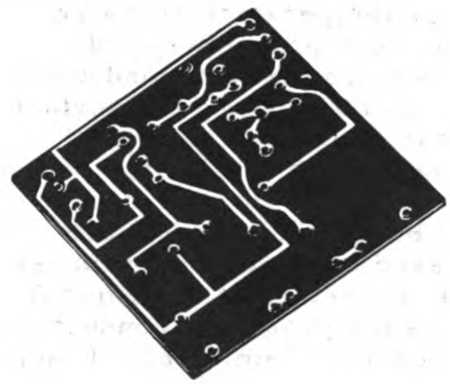


SILVER FIRED CONDUCTOR

A wide range of resistance values may be obtained but the maximum power dissipation is limited to 1/2 watt per resistor at the present time. Capacities up to 0.01 mfd. may be obtained by the proper selection of the dielectric material and dimensions. One design problem which requires care is the variation of capacity and power factor of the dielectric material with temperature, particularly above 55°C. Using present automatic fabrication techniques, tolerances of component values are wider than those normally obtained with conventional components. Stray coupling and shunting capacitances may be appreciable but can be controlled by careful design.

3.7.1.2 Stencil-Etched Circuits. Stencil-etched conductors on a plastic backing may be used to an advantage where ceramic or glass would be subject to breakage particularly when large baseplates are required. Stencil-etched conductors are widely used in small broadcast receivers, i-f strips, hearing-aid amplifiers, and various types of control instruments.

Conventional parts such as resistors and capacitors are mounted by soldering directly into eyelets which are fabricated to the stencil-etched conductors. Conductors on both sides of the baseplates are closely spaced and capacitive effects are produced which must be accounted for during the design phase. Coils having a satisfactory Q above 30 mc may be etched in the same manner as the conductors.



STENCIL-ETCHED CIRCUIT

In the stencil-etching process, the wiring pattern is formed by applying a chemically resistant compound through a stencil onto a metal foil which is bonded to a suitable plastic base material. The unprotected portions of the foil are then chemically removed leaving the desired conductor pattern on the plastic base. The base material must have a low coefficient of water absorption and provide a heat-resistant bond to the metal foil. Copper foil bonded to melamine-glass cloth and subsequently silver plated has been successfully used. Other copper-clad materials in use include Teflon, silicone, epon, and glass-cloth laminates.

Thus far, phenolic laminates have been unsatisfactory because of their poor bonding properties.

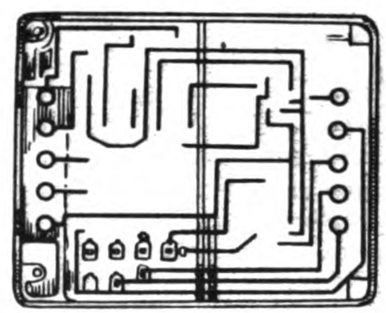
Conductor printing may be produced by stenciling, photographic processing, or offset printing. A mixture of microcrystalline wax and activated rosin has been used in the stencil-etch process to protect those portions of the copper-clad laminate that form the conductor pattern.

Adhesion of the conductor to the base material is important because it is greatly affected by subsequent soldering. Bonding may be improved by the use of a large area and a high-temperature adhesive which has been properly cured. Surface leakage between conductors is minimized by coating the surface of the base material with a good insulating varnish or plastic.

3.7.1.3 Pressed Silver Powder. The pressed silver powder process consists of a series of mechanical operations for producing conductors on thermosetting laminates. Finely powdered silver is screened on the base material which has been prepared with a compatible adhesive film. The wiring pattern is formed with a hot-press die using a predetermined schedule of time, temperature, and pressure. The remaining loose silver is then removed and the pressed pattern is given further curing cycles to improve imbedment of the pattern in the adhesive layer as well as to insure complete polymerization of the adhesive.

3.7.1.4 Stamped Conductors. In the stamped-wiring process, a die fabricated to the desired circuit layout stamps out a grid in copper or brass. The grid is removed, plated with silver or tin, and pressed into receptacle slots on the molded chassis. To maintain rigidity during the stamping operation and subsequent handling, several grid links may be left intact until the final step, after which they are cut loose. Upon pressing the grid into the molded chassis, components, connectors, and tube socket pins are soldered to the grid by conventional methods.

This type of fabricated wiring has been applied satisfactorily to amplifiers and control circuit subassemblies. An example of stamped wiring applied to an amplifier is shown in the figure below.



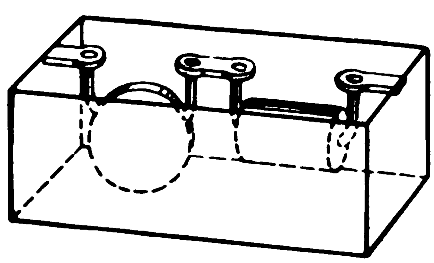
STAMPED WIRING

In another technique of stamped wiring, a preheated die is used to stamp the grid from copper foil into a phenolic baseplate. Prior to stamping, the foil is prepared with a thermoplastic adhesive which softens under heat and pressure to produce bonding to the phenolic base. The surface of the baseplate is usually roughened to improve bonding.

The die face is made with a concave surface which pinches the grid edges into the phenolic base to secure the grid mechanically to the base.

3.7.1.5 Sprayed-Copper Conductors. In the sprayed-copper wiring method of construction, the components are placed in a phenolic chassis suitably molded with grooves for the conductor paths. The entire unit is sprayed with a copper-metalizing gun thus eliminating the need of manual wiring and soldering. No mask is required if the grooves are molded with sharp edges at the outside surface. The excess copper on the top surface may be removed by wiping with a cloth or by light sanding.

The copper spray has shown optimum adhesion in grooves 0.062 inches wide and 0.040 inches deep. Adhesion is improved by roughening the grooves with longitudinal ridges. The copper conductors may be protected by a varnish coating. If desirable, the entire assembly may be potted into one unit as shown in the figure below. Extensive vibration and temperature-cycling tests have proven the sprayed-copper wiring method to be very satisfactory.



SPRAYED-COPPER CONDUCTOR

3.7.1.6 Silver-Ink Printing. Special silver inks are presently used for printing conductors on the surfaces of base materials such as polytetrafluoroethylene (Teflon), epoxy, melamine, and phenolic plastics which are in geometric form of cones, cylinders, and spheres. Silver-ink printing simplifies the manufacture of rotors, commutators, and wave-guides.

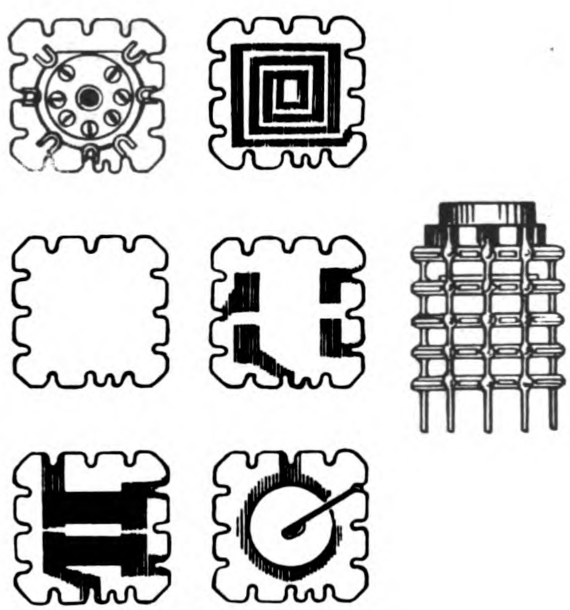
3.7.1.7 Photo-Etched Conductors. The photo-etch process is similar to the stencil-etching process, paragraph 3.7.1.2 It is an accurate method of producing printed wiring and is used in applications where precision and good detail are required. This method employs a copper-clad insulating material or laminate, such as copper foil bonded to a melamine-glass or phenolic base material. The copper surface is thoroughly cleaned and a photo-emulsion is applied. A photographic negative made from a photomaster or original drawing of the proposed circuit is used to make a contact print on the prepared copper. A high-powered light source such as a carbon arc, is then used to harden the photo-emulsion on the copper in the desired pattern. Suitable treatment is used to remove the unhardened portions of the photo-emulsion and the unwanted copper foil. The hardened photo-emulsion is then cleaned off with a solvent, leaving the finished copper conductor pattern.

3.7.1.8 Silk Screen Process. The silk screen process is less accurate than the photo-etch process for the production of printed wiring, but is more adaptable to large production runs. A stencil of the proposed circuit is prepared on a silk screen. After the copper surface is cleaned, an acid resistant ink is screened onto copper and unwanted copper foil is etched away. The ink is then removed with a suitable solvent, leaving the finished copper conductor pattern.

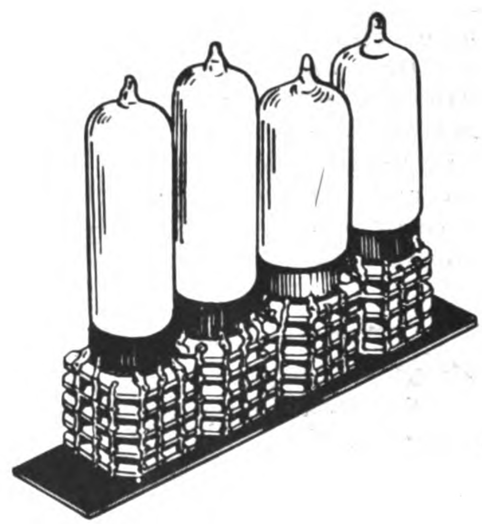
3.7.2 Automatic Assembly

Automatic assembly systems of prefabricated circuits include ceramic-wafer building blocks and copper clad laminates. For large or complex equipments, the final assembly is composed of a number of subassemblies. These subassemblies are refereed to as units or modules and the process as unitized construction or modular construction.

3.7.2.1 Ceramic Building Block System. The ceramic building block method of automatic assembly is based on a standard block, 7/8 inch square, which consists of a notched ceramic wafer. Electronic components such as resistors, capacitors, and tube sockets are made integral with the ceramic wafer. The wafers are assembled in skyscraper fashion to form a module of one or more electronic stages. The ceramic wafers, titanate capacitors, and adhesive tape resistors are produced in quantity directly from the raw materials. The basic raw materials are fed into a mechanized assembly line. In the illustrations which follow, are examples of individual wafer construction and building block assembly.



WAFER CONSTRUCTION



BUILDING-BLOCK ASSEMBLY

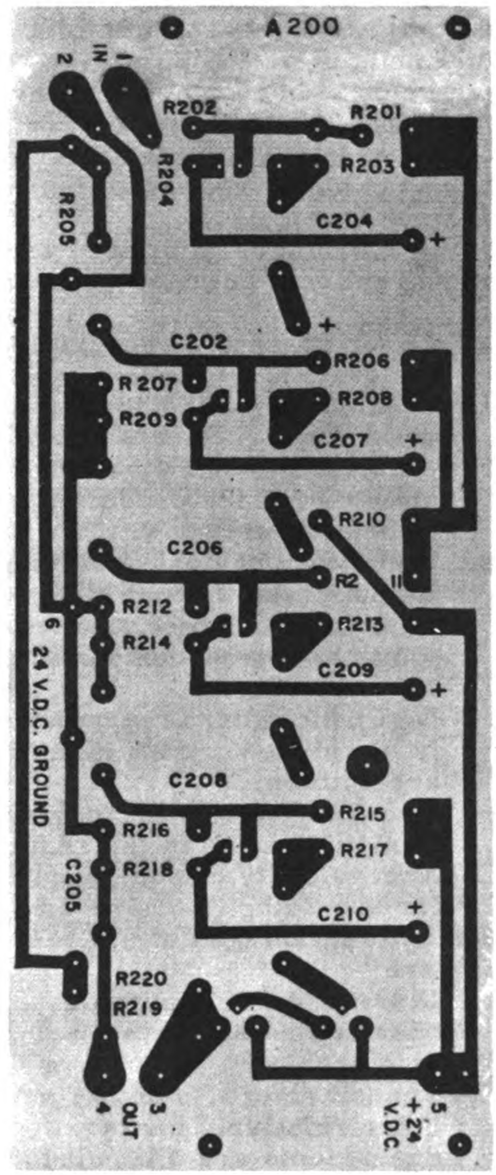
Basically, there are four operational phases in this method of assembly. In the first phase, the ceramic materials are mixed, cold pressed to shape, and fired to produce the notched wafers. In phase two, the silvered conductors, capacitors, resistors, and inductors are fired onto the wafers. The silvered conductors are brought out to the appropriate notches at the edge of the wafer where interconnecting leads are soldered in the third phase. These interconnecting leads not only produce interconnection between wafers but give mechanical support and rigidity to the wafers as well. Once the individual decks are stacked, the interconnecting leads are dip soldered into place. Tube sockets are usually mounted on the top deck. The final and fourth phase consists of impregnating and testing.

3.7.2.2 Printed Wiring System. The first step in preparing printed wiring (copper-clad laminate) circuits is the formation of a conductor pattern on the printed wiring board, as illustrated, by means of photo-etch, silk screen, or other techniques discussed in paragraph 3.7.1.

The second step consists of drilling holes through the board at specified locations, inserting the part leads through these holes, and soldering the leads to the circuit side of the board, usually by dip soldering. Eyelets or plated-through holes may be used to mount the components when specifically approved by the procuring activity.

Parts may be mounted on both sides and the conductor patterns may be formed on both sides of the board where space requirements or other considerations necessitate it. However, it is preferable to mount parts on only one side for the following reasons:

a. Design time is reduced because cross-over wiring is eliminated.
b. Fabrication time is cut as much as 50 percent because registration between sides is not necessary.
c. Soldering is required on only one side so a single dip soldering operation suffices.
d. Tracing of the circuit for testing and repairing is simplified.



CONDUCTOR SIDE OF PRINTED WIRING BOARD

The third step consists of a rinsing wash and drying cycle. This is followed by impregaation or other coating, where applicable. The fifth and final step consists of mounting the required tubes, transformers, support members, enclosures, and other parts or components. The layout of the component side of a typical printed wiring board is shown below. In a complex assembly, the individual subassemblies are stacked and interconnected in a suitable fashion to form the final equipment assembly.

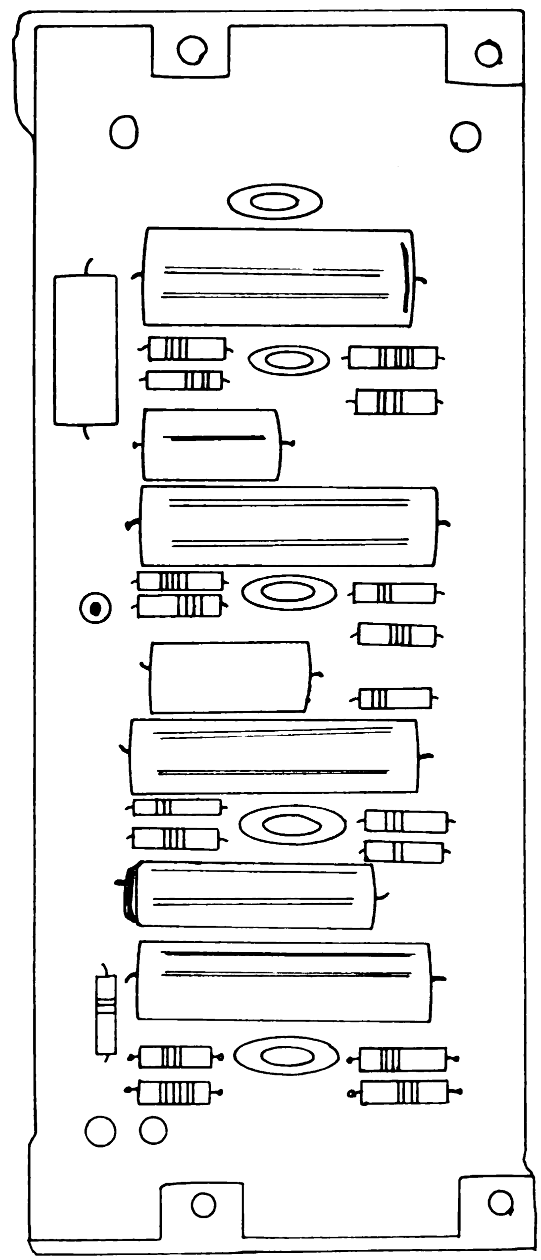
Some advantages of printed wiring over conventional point-to-point wiring are:

a. Labor costs are reduced from the drafting stage through final checkout of completed assemblies.
b. Automatic techniques are suitable for the production of printed wiring.
c. Reliability of final assembly is increased through elimination of defective solder joints by use of controlled dip soldering.
d. Reproducibility of circuits is simplified and all circuits are uniform.
e. Space and weight are saved. Miniaturization is facilitated.
f. Accessibllity of components for servicing is improved.

Some disadvantages of printed wiring are:

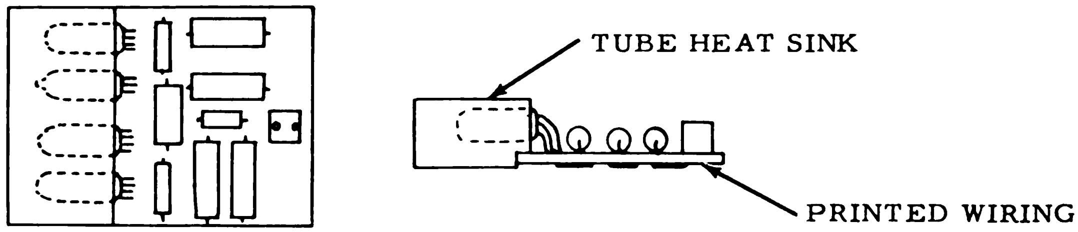
a. Dissipation of heat from board mounted parts may be a problem.
b. Transformers, chokes, and other relatively heavy components are difficult to mount.
c. Copper foil may peel from the base material.
d. Improper cleaning of the conductor pattern may cause poor solder joints.
e. Adequate shielding for components is difficult to provide.

Suggested methods for overcoming two of these disadvantages are illustrated on the following pages.



COMPONENT SIDE OF
PRINTED WIRING BOARD

To prevent overheating of the components on printed wiring boards, special designs such as the heat sink shown below, are sometimes required.

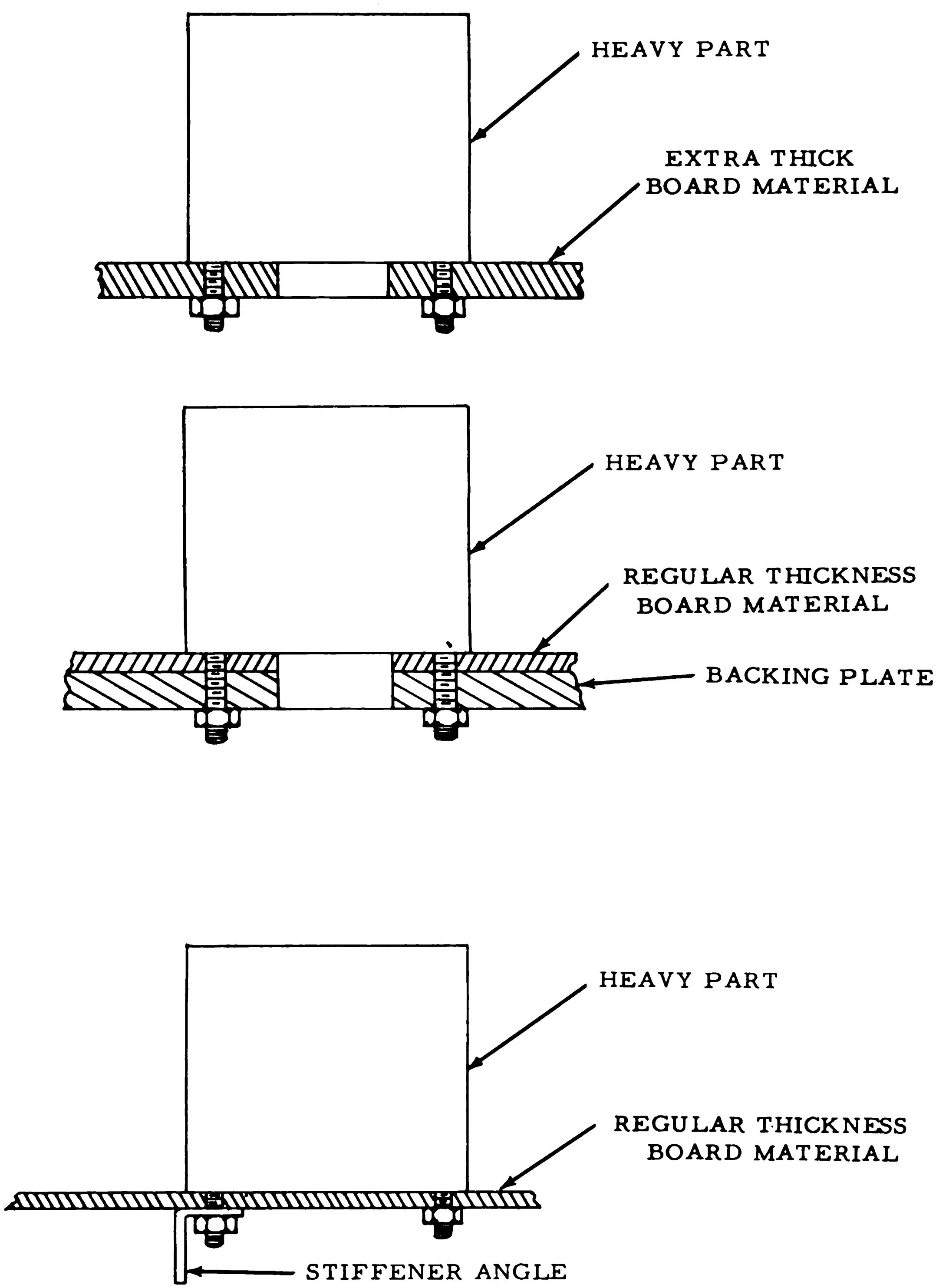


TOP

SIDE

Three alternate methods of mounting heavy parts on printed wiring boards are shown on page 3-52. This disadvantage may be overcome by the use of board material of adequate thickness; by the use of a backing plate, consisting of additional sheets of board material; or by the use of stiffener angles or brackets attached to the board at critical points.

3.7.2.2.1 Selection of Board-Base Material. The table on 3-53 which lists electrical and mechanical properties of various unclad board-base materials, may be used as a guide in selecting the proper board-base material for printed wiring applications.



METHODS OF MOUNTING HEAVY PARTS

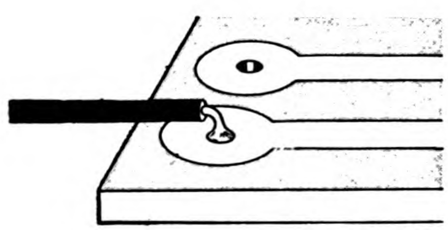
MECHANICAL AND ELECTRICAL PROPERTIES OF VARIOUS UNCLAD BOARD-BASE MATERIALS

Material, MIL Spec., NEMA Grade	Flexural Strength psi	Bond Strength psi	Peel Strength lb 1 oz Cu	Peel Strength lb 2 oz Cu	Approx. Dielectric Constant at 10^6 cps	Approx. Dissipation Factor (Power Factor) at 10^{-6} cps	Approx. Instantaneous Resistance (Megohms)	Remarks
Paper Phenolic MIL-P-78A (Type HSP) P	14,000	12,000	4.25 to 8	6 to 12	8.0	0.080	2×10^3	Relatively inexpensive; use where good electrical properties are not required; poor arc resistance; maximum operating temperature 250°F.
Paper Phenolic XXP	19,000	12,000	4.50 to 8	6 to 12	4.6	0.037	2×10^3	Good punchability; better electrically; use where humidity is low; poor arc resistance; maximum operating temperature 250°F.
Paper Phenolic MIL-P-3115B (Type PBE-P) XXXP	25,000	12,000	4.50 to 8	6 to 12	4.3	0.029	2×10^{-3}	Most widely used grade; high insulation resistance; low dielectric losses when humidity is high; poor arc resistance; maximum operating temperature 250°F.
Paper Phenolic (cold punch) MIL-P-3115B (Type PBE-P) XXXP	15,000	12,000	5 to 7	6 to 8	4.6	0.035	2×10^3	Same as above; better insulation resistance and punching characteristics; poor arc resistance; maximum operating temperature 250°F.
Melamine Glass MIL-P-15037B (Type GMG) G-5	55,000	30,000	4 to 6	5 to 8	6.8	0.020	2×10^2	High moisture absorption; good arc resistance; maximum operating temperature 300°F.
Silicone Glass MIL-P-997B (Type GSG) G-6 G-7	40,000	15,000	1.5 to 4	1.50 to 4	4.2	0.003	3×10^5	Low dielectric loss; bond strength varies; very good arc resistance; maximum operating temperature 450°F.
Epoxy Glass MIL-P-18177A (Type GEE) G-10	68,000	35,000	5 to 10	6 to 12	5.2	0.025	3×10^5	Most widely used glass; good mechanical and electrical properties; low moisture absorption; good arc resistance; maximum operating temperature 325°F.
Teflon Glass	13,000	15,000	3 to 9	4 to 9	3.3	0.001	3×10^5	Best electrically; poor mechanically; expensive; use in low-loss microwave applications; very good arc resistance; maximum operating temperature 500°F.

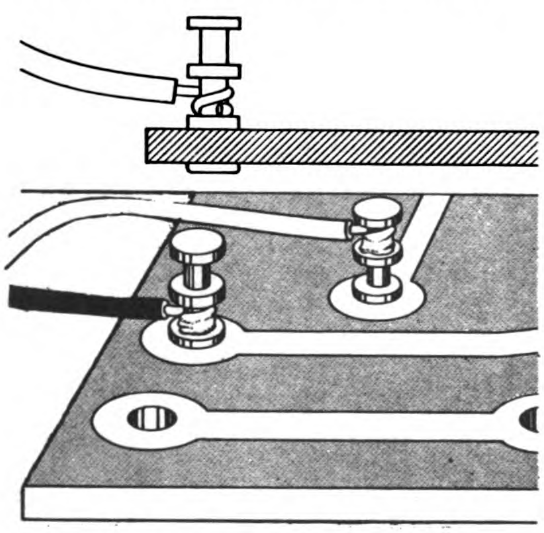
3.7.2.2.2 Attaching Leads to Printed Wiring Boards. The various methods unique to the attachment of leads to printed wiring boards are discussed in this section and are to be used as a guide by the designer when selecting connections for a specified design. Other type connections are thoroughly discussed in a later chapter of this manual.

Printed wiring connections are grouped into two broad categories; permanent and separable.

Permanent wire connections used in printed wiring are those unlikely to be disassembled during the life of equipment in which the printed wiring board is installed. Connections of this type are made by soldering as illustrated in the figures.



TINNED LEAD SOLDERED IN EYELET OR DRILLED HOLE



TERMINALS SWAGED TO PRINTED BOARDS

This type of connection does not require an electrical connector and provides a simple inexpensive method of attaching printed cicuit boards with conventional wiring. It is not a mechanically strong connection and would be unsatisfactory for applications where excessive vibration is present.

Terminals suitable for swaging are made of brass,plated to increase ease of soldering. Since silver plating tarnishes, gold plating is frequently preferred. Terminals made of steel or ferrous metals are not desirable for swaging.

Terminals of this type provide a good mechanical and electrical connection. Board layout is simplified by the fact that termination of leads can be made from any point on the board. One disadvantage to this type connection is that assembly and maintenance time is increased because leads must be individually installed and removed.

Welding or brazing leads to printed circuit boards may be employed to make a permanent connection under special conditions. In general, electrical connections made by welding or brazing are employed where structural connection is a factor. A requirement for electrical continuity in the assembly of small structural members may dictate the choice of welding or brazing rather than mechanical fastening devices or solder joints.

Connections used in printed wiring that are intended to be repeatedly made or broken for testing, maintenance, or the replacement of components are referred to herein as separable connections. This includes a wide variety that is further grouped into individual and multi-contact connections.

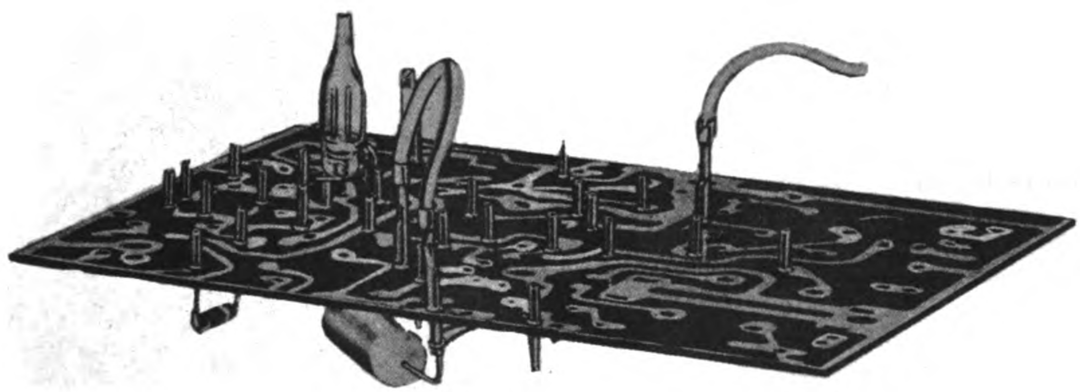
For good design, both individual and multi-contact connections must possess the following characteristics:

1. Electrically reliable
2. Mechanically reliable
3. Polarization
4. Easily removable for maintenance.
5. Sufficiently plated to insure good contact after repeated insertion.

Additional design features will be discussed with each type of connection.

Printed circuit board connections terminated into individual leads are referred to as individual connections. Usually, the leads to be connected are equipped with a crimped or soldered terminal.

The terminal attaches to the printed wiring boards by means of a terminal block, tubular or solid pins, wedge shaped connections, or slide-in electrical connectors located in the terminal area. In general, connections of this type are less adaptable to electronic equipment than soldered connections because they are bulky and not applicable to current assembly practice. Also, increased assembly and maintenance time is required since each lead must be individually installed and removed.



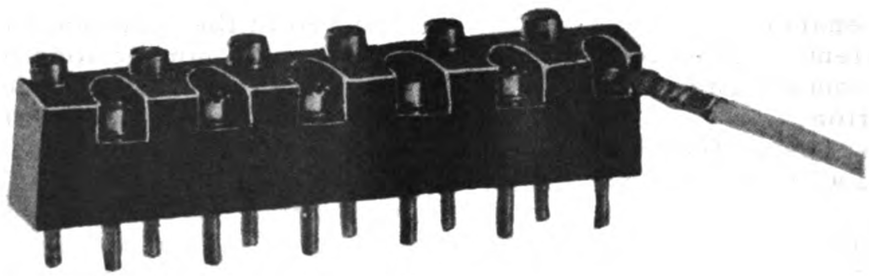
MINIATURE TUBULAR PINS FOR WIRE TERMINATION

As shown above, the following features can be obtained with the use of miniature tubular pins:

1. Pins can be permanently soldered in place.
2. Pins are available for automatic insertion.
3. Pins snap into printed boards.
4. Pin location is versatile.
5. Pins are available in many sizes.
6. Jumpers may be attached between pins.

In addition to the tubular pins previously described, solid copper pins are available for printed circuit board connections. Circuit pins of this type require only a round hole (1/8 in. dia.) in the circuit board. Special assembly equipment is not required and assembly is from one side of the board with single-stroke driving action. The base of the pin is self-locking upon insertion which makes it fully torque resistant prior to soldering. Mechanical, electrical, and vibration resistant qualities of the pin offer the ultimate in satisfactory performance. This connection is inexpensive to manufacture and is ideally suited for use in molded connector blocks. Also, it can be furnished with or without the square wire wrap area if a pin or plug type connector is required.

Terminal blocks are another interconnecting link between printed circuitry and conventional wiring. There are many design variations in terminal blocks. One version of this block is illustrated below.



PLASTIC TERMINAL BLOCK WITH SCREW TERMINALS

Slide-in electrical connectors are designed to take advantage of the extreme contact pressures that can be obtained by forcing a slotted U-shaped terminal over the edge of a printed wiring board in the terminal area. To insure reliable connections, mating surfaces are manufactured to closely controlled dimensional tolerances and care should be taken to ensure that these surfaces are not deformed prior to assembly.

As shown in the inset of the illustration, the slotted receptacles in the terminal area of the board assure that the U-shaped plugs make positive contact with the board.

Multi-contact printed circuit connectors provide a positive, space saving connection between printed circuitry and conventional wiring, and permit direct connection to a printed circuit card, cable, or a "plug" mounted assembly.

These connectors consist of two parts: a plug and receptacle. The plug is that portion of the connector assembly which is moveable.

SLIDE-IN ELECTRICAL CONNECTORS

It will mate with a corresponding receptacle attached to the printed circuit board. The connector receptacle is that portion of the connector assembly which is normally fixed, that is, rigidly attached to a supporting surface. It will mate with a corresponding printed wiring board, mating plug, or contacts attached to a printed wiring board.

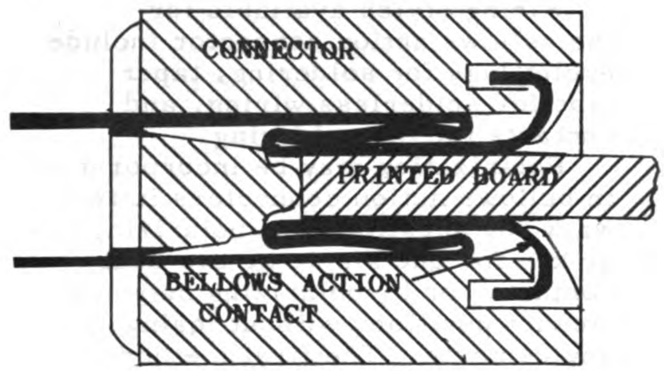
Multi-contact connectors associated with printed circuit boards fall into the five classes listed below:

1. Bellows Action Type
2. Pin and Socket Type
3. MS Printed Circuit Receptacle
4. Forked Contact Connectors
5. Miscellaneous Printed Circuit Connectors

Specific design features, advantages and disadvantages of each of the above classes are delineated in sections that follow.

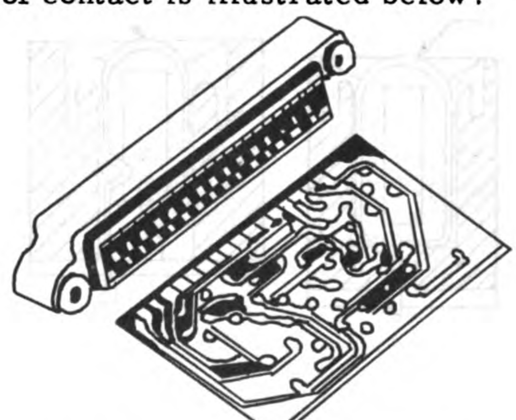
Bellows action type contacts are designed for board to board connection or for connection to conventional wiring - receptacles only with the edge of the printed circuit board serving as the plug. These connectors have a coil spring action grip that clasps the printed circuit board firmly over the contact area. This design permits the use of undersize and oversize boards while maintaining low contact resistance. Due to the contact resistance the contact rides with the printed circuit board under extreme conditions of vibration and misalignment. This bellows action has a distinct advantage over prong type contacts. Prong type contacts grip the printed circuit board at a single point. Oversize boards forced into the contact cause distortion of the spring and possibly damage to the printed circuit. When the board is undersize, contact is not firm, resistance is increased and intermittent contact can result.

Warping of the printed circuit board is held to a minimum with the use of the bellow action type connector since the pressure of the contacts is spread evenly over a large area of the board.



BELLOWS-ACTION CONTACTS

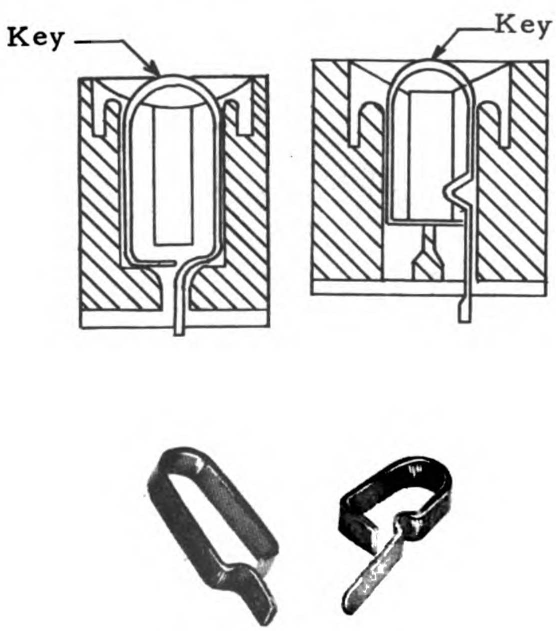
A cross-sectional view of this type of contact is illustrated below.



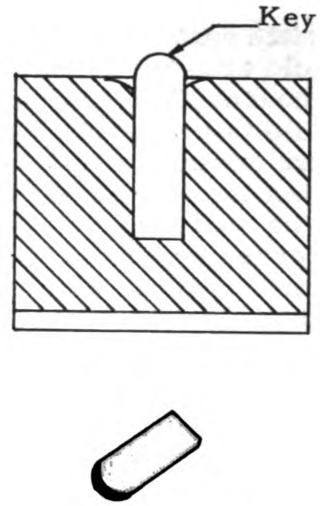
Standard bellow action type printed circuit connectors are designed to accomodate 1/16", 3/32", or 1/8" printed circuit cards. A few companies manufacture connectors of this type that will accept printed circuit boards up to a maximum of 1/4". Both single and double rows of various contact sizes are standard. Double row construction allows for use of both sides of a printed circuit card, or for redundant circuits. At present, up to 116 contacts are available.

Wiring styles available for the bellows action connector include eyelet lugs for soldering, taper tabs for solderless wiring, and contacts for dip soldering.

Polarization may be incorporated in bellows action connectors in two ways; by substituting a polarizing tab or key for one single or two dual contacts, or by polarizing between contact positions without losing any contacts. The first method uses a metal key normally installed at the factory. The second uses a plastic key that can be unstalled in the field. These keys fit in the barrier between the contacts and are retained by spring pressure against the insulator.



METAL KEYS



PLASTIC KEY

Bellows action contacts are made of spring temper phosphor bronze with gold plate over silver plate or gold plate only. The ambient temperature range of the connector is -55 degrees C to -85 degrees C.

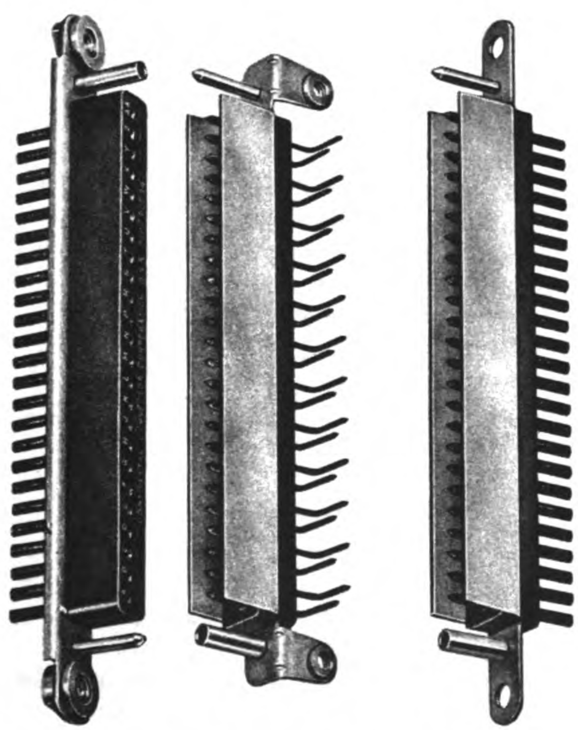
Multi-connectors of this type are available with electrical and mechanical ratings which meet or exceed the requirements of MIL-C-21097. The ratings that are of particular concern to the designer are: breakdown voltage and recommended test voltage both at sea level and altitudes of 60,000 to 70,000 feet; continuous current rating; millivolt drop across contacts; center-to-center contact spacing; minimum air space between contacts; minimum creepage between contacts; and type of terminals.

As a result of miniaturization, microminiature bellows action connectors have been designed for use with 1/32" and 1/64" printed circuit boards. These connectors possess features similar to those outlined for their larger prototypes, but the electrical and mechanical ratings are slightly lower.

Connectors are normally supplied with closed circuit contacts. When the board is inserted, contacts open and make a complete circuit with the board.

Printed circuit connectors of this type are offered in unique tandem designs that combine up to four groups of printed circuit receptacles in a single molding. An integral center barrier in the molding separates each board. Receptacles accommodating 2 or 3 boards in tandem or two or four boards in parallel tandem are available.

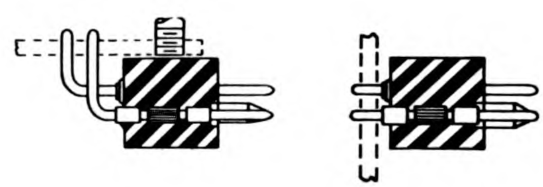
Pin and socket type connectors are designed for board to board connection or for attaching external wires to printed circuit boards. The plug of pin and socket connectors contain individual right angle pin or straight pin contacts for dip soldering to printed circuit boards.



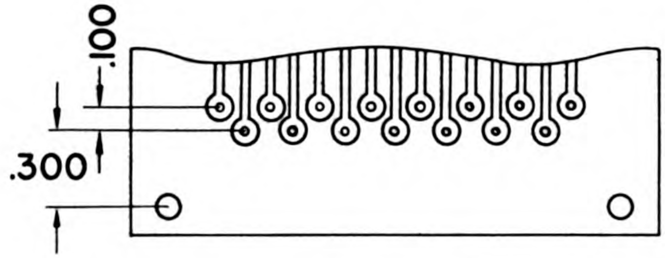
RECEPTACLE PLUG PLUG

Guide pins in the plug, and guide bushings in the socket provide guided insertion and prevent bending of contacts. Positive polarization is achieved with reverse guide pins and guide sockets. Where necessary to meet vibration requirements, polarizing screwlocks may be employed. Another method to assure alignment is the use of closed entry socket contacts, free floating contacts, or floating mounting washers in the shells. Brackets or shields can be provided as an integral part of the connector to protect contacts and also to act as a support for the printed circuit assembly.

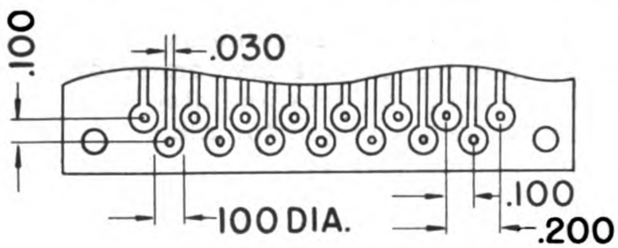
The receptacles have solder cup, turret, eyelet, straight pin, or taper pin contacts for termination.



Recommended circuit patterns for the .100" x .100" grid system is shown below for right angle plug mounting and straight style plug or receptacle mounting. For other than .100" x .100" systems the dimensions should be proportioned accordingly.



RECOMMENDED CIRCUIT PATTERN FOR RIGHT ANGLE PLUG MOUNTING



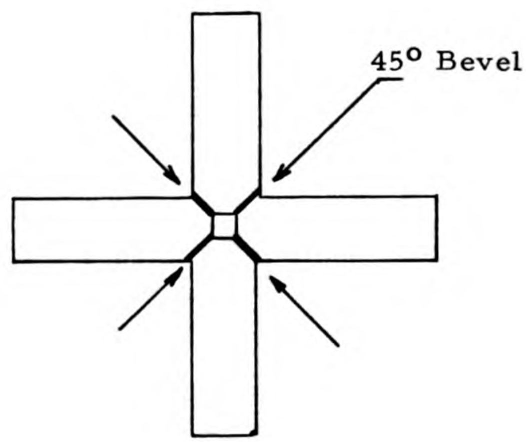
RECOMMENDED CIRCUIT PATTERN FOR STRAIGHT STYLE PLUG MOUNTING

Typical socket contacts are precision machined from phosphor bronze with gold plate over silver plate. Contacts have low resistance, are highly corrosion resistant, and are easy to solder.

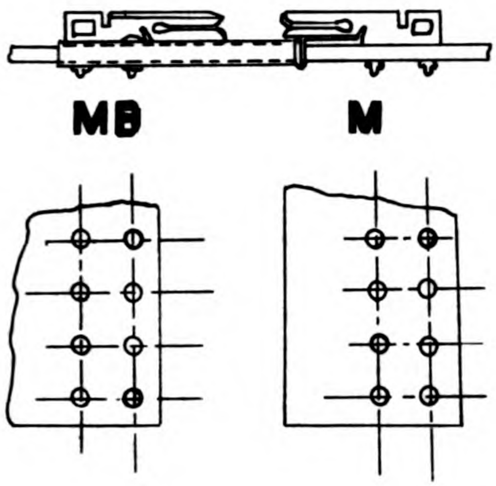
Miniaturized pin and socket connectors are available with features similar to connectors of standard size. As the size of the connector is reduced, the electrical and mechanical ratings become lower.

Forked contacts can be used with many different circuit board connections. These contacts have one or two legs which are fastened to the printed circuit board by staking. Staking of the contacts to the printed board assures a solid low resistance contact rigidly held in place. Dip soldering the board automatically provides an additional connection between contact and board, thus creating a very reliable joint.

Contacts of opposing boards are mated 90 degrees to each other to allow the forked members to mesh with each other for the entire length of the contact. Additional contact surface is provided by a 45 degree bevel running the full length of the forks. This resulting large contact area provides high voltage and current capacity, and mechanically produces positive contact at all time with no possibility of intermittents under any operational condition.



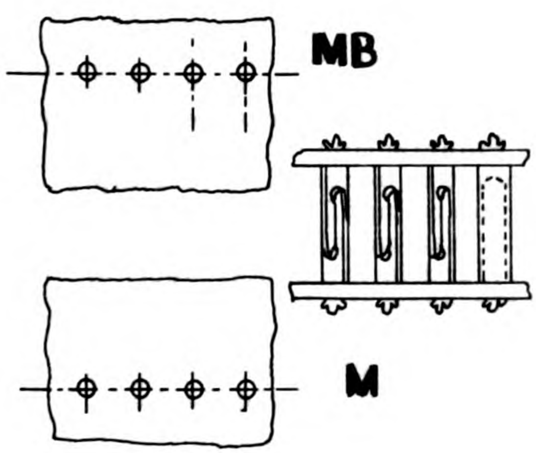
For connecting two boards in tandem on a common plane, both mother board (MB) and module board (M) use the same contact. Each contact is bent 45 degrees with respect to the board surface. Contacts are thereby mated at 90 degrees to each other.



Board thickness of 1/16" or 3/32" may be selected for either board.

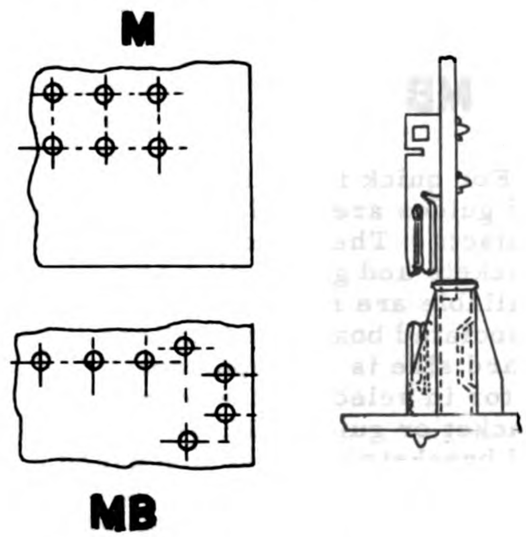
A standoff contact is used on both the mother board and the module board for connecting two boards parallel to each other. They are staked to each board with the plane of the contact at 45 degrees with respect to the centerline of the connector. Four board thicknesses; 1/16", 3/32", 1/8", or 3/16", may be selected for either board.

This standoff connector is not restricted to edge mounting. Connection can be established at any point between both printed circuit boards, thereby eliminating the necessity of carrying the printed circuit lines to the edge of the board.

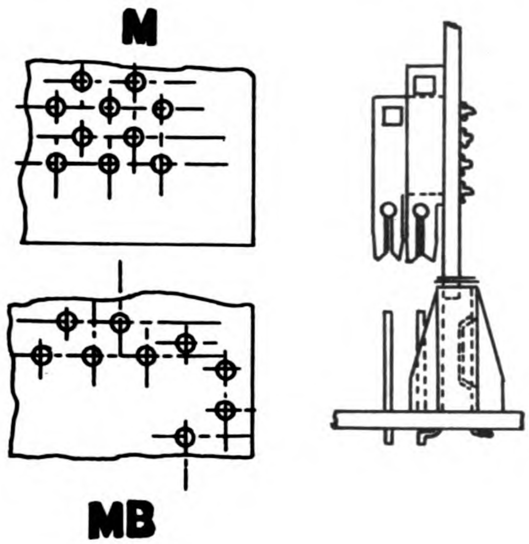


To connect two boards perpendicular to each other, using one row of contacts, a standoff contact is used. The plane of the contact is staked at 45 degrees with respect to the centerline of the connector. Contacts for three mother board thicknesses are available: 1/16", 3/32", and 1/8".

When the closest recommended contact spacing of .125" is used, the minimum air gap between adjacent contacts when mated is .031". The closest recommended spacing of module boards is .250" plus desired air gap between the contact at one board and the contact tail at the adjacent board. To increase the air gap, contacts of adjacent boards can be offset 1/2 contact spacing.



To connect two boards perpendicular to each other, using two rows of contacts, two rows of standoff contacts are used. Contact spacing for each row is .200". The two rows are spaced .125" apart. On the module board, lower and upper tier straight contacts are used. Each tier has contacts spaced .200" apart with the upper tier contacts mounted between adjacent lower tier contacts resulting in a final .100 contact spacing for this connector - lower tier and upper tier contacts on separate strips, standoff contacts on one common strip in two rows.



For quick insertion, brackets and guides are used to align the contacts. The different types of brackets and guides that are available are shown with their associated board applications. Board size is an important factor in selecting the proper bracket or guide. These guides and brackets are also discussed later in the section covering Mounting of Printed Wiring Boards.

These four methods of connecting printed circuit boards with forked contacts give the designer complete flexibility in creating his equipment.

A further application of the forked contact with printed circuit boards is found in the two part connector consisting of a plug and receptacle. The plug is composed of contacts which are staked to the board. The receptacle consists of another set of contacts mounted in a molded housing.

The outstanding feature of this type of connector is that each pair of contacts is self-aligning thereby eliminating the tolerance problems in connector registration. In addition, each contact has four chamfered surfaces which are wiped clean when the contacts are joined, thereby preserving low contact resistance. This connection also exhibits superior characteristics when exposed to shock and vibration environments.

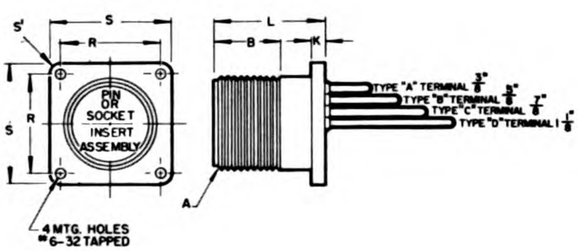
Polarization of any type forked contact is accomplished simply by insertion of a plastic polarization tab into recesses provided in the center section of the contact without loss of any contacts. Standard contact material is phosphor bronze silver plated or gold flashed.

Contacts are also available with nickel plating and gold flash. The type of plating has a significant influence on the insertion and withdrawal force but not on contact resistance.

The high packaging density achieved with miniaturized components requires smaller connectors with closer contact spacing. The same fork-like contact principle and its production method has been used to develop a microminiature contact series. Printed circuit connectors with .075" and .100" in spacing in one row or .050" and .075" in spacing in two rows are possible and have been made.

The MS printed circuit receptacle is a new type connector designed to mate with one to four printed circuit boards.

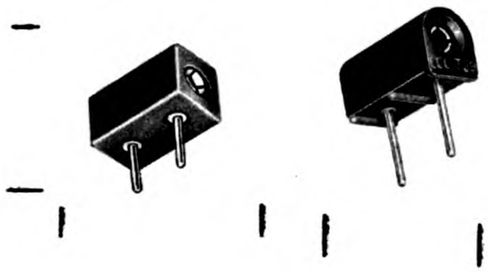
Special pins are made in various lengths at the terminal end as illustrated below. This receptacle is available in both pin and socket assemblies and will mate with all MS type plugs.



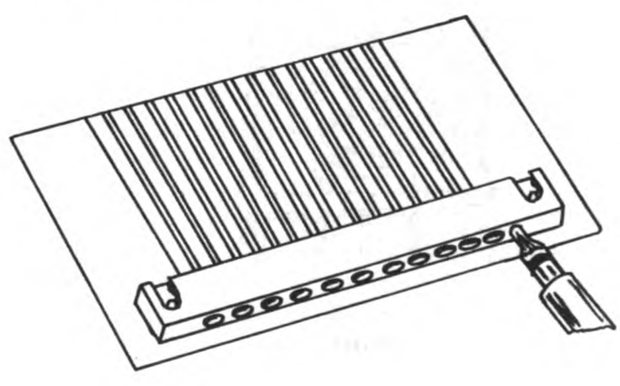
Miscellaneous printed circuit connectors include the following:

1. Test point connectors
2. Junction block connectors
3. 90 degree printed circuit tube sockets
4. Standoff printed circuit tube sockets

Test point connectors are single contact connectors of the internal type and are usually dip soldered to printed circuit boards. They can be conveniently located at any position on the board for easy test takeoff points. The connector contact accepts and holds a nominal .080 diameter test probe.

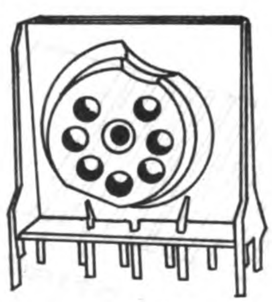


Junction block connectors are used for testing entire printed circuits without rearrangement of any components. Connectors have recessed and floating pin terminals mounted at a right angle to the test sockets and can be dip soldered to printed circuit boards with complete ease of alignment. Each socket grips and holds a standard .080" test probe. The molded body acts as a convenient handle for insertion and withdrawal of the printed circuit board.

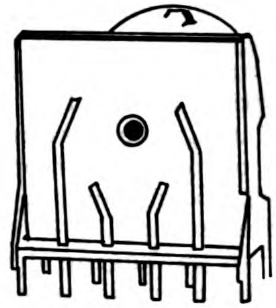


The 90 degree printed circuit tube sockets permit installation of tubes in a position parallel to the printed circuit chassis thus conserving space where height is limited. The brackets are designed to maintain rigidity and the low center of gravity offers great resistance to vibration and shock.

Contacts with long ends are used to form direct metallic connection between contact head and printed circuit lines. They are bent and guided into epoxy spacer plates to obtain excellent insulation resistance and high voltage ratings with low capacity. Spacer plates are permanently secured with air gaps to avoid moisture traps. Component design and material are similar to present military type tube sockets covered by MIL-S-12883. Therefore, all electrical and mechanical characteristics are in accordance with military specifications. Metal parts are plated to pass the salt spray test per specification QQ-M-151A. Seven and nine pin sockets with and without shields are available. The sockets will fit 1/16", 3/32", or 1/8" boards



7-PIN
Front

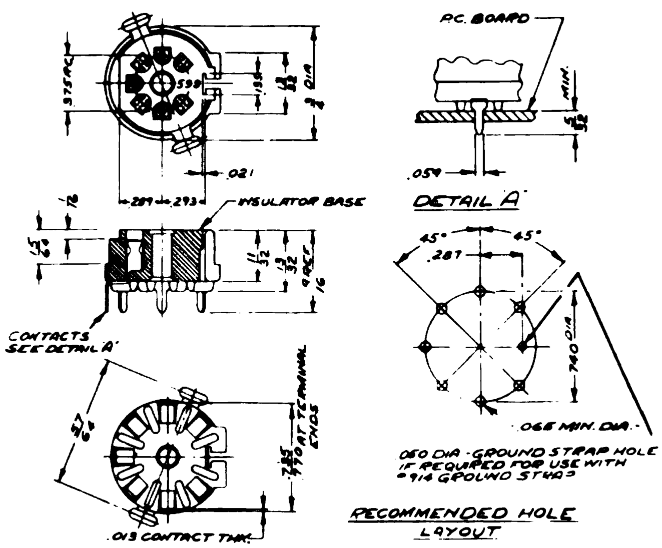


7-PIN
Rear

Printed circuit tube sockets are available for printed circuit boards of 1/16", 1/8", and 1/4" boards.

Standoff type sockets for surface mounting on printed circuit cards may be obtained in several different styles. A 7-pin socket with knob-like appendages for attaching commercially available spring type tube retainers is illustrated below.

7- PIN WITH
RETAINER
LUGS



A number of styles and qualities are available for most of the printed circuit connectors covered in this section. Selection of the most suitable connection should be based upon considerations of service conditions and design characteristics including materials, creepage distances, ability of threads to withstand tightening torques without damage, ability of socket springs to retain their spring action for the life of the equipment in which the connector is to be installed.

3.7.2.2.3 Mounting of Printed Wiring Boards. The following factors must be considered in selecting a suitable method for mounting printed wiring boards:

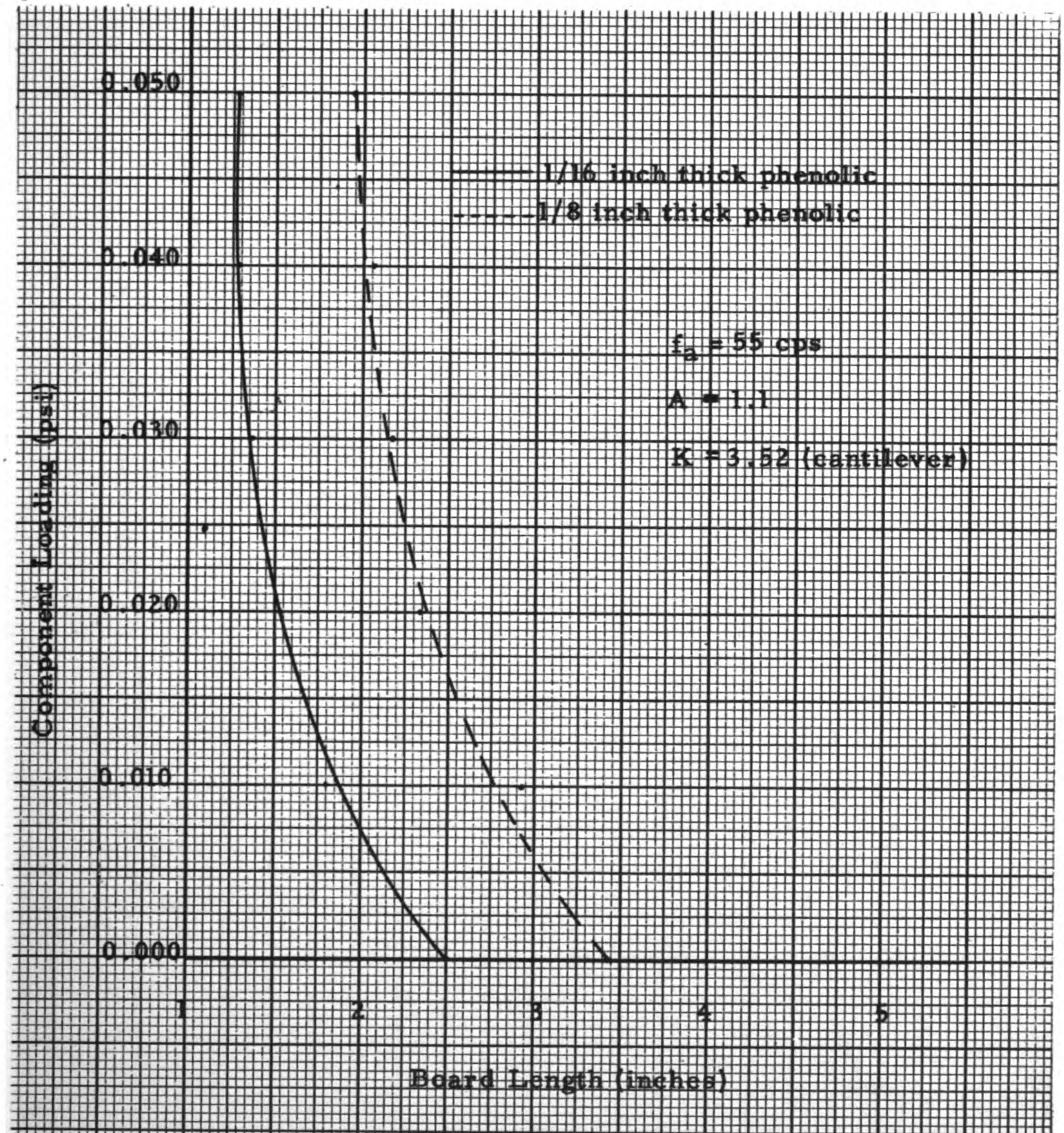
1. Board size
2. Board configuration
3. Type of connector
4. Space available
5. Accessibility
6. Vertical or horizontal mounting
7. Support and retention
8. Hardware
9. Heat dissipation
10. Type of circuit and relation to other circuits

Adequate support and retention must be provided for holding the board since friction alone is not suitable for this purpose. Boards 1/16 to 3/32 inch thick should be supported at intervals of not more than 4 inches. Boards thicker than 3/32 inch should be supported at intervals of not more than 5 inches.

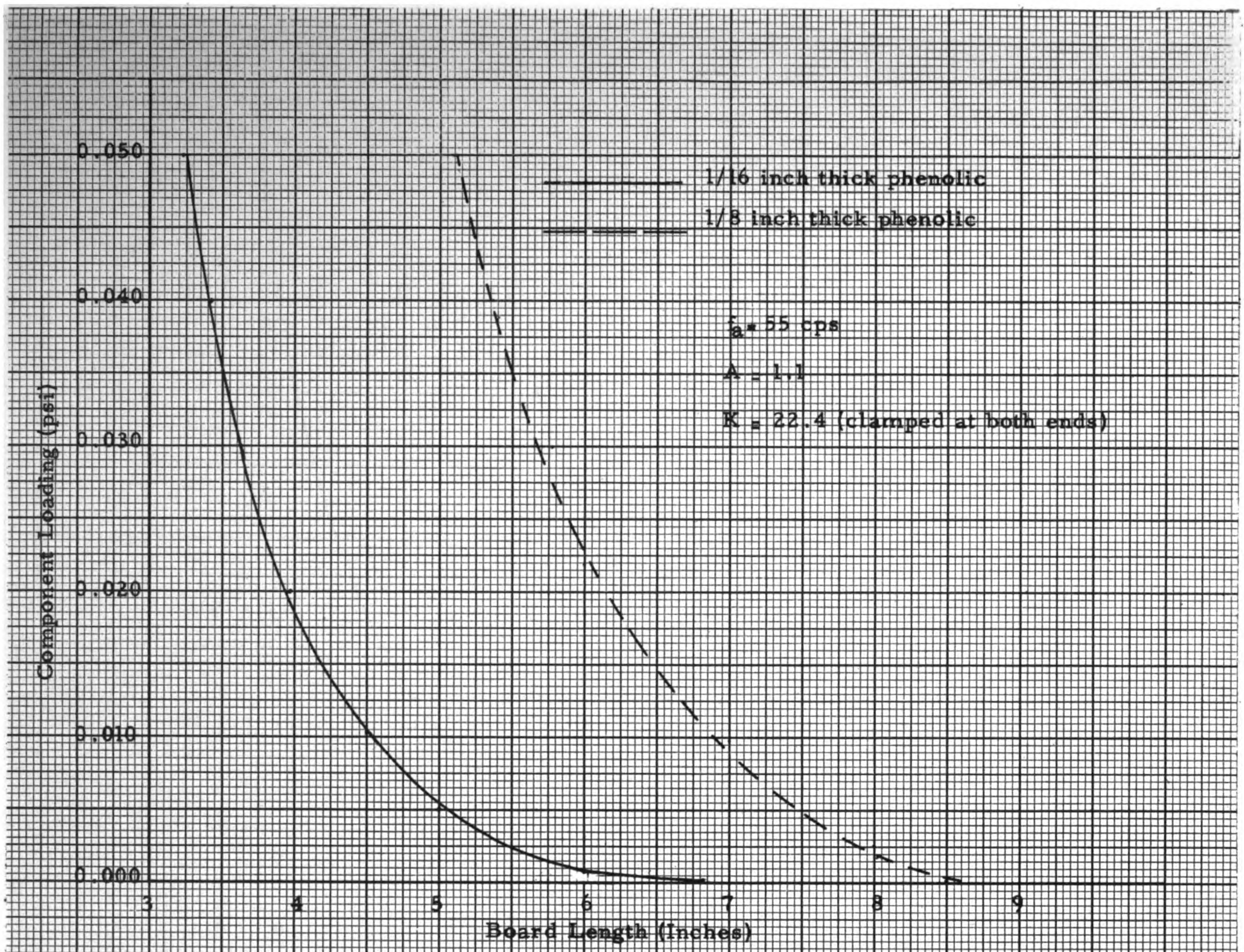
The mechanical support for the board should hold it in place and minimize its relative motion to the chassis. Both rigid support at the bottom and lateral support at the top of the board is best in order to raise the natural resonance of the assembled board structure as high in frequency as possible and to limit motion similar to that of a vibrating reed.

Apart from electrical consideration, the size of the board, which is partially determined by the method of support, must be given careful consideration.

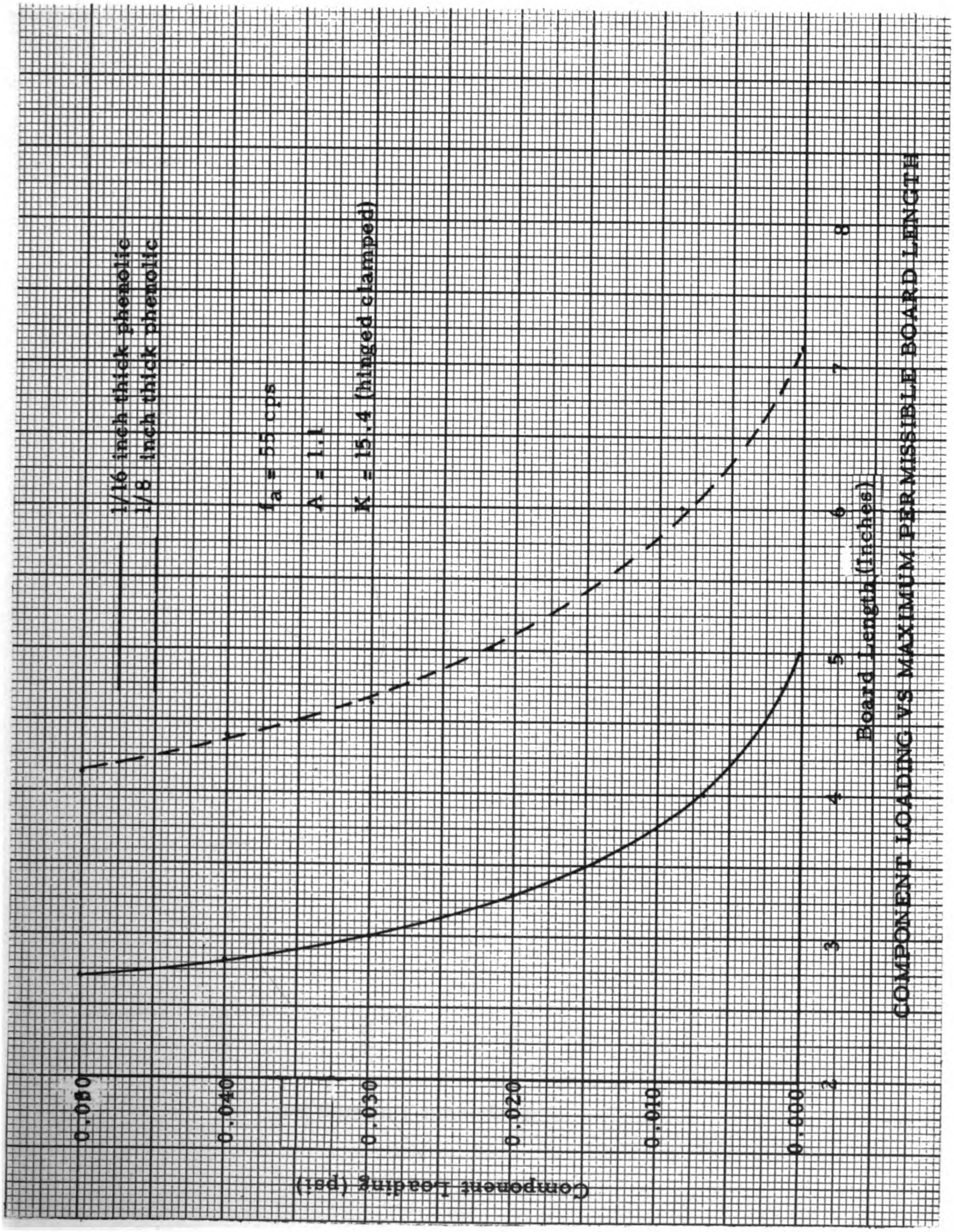
Four sets of curves are presented for four different methods of support as an aid for determining phenolic-board dimensions under vibration conditions. These curves are plotted from an equation which takes into consideration the several factors involved in deremining maximum board length.



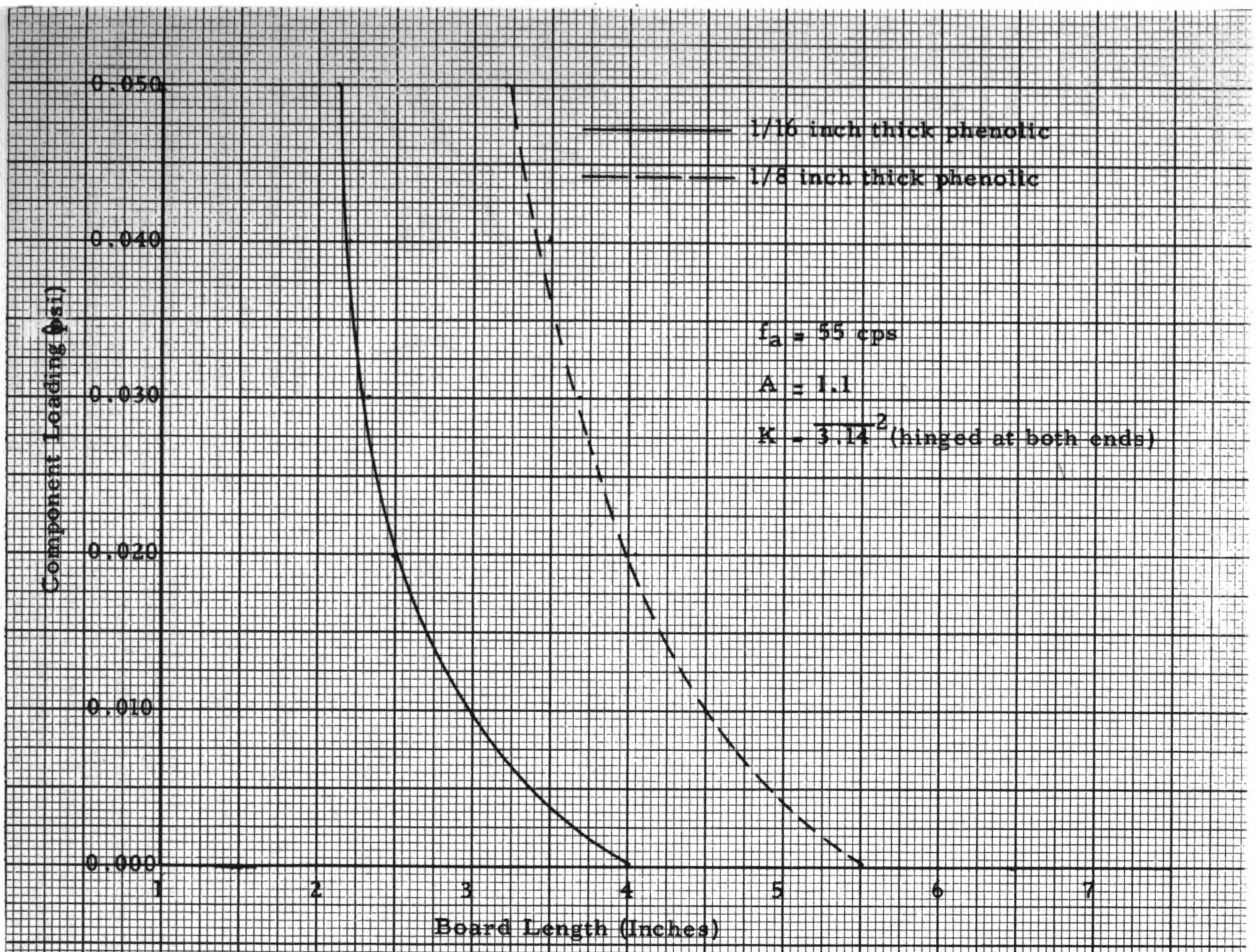
COMPONENT LOADING VS. MAXIMUM PERMISSIBLE BOARD LENGTH



COMPONENT LOADING VS MAXIMUM PERMISSIBLE BOARD LENGTH

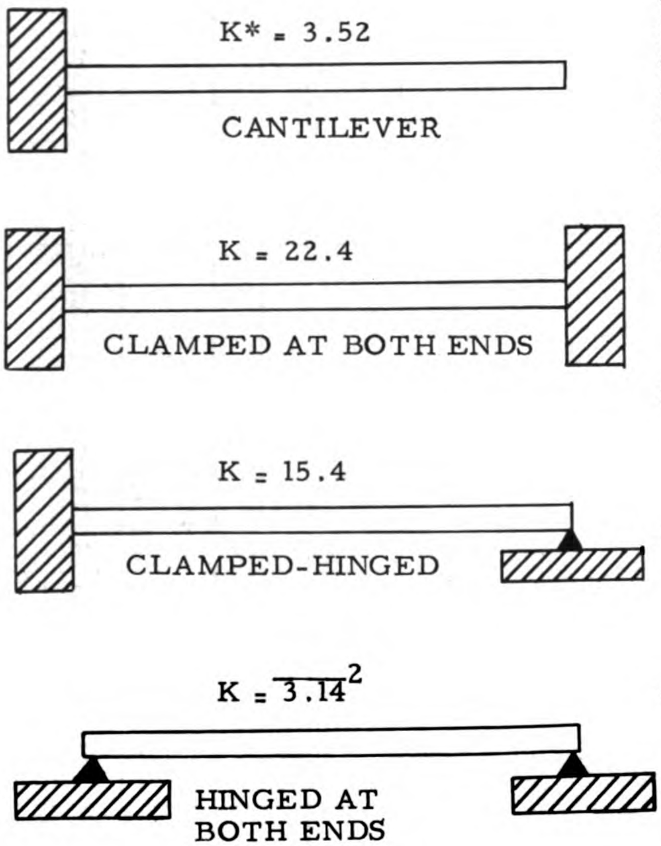


COMPONENT LOADING VS MAXIMUM PERMISSIBLE BOARD LENGTH
1/16 inch thick phenolic
1/8 inch thick phenolic
f_a = 55 cps
A = 1.1
K = 15.4 (hinged clamped)
Component Loading (psi)
0.050
0.040
0.030
0.020
0.010
0.000
Board Length (Inches)
2
3
4
5
6
7
8



COMPONENT LOADING VS MAXIMUM PERMISSIBLE BOARD LENGTH

Printed wiring boards with mounted parts use four types of support: cantilever, clamped at each end, hinged and clamped, and hinged at each end.



TYPE OF SUPPORT

*Depends on type of support

In practice, a form of cantilever mounting bracket is normally used, and in most cases this is the least desirable type of support. Therefore, cantilever mounting brackets should be avoided unless the base of the bracket at the chassis is broad in dimension and perpendicular to the board length. In addition, when cantilever mounting is used it may be necessary to add an additional bracket at the top of the board to [illegible]ve lateral rigidity.

Cantilever mounting of boards is often inadequate if the board length is much longer than 2 inches since boards mounted in this manner and longer than 2 inches can approach resonance when subjected to the standard 55 cps vibration test. Since board lengths are usually longer than 2 inches it is advisable to use a different mounting method. The clamped-at-both-ends type of mounting is normally preferred.

Various board parameters may be calculated from the following equations:

$$A = \frac{1}{1 - (f_a/f_r)^2}$$

from which

$$f_r = \frac{f_a}{\sqrt{1 - (1/A)}}$$

and

$$f_r = \left(\frac{K}{2\pi}\right)\sqrt{\frac{EI_g}{WL^3}} = \left(\frac{K}{2\pi}\right)\sqrt{\frac{Et^3}{12\mu \quad L^4}}$$

where W=bL, from which

$$L = \left(\frac{K}{\pi f_r}\right)^{1/2} \left(\frac{Et_g^3}{48\mu}\right)^{1/4}$$

where

- A = amplification factor = y_i/y_a
- y_a = amplitude of applied vibration (inches)
- y_i = amplitude of induced vibration (inches)
- f_a = frequency of applied vibration (cps)
- f_r = frequency at resonance (cps)
- K = support constant
- E = modulus of elasticity of the board (psi)
- b = board width (inches)
- t = board thickness (inches)
- I = moment of inertia = $bt^3/12$
- g = gravitation constant = 386 in/sec^2
- W = unit loading (parts, board, and hardware - psi)
- L = maximum theoretical board length (inches)

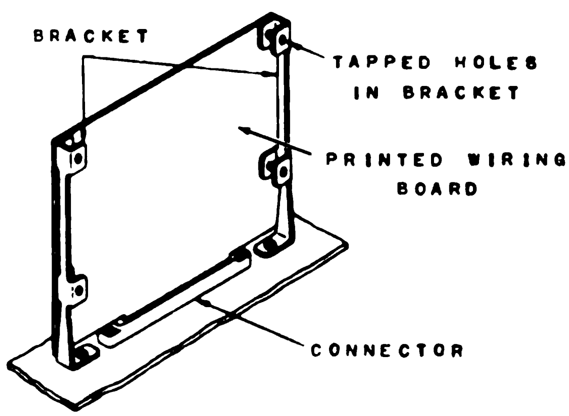
The modulus of elasticity of the board material is modified due to the increased stiffness caused by the addition of the components and wiring. For a 1/16 inch thick phenolic board, the increased stiffness was found to have a median value of about 50 percent for a phenolic material. If the majority of the components are mounted crosswise on the board, the increase in modulus of elasticity will not be as large.

Exactness is not required since the 4th root is used. In the curves shown, a factor of 50 and 25 percent were used, respectively, for the 1/16 and 1/8 inch boards.

Various methods of mounting printed wiring boards are illustrated on pages 3 - 75 to 3 - 77. The advantages and disadvantages of each method are listed and should guide the designers in selecting the proper mounting method.

For proper mounting design, the method selected should fulfill the following requirements:

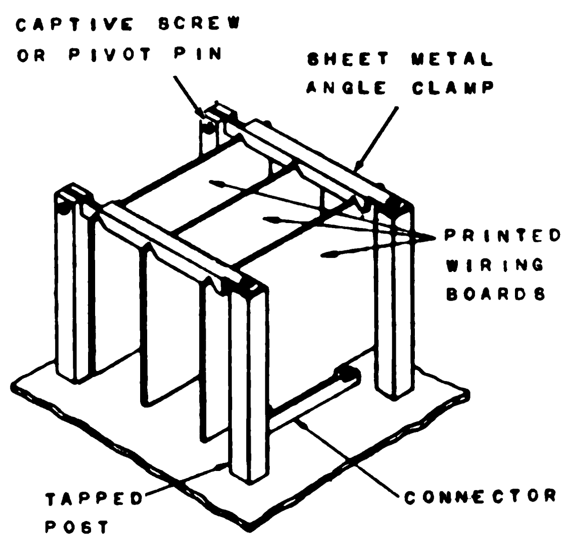
1. Method of mounting must provide maximum ease of maintenance
2. Fasteners easily removable
3. Minimum loose hardware
4. Adequate clearance between printed conductor and mounting brackets
5. Board supported at proper intervals
6. Positive board retention



VERTICAL FLANGED BRACKET

Advantages:
1. Commercially available in several sizes
2. Mounts single or double boards

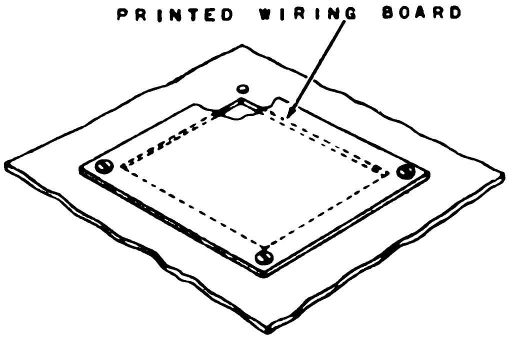
Disadvantage: Loose hardware



PIVOT CLAMPS

Advantages:
1. Suitable for retaining several boards simultaneously
2. No loose hardware

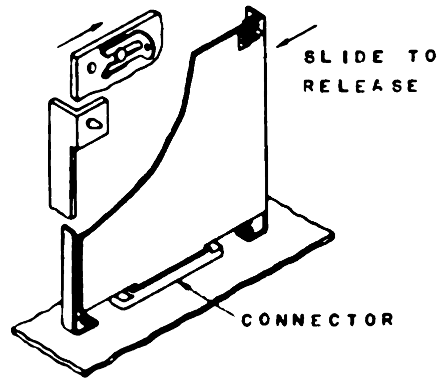
Disadvantages:
1. Relatively high cost
2. All boards must be the same height



CUT-OUT IN CHASSIS

Advantages: 1. No mounting brackets required
2. Provides accessibility to underside of printed board

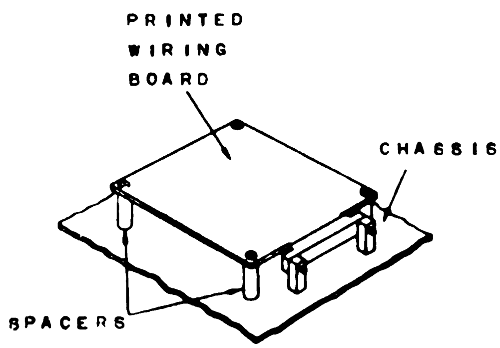
Disadvantage: Loose hardware



SNAP SLIDES

Advantages: 1. Positive retention of board
2. Easy removal and replacement

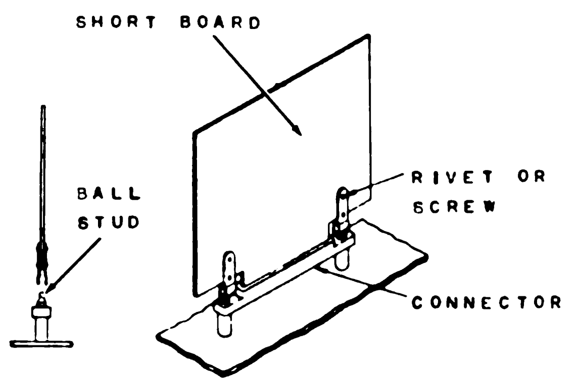
Disadvantage: Relatively high cost



MOUNT ON TAPPED SPACERS

Advantages: 1. Accomodates any size of board
2. Simple inexpensive mounting

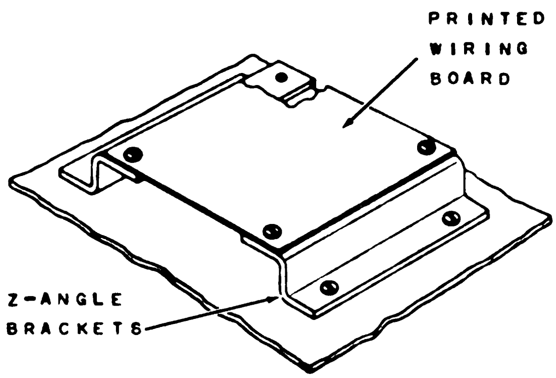
Disadvantages: 1. Loose hardware
2. Occupies large chassis area



SPRING CLAMP AND BALL STUD

Advantages: 1. No loose hardware
2. Quick insertion and removal of board
3. Commercially available

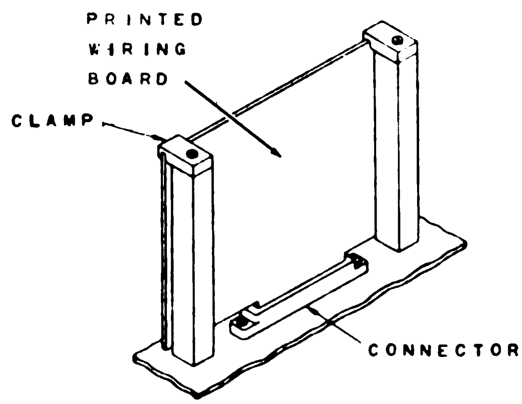
Disadvantage: Suited only for short boards unless additional support is provided



Z-ANGLE BRACKETS

Advantages:
1. Suitable for any size board
2. Provides good heat dissipation to chassis

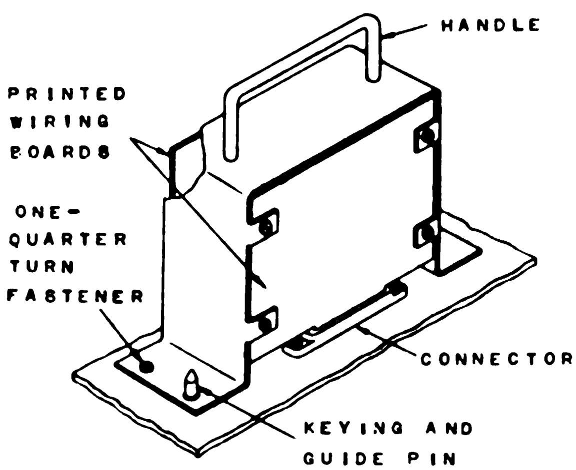
Disadvantages:
1. Loose hardware
2. Occupies large area on the chassis



VERTICAL POST AND GROOVED CLAMPS

Advantages:
1. Guides board during insertion into connector
2. Can be made to accomodate any size board

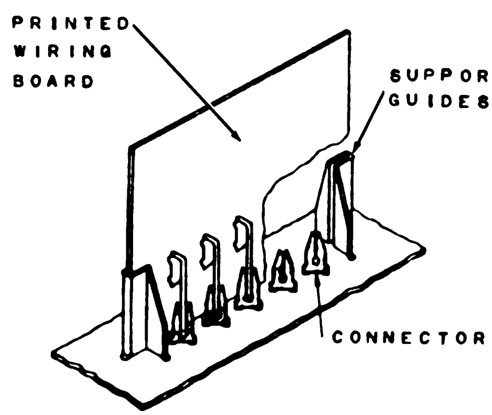
Disadvantage: Relatively high cost



DUAL MOUNTING FIXTURE

Advantages:
1. Positive retention
2. Boards can be used in pairs

Disadvantage: Additional chassis area required for mounting



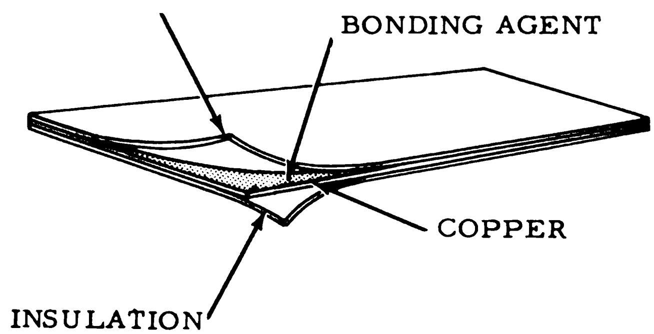
SHEET METAL SUPPORT GUIDES

Advantages:
1. Guides board during insertion
2. No loose hardware

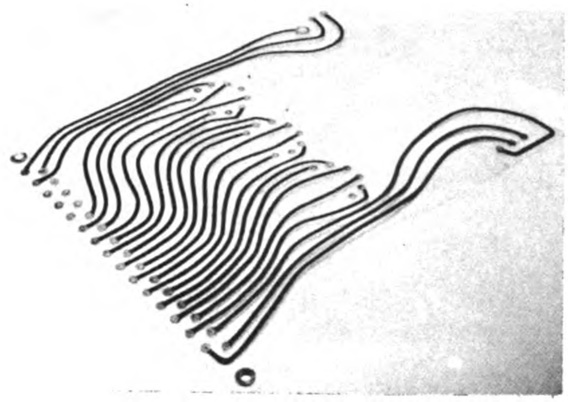
Disadvantage: No positive retention

3.7.2.2.4 Flexible Printed Wiring. Flexible printed wiring consists of a laminate of conducting material, usually copper, bonded between two layers of transparent flexible insulation as shown in the illustration below. A multi-layer construction is also possible and further facilitates conversion from more complex cable harness to flexible printed wiring. The wiring is produced as follows: rolled copper sheet is bonded to a sheet of flexible insulating plastic; the required conductor pattern is transferred to the copper, and the exposed areas are etched. The etching technique is similar to that used for rigid base materials. The copper is then cleaned and a second sheet of plastic insulation is bonded to the exposed conductors forming a sandwich. Good bonding between layers is of the greatest importance to prevent moisture penetration, corrosion, and inter-conductor leakage. When the bond is properly made, it is highly resistant to delamination and peel-strength tests normally result in the destruction of the entire laminate.

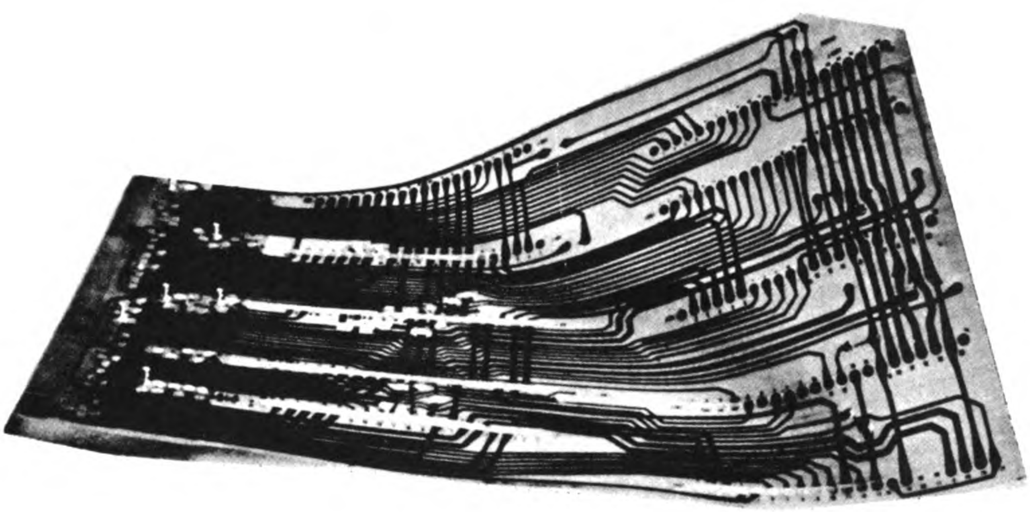
The use of several types of flexible wiring is shown on pages 3-79 to 3-81.



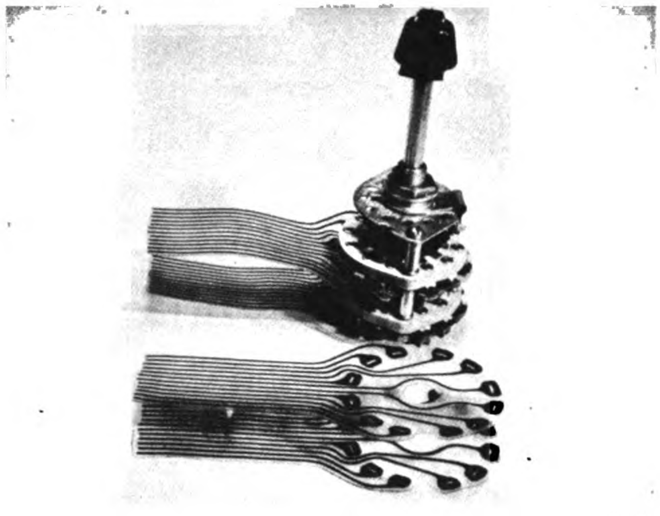
FLEXIBLE PRINTED WIRING



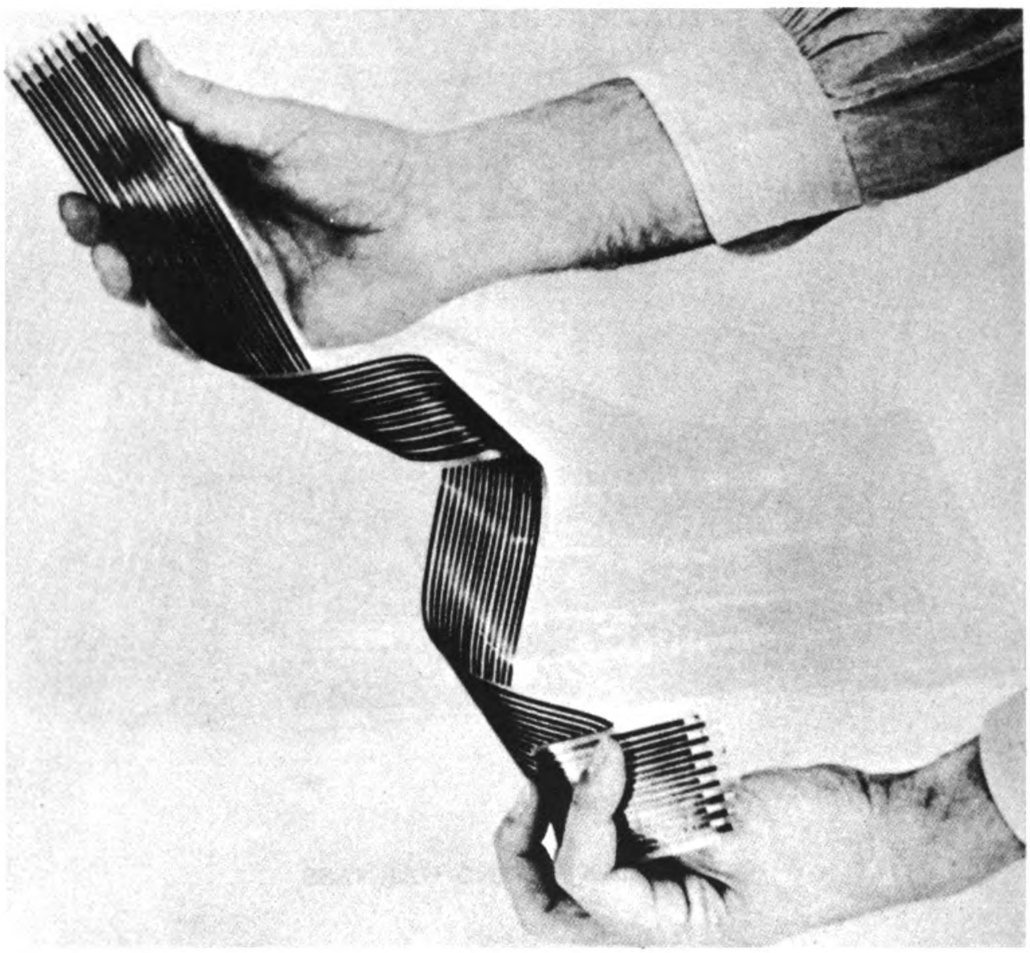
SIMPLE WIRING HARNESS



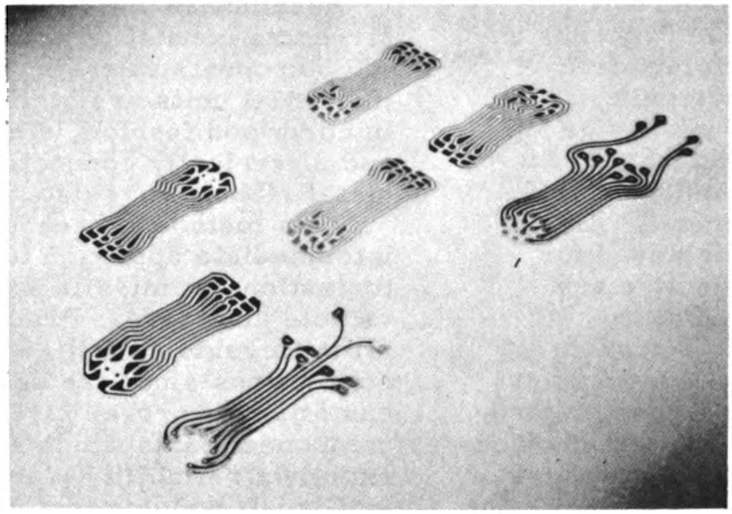
COMPLEX WIRING HARNESS



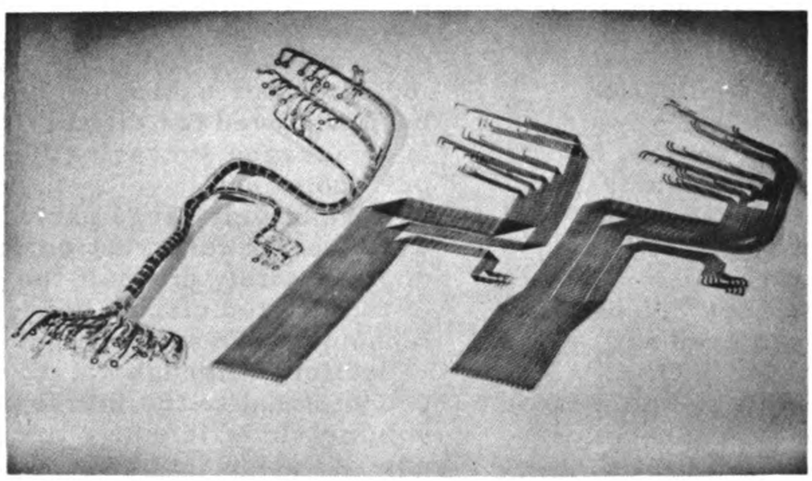
WAFER SWITCH CABLE



COMPLEX CABLE



JUMPERS



TRANSITION FROM STANDARD
TO FLEXIBLE WIRING

3.8 MINIATURIZATION

Miniaturization concerns an increase in the volumetric efficiency of electronic assemblies through design techniques that effect a reduction in the size and weight of electronic equipment. Among the techniques employed for attaining this objective are dense packaging, micromodules, microelectronics, and related techniques such as magnetic films, and electroluminessence. These techniques offer the following advantages to the design engineer: reduction in size, weight, and cost and, with careful design consideration, reliability and maintainability equal to or better than that found in conventional system design. Other benefits include greater system simplicity from the use of a minimum number of discrete parts and higher performance because the reduced size and weight permits the use of more sophisticated systems and the application of redundancy without severe penalty to overall system design.

Essentially, miniaturization may be accomplished by any one method or a combination of several methods. Although the various methods discussed herein are considered as separate approaches, the dividing line between one method and another is generally hazy.

3.8.1 Dense Packaging

Assemblies in this category represent the most advanced production state-of-the-art. Conventional components are densely packed, with or without a supporting structure, into circuit modules of various sizes and shapes.

Assemblies without a supporting structure consist of an assembly of components wherein the individual units are stacked in cordwood fashion, side-by-side, and electrically connected with metal ribbon by resistance welding.

This method represents the intermediate approach to miniaturization for missile and space vehicle hardware. Practically all such vehicles utilize welded connections since the designer can still use proven circuits and component parts which exhibit an excellent reliability history.

Circuit welding is a completely controllable process where the machine is pre-set to a pressure and energy setting determined by the characteristics of the material to be welded. This results in a joint of high tensile strength and a unit mass that is nonresonant and structurally rigid.

Welding provides a means of packaging existing electronic assemblies in the minimum possible volume. Densities up to 160 parts per cubic inch have been achieved for digital circuits, and packages averaging 100 parts per cubic inch have been produced with relatively large parts. Welded wire matrix construction occupies approximately one half the volume of the printed circuit board technique. Overall weight reduction, although not directly proportional to the increased volumetric efficiency, is considerable. Design flexibility is also excellent since the module shape can be arranged to fit unique configurations.

When a supporting structure is used, it is generally a printed wiring board although components may be packed in a small shell. The principal advantage of this type of assembly is its adaptability.

Any class or type of component may be used, and no special manufacturing skills are required. However, the degree of miniaturization obtainable is limited, a large number of connections are required, and quality assurance techniques are required at the part and the assembly level.

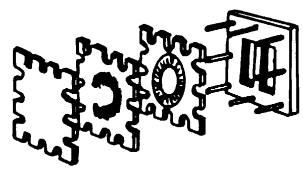
3.8.2 Micromodules

In this approach, all components are reduced to a common form factor and the assemblies are built by stacking of appropriate components to produce small cube-shaped solids consisting of wafers which assume the basic characteristics of electronic components. The resulting unit is then ready to function, based on design, as an amplifier, oscillator, filter, etc.

The resultant objectives of micromodules are:

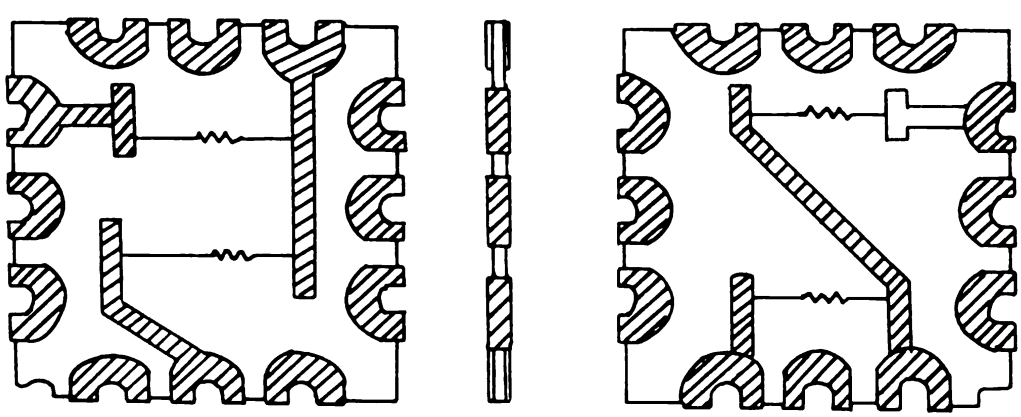
a. Appreciable reduction in size over present equipment.
b. High volumetric efficiency
c. Uniformity in size and shape
d. Versatility
e. Low power applications
f. Mass production by automation
g. Cost reduction

An exploded view of a micromodule before stacking and interconnecting is shown below.



The various waver forms used in micromodules can be manufactured from the following substrate materials: steatite, condierite, alumina, fosterite, beryllia, zircon, magnesium oxide, and pyrex glass. Of these, alumina and glass possess the most promising characteristics. Alumina is favored bacause of its superior thermal conductivity and strength, while glass provides a very smooth surface essential for deposition of uniform thin metal films.

A typical example of wafer configuration is illustrated below.



3.8.3 Microelectronics

Microelectronics concerns the following approaches utilized in the design of microminiature components: integrated circuitry on ceramic or semiconductor substrates, and functional blocks.

3.8.3.1 Integrated Circuitry.

This type of circuitry comprises the largest area of advanced research interest in microelectronics and provides the next stage in attaining significant size reduction. Most of the activity centers around the use of semiconductor active elements although magnetic devices are also being developed.

One class of devices uses a ceramic or other insulating substrate upon which is fixed separately fabricated and tested transistors and diodes. The necessary passive elements and interconnections are formed by thin film deposition techniques to complete a circuit on a single wafer. The basic advantages of this technique are: the production of a highly dense circuit with minimum weight and space used for support, insulation, and connections; the decrease in total number of connections; the replacement of soldered and mechanical connections by the ones formed during the deposition process; the reduction in the total number of processing steps; and the placement of the complete circuit in a protected environment.

A second class of integrated circuitry involves the direct formation of thin film semiconductor devices on a ceramic wafer without the need for crystal growing, cutting, polishing, or other preparatory steps. The ultimate objective is to form thin film transistors and diodes directly without added process steps. One technique employed concerns the evaporation of high-temperature metals and non-metals in a high vacuum and in the presence of injected gases. This allows vacuum evaporation of thin film microcircuit elements using one evaporation and control technique.

A third technique in integrated circuits uses a single crystal semiconductor as the substrate. Both the active and passive elements are fabricated directly on the substrate using the technology of semiconductor processing such as diffusion, alloying, etching, masking, deposition, etc. The major problems associated with this technique are the design of broad classes of circuits, and uniform producibility.

3.8.3.2 Functional Blocks.

With this technique, largely theoretical at present, individual components cease to exist and a block of a specially grown and doped crystal performs a complete circuit function. The semiconductor substrate integrated circuit approaches this concept very closely. The difference between the two is mainly the intent of the designer to use the most efficient physical process to accomplish the desired function. Therefore, the full development of this concept depends heavily on further research into the materials.

3.8.4 Related Devices

The first approach to miniaturization in this category eliminates the use of conventional components and uses interatomic action within the material as demonstrated in the thin magnetic film shift register. Digital information is fed to a strip of magnetic film and moved down the film by an associated clock wiring system and read out at the end. This action is accomplished by magnetic domain switching and requires no components. Such devices are out of the research phase and in pilot production for use in new system developments.

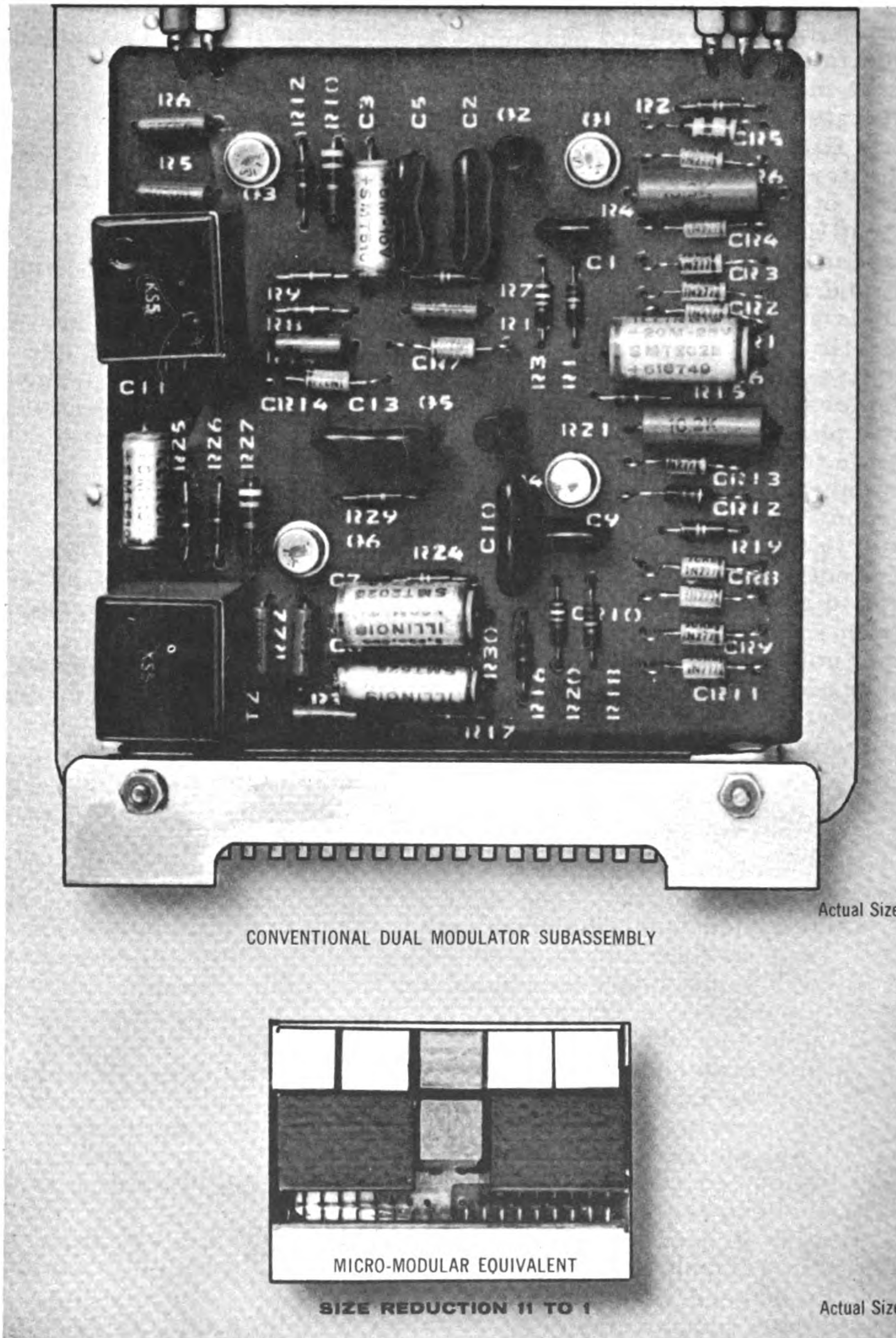
A second example of this approach is the use of a thin film of electroluminescent material to replace the mechanical devices in an analog computer. The input voltage generates light instead of mechanical torque. At the output a photoconductive film is used to convert the light into variable resistance as a replacement for the normal potentiometer which converts mechanical motion into variable resistance. Size and weight of this thin film device is greatly reduced versus the electromechanical equipment.

Longer range trends in microelectronic technology point towards the subject of bionics. These efforts in bionics deal with techniques for duplicating electronically the extremely efficient data processing system of the brain and nerves. The first probable result from these studies will be the development of completely new computer logic elements.

3.8.5 Utilization

The following illustrations show the comparison between conventional and micromodule subassemblies, such as:

a. Ten to one size reductions
b. Volumetric densities in excess of 250,000 parts per cubic foot



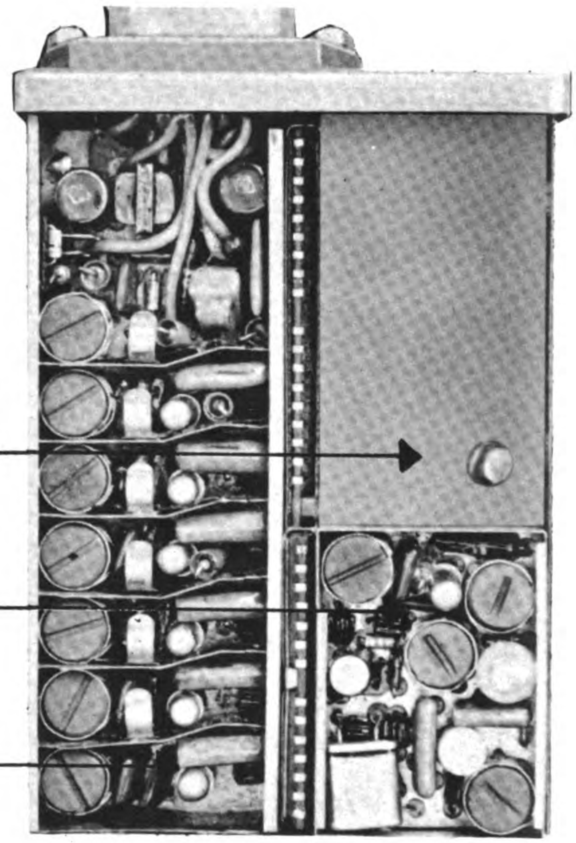
CONVENTIONAL DUAL MODULATOR SUBASSEMBLY

Actual Size

MICRO-MODULAR EQUIVALENT

SIZE REDUCTION 11 TO 1

Actual Size



Subminiature transistorized communication transceiver component density 50,000 parts per cubic foot. Actual size.

Micro-Modular Equivalent Receiver Circuits Component density 250,000 parts per cubic foot Actual size

3.9 BIBLIOGRAPHY

For specific detailed information relating to the concepts discussed within this chapter, the reader should consult the following references.

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Chapter 4

STRUCTURAL DESIGN

4.0 GENERAL

The design of equipment and its parts is determined by structural as well as functional considerations. Reliable performance depends on the ability of the structure to secure all parts in working relationship to each other, and to protect them from potentially detrimental conditions. The methods of fabricating parts and fastening them together are, therefore, primary design considerations. Tolerances should be as wide as possible but consistent with the functions of the parts and interchangeability requirements.

4.1 FABRICATING PROCESSES

The designer should be familiar with the many processes used to fabricate parts and should know their advantages and limitations. He should establish close liaison with the production department to maintain high efficiency and coordination of effort.

Factors to be considered in the choice of a fabricating process are dimensional tolerances, surface smoothness, section thickness, material characteristics, geometry of parts, quantity to be produced, and cost. Automatic or semiautomatic processes and special tools are used when justified by the quantity of parts to be produced.

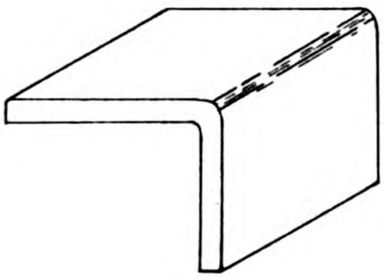
Surface finish is often important to the function of a part and is closely related to the manufacturing process used. Dimensional accuracy is dependent to a degree on the surface finish. Unnecessarily close manufacturing tolerances sharply increase cost without increasing the utility of parts. Detailed information on finishes, tolerances, and allowances is available from military publications or engineering handbooks.

4.1.1 Sheet Metal Working

Sheet metal is used widely because it lends itself to the rapid production of strong, lightweight parts. Sheet metal fabrication includes the processes of bending, drawing, blanking, piercing, trimming, shearing, rolling, ribbing, spinning, and stretching.

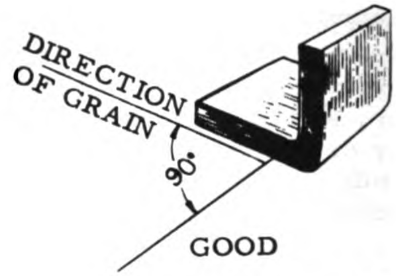
Standard strip and sheet stock, selected to meet the required performance characteristics, should be used. Where flatness is of importance to the design, the required tolerances should be specified on the drawing. Standard sizes for holes and notches should be used wherever possible.

4.1.1.1 Bending. The most important factors in bending are the characteristics of the metal used, the temperature at which the bending is done, inside bend radii, bend allowance, length of bends, springback, and bend relief. Complex shapes present difficulties in bending and usually require extensive tooling to produce the desired result. As illustrated below, bending produces stresses in the metal; too small a radius will cause excessive stressing and partial fracture, rendering the metal subject to failure in service. The allowable minimum radius is a function of the material characteristics, equipment used, and condition of tools. The minimum bend radius for a given material can be determined only by experiment under the conditions of fabrication. Springback can be compensated for by overbending.



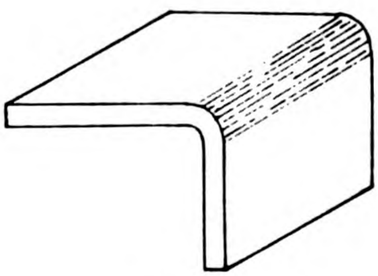
AVOID

Too small a bend radius results in skin fractures and weakened part.



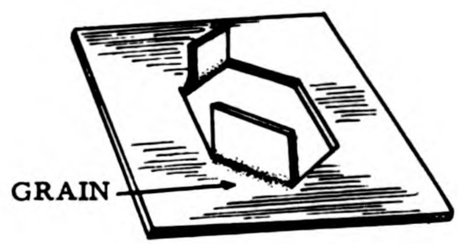
GOOD

POOR



PREFERRED

Adequate bend radius results in strong corners.



ACCEPTABLE

4.1.1.1.1 Grain Direction* in Bending. The direction of grain affects the formability of hard (e.g., spring-temper) metals but does not appreciably affect softer metals. A smaller bend radius can be used without fracturing the material when the axis of bend is at right angles to the direction of the grain. This orientation also affords maximum strength to the formed section.

* This is the same as the direction of rolling of the sheet metal at the mill.

4.1.1.1.2 Bending Radii. Because of processing variables, data in technical manuals differ as to the minimum bend radii to which various metals and alloys may be bent without fracture or damage. The tables which follow give factors used in determining minimum inside radii, or the actual radii, for various metals. The given or calculated radii should be confirmed under the actual conditions of fabrication. Where a factor is used, the radius for a given thickness of metal is obtained by multiplying the thickness by the factor. A zero factor indicates that the bend may be sharp.

When precision bends are required, angular tolerances may be one to two degrees for thin metals (0.012 to 0.060 inch, or 30 to 16 gage*) and one degree for thicker metals (0.060 to 0.164 inch, or 16 to 8 gage*), particularly for boxes, frames, chassis, and covers.

* Manufacturers' standard gage for steel sheets.

CORROSION-RESISTANT STEEL
MINIMUM INSIDE BEND RADII FACTORS
FOR 90° COLD BEND PARALLEL TO ROLLING DIRECTION (GRAIN)
(See 4.1.1.1.2)

AISI type	Temper	Sheet thickness, inch	Factor
301, 302	Annealed	To 0.050	0 - 0.5
301, 302	Annealed	Over 0.050	0 - 0.5
301, 302	1/4H	To 0.050	1
301, 302	1/4H	Over 0.050	2
301, 302	1/2H	To 0.050	1
301, 302	1/2H	Over 0.050	2
301, 302	3/4H	To 0.030	1 - 2
301, 302	3/4H	0.031 to 0.050	3
301, 302	H	To 0.050	3 - 4
304, 316, 347, 410	Annealed	To 0.050	0 - 0.5
304, 316, 347, 410	Annealed	Over 0.050	0 - 0.5

BERYLLIUM COPPER: ASTM B194, QQ-C-533
MINIMUM INSIDE BEND RADII FACTORS
FOR 90° COLD BEND
(See 4.1.1.1.2)

Temper	B & S numbers hard	Sheet thickness inch	Factor		
			Perpendicular to rolling direction	At 45° to rolling direction	Parallel to rolling direction
A	0	To 0.040	0	0	0
1/4H	1	To 0.040	1	1.5	2
1/2H	2	To 0.040	2	2.5	3
H	4	To 0.040	4	5	6

ALUMINUM AND ALUMINUM ALLOYS
MINIMUM INSIDE BEND RADII FACTORS FOR 90° COLD BEND
(See 4.1.1.1.2)

Alloy and temper designation		Factor — Approximate thickness of sheet, inch					
New	Old	0.016 1/64	0.032 1/32	0.064 1/16	0.128 1/8	0.182 3/16	0.258 1/4
1100-0	2S-0	0	0	0	0	0	0
3003-0	3S-0	0	0	0	0	0	0
1100-H12	2S-H12	0	0	0	0	0.5 - 1	0.5 - 1
1100-H14	2S-H14	0	0	0	0	0.5 - 1	0.5 - 1
2024-0*	24S-0*	0	0	0	0	0.5 - 1	0.5 - 1
3003-H12	3S-H12	0	0	0	0	0.5 - 1	0.5 - 1
5052-0	52S-0	0	0	0	0	0.5 - 1	0.5 - 1
6061-0	61S-0	0	0	0	0	0.5 - 1	0.5 - 1
3003-H14	3S-H14	0	0	0	0.5 - 1	0.5 - 1	1.0 - 1.5
5052-H32	52S-H32	0	0.5	0.5	0.5 - 1	0.5 - 1	1.5 - 2
1100-H16	2S-H16	0	0	0.5 - 1	0.5 - 1	1.5 - 2	2 - 3
5052-H34	52S-H34	0	0.5	1	1.0 - 1.5	1 - 2	2 - 3
7075-0	75S-0	0	0	0 - 1	0.5 - 1.5	1 - 2	1.5 - 3
3003-H16	3S-H16	0.5 - 1	0.5 - 1	1.0 - 1.5	1.5 - 2	2.5 - 3	3 - 4
6061-T4	61S-T4	1	1.5 - 2	1.5 - 2	2	2 - 3	4
1100-H18	2S-H18	0.5 - 1	1.0 - 1.5	1.5 - 2	2 - 3	3 - 4	4
5052-H36	52S-H36	1	1.5 - 2	1.5 - 2	2 - 3	3 - 4	4
6061-T6	61S-T6	1	1.5 - 2	1.5 - 2	2 - 3	3 - 4	4
3003-H18	3S-H18	1.0 - 1.5	2.5 - 3	2.5 - 3	3 - 4	4 - 5	5 - 6
5052-H38	52S-H38	1.5	2.5 - 3	2.5 - 3	3 - 4	4 - 5	5 - 6
2023-T3*,**	24S-T3*,**	2 - 3	3 - 4	4 - 5	4 - 6	5 - 6	6 - 7
2024-T36*	24S-T36*	3 - 4	4 - 5	4 - 5	5 - 6	6 - 7	8 - 10
7075-T6*	75S-T6*	2 - 4	3 - 5	3 - 5	4 - 6	5 - 7	6 - 10

* Alclad sheet can be bent over slightly smaller radii than the corresponding tempers of uncoated alloys.
** Immediately after quenching, this alloy may be bent over appreciably smaller radii.

CARBON STEEL AS ROLLED OR ANNEALED;
COMMERCIAL QUALITY (CQ) OR DRAWING QUALITY (DQ)
MINIMUM INSIDE BEND RADII FOR 90° COLD BEND

Sheet thickness*, inch	Minimum bend radius, inch
0.008	0
0.012	0
0.016	0
0.020	1/16
0.025	1/16
0.030	1/16
0.035	1/16
0.042	1/16
0.050	3/32
0.062	1/8
0.078	5/32
0.093	3/16
0.109	7/32
0.125	1/4
0.156	5/16
0.188	3/8
0.250	1/2

* For thicknesses not listed, use next greater thickness.

COMMERCIAL BRASS: SAE 70C, ASTM B36, Alloy 8
MINIMUM INSIDE BEND RADII FACTORS
FOR 90° COLD BEND
(See 4.1.1.1.2)

Temper	B & S numbers hard	Sheet thickness inch	Factor		
			Perpendicular to rolling direction	At 45° to rolling direction	Parallel to rolling direction
Annealed to 1/2 hard	0 to 2	To 0.0907	0	0	0
3/4 hard	3	To 0.0456	0	0	0
	3	0.508 to 0.0571	0	0	0.33
	3	0.0641	0.25	0.25	0.5
	3	0.0808 to 0.0907	0.25	0.33	1
Hard	4	To 0.0254	0	0	0
	4	0.0320	0	0	0.5
	4	0.0403	0	0	0.75
	4	0.0456	0	0.33	1
	4	0.0508	0	0.33	2
	4	0.0571	0.25	0.5	1.5
	4	0.0641	0.5	0.5	1.5
	4	0.0808	0.33	0.75	1
	4	0.0907	1	1.3	3
	4	0.1019	2.5	2.5	2.5
	4	0.1144	2	2	2
Spring	8	0.0090	0	1.75	1
	8	0.0100	0	1.5	9
	8	0.0159	1	4	10
	8	0.0201	1.5	5	11
	8	0.0254	1.25	6	10
	8	0.0320	1	5	8
	8	0.0403	1	6	6
	8	0.0508	2	5	5
	8	0.0641	2	4	4
Extra Spring	10	0.0254	2	6	10

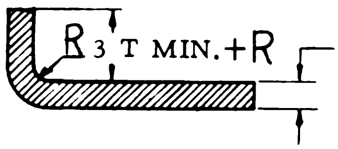
MAGNESIUM ALLOYS
ASTM B90, Alloy FS1, Alloy AZ31A, QQ-M-44
MINIMUM INSIDE BEND RADII

Sheet thickness inch	Minimum bend radius, inches			
	Annealed		Hard	
	500°F	Room temp	325°F	Room temp
0.016	0.06	0.09	0.09	0.19
0.020	0.06	0.09	0.09	0.19
0.025	0.06	0.13	0.13	0.25
0.032	0.06	0.16	0.16	0.32
0.040	0.09	0.19	0.19	0.38
0.051	0.09	0.25	0.25	0.50
0.064	0.16	0.32	0.32	0.62
0.072	0.16	0.38	0.38	0.82
0.081	0.19	0.44	0.44	0.82
0.091	0.19	0.44	0.44	1.00
0.102	0.25	0.50	0.50	1.00
0.128	0.25	0.63	0.63	1.25
0.156	0.38	0.75	0.75	1.63
0.188	0.38	1.00	1.00	1.88
0.250	0.50	1.25	1.25	2.50

PHOSPHOR BRONZE: SAE 77A, ASTM B103, Alloy A
MINIMUM INSIDE BEND RADII FACTORS
FOR 90° COLD BEND
(See 4.1.1.1.2)

Temper	B & S numbers hard	Sheet thickness inch	Factor: Perpendicular to rolling direction	Factor: At 45° to rolling direction	Factor: Parallel to rolling direction
Annealed to 1/2 hard	0 to 2	To 0.0720	0	0	0
1/2 hard	2	0.0808 to 0.1250	0.75	0.75	0.75
Hard	4	0.0201	0	1.5	3
	4	0.0320	0.5	2	4
	4	0.0403	1.5	1.5	3
	4	0.0508	1.25	2	3
XH	6	0.0456	1.5	2.75	---
Spring	8	To 0.0142	0	5	---
	8	0.0159	1	6	---
	8	0.0179	1.75	7	---
	8	0.0201	0.75	5	9
	8	0.0226	1.5	6	---
	8	0.0254	1.25	5	---
	8	0.0285	2.25	---	---
	8	0.0320	2	---	---
	8	0.0403	2.25	---	---
	8	0.0456	2	---	---
	8	0.0508	1.75	---	---
	8	0.0641	1.5	---	---

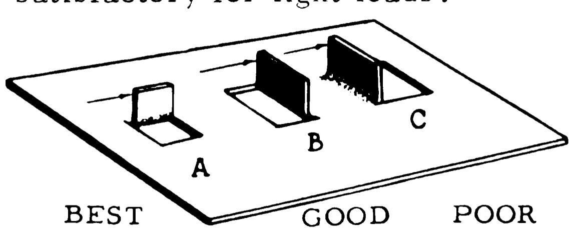
The minimum permissible length for short bends on flanges and formed legs should be three times the thickness of the metal. Any attempt to make a shorter bend may result in distortion. If a shorter flange is desired, it should be cut longer and trimmed to size after bending.



MINIMUM BEND LENGTH

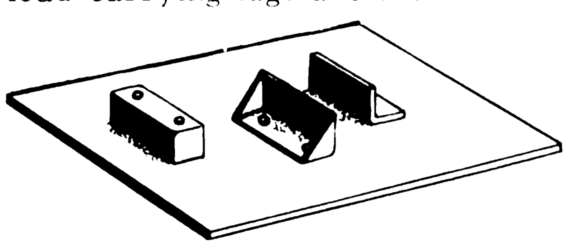
4.1.1.1.3 Contours of Flat Blanks. Where possible, the flat blank of a sheet metal part should be designed with straight lines. Curved contours require dies or jigs, increase cost, and often serve no useful purpose.

4.1.1.1.4 Ears and Lugs. The direction of the applied load is a determining factor in positioning a right-angle ear or lug, especially if considerable thrust or abuse is anticipated. Ear A, illustrated below, below, is recommended because strength in shear exceeds that in bending. Ears B and C are satisfactory for light loads.



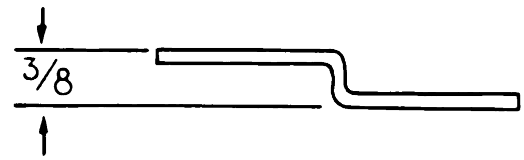
LOAD DIRECTION ON LUGS

Satisfactory methods of attaching load-carrying lugs are shown below.



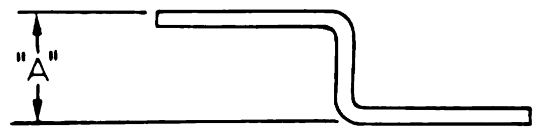
LOAD-CARRYING LUGS

4.1.1.2 Brackets. Small distances between the two levels of a bracket or similar bent metal forms should be avoided if possible.



AVOID

Small distance between bends requires difficult and expensive hand forming.

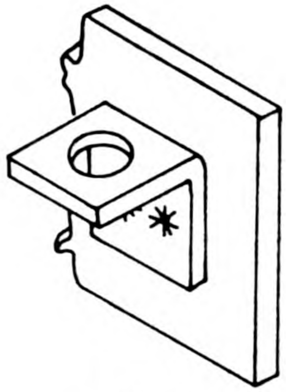


PREFERRED

Minimum dimension A as given by the following table is preferred.

Metal thickness inch	Length of "A" inches
To 0.040	15/32
0.041 to 0.072	19/32
0.073 to 0.125	1-1/4

4.1.1.3 Sharp Edges. Sharp edges on brackets and other similar supports can cut or snag. Rounded corners and smooth edges are less likely to injure personnel. Also, rounded corners have a more pleasing appearance than rectangular corners. All edges should be de-burred or smoothed by filing, sanding, or chamfering.



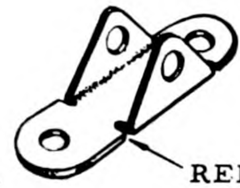
AVOID

PREFERRED

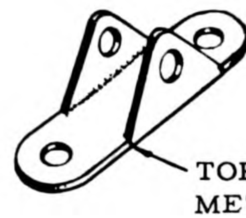
ROUNDING OF CORNERS

4.1.1.4 Notching. Notching or slotting is desirable to prevent stress concentrations at points where an abrupt change in the section occurs. Without such notching, tearing, wrinkling, or cracking are likely to occur. Such relief notches are made in the flat blank. Their width and depth are generally twice the stock thickness.

4.1.1.5 Corner Treatments. An enclosure corner can be made with a relief slot or hole which can be filled with a full penetration weld after forming.

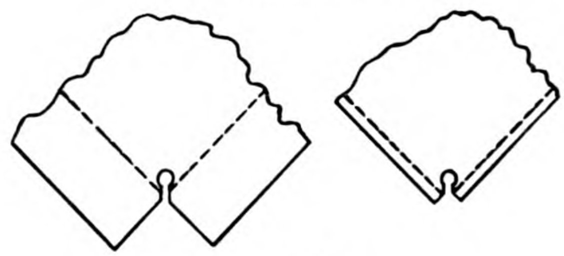


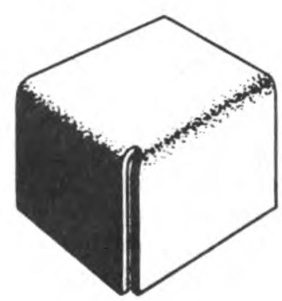
RIGHT



WRONG

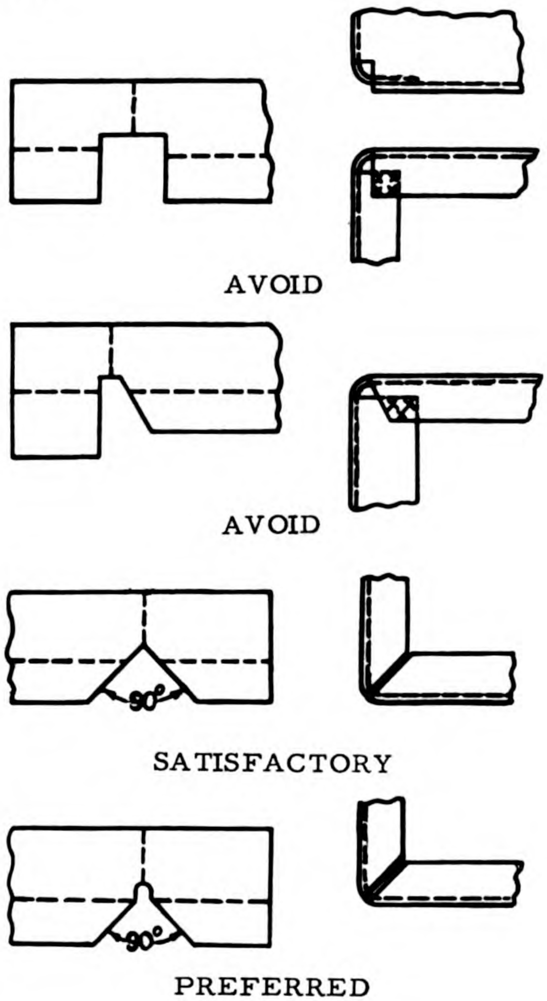
STRESS-RELIEF SLOTS





FORMING CORNERS

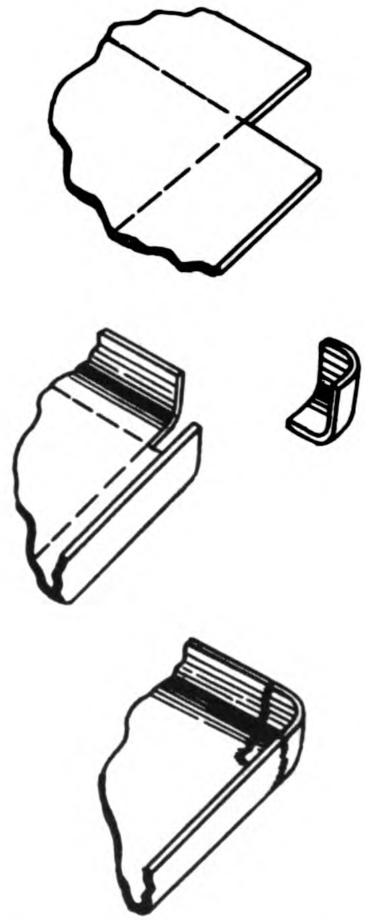
Flanged corners, formed so that one flange overlaps the other, are often spot welded. This is common practice in production of chassis, brackets, and enclosures. When flanges must be flush-butt welded, a full penetration weld is required.



CORNER CONSTRUCTIONS

A flush-welded corner provides a level bearing surface so that a plate or chassis may rest evenly. Absence of overlay eliminates a corrosion trap. Although more expensive to produce, flush-welded corners are preferred.

Rounded corners and edges are usually required in military equipment. One method of making these is to notch the corner in the flat, roll-form the edges, and fill the corner gap with a formed "knuckle". After welding the knuckle in place, the corner is ground or filed smooth.

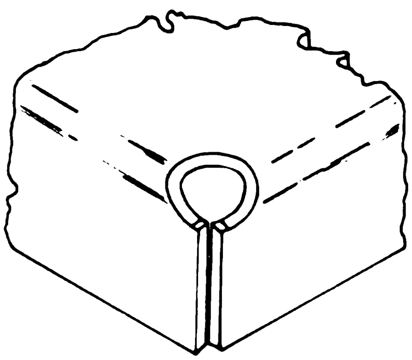


FORMING ROUND CORNER

Butting of corners in thin sections is costly and produces weak joints. Lapping and spot welding produce strong, inexpensive joints which are, however, difficult to close with a corner knuckle, and may also require sealing to preclude moisture.

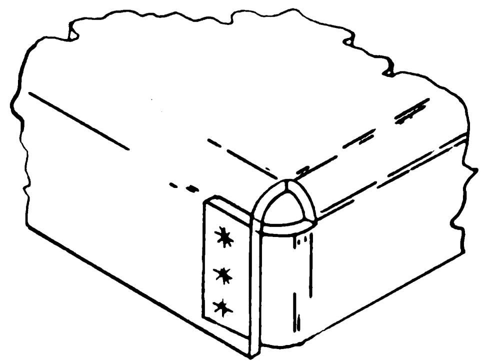
4.1.1.6 Cross Braces. Cross braces, supports, and other members having flanges should be tapered to reduce weight, make assembly easier, and provide clearance. Avoid the long taper shown below. Use partial cropping as indicated.

4.1.1.7 Hole Punching. Hole punching with a punch and die is



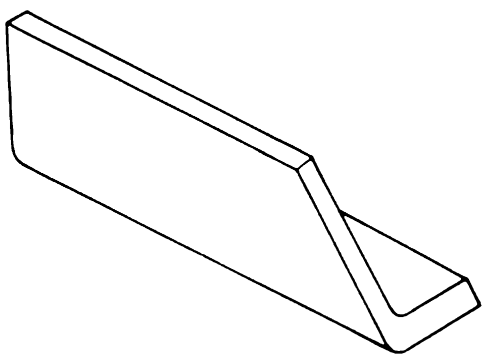
AVOID

Butting of corners in thin sections.



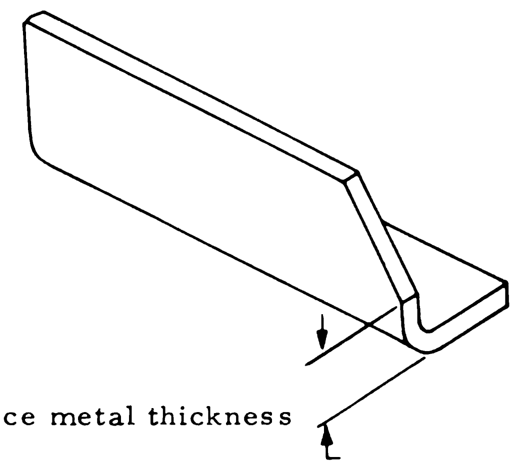
PREFERRED

Lapping and spot welding of corners results in strong, inexpensive joints.



AVOID

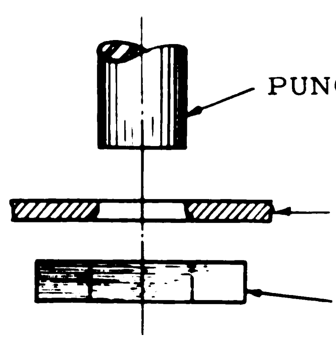
Flange should not taper to metal face.



PREFERRED

employed in small lot or mass production processes. Factors to be considered include material properties, hole size and location, stock thickness, and the clearance between the punch and die.

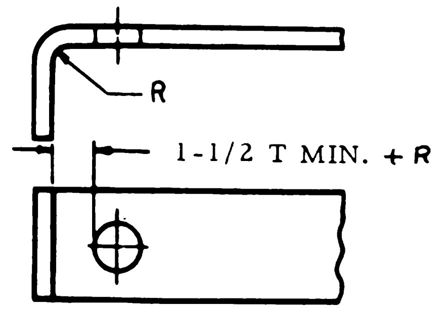
Because of the clearance needed between the punch and die, some tearing occurs; hence the sides of holes formed in this manner are not perpendicular to the stock for its entire thickness. Accurate holes must be punched undersize and reamed; or a second punching operation may be used.



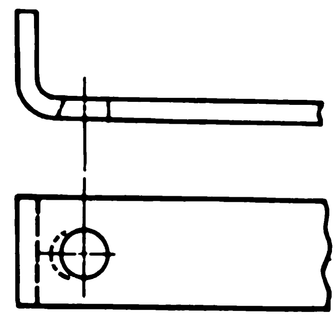
HOLE PUNCHING

Straighter holes can be punched in soft metals than in hard metals, although a subsequent deburring operation may be needed for soft metals.

4.1.1.7.1 Location of Holes. A hole located too near an edge or bend tends to deform or weaken the structure and to interfere with the use of hand or power tools. This may result in loss of accuracy. In general, the minimum permissible distance between the edge of the stock and the nearest edge of the hole should be one and one-half times the metal thickness. When a hole is larger than 3/8 inch and the stock is less than 1/8-inch thick, the minimum distance should be twice the stock thickness. For softer metals, the minimum distance should be greater than twice the stock thickness.

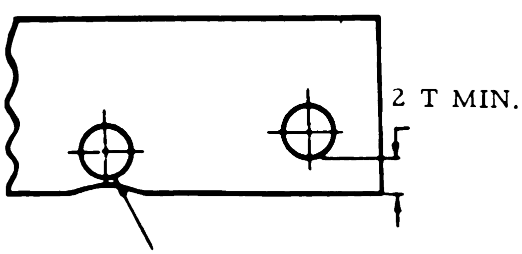


GOOD



HOLE DISTORTED

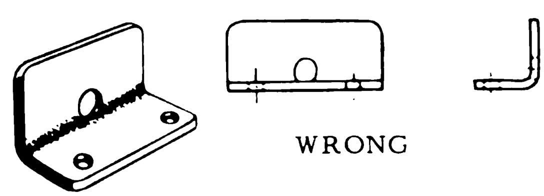
HOLES NEAR A BEND



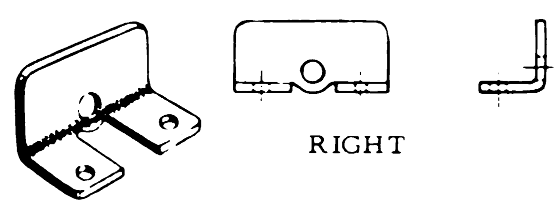
HOLE TOO CLOSE

4.1.1.7.2 Distortion of Holes. Holes near a bend should be made after the edge is formed as they might otherwise become distorted during the forming operation. The distortion is more pronounced where the circumference of a large hole is in line with the bend, and stock thickness exceeds 0.015 inches. If the holes must be made prior to bending, they should be at least one and one-half times the stock thickness plus the radius of the bend from the formed edge.

Where a hole must be placed close to a formed edge or bend, distortion can be minimized by a cutout which allows the hole to retain the desired shape. Although such a design is not always possible, its advantages justify consideration in mass production.



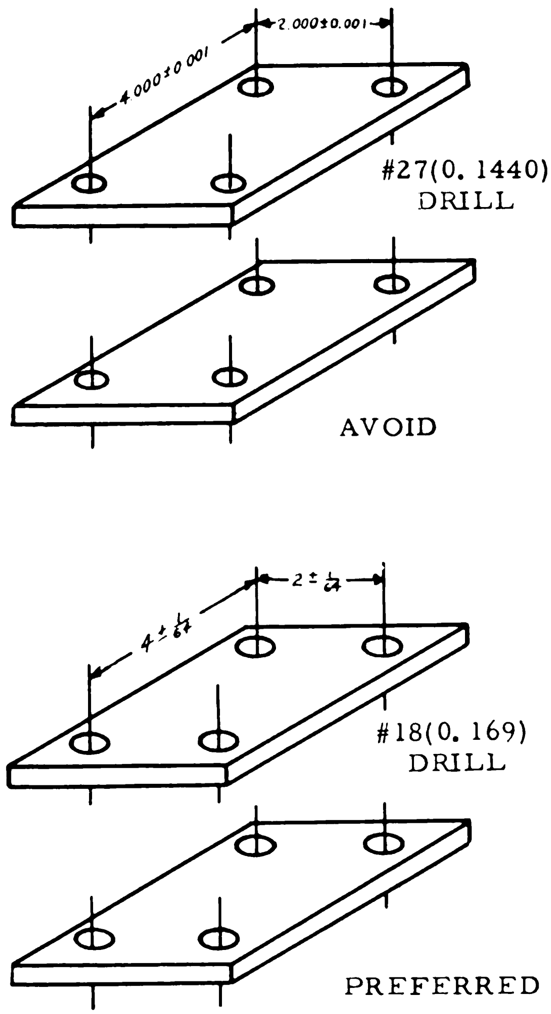
WRONG



RIGHT

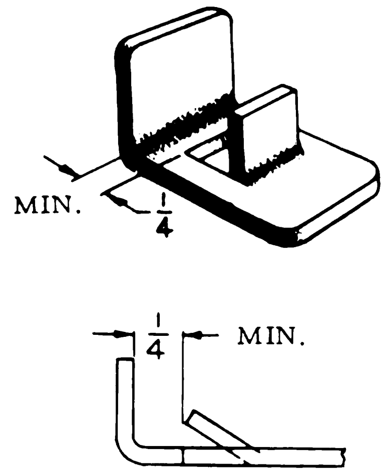
CUTOUT FOR HOLE NEAR BEND

4.1.1.7.3 Clearances. Wherever possible, ample clearances should be allowed, both for hole sizes and spacing, for ease in manufacture and assembly of parts.



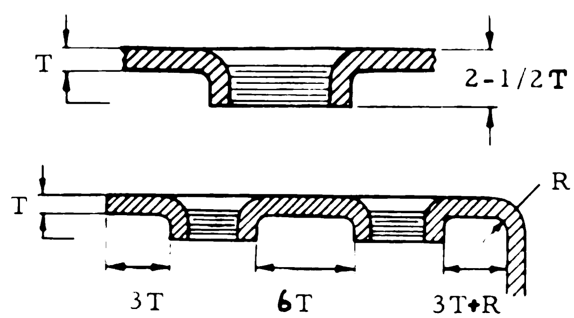
CLEARANCES FOR HOLES AND SPACING

4.1.1.8 Lancing. The factors considered in hole punching apply equally to lancing. A minimum distance of 1/4 inch should be allowed between a bend and the edge of the opening.



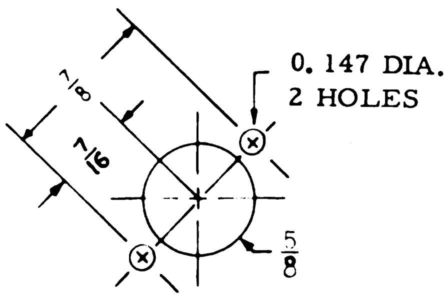
LANCING

4.1.1.9 Extruded Holes for Tapping. Holes formed by extruding sheet metal may be tapped and used for screws only when the full strength of the fastening is not required. The number of perfect threads in a large extruded hole is usually less than in a standard nut. A ductile metal gives the best results for tapped, extruded holes.

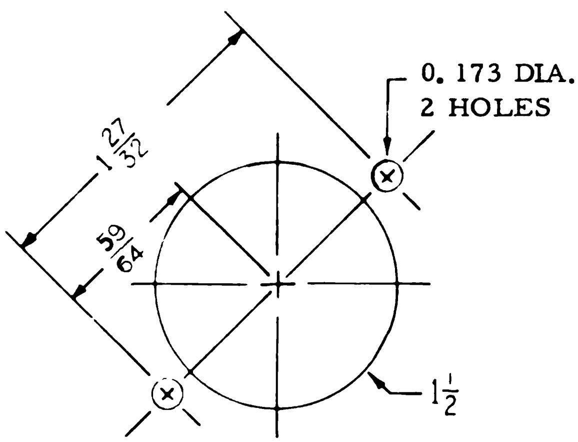


RECOMMENDED DIMENSIONS FOR EXTRUDED TAPPED HOLES

4.1.1.10 Cluster Dies. Certain mounting hole arrangements are frequently used on panel and chassis layouts. Such holes may be punched simultaneously by means of cluster dies available for JAN and MIL standard items. Cutout and mounting hole dimensions are covered by the applicable specifications. The two cutouts illustrated below are typical of those used for tube sockets.

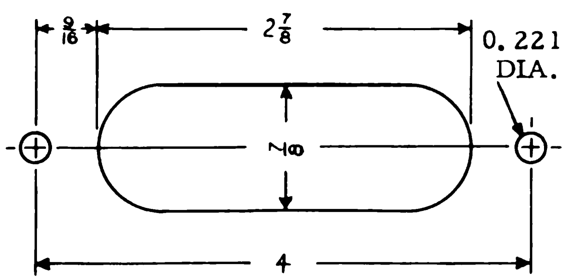


7-PIN MINIATURE SOCKET CUTOUT



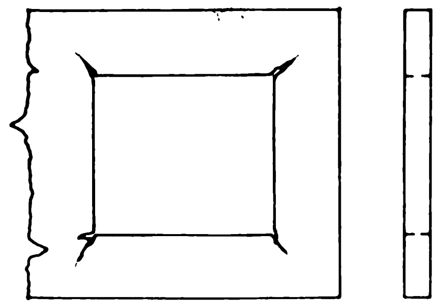
4-, 5-, or 6-PIN SOCKET CUTOUT

Cluster dies for capacitor cutouts are a necessity for production work. A typical example of a capacitor cutout is shown below.

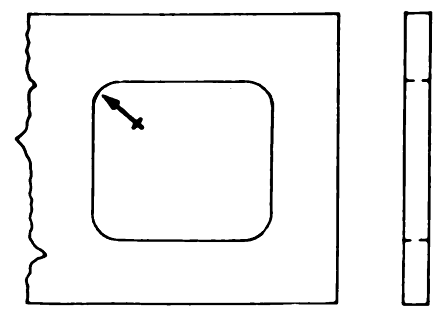


CAPACITOR CUTOUT

4.1.1.11 Hand Holes and Lightening Holes. Hand holes and those used for weight reduction should be made with rounded corners to prevent concentration of stresses which might cause tearing or fatigue cracking.



WRONG

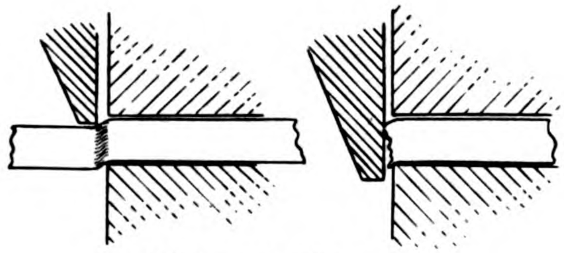


RIGHT

CORNERS IN OPENINGS

4.1.1.12 Shearing and Slitting. Certain precautions are necessary for guillotine shearing. To avoid marking the sheet metal surface, hold-down pads should be faced with rubber or other shock absorbing material. Scratches and other undesirable scuffing are often the result of rough shear beds, tables, or benches. Heavy cotton flannel fastened to the surfaces minimizes such damage.

After shearing, punching, or stamping, machining operations such as grinding, reaming, or milling are used to remove burrs and curvatures. Other deburring methods, such as barrel tumbling, are used for small parts.



BURR FORMED BY SHEARING OR PUNCHING

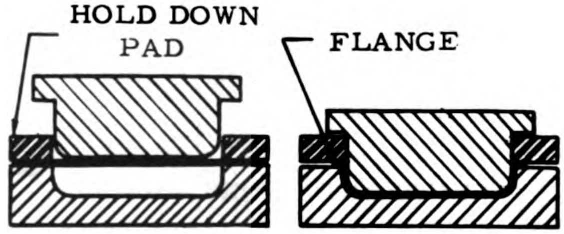
4.1.1.13 Drawing. Primary considerations in the design of a part for drawing operations are: shape, material to be worked, number of operations per piece, and the quantity of pieces to be produced as related to the cost of dies and the time required to produce each piece.

Materials must possess sufficient plasticity to be successfully drawn. Materials most commonly drawn include brass, steel, aluminum, and magnesium. Drawing magnesium at room temperatures is limited to shallow draws because of the rapid work-hardening characteristics of this metal.

Important factors in cylindrical or shell drawing operations include the ratio of height to diameter, size of corner radii, and ductility of the metal. Corner radii should be not less than four times the metal thickness when the height of a cylindrical part exceeds one-third of its diameter.

For rectangular shapes, the greatest flow of metal occurs at the corners. To prevent wrinkles and fractures, this flow must be controlled by proper die design and shape of blank. The draw radius for such parts should be a minimum of six times the stock thickness and not less than 3/8 inch.

Use of heated dies, preheated blanks, special lubricants, and specially processed material in some cases greatly improves quality and allows closer tolerances.

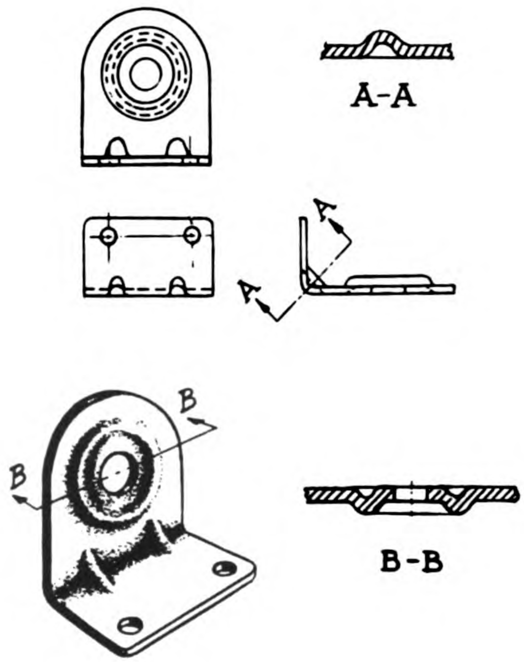


DRAWING OPERATION

4.1.1.14 Ribbing and Stiffening. The rigidity of light gage sheet metal can be improved by corrugations, ribbing, bulging, and stiffening flanges. Weight and size can usually be reduced by these methods. For more information, refer to 4.2.

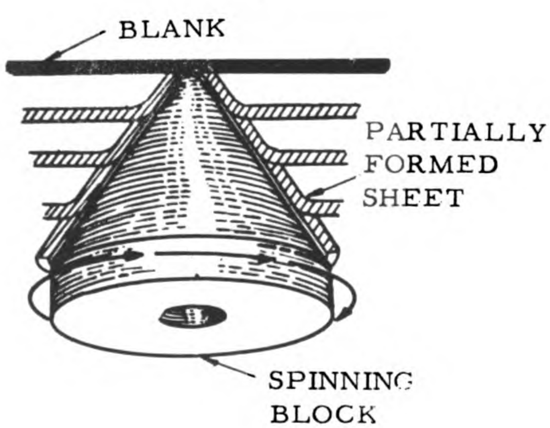
Rigidity and accuracy of a bend are increased by the introduction of stiffening ribs that are twice the stock thickness in height and equal to the stock thickness in inside radius.

The metal near a hole also can be strengthened by a rib formed around the hole (section B-B, above). To minimize distortion, the rib should be located away from the edge of the hole.

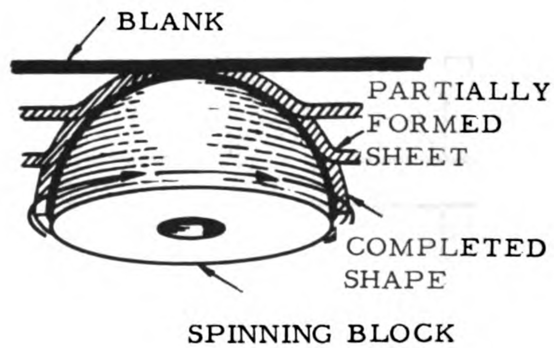


RIBS OR CORRUGATIONS

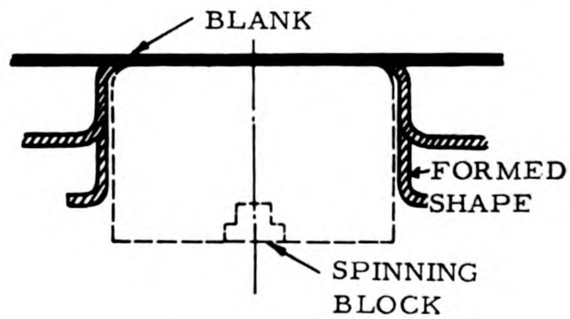
4.1.1.15 Spinning. Shapes of items which can be spun are those concentric about one axis, such as cylinders, hemispheres, cones, and variations thereof. Although a simple cylinder is easiest to produce by drawing, and cones the most difficult, the reverse is true for spinning. In cone spinning, the chuck meets the metal at small angles, thus allowing fine control in forming the metal.



The hemispherical shape is more difficult to spin because the angle of deformation becomes progressively more acute.



The straight-sided cylinder is difficult to spin and should, if possible, be formed by drawing.



Tolerances in spinning must be large, and much depends on the skill and experience of the operator. Where greater dimensional accuracy or uniformity is required, a drawing operation is recommended.

Ease of spinning is a direct function of ductility; a metal that can be deep-drawn can usually be deep-spun, and this fact can be used as a guide in selecting materials for spinning. Metals difficult to draw can often be spun, but may require more power and possibly the use of heat softening or annealing between operations.

4.1.1.16 Metal Stretching. In principle and operation, stretch-forming differs considerably from drawing. In drawing, a punch usually forces the sheet into or through a die. In stretch-forming, the sheet is clamped at opposite ends and stretched over a form or die.

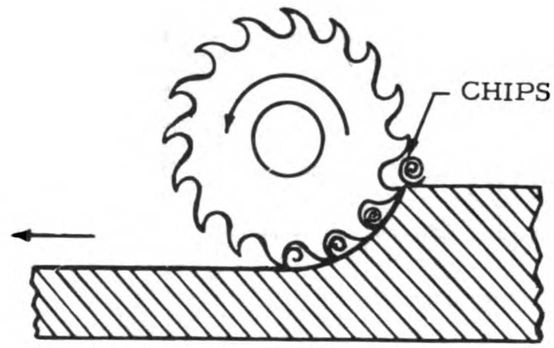
The degree of stretching depends not only on the ductility of the metal but also on the direction of the grain caused by mill rolling. Surface texture is also important because elongation is appreciably easier when the materials are cleaned and polished.

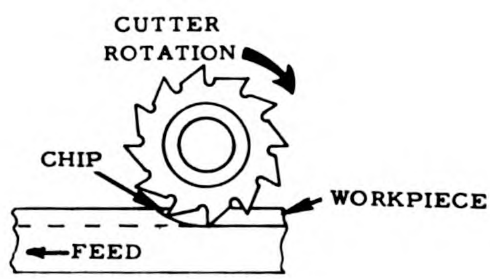
4.1.2 Machining

Machining processes include milling, lathe turning, reaming, broaching, drilling, counterboring, threading, knurling, honing, grinding, boring, and surface finishing. Materials selected must have properties suitable for both the intended application and for machinability. Adequate holding and clamping during machining improves accuracy, finish, and tool life. Pieces should be designed to permit use of standard tooling wherever possible.

4.1.2.1 Milling. Milling is generally used to form flats, slots, keyways, gear teeth, and similar surfaces. Workpieces should be without thin or weak sections, and should be easy to jig and machine without danger of distortion due to cutting or clamping pressures.

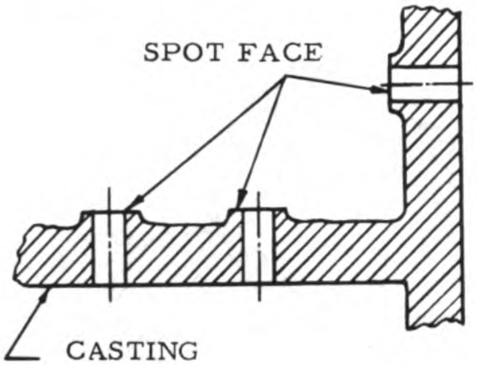
There are two general methods of peripheral milling; conventional, with the cutter rotating so that it cuts against the direction of the workpiece feed; and climb milling, with the cutter rotating so that it cuts in the same direction as the workpiece feed. The latter method, climb milling, is recommended when a high degree of finish is desired.





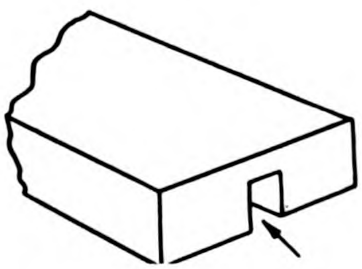
Selection of milling cutters is simplified by eliminating complicated operations that require the use of special tools. The design should permit the use of standard milling cutters wherever possible. Cutters should bear against the workpieces at such angles that forces are efficiently applied against the work and chips are easily ejected.

Pieces can often be designed to avoid the need for costly milling operations. Raised or bossed surfaces that can be spot-faced are sometimes employed.

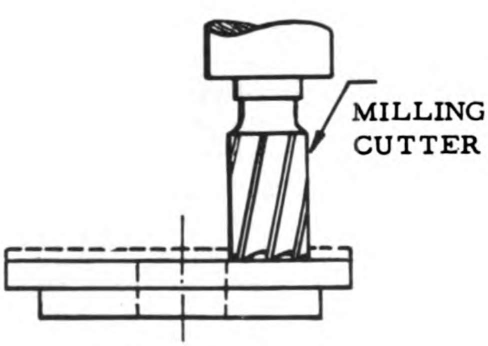


MILLING ELIMINATED

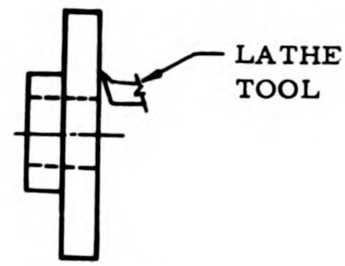
Extruded stock may be used in lieu of producing special shapes by milling. Extrusions are now available for this purpose in a variety of forms in nearly all metals. (See 4.1.5).



EXTRUDED OR MILLED PART

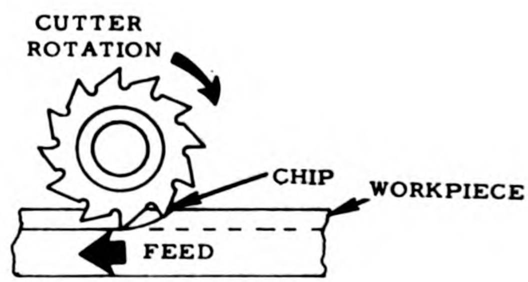


MILLED PART



ALTERNATE

4.1.2.1.1 Milling of Titanium. Titanium should be milled by climb milling, illustrated below, in lieu of conventional milling.



CLIMB MILLING

In milling titanium, the cutting edge of the tool usually fails due to chipping. This is minimized in climb milling because the area of contact between chip and tool is at a minimum when the chip is removed during each cutting cycle.

NOTE: If there is play in the feed mechanism the workpiece may be pulled into the cutter thereby damaging either the cutter or the workpiece.

4.1.2.2 Broaching. Broaching is the machining of material by use of a rod-like tool (broach) composed of a series of cutting edges, each slightly larger than the previous one. The broach is drawn through or over the workpiece. The shape of the cutting edges determines the shape of the machined surface. Broaching is employed for cutting shapes such as internal gears, keyways, and splined or slotted holes. The process may also be used for gang cutting and squaring rough surfaces.

Although costly broaching tools can be resharpened after becoming dull, this has the disadvantage of being time-consuming.

Materials which can be successfully broached include steels, cast iron, bronze, brass, magnesium, and aluminum. Steels of hardness between 25 and 35 Rockwell C are suitable for broaching. Softer steels are difficult to broach. Therefore, they must be hardened by heat treatment to the optimum hardness prior to broaching. Stainless steels harder than 35 Rockwell C tend to dull the broach, thus reducing tool efficiency. Cast and malleable irons are easily broached. Aluminum and magnesium are broached with little difficulty.

In planning broaching operations, the following require consideration: materials and heat treatments; machining prior to broaching; quality of finish desired; and the details of any required special broach support or work fixture.

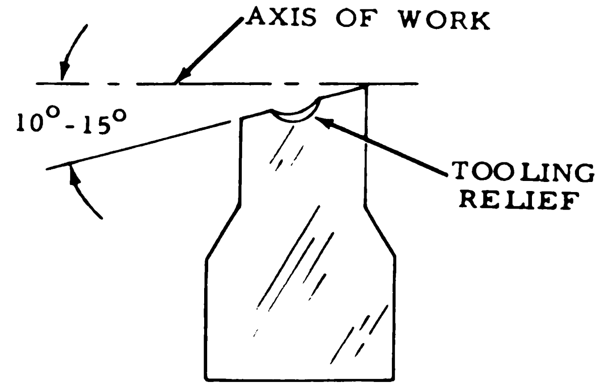
The principal advantage of broaching is that it removes all excess metal in a single stroke of the broach. It is superior to reaming for finishing round holes because the broach will retain its original size for a greater number of operations thus assuring greater accuracy.

Surface broaching is often substituted for milling when large quantities of a part are to be produced to close tolerances and fine finish. It is generally faster than finish milling and produces smoother and more accurate work. Although broaching cutters are more costly than milling cutters, they require less resharpening because the cutting load is distributed over a large number of teeth.

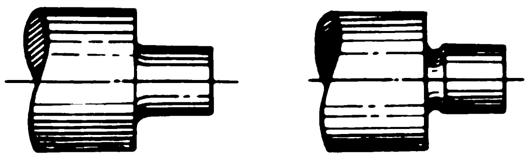
4.1.2.3 Lathe Turning. Lathes are used for a variety of machining operations, such as turning, boring, drilling, threading, and tapping. Lathe-turned products include such parts as shafts, collars, sleeves, bushings, and gear blanks. A high degree of accuracy and surface finish can be economically obtained by lathe operations. The designer should specify the straightness of lathe-turned finished shafts.

Shafts which are to rotate within bearings should be turned to a smooth finish to minimize wear.

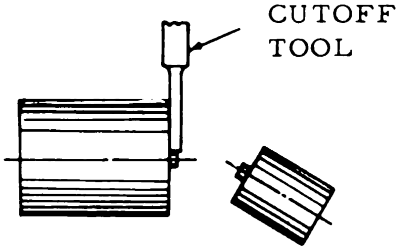
Where a radius or fillet cannot be tolerated, a rounded undercut can be made to avoid concentration of stress.



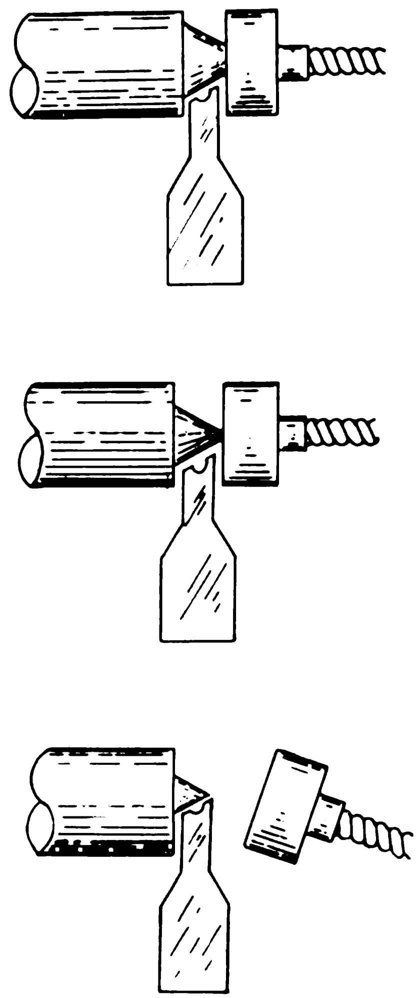
CUTOFF TOOL


UNDERCUT

Cutoffs and burrs are always present on parts turned from bar stock by the conventional method illustrated, in which a standard cutoff tool is held at a 90-degree angle to the stock. Drawings should indicate where these must be removed. Grinding, filing, or tumbling can be used to remove cutoffs and sharp burrs. The occurrence of cutoffs and burrs at the completion of the lathe-turning operation can be minimized by using a cutoff tool ground at a slight angle (10 to 15 degrees) to the axis of the work and relieved in the center, as shown below.

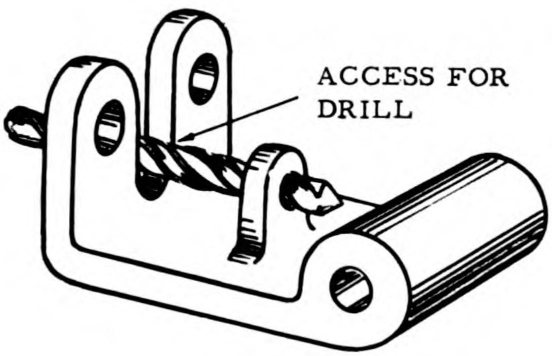


CUTOFF PRESENT AFTER CONVENTIONAL LATHE TURNING


METHOD OF ELIMINATING CUTOFFS AND BURRS

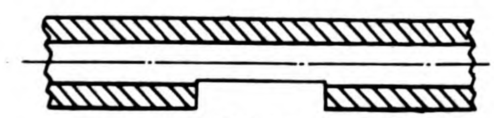
4.1.2.4 Drilling. It is difficult to control the finish and diameter of a drilled hole. Finish of the wall is characterized by a series of lines caused by rotation of the tool or work. The hole may be elliptical because of improper angle or eccentricity of the point of the drill, a slight bend in the body of the drill, or misalignment of the drill and the work.

A surface to be drilled must be readily accessible to the tool. Design should not necessitate the use of excessively long drills.



DRILL ACCESS

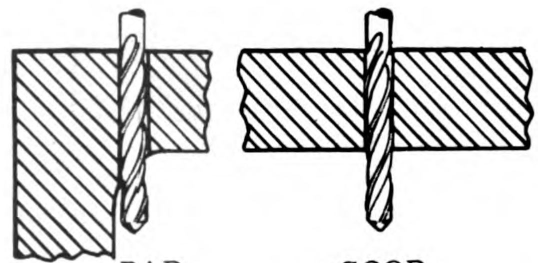
A relatively clean, straight hole results when a drill passes through solid metal. Discontinuities should be avoided.



POOR

DISCONTINUOUS METAL

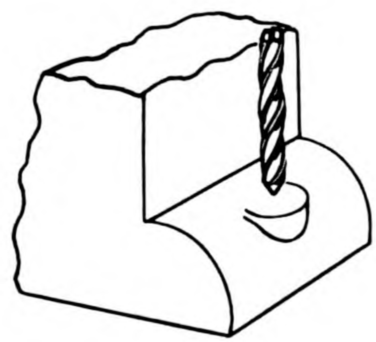
When a drill is held at right angles to the surface, it will break through cleanly. Drilling through fillets or curved or uneven surfaces is not good practice as the drill is apt to break in the hole. When breakage occurs, extra time is required to remove the broken drill and the work may be damaged in the process.



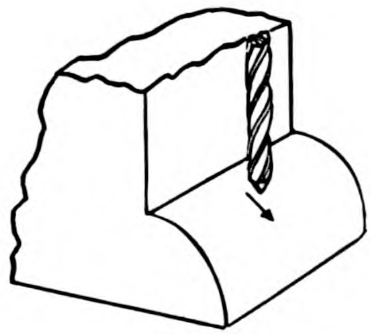
BAD GOOD

AVOID CURVE AT BOTTOM OF HOLE

Designs should avoid drilled holes originating on a curved or slanted surface.



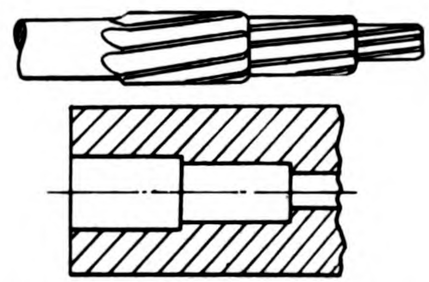
GOOD



POOR

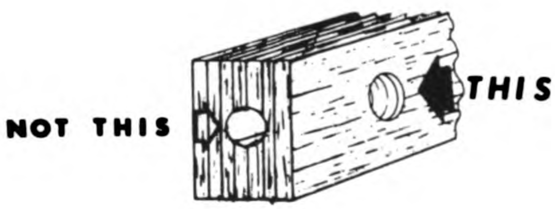
PROVIDE FLAT SURFACE FOR STARTING DRILL

Where coolants cannot be used, allowance must sometimes be provided for the expansion of materials due to drilling heat and subsequent shrinkage of hole size when the part cools.



QUESTIONABLE USE OF MULTIDIAMETER REAMER

Drilling laminated materials should be performed wherever possible at right angles to the laminations, as illustrated, to avoid splitting the laminated layers. A cloth base laminate should be used in applications where drilling parallel to the laminations cannot be avoided.

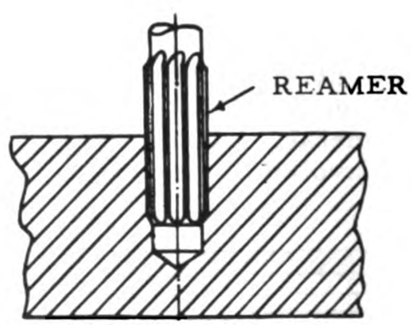


DRILLING LAMINATED MATERIALS

To prevent bottoming and consequent damage to reamers in blind holes, allowances should be made and sufficient depth provided for the accumulation of chips.

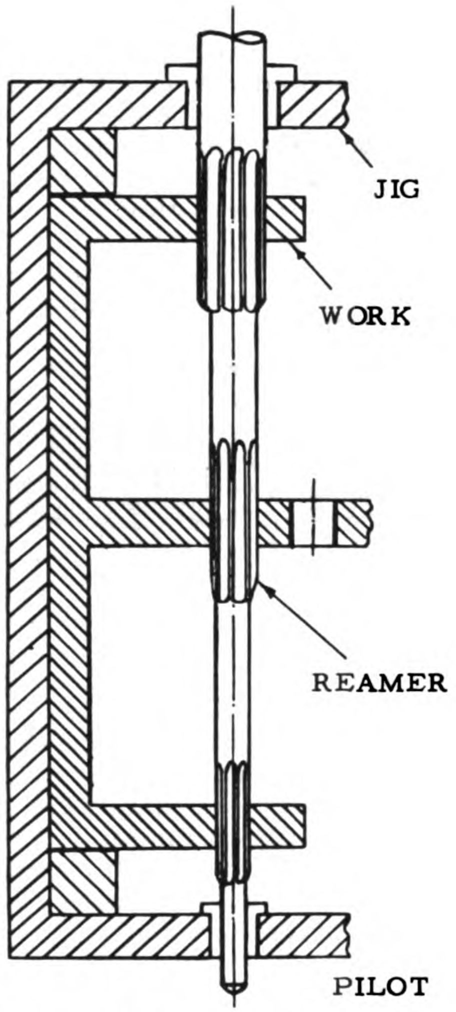
4.1.2.5 Reaming. Reaming is a precise finishing operation used for holes that have been previously drilled or punched. Tapered holes or holes for bearings require accurate reaming. The quality of the desired finish and machining tolerances should be specified for reamed holes.

Multidiameter reamers are excellent where the diameters are comparatively close to each other. If the diameters of the holes are markedly unequal, one of the holes made with a multidiameter reamer may not have desired accuracy and surface finish.



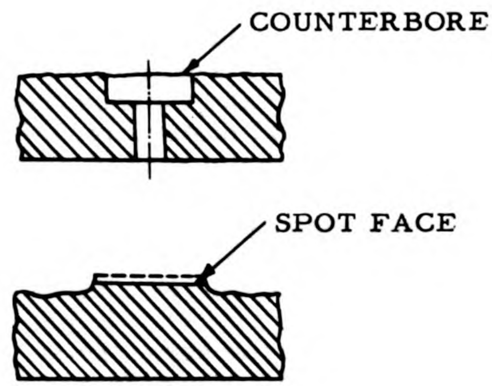
ALLOWANCE FOR REAMER CHIPS

Since in-line holes require accurate location and alignment by the use of a jig and pilot, their use in design should be kept to a minimum.



HOLES DIFFICULT TO ALIGN

4.1.2.6 Counterboring and Spot-Facing. Counterboring and spot-facing are generally used to provide flat surfaces for bolt heads, washers, spacers, bushings, and similar items. Counterboring is used to enlarge a hole and form a recessed squared surface. Spot-facing is used to square a projecting surface.



When the spot-face or counterbore is in a tight place, such as the corner of an angle or channel, allowance should be made for wrench or socket clearance during assembly. Counterbores used simply for bolt head clearance should be specified in fractional dimensions wherever possible.

4.1.2.7 Threading and Tapping. Threads are generally formed by taps, dies, milling cutters, grinding wheels, or rollers. Special processes based on supersonic vibrations and electrical discharge are particularly applicable for threading extremely hard substances and metals. The design of the part depends on the process selected to form the thread.

Rolled threads are most widely used in mass production of standard hardware items. Such threads are sufficiently accurate and have a satisfactory surface finish. The cold working in this process usually improves the hardness and strength of the ductile metal.

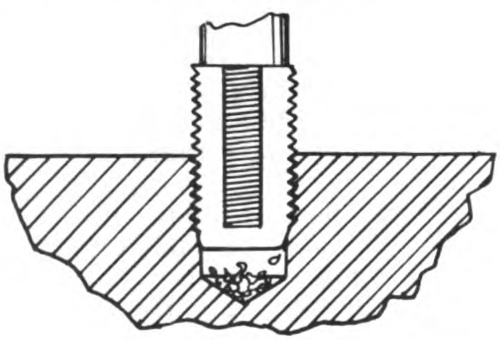
Die-cut threads are easily produced by either hand or semi-automatic machines and are acceptable for all common threaded fasteners. No difficulty is experienced in cutting threads in common structural materials.

Milled threads, in general, have a better surface finish than die-cut threads and can be formed to closer tolerances, but they are more expensive to produce.

Ground threads are characterized by a good finish without torn metal at the thread roots. High-precision threads can be ground in many types of materials.

The percentage of full thread in a tapped hole is fixed by the drill size used. The percentage of full thread is seldom over 75 percent and can be as little as 50 percent in hard metals without materially affecting the strength of the thread.

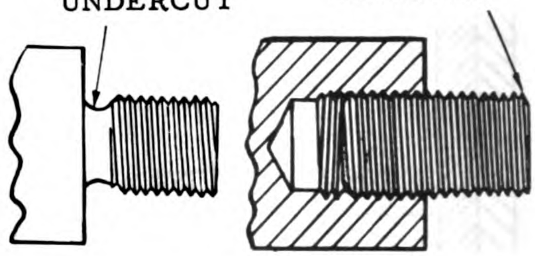
The use of blind, tapped holes should be minimized. When such holes are used, an allowance is required for chip accumulation at the bottom of the hole, and space must be provided for the tapered part of the tap beyond the thread forming section.



ALLOWANCE FOR TAP TAPER AND CHIPS

Holes to be tapped and rods to be threaded should be chamfered at least the depth of one thread to 30 to 45 degrees chamfer.

When necessary to allow seating of boltheads or shoulders, a tapped hole may be counterbored or a threaded part undercut sufficiently to clear the imperfectly threaded portions near the shoulder.



4.1.2.8 Grinding. Grinding is done by means of a bonded abrasive wheel rotating at high speed. Practically any type of material can be successfully ground, although some soft materials, such as aluminum and brass, may load the grinding wheel.

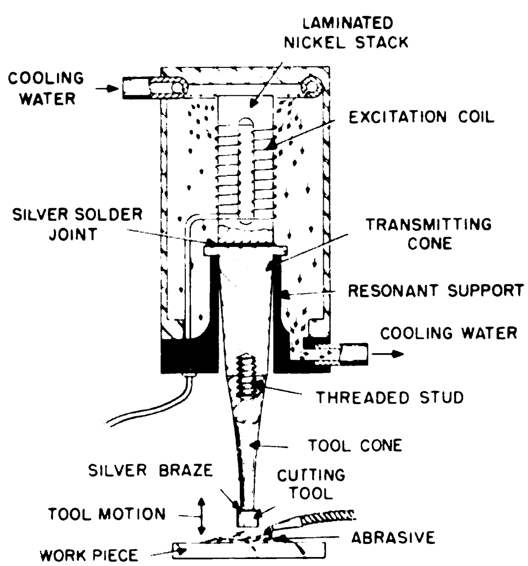
Parts can be finished to extremely precise dimensions by grinding. Rough machining usually precedes grinding. Leaving excessive material for grinding reduces production efficiency.

Parts that are to be ground must be firmly secured to avoid distortion. Discontinuities, such as slots, holes, and flats in the surfaces of parts, should be avoided since grinding grit and chips will accumulate in them and affect grinding accuracy.

Flat and circular surfaces can be ground on standard machines. Irregular shapes usually require grinding by hand or, where accuracy is important, by use of a special setup.

4.1.2.9 Ultrasonic Machining. Ultrasonic vibrations may be employed for machining holes, slots, intricate cavities, and complex hole and cavity shapes in materials such as tungsten carbide, hardened tool steel, and ceramics. Such machining is extremely difficult or impossible to accomplish with conventional equipment. This method should not be used to remove large quantities of stock, nor for applications which can be satisfactorily accomplished by conventional machining methods.

This method of machining utilizes the vibrations set up by a piezoelectric crystal under the influence of an ultrasonic frequency current. These vibrations are transmitted by means of a transducer through a shaped tool to an abrasive grit which removes material from the item being machined, as shown in the accompanying illustration.



ULTRASONIC MACHINING

4.1.3 Forging

Forging is the deformation of metal in the plastic state into a predetermined size or shape. Compared to sand castings, forged parts have improved strength, toughness, grain formation, and surface finish. Working the metal causes grain direction to follow the shape of the part. In heading operations (hot or cold), the length of the wire or rod that can be gathered into a head in a single operation, without side restraint, is limited to about three times the diameter.

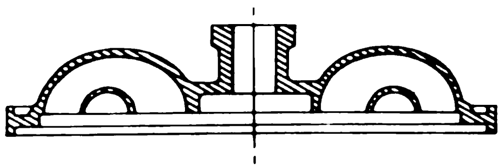
4.1.4 Casting

Various methods are associated with the process of casting. A large proportion of castings are produced by the sand casting process. Other processes, such as permanent metal mold, plaster mold, die, shell mold, and investment casting, are useful in producing better and more intricate parts. Almost any part, regardless of size, shape, or material, can be cast by some method. Limitations in size, shape, surface finish, density, material, section thickness, strength, and dimensional tolerances are determined by the process used. Investment casting, also called precision casting, is used to produce intricate parts to close tolerances.

Intricate parts for electronic equipment may also be formed by powder metallurgy or similar pressure-forming techniques.

4.1.4.1 Wall and Web Thicknesses. Proper wall and web thicknesses will prevent cold shuts and poor castings. The wall thickness of all sections of each cast part should be as nearly uniform as possible in order to avoid shrink defects and casting strains. Recommended minimum wall and web thicknesses for various metals are tabulated on page 4-30.

RECOMMENDED



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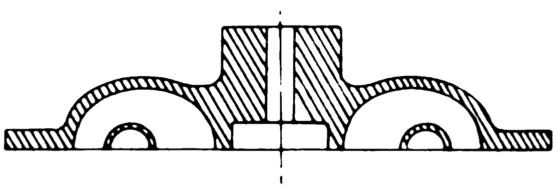
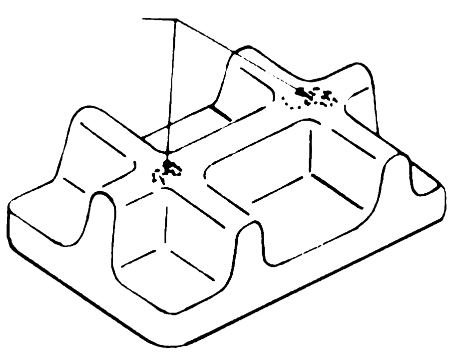


WALL THICKNESSES OF CASTINGS

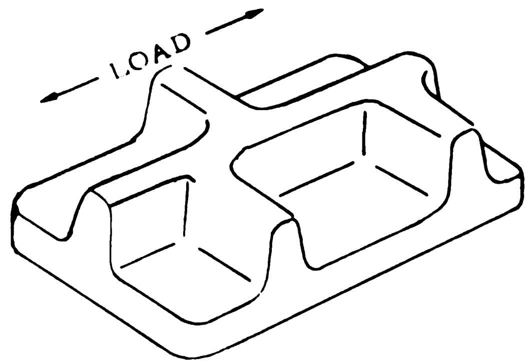
4.1.4.2 Ribs. Intersections of ribs should be staggered to avoid development of porosity during solidification, as shown below.

Ribs are used primarily for stiffening or reinforcing, and should be located so that no undercut in the mold or die is necessary. Outer surfaces of ribs should be flat with rounded corners to avoid high fiber stresses. A good rib design is shown below.

POROSITY WILL OCCUR HERE



AVOID



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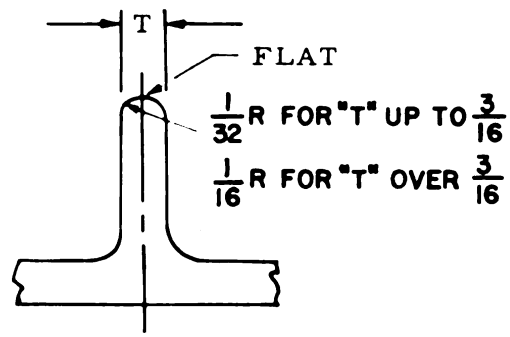
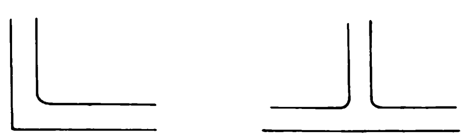


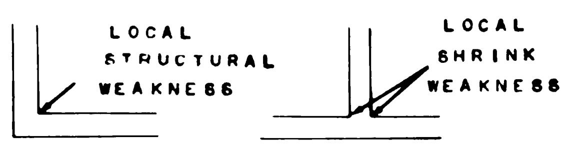
ROUNDING RIB SURFACES

4.1.4.3 Fillets. Small fillets create stress concentrations as cast metals shrink in solidifying from the molten state. Recommended minimum fillet radii for castings of uniform thicknesses are tabulated on page 4-30.

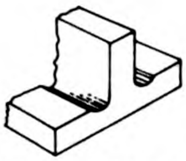
Use fillets instead of sharp corners when designing adjoining sections, as illustrated below.



RECOMMENDED



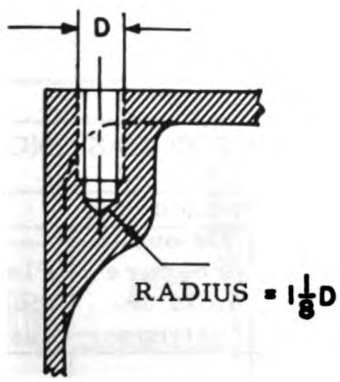
POOR

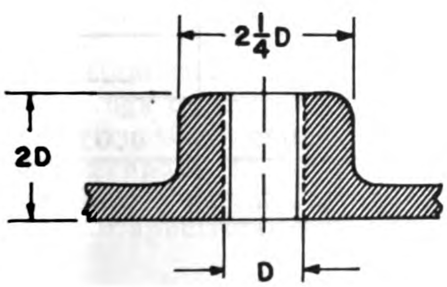


RECOMMENDED

POOR

4.1.4.4 Bosses. Bosses to be used with studs or cap screws should be designed in accordance with the values indicated in the following sketches:





BOSS DIMENSIONS

Bosses used around bolts should blend into the surrounding structure with generous fillets. The radii of the fillets should be large enough to ensure good distribution of the load throughout the surrounding casting structure.

4.1.4.5 Casting Difficulties. Difficulties in casting may arise from use of excessively thin sections; large, flat areas or long, narrow sections subject to warpage; nonuniform sections; intricate shapes; sharp edges; very thin, small or long narrow cavities; and close dimensional tolerances.

Shrinkage which occurs during cooling of castings may produce cracks, pits, sink and blow holes, and warpage.

When inserts are used, they should be firmly anchored in the casting by grooves, knurlings, or similar means, depending on the load conditions.

KNURLED INSERT ANCHOR

RECOMMENDED MINIMUM WALL OR WEB THICKNESSES

Metal	Minimum thickness, inch			
	Sand castings	Permanent and semi-permanent mold castings	Die and pressure mold castings	Plaster mold castings
Aluminum alloys	5/32	1/8	0.080	3/32
Magnesium alloys	3/16	5/32	0.080	3/32
Steel	3/16	----	----	----
Brass or bronze	5/32	----	0.080	3/32
Iron	5/32	----	----	----

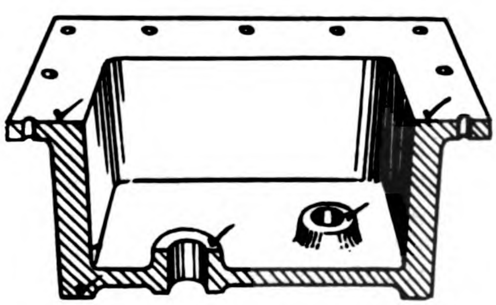
RECOMMENDED MINIMUM FILLET RADII FOR CASTINGS

Metal	Minimum radii*, inch			
	Sand castings	Permanent and semi-permanent mold castings	Die and pressure mold castings	Plaster mold castings
Aluminum alloys	5/32	1/8	0.032	0.032
Magnesium alloys	3/16	1/8	0.032	----
Steel	3/16	----	----	----
Brass and bronze	5/32	----	0.032	0.032
Iron	5/32	----	----	----

* Where the wall thickness of the casting is greater than the minimum radius shown in the table, make the fillet radius at least equal to the wall thickness.

When a cast part requires subsequent machining, material thickness allowance must be made for machining. As little machining as possible should be done on die castings in order to preserve the "skin". Surfaces that need grinding only after casting require less stock.

Devices such as bosses or hubs needed for clamping parts during machining can be cast and removed after the machining operations. Cast parts such as fluid containers or parts under hydraulic or pneumatic pressure that may "weep" or "sweat" during use may require impregnation to seal porosity.



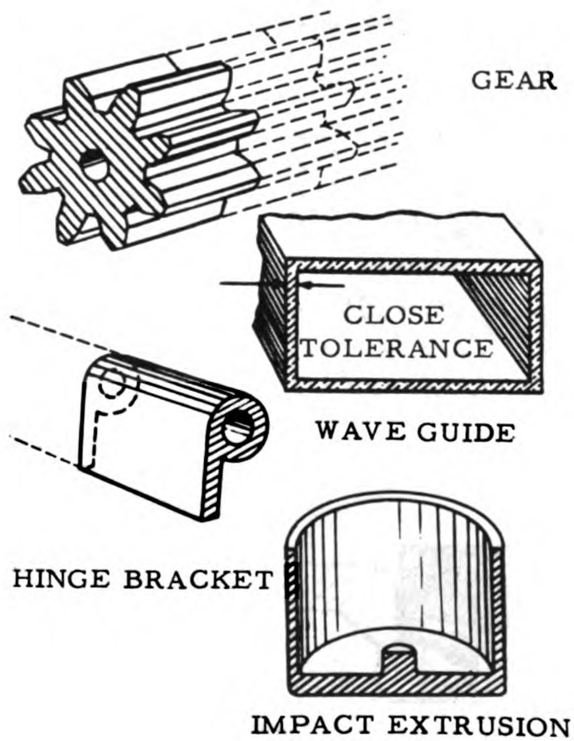
CASTING SHOWING MACHINED SURFACES

Specifications usually require that castings be inspected by a nondestructive method such as radiography. Casting materials must conform to applicable specifications.

4.1.5 Extruding

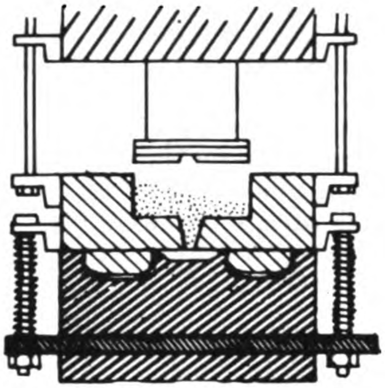
Extruding is the process of fabricating shapes by forcing material through a die. The material may be either cold or hot. Limitations of the process depend on the material used and the extrusion presses available. Die cost is relatively low. Plastics, rubber, aluminum, magnesium, brass, and most soft metals may be successfully extruded. Ductile steels have also been extruded although there is greater die wear than with nonmetallic materials and nonferrous metals. Impact extrusions are sometimes employed when short sections or special end shapes are required.

Typical extruded shapes and certain of their salient features are illustrated below.

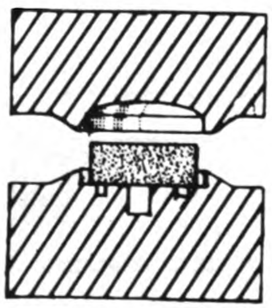


4.1.6 Plastic Molding

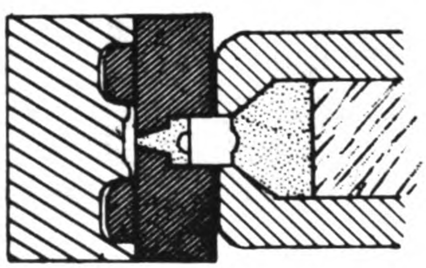
Plastic molding methods may be classified according to the type of plastic material to be molded. Compression and transfer molding are generally used for thermosetting material, and injection molding is generally used for thermoplastic material. Compression, transfer, and injection molding are illustrated below.



TRANSFER

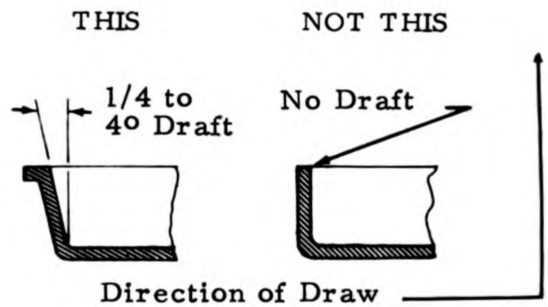


COMPRESSION

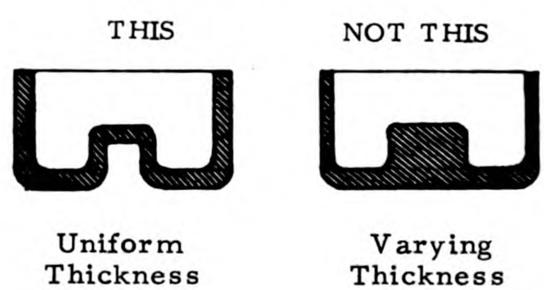


INJECTION

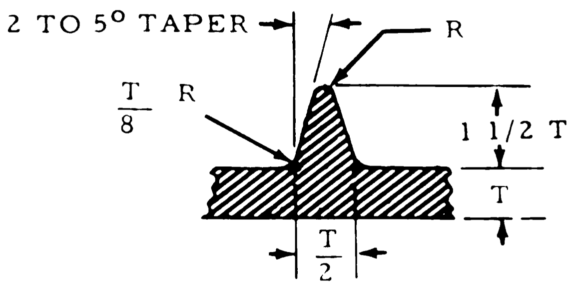
4.1.6.1 Drafts for Molds. The draft for a mold, as illustrated below, may vary from 1/4 to 4 degrees per side depending upon the length of draw, surface area, type of material, and method of ejection. The draft should be allowed in the direction of the draw on all surfaces to ease ejection of the molded part and to protect the surfaces of the part.



4.1.6.2 Wall Thickness for Plastic Molded Parts. A compression molded or transfer molded plastic part should have a minimum wall thickness of 0.0625 inch. An injection molded plastic part should have a minimum wall thickness of 0.050 inch. All the walls of a plastic molded part should be of uniform thickness, as illustrated below, in order to avoid uneven shrinkage, which in turn causes internal stresses.



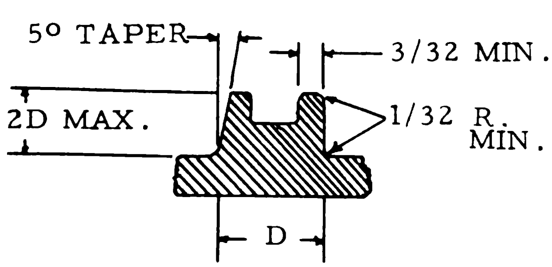
4.1.6.3 Ribs for Plastic Molded Parts. Ribs on plastic molded parts should have a minimum taper per side of 2 to 5 degrees, a radius at the top, and a 1/8 inch fillet at the base. The rib width at the base should be 1/2 the wall thickness and the rib height should be 1 1/2 times the wall thickness as illustrated below.



R = RADII

T - WALL THICKNESS

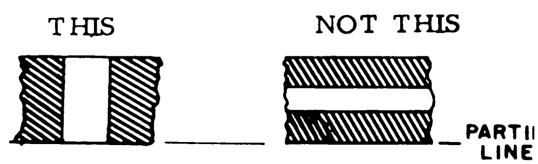
4.1.6.4 Bosses for Plastic Molded Parts. The minimum boss width at the top should be 3/32 inch and the maximum boss height should be twice the diameter of the boss. Bosses should have a minimum radius at the top and fillet at the base of 1/32 inch. High bosses should be avoided in the upper part of a mold since this portion of the mold tends to trap gases which reduce the density and the strength of the boss. However, when high bosses cannot be avoided, they should have a minimum of 5 degree taper per side, as illustrated below.



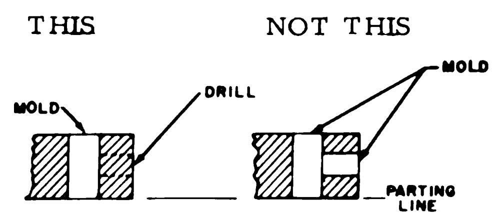
R = RADII
D = DIAMETER

An even mounting surface can often be obtained without machining by using three bosses instead of four. It is almost always necessary to machine one or more of the bosses in order to obtain an even mounting surface when four bosses are used.

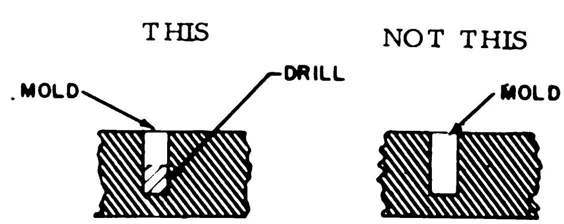
4.1.6.5 Holes in Plastic Molded Parts. Holes in plastic molded parts should be perpendicular to the parting line, as illustrated below, to permit easy removal of the part from the mold.



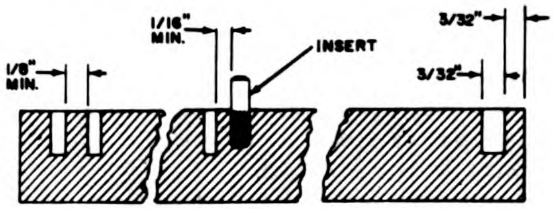
When two holes at either right or oblique angles to each other are required, the hole perpendicular to the parting line should be molded and the side hole drilled, as illustrated below.



Holes less than 1/16 inch in diameter should be drilled since they are difficult to mold. Long slender holes should be avoided but, when they are required, the first portion should be molded and the remaining portion drilled, as illustrated below.



Holes in plastic molded parts should be a minimum of 1/8 inch apart. A hole and an insert should be at least 1/16 inch apart. A distance equal to the diameter of the hole should be left between a 3/32 (or smaller) inch hole and the edge of the molded part as illustrated below.

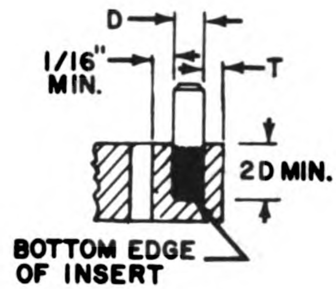


Through holes should be used whenever possible instead of blind holes, since through holes are made by mold core pins which can be supported at each end and are therefore easier to mold. However, when blind holes are necessary, holes 1/16 inch or more in diameter should not have a depth more than twice their diameter, and holes less than 1/16 inch wide should not be more than one diameter deep.

Recommended locations, widths, and lengths for both through and blind holes in plastic molded parts are shown on the following page.

4.1.6.6 Inserts in Plastic Molded Parts. Inserts in plastic molded parts should be placed at right angles to the parting line and, if possible, all on the same side of the line to avoid loading in both halves of the mold, as illustrated on page 4-36.

Rod and wire inserts should be embedded in the plastic at a depth equal to twice the diameter of the insert with a minimum of 1/16 inch clearance between the insert and the hole. There should also be sufficient plastic material under the insert to prevent the formation of a blister on the bottom edge, as shown below.

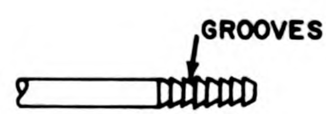


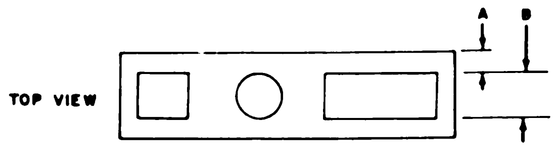
INSERT DIMENSIONS

D	T
And smaller	3/32 minimum
Over 1/4 to 1/2	1/8 minimum
Over 1/2	1/4 minimum

When inserts embedded in plastic will be subjected to both tension and torsion, their outer surface should have a diamond knurling as illustrated below.

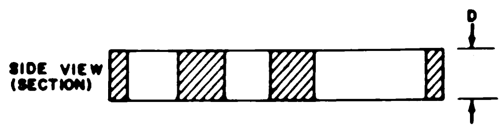
When inserts embedded in plastic will be subjected to only tension, their outer surface should have grooves as illustrated below.





THROUGH HOLES
AND BLIND HOLES

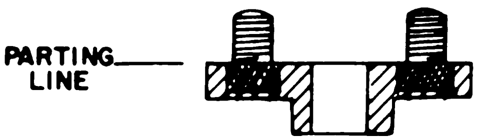
BLIND HOLES

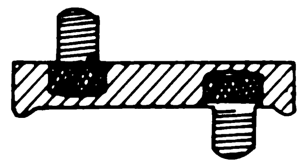


THROUGH HOLES

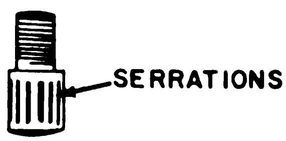
DIMENSIONS OF THROUGH AND BLIND HOLES

Min. Sidewall. Thickness, inch	Min. Hole Dia. or Width, inch	Max. Hole Length, inch	
A	B	C	D
1/16	1/16	1/16	1/8
5/64	5/64	3/32	3/16
3/32	3/32	1/8	1/4
3/32	7/64	5/32	5/16
3/32	1/8	3/16	3/8
3/32	5/32	1/4	1/2
1/8	3/16	5/16	5/8
1/8	7/32	3/8	3/4
1/8	1/4	7/16	7/8
5/32	5/16	9/16	1-1/8
5/32	3/8	11/16	1-3/8
3/16	7/16	13/16	1-5/8
3/16	1/2	15/16	1-7/8





When inserts embedded in plastic will be subjected only to torsion, their outer surface should have serrations as illustrated below.



4.2 STRUCTURAL TECHNIQUES

Military equipment demands high structural reliability with minimum weight. Supporting structures are subject to rough usage in transportation by land, sea, or air, which involves exposure to vibration, shock, and extreme climatic conditions.

For good design, the following should be considered:

a. Strength-to-weight ratio. Gravity, shock, and vibration effects on a structure are proportional to the weight of the structure; hence the effect of these forces may be minimized by keeping weights low.

b. Configuration. The static and dynamic loads that a structure can withstand depend greatly on the configuration of the structure. Spherical and cubical shapes, for example provide the greatest strength in relation to weight.

c. Rigidity. Retention of shape, desirable for operational stability, requires structural rigidity. However, it is often necessary to incorporate flexible elements to absorb vibration.

d. Stress Distribution. Ideally, all parts of a structure are stressed equally, with a minimum of stress concentration in joints or members. The most effective combination of strength, rigidity, weight, cost, material, and configuration to withstand the forces acting on the structure should be used.

Useful structural techniques including bracing, gusseting, ribbing, laminating, and rigidizing, are discussed in the following paragraphs.

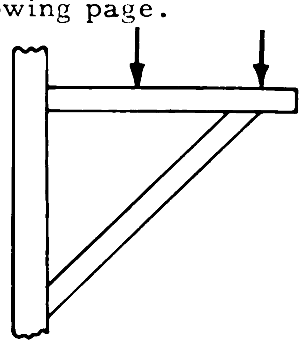
4.2.1 Bracing

Braces improve the rigidity of a structure by resisting bending, torsional, and buckling stresses. Bracing usually increases the permissible load-carrying capacity of a structure without a proportional increase in weight. The resonant frequency (natural frequency of vibration) of a structure can be varied by bracing. Greater rigidity generally raises the resonant frequency.

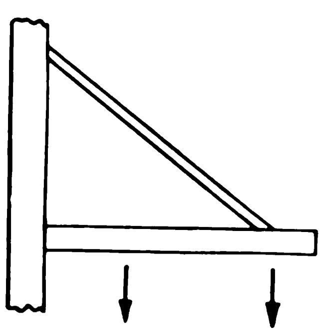
Bending within structures should be minimized. Direct tensile and compressive stresses should predominate and should be uniformly distributed. Some members of an insufficiently braced structure are likely to show excessive deflection and extreme sensitivity to small vibrational forces.

A structure with proper bracing can often be designed to have greater strength and lower weight than an unbraced or improperly braced structure. A braced and welded unit often provides maximum structural strength and rigidity with the least possible weight.

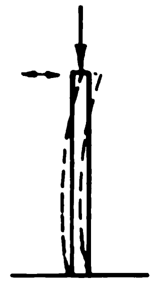
Certain types of bracing are illustrated below and on the following page.



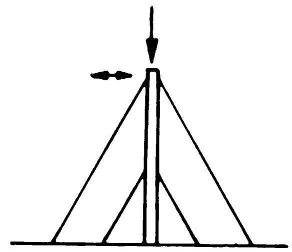
GOOD
Brace in compression.



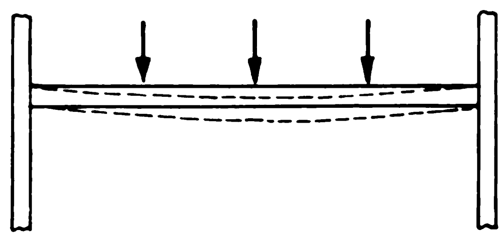
GOOD
Brace in tension; not subject to buckling.



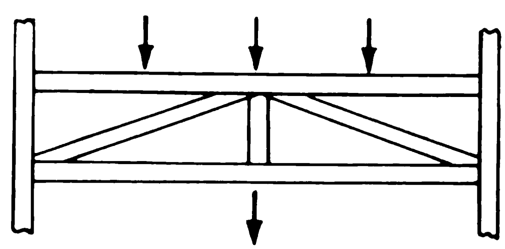
POOR
Subject to buckling and side movement.



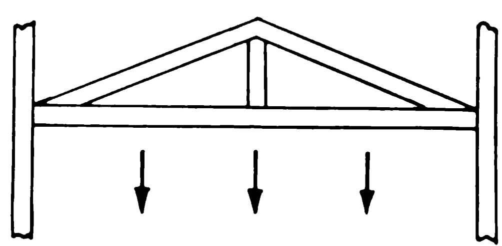
GOOD
Braced to prevent buckling and side sway.



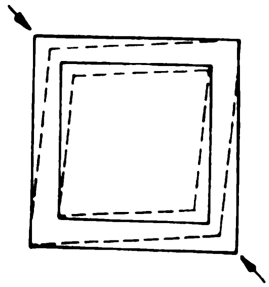
POOR
No vertical supports.



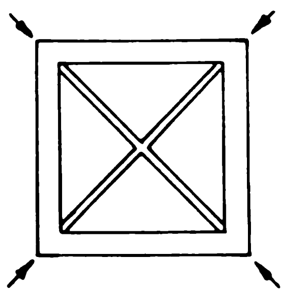
GOOD
Stresses distributed over more joints and members.



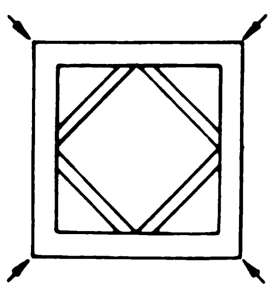
GOOD
Minimum bending stress.



POOR
No bracing. Stress concentrations at corners.



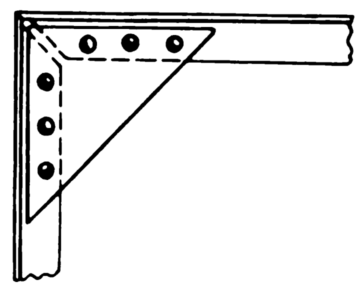
GOOD
For steady load. Thin braces provide strength light weight.



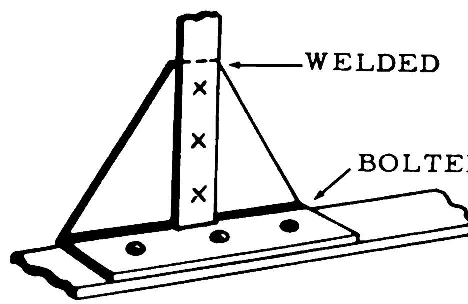
GOOD
For large frame. Stresses distributed.

4.2.2 Gusseting

Gussets are structural members employed to spread the stresses concentrated at joints over larger areas. Joints are often the weakest parts of structures and may require reinforcement. When gussets are large in proportion to joints and joint members, they act also as braces. Gussets are especially useful at joints subject to bending forces. They can substantially increase rigidity and are often the most efficient and economical means for strengthening an entire structure. Welded gussets produce the most uniform distribution of stresses, although riveted or bolted gussets are often used.



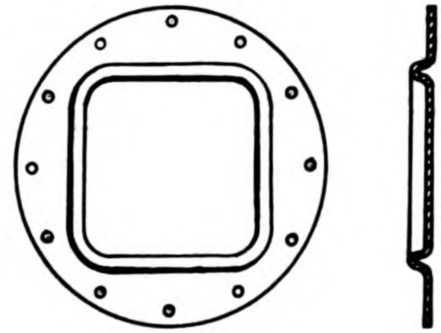
RIVETED GUSSET PLATE



COMBINATION SPOT-WELDED AND BOLTED GUSSET

4.2.3 Ribbing

A rib is a projection, ridge, or flange which effectively increases the rigidity and strength of the structure to which it is added. There are many forms of ribs. Ribs can be designed to distribute the bending forces as evenly as possible over an entire surface by making the section modulus at any point proportional to the bending stress. Care should be exercised to avoid stress concentrations which may result from improper rib design. Some examples of ribbing are shown below.



FLAT CIRCULAR PANEL RIBBED AGAINST BENDING OR WARPING

RIB ON SHEET METAL BRACKET

PANEL WITH SPOT-WELDED STIFFENING RIB

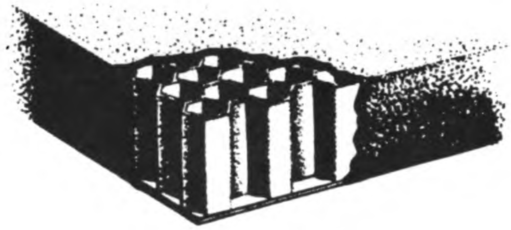
4.2.4 Laminates

Laminates are bonded layers of material used where high rigidity is desired with minimum weight. For military electronic equipment, laminates must be resistant to the effects of extreme cold, heat, moisture, and fungus.

Sheets of glass, asbestos or cotton fabric, mica, and wood or paper are impregnated with suitable binders.

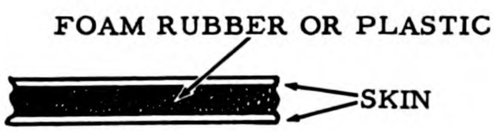
Corrugated or honeycomb interior construction combined with flat sheets provides high resistance to crushing and maximum rigidity with minimum weight.

CORRUGATED



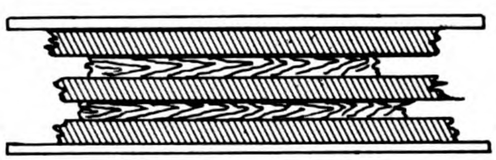
HONEYCOMB

Exterior sheets of metallic or laminated nonmetallic material with an interior of foam rubber or plastic provide light weight and rigidity.



LAMINATE

Exterior sheets of aluminum or other metal and interior sheets of plywood are used for equipment cases and cabinets. This construction combines high rupture strength, light weight, and rigidity with a hard waterproof surface.



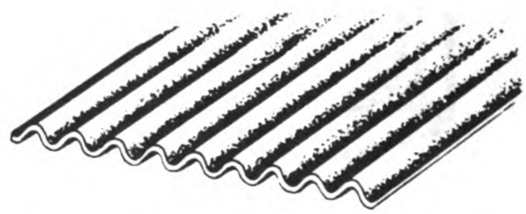
ALUMINUM AND PLYWOOD LAMINATE

4.2.5 Rigidizing

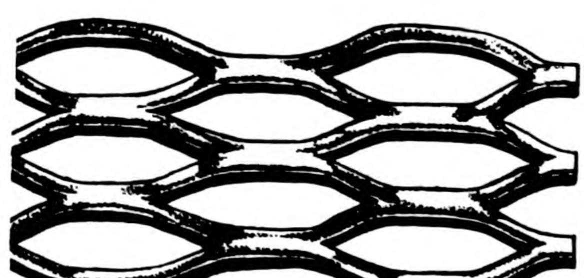
Rigidized sheet is flat stock with an embossed pattern which stiffens the stock by increasing its section modulus. Weight can often be reduced substantially by substituting thinner rigidized material for flat sheet. Rigidized sheet may also be used for its acoustic and decorative qualities.

Perforated types of rigidized sheet are often used where ventilation is required. Perforated types can often be made more rigid than plain, flat sheets of similar weights.

RIGIDIZED SHEET

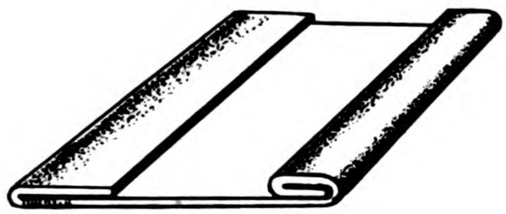


CORRUGATED RIGIDIZED SHEET
(One direction only)



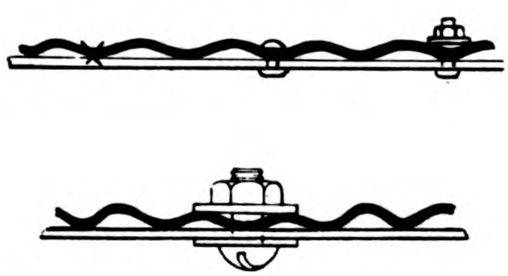
RIGIDIZED EXPANDED SHEET
(Stiffened one direction only)

A 180° flat fold can be used for stiffening sheet metal, but should be confined to the softer metals. Because of the tendency of such folded areas to trap and retain moisture, care must be taken that the metal is properly protected against corrosion by use of sealing materials and protective coatings.



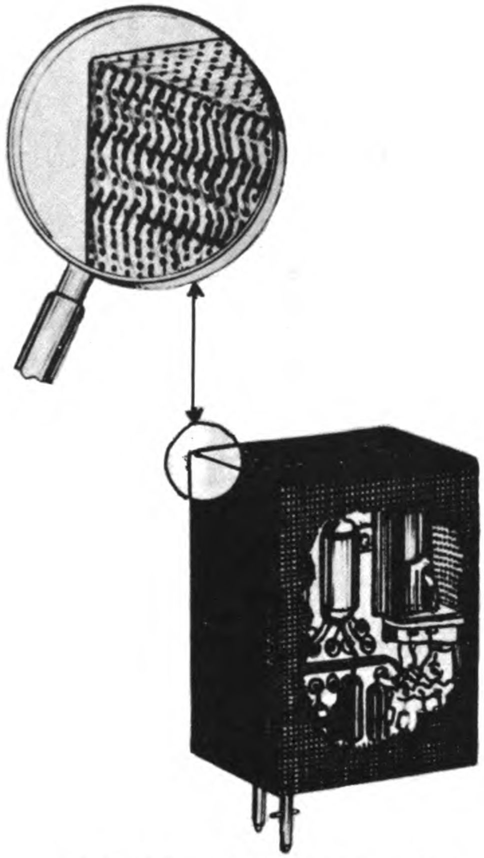
FOLDS

4.2.5.1 Assembling Rigidized Metal. Rigidized sheets should be joined to flat materials by spot welds, rivets, or small bolts at points of contact. Bolts and washers large enough to compress the rigidized metal may be used at any point. Residual stress in the metal helps to prevent loosening.



JOINING RIGIDIZED AND FLAT SHEETS

4.2.5.2 Application of Rigidized Metal. An rf shield of perforated rigidized metal provides a lightweight shield while also permitting ventilation.



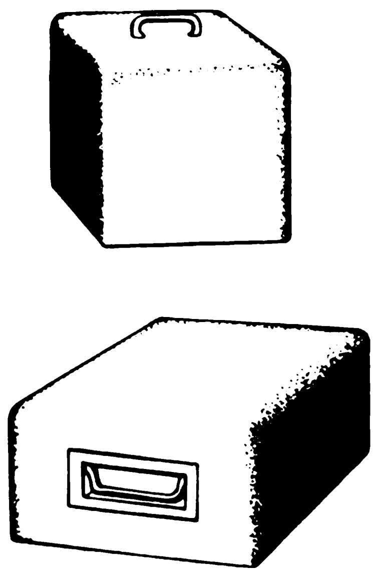
PERFORATED RIGIDIZED METAL SHIELD

4.3 MECHANICAL PARTS

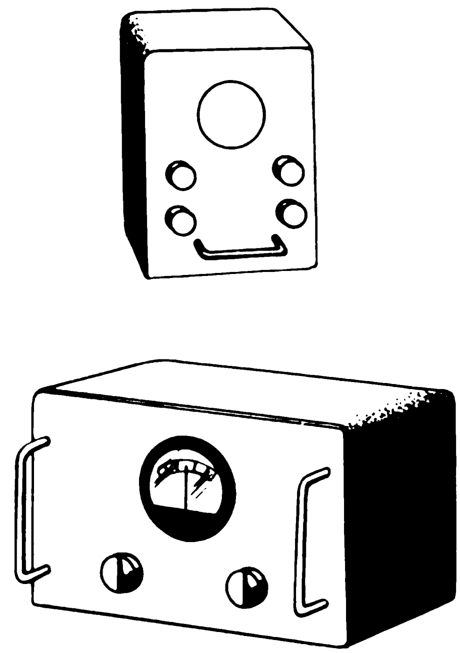
4.3.1 Handles

Carrying handles should be provided on all portable equipment. A single handle is usually sufficient for equipment weighing less than 25 pounds. For heavier or bulky equipment, at least two handles should be used, one at each end.

Handles should be smooth, large enough to allow complete entrance of four fingers, and sturdy enough to withstand at least five times the normal load. If possible, use recessed, retractable handles mounted flush with the sides of the equipment.



HANDLES



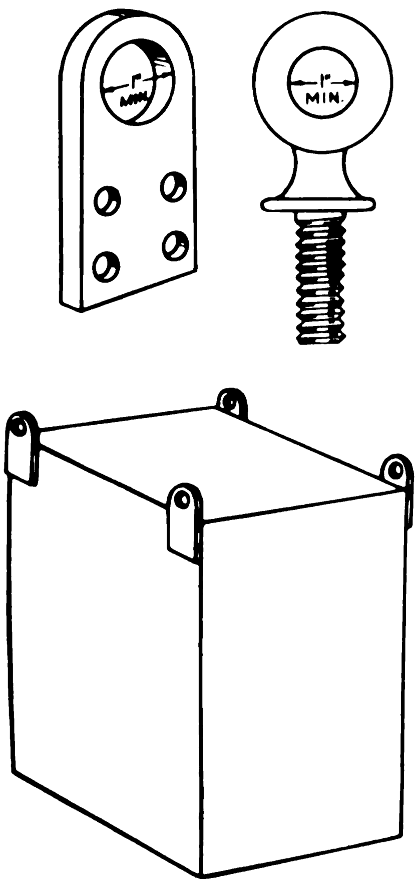
TYPICAL BAILS

4.3.2 Bails

Bails are convenient for withdrawing assemblies or mechanisms from their cabinets. They also serve as protective stands in repair operations. A single bail may be sufficient for small panels. For larger panels, a vertical bail near each end is required. Bails should be securely anchored to withstand shear, bending, and tensile forces at least twice as great as normal. For protective purposes they should extend beyond other projections on the panel. Openings should be large enough to allow entrance of four fingers. Small bails which allow entrance of only one finger may be acceptable on miniature equipment.

4.3.3 Lifting Devices

Eye bolts or similar devices for lifting and handling should be installed on apparatus weighing more than 150 pounds. They should be attached to the frame of the equipment so that components and assemblies will not be overstressed. With the full weight suspended from any one lifter, a safety factor of at least 10 should be used. The words "LIFT HERE" should be placed adjacent to the lifting device unless its function is obvious. Use removable types of eye bolts or similar devices where feasible.



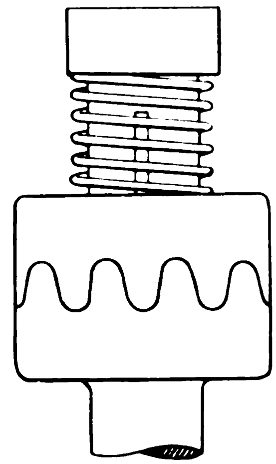
LIFTING DEVICES

4.3.4 Mechanical Safety Devices

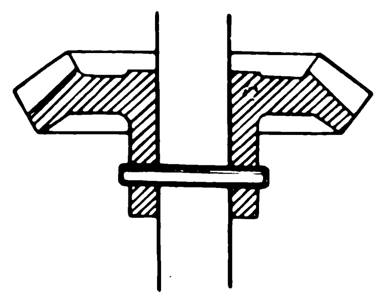
A mechanical safety device is analogous to a fuse in an electrical circuit. It is intended to protect the mechanism against damage.

Ideally, a safety device should be self-restoring when safe operating conditions have been re-established. A good example of this type of mechanism is the slip clutch. A disadvantage of the slip clutch is that continued overloading may cause wear or failure.

Positive disengagement under overload is useful under many conditions. Simple shear pins or safety links are used, but must be readily replaceable to restore operation. Spares should be available for use at all times.



SLIP CLUTCH



SHEAR PIN

A more complicated safety device will disengage or shut down the equipment under overload conditions. In this category is a type of clutch which completely disengages under overload and can only be reset manually or electrically. Other such devices are speed governors, thermostats, liquid level switches, torque switches, and pressure switches.

Warning signals, alone or in combination with safety devices, are often used. Horns, bells, buzzers, and pilot lamps (in noisy locations) are good attention getters, and are useful if rapid restoration of operation is important or equipment is remote and failure might not otherwise be noticed. The slip clutch previously illustrated is very noisy when slipping and is likely to attract attention.

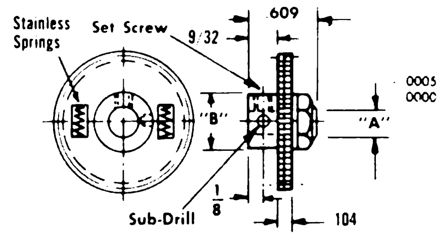
4.3.5 Gears

Gears used in military equipment differ in type and quality. Commercial gears are obtainable as standard stock items. As equipment becomes more precise, the necessity for precision gearing is increased. It is particularly important that specifications and drawings of gears indicate manufacturing tolerances and inspection requirements.

Backlash in gears is most readily controlled by providing adjustment of shaft center distances. Backlash in right-angle drives using mitre gears can be controlled by moving either gear or shaft.

If adjustment of shaft centers is not practicable, backlash should be controlled by fixing dimensional tolerances. A minimum backlash of 0.001 inch at the pitch line will provide sufficient clearance for lubrication under conditions of normal thermal expansion. If gears must not run tight and backlash must be minimized, the 14-1/2 degree tooth is preferred.

Excessive runout (eccentricity) of gears results in excessive backlash or binding. In mechanisms such as servos or recorders, where driving power is low and uniform speeds are required, binding must be avoided. A typical antibacklash gear assembly using springs is shown below.



ANTIBACKLASH GEAR ASSEMBLY

The composite gear error is the combined effect of the following factors:

a. Eccentricity of pitch circle
b. Errors in tooth form and lead
c. Clearance between shaft and hub holes
d. Shaft runout and looseness or shaft bearings.

In a newly assembled gear train, run-in (wearing-in) may be used to minimize binding due to minor runout errors and machining irregularities. Shaving, lapping, and other finishing processes may be used to minimize the need for run-in measures.

Inspection and gaging of gears are done by using a master gear suitably mounted as a mating element for the manufactured gear. All errors and significant dimensional quantities are easily measured by use of indicators. A particular advantage of this system is that a gear required for replacement can be accurately reproduced at a later date.

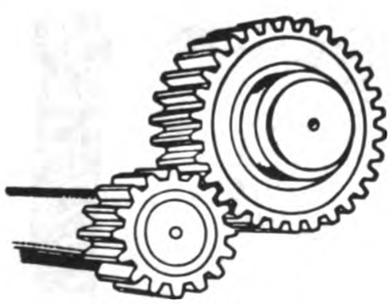
Less critical inspection of gears is done by inserting measuring pins of suitable diameter between the gear teeth and computing the pitch diameter from the distance between pins. Gear tooth verniers also are used.

Where a smooth high-torque drive is required, shafts must be rigid and nonbending, with gears mounted close to the bearings. A long sturdy hub on the gear will minimize wobbling.

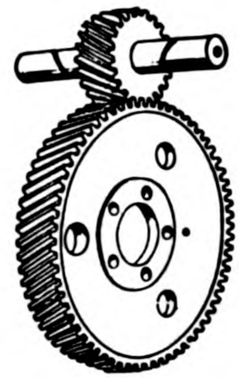
Nonferrous metals are used for lightly loaded gears. Where precision is not important, laminated phenolics, nylon, and similar nonmetallic materials are used to reduce noise. Small pinions should be of a harder, more durable material than the mating gears.

Geared shafts may be parallel, intersecting, or neither parallel nor intersecting.

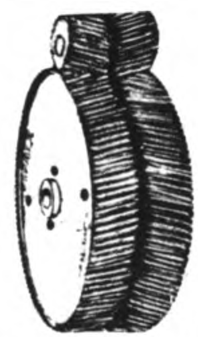
Spur, helical, and double helical or herringbone gears, illustrated below, should be used to connect parallel shafts.



SPUR GEARS



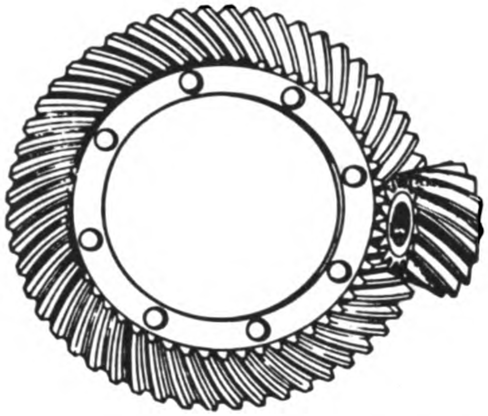
HELICAL GEARS



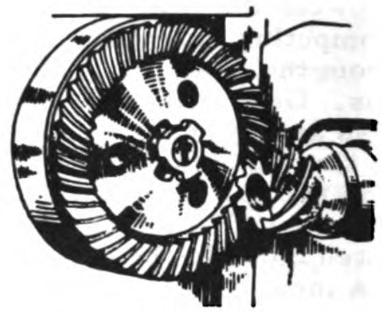
DOUBLE HELICAL OR HERRINGBONE GEARS

Straight bevel gears or spiral bevel gears, illustrated below, should be used to connect shafts which are not parallel but which would intersect if extended. These gears must be accurately aligned axially with respect to their mating gears.

STRAIGHT BEVEL GEARS



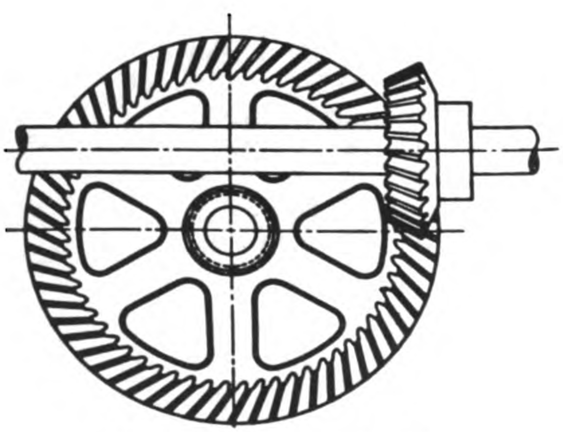
SPIRAL BEVEL GEARS



HYPOID GEARS

Skew bevel gears, hypoid gears, spiral gears, and worm gears, illustrated below, should be used to connect shafts which are not parallel and would not intersect if extended. These gears must also be accurately located axially with respect to their mating gears.

SPIRAL GEARS



SKEW BEVEL GEARS

WORM AND WORM WHEEL

4.3.5.1 Spur Gears. The straight teeth of spur gears provide limited contact areas and are generally noisy if high speeds, heavy loads, and coarse teeth are used.

4.3.5.2 Helical Gears. Helical gears provide smoother, quieter operation than the spur type because of more gradual engagement. Helical gears are particularly useful for quietness of operation at high speeds. Their principal disadvantage is that thrust bearings must be provided.

Helical gears can be machined and processed at about the same cost as spur gears. Greater friction caused by increased tooth-sliding action and greater driving force necessitates greater care in lubrication.

4.3.5.3 Worm Gears. Worm gearing is particularly suitable for speed reduction and high-torque applications. This type of gearing is also widely used for angular positioning in which the self-locking feature is advantageous. Quietness and smoothness of operation are outstanding advantages, but additional friction resulting from the sliding action of the worm markedly reduces efficiency.

Speed ratios of 100:1 or more can be obtained by using a single-thread worm having a small lead angle. Where a multiple thread of large lead angle is used, ratios as low as 1-1/2:1 are obtainable.

It is desirable to use a harder material for the worm than for the mating worm wheel to minimize friction.

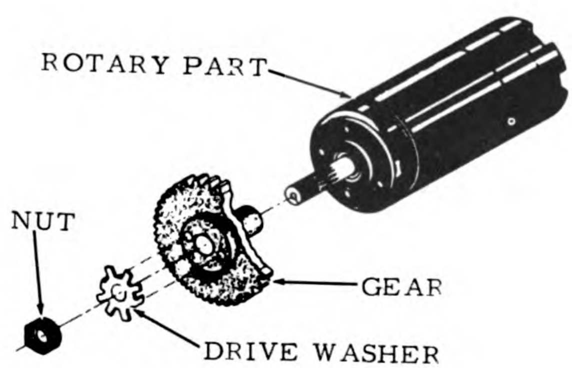
It is common practice in small motors (1/10 horsepower or less) to use laminated phenolic material for worm gears. For a precision drive, it is desirable to mount the worm gear on ball bearings and employ a specially ground worm.

Because of the high friction and heat generated, worm gearing is usually lubricated by gear oil in an enclosed bath.

4.3.5.4 Spiral Bevel Gears. Spiral bevel gearing is usually employed when an extremely quiet, efficient, and powerful right-angle drive of medium reduction ratio is required.

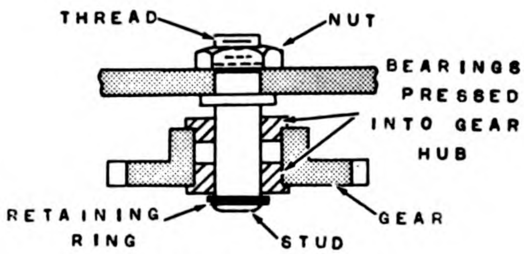
These gears are furnished in matched pairs of hardened alloy steel and are usually mounted on ball or roller bearings. Because of the curved tooth construction, such gearing is relatively expensive and is used only in mechanisms where the high cost is justified.

4.3.5.5 Attaching Gears to Shafts. Drive washers and nuts should be used to secure gears to shafts of rotary components as illustrated below.



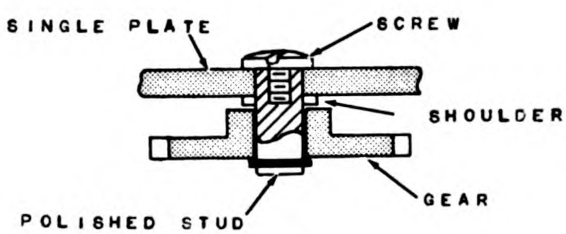
The designer should consider the following methods of mounting shafts on single plates in precision gear trains in lieu of the conventional method of mounting on double plates. The methods, illustrated below, offer the advantages of ease of assembly and inspection.

Ball bearings pressed between gear and stud provide a close precision fit.

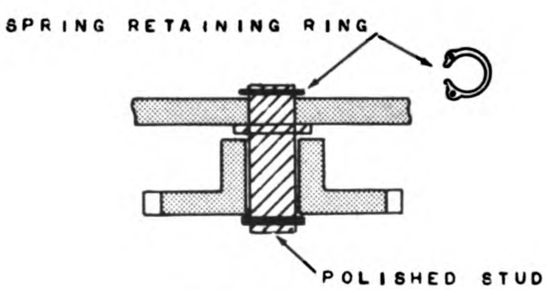


TWO BALL BEARINGS

The polished stud acts as a shaft and provides adequate bearing support.



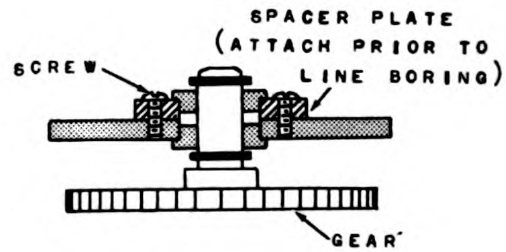
SCREW-HELD



RETAINING RING

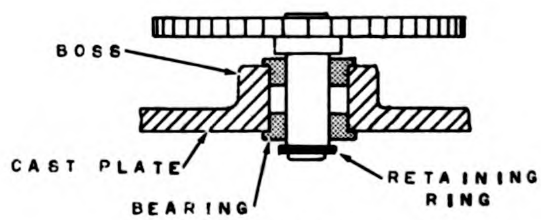
POLISHED STUDS

The spacer plate provides a means of mounting the shaft with two ball bearings in line on a single plate.



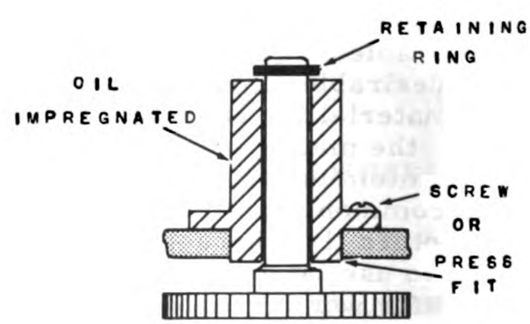
SPACER PLATE

The boss prevents misalignment and minimizes assembly time.



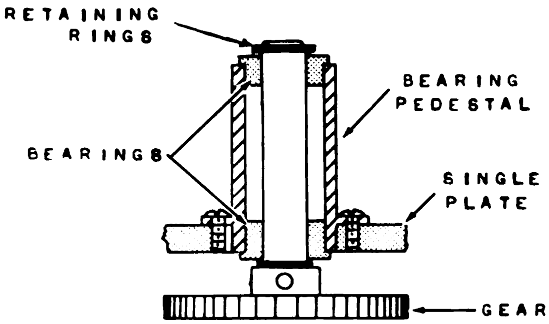
BOSS IN CAST PLATE

The self-lubricating pedestal supports the shaft and functions as a bearing.



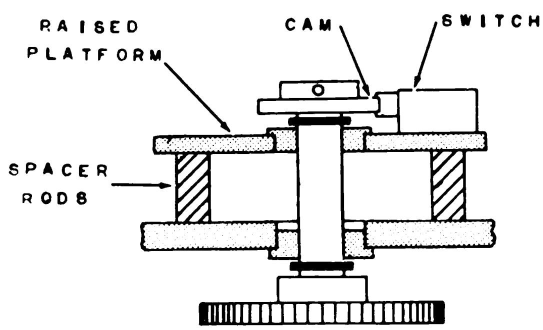
OIL-IMPREGNATED

The flanged tube eliminates bearing-alignment.



BEARING PEDESTAL

The raised platform provides accommodation for a switch or other part. The gear shaft is accessible during operation.



RAISED PLATFORM

4.3.6 Bearings

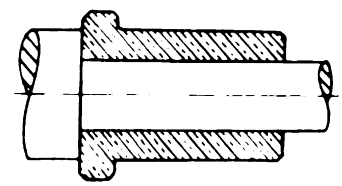
The following should be considered in the use of bearings and shafts:

a. To minimize shaft bending, bearings should be mounted as close as possible to the load.

b. Bearings should be located so that they can be readily lubricated or removed for replacement.

c. Shafts in bearings must run freely at all operating temperatures and allowance must be made for shaft expansion. The lubricant must be sufficiently fluid at the lowest required operating temperature to permit bearings to overcome friction in starting.

Sleeve bearings are usually made of cylinders, often with a shoulder at one end to permit them to act as a thrust bearing. The outer surface may be threaded to allow screwing into place in an assembly. Self-aligning sleeve bearings have a spherical outer surface which allows them to move into alignment with the major axis of the shaft.



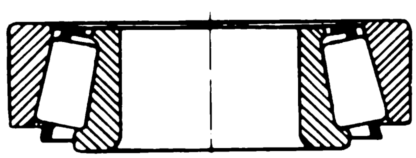
SLEEVE BEARING

Sleeve bearings are usually made of brass, bronze, or sintered nonferrous alloy. Materials should be sufficiently plastic to wear-in or conform to the shaft. Where loads are heavy, babbitt or soft electroplated material on a steel backing may be used to provide a particularly uniform stress distribution. Self-aligning bearings may be used where the better wearing properties of a harder material, such as bronze, are desirable.

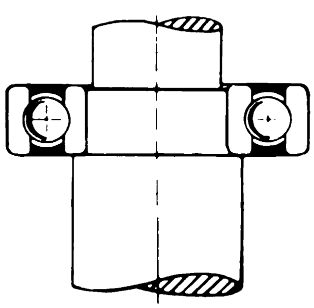
4.3.6.1 Bearing Lubrication. Lubricant may be applied to bearings by means of an oil reservoir, oil-wick, or a lubrication fitting. Where required by heavy loads and high speeds, grooves may be incorporated in the bearings to improve circulation of oil.

Where oil-impregnated, sintered materials are used in "self-lubricating" bearings, the manufacturer's installation recommendations must be carefully followed.

4.3.6.2 Ball and Roller Bearings. Ball and roller bearings are used where very low friction is desired and where the cost of the equipment in which they are used warrants their extra cost. Where heavier loads are involved, roller bearings are used. Rollers may be short or long, cylindrical (needle), or tapered. Ball bearings can be obtained with grease-retaining washers which, in many cases, contain sufficient lubricant to last the life of the equipment.



ROLLER BEARING



BALL BEARING

Bearings should not be included in any part of an electrical circuit. Particular attention should be directed towards the effect of bearings on radio frequency, and resonant frequencies of equipment.

4.3.6.2.1 Mounting of Ball Bearings. An arbor press should be used for mounting ball bearings as illustrated on the next page. The outer ring of the bearing should never be subjected to the full mounting force of the arbor press as this will cause a heavy thrust load to be applied to the balls and races before they are seated and may seriously damage the bearing.

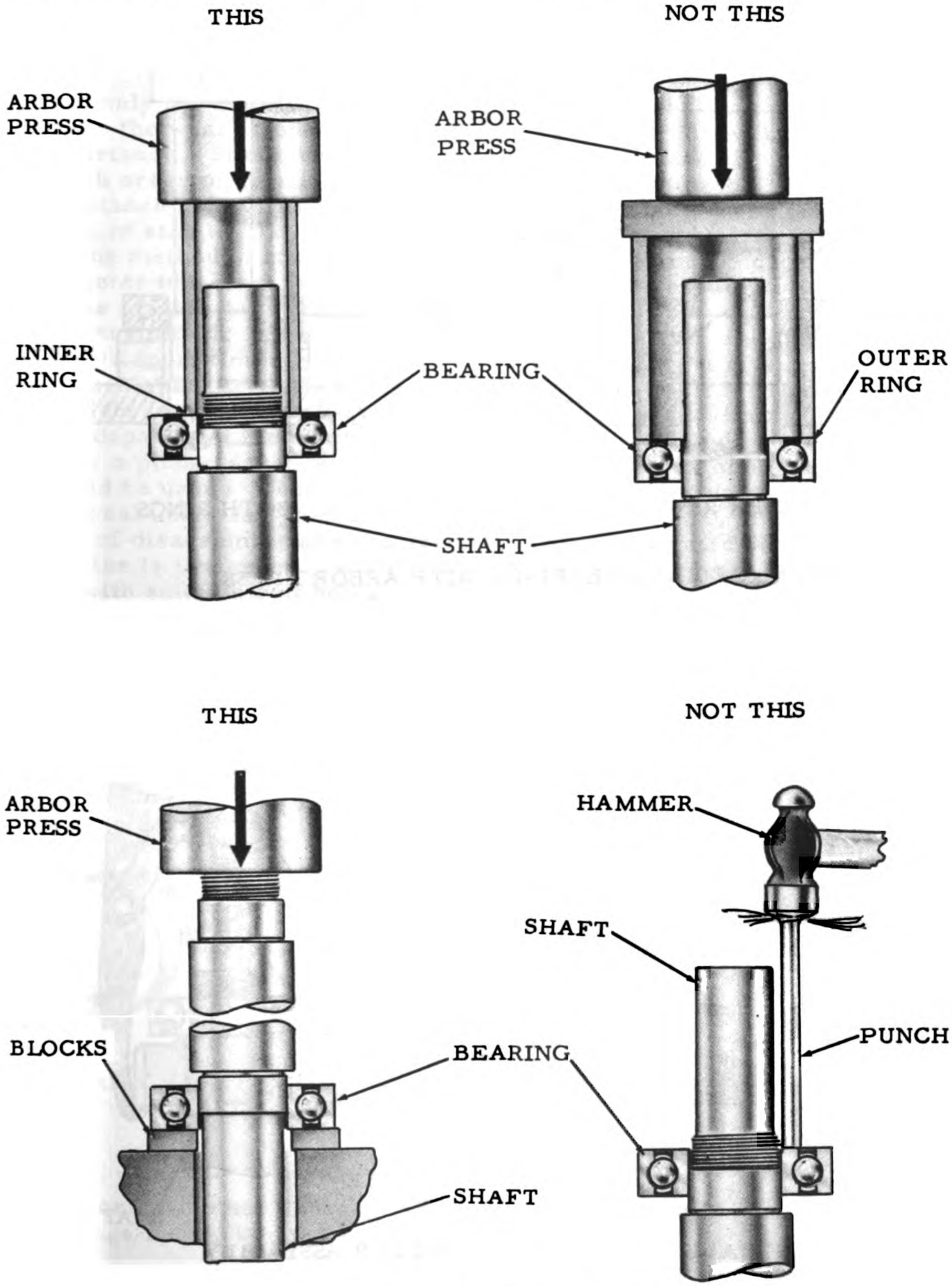
The full force of the arbor press should not be applied until it has been ascertained that the bearing is started straight and not misaligned. Forcing a cocked bearing will distort the inner race and may cause it to crack. Also, the inner race, due to its extreme hardness, is likely to burr or score the shaft seat.

A hammer should never be used to drive a bearing to its seat. Such a procedure will cause the bearing to be cocked from side to side and may result in the shaft being scored or burred or the bearing being damaged in a manner which will not show up until after the bearing has been put into service.

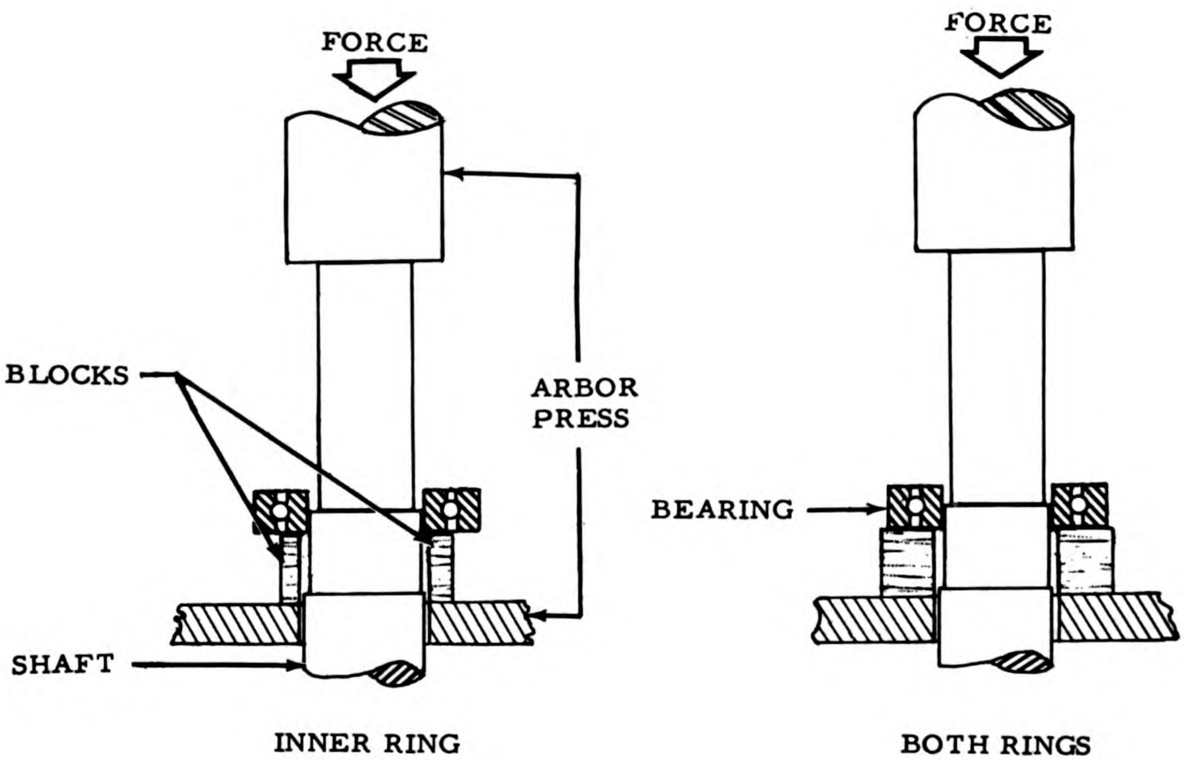
4.3.6.2.2 Removal of Ball Bearings. The correct methods of mounting bearings, given in 4.3.6.2.1, apply equally to the removal of bearings. Correct ball bearing removal with an arbor press is illustrated on page 4-52.

Bearings may also be removed with a puller, as illustrated on page 4-52.

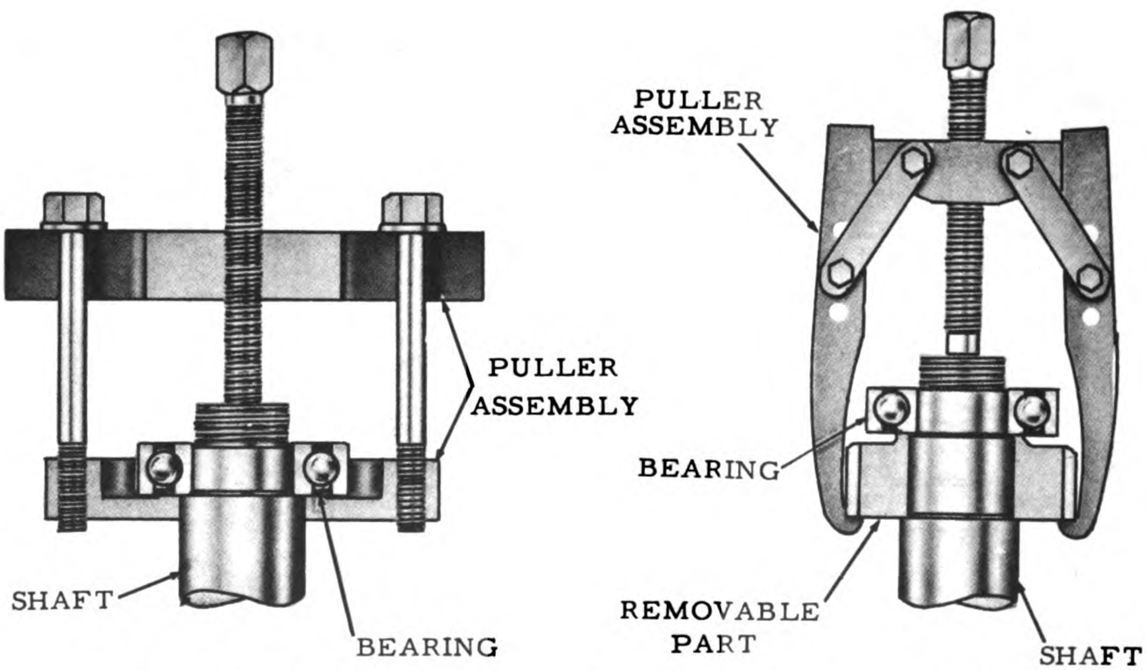
Where gears or other removable parts do not allow the puller to contact the bearing directly, the puller jaws may be placed behind the part and the part and the bearing may be removed as a unit, as illustrated.



MOUNTING OF BALL BEARINGS



REMOVAL OF BALL BEARINGS WITH ARBOR PRESS

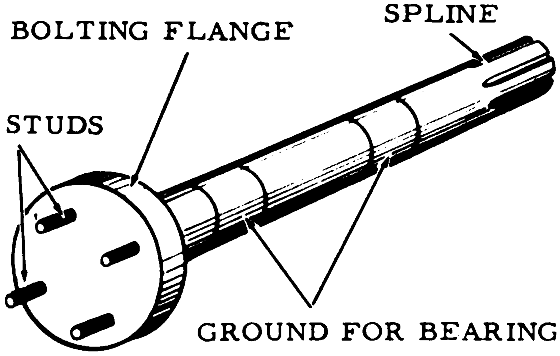


REMOVAL OF BALL BEARINGS WITH PULLER ASSEMBLY

4.3.7 Shafts

Carbon or alloy steel shafts are used in enclosed lubricated mechanisms where there is appreciable speed and loading. Brass shafts have limited application and are normally used only in small mechanisms where the wear is of minor importance. Shafts requiring a high order of corrosion resistance are sometimes made of stainless steel.

The method of attaching elements to a shaft is determined by the magnitude of torque to be transmitted. Two set screws approximately 90 degrees apart are satisfactory for light loads. Where the full load capacity of the shaft is used, a pinned arrangement should be used. Where both reversal under full load and ease of disassembly are required, a spline is preferred. A welded hub with suitable bolt holes provides a positive drive fastening. It is good practice to use press fits for spacing collars and sleeves.



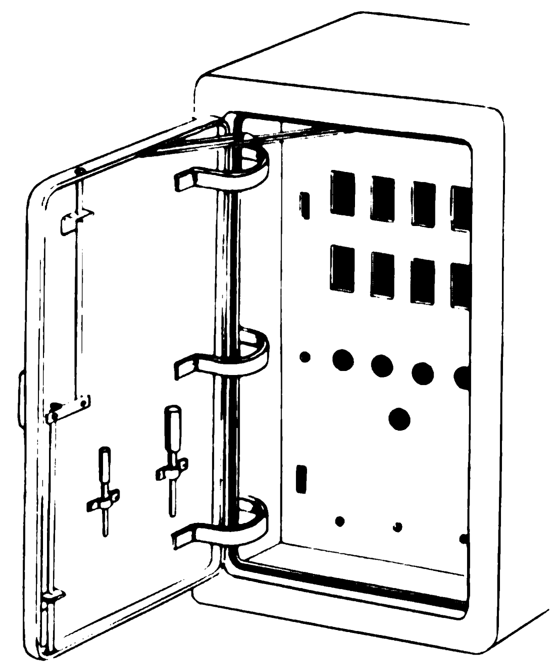
DRIVE SHAFT WITH SPLINE AND HUB

4.3.8 Doors

Doors and other access openings should be mounted so that they present a flush or continuous surface with the rest of the enclosure. They should be sufficiently rigid to withstand careless handling and clamping for sealing.

Large doors are usually of double-wall construction with edges folded back for sealing. Size should be limited to 6 feet high by 25 inches wide. Door pairs generally open from the centerline of the cabinet.

Hinges should be designed to allow for complete dismounting of doors. They should be completely out of sight when the door is closed and should not interfere with the sealing surface. The disappearing hinge illustrated is commonly used. Large doors use a number of such hinges to ensure adequate strength and rigidity.

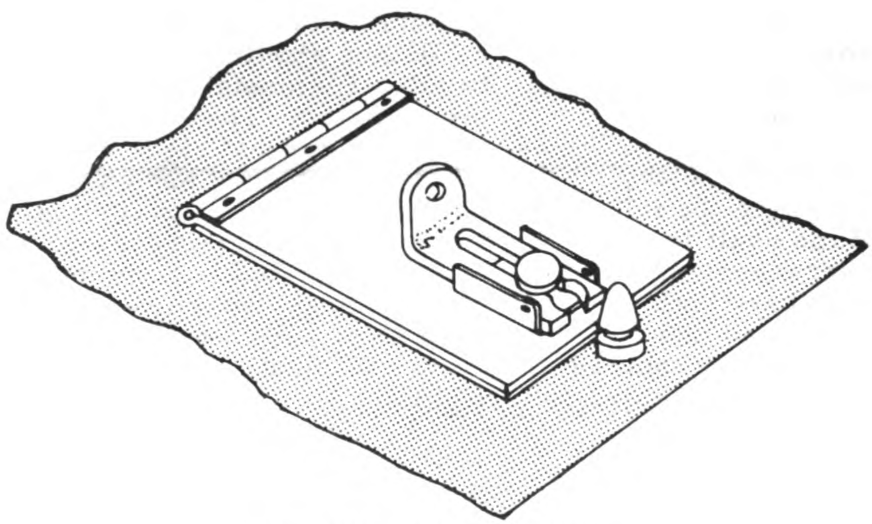


DOOR WITH DISAPPEARING HINGE

Stays should be provided to hold the door in the open position and to limit the opening to about 90 degrees. Stays should not rattle under normal shipboard vibration.

Small doors and covers are usually made of sheet metal with folded edges. When the cover is not hinged, other means, such as chain stays, should be provided to prevent accidental loss.

Covers should be used to prevent inadvertent maladjustment and the entry of foreign material into the equipment. These covers should be of the captive type and should be equipped with captive type fasteners. One method of accomplishing this is illustrated below.



CAPTIVE TYPE COVER

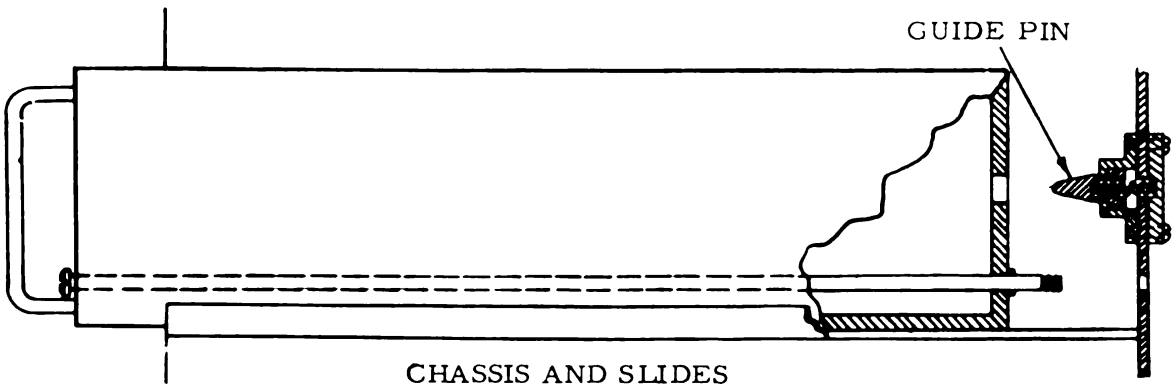
4.3.9 Slides

In large equipment it is particularly important to provide durable chassis slides and mounts. Possible service shock loads and inclination should be considered in designing these. Provision should be made for readily disengaging the chassis from the slides.

Guide pins are used for alignment and to prevent the rear of a slide-out chassis from moving during vibration. Threaded rods or other means may be used to secure the assembly in position.

Assembled slides of the ball or roller type are usually bolted to the enclosure for ease of maintenance. Welding should be used only when it is necessary to provide a proper structural mounting area for the slide.

Simple runner-guide slides are often satisfactory. When used, they should be bolted or welded in place. Nylon plastics may be used for sliding surfaces. Slides should be provided with automatic latching devices to stop the chassis from withdrawal beyond the servicing position. For additional information, see 2.2.2.

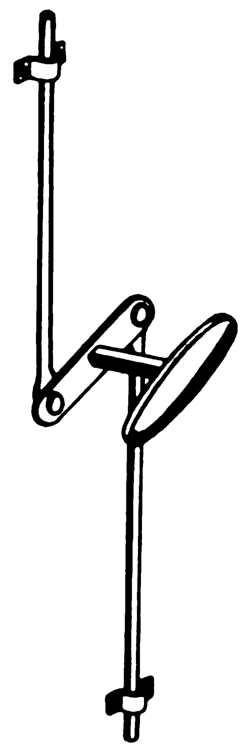


CHASSIS AND SLIDES

4.3.10 Latches

Latches should be provided with handles where necessary. Latch engagement should be positive despite reasonable flexure of door and cabinet. On large doors, the latch should hold the door at top and bottom; a center stay may also be of value. When the latch is disengaged, door closure under normal forces should not damage the latch or lock.

If a door or cover is sealed against a gasket, the latch should also serve to pull the cover in against the gasket. A latch for a dust cover need not have this provision, but should prevent the cover from rattling.

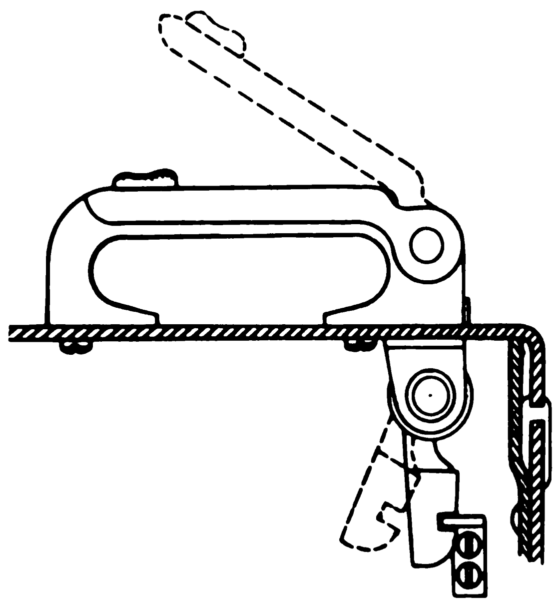


DOOR LATCH

4.3.11 Gaskets

Selection of particular materials for gaskets depends on the conditions to be met, such as roughness and finish of sealing surfaces, temperature, pressure, and medium being sealed.

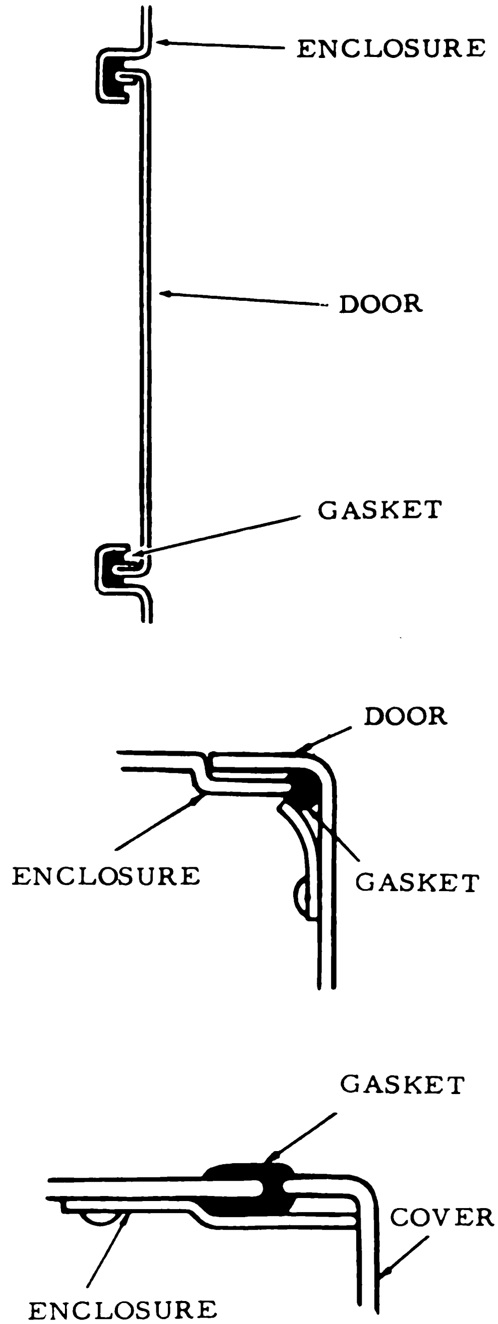
As far as possible, gaskets should be confined in a groove, especially if soft gasket materials are used. Dimensions of 0-ring



LATCH FOR SEALING

grooves should follow manufacturers' recommendations. A flange or shoulder may be used to limit the deformation and prevent crushing. It is generally easier to seal a uniformly narrow surface than a broad surface. Bolts should not extend through gaskets or cause discontinuities in the sealing surface.

Joints which must operate under pressure should be accurately fitted with gaskets. A smooth machined surface at the joints is not necessary, but machining should be done so that tool marks run parallel to the gasket groove. Gaskets should be continuous: if ends are spliced together, great care must be exercised in cutting or grinding the spliced ends. A long scarf joint between ends will minimize leakage.



SEALING GASKETS

Gaskets for sealing doors, hatches, and covers should be made of soft material. Rubber or cork and rubber having an approximate durometer hardness of 30 to 50 are good for most purposes. To minimize permanent set, materials should not be over-compressed. Because of such set, covers should always be replaced in the same grooves from which they were removed. Paper, fiber, and similar materials are generally unsatisfactory for gaskets except for small dustproof covers.

4.3.11.1 Gasket Selection. The table on pages 4-58 through 4-62 which lists the characteristics, applications, limitations, and permissible temperature range for various gasket materials, may be used as a guide in the selection of gasket material for electronic equipment.

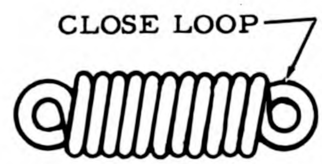
4.3.12 Springs

Carbon steel is the preferred material for springs. When it is plated for corrosion resistance, it must be suitably heat treated after plating to avoid hydrogen embrittlement. In oil-filled housings, steel springs are usually not plated.

Stainless steel, monel metal, and copper alloys are used where a high level of corrosion resistance is required. To avoid undue creeping, these materials should be used only for lightly stressed springs.

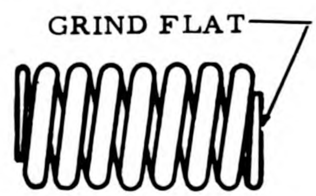
Tension springs should not be stressed beyond 50 percent of the yield point. End loops should be completely closed to prevent unfastening under dynamic loading. Special end loops or bends should be avoided, as they usually require an extra operation. All springs exposed to hydrogen evolved in any treatment in the process of manufacture, such as pickling and plating, must be relieved by baking. Unitl this is done, the spring must not be flexed as presence of hydrogen causes embrittlement. Work-hardened spring material should be stress-relieved to improve durability in service.

Compression springs should be adequately piloted to avoid bending. Ends should be squared. Closure of compression springs should be limited to 75 percent of free height.



TENSION SPRING

TORSIONAL SPRING



COMPRESSION SPRING

Flat springs are relatively inexpensive and are well suited for use in precision mechanisms where deflections are small. Unless they are to be bent or pierced they can usually be made from fully hardened strip stock. Unnecessary holes, notches, or other discontinuities in flat springs should be avoided.

CHARACTERISTICS, USES, AND LIMITATIONS OF GASKET MATERIALS

Materials	Characteristics	Applications	Temp Range °F	Remarks
Lead	Excellent corrosion resistance.	Widely used for sulfuric acid and other corrosives at temperatures below 212°F.	to 212 (400 in a confined joint)	Excessive creep at above 212°F.
Tin		For pure neutral solutions.	to 200	Strongly attacked by acids and alkalis.
Aluminum	High corrosion resistance. Oxide film forms protective coating.	Used for corrosion resistance. Good against hot, sulfur-bearing gases.	to 800	Attacked by some strong acids and alkalis.
Copper, and brass	Excellent corrosion resistance.	Good general-purpose gasket for corrosion resistance at moderate temperatures.	to 600	Attacked by oxidizing acids, wet NH_3, chlorine, sulfur. Embrittlement at high temperature when exposed to H_2, CO, unless metal is deoxidized. Electrolysis sometimes objectionable.
Monel	High resistance to corrosion at all temperatures.	Versatile material, for most corrosives, acids, alkalis, and for steam and other high-temperature applications.	to 1500	Attacked by strongly oxidizing acids and strong hydrochloric acid. Embrittlement in sulfur-bearing gases above 500°F. Stress corrosion likely with steam above 800°F.
Nickel	Somewhat lower all-around corrosion resistance than Monel.	Good against chlorine up to 950°F.	to 1400	Subject to embrittlement by steam over 800°F.

CHARACTERISTICS, USES, AND LIMITATIONS OF GASKET MATERIALS (Cont'd)

Materials	Characteristics	Applications	Temp. Range °F	Remarks
Iron, steel	SAE 1010 to 1020	For joints with low gasket stress. For most alkalis.	to 1000	Strongly attacked by sulfur-bearing gases over 600°F. High gasket stress causes corrosion.
Chrome steel	Type 502 (4-6Cr, 5 Mo) Good against steam.	For resistance to oxidation. Widely used in ring-type joints.	to 1200	Generally more corrosion resistant than iron.
	Type 410 (11-14-Cr)	Special use for resistance to oxidation at high temperature.	to 1300	Special purpose material only.
Stainless steel	Type 304 (18-8)	Most widely used gasket for corrosive service.	to 800	Attacked by sulfuric acid and wet halogens. Subject to intergranular corrosion, after long service at 800-1500°F.
	Type 347 (18-8, Cb stabilized)	For extremely high temperature.	to 1700	Corrosion resistance is not raised by stabilization.
	Type 316 (18-8, with Mo.)	For cases where additional corrosion resistance is required.	to 800	Subject to intergranular corrosion at 800-1500°F.
Teflon	Low resiliency. High incompressibility. Good heat resistance. Very inert to chemicals. Not adhesive. Very low coefficient of friction.	Best used in combination with other materials that give resiliency to gasket.	-90 to 500	Some cold flow when first loaded. Emits corrosive gases above 475°F. Decomposes to gas above 750°F. High coefficient of expansion makes it poor dynamic seal.

CHARACTERISTICS, USES, AND LIMITATIONS OF GASKET MATERIALS

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CHARACTERISTICS, USES, AND LIMITATIONS OF GASKET MATERIALS (Cont'd)

Materials	Characteristics	Applications	Temp. Range °F	Remarks
Kel-F	Resilient. Stays flexible at low temperatures. Resistant to chemicals, solvents, weathering, low cold flow. Nonflammable.	For resistance to chemical attack. Unplasticized form has extreme chemical inertness.	-320 to 390 (unplast. form)	Plasticized form shows some shrinkage with some hydrocarbons, solvents, and hot water.
Poly-ethylene	Resilience comparable to natural rubber. Stays flexible at low temperatures.	For chemical resistance and low temperature service.	-80 to 240	Not resistant to glacial acetic acid, aniline (100 percent), formaldehyde, nitrobenzene, or HCL at high temperatures.
Phenolic resins	Strong and solid. Hard and impervious.	Combination gasket and insulation (electric) to restrict flow of stray currents.		Generally restricted to use in insulating flanges for control of electrolytic corrosion.
White asbestos	Soft and pliable in woven cloth. Tough and durable in compressed sheets.	Good for relatively high temperature use. For use with weak acids, alkalis, oil, solvents, steam, and hot water.	to 750	Temperature range depends on binder or reinforcement.
Blue asbestos	About equal or inferior to white asbestos in physical properties.	Higher resistance to acids than white asbestos.	to 750	Temperature range depends on binder or reinforcement.
Natural rubber	Tough, resilient, impervious.	With hot or cold water solutions, low pressure steam and gas, and some dilute acids and alkalis.	-65 to 250	Low pressure only, except in confined joints. Not for strong acids. Never for oil or petroleum derivatives. Poor ozone resistance.

CHARACTERISTICS, USES, AND LIMITATIONS OF GASKET MATERIALS (Cont'd)

Materials	Characteristics	Applications	Temp. Range °F	Ramarks
GR-S	Better water resistance than natural rubber. Good shear strength.	With water, dilute acids and alkalis.	-70 to 250	Unsuited for gasoline, oil, solvents, concentrated acids. Poor ozone resistance.
GR-N	Good abrasion resistant. High tensile strength. Low compression set. Nonadhesive.	With hot or cold water, steam, dilute acids and alkalis, gasoline, oil, and aromatic and aliphatic solvents. Good for O rings.	-65 to 300	Not for oxygenated or halogenated solvents. Poor ozone resistance.
Neoprene	Good resistance to abrasion and tear. Weather resistant, Fairly low swell in oil.	With hot or cold water, gas, nonaromatics, oils with aniline point over 180°F, some solvents. Good for O rings.	-20 to 250	Not for aromatic gasolines. Low aniline point pols cause severe swelling. About 10% swell with 180°F A.P. oils. Good ozone resistance.
Butyl	Low gas permability. Good aging qualities. Good resilience at high temperature, poor resilience at room temperatures and below.	With water, steam, gas, alkalis, dilute acids. Gas seal. For O rings in contact with phosphate esters.	065 to 250	Poor resistance to petroleum oils.
Thiokol	Good low temperature properties. Low swell, shrinkage. Best solvent resistance of any rubber.	With hydrocarbons, esters, ethers, ketones. Good for O rings, where high solvent resistance is important.	-65 to 212	Not for joints with high bolt loads. Not good against halogenated solvents.

CHARACTERISTICS, USES, AND LIMITATIONS OF GASKET MATERIALS (Cont'd)

Materials	Characteristics	Applications	Temp. Range °F	Remarks
Silicone	Flexible over wide range of temperatures. Relatively low tensile strength. Good heat stability. Resists oxidation and weathering.	For high and low temperatures. Also for oils with high aniline point.	- 100 to 450	Attacked by low aniline point oils. Not good with solvents such as gasoline and benzene. Not good with steam at high pressures.

Electrical contact springs may be of beryllium-copper, beryllium-cobalt-copper, chromium-copper, palladium-copper, silver-copper, iridio-platinum, phosphor-bronze, or nickel-silver, tempered and plated as necessary.

Beryllium-copper springs should be heat treated after forming to obtain the correct temper. When flat springs are made from materials which cannot be heat treated, the direction of grain should be within 45 degrees of the longitudinal axis.

4.3.12.1 Selection of Spring Material. The table on the following page may be used as a guide in the selection of material for springs.

4.4 FASTENING TECHNIQUES

Methods of fastening are determined by the type of joint, strength required, materials, and disassembly requirements. Tensile strength of the joint should approximate that of the members joined, and stresses should be distributed as uniformly as possible.

Defective mechanical connections are a major cause of defects in military equipment. Although some defects can be traced to improper design, many are due to poor workmanship as evidenced by loose screws, improperly driven rivets, and cracked welds.

To minimize such defects and improve reliability, equipment such as automatic machines for welding and torque wrenches for tightening fasteners may be used. Reliable joints can also be produced manually, but good training and adequate supervision of personnel and proper inspection and testing are required.

4.4.1 Welding

Welding has many advantages over other methods of joining parts such as high strength, simplicity, and uniform stress distribution. Cost of tooling and labor is relatively low and welded parts require a minimum of machining prior to assembly.

The three principal types of welding are resistance, arc, and gas welding. These types may be further classified as follows:

a. Resistance: spot, line, projection, percussive, mash, flash, and butt.

b. Arc: metal arc with bare electrodes or with coated (shielded arc) electrodes in reducing flame, atomic hydrogen arc, carbon arc (shielded or unshielded), inert gas shielded arc, and submerged arc.

c. Gas: acetylene and oxyhydrogen.

Bonding materials used in welding are similar in composition to the base metals. All of the common metals including iron, steel, aluminum, and magnesium can be welded. The joint is usually harder and more brittle than the surrounding metal. Depending on the material used, stress relief annealing, cold working, or heat treating may be needed to improve the mechanical properties of the joint.

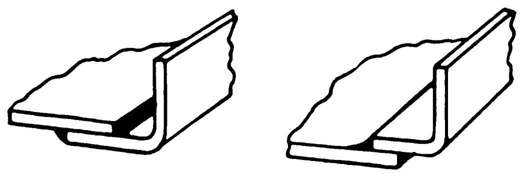
Inspection is sometimes required before the finishing of welded joints. Destructive testing is specified for sample lots or specimens. This is not usually required for production runs which are inspected by

SPRING MATERIAL SELECTION CHART

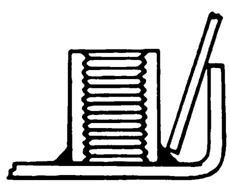
Material and Gov't. Spec.	Moduli x 1,000,000 G - Torsion E - Tension	Comm'l. Range of Sizes	Maximum Recommended Working Stress: psi x 1000 — 75 Percent Preload, 1000 Cycles	50 Percent Preload, 10,000 Cycles	25 Percent Preload, 100,000 Cycles	No Preload Infinite Life	Maximum Service Temperature	Application
COMMON USE								
Music Wire QQ-W-470	G 11.5 E 30	0.005 to 0.250	115	95	80	50	107°C (225°F)	High quality and uniformity; good plating surface; withstands high stresses; good fatigue properties.
Oil Tempered QQ-W-474	G 11.2 E 29	0.032 to 0.500	90	75	65	45	162°C (324°F)	Carbon steel wire; used in sizes from 1/8 inch to 1/2 inch.
CRES 18-8 QQ-W-423(302)	G 10 E 26.5	0.010 to 0.375	85	70	60	40	274°C (523°F)	Most popular cold drawn corrosion resisting steel wire; sizes to 3/16 inch.
Phosphor Bronze QQ-W-401	G 6 E 14.5	0.005 to 0.258	55	45	35	--	51°C (124°F)	Most popular cold drawn non-ferrous alloy; good resiliency, fatigue, and electrical properties.
SPECIAL USE								
Chrome Vanadium MIL-W-8696	G 11.2 E 30	0.062 to 0.500	125	100	80	50	204°C (399°F)	An ideal material for highly stressed springs and impact loads with wire diameters over 1/8 inch; pre-tempered or annealed.
Beryllium Copper QQ-C-530(1/2HT)	G 7.3 E 17.9	0.005 to 0.258	85	75	60	45	136°C (277°F)	A precipitation hardening alloy which can be jig-hardened for great dimensional accuracy; highest electrical conductivity of common spring alloys.
Inconel QQ-W-390	G 10.5 E 26	0.010 to 0.438	65	55	45	35	385°C (725°F)	High temperature resistance by a cold drawn material; special corrosion resisting applications.
K-Monel	G 9.5 E 26	0.005 to 0.438	60	55	45	35	246°C (475°F)	Age-hardening material with outstanding corrosion resistance (fresh, salt, or polluted water, and sulphuric or hydrochloric acid, etc.).

nondestructive methods such as magnetic-particle, fluorescent-dye, x-ray, or other radiographic tests.

Parts to be welded must be designed so that the joint is accessible to electrodes and welding rods.



AVOID GOOD



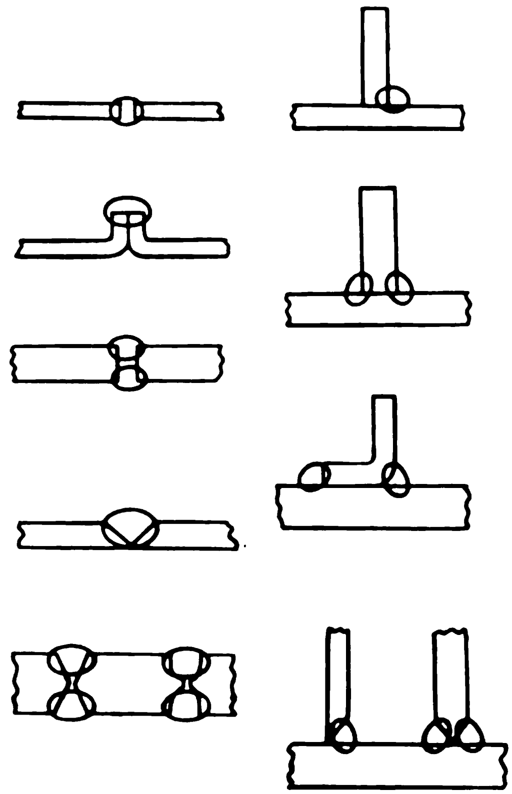
AVOID

ACCESSIBILITY FOR WELDING

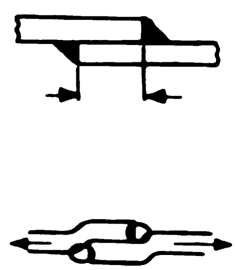
Welding should not be used where partial or entire disassembly may be required.

In selecting the type of welded joint to be used, cost and maximum effectiveness must be considered. Both electrode material and the preparation of edges are costly. A long thin seam is usually stronger than thick intermittent welds. Thin parts should be fastened together by more than one weld. Butt or T-joints are preferred to lap joints where corrosion traps formed by lap joints might retain corrosive plating fluids and moisture.

Surfaces to be welded should first be cleaned of all foreign material such as slag, grease, and oxides. Wire brushing or grinding, followed by chemical cleaning, usually serves this purpose.



BUTT WELDS FILLET WELDS

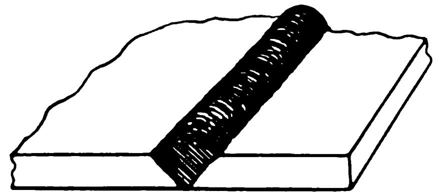


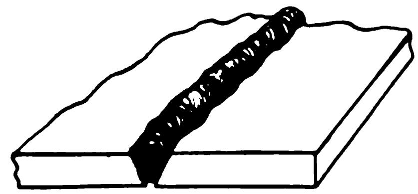
LAP WELDS

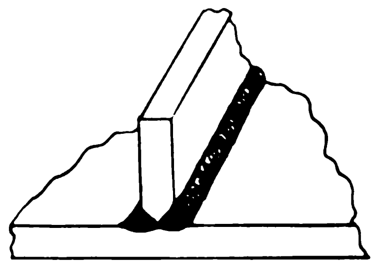
When necessary, proper fixtures should be used to position and secure the parts during welding of the joint.

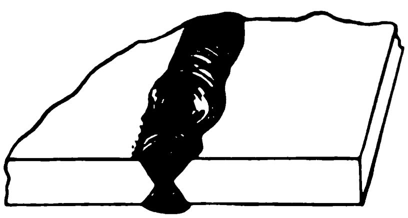
The distortion of parts due to welding can be minimized by proper placement of parts in fixtures by controlled welding techniques. Greatest distortion is produced where welding is performed continuously on only one side of a seam.

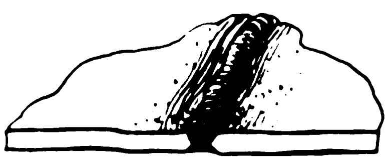
A good weld is smooth, dense, and free of "cold shuts", cracks, checks, burned spots, blisters, and foreign matter. Most welds weaken the metal adjacent to the joint and reduce fatigue resistance in the heat-affected zone.

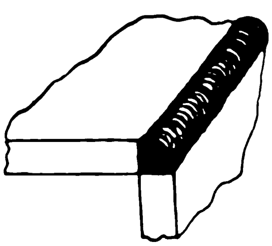

GOOD BUTT WELD

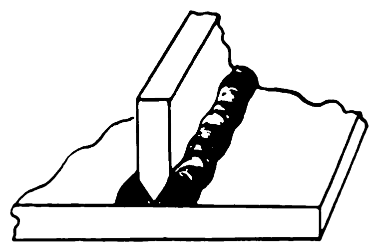

LACK OF PENETRATION


GOOD FILLET WELD


BURNED WELD

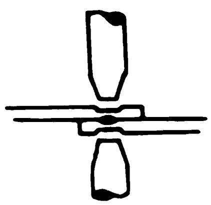

EXCESSIVE CURRENT


GOOD CORNER WELD

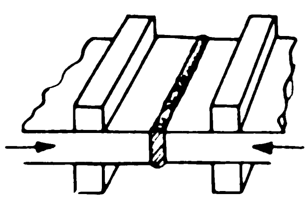

INSUFFICIENT PENETRATION

Where extensive fillets are used in weldments subject to bending loads, stresses in weldments tend to become complex. In general, the strength of the welded joint should be equal to, or slightly greater than, that of the parts joined. The type of joint preparation, size of fillets, and any treatment after welding should be specified.

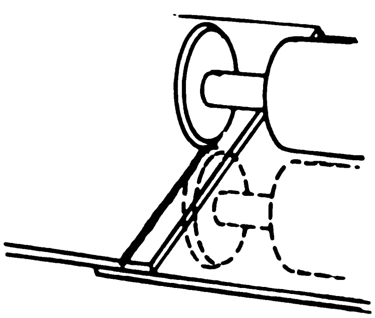
4.4.1.1 Resistance Welding. When an electric current of sufficient magnitude is passed through two adjacent metal parts heat is generated at the point of contact. This heat, in conjunction with the localized pressure exerted by the electrodes supplying current, welds the metals together. The type of lap joints called seam welds may be formed by use of the proper resistance welding equipment. Butt joints can also be made by resistance welding.



SPOT WELD

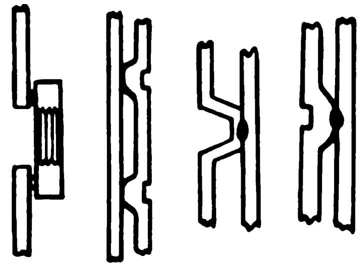


BUTT WELD



SEAM WELD

For resistance welding, projections are commonly used to localize the weld area and minimize distortion. This technique also permits welds to be completed simultaneously at several different points. Sheets thicker than 1/16 inch can be readily welded in this manner.



PROJECTION WELDS

The amount of heat must be carefully controlled by adjusting the current and its duration. Electrodes must be properly shaped and cleaned in order to conduct current efficiently through adjacent parts. Control of electrode pressure is also an important factor.

Spot welds should be designed to resist shear or compression forces. Spot welds should not be used in tension, but if assemblies of thin metals contain a long row of spot welds that may be subject to bending, it is advisable to use rivets instead of spot welds, or to insert a rivet at each end and space a few along the row.

For economy in spot welding, it is of utmost importance to design parts so that they are accessible to welding apparatus. Wherever possible, designs should permit the use of simplified electrode components with a minimum amount of off-setting.

Zinc- and cadmium-plated parts can be spot-welded, but this practice is not recommended where maximum strength of the joint is required. Cracking around the weld may occur on parts with thick zinc deposits. Cadmium fumes generated in welding cadmium-plated parts are a health hazard. Where plating is removed prior to welding, a protective coating should be applied by metal spraying, brush electroplating, or painting.

4.4.1.1.1 Electrode Materials. The three classes of alloys shown in the table on page 4-69 are satisfactory electrode materials for the majority of spot welding applications.

Class 1 alloy electrodes should be used to spot-weld aluminum alloys, magnesium alloys, brass, bronze, terne plate, tin plate, cadmium plate, and galvanized iron in applications which require high electrical and thermal conductivity.

Class 2 alloy electrodes should be used to spot-weld mild steel, low-alloy steel, stainless steel, low-conductivity brass and bronze, white brass, and nickel alloys in applications which require moderately high electrode force and high thermal conductivity.

Class 3 alloy electrodes should be used to spot-weld materials with high electrical resistance such as inconel.

4.4.1.2 Arc Welding. In arc welding, either carbon or metal electrodes are used depending on the materials being welded. The arc extends from one electrode to the other or, where only one rod or electrode is used, from the electrode to the work which is connected to the electrical circuit by clamping

The quality of the weld is affected by current density, electrode material, and arc length. The selection of proper electrodes is of great importance since these affect the electric current polarity, slag removal, hydrogen embrittlement, and joint strength. Electrode types and sizes are listed in military specifications and in publications of the American Welding Society.

4.4.1.2.1 Metallic Arc. In the metallic arc process, only one electrode is used and it is generally made of a material similar to the metals to be welded. The rod is coated with a flux, deoxidizer, and ionizer which protect the filler when molten. Flux in the form of bin-fed granules is sometimes used to cover the rod and arc. Metallic arc welding can be adapted to automatic processes for producing long welds such as pipe seams.

Most ferrous metals, including stainless and high-alloy steels, can be welded satisfactorily if the correct type of welding rods or electrodes are used. It is sometimes necessary to heat treat the weldment after welding in order to develop desired mechanical properties.

Aluminum alloys, such as 1100, 3003, 5052, and 6061, can be welded by the metallic-arc process. In butt welding these alloys, best results are achieved when the stock thickness exceeds 1/8 inch. A backing strip is often used during welding to prevent the soft filler metal from falling through the joint.

4.4.1.2.2 Carbon Arc. In carbon arc welding an electric arc is generated between a carbon electrode and the work. Flux

Alloy Class Resistance Welder Mfrs' Assoc. (R.W.M.A.)	Round Rod Stock			Square, Rectangular, Hexagonal Bar Stock		Forgings		
	thru 1" dia.	1" thru 2" dia.	2" thru 3" dia.	thru 1" thickness	over 1" thickness	thru 1" thickness	1" thru 2" thickness	over 2" thickness
HARDNESS (Rockwell "B")								
Class 1	65	60	55	55	50	55	50	50
Class 2	75	70	65	70	65	72	70	65
Class 3	90	90	90	90	90	90	90	90
PROPORTIONAL LIMIT, TENSION (PSI)								
Class 1	20,000	17,500	15,000	20,000	15,000	20,000	15,000	15,000
Class 2	35,000	30,000	25,000	35,000	25,000	35,000	30,000	25,000
Class 3	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
ULTIMATE TENSILE STRENGTH (PSI)								
Class 1	60,000	55,000	50,000	60,000	50,000	60,000	50,000	50,000
Class 2	65,000	60,000	55,000	65,000	55,000	65,000	55,000	55,000
Class 3	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
CONDUCTIVITY (Percent)								
Class 1	80	80	80	80	80	80	80	80
Class 2	75	75	75	75	75	75	75	75
Class 3	45	45	45	45	45	45	45	45

is applied directly to the work or by a flux-coated welding rod supplying the filler material to the weldment. Backing strips are required to support the weld where thin material is used. Both manual and automatic carbon arc welding are suitable for aluminum. Magnesium can also be successfully welded by this process. Carbon arc welding is generally limited to metals less than 3/8 inch thick.

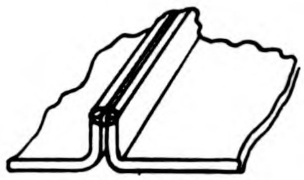
4.4.1.2.3 Shielded Arc. Shielded arc welding uses an inert gas, usually helium or argon, to shield the arc from the atmosphere during welding. This process minimizes oxidation and requires little or no flux. Shielded arc welding is used extensively in welding magnesium and aluminum alloys. If the joint is properly designed, no filler metal is required. The intense arc is struck between a virtually nonconsumable tungsten electrode and the work. If filler is used, it is of the same alloy as the base metal. The process is the same as in oxyacetylene welding, (4.4.1.3), except that no flux is used, and corrosion due to trapping of flux is avoided. Also, cleaning after welding may not be required.

4.4.1.2.4 Atomic Hydrogen Arc Welding. In atomic hydrogen arc welding a fine jet of hydrogen is forced into the arc struck between two tungsten electrodes, dissociating the gas into atoms. The hydrogen atoms recombine into the molecular form when they leave the arc. The heat absorbed during dissociation of the hydrogen is given up upon recombining and produces a jet flame of molecular hydrogen burning in a hydrogen atmosphere at extremely high temperature (though a lower temperature than that of the arc itself). Heat transferred to the work is highly concentrated and more intense than in other welding methods. The welding rod is fused in the flame and deposited as in gas welding. Extremely thin sheets can be welded by this method and it is recommended where fine contours are to be minimized. This type of welding is often used in the repair of aluminum castings.

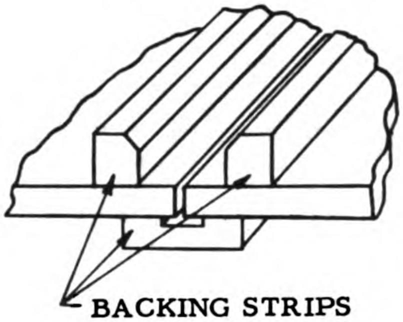
4.4.1.3 Gas Welding. A number of mixtures are used in gas welding, including air-acetylene, oxyacetylene, and oxyhydrogen. Metal from a welding rod is usually puddled into the joint to form a part of the weld. Although gas welding is not as fast as arc welding, the slower evolution of heat permits greater control and prevents "burn-through" in the welding of thin ferrous materials.

When the section to be welded is thicker than 1/8 inch, the edges of the joint should be suitably prepared by grinding or machining followed by cleaning. Proper fluxes and cleaning are essential to minimize oxidation. Slag and oxidation products must be removed after welding.

Gas welding should be used only for small parts. With proper tip selection, mild steel as thin as 0.005 inch can be readily welded. Thin sections of aluminum (0.030 inch minimum) can also be easily welded by this process. Softening or fusion temperature are not evidenced by change of color, however, and careful heat control is required to produce a sound weld. Backing strips, or "chill blocks" may be employed to help control the heat.



SEAM WELD



BACKING STRIPS

When objects of large area are gas welded, distortion may result. It is therefore desirable to preheat the area surrounding the joint before welding. Cooling stresses may be large enough to produce failure in ferrous metals of high carbon content. Annealing the entire part after welding will improve the quality of the weld for any material.

4.4.1.4 **Welding of Aluminum Alloys.** The suitability of the various welding processes for joining aluminum alloys is shown in the table.

METHODS FOR WELDING ALUMINUM ALLOYS

Aluminum Alloy Association Designations	Gas Welding	Arc Welding	Resistance Welding (Including Spot and Seam)
WROUGHT			
3003	Excellent	Excellent	Good
2014	Poor	Good	Good
2024	Poor	Good	Good
5052	Excellent	Excellent	Good
6061	Excellent	Excellent	Excellent
7075	Poor	Poor	Good
CAST			
43	Excellent	Excellent	Excellent
122	Fair	Fair	Fair
142	Fair	Fair	Fair
195	Fair	Fair	Fair
220	Poor	Poor	Poor
356	Good	Excellent	Good
A612	Fair	Fair	Fair

4.4.1.5 Welding of Titanium. Titanium alloys can be fusion welded by techniques similar to those used for other metals. The major difference is that hot and molten titanium must be protected from air and foreign materials. The molten weld metal and heat-affected zones must be shielded from contaminating elements by a protective blanket of inert gases. Coated electrodes or fluxes cannot be used in this welding process; thus, titanium can be fusion welded only by inert-gas shielded-arc welding procedures, which include both the nonconsumable (tungsten-arc) and consumable (sigma) electrode processes.

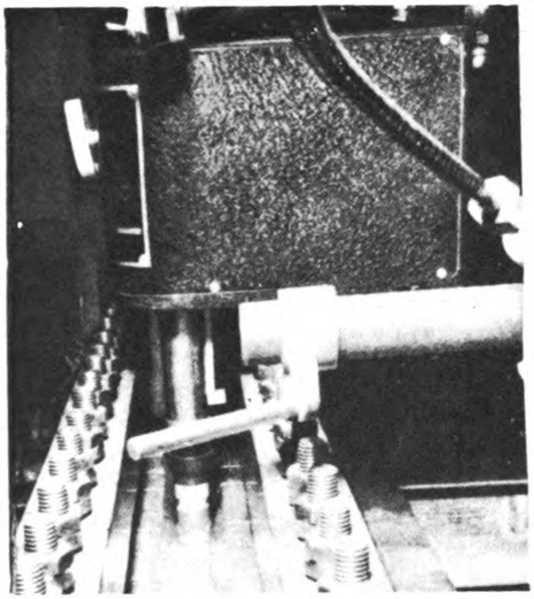
A. Nonconsumable Electrode Process. The nonconsumable (tungsten-arc) process offers many advantages: the physical aspects of the weld such as penetration and width of the fusion zone, may be accurately controlled; there is no spatter; the weld appearance is smooth and uniform whether or not filler is used; it can be used very effectively on sheet materials up to thicknesses of approximately 0.125 inch; and it can be accomplished manually or by machine, with or without filler material. The two factors which govern the use of filler material are gage and joint fit-up. With good joint fit-up, using material heavier than about 0.090 inch, filler is generally required to avoid undercutting adjacent to the weld bead. With bad joint fit-up, filler may be required in gages lighter than 0.090 to avoid burn-through as well as undercutting.

The major disadvantage of nonconsumable electrode welding is the possibility of tungsten contamination of the weld during manual operations if the operator allows the electrode to contact the molten puddle. This contamination is minimized by the use of fully automatic or semiautomatic machines.

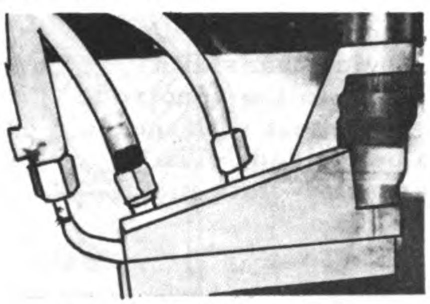
B. Consumable Electrode Process. Inert-gas shielded-arc (sigma) electrode should be used for materials heavier than 0.125 inch. Consumable electrode welding offers the advantage of more weld-metal deposit per unit time and unit of power consumption. One of the main disadvantages of this type of welding is excessive spatter.

C. Inert-Gas Shielding. Inert-gas shielding is of two types: open air-shielding, and enclosed-chamber shielding.

Generally, shielding is by the open-air method with a combination of inert-gas shields and inert-gas back-up shielding. In this method, the weld puddle and adjacent heat-affected zones on the face of the weld are protected by the nozzle gas (primary shielding). Trailing shields are used to protect the hot solidified metal and heat-affected zones behind the weld puddle. Back-up shielding is used to protect the root of the weld and the adjacent heat-affected zones. An example of open-air nonconsumable electrode welding of a titanium sheet sample with automatic equipment is illustrated on the following page.



Trailing shields, used to protect the weld metal during solidification and cooling, may be mounted on manual, semiautomatic, or automatic electrode holders, or on guns, as illustrated below.



TRAILING SHIELDS

The following are factors in the design of a trailing shield:

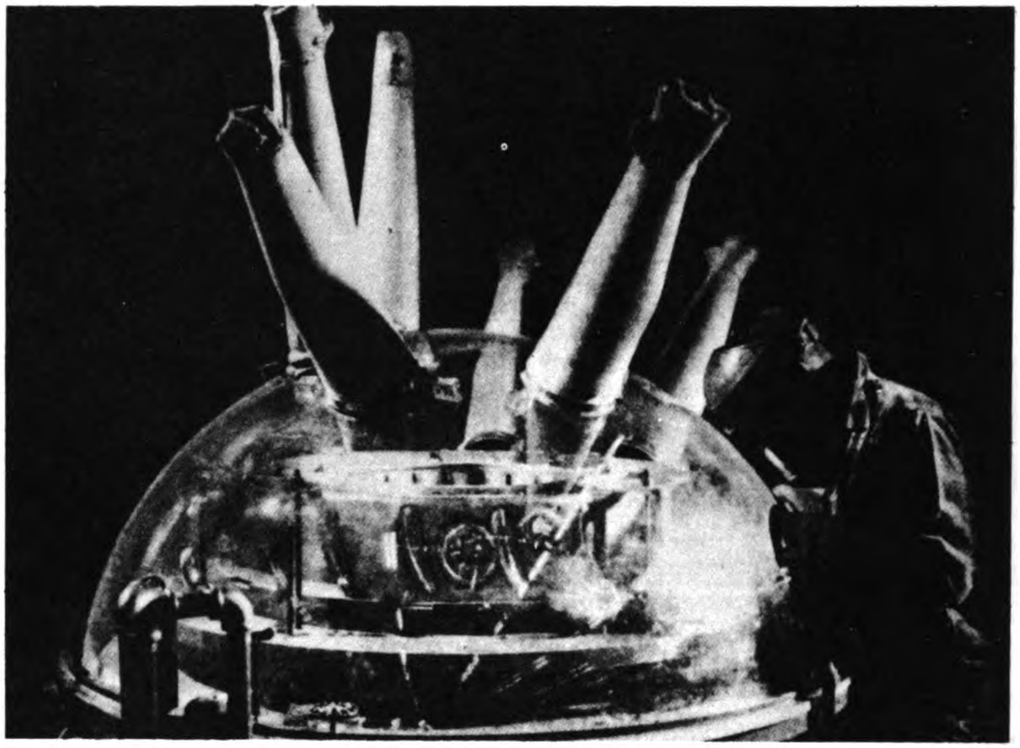
a. Large shields with high usage rates should be water cooled
b. Release of the inert gas into the inside chamber must be controlled
c. Turbulence from outside sources should be prevented.

Back-up shielding is accomplished by the use of back-up bars which should always be grooved with the groove centered directly beneath the weld joint to provide a passage for inert-gas flow under the joint. The groove should be 1/4 inch wide by 1/100 to 1/16 inch deep for material up to 0.050 inch thick. The groove should be 3/8 inch wide by 1/16 deep, with an additional groove at the bottom center measuring 3/16 inch wide by 1/16 inch deep, for material from 0.050 to 0.125 inch thick.

Enclosed-chamber shielding, illustrated on the following page, is used primarily to weld small parts and complex shapes which are difficult to shield adequately by the open-air method.

4.4.1.6 Ultrasonic Welding. The following tabulation shows various combinations of metals which can be successfully joined by ultrasonic welding:

Material	Welded to
Aluminum	Beryllium, copper, germanium, gold, kovar, magnesium, molybdenum, nickel, silver, steel, tantalum, tin, titanium, zircaloy
Copper	Aluminum, kovar nickel
Germanium	Aluminum, gold, platinum.
Gold	Aluminum, germanium, kovar, nickel, silicon



ENCLOSED-CHAMBER SHIELDING

Material	Welded to
Molybdenum	Aluminum, nickel, tantalum
Nickel	Aluminum, kovar, molybdenum, copper, platinum, steel
Platinum	Aluminum, germanium, gold, kovar, nickel
Silicon	Aluminum, gold
Zirconium	Aluminum, copper, steel

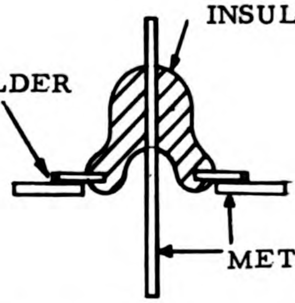
This method of welding utilizes the vibrations set up by a piezoelectric crystal or magnetostrictive material subjected to an ultrasonic frequency electro-magnetic field. A coupling device transmits the vibrations to the sonotrode which is in contact with the pieces to be welded. The result is a solid-state metallurgical bond.

4.4.2 Soldering and Brazing

Soldering and brazing are generally less expensive than similar welding operations; joints are neater and less finishing is required. Furthermore, parts that are too thin to be welded may be soldered or brazed satisfactorily.

Soldering and brazing materials have lower melting points than the base metals. Soft solders are composed of tin and lead and melt at temperatures below 700°F. Hard solders, often called brazing alloys, melt at temperatures ranging from 700° to 1600°F.

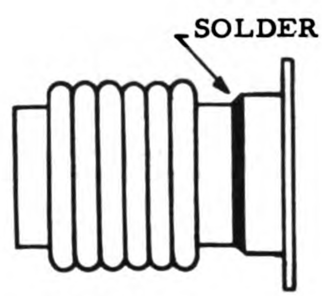
4.4.2.1 Soft Soldering. Because of its low melting range, soft solder is widely used for bonding electrical connections, hermetic sealing, and for joining metals to metals or to metal-coated ceramics. Soft solder joints are weak compared to the metals joined, and fatigue easily. These disadvantages are overcome by securing the parts mechanically before soldering, e.g., hooking wires to terminals or locking seams together. If parts cannot be secured mechanically, the area of the joint must be increased. Properly designed lap joints are adequate for lightly stressed parts.



JOINING METALS AND NONMETALS

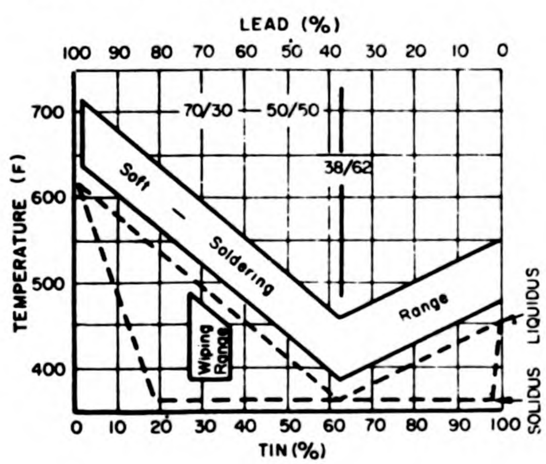
See 7.3.6 and 7.3.7 for soldering of electrical connections.

The requirements for successful soldering are relatively simple. The solder must be capable of wetting and spreading on the metals to be joined and alloying with them. The surfaces to be soldered must be free of dirt, oil, and corrosion products before flux is applied. At the soldering temperature, flux dissolves residual oxides and prevents further oxidation of the prepared metal.



BELLOWS

4.4.2.2 Soft Soldering Alloys. Lead-tin alloys are used for most soft soldering. The solder temperature should be 25° to 100°F above the upper melting temperature (liquidus), as shown in the following chart.



TEMPERATURE RANGES FOR SOFT SOLDER COMPOSITIONS

Commonly used solder and soldering specifications are:

QQ-S-571 Solder: lead alloy, tin-lead alloy and tin alloy

JAN-S-627 Solder, low-melting-point

MIL-S-19234 (NOrd) Solder, cadmium-silver

MIL-S-6872A Soldering process, general specifications for

MIL-S-12204 Solder, aluminum alloy

Antimony increases the strength and raises the melting range of solders but lowers the ductility of the lead-tin alloys. If some increase in strength is desired, a higher antimony content and range is specified; but for good ductility, the maximum antimony content is kept low. In addition, tin-lead solders containing over 0.5 percent antimony should not be used on zinc, cadmium, or galvanized iron since a brittle joint will result when antimony combines with these metals. The presence of other metals lowers the melting point of the alloys; but this is an insignificant factor if only small amounts are present.

Where solders are to be molded, as in wiped joints and sealing applications, alloys containing 30 to 35 percent tin are used because of their broad melting range. Because of the scarcity and high cost of tin, which is a strategic metal, alloys low in tin should be used wherever possible. Low-tin alloys require higher soldering temperatures and do not spread and wet as readily as those containing larger amounts of tin. The most commonly used solders are those with tin content of 40 to 50 percent.

When tin is in short supply, soft solder may be composed of lead with 2-1/2 percent silver, melting at 600°F; or of lead with 1-1/2 percent silver and 1 percent tin, melting at about 590°F. Because of their higher melting points, these solders may require the use of higher capacity heat sources than the lead-tin solders.

4.4.2.3 Forms of Soft Solders. Soft solders are commercially available as bars, stocks, wire, sheet or ribbon, segments, drops, and powder. Rosin core wire and acid core wire are available. The former is widely used to join wire and posts. Dry mixtures of powdered alloy and flux, and pastes containing fluxes and solder, can be obtained.

4.4.2.4 Fluxes for Soldering. Soldering fluxes must be carefully selected. Their chief function is to remove oxides formed on the metal surfaces at the soldering temperature. Clean copper and brass surfaces can be fluxed with organic materials, such as rosin, petroleum jelly, or tallow. For other metals, such as aluminum, stainless steel, or zinc, more corrosive fluxes, such as ammonium or zinc chloride, may be required.

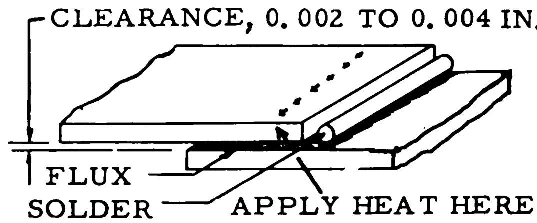
Zinc chloride and mixtures of zinc chloride and ammonium chloride remove oxide film which, although invisible to the eye, forms almost immediately on freshly exposed and cleaned metal surfaces at soldering temperatures. These acid fluxes are quick-acting and promote good wetting. They are available as powders, pastes, and solutions. Flux residues remaining after soldering are corrosive and must be completely removed from the surface by washing with hot water, and, if necessary, a petroleum solvent. No flux or cleaning compound should be allowed to remain. If corrosive fluxes cannot be effectively removed after the soldering operation, parts should be cleaned, pretinned, and then joined, using non-corrosive flux.

Where cleaning after soldering is difficult, impracticable, or forbidden, rosin flux must be used. A paste flux consisting of powdered rosin mixed with petrolatum is available. Levulinic acid in alcohol is used for soldering terne plate and tin-plated sheet and wire stock.

4.4.2.5 Soldering Process. Metal that is to be soldered should be cleaned of all dirt, grease, and corrosion films. Any heavy scale or oxide must be removed by pickling or by some mechanical means such as filing, sanding, or wire brushing. Chemical cleaning is superior to mechanical methods. The oxides that can be removed by the flux are thin, invisible oxides or, at most, only a discoloration on the surface. Surfaces should be soldered as soon after cleaning as practicable.

Temperature control is important in soldering although it is not often measured. Overheating should be avoided, as it causes excessive oxidation of both the work and the solder, and may also result in buckling and discoloration of the work. If flux chars, it will prevent close contact between joining surfaces, prevent solder from wetting the metal, and result in a poor, mechanically weak joint. These difficulties can be minimized by applying the heat a short distance from the joint and allowing the joint to come to the proper temperature by conduction.

Conditions for soldering a lap joint are illustrated below.



SOLDERING A LAP JOINT

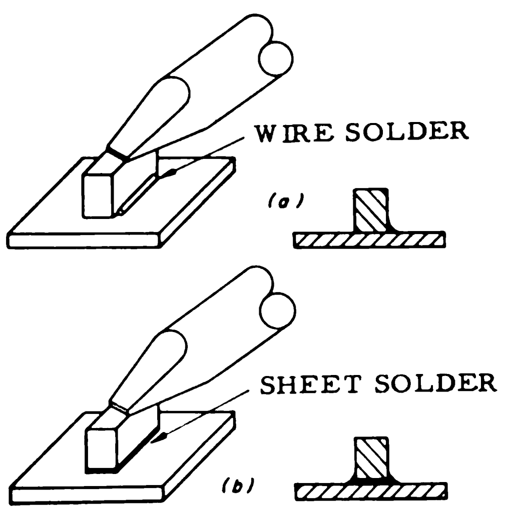
The two pieces to be joined are cleaned, coated with a thin layer of flux, and supported on blocks or clamped in the desired relative positions. If clamps are used, they should contact the edges rather than the faces, to allow the necessary clearance of about 0.002 to 0.004 inch for the flux or the solder. Place a piece of wire solder against the edge, and apply heat as indicated in the illustration to bring the sheets to soldering temperature. The solder will melt and be drawn into the space by capillary attraction.

If the length of lap is large, heat should be applied to the top sheet just over the end of the bottom sheet. On perfectly clean, fluxed sheet assemblies, solder can travel several inches by capillary attraction. Where considerable overlap is involved, it may be necessary to add more solder where required. As soon as the solder has been properly distributed, heating is stopped and the joint allowed to cool until the solder solidifies. Movement during solidification or rapid chilling to hasten cooling will result in an extremely poor joint. A test piece may be broken to check soldering quality and coverage.

4.4.2.6 Heating Methods. For small areas or thin metal, the heat from an iron is generally sufficient. For larger work, a gas-air, acetylene-air, or gasoline blowtorch flame will be required to bring the temperature of the joint above the liquidus temperature of the solder.

Induction or resistance heating and oven heating are used in production, when parts can be cleaned, fluxed, and assembled with the solder.

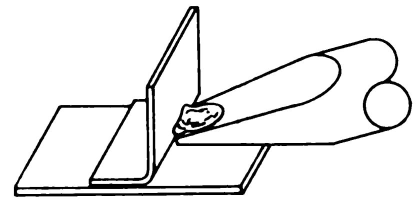
The use of an iron to heat an area remote from the joint is illustrated below. Where surfaces have no clearance, solder remains on one side. This results in a weak bond useful only for tacking. By pretinning one or both pieces or by use of sheet solder, a full bond can be secured.



Wire solder may not penetrate 'nt if fit is too close.

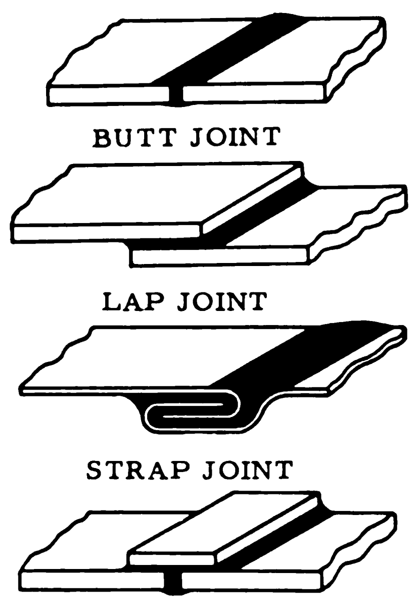
;E OF REMOTE HEAT SOURCE

Molten solder may be used to conduct heat to areas to be soldered, for instance, in soldering thin sheets.



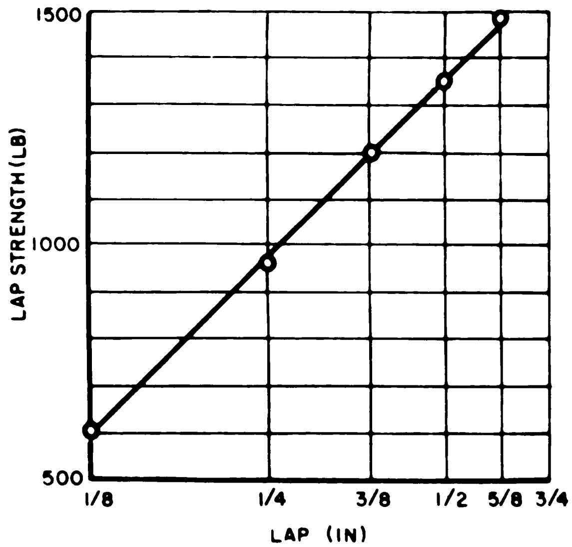
HEATING BY SOLDER

4.4.2.7 Strength of Soldered Joints. The tensile strength of soft solder is about one tenth the tensile strength of the base metals (4000 to 8000 psi as compared to 40,000 to 80,000 psi). For this reason it is necessary to have as large a contact area as practicable for a strong joint. Illustrated below are various joint designs used to provide a soldered area larger than that provided by a butt joint.



TYPES OF SOLDERED JOINTS

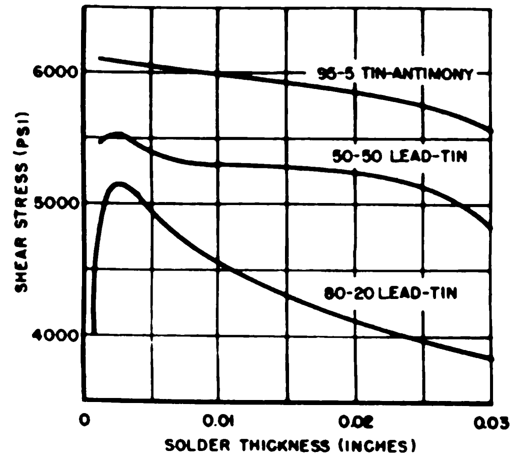
The loads required to shear soldered lap joints 1 inch wide are shown below for 70-30 solder 0.002 inch thick. Shearing strength increases in proportion to the length of lap.



STRENGTH OF LAPPED SOLDERED JOINTS, 1 INCH WIDE

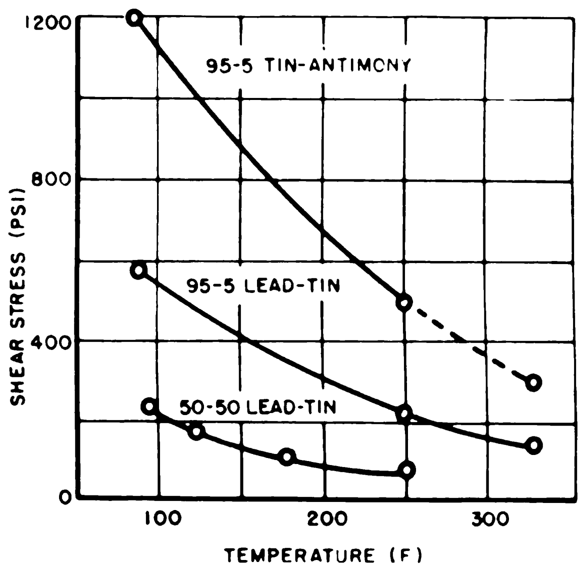
The effect of solder thickness on the strength of a joint is shown below. In general a thickness of 0.002 to 0.003 inch is desirable for maximum strength. This requires good positioning of the parts to be soldered, for example, by crimping or locking of the parts.

Relative movement must be avoided while the solder is solidifying to prevent weakening of joints.



EFFECT OF SOLDER THICKNESS ON STRENGTH OF JOINT

Heat affects the shear strength of soldered joints as shown in the following chart.



EFFECT OF TEMPERATURE ON SHEAR STRENGTH OF SOLDERED SLEEVE JOINTS

4.4.2.8 Solderability of Metals. The relative solderability of various metals with lead-tin solders are listed below in order of decreasing solderability. The low solderability of magnesium and aluminum is due to the formation of a thin oxide film on the surface.

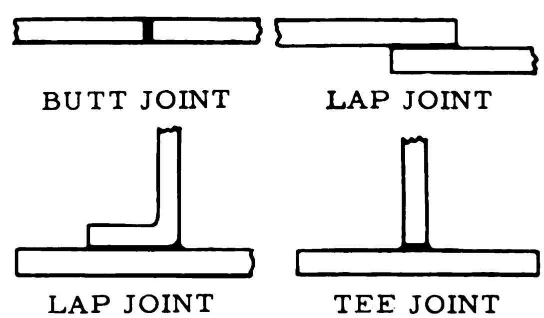
Metal	Relative Solderability
Tin and tin alloys	1
Silver	1
Copper and copper alloys	2
Steel	3
Nickel	3
Monel	3
Lead	4
Cadmium	4
Zinc	4
Stainless steel	5
Magnesium	6
Aluminum	6

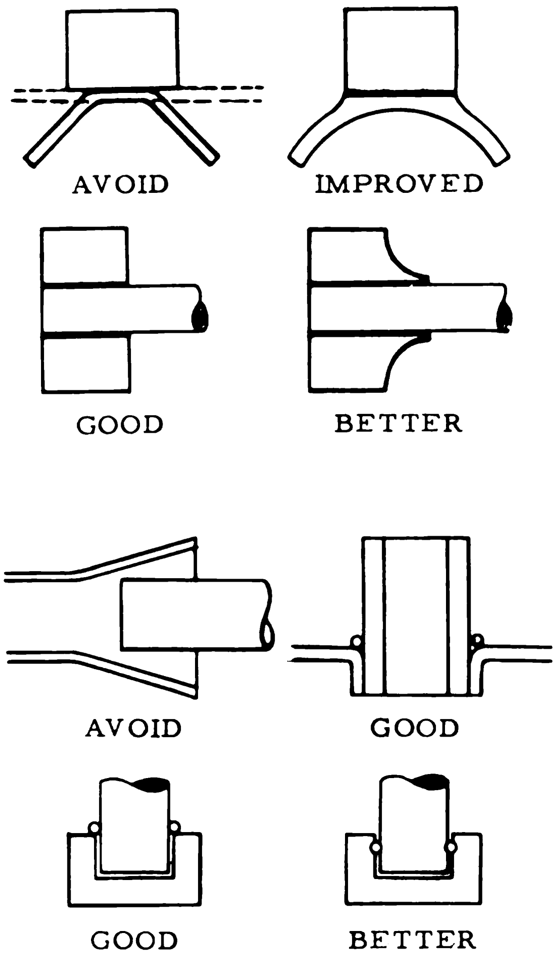
To improve solderability, metals are often "tinned" or coated with a more solderable metal such as tin, copper, or silver, applied by hot dipping or electroplating. Copper wires are often electroplated with tin to prevent the formation of copper oxide which forms readily in storage. Solderability is often a factor in the selection of electrodeposited coatings. Tin and tin alloys are used for electroplating of instrument parts; tin-zinc, and tin-copper-zinc alloys providing easy soldering. Copper and copper alloy parts used for electrical connections are often silver plated to improve conductivity and solderability.

4.4.2.9 Brazing. Many common metals, whether similar or dissimilar, can be joined by brazing with copper alloys or silver alloys to facilitate fabrication of complex assemblies. Brazing is done at temperatures higher than those for soldering and lower than those for welding. Distortion is less likely with brazing than with welding because of the lower temperature range. Strong hermetically sealed units can be readily produced by brazing. Some plated parts can also be brazed.

Lock-seam, tee, line contact, or lap joints are preferred to butt or scarf joints. Brazed lap joints with overlap equal to two or three times the metal thickness are generally stronger than the thinner member.

The strength of a brazed joint varies with the clearance and brazing material used. When the joint is properly prepared, the resulting bond may be stronger than the base metal. High stress points should be avoided through proper design.





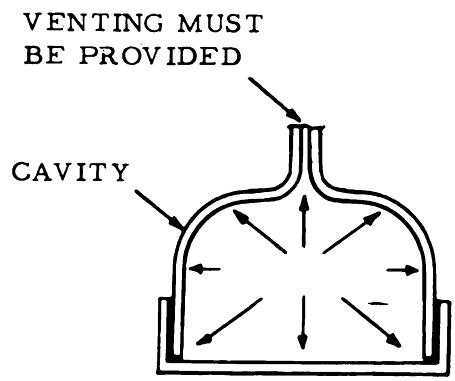
BRAZED JOINTS

Clearance between the parts to be brazed must be provided for the flow of brazing material. Flow and wetting characteristics of the brazing alloy determine the amount of clearance required. Since flow depends on gravity and capillary forces, very loose and very tight fits must be avoided. When copper-base material is used, clearance may vary from 0.001 to 0.002 inch.

For silver-base alloys (called silver solders), a 0.002- to 0.005-inch clearance results in good shear strength. The optimum clearance for any given type of joint is best determined by experiment.

The tensile strength of joints brazed with a silver alloy may be as high as 120,000 psi. Impact strength of brazed members depends on the alloys used, clearances, and joint design. Localized stresses must also be considered.

Brazed parts should be restrained to prevent movement during brazing. In closed containers, provision should be made for releasing gases generated during heating.



VENTING OF CONTAINER

Surfaces must be thoroughly cleaned prior to brazing. Dirt, oxides, grease, and oil must be completely removed either mechanically or chemically.

In brazing silver alloys, the melting temperatures of the brazing materials range from 950° to 1550°F; for copper alloys, from 1330° to 2100°F. Aluminum brazing alloys consist of aluminum alloyed to give a melting point lower than the softening point of aluminum (1200°F).

Flux is used to protect metal surfaces from oxidation, to dissolve oxides that may form, and to assist the flow of molten brazing alloy.

Heat can be applied by torch, gas-air flame, electric arc, induction, resistance, furnace, dipping in molten alloys or salts, or other means. Torch flames should be neutral, that is, neither oxidizing nor reducing. In furnace heating, a neutral or reducing atmosphere is desirable, Hydrogen and inert gases can also be employed to reduce flux requirements. Induction heating rapidly develops heat over a controlled area. Coils and joint members should be arranged to produce heat uniformly through the parts. Incandescent carbon heating allows application of pressure during brazing. In this method, flat work is placed between carbon plates and then the heating current is applied. Dip brazing, using a molten salt or metal bath, is useful for small parts.

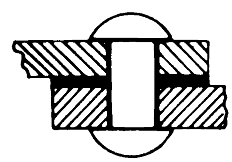
After brazing, joints should be cleaned to remove all traces of flux. Most brazing fluxes contain fluorides or bifluoride salts which are highly corrosive. Corrosion due to dissimilarity of metals may be severe unless precautions are taken. For example, 18-8 stainless steel is severely corroded if brazed with an alloy containing no nickel.

All conditions should be evaluated experimentally to aid in selecting the bonding process and material. Calculations based on previous jobs or handbook data are not always applicable or reliable.

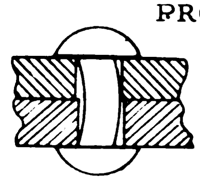
4.4.3 Riveting

Riveting is one of the most widely used methods of making rigid, permanent joints. Like welding, riveting is usually applied over large areas, but in some constructions, a few rivets may be used to advantage.

4.4.3.1 Characteristics. A structurally sound joint is provided by correctly set rivets with minimum clearance between holes and rivets. Slippage of the two faying surfaces cannot occur unless the shearing strength of the rivets is exceeded, or the plate or shape on which the rivets bear fails by crushing or tearing.



PROPERLY SET

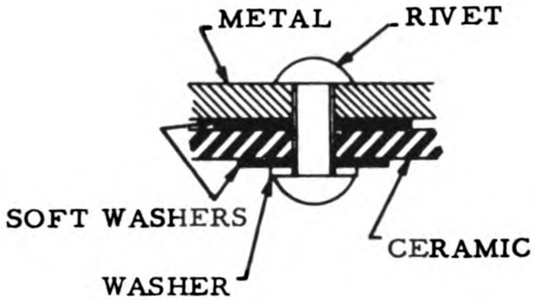


POORLY SET

RIVETED JOINTS

Warping due to thermal expansion is not likely to occur where parts are riveted since mechanical properties of the joined metals remain unchanged. (In welding, the properties of parts are sometimes seriously affected.)

In riveting brittle materials, washers must be used to distribute the stresses over a larger area and prevent cracking.



RIVETING BRITTLE MATERIAL

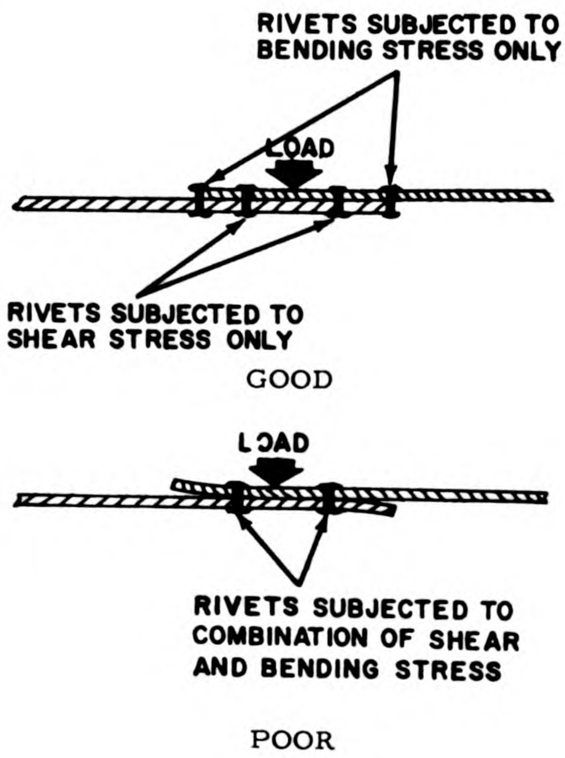
4.4.3.2 Rivets Versus Spot Welds. Riveting is relatively expensive compared to spot welding, but results are slightly more uniform and consistent. Thin or dissimilar metals and nonmetals of any reasonable thickness may be joined by rivets. "Blind" rivets can be used to join pieces in areas not accessible to welding equipment.

4.4.3.3 Limitations of Riveting. Parts joined by riveting cannot be easily disassembled. Electrical and electronic items including resistors, capacitors, inductors, transformers, and motors, should not be secured by rivets because of difficulty in replacement. However, pieces within a readily replaceable part may be secured by rivets or eyelets, providing electrical contact is not involved. Where riveting results in a major structural improvement and involves only minor servicing difficulty, it is considered desirable.

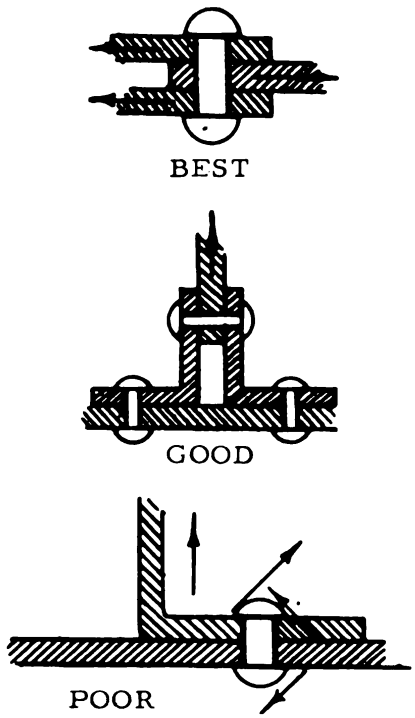
NOTE: Rivets or riveted sections must never be used as a part of an electrical circuit, including grounding of shields.

If sealing is required in riveted joints, special provisions must be used to seal the faying surfaces. A correctly set cold-formed rivet will often be self-sealing. Hot-formed rivets seldom leak. Heavy sections may be caulked for better sealing.

4.4.3.4 Stresses in Rivets. Loads on rivets should be in simple shear. To develop maximum strength in multiple-rivet designs, the holes must be accurately aligned by line reaming. Avoid tensile and cantilever loads on rivets.



STRESSES ON RIVETS



LOADS ON RIVETS

4.4.3.5 Design. Precise test values and other data for riveting can be obtained from available engineering handbooks. Recommended rivet sizes and other values for use with common sheet gages are tabulated below.

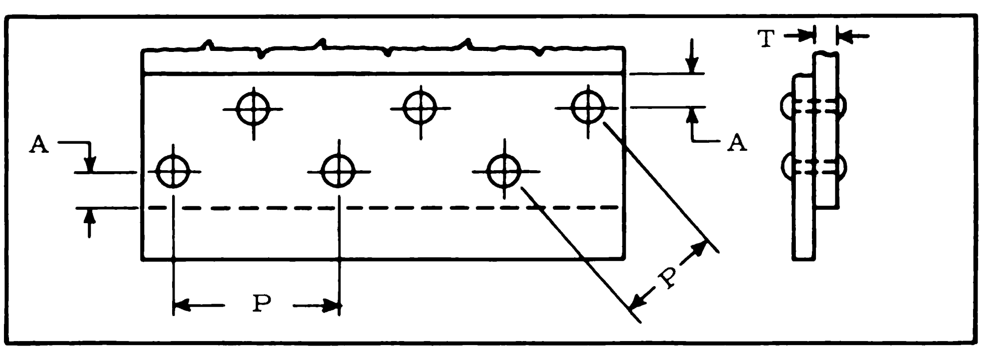
Edge distance (the distance from the edge of the part to be joined to the center line of first rivet hole) should be at least twice the rivet diameter to assure optimum bearing stress and minimum bulging about the rivet head.

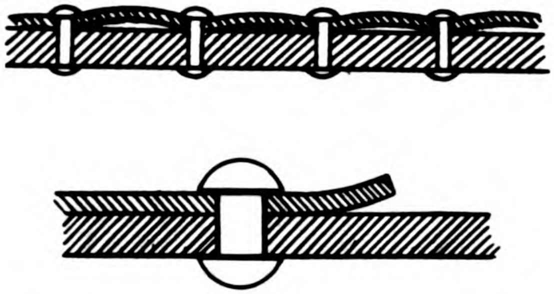
Pitch (the center-to-center distance between rivets) should be at least three times the rivet diameter.

Bulging and warping are aggravated by spacing rivets too widely in thin materials. Wide spacings reduce structural rigidity and prevent sealing of faying surfaces.

Thickness of sheet, T	Rivet diameter	Edge distance A	Minimum pitch P
0.000 to 0.064	3/32	3/16	9/32
0.065 to 0.093	1/8	1/4	3/8
0.094 to 0.125	5/32	5/16	15/32
0.126 to 0.187	3/16	3/8	9/16
0.188 to 0.250	1/4	1/2	3/4
0.251 and up	1.4 T	2D	3D

RIVETING DATA
(Dimensions in inches)





BULGING DUE TO WIDE SPACING

Selection of the type of rivet to be used should be made on the basis of an analysis of joint stresses and other requirements. Whenever practicable rivets should be made of the same material as the plates they fasten. Countersunk heads are weaker than round heads and should not be used where head height exceeds metal thickness. Preferred types of rivets are shown in specifications and standards, for example, FF-R-556 (copper), MIL-R-7885 (aluminum alloy), MS—35743 (steel).

4.4.3.6 Rivet Holes. Before large quantities of rivets are ordered, the optimum size of rivet for a given hole size should be determined by a driving test. To develop full strength when multiple rivets are used, holes should be drilled slightly undersize then reamed slightly larger than the rivet. Where the full shear strength of the rivet is not required, reaming may not be necessary.

4.4.3.7 Aluminum Rivets. Practically all the wrought aluminum alloys, such as 1100, 3003, 2017, 2024, 5053, 5056, and 6061, can be used. Data for handling rivets in assembling are tabulated on page 4-86.

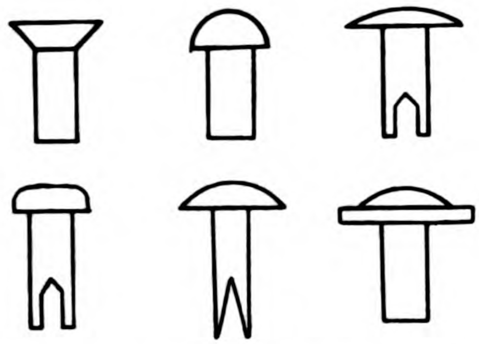
REAMING OF RIVET HOLES

4.4.3.8 Tubular and Split Rivets. Tubular rivets are used in pre-pierced holes where maximum shear strength is not required. The hole in the rivet is usually slightly deeper than the thickness of the parts being joined. Ease in clinching the head reduces joint deformation and material fracture. Tubular rivets, including eyelets, may be used to pierce their own holes in wood, plastics, leather, canvas, and other nonmetallic materials. Stresses in clinching the head are low, but, in soft materials, washers or backing strips may be required to avoid cutting into the material. Split rivets may be driven directly into steel 0.040 inch thick and clinched over. In specifying the length for a split

ALUMINUM RIVET DATA

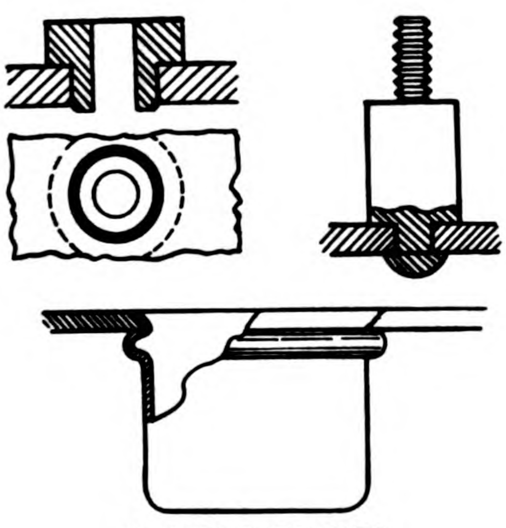
Alloy and temper as supplied	Temper after driving	Data and conditions for driving
(1100) 2S-F (3003) 3S-F	F F	As fabricated (F). Relatively soft, and may be stored indefinitely.
(2117) A17S-T4	T3	As received; but if aged, re-treat.
(2017) 17S-T4	T3	As received; but if aged, re-treat.
(2017) 17S-T4	T31	Immediately after reheat-treating and quenching.
(2017) 17S-T4	T41	Hot, 940° plus or minus 10°F.
(2024) 24S-T4	T31	Immediately after reheat-treating and quenching.
(5053) 53S-T4	T41	Hot, 960°F and 1050°F.
(5053) 53S-T6	T6	As received. May be stored indefinitely.
(5053) 53S-T61	T61	As received.
(5056) 56S-F	H321	As received. May be stored. Good for magnesium structures.
(6061) 61S-T4	T43	Hot, 1020° plus or minus 30°F.
(6061) 61S-T6	T6	As received.

or hollow rivet, it is good practice to add up to 100 percent of the shank diameter to the required finished thickness of the assembly.



TUBULAR AND SPLIT RIVETS

4.4.3.9 Special Rivets. If part of the rivet must be used for functions other than joining, the so-called formed or clinch head is made by staking, spinning, crimping, or similar operations. Such formed heads have relatively low strength, but are adequate for some purposes.

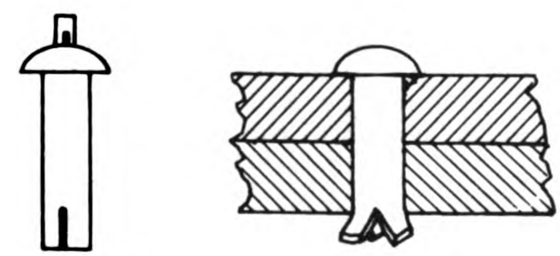


SPECIAL RIVETS

4.4.3.10 Blind Rivets. Where accessibility is limited blind rivets may prove necessary. Warping and distortion are minimized by lower head pressures. The rivet can be driven without the use of a bucking bar. Prior approval for the use of blind rivets should be obtained from the cognizant agency.

The most common types of blind rivets are the drive-pin, pull-stem, and chemically expanded types.

Drive-pin rivets, illustrated below, consist of two parts - a slotted shank, partially drilled from the head side, and a grooved pin. As the pin is hammered in, the shank segments are forced apart, locking the rivet in place. This type of rivet does not require finishing of the head after setting. It should be used only on material sufficiently rigid to withstand the blow necessary to drive the pin into the rivet.

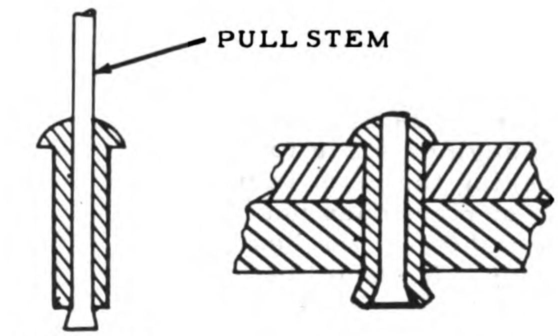


PRIOR TO INSERTION

AFTER INSERTION

DRIVE-PIN RIVET

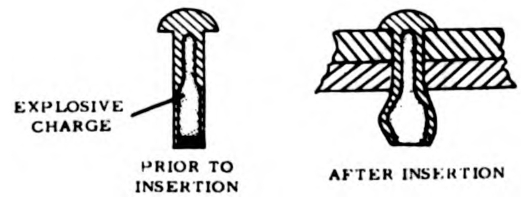
Pull-stem rivets, illustrated on the following page, consist of a hollow shank on a pull stem. The stem is pulled through the shank after the rivet is inserted, and an upsetting head on the end of the stem forms a "tulip head" on the blind end of the shank. In some designs the stem remains within the shank and is broken off flush with the rivet head, while in others the stem is, completely withdrawn. A sealing pin may be driven into the shank to provide greater shear strength or better sealing of the joint.



PULL STEM RIVET

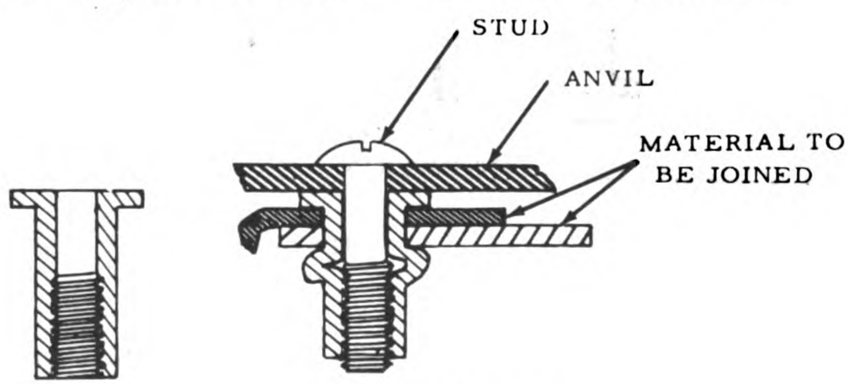
Chemically expanded rivets are one-piece fasteners which enclose a chemical explosive charge. The charge is centered and runs the length of the shank. Heat applied to the head ignites the charge causing it to explode and set the rivet.

> CAUTION: Equipment specifications must be checked for limitations on the use of rivets and on permissible rivet types.



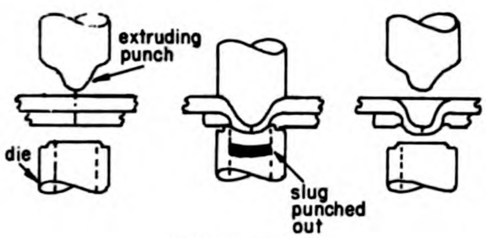
CHEMICALLY EXPANDED RIVET

The blind rivet illustrated below is a combination of a rivet and a threaded fastener. When the rivet is placed in a suitably drilled hole, the threaded section is pulled by a threaded stud, while the head is held by a tool anvil. This action causes the shank of the rivet to expand at the center section and lock in place. The principal use of this type of rivet is in joining sheet metal sections which cannot withstand the blows necessary to install drive-pin rivets.

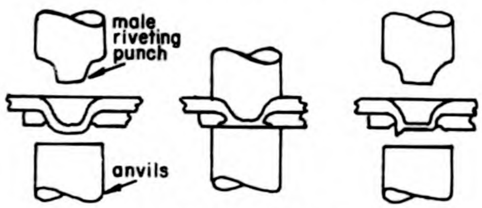


COMBINATION RIVET AND THREADED FASTENER

4.4.3.11 Extruded Rivet Process. The extruded rivet process provides an airtight joint for metals. A punch forces metal from the top sheet through the under sheet, punching a hole in the latter. Step one of the process is shown below.



STEP ONE



STEP TWO

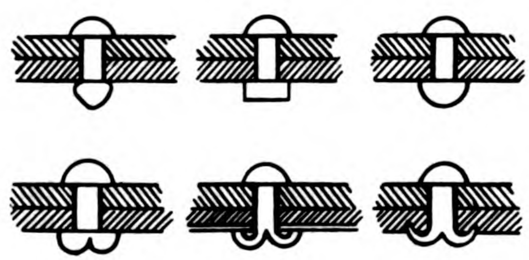
FORMING EXTRUDED RIVETS

In step two, the riveting punch and flat anvil rivet the two pieces together. The top sheet remains unpierced and is therefore completely airtight.

4.4.3.12 Setting Rivets. Heads of any type of rivet must be properly formed and squarely seated, without damage to the parts, to provide a tight joint. Rivet-setting tools should not strike the plates. Polished surfaces on the rivet set aid metal flow in the rivet head.

Rivets can be set manually or automatically. Standard or squeezer types of riveting machines are preferred, since these do not require a separate bucking bar, and expansion of the shank in the rivet hole is assured. The slow-acting squeezer type is recommended for aluminum and magnesium, as it reduces rivet cracking. Where accessibility is limited, pneumatic and manual hammering methods may be used. With these methods, separate bucking bars of sufficient mass to assure expansion of the rivet shank must be provided. The recess in the nose of the bucking bar should center on the rivet head in order to transfer compressive forces to the rivet shank.

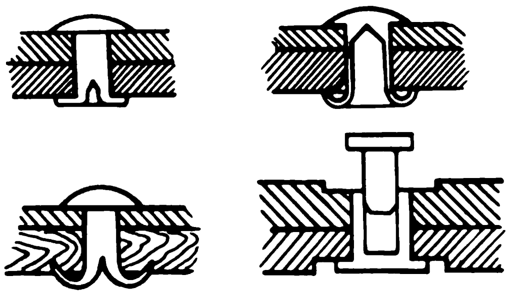
BUCKING BAR RECESS



SET RIVETS

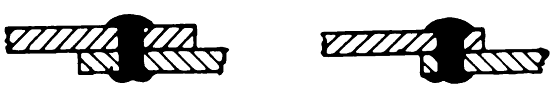
A cone head forms most easily for a given rivet strength, and it is recommended for aluminum rivets, where the relatively large size of heads requires considerable force. For softer materials and smaller sizes, small pneumatic hammers, riveting presses, or riveting machines can be used. Hot-forming is generally used for large steel or alloy rivets.

Where high strength is not required, the heads and shanks need not be fully formed, and the rivet may be of the hollow, semitubular, split, shoulder, or similar type.



HOLLOW RIVETS

4.4.3.12.1 Edge Clearance. There should be sufficient clearance between a rivet and the edge of the material being joined to permit solid positioning of the riveting tool, as illustrated below.

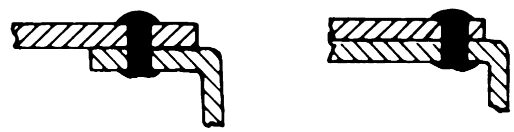


THIS NOT THIS

4.4.3.12.2 Hole Clearance. Excessive hole clearance for rivets should be avoided because this will often result in buckling of the rivet, as illustrated below, during the riveting operation.

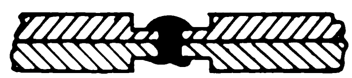
THIS NOT THIS

4.4.3.12.3 Flange Clearance. When it is necessary to locate a rivet joint near a flange there should be adequate clearance between the two in order to avoid interference with the riveting operation, as illustrated below.



THIS NOT THIS

4.4.3.12.4 Counterbore Clearance. When a riveted joint requires a counterboring operation the counterbore should be large enough to allow complete entry of the setting tool, as illustrated below.



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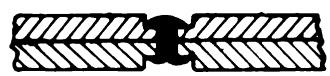
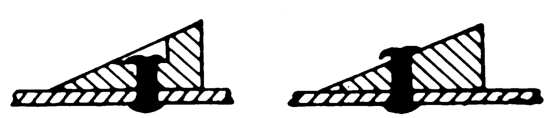


NOT THIS

4.4.3.12.5 Riveting Angular Pieces to Flat Pieces. When angular pieces are joined by riveting to flat pieces a flat should be provided on the angular piece, as illustrated below, to permit a uniform clinch which will result in a stronger joint. Do not form the clinch on an inclined, round, or uneven surface.



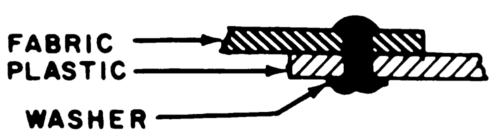
THIS NOT THIS

4.4.3.12.6 Riveting Unequal Thicknesses of Metal. When unequal thicknesses of metal are joined by riveting, the rivet head should be located over the thinner member and the clinch formed under the heavier member as illustrated below.

THIS

NOT THIS

4.4.3.12.7 Riveting Nonmetallic Materials. When two nonmetallic materials, such as fabric and plastic are joined by riveting, the rivet head should be located over the weaker material and the clinch formed under the stronger material, as illustrated below. A washer should also be used under the clinch, as illustrated, to prevent tearing of the material and provide a foundation for a tight clinch.



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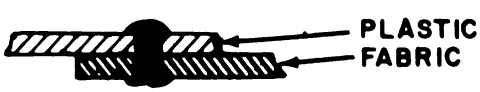


NOT THIS

4.4.4 Threaded Fasteners

Threaded fasteners are used where ease of assembly and disassembly are required. Proper functioning of threaded fasteners may entail controlled tightening methods with adequate safeguards to prevent inadvertent loosening.

The Unified Thread Standard series should be used for screw thread sizes 0.250 inch and larger; the American Standard Thread series for screw thread sizes between 0.250 inch and 0.060 inch; and the National Miniature Screw Thread series for screw thread sizes between 0.055 inch and 0.0118 inch. Dimensions of screw threads for each of these series are specified in Handbook H28, Part I.

4.4.4.1 Thread Classes. Classes of fit between mating parts of a threaded fastener are given in Handbook H28-Screw Thread Standards for Federal Services. Classes range from 1, the loosest fit, to 4, the tightest. Threads used by the Armed Forces conform to the Unified Series in the Screw-Thread Standards for Federal Services. The most commonly used thread fit for ordinary fasteners is Class 2.

4.4.4.1.1 Unified and American Screw Thread Series. Class 2A external threads and Class 2B internal threads should be used for general applications when the sole function of the threaded member is to act as a fastener. The Class 2A and 2B fits were established to allow for manufacturing and plating tolerances while still providing a fit that will enable the full strength of a bolted assembly to be developed without thread stripping. The fit also provides for ease of bolt, screw, and nut assembly in production.

Class 3, 3A, and 4 thread fits should be used only when the threaded member has to perform a function other than fastening such as for adjustment or positioning where lead angle tolerances and pitch diameter tolerances must be held closer than usual in order to attain a more exact ratio of longitudinal movement to rotary motion.

Since Class 5, or interference fits, are difficult to work with, they should be avoided unless it is impossible to use a Class 2B fit. The Class 5 fit is a wrench fit intended for studs and tapped holes which are to be assembled permanently. Unless the tolerances of the tapped hole are held very close, the stud tends to be too loose after insertion or thread interference becomes so great that the threads lock and the stud cannot be inserted all the way. Wherever practicable, use a conventional bolt or cap screw in a hole tapped to a 2B fit in preference to a stud in a tapped hole.

4.4.4.1.2 National Miniature Screw Thread Series. The National Miniature Screw Thread Series has only one class of thread.

4.4.4.2 Thread Series. Screw threads have been standardized in three series, coarse threads (UNC), fine threads (UNF), and extra fine threads (UNEF).

The coarse thread series (UNC) is used for bolts, screws, and nuts where operating conditions do not necessitate a thread of finer pitch.

The fine thread series (UNF) is used where vibration is severe.

For thin-walled tubes, ferrules, couplings, or similar applications, extra fine (UNEF) threads may be used.

The use of special thread forms and fits should be avoided, but if required, should be in accordance with Handbook H28. When a suitable screw thread is not available in the Unified Series, a satisfactory one should be selected from the American Series in Handbook H28.

4.4.4.2.1 Unified and American Screw Thread Series. Coarse threads should be used for applications requiring rapid assembly or disassembly; when threading into low-strength materials such as castings, soft metal, and plastics; and in most general applications. Coarse threads are stronger, less subject to thread nicking in handling, better adapted to subsequent plating or coating, and less affected by decarburization of the screw blank and by corrosion that may result from exposure to a corrosive atmosphere.

Fine threads should be used only where:

a. A smaller longitudinal movement is required relative to the rotary motion;
b. A closer ratio is necessary between the static strengths of the bolt or screw and nuts;
c. Length of engagement is limited;
d. Smaller lead angle is desirable; or,
e. The wall thickness precludes the use of a coarse thread. Fine threads should not be used in castings, soft metals, plastics, or similar low-strength materials.

Extra-fine threads should be used only where:

a. Thin-walled material is

to be threaded;

b. Thread height of nuts clearing ferrules, coupling flanges, and similar objects must be held to a minimum;

c. Limited length of engagement requires the maximum practicable number of threads within a given distance.

4.4.4.2.2 National Miniature Screw Thread Series. The miniature threads of the National Miniature Screw Thread Series should be used only for general purpose fastening screws and other similar uses in watches, instruments, and miniature mechanisms.

4.4.4.3 Materials and Plating. Stainless steel, monel, bronze, and brass are used where corrosion resistance is required. Carbon or alloy steel may be used in high-stress applications or if protection against corrosion is provided.

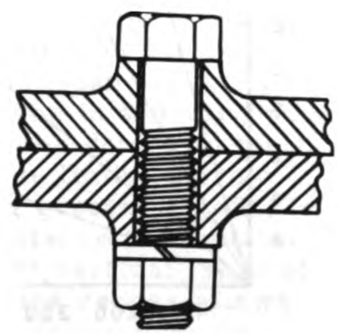
Aluminum threaded fasteners are weak compared to steel fasteners of the same relative size. They are acceptable if suitably proportioned to the load but should not be employed where frequent disassembly may be necessary.

For corrosion protection, steel bolts, nuts, and screws should be plated with cadmium or zinc. In joining aluminum, cadmium-plated steel is an acceptable alternate to aluminum fasteners. Where corrosion may be severe, nickel-plated steel fasteners should be used. Aluminum threaded devices should be given a suitable chemical corrosion-resistance treatment or anodized, and antiseize compound should be applied. Destructive galvanic couples should be avoided.

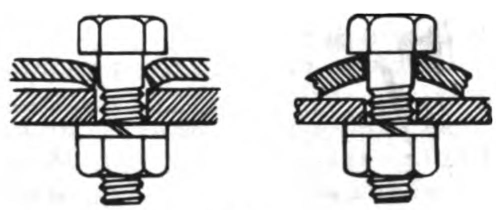
After plating, external threads should not exceed the basic size and internal threads should not be smaller than the basic size, as specified in Handbook H28.

4.4.4.4 Fastener Performance. The loosening of nuts and bolts is the greatest single cause of joint failure, usually as a result of shock and vibration.

Other conditions which may diminish the useful life of fastenings are thermal effects, plastic creep of metals, and improperly mated bearing surfaces and insufficient bearing areas.

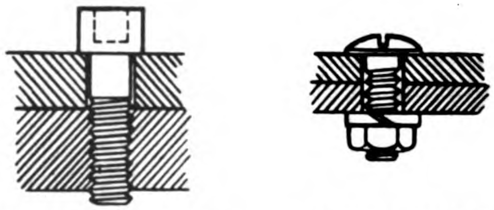


GOOD



POOR

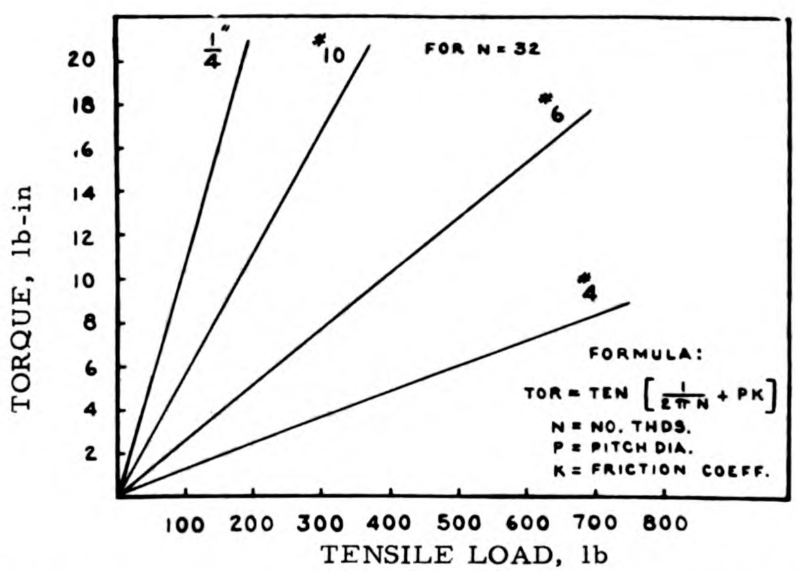
BEARING SURFACES



BEARING AREAS

A torque wrench or similar device should be used for securing threaded fasteners in critical or high-strength applications. It is recommended that the torque be 60 to 80 percent of the failure value as determined by actual test, unless fasteners are furnished with locking devices. Lubrication of the threads should be avoided.

The graph which follows shows the approximate tensile load developed in typical screws at various torque values taking into account thread friction only. If nut or head bearing friction is included, the torque values are approximately doubled.

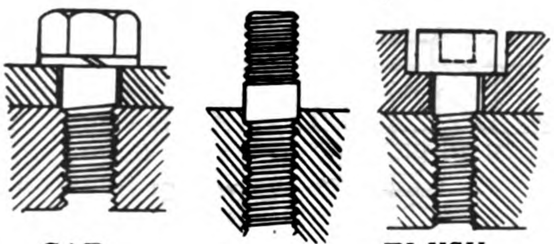


RELATION BETWEEN TENSILE LOADS AND TORQUES

4.4.4.5 Bolt and Screw Selection. Bolt and nut combinations are satisfactory where the location of parts and spacing of holes are not critical and where metals are thin. Usually, hole clearances are generous. Wherever possible, parts should be fastened by more than one bolt.

For accurate part location and high shear strength, and where metal thickness is adequate, studs or cap screws are preferred. Many castings and metal sections are of such shape and thickness that either studs or cap screws must be used. In castings, sufficient bearing area and section thickness must be provided to prevent cracking.

Self-tapping screws are not generally acceptable in military equipment and approval should be obtained from the bureau or agency concerned prior to their use.



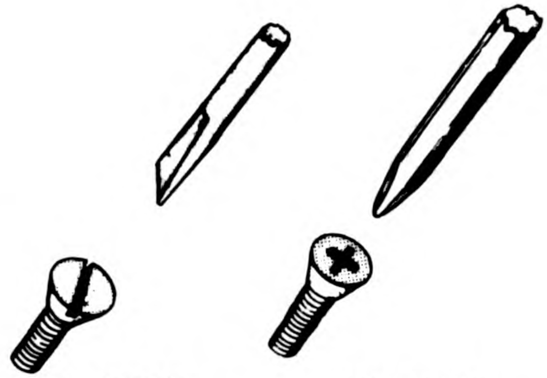
CAP SCREW   STUD   FLUSH SOCKET-HEAD SCREW

Screw lengths should be chosen so that components may be readily assembled. After the nut is tightened, the screw thread should project through the nut for at least one and one-half threads, but not more than 1/4 inch. Excessive thread projection interferes with easy servicing. The ends of screws must not be clipped or deformed to secure these conditions.

Screws less than 1/4 inch in length should have slotted screw driver heads of the flat, pan, or fillister type.

Do not use odd-sized or special threads or nonstandard types of heads. Proprietary screws are permitted only under certain conditions. Socket-head screws may be used for flush mounting or in counterbored holes.

All machine screw styles except the hexagon head are available with slotted driver recesses and cross-recessed driver slots of the Phillips head design. These two types with their associated drivers are illustrated below.



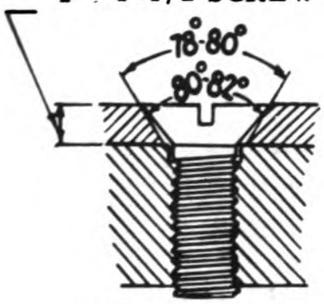
SLOTTED HEAD   PHILLIPS RECESSED HEAD

The main advantage of the slotted-head screw styles is that they do not require the use of special screw drivers so that maintenance and repair work are not hampered or delayed through lack of suitable drivers.

The principal advantage of screws with the Phillips head is that they can be easily power driven even in awkward places. They can be driven to their full torque limit, thereby obtaining greater rigidity and resistance to vibration. The slight vertical taper of the Phillips recess allows variation in dimensions of either part within allowable tolerances, yet keeps the point of the driver above the bottom of the recess. Four sizes of screw drivers span the entire range of Phillips head screws (No. 2 through 1/2 inch). The disadvantage of this type of head is that maintenance personnel must stock the special Phillips screw drivers and when damaged they cannot be reground.

The selection of the slotted versus the Phillips head designs should be governed by the applicable equipment specification.

4.4.4.5.1 Flat-Head Screws. The correct use of an 80° to 82° flat-head screw seated in a 78° to 80° countersunk hole is illustrated below. The metals flow somewhat under the application of pressure in assembly and provide good seating.

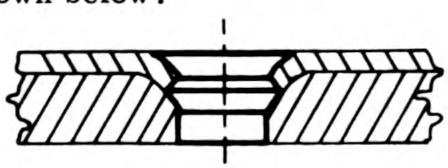


CORRECT USE OF
FLAT-HEAD SCREW

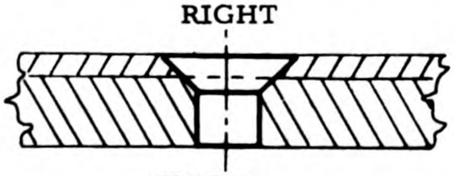
Flat-head screws should be used only where flush-finished surfaces are necessary since their use requires a countersinking operation which increases production cost.

Do not attempt to countersink screws in sheet metal too thin to take the full depth of the screw head as this will result in an extremely weak joint.

When it is necessary to countersink in thin metal, it should be dimpled into the countersunk mating piece as shown below.



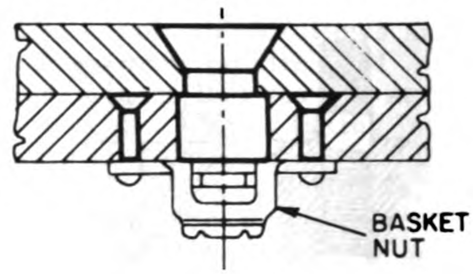
RIGHT



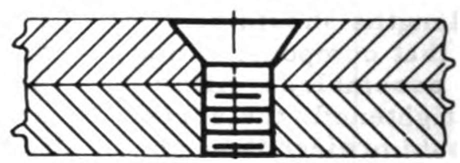
WRONG

COUNTERSINKING IN THIN METAL

Where a countersunk hole must match a tapped hole in a mating part, careful alignment is necessary and the operation is costly from a production standpoint. The use of floating basket nuts is preferred.



PREFERRED
Use floating basket nuts whenever practical.



AVOID
Countersunk hole matching tapped hole in mating part. (Alignment problem)

ALIGNMENT OF
COUNTERSUNK HOLES

The 82° flat-head screw should be used for general applications requiring a flush assembly. The material should be at least 1-1/2 times the screw head height. This screw is available in sizes ranging from No. 0 through 3/4 inch.

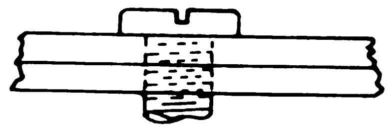
Use of the 100° flat-head screw should be restricted to thin or soft materials where the 82° flat-head screw is not satisfactory. The increased angle distributes the load over a larger surface and is therefore adaptable to thinner sections. This screw is available in sizes ranging from No 0 through 3/4 inch.

4.4.4.5.2 Set Screws. Use set screws of the hardened hexagon-socket type, preferably No. 6 or No. 10, except for control knobs where slotted-head set screws may be used. Refer to Specification FF-S-103 for data. Use cup-pointed set screws except where engaging surfaces are suitably countersunk, in which case a cone-pointed set screw may be employed. Cone points deform the shaft surfaces and make removal of parts difficult. When a part is not adjustable in angular relationship to the shaft on which it is secured, flat surfaces for engagement of cup-point screws should be provided. Where two set screws are used, make the angle between them not less than 90 degrees, nor more than 120 degrees.

4.4.4.5.3 Pan Head Screws. Pan head screws should be used (in lieu of round, binding, truss, and fillister head designs) for general applications which do not require a flush assembly. The pan head design has a large bearing area which distributes the load over a greater surface than other head designs. It also has the advantage of being the most economical of the removable-type fasteners. The pan head screw, available in sizes ranging from No. 0 through 3/8 inch, is illustrated below with the slotted driver recess. It is also available with a cross-recessed driver slot of the Phillips head design.

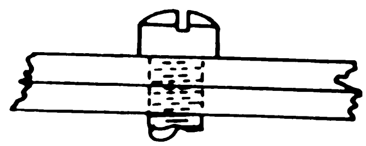
The selection of the slotted versus the Phillips head designs should be governed by the applicable equipment specification.

THIS



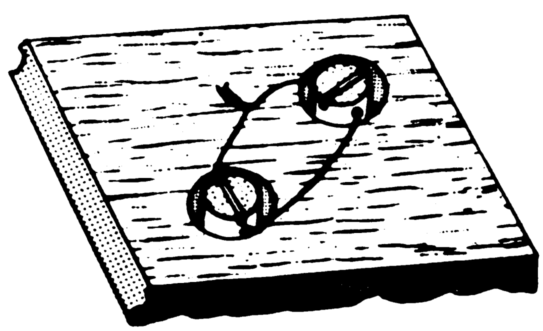
PAN HEAD

NOT THIS



FILLISTER HEAD

4.4.4.5.4 Drilled Fillister Head Screw. The drilled fillister head screw should be used only where the small head diameter is necessary because of space limitations, or where it is desired to lock the screw in place by a wire to prevent loosening of the screw. To obtain a flush assembly, this type of screw may be used in counterbored holes as illustrated below.

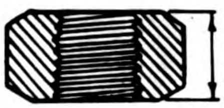


DRILLED FILLISTER HEAD SCREW
WITH LOCKING WIRE

The drilled fillister head screw is available in sizes ranging from No. 2 through 3/8 inch.

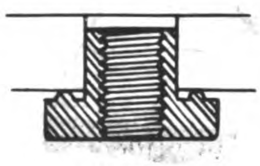
4.4.4.6 Nut Selection. Nuts should be sufficiently thick and strong not to fail before the bolt or screw fails in tension. Shearing stresses in thick nuts are usually low enough to preclude shear failure.

Nuts are usually of the same metal as the bolts. Hexagonal finished steel nuts are recommended for heavy equipment and for highly stressed parts. Where corrosion resistance is required, stainless steel nuts may be used. Thin nuts should be avoided.

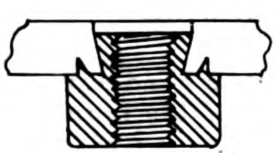


TYPICAL NUT

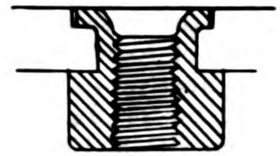
Clinch, anchor, weld, and other types of secured nuts should not loosen if they have been properly set. Such nuts are used to resist shock and vibration. More intensive inspection of these types is required. They are usually zinc plated for corrosion protection, and sometimes hardened to improve their mechanical properties.



WELD



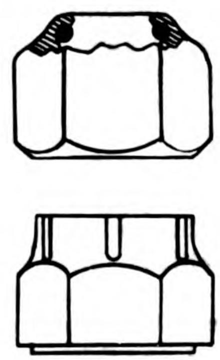
ANCHOR



CLINCH

Locknuts are used to maintain thread friction when bolt tension is reduced to zero, but they must be drawn up tight to insure adequate contact at bearing surfaces.

Supplementary locking devices are recommended where vibration is severe and where the nut must be constrained. Temperature limitations for plastics must be taken into account when the locking action depends on a plastic insert. Lockwashers are usually unnecessary when locknuts are used.



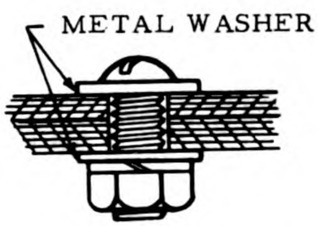
LOCKNUTS

Safety wiring should be used if the nut must be kept from backing off under any conditions. Cotter pins are used in the bolts where only occasional disassembly is contemplated. Cotter pins and safety wire must never be reused, as repeated bending weakens the material.

4.4.4.7 Flat Washers. Flat washers are used to increase the load-bearing area, aid in tightening of nuts or screws, prevent loosening, and protect surfaces. They are necessary where hole clearances are large. Flat washers minimize buckling of thin materials.

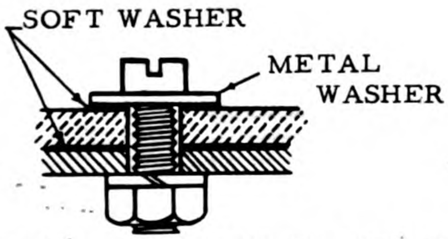
JOINING THIN MATERIALS

Washers for plastics, leathers and soft metals must be large enough to distribute the load so that the materials will not be cracked or unduly deformed.



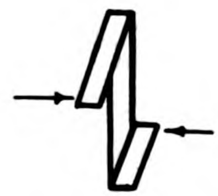
JOINING PLASTICS

In joining ceramics or glass, a soft washer is usually used to prevent cracking.

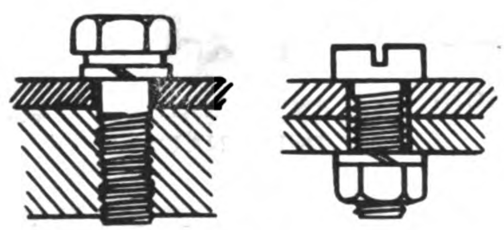


JOINING CERAMICS TO METAL

4.4.4.8 Spring Type Lockwashers. Lockwashers are used to increase bearing friction and thus prevent loosening. Spring type lockwashers are usually of hardened steel or a suitable noncorrosive material. They are used where considerable spring force is desirable to prevent loosening. The outer diameter should be at least equal to that of the bearing area of the screw head or nut. Thicker washers give greater spring force. A lockwasher may be used under the nut of a nut and screw combination or under a screw head.



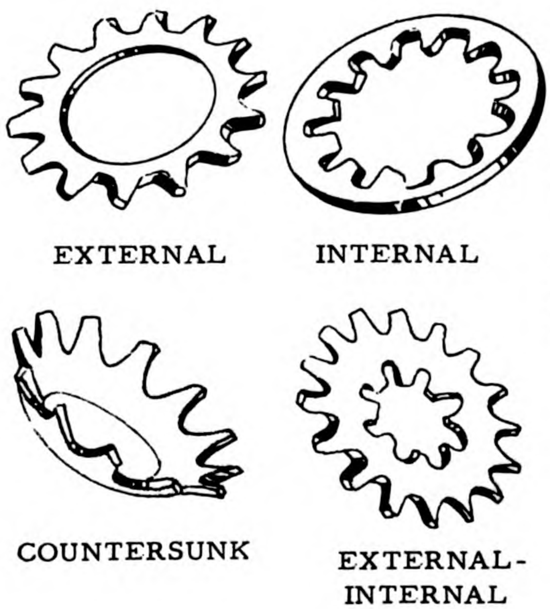
SPRING TYPE LOCKWASHER



CORRECT USE OF LOCKWASHER

4.4.4.9 Tooth Type Lockwashers. Lockwashers with external teeth, conforming to MIL-W-6986, are preferred for making electrical bonds, noise suppression, and external grounding. Cup types are used under flat- or oval-head screws.

Countersunk tooth type lockwashers are designed specifically to provide locking action for the 82° to 100° flat-head screws when used in tapped holes. The countersunk hole should be enlarged sufficiently to accommodate the added material thickness when this type of lockwasher is used. These lockwashers are available with external teeth in screw sizes ranging from No. 2 through 1/2 inch for use with the 82° flat-head screw, and in screw sizes No. 4, 6, 8, and 10 for use with the 100° flat-head screw.



TOOTH TYPES OF LOCKWASHERS

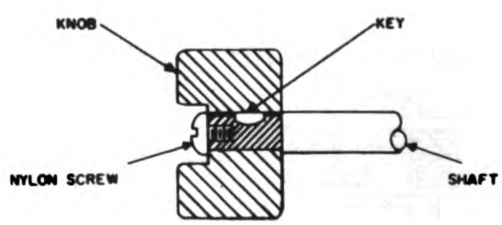
Tooth type washers of hardened material bite into softer metals, thus increasing bearing friction. Calculations for tightening torque must take into account the added bearing friction. Tooth type washers should not be used for screws over 1/4 inch in diameter or where their biting action will destroy protective coatings on the joined parts

Washers with internal teeth tend to bite into the clearance hole in soft metals and plastics and should be used only in exposed locations.

Sealing compounds and staking are other means for improving the locking of nuts and screws. These are particularly suitable for small nuts and screws. Sealing materials should be tough and have good adhesion to metals.

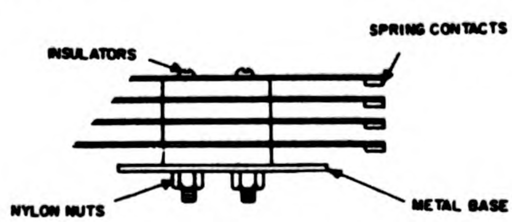
4.4.4.10 Nylon Screws, Nuts, and Washers. In electrical devices involving brushes, contacts, and other parts insulated from their holders, nylon screws, nuts, and washers may be used to advantage, for example, where a contact spring must be secured to and insulated from a metal base.

A nylon screw may also be used to eliminate electrical hazard where a removable control knob is mounted on a metal shaft.

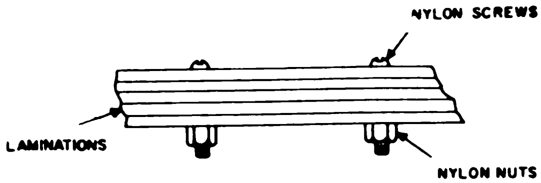


Spring contact blades on insulating strips may be secured by nylon nuts and screws to provide unbroken insulation.

Nylon screws and bolts are also useful for attaching metallic laminations where metallic or magnetic fasteners must be avoided.



GOOD



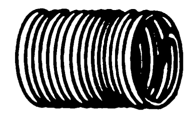
GOOD

4.4.4.11 Inserts. Inserts are used to provide load-bearing or wear-resistant threads in soft or thin materials. These inserts are internally threaded and are available as bushings or linings with various locking devices. Materials and finishes are similar to those used for screws and nuts, with steel and stainless steel the most common materials. Heli-Coil, Rosan, and Nylock inserts are illustrated below.

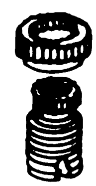
The Heli-Coil is a screw thread insert coiled from stainless steel wire with a diamond cross section. The bottom end of the coil is offset to provide a simple driving member called the tang. The insert is installed in a pretapped hole by applying torque to the tang.

The Rosan insert is a tubular bushing with threads cut on both interior and exterior surfaces. A locking ring is provided which has serrations on both inner and outer surfaces. This insert is installed in a tapped hole and the locking ring is pressed into position with the inner serrations engaging the insert and the outer serrations broaching the parent material.

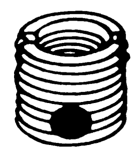
The Nylock insert is an internally and externally threaded bushing with a nylon plug projecting past both inner and outer threads. The nylon plug provides a locking torque to internal and external threads so that the screw may be removed without unseating the insert.



HELI-COIL INSERT



ROSAN INSERT



NYLOCK INSERT

4.4.5 Stapling

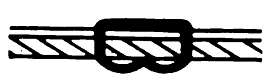
In mass production, thin metals and nonmetals may be joined by stitching or stapling without precleaning, drilling, punching, or hole alignment. Stitching permits savings of as much as 90 percent of the time required in riveting. Mating and clamping requirements are less critical than in riveting or welding. As no heat is generated, warping is largely avoided, and coatings already applied are not affected. Most stitched parts can be disassembled without damage.

4.4.5.1 Application. Stapling successfully joins such materials as canvas, rubber, wood, and metals. Fatigue and shear strength are excellent in a well-designed stapled joint, but staples should not be used in tension. Lap joints can be stapled up to a thickness of 0.250 inch for aluminum and 0.040 inch for cold rolled steel. The practical thickness limit for dense plastics and fiber board is about 3/16 inch.

The preferred spacing between individual stitches is approximately 1/2 inch. Tests indicate that no vibration tearing occurs around stitch holes, even in sandwich combinations, as the staple leg, driving its own hole, is snugly fitted in each layer of sandwich and allows no play.

To avoid corrosion where steel staples are used in aluminum, the wire should be cadmium- or zinc-coated. For high-temperature applications, stainless steel wire should be used. Flange widths on joined parts can be as little as 1/4 inch. Production speeds range from 80 to 100 stitches per minute.

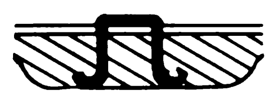
4.4.5.2 Clinch Forms. Staples are clinched in two basic forms: loop and flat. Loops are further classified as standard, by-pass, or outside. These basic clinch forms are shown below, with general data regarding each.



STANDARD LOOP

7/16-inch crown
Used in 95 percent of all metal stitching applications. Metallic and nonmetallic materials fastened to thin metal sections.

BY-PASS LOOP
1/4-inch crown
Used for assembling all types of metallic and nonmetallic combinations. Especially effective in attaching rods, small tubes, and springs to metal sections.



OUTSIDE LOOP
1/4-inch crown
Used when it is desired to bury the stitch ends in nonmetallic materials.

LOOP CLINCHES

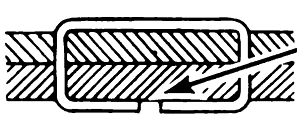
The crown size of any metal stitch is the distance between the insides of the legs of the formed stitch regardless of wire size. Special crown sizes are available for unusual applications.

Loop clinches are used most frequently. They are formed by bending the legs with dies.

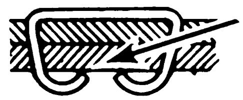
The flat clinch is formed by folding the legs flat against the bottom material with an upward-moving die. Flat clinches are used where the stitched joint must carry substantial loads. However, this form is unsuitable for heavier gages of metal, or for nonmetallic material over 1/4 inch thick. In the thicker materials, the legs of the stitch wander as they are driven through and tend to miss the guideways in the clincher die.

FLAT CLINCH
Used when stitched joint must carry substantial loads. Mostly for aluminum and lighter gages of steel.

A flat clinch is preferred for metal-to-metal assembly as it provides solid full-line contact, whereas the ends of loop stitches make contact only at the leg ends. Under vibration, leg ends may cut into the sheet.



FLAT STITCH
Solid clinching pressure



CURVED STITCH
Springy; weak pressure

Use of 1/4-inch crown stitching is increasing for this increases machine capacity and the legs penetrate better without wandering. Special crown sizes as small as 1/8 inch and as large as 1.201 inch have been used. Stitches with smaller crowns have better appearance and higher strength. Flat clinch crowns are flush within about 0.002 inch of the top surface and 0.005 inch of the bottom.

4.4.5.3 Shear Strength. Shear strengths of the flat clinch in various positions are tabulated below in pounds per stitch of Type 290 wire clinched through sheets of 2024T aluminum of three different thicknesses.

4.4.5.4 Stitching Wire. Wire for stitching is obtainable in low or high carbon steel, monel, copper, bronze, and stainless steel. Those listed below are in general use and readily available. Copper, brass, and monel wire can be obtained on order.

Wire	Data
Zinc-coated high carbon aircraft stitching wire	No. 18 gage, type 290, with 0.0015-inch zinc coating. Total diameter 0.051 inch. See MIL-W-6714.

Wire	Data
Stainless steel	No. 18 gage, type 302, no. 213 finish 163,000 to 230,000 psi tensile strength.
Phosphor bronze	No. 18 gage, type S-54.

Carbon steel wire is available with the following coatings:

a. "Liquor": light tin or copper plating - very little rust resistance.
b. Tin - some rust resistance.
c. Galvanized - high rust resistance.
d. Copper - some resistance to corrosion.
e. Zinc - coated 0.0015 inch, to comply with U. S. Air Force specifications for stitching aluminum.

SHEAR STRENGTH OF STAPLES

In pounds per stitch using Type 290 wire, flat clinched through 2024-T aluminum

Position of staple		Thickness of aluminum sheet inch 0.032	0.040	0.051
		lbs. per stitch		
Perpendicular		431	557	601
Parallel		433	476	480
Diagonal		Same as perpendicular, but preferable because of both parallel and perpendicular coverage.		
Butt, reinforced		196	232	252
Butt		Not recommended without reinforcement.		

Standard sizes for stitching wire are:

Steel wire gage no.	Dia. inch	Extent of use
18	0.0475	98 percent of all applications
20	0.0348	1.5 percent of all applications
16	0.0625	0.5 percent or less of all applications.

Tolerance for diameter is plus or minus 0.001 inch. Wire must not be more than 0.001 inch out of round.

Wire is available in 5- and 10-pound spools. There are 166 feet per pound for 18-gage; 309 feet per pound for 20-gage wire. MIL-W-6714 covers specifications for galvanized drawn steel stitching wire.

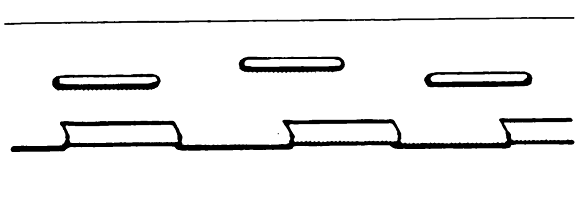
The tensile strength of high carbon steel stitching wire is as follows:

Grade	Tensile strength, psi
230	220,000 to 249,000
260	250,000 to 289,000
290	290,000 to 319,000
330	320,000 to 360,000

All sizes and grades of wire must be ductile enough to withstand a 180-degree bend without fracturing or breaking.

4.4.5.5 Maximum Thickness of Materials. The table on the following page may be used as a guide to determine maximum thicknesses of materials to be joined by stitching. Maximum metal thickness and metal-to-nonmetal assembly data are listed. The table covers only the loop clinch except as noted.

4.4.5.6 Typical Stitched Sections. A full-length aluminum hinge stitched to the edge of a plastic panel is shown below as typical of a stitched section.

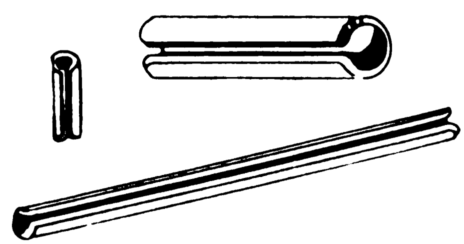


Shown on page 4-107 are other applications in which stitching can be used to advantage, including fastening tubing to metal sheet and a spring to a nonmetallic material. Location of stitches and type of arm are indicated. Use of straight arm, gooseneck, or tapered-post clinch arms allows various assemblies.

4.4.6 Miscellaneous Fasteners

Other types of fasteners include tubular, groove, and cotter pins; keys; splines; retaining rings; and captive types.

4.4.6.1 Tubular Pins. Spring-type tubular pins should be used in preference to solid pins. Tubular pins may be used in ordinary drilled holes and reaming is not required. Hardened pins have high shear strength and, because of the spring feature, remain tight during vibration.

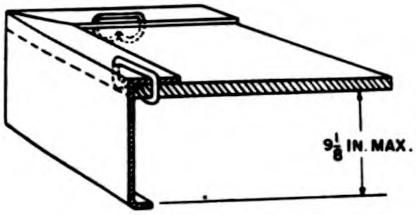


TUBULAR PINS

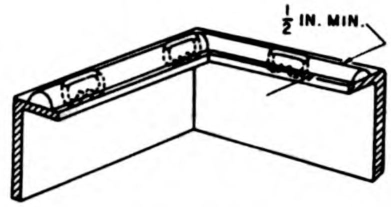
MAXIMUM THICKNESSES OF STITCHED MATERIALS
Using staples of 18-gage wire, grade 330, white

Material and condition	Maximum thickness inch	
Metal-to-metal	One sheet	Other sheet
Aluminum, SO	0.093[a]	0.125
Aluminum, 2024-T	0.040[a]	0.064
Alclad	0.040[a]	0.064
Aluminum, extruded	0.062[a]	0.093
Steel, cold rolled, 1010[b]	0.050	0.078
Steel, hot rolled[b]	0.037	0.062
Steel, galvanized[b]	0.037	0.050
Stainless, full-hard	0.010	0.020
Stainless, half-hard	0.012	0.025
Stainless, quarter-hard	0.015	0.030
Stainless, annealed	0.020	0.040
Brass, soft	0.030	0.050
Copper	0.035	0.064
Nonmetal-to-metal[c]		
Asbestos sheet	1/4	
Cork sheet	1/2	
Felt	3/8	
Fiber sheet	1/2	
Flannel	1/2	
Leather	3/8	
Masonite, standard	3/8	
Masonite, tempered	1/4	
Plastic sheet[d]	3/16	
Phenolic sheet[d]	1/8	
Rubber, solid	1/4	
Rubber, sponge	1/2	
Wood[e]	3/8	

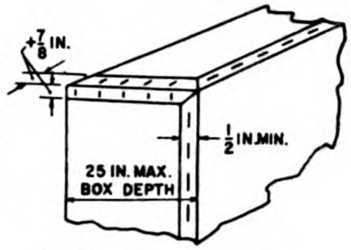
a Flat or loop clinch
b Rockwell B 50 or softer.
c The nonmetals may be joined to any of the metals listed above, but combinations of maximum thicknesses are not always feasible.
d Stock must be soft enough to permit penetration without cracking.
e Grain structure may cause legs to wander. Straight-grain stock up to 1/2 inch may be used.



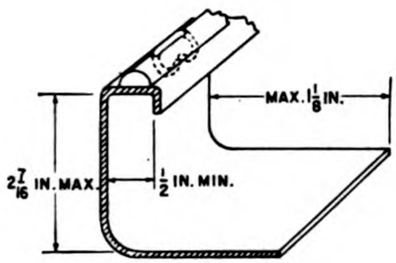
Bottoms to Inside Flange on Open Top Box Drop Gooseneck Arm



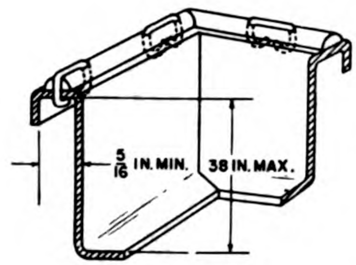
Open Top Box with Inside Flange Overhang Arm



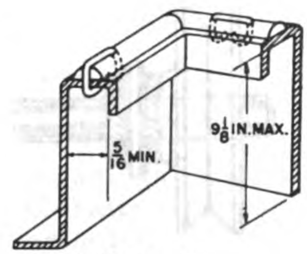
Sides to Bottoms and Corners Straight Arm



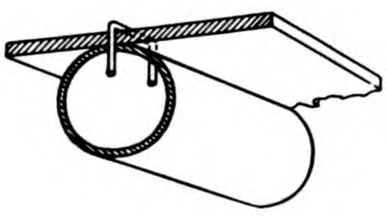
Hidden Channels Reverse Gooseneck Arm



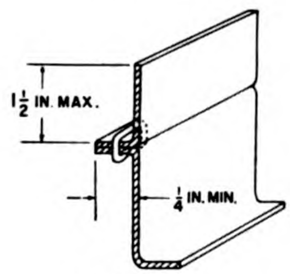
Outside Channels Clincher to Front Drop Gooseneck Arm



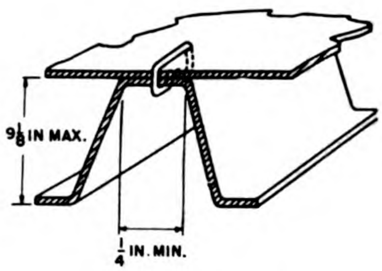
Inside Channels Clincher to Rear Drop Gooseneck Arm



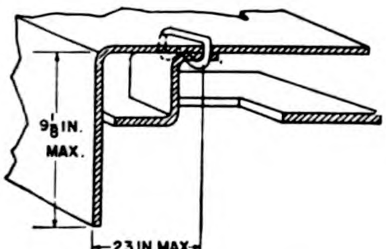
Non-Metallic Tacked to Metal Tube (16 ga. max.) Straight or Drop Gooseneck Arm No Clincher Special Work Holder



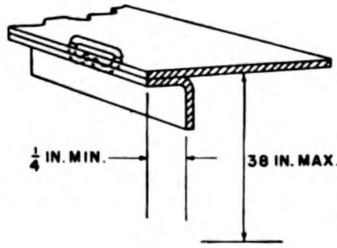
Outside Flange Straight Arm



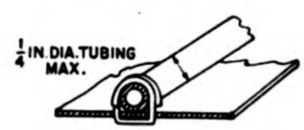
Corrugation Drop Gooseneck Arm Narrow Tapered Post



Baffle Plates with Punched Tabs Drop Gooseneck Arm



Outside Edge Flange Straight Arm



Tubing to Metal Plate

Coil Springs to Non-Metallic Base

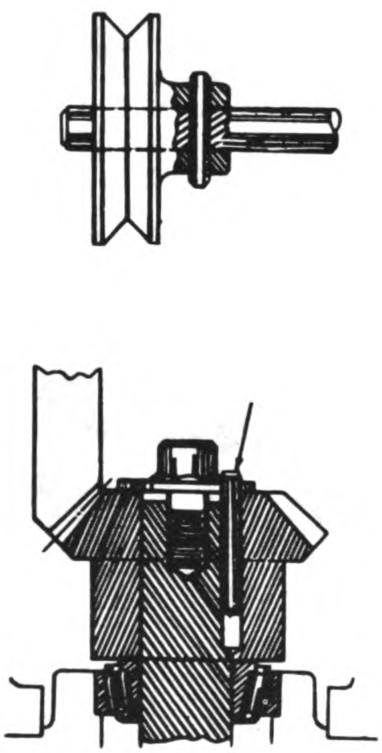
TYPICAL STITCHED SECTIONS

Drives easily by hammer, arbor press, or air cylinder and can be readily adapted to an automatic hopper feed. Requires only a standard hole, drilled to normal production-line tolerances.

Removes readily with a drift pin without damage to pin or hole, can be used again and again in original hole.

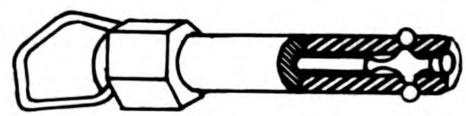
Locks securely in place without using a secondary locking device; won't loosen despite impact loading, stress reversals, or severe vibration.

INSERTION AND REMOVAL OF TUBULAR PINS

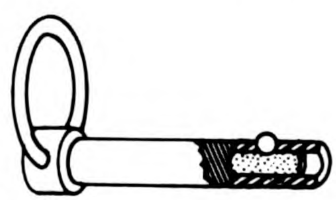


TYPICAL USES FOR TUBULAR PINS

4.4.6.1.1 Quick Release Pins. Quick release pins are available in two major types as illustrated below. In one type, protruding steel balls are the locking element engaged by a notched spring-loaded plunger which operates on a push-pull movement. In the rubber core type, the projecting metal knob is backed up by the spring action of a rubber core. Pressure on the stem forces the knob into the core permitting release of the pin.

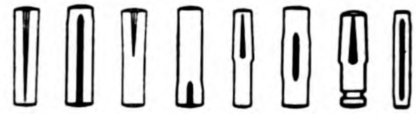


BALL LOCKING PIN



RUBBER CORE PIN

4.4.6.2 Groove Pins. Groove pins have three longitudinal slots equidistantly spaced. The grooves may be straight or tapered, may run the full length of the pin, part of the length, or only in a bulged section. Some of the standard types are shown below.



GROOVE PINS

Groove dowel and clevis pins are often used instead of spring-type tubular pins.

4.4.6.3 Cotter Pins. Cotter pins should be used only as retaining devices and should not carry any appreciable load. They are obtainable with various types of ends such as square cut, extended mitre, hammer lock, or bevel point.

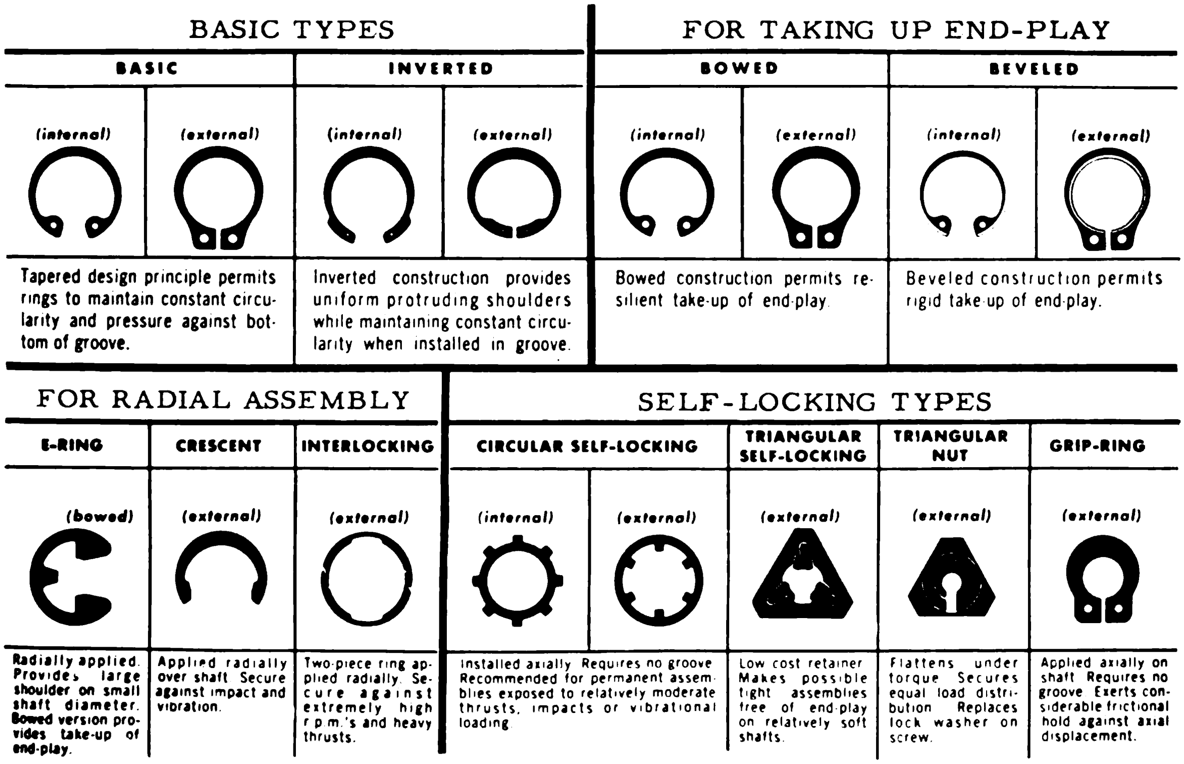
4.4.6.4 Keys and Splines. Keys and splines are used to prevent relative rotational movement between parts on shafts.

4.4.6.4.1 Keys. Keys may be parallel, or tapered with parallel sides. They may have gib heads to limit motion.

The Woodruff key is made in the form of a segment of a disc. It is tightly fitted in a keyway formed longitudinally in the shaft by a key slot cutter. A portion of the key projects beyond the shaft surface to engage a keyway in the hub or part fitted to the shaft. This type is particularly suitable for gears.

4.4.6.4.2 Splines. Splines function as multiple keys and keyways, but are integral parts of the shafts and the fitted part. The 4, 6, 10, and 12 parallel-side splines are standard forms. Splines give the greatest strength, but are the most expensive form of keying.

4.4.6.5 Retaining Rings. Retaining rings or snap rings are used to retain bushings, collars, cams, bearings, and similar parts on shafts or studs or in recesses or holes. Grooves for such retainers must be carefully machined in accordance with the manufacturer's recommendations, preferably with special grooving tools.



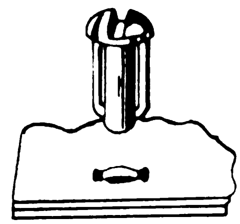
RETAINING RINGS

External-type rings may be slipped on shafts fairly easily by hand. Internal-type rings are best applied by plier-type tools which engage holes at the extremities of the ring. This tool may also be used to remove rings without damage.

Self-locking retaining rings are not approved. Internal rings are especially suited to retain bearings mounted in recesses as they are designed to take simple thrust loads without excessive rotary friction at their faces.

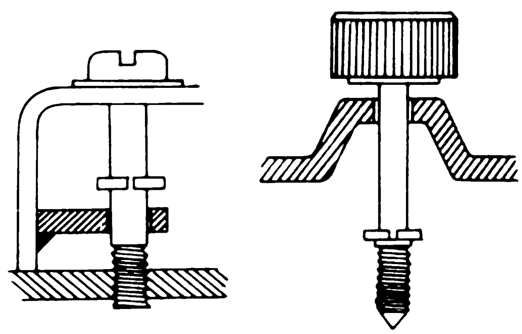
4.4.6.6 Captive Fasteners. Where covers, units, assemblies, doors, panels, or other interchangeable parts require rapid or frequent removal, the fastening mechanism should be a "captive" type; that is, one which will prevent separation of the fastener. The fasteners should have adequate strength to hold the parts together under special service conditions. There are a number of proprietary fasteners available, but specifications such as MIL-F-5591 should be consulted for those acceptable for a particular purpose.

The simple one-piece fastener for blind holes shown below has a steel spring wire which locks in position and prevents loosening under vibration. It is self-adjusting for various material thicknesses and locks or unlocks by twisting.



ONE-PIECE CAPTIVE FASTENER FOR BLIND HOLES

4.4.6.6.1 Common Types. Captive type screws should be used for retaining access panels and covers. Anchor nuts and nut plates may be used, when practicable, for threaded engagements in light sheet metal.

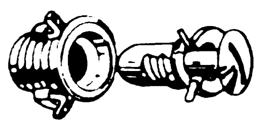


TYPICAL CAPTIVE FASTENERS

Pawl fasteners may be used as quick-operating latches for doors or to fasten chassis-panel assemblies in cabinets. They should not be used where there is the possibility of over tightening and consequent deformation.

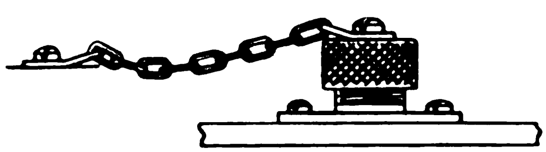
Screwdriver-operated devices are preferred to wing nuts. A wide slot may be used to permit operation by means of a coin or other relatively thick piece of metal.

4.4.6.6.2 Self-Ejecting Type. The self-ejecting fastener shown below is for weather-tight applications.



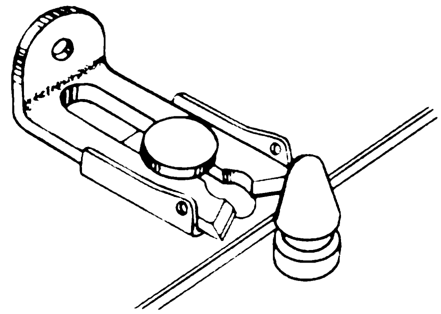
SELF-EJECTING FASTENER FOR WEATHER TIGHTNESS

4.4.6.6.3 Chained Type. Chains attached to covers, doors, and detachable parts prevent their loss and can also prevent injury to personnel caused by accidental dropping. Such devices must be installed so that they cannot damage equipment.



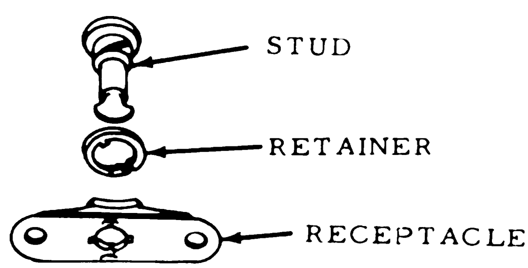
CHAINED FASTENER

4.4.6.6.4 Cowl Fasteners. Cowl fasteners are used for mounting light chassis panels, covers, and similar assemblies.



COWL FASTENER

4.4.6.6.5 Quarter-Turn Fasteners. Quarter-turn fasteners are a type of captive fastener available in a variety of styles and sizes. These fasteners have three major parts; a stud, a stud retainer, and a receptacle. Spring action either on the stud or the receptacle presses the fastened surfaces together when the stud is engaged in the receptacle. Quarter-turn fasteners are supplied with slotted, wing-nut, or knurled stud heads. Receptacles can be attached by spot welding or riveting. A typical quarter-turn fastener is shown below.



QUARTER-TURN FASTENER

4.4.7 Cementing

Metal fasteners, welding, and soldering are the most widely used joining methods, but use of adhesives is practical for many materials under some conditions. Recent developments in adhesives provide advantages worth investigating.

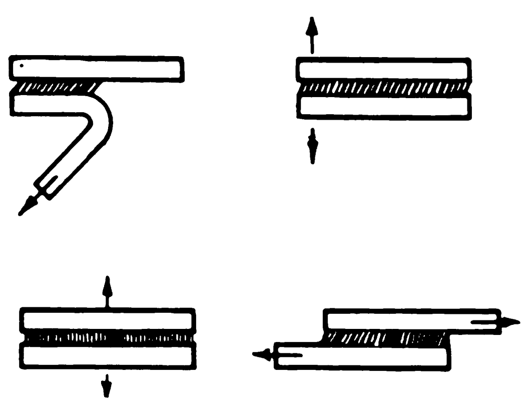
4.4.7.1 Advantages. Use of adhesives for joining has the following advantages:

a. Heavy gage material can be joined to thin sheets where other methods are impractical.
b. Shearing and other stresses are distributed uniformly.
c. In dissimilar metals, insulating effect prevents electrolytic corrosion.
d. Lower weights often result from elimination of metallic welds or fasteners and use of honeycomb cores.
e. Stresses resulting from flexing, vibration, and thermal expansion may be absorbed.
f. Elimination of voids and gaps.
g. Smoother contours.
h. Inconspicuous joints.
i. Joining of complex shapes not possible by any other method.
j. Sealing of joints.
k. More rapid assembly by elimination of drilled or punched holes, jigs, and care in matching.
l. Elimination of need to stock many sizes and types of fasteners.
m. Facilitation of disassembly without damage, by use of heat or a solvent.

4.4.7.2 Disadvantages. Adhesives have the following disadvantages:

a. Some adhesives require a long time for drying and curing, necessitating extra storage space.
b. Expensive jigs and fixtures and application of heat and pressure may be required for curing.
c. Control of humidity and temperature may be necessary.
d. Questionable durability of some new adhesives under severe or unusual conditions or in use.
e. Instability of organic materials at higher temperatures.
f. Instability of organic materials at higher temperatures.
g. Insulating effect of adhesive is sometimes objectionable.
h. Possibility of softening at high temperatures.
i. Difficulty of bonding some materials, such as Teflon and polyethylene.
j. Low peel strength.

4.4.7.3 Properties of Adhesive Joints. Because tensile and shear forces are fairly uniformly distributed, relatively large loads can be carried. Yield strengths as high as 5000 pounds per square inch are attainable, but relatively low forces concentrated at an edge can cause easy separation.



LOADS ON ADHERED JOINTS

4.4.7.4 Use in Electronic Equipment. Adhesives offer certain advantages over other fastening methods especially where there is vibration or the presence of screws or rivets is objectionable. Uniform adhesive bonding eliminates dimples and wrinkles which may occur on thin sheet metal joined at only a few points. The high shear strengths of some adhesives are of particular advantage in bonding thin sheet metal subjected to low tensile loads. Adhesive bonds are also useful in sealing pressurized equipment used at high altitudes.

4.4.7.5 Classification. Adhesives may be classified by general chemical type or origin, or by physical properties or methods of use.

4.4.7.5.1 Chemical Classification. The general chemical types of adhesives are:

I Thermosetting
II Thermoplastic
III Cellulose derivatives
IV Rubber
V Rubber-resins

Certain other adhesives such as shellac, asphalts, starches, gum arabic, oleoresins, and sodium silicate, are also used, but not to any great extent in electronic equipment.

Thermosetting resins, e.g., phenolics, are permanently set by heat, can be used over a wide temperature range, and have high water and solvent resistance.

Thermoplastic resins, e.g., vinyls and cellulose derivatives, soften and flow when heated and should not be used in equipment subject to high temperatures. Also, resistance to organic solvents is usually poor.

Natural and synthetic rubbers are used for flexibility. Different types of rubber vary in resistance to solvents and to high or low temperatures.

Mixtures of adhesives are often used to obtain the properties of different materials. For example, thermosetting and thermoplastic materials may be combined to secure sufficient flexibility for conditions of vibration or differential thermal expansion. Compounded adhesives are usually described under the name of the major constituent.

4.4.7.5.2 Physical Classification.

4.4.7.5.2.1 Pressure Sensitive. Pressure-sensitive adhesives retain their tack, cohesive properties, and adhesive properties for a long time. After an initial rapid evaporation of the solvent, the elastic modulus remains essentially constant. Parts are simply brought into contact or pressed together at room temperature to complete the bond. Both surfaces should be coated. Such bonds are flexible, comparatively weak, and subject to plastic creep. Continuous and appreciable loads must be avoided. These adhesives are thermoplastic and possess the same general physical properties as highly viscous fluids. Vinyls, rubber-base compounds, and other formulations are used, with and without catalyzers.

Many materials are available as pressure-sensitive tapes and films. Base materials for these tapes include such versatile substances as silicones and other snythetic rubbers, Teflon (polytetrafluoroethylene), fiber-glass (including fiberglass-impregnated silicones and Teflon), Mylar (polyester), phenolics, and copper foil. Most of these are coated with a silicone adhesive. They are used for electrical insulation, for color coding, as hermetic seal surfaces, for printed wiring boards, for bonding rigid materials, and in applications where resistance to heat, chemicals, friction, and wear is important.

4.4.7.5.2.2 Temperature Sensitive. Temperature-sensitive adhesives used in heat-cured or heat-softened bonds are usually stronger than others. Often the cohesive forces within a cement are weaker than the adhesive forces bonding the adhering surfaces. Curing at elevated temperatures quickly produces structural changes through oxidation, polymerization, and solvent migration. When heat cured, thermosetting adhesives are usually stronger than the thermoplastic types. For joining metals, the phenolic-elastomer type offers a good combination of strength, resistance to solvents and high temperature, and low water absorption.

4.4.7.5.2.3 Reaction Sensitive. In reaction-sensitive adhesives, catalysts are added to facilitate oxidation or polymerization, and to eliminate or minimize heat curing. For curing at room temperatures, the catalysts are strongly acid and comparatively large amounts are required. "Pot" life for some of these adhesives is short. Higher temperatures reduce the curing time.

Epoxy and resorcinol resins can be cured at room temperature in a reasonable time. Resorcinol resins are excellent for all materials except metals and glass. The epoxys are good or excellent on all materials, but are somewhat sensitive to thermal conditions.

4.4.7.6 Properties of Various Adhesives. Data on the various types of adhesives are tabulated on pages 4-116 to 4-128.

4.4.7.7 Selection of Adhesives. By due consideration of the various factors involved, the choice of adhesives for a particular purpose can be narrowed down to the few most suitable from which the final choice can be made.

First, adhesives must be selected which will bond with the materials to be joined. Some types of adhesives bond poorly or not at all with certain materials. For joining like materials with identical thermal expansion such as thermoplastics, a solvent might be chosen. Where unlike materials are to be joined, adhesives must be compatible with both adherends. For example, to join steel and rubber, one of the following is indicated: phenol formaldehyde, epoxy, neoprene, or phenol formaldehyde-vinyl acetal.

Other factors must then be considered and some compromise is often necessary. Materials which are softened by heat cannot be bonded readily with adhesives requiring heat and pressure for curing. Use of pressure-cured adhesives for irregular shapes would require expensive fixtures.

Selection of adhesives will also depend on service conditions which may affect joints such as high and low temperature and presence of water, oil, solvents, or other fluids. For example, thermoplastic adhesives are not resistant to chemicals similar to the solvents used in making them, nor to high temperatures.

Adhesives suitable for particular materials are tabulated in 4.4.7.7.1. Solvents for use with thermoplastics are listed in 4.4.7.7.2. Adhesives suitable for particular service conditions are tabulated in 4.4.7.7.3.

4.4.7.7.1 Adhesives for Various Materials. Adhesives for particular materials are listed on pages 4-129 and 4-130. Materials which can bond to themselves by use of a solvent are identified by letters referring to the appropriate solvents listed in 4.4.7.7.2.

4.4.7.7.2 Use of Solvents. Some thermoplastics may be cemented to themselves by use of solvents. Surfaces to be joined are immersed in solvent until they soften, usually in a few minutes, then held together under light pressure until the solvent evaporates. Some solvents in general use are:

a. Ethylene dicholoride
b. Methyl ethyl ketone 50 percent, toluene 50 percent
c. Methyl ethyl ketone 80 percent, propylene oxide 20 percent
d. Acetone
e. Acetone 70 percent, ethyl lactate 30 percent
f. Acetone 70 percent, methyl cellosolve 30 percent
g. Xylene
h. Diethyl benzene

I. PROPERTIES OF SYNTHETIC THERMOSETTING ADHESIVES

Type	Forms, curing, color	Strength	Application	Remarks
Allyl monomer	----	----	Optical cement and for laminating fibrous materials.	One form has superior optical qualities, good weathering resistance, and gives strong bond with glass. Partially thermoplastic. Insoluble. Water-clear.
Epoxy Ethoxy	Solid or liquids; powder or stick. Solid cures at 390°F in 1 hour under slight pressure. Curing agent may or may not be included. Liquid uses separate curing agent; cures at 75° to 100°F under low pressure. Higher temperatures accelerate curing. Tan.	High tensile strength. Typical shear strength with aluminum strips, approx. 4,500 psi.	Bonding wide variety of porous and non-porous materials; ceramics, glass, metal, glass cloth laminates. Bonding carbide tips to reamers.	Good adhesive qualities. Low shrinkage. Good "gap-filling" properties. Rigid.

I. PROPERTIES OF SYNTHETIC THERMOSETTING ADHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Furane resins Furfuryl alcohol Furfuraldehyde	Cure at room temperature. Higher temperatures accelerate curing. Brown.	----	Bonding wide variety of materials. Recommended for thermosetting plastics, ceramics, and acrylics.	Unsuitable for bonding wood or other acid-vulnerable materials. Rigid.
Melamines	Curing requires little pressure.	----	Bonding imperfectly fitting parts, such as wood and plywood structures.	Higher resistance to moisture, boiling water, and acids than ureas, but more expensive.
Phenol Formaldehyde	Film, powder, or liquid. Film placed between veneers, heat and pressure cured. Powder mixed with water, alcohol, acetone, or combination of all three. Brown.	----	Plywood gluing.	Excellent resistance to water, weathering, chemical and bacterial action, and temperature variations. Good "gap-filling" properties. Rigid.

I. PROPERTIES OF SYNTHETIC THERMOSETTING ADHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Resorcinol formaldehyde (Resorcinol resin)	Liquid with separate curing agent. Cures at room temperature.	Adherend[1] / Tensile psi / Shear psi: Paper-phenolic laminate: 820 / 1,370 Birch-wood: 1,180 / 1,940 Hard rubber: 1,340 / 590	Boatbuilding and aircraft work.	Good resistance to deterioration. Good "gap-filling" properties. Rigid.
Resorcinol-nylon	Cures at room temperature.	----	Bonding thermosetting and thermoplastic materials.	Produces relatively nonporous bond. Reduces strains caused by shrinkage or temperature differentials.
Silicones	Aromatic hydrocarbon solution. Requires 390°F and high pressure to cure. Amber.	----	Bonding silicone and other types of rubber to nonporous materials.	Highest heat-resistance. Rigid.

1 Materials being bonded.

I. PROPERTIES OF SYNTHETIC THERMOSETTING ADHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Urea formaldehyde	Water-soluble powder, with curing agent combined or separate; syrupy water solutions with curing agents separate. Light color.	----	Replacing casein in plywood manufacture.	Less resistant to chemicals, heat, and weathering than phenolics. Film brittle and tends to craze, unless cellulose filler and thin glue line are used. Suitable up to 160°F. Rigid.

II. PROPERTIES OF SYNTHETIC THERMOPLASTIC ADHESIVES

Type	Forms, curing, color	Strength	Application	Remarks
Acrylates	Colorless.	----	For nonporous materials: glass and metals.	Pliable, tough. Good aging properties.
Methacrylates	Ester, aromatic hydrocarbon, or ketone solvents. Cures by solvent release. Separate catalyst or activator added before use. Colorless.	----	Similar to acrylates.	Film is water-clear. Good weathering and aging properties. Higher softening points and tougher than acrylates. Flexible.
Polystyrene	Ester, aromatic hydrocarbon, or ketone solvents. Separate catalyst or activator added before use. Colorless.	----	Electrical and electronic parts.	High dielectric strength. Good water resistance. Rigid.

II. PROPERTIES OF SYNTHETIC THERMOPLASTIC ADHESIVES - continued

<table>
<tr><th>Type</th><th>Forms
curing, color</th><th>Strength</th><th>Application</th><th>Remarks</th></tr>
<tr><td>Polyvinyl acetate</td><td rowspan="3">All vinyls can be bonded cold or hot. Cold bonding not suitable for non-porous surfaces, which tend to trap solvent and retard evaporation. Fabrication must be rapid, before solvent evaporates. Hot bonding: Applied as hot melt or solution, cures in a few minutes at 225° to 250°F; can be bonded at later date by use of heat and low pressure. Colorless.</td><td>Adherend / Tensile psi / Shear psi
Stainless steel / 3,600 / 2,960
Aluminum alloy / 3,270 / 3,560
Paper-phenolic laminate / 1,060 / 2,480
Glass / 2,430 / 2,310
Birchwood / 960 / 1,990
Hard rubber / 400 / 630</td><td>Bonding of glass and metals.</td><td>Approximately same refractive index as glass. Good resistance to discoloration due to aging. Tough, elastic joint.</td></tr>
<tr><td>Polyvinyl alcohol</td><td>----</td><td>Bonding practically any material, porous or nonporous.</td><td>Clear, tough. Resists fats, many organic solvents. Stable and impermeable to gases. Soluble in water at 160°F.</td></tr>
<tr><td>Polyvinyl butyral</td><td>----</td><td>Bonding safety glass, and flexible mica sheets. Compounded with other resins to provide special adhesives.</td><td>Does not haze.</td></tr>
</table>

II. PROPERTIES OF SYNTHETIC THERMOPLASTIC ASHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Polyvinyl chloride	Same as polyvinyl acetate, above.	----	----	Brittle film. Less adhesive than acetate. Good moisture resistance. High chemical resistance. Brittleness can be modified by plasticizers, but these impair adhesive properties.
Polyvinyl-chloride acetate	Same as polyvinyl acetate, above.	----	----	Combines chemical and moisture resistance of chloride with toughness of acetate.

III. PROPERTIES OF CELLULOSE-BASE ADHESIVES

Type	Forms, curing, color	Strength	Application	Remarks
Cellulose acetate	Ester or ketone solvents. Cures by release of solvent. Colorless.	----	Cementing glass, metals, cloth, ceramics.	Superior to cellulose nitrate in aging properties and resistance to fire, but inferior in moisture resistance and adhesive qualities. More expensive. Flexible.
Cellulose acetate butyrate	----	----	Similar to cellulose acetate.	Greater durability and moisture resistance then cellulose acetate.
Cellulose nitrate	Ester or ketone solvents. Cures at moderate temperature by release of solvent. Colorless.	Adherend / Tensile psi / Shear psi: Stainless steel 2,180 1,580 Aluminum alloy 1,500 1,360 Paper-phenolic laminate 860 1,680 Glass 1,080 1,680 Birch-wood 1,100 1,390 Hard rubber 590 1,000	Glass, leather, cloth, ceramics	Care must be used in handling. Flexible. Replaced by polyvinyl resins because it discolors in sunlight and is flammable.

III. PROPERTIES OF CELLULOSE-BASE ADHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Ethyl cellulose	Solution or hot melt.	----	Bonding paper, cloth, metal foil.	More resistant to chemical action than other cellulose derivatives.

IV. PROPERTIES OF RUBBER-BASE ADHESIVES

Type	Forms, curing, color	Strength	Application	Remarks
Butadiene acrylonitrile	Solution.	----	----	Very resistant to oils and fuels. Specially compounded to resist deformation.
Butyl (GR-I)	Petroleum is best solvent.	Fair tensile strength.	----	Poor aliphatic resistance. Best resistance of rubber group to natural aging; resistance to high-temperature aging. Cold flows under low loads.
Butadiene-styrene (GR-S)	Petroleum best solvent. Available as solution or latex.	Fair tensile strength and elongation.	----	Poor aliphatic resistance. Fair resistance to natural or high-temperature aging. Lacks tack.

IV. PROPERTIES OF RUBBER-BASE ADHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Natural rubber	Best solvents are aliphatic or straight chain hydrocarbons. Air drying at room temperature. Vulcanizing types may be cured under pressure and high temperature for greatest strength.	From benzene solvent, with high temperature-pressure cure: Adherend — Tensile psi — Shear psi Stainless steel — 260 — 270 Aluminum alloy — 390 — 250 Paper-phenolic laminate — 160 — 130 Glass — 34 — 43 Birch-wood — 170 — 160 Hard rubber — 130 — 190 Air-drying type is much lower in strength.	Bonding cloth, felt, and rubber to metal.	Has poor aliphatic resistance. Ages rapidly in sunlight. Has good tack and tack retention. Flexible.
Neoprene	Available as solution or latex. Ester or ketone solvents. Tan.	In tensile strength and elasticity, compares well with natural rubber. Adherend — Tensile psi — Shear psi Stainless steel — 170 — 90 Aluminum alloy — 290 — 130 Paper-phenolic laminate — 170 — 250 Glass — 90 — 100	Most popular of all synthetic rubber adhesives.	Gives best resistance of all rubber group to organic solvents, sunlight, heat, oxidation, and chemicals. Continuous exposure to high temperatures liberates acid and may corrode metals. Compares well with natural rubber in tensile strength and elasticity.

IV. PROPERTIES OF RUBBER-BASE ADHESIVES - continued

Type	Forms, curing, color	Strength	Application	Remarks
Neoprene (continued)		Birch-wood 340 180 Hard rubber 240 230		
Nitrile (acrylonitrilebutadiene, Buna N)	Available as liquid or tape. Ketone solvents. Tan.	Fair elongation. Moderately good tensile strength. Fair bond.	----	Do not weld readily to themselves and must be bonded with considerable solvent. Good aliphatic resistance. Fair aging resistance.
Polysulphide rubber (thiokol)	Chlorinated hydrocarbon solvents.	Low tensile strength and elongation.	Where bonds must be oil and solvent resistant.	Excellent resistance to aging. Best of all rubbers in resistance to solvents, greases, and oils. Low permeability to gases.
Reclaimed rubber	Reclaimed from discarded vulcanized rubber products. Commonly black, but red and gray available.	----	Bonding cloth, felt, and rubber to metal.	Lower in cost than natural rubber. Almost as good as natural rubber adhesives.

V. PROPERTIES OF RUBBER-RESIN ADHESIVES

Type	Forms, curing, color	Strength	Application	Remarks
Liquid phenol formal-dehyde plus resin.	Cures in 15 min. at 300°F, at 300 to 500 psi.	Shear strength with aluminum strips: 5,000 psi.	Structural bonding, wood to aluminum alloys, stain-less steel, magnesium, and chrome steel.	Not good for nickel, its alloys, lead, or copper.
Phenolic-elastomers	Film with liquid primer for metals; liquid two-component powder and liquid combination. Require high tempera-ture and pressure for bonding.	Combines adhesive pro-perties and strength of phenolic resins with flexibility of rubber.	Joining of stain-less steel and aluminum. Good for all metals, and non-metals not affected by curing heat and pressure.	Possesses character-istic phenolic resist-ance to corroding conditions.
Phenolic-synthetic rubber	Cures in 30 min. at 325°F, at 50 psi.	Shear strength with aluminum strips: 3,000 psi.	Waffle-type sandwich type constructions and attaching reinforcing stringers to sheets.	----
Rubber-resin (phenolic or nylon)	Cures at 325°F, bonds in 15 to 20 min. at 200 psi.	Shear strength with aluminum strips: 4,000 psi.	Sandwich con-struction.	Must be protected from saltwater spray. Good oil resistance.

ADHESIVES FOR VARIOUS MATERIALS

Material	Solvent (see 4.4.7.7.2)	Adhesive
Rubber	---	Phenol formaldehyde, resorcinol formaldehyde, epoxy, neoprene, nitrile rubber, phenol formaldehyde-vinyl acetal
Ceramics	---	Vinyl acetate, vinyl butyral, furfuryl alcohol, epoxy, polyurethane, neoprene, nitrile rubber, phenol formaldehyde-vinyl acetal
Acrylics	a	Melamine formaldehyde, resorcinol formaldehyde, nitrile rubber, phenol formaldehyde-nitrile rubber
Vinyls	b, c	Vinyl acetate, neoprene, phenol formaldehyde-nitrile rubber, resorcinol polyamide
Vinylidene chloride	---	Vinyl acetate, neoprene
Polyester	---	Silicone, epoxy, nitrile rubber
Polyamide	---	Resorcinol formaldehyde, neoprene, nitrile rubber, resorcinol polyamide
Polystyrene	g, h	Methyl methacrylate, styrene, alkyd, nitrile rubber
Thermosets: phenolics, ureas melamines	---	Phenol formaldehyde, urea formaldehyde, resorcinol formaldehyde, furfuryl alcohol, silicone, epoxy, neoprene, nitrile rubber, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral.
Steel	---	Vinyl acetate, phenol formaldehyde, epoxy, polyurethane, reclaimed rubber, neoprene, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral

ADHESIVES FOR VARIOUS MATERIALS - continued

Material	Solvent (see 4.4.7.7.2)	Adhesive
Aluminum	---	Vinyl acetate, polyisobutylene, phenol formaldehyde, epoxy, polyurethane, reclaimed rubber, neoprene, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral.
Magnesium	---	Silicone, epoxy, polyurethane, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal
Zinc	---	Neoprene, nitrile rubber, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl butyral
Copper, brass, bronze	---	Vinyl acetate, silicone, epoxy, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl butyral
Nickel	---	Epoxy, neoprene, nitrile rubber
Tin	---	Epoxy, nitrile rubber
Silicones	---	Silicone, epoxy
Fluorocarbons	---	Silicone, epoxy
Leather	---	Vinyl acetate, vinyl butyral, resorcinol formaldehyde, epoxy, neoprene, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, resorcinol polyamide
Paper, textiles, felt, cork	---	Cellulose acetate, methyl methacrylate, vinyl acetate, vinyl butyral, phenol formaldehyde, urea formaldehyde, melamine formaldehyde, resorcinol formaldehyde, epoxy, neoprene, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, resorcinol polyamide
Cellulose derivatives	d, e, f	Cellulose nitrate, cellulose acetate, resorcinol formaldehyde, polyurethane, nitrile rubber.

ADHESIVES FOR VARIOUS MATERIALS - continued

Material	Solvent (see 4.4.7.7.2)	Adhesive
Wood	---	Vinyl acetate, phenol formaldehyde, urea formaldehyde, melamine formaldehyde, resorcinol formaldehyde, furfuryl alcohol, neoprene, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal
Teflon (polytetrafluoroethylene)	d, e, f	Epoxy, silicone, phenol formaldehyde synthetic rubbers

4.4.7.7.3 Adhesives for Various Service Conditions. Adhesives suitable for various service conditions are listed on page 4-132.

4.4.7.8 Additional Data. Additional data on adhesives are tabulated on pages 4-133 through 4-135. Separate data are given on adhesives for rubber, porous materials, and structural purposes.

4.4.7.9 Bonding Details.

4.4.7.9.1 Surface Condition. High-strength bonds are obtained where the adhering surfaces are attacked or dissolved slightly by the adhesive. An intermolecular or welding action is thus effected. Where the adhering surface is rough, cellular, or porous, the effective adherent area is increased and an interlocking action is obtained.

Adhesion of smooth surfaces of the type presented by a highly finished metal, glass, and similar materials depends solely on the adhesive bond. All such surfaces must first be carefully cleaned by chemical or mechanical means so that the adhesive will wet the surface. The intimacy of contact is extermely important. Localized deformations and possible separation of flexible materials should be counteracted by using flexible cements.

4.4.7.9.2 Application of Adhesive. For wet bonds, the adhesive is applied to one surface, usually the less porous, and the other surface is brought immediately into contact. Insulating materials and fabrics are usually joined by this method.

For tacky bonds, both parts are usually coated, air dried until tacky, and then pressed together.

ADHESIVES FOR VARIOUS SERVICE CONDITIONS

Service condition	Adhesives
Static loads	Phenol formaldehyde, urea formaldehyde, melamine formaldehyde, resorcinol formaldehyde, furfuryl alcohol, alkyd, silicone, epoxy, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral, resorcinol polyamide.
Impact or vibration	Cellulose nitrate, cellulose acetate, methyl methacrylate, vinyl acetate, vinyl butyral, polyisobutylene, natural rubber, reclaimed rubber, neoprene, nitrile rubber, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral, resorcinol polyamide
Presence of water	Vinyl acetate, styrene, polyisobutylene, phenol formaldehyde, melamine formaldehyde, resorcinol formaldehyde, silicone, epoxy, neoprene, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral, resorcinol polyamide
Presence of solvent	Phenol formaldehyde-nitrile rubber, phenol-formaldehyde, urea formaldehyde, melamine formaldehyde, resorcinol formaldehyde, furfuryl alcohol, epoxy, polyurethane, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral, resorcinol butyral
High temperature	Phenol formaldehyde, melamine formaldehyde, resorcinol formaldehyde, furfuryl alcohol, silicone, epoxy, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butryal, resorcinol polyamide
Low temperature	Phenol formaldehyde, urea formaldehyde, melamine formaldehyde, resorcinol formaldehyde, silicone, epoxy, phenol formaldehyde-nitrile rubber
Differential expansion	Cellulose nitrate, cellulose acetate, methyl methacrylate, vinyl acetate, vinyl butyral, natural rubber, reclaimed rubber, neoprene, nitrile rubber, phenol formaldehyde-nitrile rubber, phenol formaldehyde-vinyl acetal, phenol formaldehyde-vinyl butyral, resorcinol polyamide

ADHESIVES FOR RUBBER

Type	Strength	Static load	Tack	Resistance to Water	Resistance to Oil	Resistance to Gasoline	Resistance to Heat	Resistance to Cold	Resistance to Aging
Nitrile rubber	E	F	P-G	E	E	E	G	G	G
Butyl rubber	F	P	G	E	P	P	P	G	E
GR-S	F	P	F	E	P	P	F	G	F
Natural rubber	G	P	E	E	P	P	P	G	F
Neoprene	E	G	P-G	E	G	G	G	G	G-E
Reclaimed rubber	G	P	G	E	P	P	P	G	F
Thiokol	F	P	F	E	E	E	F	E	E
Cyclized rubber	G	F	G	E	P	P	F	M	G
Chlorinated rubber	G	F	G	E	G	G	M	M	G

Code: E, excellent; G, good; M, moderate; F, fair; P, poor.

ADHESIVES FOR POROUS MATERIALS

Adhesive type	Supplied as	Mix with	Pot life hours	Sets at °F	Resistance to					Suitable for
					Water	Weather	Fungus	Heat	Solvents	
Melamine	Powder	Water	24 to 48	240 to 280	E	G	E	E	E	Exterior
Phenolic, acid catalyst	Liquid	Hardener	1 to 6	70 to 210	E	E	E	E	E	Exterior
Phenolic, hot set	Liquid, film, or powder	---- ---- Water	Indef ---- Indef	250 to 300	E	E	E	E	E	Exterior
Resorcinol	Liquid	Hardener	1 to 6	70 to 210	E	E	E	E	E	Exterior
Urea	Powder or liquid	Water or hardener	1 to 24	70 to 210	G	M	E	M	E	Interior
Vinyl acetate	Liquid	----	Indef	70	F-M	P	G	P	F	Interior

Code: E, excellent; G, good; M, moderate; F, fair; P, poor.

ADHESIVES FOR STRUCTURAL PURPOSES

Adhesive	Supplied as	Mix with	Requires drying	Curing temp °F	Resistance to					
					Water	Oil	Gasoline	Glycol	Heat	Cold
Epoxy	Liquid	Hardener	No	70 to 250	F-G	E	E	G	F	G
	Powder	----	No	250 to 500	F-G	E	E	G	G	G
	Rod	----	No	250 to 500	F-G	E	E	G	G	G
Polyester	Liquid	Hardener	No	70 to 220	G	E	E	E	G	M
Phenolic-vinyl	Liquid	----	Yes	240 to 500	E	E	E	E	G	G
	Film	----	No	240 to 500						
Phenolic-nitrile rubber	Liquid	----	Yes	325 to 500	E	E	E	E	E	P-G
	Film	----	No	325 to 500						
Phenolic-neoprene	Liquid	----	Yes	325 to 500	E	E	E	E	G	E
	Film	----	No	325 to 500						
Phenolic-nylon	Liquid	----	Yes	325 to 500	G	E	E	G	F-M	G

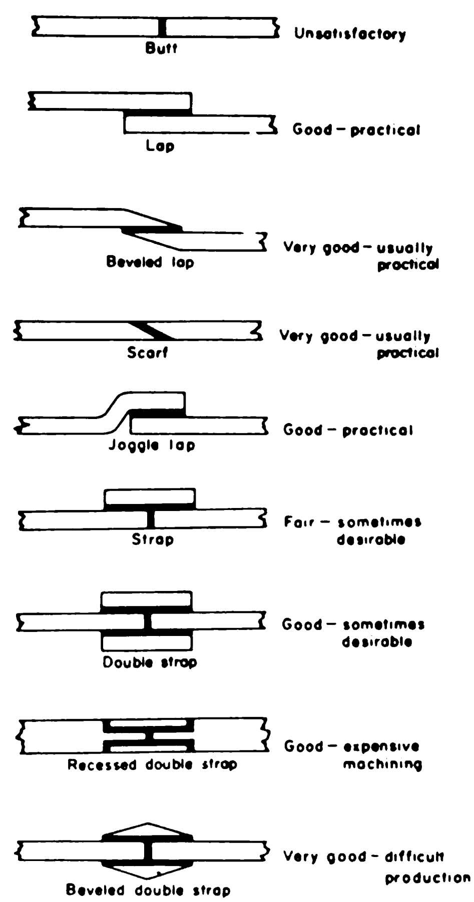
Code: E, excellent; G, good; M, moderate; F, fair; P, poor.

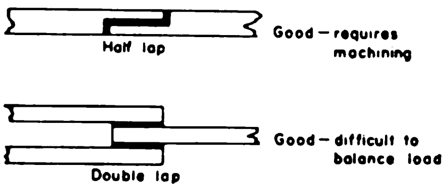
4.4.7.9.3 Solvent Release. Solvents are used only to facilitate spreading of the adhesive and to set the surfaces to be cemented. On reverting to its viscous or semisolid state, the adhesive becomes stronger. On further drying to a solid state, maximum strength is attained. After application, the strength and cohesion of adhesives should be allowed to develop fully without disturbance during solvent release. Temperature and humidity affect the rate of evaporation and should, therefore, be carefully controlled in accordance with the manufacturer's instructions. If surfaces harden beyond the tacky stage they can be reactivated with a "flash" of solvent just before joining. Where the tack of the adhesive is stable for a long time, contact under slight pressure is adequate. The adhesive should be kept free of dust and other foreign matter before joining.

4.4.7.9.4 Use of Heat. Thermoplastic adhesives may be reactivated or softened by infrared heat or other methods. When sufficient tack is developed, pressure may be applied to bond the joint.

Heat- or accelerator-cured adhesives are applied wet and the parts pressed together. Because of the short pot life of some adhesives, it is better to reduce the amount of accelerator and depend more on heat curing.

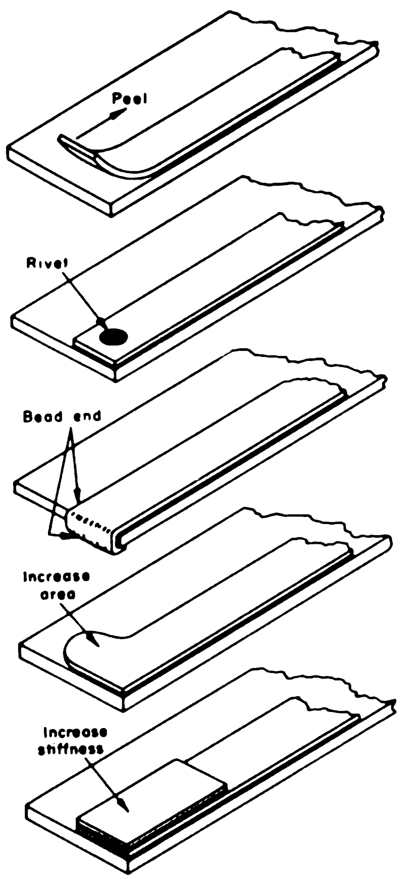
4.4.7.10 Adhesive Joint Design. Since most of the adhesives used for bonding metal to metal are relatively rigid, strong in shear, and weak in peel strength, joints are usually designed to place the adhesive in shear and prevent or minimize peel stresses. Butt joints are not satisfactory. Lap joints with square, tapered, or scarfed ends are good. Materials should overlap at least 15 times the thickness of thin sheets. It is best to provide as much contact area as possible as adhesives have less unit strength than metal fasteners. Joints should be designed so that tensile and shear loading bring the whole adhered area into play. Various types of joints are shown below and on the opposite page.





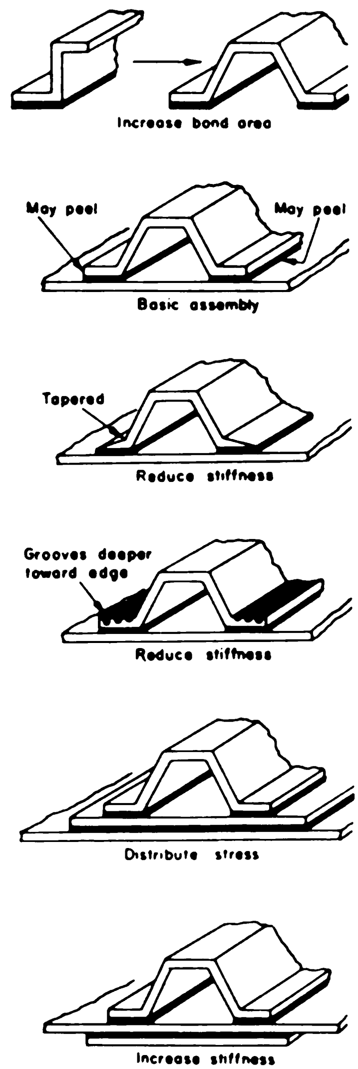
ADHESIVE JOINTS
FOR FLAT METAL

Peel or stripping strength of adhesives is rather low: about 10 to 65 lb per linear inch. Peel stresses can be reduced by increased areas, wraparound ends, and supplementary rivets, as shown below.



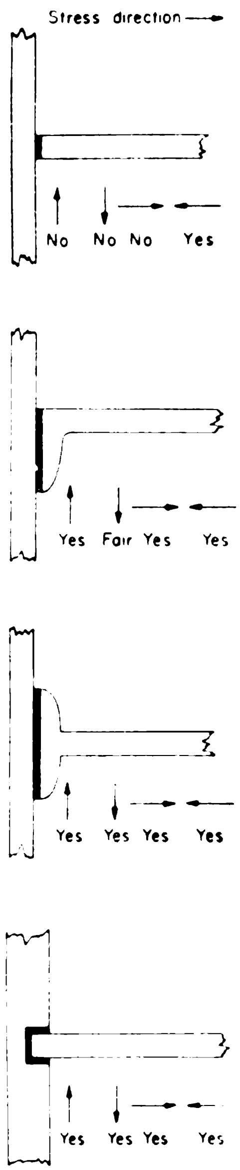
METHODS OF MINIMIZING
PEEL STRESSES

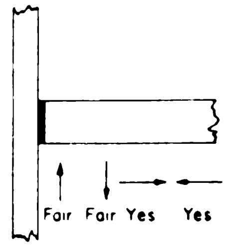
Thin sheets to which stiffening members are cemented may deflect in service producing peel stresses. When the flanges on the stiffeners are made to deflect with the sheet, minimum difficulty from peel is expected. Typical means of changing stiffness are shown below.



METHODS OF REDUCING
PEEL STRESSES

In bonding heavy sections, parts should be designed so that the adhesive is in shear. Peeling stresses can also be minimized by increasing the area in tension, as illustrated below.





INCREASING BONDED AREA

4.5 BIBLIOGRAPHY

Reference books to aid designers, who may require additional authoritative information on the subjects covered in this chapter, are listed below.

Design Work Sheets. Compiled by the editors of Product Engineering. McGraw-Hill. Published periodically.

Engineering Tables. American Society of Mechanical Engineers, 1956.

Fasteners Handbook. J. Soled. Reinhold Publishing Corporation, 1957.

Handbook of Fastening and Joining Metal Parts. V. H. Laughner and A. D. Hargan. McGraw-Hill, 1956.

Handbook H28; Screw-Thread Standards for Federal Services, U. S. Department of Commerce, National Bureau of Standards, 1957.

Machining; Theory and Practice. American Welding Society, 1955.

Mechanical Design for Electronics Production. J. M. Carroll. McGraw-Hill, 1956.

Mechanical Engineers Handbook. L. S. Marks, editor. 6th ed. McGraw-Hill, 1958.

Metals Engineering; Design. American Society of Mechanical Engineers, 1953.

Metals Engineering; Processes. American Society of Mechanical Engineers, 1958.

Metals Handbook; 1948 Edition. (See also 1954 and 1955 Supplements). American Society for Metals.

Modern Plastics; Encyclopedia Issue. Breskin Publications, Inc. Published annually.

Product Engineering; Design Digest Issue. McGraw-Hill. Published annually.

Tool Engineers Handbook. American Society of Tool Engineers. McGraw-Hill, 1959.

Welding Handbook. Section I. American Welding Society, 1957.

The designer should also refer to current issues of applicable serial publications to obtain up-to-date information on the subjects covered in this chapter.

Chapter 5

PROTECTIVE COATINGS

5.0 NEED FOR COATINGS

Protective coatings of various types are applied to the surfaces of electronic equipment and parts to protect against deterioration by corrosion, abrasion, and rough handling. Such coatings often enable the use of cheaper or less critical basic materials.

Coatings are also used for sealing, improving paint adhesion, improving solderability, increasing or decreasing reflectance, and for decoration. Nonmetallic coatings are used to provide or enhance electrical insulating properties. Metallic coatings are used to improve electrical conductance of metallic surfaces, to enable soldering of connections to ceramic materials, and as conductors in printed circuits.

The following list rates various treated and untreated metal surfaces in the approximate order (top to bottom) of their need for additional corrosion protection.

a. Magnesium alloys
b. Untreated magnesium
c. Untreated steel and iron, and their alloys, except stainless steel
d. Steel or iron plated with chromium, nickel, copper, silver, or tin for other than decorative purposes.
e. Steel or iron plated with cadmium, zinc, terne, or lead
f. Untreated silver, copper, brass, bronze, beryllium, lead, cadmium, zinc, babbitt, and all aluminum alloys
g. Untreated stainless steel, monel metal, alclad aluminum, or titanium
h. Any surface plated for decorative purposes

5.1 SURFACE PREPARATION

Before the application of any protective or decorative coating, it is essential that the surface be clean and properly prepared. Various methods of surface preparation are discussed below.

5.1.1 Cleaning Methods

The choice of cleaning method depends on the metal to be cleaned, type of soil to be removed, and the coating to be applied. Oils and greases are generally removed by organic solvents or alkaline detergent baths; tarnish, rust, and scale are removed by acid baths or special alkaline processes. The speed of the cleaning process may be increased by using the bath as an electrolyte. The work is suspended from a rod in the electrolyte and is made cathode or, if applicable alternatively cathode and anode. This method is advantageous when burned-on or thick deposits must be removed.

When more than one bath is required for cleaning, water rinses or sprays are used to remove the adhering solutions from one bath before immersion in the next. Hot water rinses are often required to remove the last traces of products resulting from chemical cleaning since these might affect adhesion, subsequent processing, or performance of the protective coatings to be applied.

Ultrasonic methods may be employed for cleaning (or degreasing) metal parts. Dirt, grease, chips, lapping and honing compounds, and metallic dust can be removed from metallic materials by this method more quickly and thoroughly than by conventional methods. Ultrasonic cleaning is primarily used for cleaning small precision parts when speed of cleaning is of prime importance and conventional methods are not sufficiently thorough.

5.1.1.1 Steel. Vapor degreasers, organic solvents, single-phase and diphase solvent-emulsion cleaners, and alkali baths are used for removing oils and greases. Heavy burned-on soils may require pressure-spray cleaning. Electro-chemical treatments in near-boiling alkaline baths are sometimes used with the work treated as cathode, or alternatively cathode and anode. Acid dips are used to remove smut or light oxide films and to brighten parts. This process is called "pickling", "bright dipping", or "pickle polishing".

Low carbon steels rarely require hydrogen embrittlement relief after cleaning. Steels with more than 0.35 percent carbon and case-hardened steels of hardness greater than Rockwell C40 should be relieved by heating at 350° to 400°F for at least 2 hours. Ordinarily, this treatment will not materially affect hardness. In some cases, a mechanical test for relief of hydrogen embrittlement may be required. Springs being cleaned, plated, or coated must not be flexed until after treatment for hydrogen relief.

5.1.1.2 Stainless Steels. Removal of soils fron stainless steel may be carried out as described in 5.1.1.1. Alkali cleaning is preferred. On exposure to air, stainless steels quickly develop a thin, tenacious oxide film. Passivation treatment (see 5.2.2.2.4) is used to increase corrosion resistance by formation of a passive film and to remove embedded particles of other metals. This film prevents adhesion of plating so that, immediately before or during electroplating, the film must be removed. If hydrogen is evolved in the film removal, hydrogen embrittlement must be relieved as described in 5.1.2.

5.1.1.3 Cast Iron. The surface of cast iron should not be disturbed any more than necessary. Prolonged cleaning or pickling develops carbon smuts that are difficult to remove. If not removed, they seriously interfere with the adhesion of subsequent coatings. Hydrogen embrittlement is not a problem in cleaning cast iron, but if nickel or chromium platings are to be applied to cast iron, occluded hydrogen will adversely affect adhesion of the electro-deposit and must, therefore, be removed by suitable heat treatment after plating.

5.1.1.4 Copper and Brass. The surfaces of copper and brass tend to pick up solid particles which are sometimes difficult to remove. For cleaning, vapor degreasers, solvents, etc. are used. Special cleaners of controlled alkalinity or with inhibitors are available. Bright dips (usually acid) and stain removing chemicals are frequently used.

5.1.1.5 Zinc. Solvent-type cleaners may be used to remove grease and oil. Alkaline and acid cleaners attack zinc and should not be used without proper control. Anodic cleaning is preferred to cathodic as the film produced is more easily removed in the subsequent acid bath. Cleaners especially formulated for zinc die castings are available. A mild acid dip to neutralize the last traces of alkaline products is often used.

5.1.1.6 Aluminum. Aluminum should not be allowed to pick up metallic particles during processing. These are difficult to remove and may cause destructive electrolytic action. Strong alkaline cleaners attack aluminum, but cleaners of controlled alkalinity may be used. Anodic cleaning is not used. A bright etched surface may be obtained by using a hot alkaline solution with accurate control of time of immersion.

5.1.1.7 Magnesium. Unlike aluminum, magnesium is not appreciably attacked by caustic solutions. Heavy duty alkaline cleaners of the type used for steel are satisfactory, particularly for removal of old chrome pickle, dichromate coatings, oil, or grease. Acid pickles are used to strip off up to 0.002 inch of metal to assure the removal of embedded soils. The various types of pickles remove part of the surface, and the designer should, therefore, indicate dimensional tolerances for the finished items.

5.1.2 Hydrogen Embrittlement

Cleaning and other treatments in which hydrogen gas is released (pickling, plating, cathodic cleaning, and acid brightening) may result in occlusion of this element by the metal. With high carbon or surface-hardened steels, this occluded hydrogen may cause embrittlement and consequent failure of the part in service; provision must be made for its removal. Typical hydrogen-removal treatment is to heat the parts at 300° to 500°F, from 2 to 5 hours. The need for such treatment to relieve hydrogen embrittlement is indicated in the text.

Absorption of hydrogen causes internal pressures to develop in the surface of steel, with a resultant reduction of fatigue strength and ductility. Occluded hydrogen may also produce blistering, cracking, gas pits, peeling, and generally poor coating adhesion.

Although it is common practice after plating to heat treat a part for several hours at temperatures up to 500°F, the complete removal of hydrogen is not always attained, particularly where a relatively thick electrodeposit exists. This is especially true of cadmium or zinc deposits, which act as efficient barriers to hydrogen effusion. A simplified, more effective technique has been developed for the relief of hydrogen embrittlement in such deposits. This process involves first flash plating the part, i.e., depositing a thin layer of the plating metal, next baking the part to release occluded hydrogen, and then completing the electroplating operation by depositing a coating of any desired thickness. The baking time is shorter than that normally required, and the part will not require additional hydrogen relief treatment after the full plate is deposited.

This process has been evaluated and is being used for cadmium-plated steel parts, but it may be applicable to other electroplates as well.

5.2 COATINGS

Coatings may be divided into three main types: metallic, chemical conversion, and painted coatings. Metallic coatings are often subjected to chemical conversion to provide additional corrosion resistance.

5.2.1 Metallic Coatings

Electrodeposited metal coatings useful in the electronics field are discussed below.

Some general rules regarding the use of metallic coatings are:

a. Parts should not be ground or machined after electroplating - drawing should allow for coating thickness by specifying dimensions after plating.
b. Thicker coatings usually afford better corrosion protection, but they are more expensive, and economy demands use of the thinnest adequate coating.
c. The end use of the part to be plated is the governing factor in selecting a particular coating (see 5.5).
d. Choice of one coating material over another should be determined by cost and degree of protection afforded by alternative materials.
e. Surfaces must be properly prepared. Adequacy of metallic coatings is directly dependent on pretreatment of the surfaces to be plated (see 5.1).

It is also advisable to refer to applicable Government specifications for performance requirements and tests. The following table lists a number of Government specifications covering metallic coatings.

METALLIC COATING SPECIFICATIONS

Specification No.	Title	Discussed in Paragraph No.
QQ-C-320	Chromium Plating (Electrodeposited)	5.2.1.1.2
QQ-P-416	Plating, Cadmium (Electrodeposited)	5.2.1.2
MIL-C-14550(Ord)	Copper Plating,(Electrodeposited)	5.2.1.3
QQ-N-290	Nickel Plating (Electrodeposited)	5.2.1.4.1
MIL-P-14535(Ord)	Plating, Black Nickel (Electrodeposited)	5.2.1.4.1
MIL-P-18317(Nord)	Plating, Black Nickel (Electrodeposited) on Brass, Bronze, or Steel	5.2.1.4.2
QQ-Z-325	Zinc Plating (Electrodeposited)	5.2.1.5
MIL-Z-17871	Zinc-Coating (Hot-Dip Galvanizing)	5.2.1.5
QQ-T-425	Tinplate (Hot-Dip and Electrolytic)	5.2.1.6
MIL-T-10727(Ord)	Tin Plating: Ferrous and Non-Ferrous Metals	5.2.1.6
MIL-L-13808(Ord)	Lead Plating (Electrodeposited)	5.2.1.8
QQ-S-365	Silver Plating (Electrodeposited)	5.2.1.9
MIL-G-45204(Ord)	Gold Plating (Electrodeposited)	5.2.1.10

5.2.1.1 Chromium. Electrodeposited chromium combines brightness with wear resistance not found in any other commonly used metal. It may be used in contact with rubber.

5.2.1.1.1 Decorative Chromium. The chromium electroplate used for decorative purposes is generally very thin and porous, and, by itself, is of little value for protection against corrosion. For corrosion resistance, chromium is deposited over a plating of nickel, copper, or a combination of the two. Copper is applied first to secure a tight bond to the base, followed by nickel. The latter is much harder than the copper and affords a good intermediate for the still harder chromium. If chromium is plated directly onto a relatively soft metal, the harder chromium film (about 1000 Brinell) will crack, split, or flake off.

The combined thickness of undercoats of copper and nickel ranges from 0.5 to 2.0 mils (0.0005 to 0.002 inch). Chromium plating over copper-nickel is usually 0.01 to 0.02 mil thick.

5.2.1.1.2 Engineering Chromium. Engineering chromium plate is bright chromium with a hardness of about 1020 Brinell. In addition to its hardness, the good resistance to seizure is of advantage. Other chromium platings such as "burned" deposits (generally nodular) up to 1165 Brinell hardness, "milky" types (due to low current densities) which average about 830, and matte or dull, as low as 640 are not used for engineering plating.

Engineering plating may vary from 0.01 to 10.0 mils depending on the application. As a general rule, plating is applied 1.0 to 3.0 mils thicker than required for the finished item to allow for honing, lapping, and polishing to final dimensions.

Specification QQ-C-320 covers different classes of chrome plating; MIL-E-16400 gives requirements for electronic equipment.

5.2.1.1.3 Crack-Free Chromium. Crack-free chromium plating provides a deposit which is light gray, matte, and can be buffed to a high luster. The bath used has good throwing power. When heated to 1000°F and then plunged into cold water it remains adherent and crack-free. Moreover, it has marked leveling properties. A plating of 0.3 to 0.4 mil applied over a 30 to 50 microinch surface roughness gives a final finish of 3 to 7 microinches. This plating applied directly on a steel base has corrosion resistance equivalent to that offered by the standard copper-nickel-chromium composite. The plating is softer and more ductile than those described above.

5.2.1.2 Cadmium. Cadmium protects by sacrificial corrosion. Electroplating baths have excellent throwing power, while barrel plating is a good process for screws and small hardware. Cadmium applied directly to steel is more resistant to moisture and salt air than zinc; consequently, it is commonly specified for Naval applications. It has less resistance than zinc to industrial atmospheres. Cadmium is a strategic metal and more expensive than zinc.

Cadmium plating develops white nonadherent corrosion products when exposed to moisture, humid tropical conditions, or marine atmosphere, and, therefore, should be given a supplementary chromate treatment. For items to be painted, the surface should be phosphatized for additional protection and to provide a good adhesive surface for the paint. See Specification QQ-P-416.

Cadmium plating should not be used in unventilated equipment where unstable organic materials are present. Such materials as impregnated paper, cloth, sealing compounds, some plastics, and paints that contain vegetable oils decompose under elevated temperature and humid conditions, forming volatile organic acids which will attack cadmium, especially where moisture is present.

Cadmium coatings may be deposited to a thickness of about 0.3 mil in 10 minutes of immersion electroplating. When the cadmium is plated by the barrel process, it takes about 30 minutes to deposit a 0.3 mil coating.

Cadmium plating is used in thicknesses ranging from 0.2 to 0.5 mil. A coating of about 0.5 mil is recommended for work which will not be painted. Thinner plating, about 0.2 to 0.3 mil, is used where dimensional tolerances limit thickness, or where painting is to be done. Platings range from dull to bright but the latter should not be used on exterior surfaces.

Cadmium is deposited directly on the basic metal without preliminary plating except in the case of parts made of corrosion-resistant steel. For this metal, a preliminary coating of nickel is permissible prior to cadmium plating. Resistance to abrasion is very poor, as hardness is only 35 to 50 Brinell. Any welding should take place before plating with cadmium because cadmium fumes are poisonous.

Cadmium has fair solderability, but where this is important, an alloy with 20 percent zinc should be used. This alloy also is more corrosion resistant than cadmium and as easily plated.

5.2.1.3 Copper. Copper electroplating on ferrous alloys is used as an undercoat for nickel or chromium plating and to improve electrical conductance and solderability. However, copper stains or tarnishes quickly and requires lacquering if luster is to be retained. Sulfides and marine atmospheres corrode copper. Copper plating 1.0 mil or more thick is relatively free of pores and affords good corrosion resistance, but is rarely used by itself or over an undercoat. Platings range in hardness from 60 to 150 Brinell, and are easily buffed smooth to serve as a base for deposits of other metals. By selection and control of plating baths, bright coatings can be secured without polishing, and platings varying in hardness may be produced.

As an undercoat for nickel plating, copper should be about 0.6 mils thick. To improve electrical conductance, copper coating should be 0.5 to 1.0 mil thick. Copper plating is generally given a water-dip lacquer coat to minimize soiling and fingerprinting during assembly and to retard tarnishing in service. The thin lacquer coat does not interfere with soldering or grounding in assemblies secured with bolts or rivets.

To improve solderability of ferrous metals, a copper plate about 0.3 mil thick is used, sometimes with the addition of 0.2 mil of tin. For small items, a coating of 2.0 mils of silver may be used over the copper, plus a water-dip lacquer. For ease in soldering chromium-nickel stainless steel, a copper electroplate 0.3 mil thick followed by an electrodeposited tin coating 0.2 mil thick is recommended. Copper plating is also used as a stopoff for selective carburizing or nitriding.

Unless covered with zinc or cadmium, copper electroplates accelerate corrosion of aluminum and magnesium in the presence of an electrolyte.

5.2.1.4 Nickel

5.2.1.4.1 Metallic Nickel. Nickel electroplating is rarely used alone. It is used over an undercoat in a variety of applications because it has excellent corrosion resistance and good wear resistance. The plating can be bright, and hard or soft, as required, ranging from 150 to 500 Brinell hardness. Some electrolytically deposited nickel coatings are as hard as the softer chromium platings. The softer nickel platings are tough and more resistant to fracture than the harder coatings.

When thicker than 2.0 to 3.0 mils, nickel electrodeposits are practically pore-free with good corrosion resistance and sufficient hardness so that they can often be substituted for the more expensive copper-nickel-chromium plating. Nickel plating may be used over base metals (e.g., copper) that are not compatible with rubber.

Decorative bright nickel platings range from 0.3 to 1.5 mils on steel, and 0.2 to 0.5 mils on brass or copper. Engineering coatings, generally hard, range from 3.0 to 30.0 mils thick.

Specification QQ-N-290 covers various types of nickel plating.

5.2.1.4.2 Black Nickel. Black nickel suitable for providing a nonreflective surface on brass, bronze, and steel in optical equipment can be obtained by electrodeposit. The coating is nonmetallic (largely composed of nickel oxide and nickel sulfide) with poor adherence and ductility. It affords little protection against corrosion and is therefore suitable only for protected surfaces within equipment unless applied to a nonferrous undercoat or base. Very thin deposits withstand moderate bending. Black nickel can be deposited on copper, brass, nickel, cadmium, and zinc, or over electrodeposits of these metals. Smooth, adherent coatings can be obtained on zinc and cadmium. A nickel undercoat aids in providing greater resistance to scratching and marring.

Specification MIL-P-18317 discusses black nickel electrodeposited plating on brass, bronze, or steel; specification MIL-P-14535 discusses black nickel electrodeposited plating on zinc, cadmium, and nickel.

5.2.1.5 Zinc. Zinc protects by sacrificial corrosion with the degree of protection depending upon the thickness of the coating.

Normally, undercoatings are not used. However, corrosion resistance may be enhanced by supplementary chemical treatment.

Zinc coatings may be applied by electrodeposit, hot-dip galvanizing, spray, or chemical immersion (zincating). Electrodeposited coating thicknesses vary from 0.2 to 1.0 mil. Hot-dip coats may be as heavy as 2.5 ounces per square foot, and, because of the heating involved, may cause warping of the metals. Hot dipping is not suitable where even coatings and close tolerances are required. To prevent the formation of white corrosion products, a supplementary chromate treatment is applied. Such treatment is required for items exposed to marine atmosphere. When the article is to be painted, a supplementary phosphate treatment is used. See Specification QQ-Z-325.

Zinc plating baths have good throwing power and are particularly suited for barrel plating small hardware. Abrasion resistance is poor, with hardness ranging from 40 to 50 Brinell. Platings have excellent solderability and fair flexibility. Zinc is attacked by acids, alkalies, moist air, and live steam. It is seldom used where the temperature may rise above 212°F.

5.2.1.6 Tin. Tin coatings may be applied by hot dipping (tinning), spraying, immersion coating, or electroplating. Hot-dipped coats vary from 0.5 to 1.0 mil. For electroplating on copper bases, thickness should be 0.3 to 0.5 mil. On steel for indoor or protected service, thickness should be 0.1 to 0.3 mil; for outdoor or industrial atmospheres, 0.75 to 1.0 mil. Tin coatings are used universally to improve solderability, and, on steel, should be 0.1 to 0.15 mil thick. As a mask for selective nitriding, a 0.2- to 0.6-inch thickness is used.

The porosity of an electrodeposited tin coat may be reduced by melting and reflowing at about 50°F above the melting point of tin. Tin has good resistance to mineral acids, alkalies, and marine atmosphere. It should not be used where temperatures exceed 400°F. Platings have good flexibility but poor abrasion resistance.

5.2.1.7 Aluminum. Aluminum plating cannot be deposited electrochemically, but may be sprayed or applied by hot dipping. The latter improves the resistance of ferrous metals to corrosion and high temperatures. With subsequent heating, the aluminum coating will diffuse and alloy with the base metal. The surface has a hardness of Rockwell C 50 to 60. A coating averaging only 5.0 mils in thickness greatly improves the resistance of ferrous metals to oxidation at high temperatures.

5.2.1.8 Lead. Lead is a very soft metal with poor wearing qualities. Its use is restricted to applications where resistance to certain acids and other corrosive liquids is important.

Lead may be plated directly on ferrous and cuprous metals. Deposits of 3.0 mil are usually sufficiently impervious, but for severe conditions, coatings 50.0 mils or thicker are sometimes used.

5.2.1.9 Silver. Silver has good corrosion resistance but tarnishes rapidly in the presence of sulfides. It possesses excellent solderability. By application of very thin water lacquer or chromate coating, surfaces may be made resistant to tarnishing, while remaining solderable.

To improve the solderability of surfaces, such as those of terminals, a 0.3-mil silver electrodeposit is applied. For corrosion protection of nonferrous metals or for increasing conductance of base metals, a thickness of 0.5 mil is usually used. For electrical contacts, from 0.5 to 10.0 mils is used, the exact thickness depending upon pressure, friction, and electrical load. Silver plating should not be used when severe arcing or corona is likely to occur. Electrodeposited silver is covered by Specification QQ-S-365. For higher resistance to tarnishing, corrosion, and wear, a silver-indium diffusion coating can be used. (Refer to 5.2.1.14).

5.2.1.10 Gold. Gold is a noble metal and does not oxidize in air. It is used for plating electrical contacts and infrared reflectors. Platings from ordinary baths are very soft, with poor wearing qualities, but certain processes give fairly hard, abrasion-resistant coatings. Gold has good solderability and is used on some replaceable contacts. Gold platings range from 0.02 to 0.05 mil in thickness.

Acceptable gold electrodeposits can now be obtained in thicknesses up to 5.0 mils for special applications.

Gold coatings which are fine grained, dense, adherent, and uniformly thick, and which have good corrosion resistance, heat reflectivity, and emissivity characteristics can be obtained with commercially available processes. The deposits do not tarnish and are easier to solder than silver plate. Many of the difficulties normally encountered with silver plate are eliminated, although gold electrodeposits are usually more expensive than silver. The combination of a relatively thin electrodeposited gold plate over silver plating may be less expensive than a thick gold deposit and yet effectively improve tarnish resistance and solderability.

Gold plating is used on printed circuits, wave-guides, and electrical contacts. The gold deposits duplicate the contour of the surface to be plated and prevent galling in sliding and wiping types of electrical contacts.

5.2.1.11 Palladium. Palladium is finding increased application in the electronics field as a nontarnishable coating for silver-plated wave-guides and other parts. It is customary to apply a 0.5-mil coating of silver, then a 0.04-mil coat of palladium. Palladium electroplates are very sensitive to fingerprint staining.

5.2.1.12 Platinum. The platinum group metals (palladium, platinum, rhodium, osmium, iridium) are used as electrodeposits where high temperature resistance and arc resistance are major requirements. Rhodium and palladium are the most frequently used, but where continuous exposure to local temperatures up to 2000°F is required without oxidation, platinum plating is preferred to these metals. Fine-grained, uniformly dense, low-stress platinum electrodeposits are now producible in thicknesses up to 1.0 mil. An undercoating of nickel is generally recommended for platinum electroplate.

5.2.1.13 Rhodium. Rhodium is used for electrical contacts where a hard corrosion-and wear-resistant plating is required. The deposits are smooth and brilliant in appearance. Rhodium may be electroplated over copper, nickel, silver, palladium, platinum, gold, and most of their alloys. If the plating area includes soft solder, a copper undercoat should be applied, followed by a soft nickel coating. This improves both the appearance and wear resistance of the rhodium. In electronics, rhodium deposits up to 1.0 mil thick are now being used. However, deposits greater than 0.5 mil generally tend to become coarse-grained, brittle, and highly stressed, causing peeling of the plating from the basis metal. Certain proprietary processes are available which will provide deposits of 0.5 to 1.0 mil. These deposits exhibit good adhesion and are relatively free from locked-in stresses. Rhodium-plated surfaces exhibit relatively poor solderability unless the plate is extremely porous (usually not desirable), thereby allowing the solder to flow to, and alloy with, the basis metal.

5.2.1.14 Indium. Indium is a soft white metal of about the same color and reflectance as tin. Because of its low melting point (311°F), it may be diffused into copper, brass, bronze, lead, and silver, forming surface alloys. A silver-indium diffusion coating is used over silvered electrical contacts to obtain higher resistance to tarnish, corrosion, and wear. The silver coating 1.0 to 5.0 mils thick is plated with 0.1 to 0.5 mil of indium, depending upon service required, then heated and held at 350°F for 2 hours. The throwing power of indium in the plating bath is excellent.

5.2.2 Conversion Coatings

Conversion coatings are inorganic films on metal surfaces, formed either by electrolytic action known as anodizing or by chemical conversion. The films so formed are oxides, chromates, or phosphates of the metal treated and often of additional metals in the solution.

5.2.2.1 Anodizing. Aluminum and magnesium may be anodized by electrolytic treatment. The processes used for these metals are described below.

5.2.2.1.1 Anodic Treatments for Aluminum. Anodic treatment is widely used on aluminum alloys. The anodizing processes are identified by the electrolyte employed, e.g., chromic or sulfuric acid.

Anodizing produces a thin, inert, hard, durable oxide surface with excellent abrasion and corrosion resistance. Films range from colorless transparent to varying shades of gray, silver, and tan, depending upon the process and the alloy. The films readily absorb and retain dyes and serve as a good base for adhesion of paints.

Anodic films on aluminum have high dielectric strength, so anodizing should not be used on parts (such as chassis, panels, and racks) which may need electrical grounding. Such parts can be made of Aluminum Alloy 1100, 3003, 5052, 6053, 6061, 6063, 7072; or any equally corrosion-resistant alloy. Surfaces that are to be grounded may be cleaned with an inhibited alkaline cleaner without further treatment, or Specification MIL-C-5541 treatments may be used.

After formation, the oxide coating may be converted into the monohydrate by treatment in boiling water to increase the volume and close the pores. Anodic coatings may also be sealed by treatment in chromate or dichromate solutions. This adds to the protection and imparts a yellowish color to the coating. Copper-bearing aluminum alloys produce coats of relatively dull shades and lower durability. Silicon imparts a gray color, and alloys with more than 5 percent should not be used if bright dye colors are desired.

Although anodizing may be done in phosphoric, boric, boric-sulfamic, oxalic, and other acids, only the chromic and sulfuric acid processes covered by Specification MIL-A-8625 are approved for military applications. A tabulation of various anodic treatments for aluminum is given on pages 5-13 and 5-14.

5.2.2.1.2 Anodic Treatments for Magnesium. The various anodic treatments for magnesium are shown on page 5-15.

5.2.2.2 Chemical Conversion Coatings. Chemical conversion coatings are oxide, chromate, or phosphate films produced by chemical action on metal surfaces.

5.2.2.2.1 Chromate. Zinc- or cadmium-plated steel, zinc die castings, aluminum, copper alloys, magnesium, and silver plating can be chromated. The color of the film varies according to the base metal: colorless, blue, yellow, olive-drab, or bronze on zinc and cadmium; clear to brown on aluminum; clear to light brown on copper alloy; dark brown on magnesium; and pale yellow on silver. Darker shades are produced by heavier coatings. The coatings may be dyed red, black, blue, or green.

Chromate coatings have very poor abrasion resistance. Chromates on zinc and cadmium are not as hard as those produced on aluminum. All chromates increase in hardness with age. Chromate coatings on hot-dip zinc and on zinc alloys should meet the requirements of Specification MIL-C-17111.

Chromate films improve the adhesion of paint to metal. On silver, chromating produces a pale yellow protective film which has excellent resistance to tarnishing. Soldering is easy without precleaning.

Chromate coatings are used on zinc and cadmium

ANODIC TREATMENTS FOR ALUMINUM

Process	Characteristics of surface	Color	Dimensional increase mil	Notes
Chromic acid, Specification MIL-A-8625, Type I	Smooth, non-reflective	Clear (colorless) gray, or greenish-gray. Dye as required.	Not dyed: negligible. Dyed black: wrought, 0.15 cast, 0.1 to 0.4.	Film is about 0.05 mil thick. Excellent base for paint. Preferred to sulfuric-acid process on bolted, riveted, or spot-welded assemblies where solution may be entrapped. Not used on alloys with more than 7-1/2 percent total alloying elements or more than 5 percent copper. If not dyed, no sealing treatment required. Assemblies with nonaluminum inserts must be masked.
Sulfuric acid, Specification MIL-A-8625, Type II	Smooth, non-reflective	Clear (colorless) transparent to opaque. Dichromate seal gives yellow color. Dye as required.	Not dyed: negligible. Dyed black: wrought, about 0.15; cast, 0.1 to 0.4. Clear or dichromate seal: 0.05 to 0.2.	Most economical method. Film about 0.1 to 1 mil thick. Must not be used on assemblies where solution may be trapped. Dichromate seal used to improve corrosion resistance if yellow color not objectionable, as on castings. Items with non-aluminum inserts must be masked.

ANODIC TREATMENTS FOR ALUMINUM - continued

Process	Characteristics of surface	Color	Dimensional increase mil	Notes
Phosphoric acid	Smooth, non-reflective	Clear (colorless) transparent.	Negligible.	Clear, durable, hard film. Satisfactory base for subsequent electroplate coatings, in place of zincating chemical treatment. Alloys high in silicon or copper can be treated by modified solutions.
Battelle process	Reflective	Silvery.	Approximately 0.2 decrease.	To obtain high reflectance on aluminum sheet. Uses sulfuric-phosphoric acid bath.
Electro-polishing	Reflective	Silvery.	Negligible.	Reflectance 85 percent. Surfaces polished and anodized have clear, (colorless) transparent film with good outdoor corrosion and abrasion resistance. Clean with mild soap occasionally to remove grime and restore reflectance.
Hard anodizing	Smooth, non-reflective	Gray.	As required, usually 3.0 increase.	Good heat and corrosion resistance. Wear resistance comparable to hard chromium plating or cyanide case-hardened steel. Used on sliding parts. Coatings over 3.0 mils thick are porous and less resistant.

ANODIC TREATMENTS FOR MAGNESIUM

Process	Characteristics of surface	Color	Dimensional change mil	Notes
Caustic anodizing, Specification MIL-M-3171, Type V	Smooth, non-reflective	Light gray to tan.	Increase, 0.3.	For all alloys and shapes. Relatively high abrasion resistance. Chromate neutralizer, if required, imparts a yellow color, but provides a good paint base. Metallic inserts must be stopped off with lacquer. Good dielectric strength. Can be dyed.
Galvanic anodizing, Specification MIL-M-3171, Type IV	Smooth, non-reflective	Dark gray to black.	Negligible.	For all alloys and shapes. Use for alloys which cannot be dichromate treated, notably magnesium-manganese and magnesium-cerium alloys, Good paint base and good resistance to corrosion. Brass, bronze, cadmium-plated, and steel inserts not affected.

electroplatings for supplemental corrosion resistance, especially where there is exposure to marine atmosphere. Immersion in chromating solution causes precipitation of a gelatinous slime which becomes harder and more adherent upon rinsing, and much harder and more adherent on exposure to air. A certain amount of plating is removed in the process, and allowance must be made for this. Most processes produce a minimum chromate film thickness of 0.15 mil. The salt-spray resistance requirements for chromate-treated zinc and cadmium platings are given in Specifications QQ-Z-325 and QQ-P-416.

Chromate films on aluminum are often used in place of anodizing for paint bonding or to retard corrosion, and particularly to prevent intergranular corrosion.

On copper and its alloys, chromating is sometimes used to retard corrosion or to provide a good base for painting. The heavier coatings may be colored with organic dyes.

5.2.2.2.2 Phosphate. A phosphate coating on steel, zinc castings, zinc-plated steel, or aluminum increases paint adhesion and durability, which greatly improves corrosion resistance. If not painted, heavy phosphate coatings should be treated with rust-preventive oils. Phosphating is usually done by immersion in chemical baths, but some solutions may be sprayed or brushed on.

Manganese- or zinc-base type heavy phosphate coatings build up 0.2 to 0.6 mil. Accordingly, the design must provide for dimensional changes, except where the coating is used to break in bearing surfaces, or in drawing or extruding.

Treating solutions and phosphate coatings intended for paint bonding are covered by Specification MIL-C-490. Heavy phosphate coatings supplemented by preservative oils are covered by MIL-C-16232.

5.2.2.2.3 Black Oxide. Black oxide coatings on carbon steels are produced by a low-temperature, alkali-oxidizing process. A high-temperature, fused sodium dichromate process is used for stainless steels. Black oxide surfaces are oiled and used for sliding surfaces. Refer to Specification MIL-F-13924.

For copper or high copper alloys, Specification MIL-F-495 may be used. This gives a more scratch-resistant coating than that obtained by black nickel plating. Other processes are available for producing a jet-black color on zinc-base alloys and zinc electroplates.

5.2.2.2.4 Passivation. After treatment with an oxidizing agent, such as nitric or chromic acid, the surface of steel (and some other metals) becomes "passive" due to the formation of a thin oxide film which resists corrosion. This treatment is especially important for stainless steel which has been contaminated by embedded particles of other metals during machining, wire brushing, etc.

The usual treatment for ordinary chromium stainless steel is immersion for 15 to 30 minutes at 110° to 130°F in a 50- to 70-percent nitric acid solution, or in a solution of 20 percent nitric acid with 2 percent sodium dichromate. For chromium-nickel stainless, a 20- to 30-minute immersion at 120°F in a solution of 25 percent nitric acid is suitable, or the above nitric-dichromate solution may be used. After immersion, the parts should be rinsed in water and dried.

5.2.2.2.5 Treatments for Aluminum. Specification MIL-C-5541 covers chemical conversion treatments for aluminum. See also SAE Aeronautical Material Specifications AMS 2473, AMS 2474, and AMS 2475A.

Aluminum may be colored either by dyeing the anodic coating or by electroplating gold, silver, copper, or other metal over a zincate coating (5.2.2.3). Sulfuric anodizing baths produce the best coatings for dye work. Chromic acid anodic coats can be dyed, but the opaque nature of the film has a dulling effect. Fastness of dyes must be considered.

Various chemical treatments used to etch, brighten, or produce conversion surface films on aluminum are tabulated on pages 5-18 to 5-20.

5.2.2.2.6 Treatments for Magnesium. The various chemical treatments for magnesium are tabulated on pages 5-21 and 5-22.

5.2.2.3 Zincating. Zincating is a chemical process for rapidly forming a thin coating of pure zinc on clean aluminum or magnesium. Chemical action takes place when these metals are immersed in a solution of sodium hydroxide containing zinc oxide. This coating provides a base for electroplating and should be uniform and adherent to assure good bonding of the platings applied over it. A copper-base coat over the zinc film should be used before further plating with brass, copper, cadmium, chromium, silver, zinc, or nickel. The zincating process is particularly useful for metals whose cleaned surfaces develop thin, transparent oxide films upon exposure to air.

Electrodeposition of metals on aluminum and magnesium is possible over the coating produced by an electrolytic phosphoric acid bath. However, the zinc film produced by zincating affords a better metallic base and is the standard procedure. Successive platings may be applied if the necessary buffing, electrocleaning, rinsing, etc., are done between platings. Data on the various electrodeposited metal coatings which may be applied to zincated aluminum and magnesium are given on pages 5-23 and 5-24.

5.2.3 Painted Coatings

Painted coatings are applied by brushing, dipping, or spraying, and include pretreatment coatings, primers, paints, enamels, varnishes, and lacquers. Refer to NAVORD OSTD 52 for surface treatments, painting procedures, and systems approved for Naval Ordnance equipment. Data on surface preparation are given in 5.1.

CHEMICAL CONVERSION TREATMENTS FOR ALUMINUM

Process	Characteristics of surface	Color	Dimensional change mil	Notes
Caustic etch	Frosted	Silver white.	Approx 0.2 decrease.	Surface generally sealed with anodic film, lacquer, or enamel, which returns stock almost to original dimensions. For indoor exposure only. Chromatizing is preferred where good electrical ground is desired.
Oxidation	Oxide	Varies with alloy; usually yellowish-green after dichromate seal.	Increase about 0.02.	Applied by immersion bath, brush, spray, dip, or tumbling. Thinner, softer, more porous than anodic film, but more economical and easier to apply. Sealed in hot dichromate bath; may be dyed. Excellent base for paint. Nonconducting. Less resistant to corrosion than anodic film. Good for bulk treatment of small parts. Touch-up possible on damaged areas.
Phosphatizing	Complex phosphate	Iridescent yellow to green.	Increase 0.1 for paint base; 0.2 for better corrosion resistance.	Applied by immersion, brush, spray or tumbling. Improved by chromate seal rinse. Nonconducting. Cannot be dyed satisfactorily. Abrasion resistance relatively low. Less resistant to corrosion than anodic film. Adaptable to bulk treatment of small parts. Simplest and cheapest process for preparing surfaces for painting. Use only for paint base.

CHEMICAL CONVERSION TREATMENTS FOR ALUMINUM - continued

Process	Characteristics of surface	Color	Dimensional change mil	Notes
Chromatizing	Thin film	Clear (thin coat) to yellow or brown for heavier coat.	Increase 0.01 to 0.02.	Applied by immersion, spray, brush, or tumbling. Improves weldability for shielded arc welding. Abrasion resistance relatively low. Less resistant to corrosion than anodic film. May be dyed and masked. Used as paint base and medium duty protection of unpainted surfaces, also on chassis and panels where electrical grounding is required. Good for small parts and touch-up of damaged areas.
Zincating	Pure zinc	Zinc.	Increase 0.2.	Zinc deposited by chemical action. Firmly adherent. Used where subsequent electroplate is to be applied.
Chemical polishing	Mirror-bright	Silver.	Negligible	Clear, transparent protective film with good abrasion and corrosion resistance. Up to 86 percent reflectance, not appreciablly dulled by anodizing. Good for outdoor service. Clean with mild soap to remove service grime.

CHEMICAL CONVERSION TREATMENTS FOR ALUMINUM - continued

Process	Character-istics of surface	Color	Dimensional change mil	Notes
Chromate	Complex chromic oxide	Varies; usually clear to yellow-ish iridescent	Increase 0.02	Applied by immersion bath, brush, spray, dip, or tumbling. Economical and easy to apply. Can be welded. Conductive. Can be dyed. More resistant to corrosion than anodic film. Can be used for all parts. Conforms to MIL-C-5541.
Phosphate	Complex phosphate	Varies; usually gray to irides-cent green	Increase 0.02	Applied by immersion bath, spray, dip or tumbling (not brush). Economical and easy to apply. Nonconducting. Can be dyed. More resistant to corrosion than anodic film. Usually used as pretreatment for painted parts. Conforms to MIL-C-5541.

CHEMICAL CONVERSION TREATMENTS FOR MAGNESIUM

Process	Characteristics of surface	Color	Dimensional change mil	Notes
Chrome-pickle, Specification MIL-M-3171, Type I	Smooth, Pebbled-on coatings	Yellow to yellow-red iridescent.	Decrease, 0.6 to 1.0.	Simple dip treatment. Cheapest, but not attractive in appearance. Does not affect bronze, steel, and cadmium-plated inserts. Attacks galvanized inserts, and etches brass and polished steel. Good paint base. For protection during storage and shipment, or touch-up. Sand and permanent mold castings usually treated by this process.
Chrome-pickle with $MgSO_4$	Smooth	Bronze.	None.	Low dielectric strength. Does not affect brass, bronze, cadmium, or galvanized inserts, but they may cause discolorization or discontinuity of film. Good for alloys containing more than 5 percent aluminum.
Chrome-alum	Smooth	Dark brown to black.	Negligible.	Does not affect bronze, steel, and cadmium-plated inserts. Attacks zinc, and etches brass. If item is to be painted, use less expensive chrome-pickle. Not good for prolonged outdoor exposure or severe service unless given additional paint protection. Good decorative finish for die castings.

CHEMICAL CONVERSION TREATMENTS FOR MAGNESIUM - continued

Process	Characteristics of surface	Color	Dimensional change mil	Notes
Dichromate, Specification MIL-M-3171, Type III	Soft, Smooth	Light brown to black.	None.	Does not attack inserts, studs, or bearings of brass, bronze, steel, or cadmium-plated steel, nor do they affect treatment. Attacks galvanized and aluminum inserts. Not suitable for manganese or rare earth alloys. Best combination of paint base and long tine protection for castings and most wrought alloys.
Sealed Chrome pickle, Specification MIL-M-3171, Type II	Smooth	Matte gray to yellow red iridencence, plus brown.	Decrease, 0.6 to 1.0.	Dichromate boil following fresh chrome pickle. Commonly used on wrought alloys, but also good for castings and welded assemblies. Good paint base. Long time protection. Avoid bright yellow coat which indicates excess acid.

ELECTROPLATED COATS FOR ZINCATED ALUMINUM AND MAGNESIUM

Metal	Thickness mil	Notes
Copper	0.5 to 2.0	For soft soldering, use 1.0 mil. As undercoat for nickel, use 0.4 to 0.6 mil.
Chromium	0.02 to 5.0	Best applied over undercoats of 0.1- to 0.2-mil copper and 0.2- to 3.0-mil nickel, buffed to attain polish desired. For abrasion resistance, film should not be less than 0.5 mil. For hard chrome (QQ-C-320), ground to dimensions, allow 3.0 mil excess for grinding and finishing. Hard coated metal should be heated to remove occluded hydrogen.
Porous chromium	Over 5.0	Plated over zincate or nickel undercoat, then etched; peaks leveled by honing; cleaned with hot, mildly alkaline blast to remove dirt from pores. Adhesion may be tested by heating to 500°F, which also removes hydrogen. Retains lubricant when used as a bearing surface.
Brass	0.5 to 2.0	Color ranging from deep bronze to light yellow obtained by altering plating conditions and formulations to match any brass or bronze color.
Nickel	0.25 to 1.0	Applied over zincate or phosphoric acid anodic coating. Best if 0.3- to 0.5-mil nickel is plated over 0.2- to 4.0-mil copper. Heavy coats give better corrosion resistance. For decoration, matching, or moderate abrasion resistance. Refer to Specification QQ-N-290.
Tin	0.7 to 1.0	For soldering, use 0.7 to 1.0 mil over zincate. For corrosion resistance, use 0.2 to 0.4 mil over 0.3-mil copper on zincate.

ELECTROPLATED COATS FOR ZINCATED ALUMINUM AND MAGNESIUM - continued

Metal	Thickness mil	Notes
Zinc	0.2 to 1.0	Over zincate, use 1.0 mil without supplementary treatment; 0.2 mil if phosphate treated (QQ-Z-325). For soldering, use 0.5 to 1.0 mil. The yellow chromate gives maximum corrosion protection.
Cadmium	0.3 to 0.5	When the cadmium is to be chromated, use a minimum of 0.3 mil of cadmium; for phosphatizing, use a minimum of 0.2 mil of cadmium.
Silver	0.5 to 10.0	Silver undercoat over zincate, then silver plate. For solderability use 0.3 mil; for contacts, 0.5 to 10.0 mils; for corrosion protection and increased conductance, 0.5 mil.
Gold	0.2 to 5.0	Nickel, brass, or copper undercoat. The color of thin gold plating will be light yellow over nickel, darker yellow over brass, and dark red over copper. Heavy gold coating has the color of pure gold.
Indium	0.1 to 0.5	Silver plate 1.0 to 5.0 mils over zincate, followed by 0.1- to 0.5-mil indium diffused for 2 hours at 350°F.
Rhodium	0.5 to 1.0	Where hard corrosion-resistant electrical contact surface is required, apply copper 0.2 mil over zincate, 0.5-mil nickel, then up to 1.0-mil rhodium.
Palladium	0.04	Nontarnishing coating for silverplate on waveguides and electronic components. Use 0.5 mil silver over zincate, then 0.04 mil palladium.

Phosphating solutions and pretreatment coatings (e.g., MIL-C-15328) contain phosphoric acid to etch the metal, which provides "tooth" for better bonding of primers.

5.2.3.1 Primers. A primer is a coating designed to adhere to a properly cleaned and prepared surface, aid in protecting metal against corrosion, and serve as a bond for one or more subsequent paint coats. Various primers covered by specifications are listed below.

5.2.3.2 Paints. Paints are mixtures of drying oils, resins, driers, thinners, and pigments. Drying starts with evaporation of the thinner and continues by chemical reaction (also called "drying") of the oils with oxygen and subsequent or simultaneous polymerization of resins and oils. The process usually requires several hours. Slow drying precludes use of most paints on electronic equipment made on fast-moving production lines. Approved paints for Naval Ordnance are listed in NAVORD OSTD 52.

SPECIFICATION PRIMERS

Spec. No.	Title	Notes
TT-P-641	Primer, Paint; Zinc Dust-Zinc Oxide (for Galvanized Surfaces)	For galvanized surfaces.
TT-P-664	Primer, Coating, Synthetic, Rust-Inhibiting, Lacquer-Resisting	Fast-drying, for use on bare or chemically treated ferrous metal surfaces. Suitable for use under synthetic enamel or lacquer-enamel top coats.
MIL-T-8585	Primer, Zinc Chromate	For general use, particularly over treated aluminum and magnesium.
MIL-P-15930	Primer, Paint, Vinyl-Zinc Chromate Type	Good undercoat for exterior service. Four coats of primer and two or more top coats are used for best protection.

5.2.3.3 Enamels. Enamels are paints that contain relatively large amounts of resins which impart a smooth finish. They are often fast drying, and may be obtained in various degrees of gloss, from lusterless to high gloss. Both air-drying and baking types are available. They are preferably applied to chemically-treated and primed metal surfaces. Enamels approved for Naval Ordnance are listed below.

SPECIFICATION ENAMELS

Spec. No.	Title	Notes
JAN-E-480	Enamel, Baking, Phenol- or Urea-Formaldehyde	Type I, phenol formaldehyde resin base, primarily for use over steel. Type II, urea-formaldehyde, for zinc-coated steel.
MIL-E-74	Enamel, Lustreless, Quick-Drying	Maximum specular gloss, 6 percent.
MIL-E-5556	Enamel, Camouflage, Quick-Drying	Lusterless enamel.
MIL-E-5557	Enamel, Heat Resisting, Glyceryl Phthalate, Black	Gloss black.
MIL-E-15090	Enamel, Equipment Light Gray	Class 1, gloss. Class 2, semi-gloss.
MIL-E-16583	Enamel, Electrically Conductive	For grounding static electricity only.
TT-E-489	Enamel; Gloss, Synthetic (for Exterior and Interior Surfaces)	For general use on primed exterior and interior wood and metal. Class A is brush- or spray-applied. Class B is sprayed-applied only.
TT-E-529	Enamel, Synthetic, Semi-Gloss	General use semi-gloss enamel.

5.2.3.4 Varnishes, Varnishes contain resins, or resins and drying oils, in a volatile solvent. The coatings are transparent or translucent and usually glossy. Baked varnishes are usually harder and more durable than air-dried types. Varnishes approved for Naval Ordnance use are listed below.

5.2.3.5 Lacquers. Lacquers usually contain cellulose compounds and synthetic resins in a volatile solvent. They dry rapidly by evaporation. While sometimes applied by brushing, they are generally sprayed. Hot spraying is used to achieve rapid coverage. Approved lacquers are listed below.

SPECIFICATION VARNISHES

Spec. No.	Title	Notes
MIL-V-173	Varnish, Moisture- and Fungus-Resistant	Phenolic base varnish for spray, brush, or dip application. Good moisture resistance and dielectric strength.
MIL-V-1137	Varnish, Electrical-Insulating	For electrical equipment. Air-drying or baking, black or clear.
MIL-V-1174	Varnish, Spar, Water-Resisting (Formula No. 80)	For general use. Phenolic resin, tung oil and linseed oil types. Vehicle for aluminum paint.
MIL-V-16399	Varnish, Moisture-Proof	Phenolic resin, tung oil type.
TT-V-51	Varnish, Asphalt	For waterproofing.
TT-V-109	Varnish, Spar, Alkyd-Resin	For general use.
TT-V-119	Varnish, Spar, Phenolic-Resin	Clear, air-drying. For exterior use on metal and wood.

SPECIFICATION LACQUERS

TT-L-31	Lacquer, Cellulose Nitrate, Gloss	For general use.

5.2.3.6 Heat-Resistant Painted Coatings. Silicone-base varnishes resistant to moderately high temperatures are usually applied by dipping or spraying, and must be baked at 350° to 425°F.

5.2.3.7 Fire-Retardant Paints. Alkyd-chlorinated rubber-base paints are used where fire retardance is needed. These paints are covered by Specifications MIL-P-17972, MIL-P-17973, and MIL-P-17974.

5.2.3.8 Moisture- and Fungus-Resistant Treatments. Most electronic equipment specifications require the use of materials which resist deterioration by moisture and fungus. Most susceptible to such deterioration are natural fats, proteins, callulose, and carbohydrates contained in such materials as leather, paper, cork, wood "fiber", hair, and wool. Unless protected, these materials may absorb water, swell, decay, mildew, or nurture fungi with consequent deterioration of electrical and mechanical properties. Note that materials of this type are often used as fillers in plastics and rubber, or as constituents of insulation, spacers, cushioning, packings, and gaskets. When use of such materials cannot be avoided, or when they are not protected by potting, immersion in oil, hermetic enclosure, or heat, they should be treated before assembly into the equipment by approved mildew-proofing treatments, moisture- and fungus-resistant varnish, or preservative such as those covered by the following specifications:

- O-L-164, Leather Dressing, Mildew Preventive
- TT-W-571, Wood Preservative, Recommended Treating Practice
- MIL-V-173, Varnish, Moisture- and Fungus-Resistant
- MIL-T-3530, Treatment, Mildew Resistant, for Thread and Twine
- MIL-T-20618, Treatment; Fire-, Laundry-, Dry-Cleaning- and Mildew-Resistant (For Cotton Fabrics)

5.2.4 Metalizing Nonmetallic Materials

Various methods of metalizing the surfaces of nonmetallic materials are now in use, particularly for printed circuits and components (see 3.7). By means of stenciling, stamping, or spraying, a plastic or other nonconductor can be given a metalized conducting surface layer, or necessary circuits for hookup of parts, such as inductors, resistors, and capacitors. Metalizing is also used to provide solderable connections on ceramic materials, glass, and quartz. The most commonly used metalizing methods are:

a. Chemical reduction
b. Spraying
c. Metal evaporation
d. Conducting paints
e. Gas plating

5.2.4.1 Chemical Reduction. In this process, a conductive film is formed by chemical reduction of a metallic salt solution, First, smooth surfaces of plastics are roughened, then sensitized by a stannous chloride solution, followed by deposition of the chemical reduction film. The latter can then be electroplated.

Silvering and electrolysis nickel deposition are examples of the chemical reduction method.

5.2.4.2 Spraying. Under controlled conditions molten metals, such as copper, can be sprayed and deposited on properly prepared surfaces of plastics or ceramics.

5.2.4.3 Metal Evaporation. This process consists of evaporating heated metal under low pressure and causing the metal vapor to deposit on nonmetallic surfaces. Coats of lacquer aid adhesion and protect the metal after deposition.

5.2.4.4 Conductive Paints. Conductive paints are usually fine powders with an organic binder applied to a plastic or ceramic and then air dried or baked. For wiring on printed circuits, conductive silver paints are applied by methods such as silk screening or transfer painting.

5.2.4.5 Gas Plating. Gas plating is a process of depositing metal by thermal decomposition of gaseous metallic compounds such as the carbonyls, nitrosyls, and hydrides. This process is quite rapid and requires little surface preparation.

5.2.5 Other Coatings

In addition to the commonly used protective coatings treated in the preceding sections, there are a number of newer or more specialized coatings and methods of applying them. Some of these which are used in electronic equipment are discussed in the following paragraphs.

5.2.5.1 Electrophoretic Coatings. Electrophoretic coatings are obtained by the process of electrophoresis which is the movement of charged particles dispersed in a liquid by the application of and electrostatic field. For example, if two electrodes are immersed in a suspension of the coating material and a potential is applied, a deposit of the suspended material forms on one of the electrodes. In practice, the article to be coated is made one of the electrodes, and its polarity is held opposite to that of the suspended coating material. The deposition is followed by bonding or structural unification of the coating layer with the substrate. Electrophoresis differs from standard electroplating processes since undissolved particles are deposited from dispersions rather than neutralized ions from solutions.

Many materials can be deposited by electrophoresis. Although commercial methods of electroplating are usually more economical, electrophoretic coatings may be preferable when the following special characteristics are required:

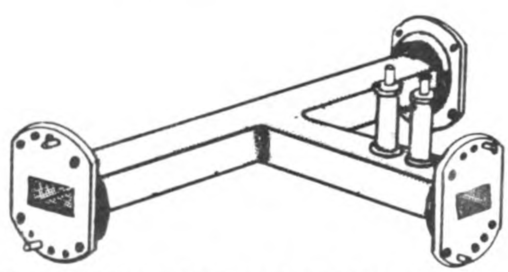
a. High thermal shock resistance
b. Reduced porosity of coatings
c. Carefully controlled thickness, density, and adhesion of coatings
d. Greater uniformity of thickness of coating on irregularly shaped objects.

Electrophoresis may also be used for the deposition of water-insoluble materials such as ceramics or refractories to form coatings with a high degree of resistance to wear and chemical attack.

In electrophoretic deposition of ceramics or refractory materials, an additional step is required to effect the bonding of the coating to the basis metal. Bonding is accomplished by sintering (controlled heating) or by the deposition of a metal binder coating between the final coating and the basis metal.

5.2.5.2 Electroforming. Electroforming or electrofabrication is a method of fabricating or reproducing an item by electrodeposition. The shape of the part is determined by a removable mold on which metals, such as copper, nickel, silver, and iron, are deposited. Other metals such as gold, chromium, lead, and certain alloys, can also be used if desirable.

Electroforming can be used for the production of intricately shaped parts, precision parts, and other special items, such as wave-guides and fittings, as shown below.



ELECTROFORMED WAVE-GUIDE

Electroforming is also used in the manufacture of printed circuits and other plastic-metal combinations.

The process is advantageous when the following characteristics are desired:

a. Extremely close tolerances (.0001 inch)
b. High surface finish (2 microinches)
c. Intricate shape
d. Precise duplication of detail
e. Close control of metallurgical properties (hardness, tensile strength, etc.)

Theoretically, there is no limit on the size of electroformed parts and deposit thicknesses ranging from a fraction of a mil to over one-half inch are obtainable. The process is particularly useful for small production runs where tooling costs would be unreasonably high.

Electroforming, however, is relatively expensive for most applications and production times are long. It should not be used where machining, casting, stamping, or other less expensive processes are satisfactory.

Unwanted scratches and other imperfections in the mold are reproduced along with the desired details, and for this reason the required mold or form must be extremely accurate.

5.2.5.3 Electropolishing. Electropolishing is the process of selectively dissolving a metal treated as an anode under suitable conditions to effect a smooth, brilliant surface. The process is the reverse of electroplating where metal is deposited on, rather than removed from, the work piece.

Electropolishing may be used as a machining process because it removes a controllable amount of metal from the work piece. As an added advantage, however, it produces surfaces free of scratches, strains, metal debris, smeared metal (Beilby layer), and embedded abrasives which are characteristic of mechanically polished surfaces. Irregularly shaped objects and parts difficult to machine mechanically are particularly adaptable to electropolishing.

Electropolishing is used not only to obtain a decorative surface, but also as a pretreatment for parts to be plated, to produce mirror surfaces, for precision machining, for deburring, and for relieving sharp corners and edges. Increased adhesion and corrosion resistance of a plated part results when an electrodeposited coating is applied over an electropolished surface as compared with the same coating over a mechanically polished part. This is due to the relatively stress-free substrate of the electropolished surface.

5.2.5.4 Barrel Finishing. Barrel finishing is a surface finishing operation particularly useful in the mass production of small parts.

Some of the advantages of barrel finishing over other methods of finishing are:

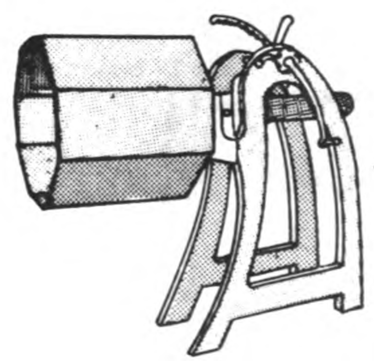
a. No need for skilled labor
b. Less manpower required
c. Higher productivity
d. Fewer rejections
e. Uniformity of all pieces in a single batch

These advantages result in a reduction of manufacturing costs.

This process cannot replace the buffing operation, if it is required, since it is impossible to avoid a very slight peening effect, or to localize the finishing action to one area of work in the barrel.

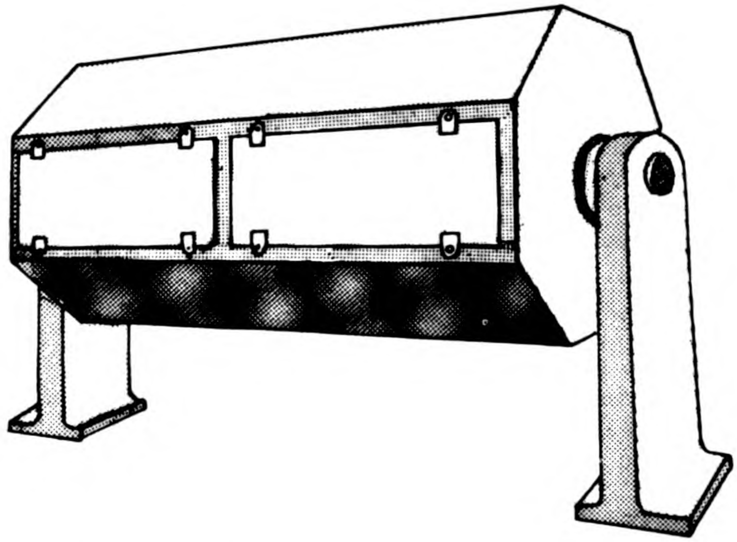
Although parts weighing from a fraction of an ounce to as much as 75 pounds have been barrel finished, there are restrictions on the size, shape, and weight of parts which can be satisfactorily handled by this method. In general, intricately shaped parts weighing more than 5 ounces and compact parts weighing more than one pound cannot be satisfactorily barrel finished.

The triple-action barrel is particularly useful for handling flat pieces because the inclined sides prevent the parts from clinging to the side walls.



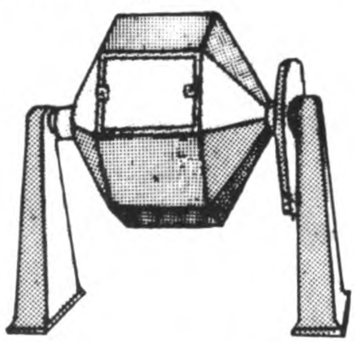
TRIPLE-ACTION BARREL

The standard horizontal barrel is available in many modifications and is particularly adaptable for use with heavy pieces.



HORIZONTAL BARREL

The oblique barrel permits rapid loading and unloading. This type of equipment can be adjusted to handle many sizes and shapes of work by changing the barrel angle.



OBLIQUE BARREL

There are various other types of barrel finishing equipment designed to meet the needs of a particular part or process.

5.2.5.5 Plasma-Arc Torch Coatings. The plasma-arc torch process is a recently developed method of producing coatings from materials with extremely high melting points. The process is relatively simple and will permit, theoretically, the deposition of any material which can be melted without chemical break down. Some of the materials which can now be satisfactorily deposited by this process are titanium, palladium, platinum, molybdenum, tungsten, and alumina (aluminum oxide). Almost any base material and any size part can be coated. Coatings produced by this method are dense and highly pure, with good resistance to heat and wear.

5.3 IMPREGNATION, ENCAPSULATION, POTTING, AND EMBEDDING

There are several processes in which liquids are used to seal, insulate, or support parts. The liquids may solidify by drying or by chemical action, or may remain in a semiplastic state.

Impregnation is used to seal pores in materials and to secure coil windings or other parts.

With thin liquids, spraying, painting, dipping, or immersion methods are used. Vacuum processing gives greater penetration and elimination of air pockets. Impregnation may be followed by encapsulation or embedding.

Encapsulation consists of dipping in fairly viscous plastics so that all surfaces are coated with a protective layer or shell. Impregnation can be combined with encapsulation by using a thinned first coat and allowing a soak or absorption period, followed by one or more heavier coats for encapsulation.

Potting consists of pouring a molten or liquid material into a component housing, such as a transformer case. The container becomes an integral part of the component, and the potting compound prevents shifting of parts or entrance of moisture and dirt.

Embedding is similar to potting, except that a temporary mold is used and removed after casting and curing.

5.3.1 Impregnation.

Impregnating materials include solutions or dispersions of bitumens (asphalts), waxes, and various resins including silicones and fluorocarbons. Service requirements, such as operating temperature range, vibration resistance, and dielectric properties, must be considered in selecting the most suitable impregnating materials. Some compounds are friable and pulverize under vibration. Soft compounds are apt to run or to fail to hold windings.

Specification MIL-I-2707 covers a liquid impregnating varnish. Specification MIL-V-1137 covers electrical insulating varnishes for general use.

5.3.2 Encapsulation

Encapsulation is an excellent means of protection for electronic parts, such as glass tubes and capacitors. Tubes may be treated by the following methods:

a. Insertion in resin-tight tube cans followed by encapsulation in epoxy resin.
b. Coating with silicone rubber and encapsulation in epoxy resin.
c. Coating with silicone oil and encapsulation epoxy-polysulfide rubber copolymer.
d. Encapsulation in polyester resin.

Where weight must be kept low, encapsulation in epoxy-polyamide should be considered. It adheres well to clean surfaces and does not require the use of tube cans. The parts should be given a thin coat followed by two thick coats. A release agent should be used on terminals and screw holes.

5.3.2.1 Fluidized Bed Coatings. A recently developed encapsulation technique called "fluidized bed coating" employs an epoxide or other thermosetting coating material in fine powder form. The process involves placing the object to be coated in an open-top chamber in which the coating powder is suspended by an air stream. The object is previously heated so that when the particles of plastic powder make contact with it, they adhere, melt, and coalesce with neighboring particles to produce the coating. When the required coating thickness has been deposited, the object is moved from the chamber to an oven for final resin cure. The epoxide powder is formulated so that it will not drain off during the curing process.

Coatings produced by the fluidized bed process are rigid and extremely uniform; they are moisture resistant and have good electrical properties. Even sharp edges and undercuts on electronic components or small parts are evenly coated. An object must be able to withstand preheating and curing temperatures of 250°F or higher, if it is to be coated by this method.

5.3.3 Potting and Embedding

Potting and embedding permit reducing the number of mounting attachments required to hold parts in place, and closer spacing is also often possible. Metal inserts may be used for heat dissipation.

5.3.3.1 Epoxy Resins. Epoxy resins are useful for potting or embedding, where parts can withstand their high curing temperatures. Specification MIL-I-16923 covers types for high-frequency, general purpose, and shock-resistance applications. Epoxys have outstanding adhesion to most clean surfaces, relatively low shrinkage, and excellent dielectric properties. By use of appropriate catalysts, hardeners, fillers, plasticizers, and diluents, epoxy resins can be modified to meet a wide range of operating conditions.

Epoxy resins may be blended with other resins, e.g., thiokols, polyesters, phenolics, nylons, and vinyls to modify properties.

Protective clothing, adequate ventilation, and a clean working environment should be provided for personnel handling epoxy resins and their curing agents. These precautions will minimize the dangers of dermatitis (a skin irritation) which may result from prolonged contact with these materials, and of irritation of the mucuous membranes which may be caused by breathing the fumes from the curing agents.

5.3.3.2 Silicones. Silicone rubber pastes are used to fill voids and calk terminal outlets. The pastes form rubbery solids, protecting lead wires from vibration and terminals from moisture and dirt. Silicone rubbers have better resistance to heat, oxidation, moisture, and weathering than ordinary rubbers. Commercially, they are supplied as two components to be mixed. Consistencies range from heavy and putty-like to viscous fluid. Upon mixing, the catalysts contained in the separate components combine, and the mixture vulcanizes without heat or pressure to produce a rubbery solid. Curing takes about 24 hours, and optimum physical properties are developed in 4 to 7 days.

Silicone resins possess good dielectric properties, and are particularly desirable for high temperature applications (up to 500°F), although they are relatively expensive. They are also resistant to fungus attack, do not crack on aging, and possess high thermal conductivity and low moisture absorption. In addition to their common usage in potting and embedding, silicone formulations are now available for encapsulation of electronic components and subassemblies. Silicone elastomers or rubbers are also widely used for gaskets, seals, electrical insulation, and other similar items. Glass fiber-filled silicones can be molded for extra mechanical strength, although this process is expensive.

Liquid silicones are available for use as dielectrics into which complete electronic assemblies can be immersed. Some of the advantages of liquid silicones are:

a. They are void-free
b. They act as good heat transfer media
c. They eliminate corona and resultant electrical interference
d. They afford protection against humidity and altitude
e. They permit appreciable space savings compared to gaseous dielectrics
f. They have good thermal stability
g. They are more economical than fluorocarbons and many other liquid dielectrics
h. They are relatively unaffected by frequency
i. They have little effect on materials with which they come in contact
j. Their dielectric properties are relatively unaffected by nuclear radiation
k. They insure a constant environment for the components and subassemblies which they protect

Some precautions which should be observed in the use of liquid silicones and other liquid dielectrics are:

a. Exposure to the atmosphere should be prevented
b. Even trace amounts of moisture in the compounds should be eliminated
c. Allowance should be made for their expansion at increased temperatures

5.3.3.3 COPU. Castor Oil Polyurethane or COPU is a low-viscosity liquid which cures without evaporation loss and with little heat generation or shrinkage to form a transparent, pale yellow, rubbery solid. It is relatively "dead" (without "bounce"), and thus has excellent shock-damping properties. It becomes harder but not brittle at low temperatures. Its electrical properties are good except at high frequencies.

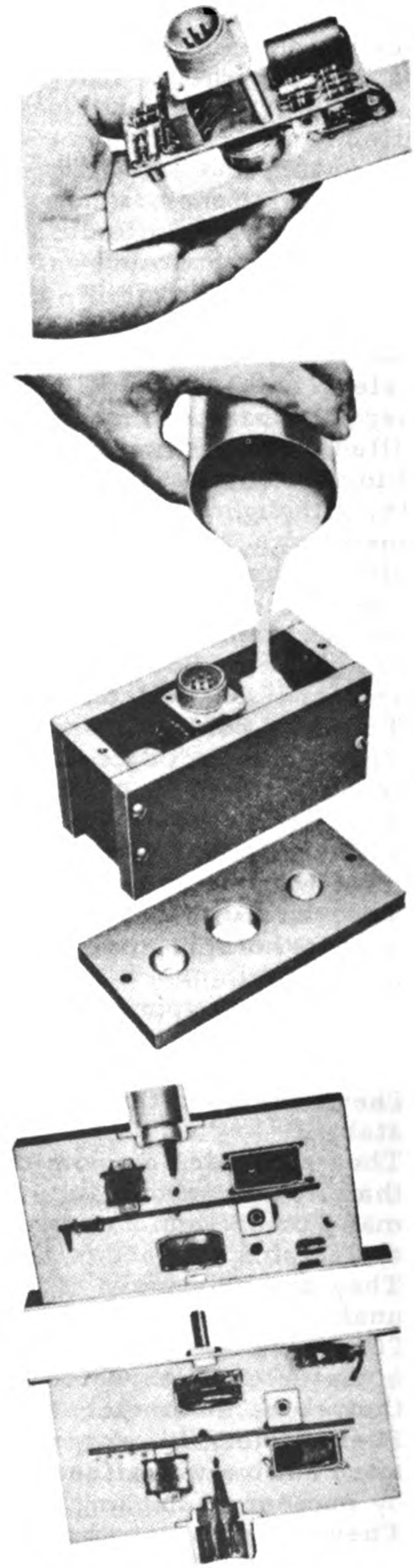
5.3.3.4 Cellular Types. Foamed-in-place plastics or elastomers, such as polystyrene and the polyurethanes, are used as embedding materials where weight must be kept low. When mixed and poured into place, the materials generate gas, and the resulting foam fills the mold. The cellular structure is advantageous where good thermal insulation is desired.

Another method uses tiny nitrogen-filled spheres of phenolic resin added to an epoxy resin. A mixture of resin and the preformed spheres is poured into the mold, leveled, and allowed to harden. This gives a cellular structure of very low, controlled density. There is no need to control volume to prevent overflow, as in the foamed-in-place method.

Various formulations are available to meet physical and electrical requirements. In the accompanying illustration, the assembly is first shown ready for processing. Next, it is shown inside the form with the compound being poured. The form has been treated with a release agent to permit easy removal. When the measured quantity has been added and evenly distributed in the form, the top plate is bolted in place with the connector extending through it, and the assembly set aside to allow foaming. Any excess compound will escape through the relief holes in the top plate. The completed unit is shown in section with all spaces filled.

5.3.3.5 Problems in Embedding. In using any of the available embedding compounds, their effect on the parts to be embedded must be considered. Compounds such as epoxys, which release considerable heat, may affect some of the materials in the parts and cause loosening of adhesives, separation of wires and resistor films, or cracking of insulators. In such cases, it may be necessary to use other types of embedding materials.

Expansion of parts in operation may cause cracking of rigid resins. Unequal expansions or shrinkages of parts and embedding material may cause loosening of windings or insulation. The use of metallic strips for heat



STEPS IN FOAM EMBEDDING

dispersal is often necessary. In some cases, it may be desirable to use encapsulation with a smaller amount of material rather than to embed.

Parts which are particularly sensitive to heat include germanium diodes and selenium rectifiers. Such parts, when used as tubes, are often encased in soft materials such as plastic sleeves, prior to potting or embedding.

Dissipation of heat is a problem in embedded circuits. Marked increase in the surface temperature of parts such as vacuum tubes is due to the poor thermal conductivity of the resins.

The weight of embedded units may be excessive in some applications and should receive design consideration.

Most casting resins have low resistance to strong oxidizing agents and should not be used in areas where such oxidants are present. Special casting resins are available which resist many oxidants and should be used to meet this special condition.

Moisture absorption and moisture transmission occur to some degree in all resins and must be considered in determinations of deterioration with time. Moisture transmission through the embedding compound will have a direct harmful affect on circuit elements. This difficulty can be somwhat alleviated by increasing the thickness of the resin.

Moisture tunneling into the embedment at the interface with metal leads can be serious. It is good practice to lessen the possibility of moisture tunneling by using solid, bare, single-conductor leads at the entry point, or to locate leads so that the plastic material shrinks onto the surface at which a seal is desired.

Embedded parts should be considered as expendable and replaceable as a unit because of the impracticability of repairs.

5.4 PRESERVATIVES

Preservatives are temporary coatings used to protect materials during transportation and storage, and to protect parts whose functions do not permit the use of permanent coatings. Preservatives should be readily removable by wiping or use of solvents. Preservation methods and materials are covered in Specification MIL-P-116, and include various films, oils, greases, waxes, wraps, barriers, desiccants, and containers.

5.5 SELECTION OF COATINGS

Selection of a suitable coating from the types described in 5.2 should be based on the type of exposure and other requirements such as abrasion resistance, surface reflection, and appearance. It may be assumed that Naval Ordnance electronic equipment will be exposed to the most severe marine environment. Therefore, exposed metals, both nonferrous and ferrous, must be given the most corrosion-resistant protection available. Conversion coatings of aluminum and magnesium alloys are covered in 5.2.2. Additional protection with paints is usually required for exteriors of equipment. Ferrous metals, except stainless steels, should always be phosphate coated (5.2.2.2.2), and if exposed to the weather, painted, using one of the systems given in NAVORD OSTD 52. Zinc- or cadmium-plated steel or iron should always receive a supplementary chemical treatment as described in 5.2.2.2 and be painted if protection against the weather is required. Various types of platings and treatments for wear resistance, decoration, and electrical purposes, are covered in 5.2.1 and 5.2.2. Metals plated with nickel, chromium, silver, gold, or the platinum metals are usually not painted.

5.6 DISSIMILAR METALS IN CONTACT

5.6.1 Galvanic Corrosion

Metals which are far apart in the electromotive series of elements, e.g., aluminum and steel, are subject to galvanic corrosion when in close contact. The more active metal, aluminum, is anodic to the less active (cathodic) steel and will be corroded by anodic action or oxidation. Similarly, iron in contact with copper will be corroded rapidly. Galvanic corrosion is particularly rapid where moisture or salts are present, as in marine or tropical environments. Specific information pertinent to galvanic corrosion is included in Table I of MIL-E-16400. This table presents a qualitative guide to what may be expected when different metals and alloys are combined with different area relationships in a sea water environment.

5.6.2 Similar and Dissimilar Metals

Metals may be grouped to show similarity. The metals in any one group are least likely to be corroded when in contact with one another. Metals in different groups will tend to corrode if placed in contact; and the farther apart the groups, the greater the tendency to corrode. This holds true for metal plating.

- Group 1 Magnesium and its alloys.
- Group 2 Cadmium, zinc, aluminum, and their alloys.
- Group 3 Iron, steel, lead, tin, and their alloys, except stainless steel.
- Group 4 Copper, copper alloys, chromium, nickel, silver, gold, platinum metals, and stainless steel.

5.6.3 Protection of Faying Surfaces

Surfaces of metals in contact are called faying surfaces. When such surfaces move with respect to each other (e.g., steel or bronze bearings), they are usually lubricated and require no other protection. Galvanic corrosion of faying surfaces which are fixed or fastened to each other depends on whether the metals are in similar groups (5.6.2).

Where it is necessary to assemble a combination of dissimilar metals, the following methods are used to minimize electrolytic corrosion:

a. Interposition of a metal compatible with each of the metals involved, e.g., zinc or cadmium plating.

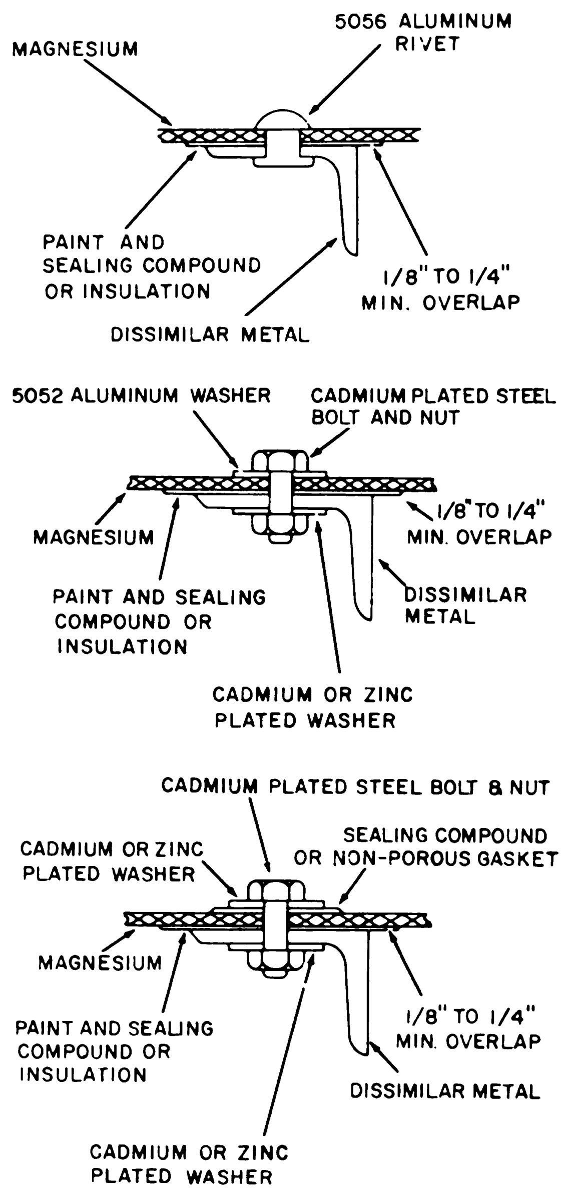
b. Interposition of inert nonmetalic materials such as gasketing or tape, Specification MIL-P-2829; or zincchromate primer, Specification MIL-T-8585.
c. Use of relatively large cathodic and small anodic metal areas.
d. Encapsulation or hermetic sealing to exclude moisture.
e. Use of a sacrificial cathode.

5.6.3.1 Methods for Magnesium Alloys. Magnesium alloy assemblies require great care to prevent electrolytic corrosion, and the methods employed illustrate techniques used for other metals. Although magnesium alloy surfaces in contact with each other may show only slight attack, good practice requires a coat of zinc chromate primer on the faying surfaces. Primers containing lead oxide pigments must not be used on magnesium.

Zinc-chromate impregnated tape or other insulation must be used where magnesium is in contact with dissimilar metals (5.6.2).

5.6.3.2 Fasteners. Electronic assemblies should be fastened with rivets, bolts, and screws of the same or similar metal as the parts fastened. Since fasteners of magnesium alloys are not available, those of other metals must be used. Where magnesium-to-magnesium, or magnesium-to-aluminum assembly is involved, the following aluminum alloys (given in order of preference) may be used: 5056, 6053, 6061, 5052, 6063. Rivets should be anodized or chemically treated before use.

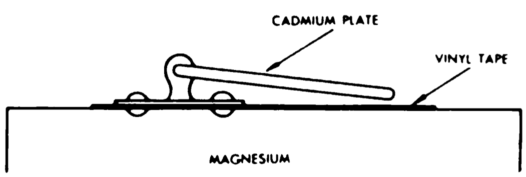
Where magnesium is joined to steel, the steel should be coated with one of the following (given in the order of preference): zinc electroplate; zinc, hot-dip; cadmium electroplate. Magnesium should not be used in contact with stainless steels, titanium alloys, aluminum alloys 2024, 3003, and 7075, copper, brass, or monel.



PROTECTION OF MAGNESIUM FROM DISSIMILAR METALS

5.6.3.3 Protection by Paint. Zinc chromate paint, Specification MIL-T-8585, may be used to separate dissimilar metals. Two coats, each thoroughly dried, should be applied to each faying surface.

5.6.3.4 Use of Insulation. Use of insulation to prevent corrosion of dissimilar metals is shown in the accompanying illustrations. Generous overlap of the separator is suggested to prevent bridging by moisture. Where a plastic sealing compound is used, it should be filleted or beaded to prevent contact at the metal edges. Increased protection can be obtained by giving the assembly an additional coat of zinc chromate paint. Sufficient allowance must be made for variations in thicknesses of such assemblies.



SEALING TAPES MUST EXTEND FAR ENOUGH TO PREVENT ANY POSSIBILITY OF GALVANIC ACTION

Lifting rings or other parts which may touch dissimilar metal may require an insulating membrane, as shown in the diagrams.

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Chapter 6

ELECTRICAL AND ELECTRONIC PARTS

6.0 GENERAL

This chapter deals with the selection, marking, location, interchangeability, and reliability of parts, and mounting methods for parts.

6.1 SELECTION CRITERIA

Selection of proper parts is a controlling factor in ease of construction since sizes, shapes, and functions largely determine the feasibility of layout, mounting, wiring and clamping.

Space utilization, miniaturization, and reliability requirements also must be considered.

The total number and variety of parts should be held to a minimum. Use standard parts whenever possible. In a particular model or series of models, parts should be of the same type and ratings as far as practicable.

6.1.1 Standard Parts

Federal and military specifications and standards for parts are issued to establish minimum requirements, reduce varieties, and assure interchangeability. Use of these standard parts is usually required by equipment specifications, and nonstandard parts, if necessary, must be approved by the contracting agency prior to use.

Approved electrical and electronic parts should be selected from the following:

- Coordinated Military Specifications and Standards
- Coordinated Federal Specifications and Standards
- Limited coordination Military, and interim Federal Specifications and Standards

6.1.2 Interchangeability

Mechanical and electrical interchangeability of parts must be assured regardless of supplier or manufacturer. Dimensions and tolerances which affect interchangeability must meet specification and drawing requirements to prevent the need for selective fitting and to assure adequate clearances.

Parts must not require special selection to obtain proper equipment performance within published recommended ratings. Avoid the need for special tools, fixtures, or procedures to replace parts.

Where close control of performance is required, special care should be taken to assure interchangeability or adjustability. For example, capacitors used in critically tuned circuits must be combined with adjustable padders to obtain correct operating values.

6.1.3 Reliability

Reliability of a part is the probability that it will operate within specified tolerances for a given economic life. Reliability may be measured in percentage of parts surviving the assumed life.

Reliability also involves compatibility and reproducibility. Compatibility is the adaptability of a part to efficient operation with other components and devices in the same circuit. Compatibility depends on both inherent characteristics and environmental effects. Reproducibility is the degree of uniformity of a part in manufacture.

Economic life is the minimum life in hours that may be expected or required for a particular component or device, with due regard for practical considerations. For components in industrial products, this time may be as much as ten years of daily, two-shift service, some 40,000 hours or more. For a guided missile, it may be only a few minutes more than testing and warm-up time.

A summary of relative reliability and failure data on electronic parts is tabulated below.

requirements or insufficient care in selection to meet operational and environmental requirements. Parts may fail because of overloading or subjection to conditions, such as temperature, vibration, humidity, or shock, for which they were not intended. Duplication of certain parts is sometines possible to prevent failure of the entire equipment. For example, relays and connectors used in simple parallel "redundant" circuits improve the over-all reliability of most equipment.

6.1.4 Repairability of Components. Components or subassemblies may be divided into three categories: fully repairable, partially repairable, and nonrepairable.

RELATIVE RELIABILITY AND FAILURE DATA

Part	Reliability percent	Common cause of failure	Percent of total failures
Carbon composition resistors	99	Open	50
Tubular paper capacitors (125°C)	98	Short	80
Transformers	98	Short	70
Wirewound precision resistors	96	Open	80
Deposited carbon resistors	92	Open	80
Connectors	92	Open or intermittent*	80
Tubes	50	----	---
Relays	25	Open or intermittent*	50

*Including variation in contact resistance

Part failures may be due to failure to meet specification

6.1.4.1 Fully Repairable. A fully repairable assembly should be designed so that all parts have maximum life expectancy, are easily accessible, and can be removed without special tools. Insulated parts should be used to eliminate the necessity of protective coatings.

6.1.4.2 Partially Repairable. In a partially repairable assembly, the replaceable parts should be chosen so that their life expectancies are approximately equal. Covers should be removable and replaceable without special tools. Tubes should be readily accessible.

6.1.4.3 Nonrepairable. A nonrepairable subassembly should have parts of approximately equal life expectancies. If casting resins are used, the entire subassembly should be readily replaceable.

6.1.5 Nuclear Radiation Effects

As a general rule, organic materials are more affected by radiation than are inorganic materials.

Gas tubes, particularly those used in control circuits, voltage regulator tubes, and oil-filled or oil-impregnated capacitors, are particularly susceptible. Some types of resistors have been known to change values while or even after being irradiated, but most carbon and wirewound resistors seem to suffer little damage up to about 10^{18} nvt.*

*Total neutrons, per square centimeter, i.e. neutron flux, nv (neutrons/cm^2/sec), multiplied by time, t, in seconds.

The characteristics of transistors and other semiconductor devices can be radically altered by the effects of radiation. In selecting transistors for resistance to radiation, the PNP Germanium (Ge) transistor is the least susceptible to radiation damage. The damage constant for this type transistor is in the order of 4×10^7 nvt.*

Tunnel diodes can withstand a greater amount of radiation than the best transistors. The radiation resistance of tunnel diodes also appears to be higher than some tubes, especially glass envelope types. Tunnel diodes using Gallium Arsenide (Ga As) are better than Ge or Silicon (Si) diodes in this respect.

Many materials for shielding components from the effects of nuclear radiation are now being developed and evaluated. For example, epoxy resins loaded with lead or iron have been produced for this purpose and are now commercially available in rod and sheet stock, or in liquid form as casting resins. Platings, coatings, or dispersions of boron and cadmium in a binder material are also being used for protection against radiation.

Certain inorganic materials, such as ceramics and carbides, are superior in performance to many organic materials such as polyethylene, polystyrene, nylon, neoprene, polyvinyl chloride butyl rubber, Kel-F, and Teflon, which are adversely affected by prolonged or excessive radiation and should not be used for shielding against radiation.

When nuclear radiation is a potential problem, components and shielding materials should be selected which are known to be unaffected by radiation, or which have been tested under specific service conditions which involve exposure to radiation.

6.2 USE OF ADVANCED-DESIGN ITEMS

The preceding paragraphs on selection criteria recommended that equipment designers use specification items wherever possible, but they are not intended to discourage the selection of products of advanced design which, although not yet covered by specifications, have distinct advantages. Existing specifications may be used as a pattern for tests to determine suitability.

6.3 LOCATION OF PARTS

The location of parts in equipment should be determined by careful evaluation of operating conditions, such as temperature, shock, vibration, accessibility, and circuit requirements.

6.3.1 Heat Transfer

Parts generating heat should be placed to allow good heat dissipation. Parts subject to deterioration at high temperatures should be located in the coolest spots available. A frequent design fault is to locate electrolytic capacitors in proximity to electron tube rectifiers. Sequential layout of parts in accordance with circuit diagram often neglects heat protection. The result is shortened service life of the equipment.

Electron tubes develop considerable heat and bulb temperatures are usually quite high. Although some of this heat is conducted from the tube through the base, the greater portion is dissipated by radiation. Electron tubes should be located near a panel or at the side of the equipment enclosure to utilize these surfaces as a heat sink.

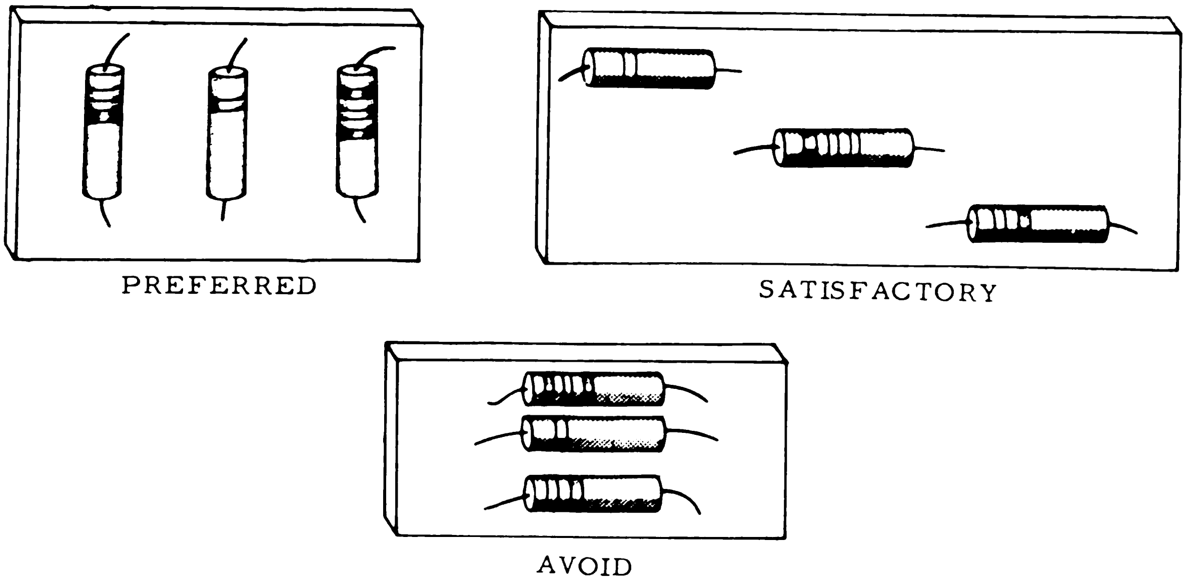
A reflective surface is sometimes used as a heat deflector to protect individual parts, but decrease of reflection with age lessens its usefulness.

The internal temperature of totally enclosed parts such as transformers may be quite high, so all possible means for rapid heat dissipation must be provided. Electron tubes should be located no closer to the housings of such units than is absolutely necessary.

Coils, tuning capacitors, and other frequency-determining elements should be located away from surfaces which are subject to large fluctuations in temperature.

Additional information on heat transfer can be found in 3.1.

6.3.1.1 Cooling Resistors. When several resistors are located in close proximity to each other, the spacing between them should be as great as possible to allow for heat dissipation. If the resistors are mounted on the vertical plane in a chassis, as is commonly done to conserve space, their axes should preferably be vertical. If it is not possible to mount them with the axes vertical, the resistor bodies should be staggered to allow adequate cooling, as illustrated below.



SPACING OF RESISTORS

Additional design techniques that may be utilized to provide effective cooling of resistors are as follows:

a. Clamp resistors to a heat sink
b. Use short leads
c. Mount resistors in free-flowing air
d. Mount single resistors over 5 inches in length vertically

6.3.1.2 Cooling Semiconductor Devices. Semiconductor devices are usually required to operate in small enclosures with critical parts subjected to high current densities. The low thermal mass gives very little heat storage capacity so that knowledge and control of circuit conditions is needed to stay within the overload capacities of the device.

Semiconductor devices are easily damaged by voltage surges and should be protected from such transients. In addition, consideration should be given to protecting semiconductor devices in case of sudden faults elsewhere in the circuit.

Voltage Surges: Voltage surges will occur when either the primary side of the power transformer or the load is switched on or off. In the case of power amplifiers, surges can occur as large currents are interrupted when either the excitation or the load is removed while power is still supplied. In some cases the interrupting switch can be selected to be slow acting. Otherwise, energy storage and dissipative elements must protect the semiconductor device: for example, a capacitor-resistor series circuit or zener diode in parallel with the device.

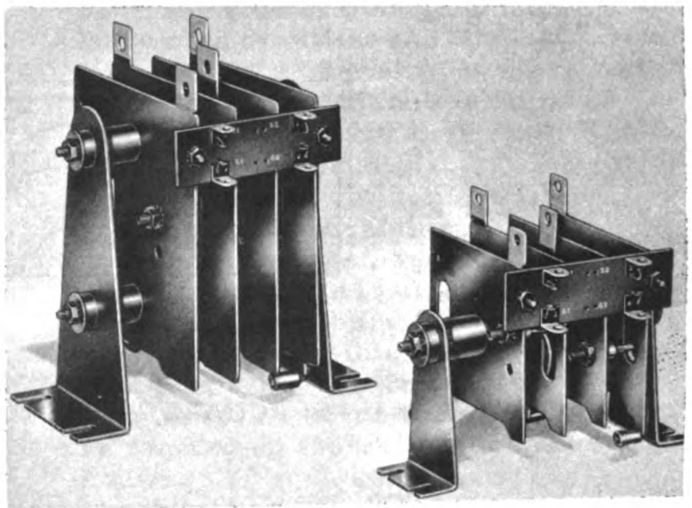
Fault Protection: Current limiting fuses or electronic circuit breakers should be provided to protect semiconductor devices against possible faults elsewhere in the circuit.

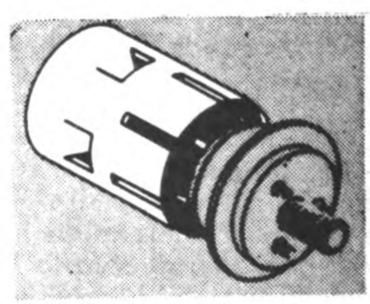
Most semiconductor devices are able to absorb a definite amount of transient energy prior to fuse blowout. This energy is given by the manufacturer as an I^2t rating. A fuse with a lower total rating can then be specified for protection. For data on specific I^2t ratings, the designer should refer to curves or other data published by the fuse manufacturer.

Power Dissipation: Inadequate cooling of semiconductor devices may result in permanent damage through melting or temporary malfunction because of internal crystal changes.

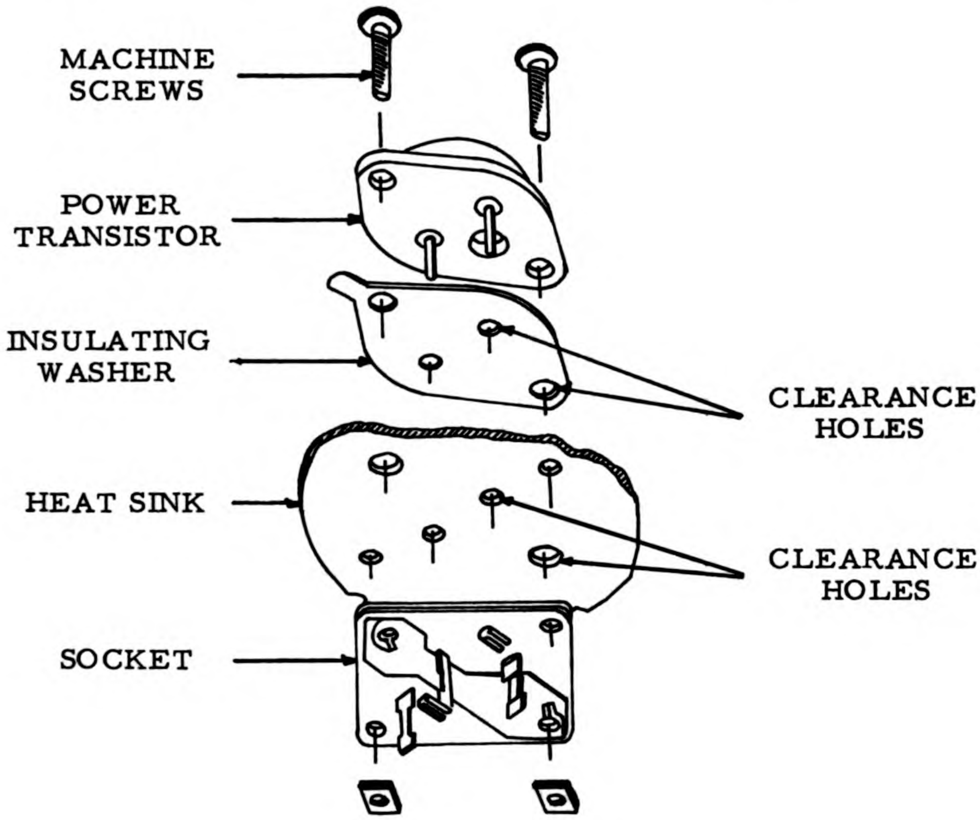
Many high-power devices are supplied with integrally-mounted cooling surfaces (see illustration) complete with manufacturer's data giving temperature rise vs. dissipation (thermal resistance) for that particular assembly. The sum of ambient plus maximum rise must not exceed the rated operating temperature of the device.

In many cases, the designer may have to attach cooling surfaces to semiconductors which do not have built-in provisions for cooling. Small transistor cases can be supplied with heat-conducting caps; the style with spring finger and mounting screws in the cap is most effective, typically providing 5 degrees C/watt thermal resistance when mounted on a 6 x 7 x .09 inch aluminum plate, and 40 degrees C/watt on a 2-1/4 x 4-1/4 inch printed circuit board.





At medium power levels the mounting form is often as shown in the illustration below. Here, the use of an electrical insulating washer is illustrated. All medium-to-high power semiconductors have the cooling surface electrically connected to one of the terminals to obtain maximum thermal conductivity.



TRANSISTOR MOUNTING

At higher levels the device usually has the form of a large stud which provides both the electrical and the thermal conducting path.

If it is necessary to mount a semiconductor on a single plate or fin to provide sufficient dissipation of heat and manufacturer's data is not available, the following relations can be used. The rate of heat flow, q, per unit time from the fin to the ambient air is given by:

$$q = hA\,\eta\,(T_s - T_a) \text{ in watts}$$

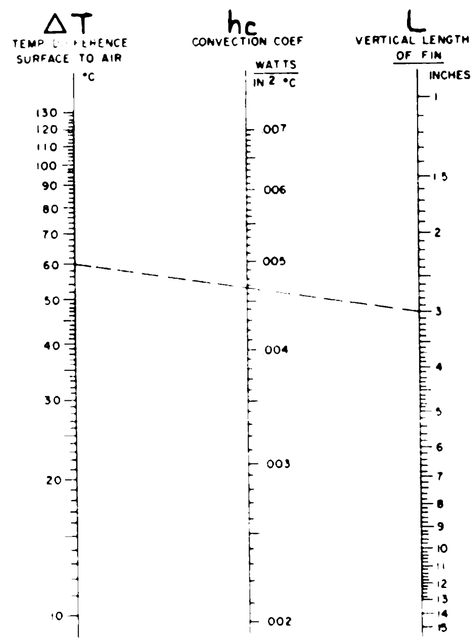
where T_s and T_a are maximum fin temperature and ambient temperature respectively in degrees C; A is the area, η is a "size effectiveness" factor, and h is the sum of radiation (h_r) and convection (h_c) heat transfer coefficients. Methods for determining these factors are outlined below.

The radiation transfer coefficient (h_r) for a single fin of surface emissivity $\epsilon \geq 0.9$ is given by:

$$h_r = 1.47 \times 10^{-10}\,\epsilon\,(1-F)\left(\frac{T_s + T_a}{2} + 273\right)^3 \frac{\text{watts}}{\text{in}^2\,{}^\circ\text{C}}$$

The emissivity, ϵ, is 0.7 to 0.9 for anodized aluminum, 0.85 to 0.91 for air drying enamel (any color), 0.92 to 0.96 for oil paints (any color), 0.95 for lampblack in shellac, and 0.89 to 0.93 for varnish. F is a shielding factor due to stacking. For single unstacked fins, F can be taken as zero.

The free convection transfer coefficient (h_c) can be obtained from the nomogram for a vertical fin shown below. If the fin or plate is horizontal, the quantity obtained from the nomogram should be reduced by 25%, the vertical length then should be taken as the average of the side lengths. The effect of altitude is to reduce the nomogram result by 25% at 15,000 feet and 50% at 36,000 feet.



If forced convection is used rather than free convection, the convection transfer coefficient (h_c) becomes

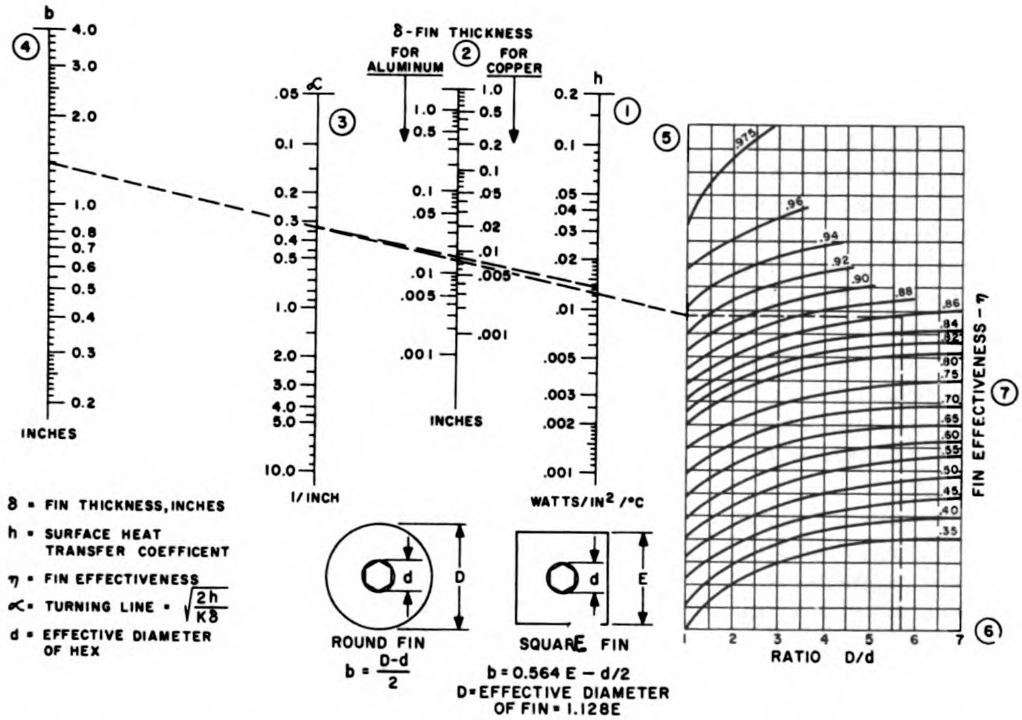
$$h_c = 11.2\,\frac{V}{L} \times 10^{-4} \text{ watts/in}^2/\text{C}$$

V = velocity of air flow in ft/min

L = inches of fin parallel to flow

This equation is based on laminar (non-turbulent) air flow which exists for smooth fins. In the event the air flow across the fin surface becomes turbulent, the heat transfer is improved. However, turbulent air flow places a higher power requirement on the main ventilating system.

Finally, the factor η is given in the nomogram below with numbers encircled to indicate the sequence of solution. After a point on column α is obtained by moving through the columns and h ($h = h_r + h_c$ determined above), the line connecting α and b is projected to the edge of the η chart. A vertical line from the D/d axis and the horizontal line from the above mentioned projection on the edge of the η chart define a value for η .



The heat-sink thermal resistance (R_H) can be expressed mathematically in terms of h, A, and η as:

$$R_H = \frac{1}{hA\eta} \text{ C/watt.}$$

The total thermal resistance (R_T) from semiconductor junction to ambient is the sum of the device resistance (R_D) (confined to the device case or stud surface), the insulator (if used), thermal resistance, and the heat-sink resistance (R_H).

It is often necessary to supply electrical insulation between the semiconductor case and heat-sink. Common insulating washer materials are mica, bonded fiberglass and anodized aluminum. Mica is most frequently used. The theoretical thermal resistance of mica is 0.067°C in^2/watt-mil. By using a mica insulating washer the overall thermal resistance may be increased up to a factor of 5. If specific information is not available, the resistance of the insulator used should be measured.

Where the possibility of corrosion exists between the semiconductor case and the heat-sink (if directly mounted), the case should be plated with nickel or silver and corrosion inhibitor applied. A pressure Belleville spring washer should be used between stud nuts and the heat-sink to account for differential thermal expansion of case relative to the heat-sink. Care should be taken to insure that there are no defects to prevent uniform contact between heat-sink and semiconductor case. Nuts should be tightened with a torque wrench to manufacturer's specification. Silicone grease should be applied to the interface before joining, since a dry interface may increase the total thermal resistance by 10 to 40 percent.

An example is given below to illustrate how the principles discussed above are used to provide sufficient dissipation of heat for a typical semiconductor installation. Assume that an assembly must be arranged to properly cool a stud-mounted semi-conductor operating at 20 watts continuously in a 60 degree C ambient. The semiconductor is to be mounted by a 2-mil mica washer to an aluminum heat-sink of unknown size in free air. The maximum junction temperature must be less than 80 degrees C with a junction-to-stud thermal resistance of 0.5 C/watt. The effective hex area is $3 in^2$ with a 1/2 inch stud.

As previously stated, the total thermal resistance (R_T) is given by $R_T = R_D + R_I + R_H$ where R_D represents device to stud, R_I insulator, and R_H heat-sink-to-air thermal resistance. The temperature differential, ΔT (maximum junction temperature minus ambient temperature) is given by $\Delta T = PR_T$. Solving for R_T yields $R_T = \frac{\Delta T}{p} = \frac{20 \quad C}{20 \text{ watts}} =$ 1°C/watt. Since R_D is given as 0.5°C/watt, $R_I + R_H$ must be 0.5°C/watt. Using the theoretical thermal resistance for mica (0.067°C in^2/watt-mil) and assuming a well greased, tight joint,

$$R_I = \frac{2 \text{mil}}{3 \text{mil}} \times \frac{.067^\circ C\text{-}in^2}{\text{watt-mil}} = .05^\circ C/\text{watt}.$$

Thus R_H must be ≤ 0.45 C/watt.

Assume that available space permits the use of a horizontal 4 x 4 inch aluminum plate, 0.25 inch thick. To obtain the best emissivity, the fin will be painted black except under the washer. To compute h_r, the surface temperature (T_s) must be known.

This is given by $T_s = 80$ C - 20 watts x (0.5°C/watt) = 70°C. The radiation transfer coefficient (h_r) is then .0055 watts/in^2°C. From the free convection nomogram $h_c = .0027 \times 75\% =$ .002 watts/in^2°C. The total h = .0075 watts/in^2°C.

To enter the η diagram, the values for b and D/d must be calculated as defined on the diagram. From the diagram, b = 2.26 - .25 = 2.0 in. and $D/d = \frac{1.13 \times 4}{.5} = 9$. The h column is entered at .0075 and a line is drawn across $\delta = 0.25$ in. to $\alpha = 0.1$ in. From b = 2.0 inch, another line is drawn back through $\alpha = 0.1$ to the η chart where the point of intersection with the left edge of the chart is noted and a horizontal line drawn across the chart through the point. A vertical line is drawn up from $D/d = 9$ (off the chart in this case) and $\eta = 0.96$ is taken as the estimated crossing point of the horizontal and vertical lines just drawn.

Using the above determined values, the heat-sink thermal resistance can be calculated:

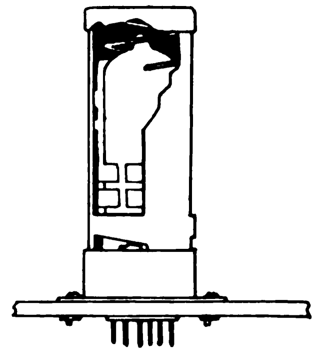
$$R_H = \frac{1}{hA\eta} \times \frac{1}{.0074 \times 16 \times .96} =$$

$$\frac{1}{.109} = 9.2^{\circ}C/\text{watt}.$$

This value is about 20 times too large. An acceptable solution could be obtained by one of the following expedients -- increasing the size of the plate, employing forced convection, stacking additional fins thermally bonded to the first, or choosing a semiconductor with a higher allowed junction temperature.

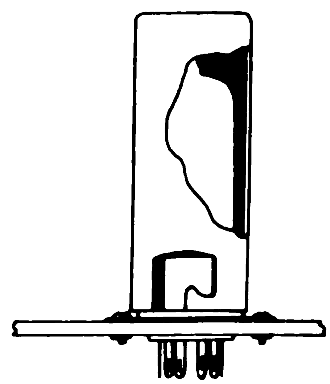
6.3.1.3 Cooling Electron Tubes. Cooling to prevent overheating will considerably increase the life of electron tubes.

6.3.1.3.1 Natural Air Cooling. The conduction shield, illustrated below, has vertical slots equally spaced around the periphery to allow air to contact the surface of the tube. Heat is removed by convection from the portion of the tube exposed to the air. Part of the heat emitted by the tube is removed by conduction through the metal shield. This type of shield dissipates heat more efficiently than the so called JAN shield.



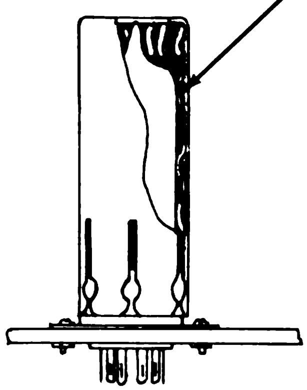
CONDUCTION SHIELD

The shield illustrated below, (known as a JAN shield) although intended to absorb the heat and conduct it away from the tube, actually raises the operating temperature above that of the tube operating without a shield.

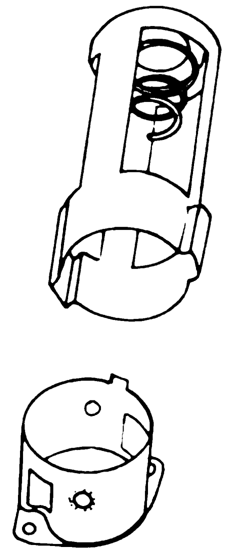


JAN SHIELD

As illustrated below, to provide satisfactory cooling, JAN shields in existing electronic equipment may be replaced during maintenance or overhaul with type R shields specified in MIL-S-19786A (Navy).



TYPE R SHIELD



RADIATION-CONVECTION SHIELDS

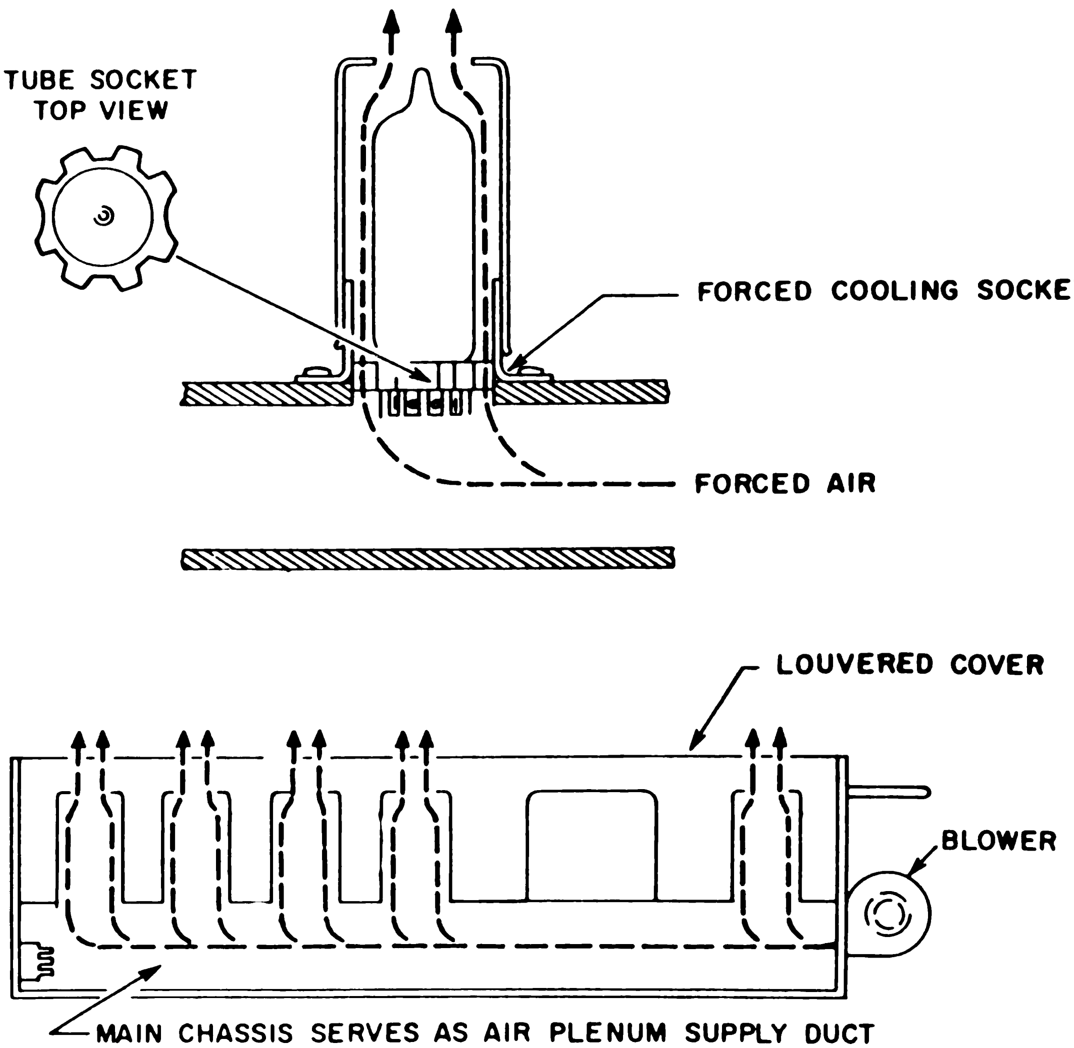
6.3.1.3.2 Forced-Air Cooling.

A. Cross-Flow Cooling - A tube shield for cross-flow cooling must have slots or windows around the periphery to allow the air to contact the tube surface, as illustrated previously by the conduction shield. Otherwise, the shield must be fitted with a metal liner or fingers, similar to the type R shield shown above, in order to insure adequate glass-to-metal contact for the removal of heat by conduction to the air stream. However, during operation, conduction shields radiate heat to surrounding objects and should not be used near other tubes or temperature-sensitive parts.

Radiation-convection shields, illustrated below, should be used on tubes which must be mounted near temperature-sensitive components since they do not become as hot as conduction shields.

B. Parallel-Flow Cooling - Shields with metal liners (conduction, JAN, and radiation-convection) serve efficiently for parallel-flow forced-air cooling because they guide the air around the tube surface and increase the turbulence of the air stream. An example of this type of cooling is shown on page 6-13. Slotted plastic inserts in the miniature tube sockets act as nozzles for the cooling air. The chassis must be closed and relatively air-tight to serve effectively as a plenum for the forced air.

All types of tube shield designs should have the inner surface which contacts the tube envelope blackened to produce a high absorbent surface. Blackening is important to prevent the rise in plate temperature which results from reflection of radiant energy back to the plate. All shield designs should be checked to insure that plate



FORCED-AIR COOLING SOCKET ON
CONVENTIONAL PAN CHASSIS TYPE EQUIPMENT

temperatures of shielded tubes are lower than corresponding temperature in bare-bulb operation.

6.3.2 Circuit Considerations

A satisfactory parts layout is more readily achieved if the circuit is sectionalized. Location of the individual sections is determined by operation, wiring, and heat dissipation requirements.

Associated parts should be located adjacent to each other in a functional sequence consistent with temperature considerations. If separate sections are used, the cabling requirements will be limited to input, output, and supply leads. Leads within each section will be short; common coupling impedances will be reduced; stray fields can be minimized; and a more satisfactory ground return will be provided. Inputs and outputs of subassemblies should be of low impedance for easy interconnection.

A direct-current power supply section might be arranged as follows: transformer and choke oriented for minimum hum fields; the rectifier tube placed close to the side of the enclosure; filter capacitors, voltage dividers, and resistor mounting boards placed close together. Suppressors and line filters would also be included.

In a manually tuned oscillator-amplifier arrangement, the section usually contains coil switches, coils, and variable and fixed capacitors. Tubes are mounted independently; short leads connect to the variable capacitors. Undesirable circuit coupling may be minimized by proper spacing or by the use of individual shields.

In general, transistor circuits are more tolerant of wiring capacitance than tube circuits because of the considerably lower impedance levels normally employed. Circuit layout to minimize capacitance is still desirable for high-performance computer switches. Usually, the most important area in which to maintain low capacitance in layout is the path between collector and base. High performance transistors in the emitter-follower configuration may oscillate because of the above mentioned feedback path if the collector by-pass capacitor is too far from the collector or has high rf impedance, and the emitter drives a capacitance or tuned circuit.

Other undesired modes are possible with emitter-follower circuits, some depending on excess capacitance between collector and emitter. One effective means of removing all modes has been to thread one or more small ferrite cores around the emitter lead. The cores have a large damping characteristic at high frequencies.

In high-current, high-frequency applications, transistors may show such a low impedance that short, heavy wire runs to minimize lead inductance are generally required. It is possible to degrade the performance of certain r-f power amplifiers by an extra inch of unbypassed wire. A single lead above ground plane may have 30 to 50 nanohenries/inch inductance.

Tunnel diode performance depends strongly on series inductance and shunt capacitance presented to it by the external circuit. For this reason, UHF and microwave circuits must be carefully positioned, usually in stripline configuration. For the same reason, tunnel-diode low-frequency circuits often oscillate in an uncontrolled fashion because the layout did not include a local rf circuit around the tunnel diode.

6.3.3 Clearances

Equipments are required to be as compact as possible, consistent with reliable performance and ease of servicing. Small compact units usually withstand shock and vibration better than larger units. Parts may be closely spaced if access to fastenings and mountings is provided. Mountings should not be obstructed by wiring unless such wiring can be readily moved without detrimental effects.

Close spacing of components is usually possible in low-impedance circuits. With high-impedance circuits, undesirable electrical coupling between components prohibits close spacing unless parts are properly oriented or electrostatic and magnetic shielding is provided. Shields are provided on many parts, but for resistors and capacitors, simple electrostatic shields usually suffice.

Parts which carry high voltages require adequate separation. Surfaces of conductors should be polished and well rounded. At potentials greater than 5000 volts, both leakage and corona must be guarded against. Means should be provided to eliminate any corona which is detectable at voltages up to 25 percent above normal. Shields in the form of rounded, polished metal caps or balls are frequently effective in eliminating corona.

6.3.4 Accessibility

The following criteria for accessibility should be considered in locating components. Components should be placed so that:

a. They are accessible without removing other parts and subassemblies.
b. There is sufficient space to use test probes, soldering irons, and other required tools.
c. Structural members of units do not prevent access to these components.
d. They will not be damaged during maintenance.

Internal controls, such as switches and adjustment screws, should not be located close to dangerous voltages. If "blind" screwdriver adjustments must be made, safety guides should be provided.

6.4 MOUNTING OF PARTS

6.4.1 Lead-Supported Parts

Resistors and capacitors should be mounted by their leads on terminal boards whenever circuit impedance and mechanical strength permit. Component leads should not be attached to tube-socket lugs unless such mounting is mandatory for circuit performance.

Rectangular capacitors mounted on edge should be adequately spaced to enable easy reading of code markings.

Bending of component part leads can be a critical factor in the mounting of parts. Leads should always be bent using round nose pliers or other tools having a rounded edge. Sharp edged tools or overly sharp bends can cause nicks or other defects on the surface of the lead, which may result in breakage under vibration. A minimum bend radius of approximately 0.03 inch should be used on all leads.

Component parts associated with printed wiring should be mounted singly on the side of the board opposite the conductor pattern and in either the vertical or horizontal plane to reduce the need for circuit cross-over. If cross-overs are required, however, to achieve the required component layout, wires may be used. Such wires should be treated as electronic components. (See also 3.7.2.2).

If several part leads terminate at a common junction, each lead should be mounted individually in one of the holes which are grouped on the board to form the junction. This eliminates the necessity for unsoldering additional leads when only one part requires replacement. Part replacement should not call for special tools. Flush-mounted or multiple-contact parts should be avoided, as they are difficult to replace.

The component part lead spacing specified in MIL-P-21193 (NOrd) is on a grid system of 0.1 inch. Where high part density is required, the grid system may be reduced in increments of 0.025 inch. When mounting axial-lead parts, it is often advisable to allow for additional length in the over-all mounting dimension to compensate for component body variations.

Special care is necessary to prevent the altering of part values while straightening, cutting, bending, inserting, or clinching component leads.

When the leads of axial-lead or pigtail parts must be clinched to a printed wiring board, the following procedures are recommended:

a. The clinched end on the opposite side of insertion should follow the direction of the conductor pattern.
b. At least 1/16 inch of the clinched end should lie on and in the direction of the conductor.
c. Minimum required conductor spacing should be maintained between clinched lead ends and non-connected conductor patterns.
d. The clinch should give the part enough rigid support and mechanical bond to permit a good solder joint.
e. The minimum length of straight lead required, measured from the part body to the first bend, should be sufficient to prevent physical or electrical damage to axial-lead parts.

The component body should never be mounted so that it is in contact with printed conductors or the following serious difficulties may arise:

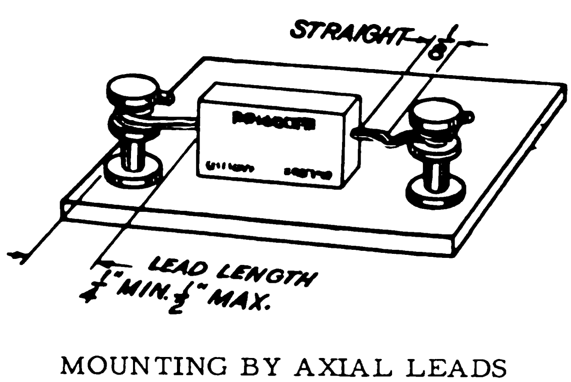
a. Current leakage may occur since some component markings, such as tolerance bands on carbon composition resistors, are relatively conductive.

b. Harmful capacitive or inductive effects may result.

c. Circuit operation may be impaired by entrapped flux and other contaminants.

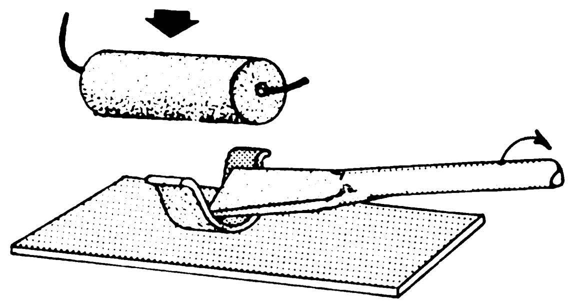
6.4.1.1 Axial-Lead Type. Parts weighing not more than 1/2 ounce may be mounted by the leads alone. In this case the distance between the body of the part and each terminal should be from 1/4 to 1/2 inch.

Leads should extend straight out at least 1/8 inch beyond the body since most vibration failures occur at the junction of lead and body where flexure stress is greatest. This practice will also prevent breakage of the seal between the lead and body. A small smooth loop free of nicks, near the terminal, is satisfactory for limiting tension in leads.



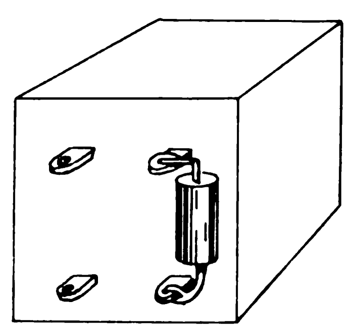
MOUNTING BY AXIAL LEADS

Heavy parts mounted in fuse-type clips should not be snapped into place in the clips because this may damage the parts. A screw driver or other appropriate tool should be used to spread the clips to facilitate insertion of the parts without exerting excessive force on them, as illustrated below.



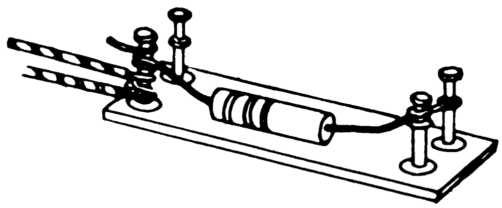
MOUNTING IN FUSE-TYPE CLIP

Parts should not be mounted on other parts unless circuit requirements so dictate. Approval is generally required for such practice.



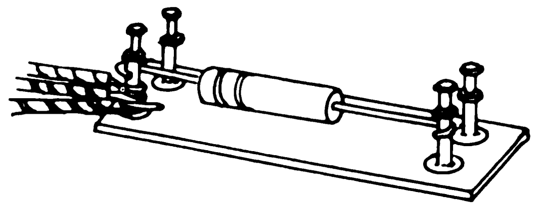
MOUNTING OF RESISTORS AND TUBULAR CAPACITORS

PREFERRED



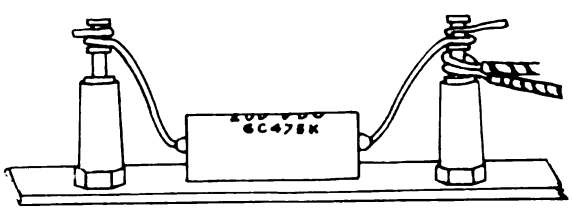
a. One-quarter to one-half inch distance between body of part and terminal
b. Tight, 3/4 to one turn lead wrap
c. Small loop present in component lead
d. Maximum of three connections per terminal
e. Component resting on board

AVOID



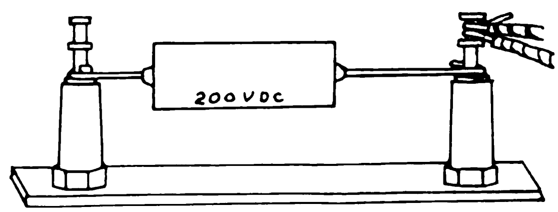
a. Distance between body of part and terminal not within limits of one-quarter to one-half inch
b. Insufficient wrap of component lead
c. Small loop omitted in component lead
d. Too many connections per terminal
e. Component not resting on board

PREFERRED



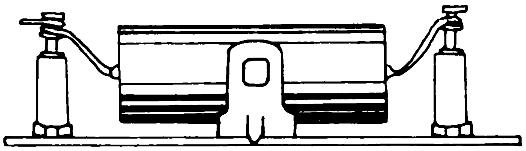
a. One-quarter to one-half inch distance between body of part and terminal
b. Tight, 3/4 to one turn lead wrap
c. Small loop present in component lead
d. Component connected at top of terminal; hook-up wire connected at bottom
e. Part numbers visible
f. Component resting on board

AVOID



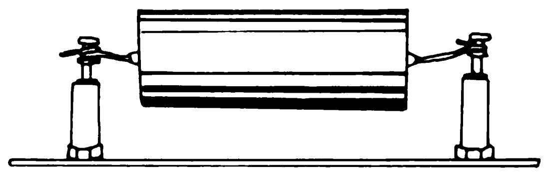
a. Distance between body of part and terminal not within limits of one-quarter to one-half inch
b. Insufficient wrap of component lead
c. Small loop omitted in component lead
d. Component connected at bottom of terminal; hook-up wire at top
e. Part numbers obscured
f. Component not resting on board

PREFERRED

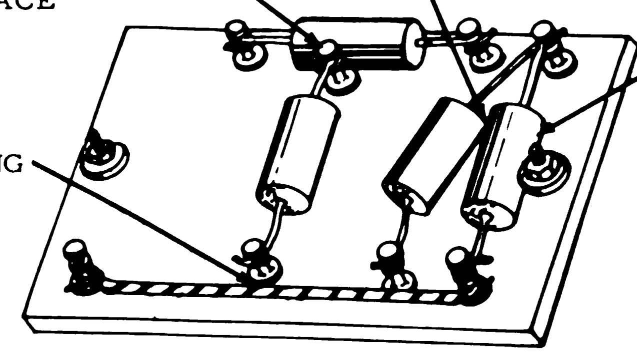


Heavy component (over one-half ounce) mounted with clip

AVOID

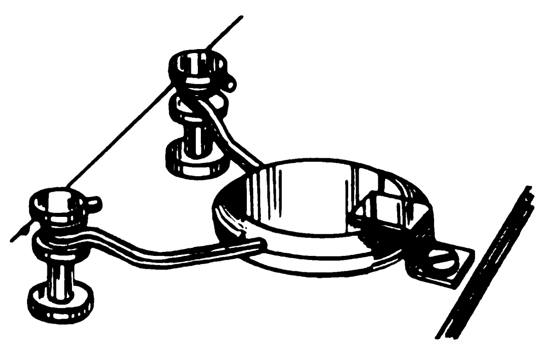


Heavy component mounted without clip



The poor mounting practices used in the terminal board shown above should be avoided.

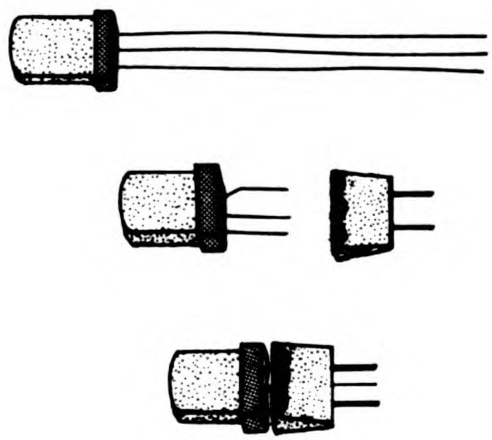
6.4.1.2 Radial-Lead Type. Radial-lead mounting is characterized by low mechanical resonant frequencies. It is not recommended unless the leads are rigid enough to raise these frequencies above 100 cps. Certain miniature parts with short leads and small body mass meet this requirement. Large parts such as wire-wound resistors and printed-circuit assemblies of the radial-lead type require mechanical clamping.



CLAMP IMPROVES MOUNTING

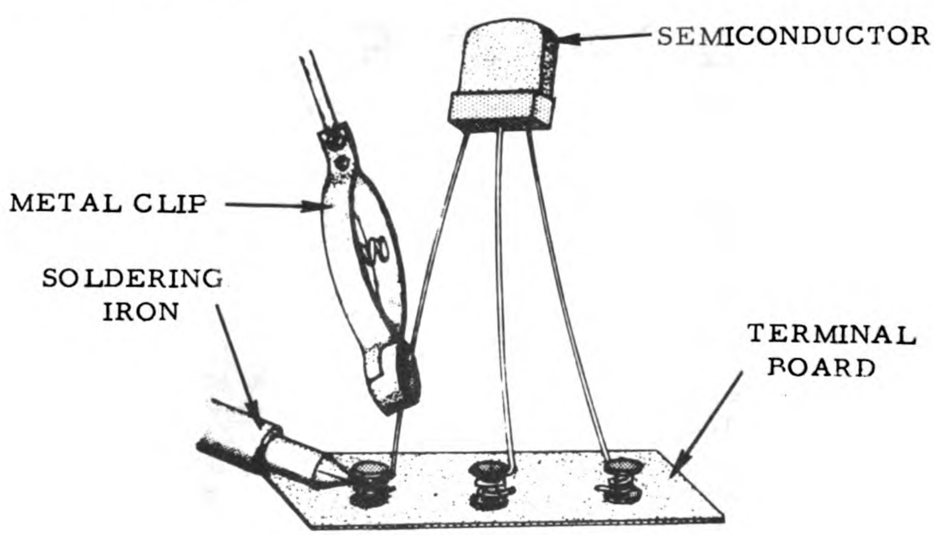
6.4.1.3 Semiconductor Type. Transistors and other semiconducting devices may be mounte(with standard subminiature transistor or tube sockets, or may be soldered permanently in the circuit.

The long leads usually supplied with transistors must be clipped when using sockets, as shown.



MOUNTING TRANSISTORS IN SOCKETS

Transistors, solid-state diodes, and other heat-sensitive components must be soldered carefully to prevent damage. The leads may be cut to any convenient length, but normally should be left as long as practicable. Sharp bends in the leads close to the component body should be avoided. A hot, clean, well-tinned soldering iron with a small tip should be used, and should not be overheated. A heat sink is required to minimize heat transfer to the component during soldering. The use of a metal clip as a heat sink is illustrated. Another equally satisfactory method of dissipating heat during installation of semiconducting devices is to grasp the lead being soldered with a pair of long-nose pliers at a point between the body of the component and the connection terminal. The part should be clamped (by any approved means) after soldering if the equipment is to be subjected to vibration.



SOLDERING TRANSISTORS

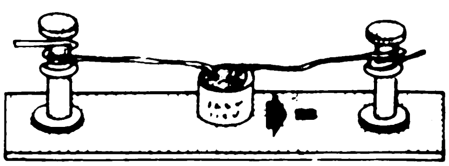
Most soldering irons have enough leakage voltage to damage transistors. For this reason, the frame of a soldering iron should be grounded to the equipment chassis when transistors or transistor circuits are being soldered, or a three-wire soldering iron or gun with the third wire grounded should be used. Alternating-current test equipment should be grounded for the same reasons when transistor circuitry is being tested.

As an additional precaution, the leads of the transistor should not be held in the hand because the capacity of the human body may be charged through the transistor and result in permanent damage to the part.

Mounting of diodes is shown below.

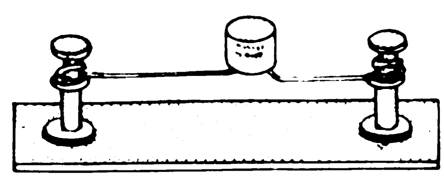
MOUNTING OF DIODES

PREFERRED



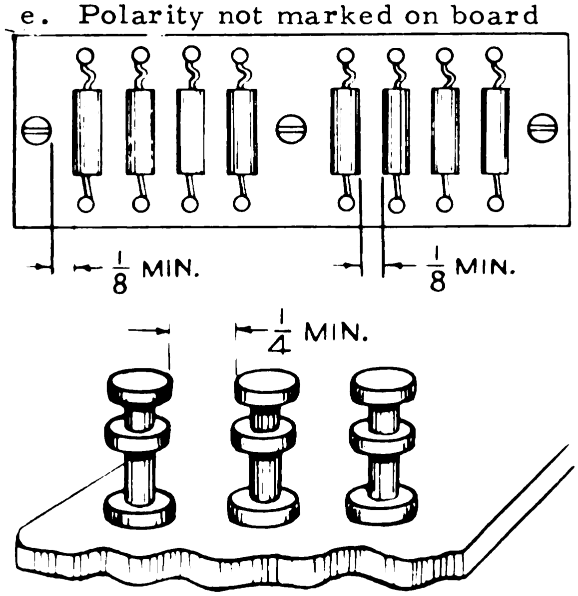
a. Leads dressed to clear diode can
b. Service tab present on lead
c. Diode mounted lead side up
d. Leads connected at top of terminal
e. Polarity marked on board

AVOID



a. Tight leads; touching diode can
b. Service tab omitted on lead
c. Diode mounted lead side down
d. Leads connected at bottom of terminal
e. Polarity not marked on board

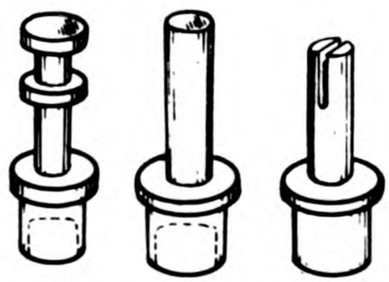
6.4.1.4 Mounting Boards and Terminals. Mounting boards, used for mounting lead-supported parts, are usually rectangular and equipped with mounting terminals for ease in connecting wires or components. Mounting terminals are spaced to provide at least 1/8 inch between adjacent components to provide for circulation of air about the parts.



MOUNTING BOARDS

Shock and vibration requirements necessitate closely spaced board-to-chassis mounting studs. Adequate clearance must be provided between board mounting screws and circuit components.

Mounting terminals should be of solid metal suitably annealed for secure seating of material into terminal boards. An adequately shouldered shank with a double-shouldered or split stem is recommended.

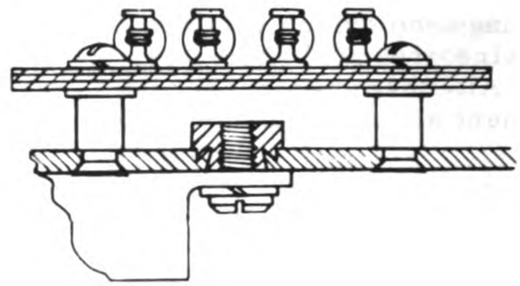


MOUNTING TERMINALS

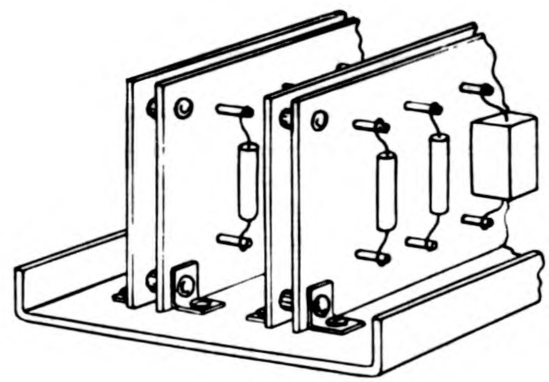
Mounting boards should be fastened with machine screws threading into tapped spacers affixed to the chassis. Spacer studs should be long enough to permit maximum accessibility during servicing, and circulation of air. As a rule, vertical or cantilever mounting should be avoided.

Screws of ample size, with flat washers, are used at board edges. Where a board is long or flexible, additional supports are necessary to prevent warpage and damage by vibration. Mounting holes should be located at least three times the screw diameter from the edge of the board. No. 8 screws are the minimum size for most applications.

Where a board of molded material is mounted flat against a chassis, a compliant non-metallic sheet gasket between board and chassis will minimize stress concentrations around the holes.



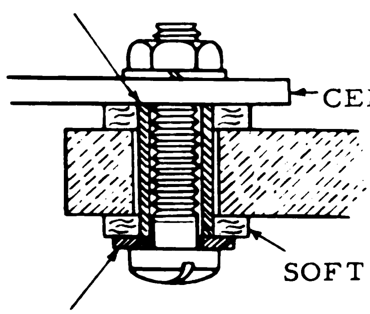
SATISFACTORY



AVOID

MOUNTING BOARD INSTALLATION

Where ceramic or other stiff material is used as a mounting board, two-point mounts are usually satisfactory, unless large areas are to be supported. Three-point mounts may be used, providing undue stresses are not introduced.



MOUNTING CERAMIC MATERIAL

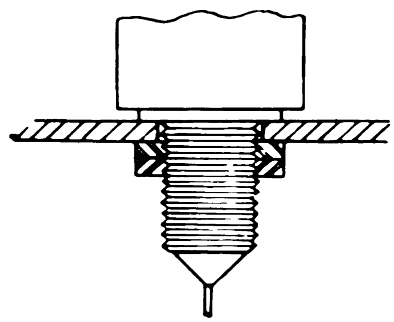
Properties to be considered in the selection of materials for mounting boards are strength, water absorption, softening temperature, dielectric strength, power factor, arcing products, fungus resistance, warpage, and resistance to aging.

Melamine-bonded glass cloth, Specification MIL-P-15037, is preferred for component mounting boards, especially where high-impedance circuits are involved. For high temperatures, silicone-glass laminate, Specification MIL-P-997, is preferred. The use of phenolic materials should be limited to low-voltage, low-impedance applications. For high voltages (over 500 volts) and radio frequencies, ceramic materials are more reliable.

Insulation that is not moisture and fungus resistant should not be used. Cotton, paper, or wood-filled materials are particularly susceptible, and their use should be avoided.

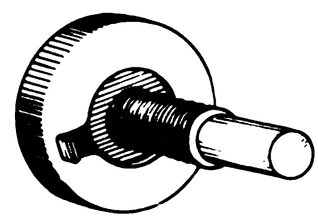
6.4.2 Body-Supported Parts

6.4.2.1 Single-Hole Mountings. Single-hole mountings are adequate where torsional stress is low but long slender parts so mounted are subject to severe strain under shock and vibration. Mountings with resonant frequencies below 100 cps should be avoided.



SINGLE-HOLE MOUNTING

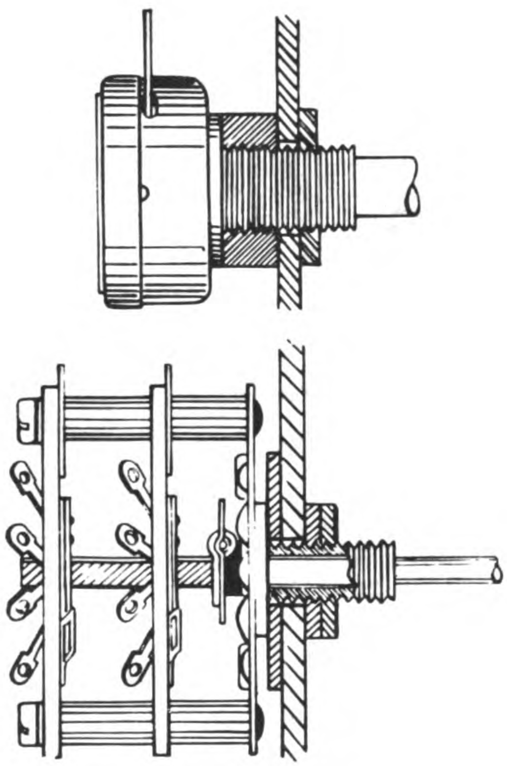
To withstand torsional stress, bolt and nut sizes must be much larger than for multiple-point mountings. Switches, controls, and similar parts which require rotary motion for operation must be provided with positioning lugs.



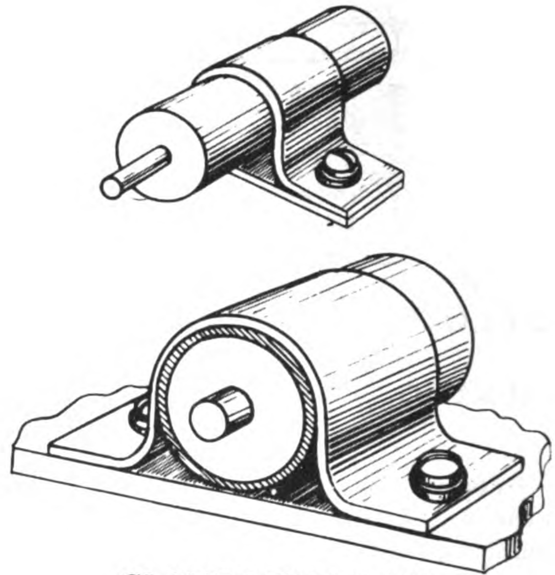
CONTROL WITH POSITIONING LUG

Mounting rods on rotary controls should be of adequate length and area. The panel hole should be made to fit the panel bushing without too much play. A double lock nut provides the most secure fastenting.

Accommodation for variations in panel thickness should be made by means of bushings or flat washers. Toothed lock washers should be avoided.



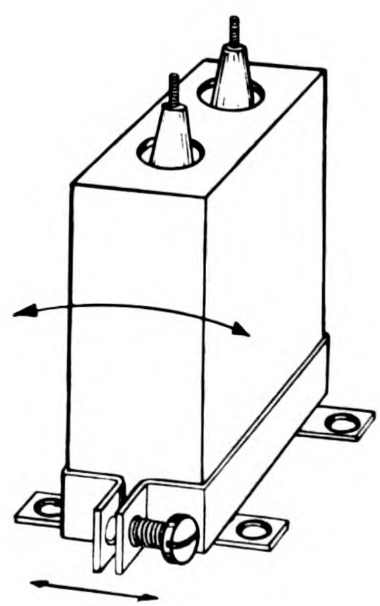
CONTROL AND SWITCH MOUNTINGS



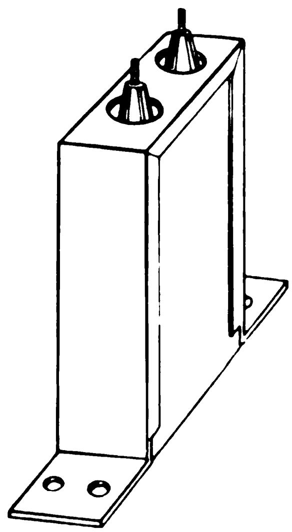
CLAMP MOUNTINGS

Large capacitors and other parts not provided with satisfactory mountings should be firmly secured by auxiliary clamps.

6.4.2.2 Clamp Mounting. Axial or radial lead parts weighing more than 1/2 ounce must be constrained by suitable clamping.



SATISFACTORY
(AUXILIARY CLAMP)

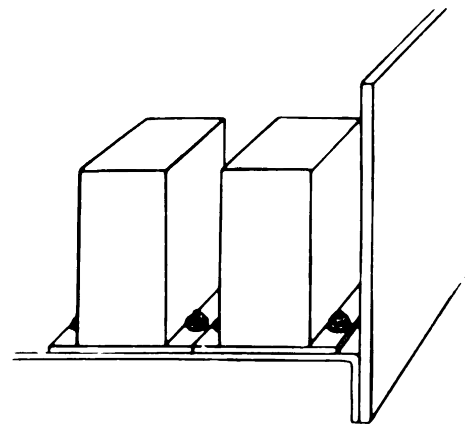


PREFERRED
(MOUNTING PROVIDED)

6.4.2.3 Machine-Screw Mounting. Mounting of parts with machine screws facilitates disassembly under service conditions. Carefully selected fasteners, properly tightened, improve resistance to shock and vibration. Mounting studs integral with the part are recommended, but nuts attached to the part or the chassis may be used.

A bolt, nut, and washer assembly is often used, particularly where holes and mating parts are difficult to align; but assembly is more difficult because these are separate from other parts, and additional faying surfaces are introduced. Screws should be large enough to prevent motion.

Clearance should be adequate for alignment, location, and replacement of parts and fasteners. Hole sizes should be ample, and where mating holes, studs, or secured nuts are used, additional clearance should be provided to allow for variations in hole, stud, or nut location.



AVOID INACCESSIBLE MOUNTINGS

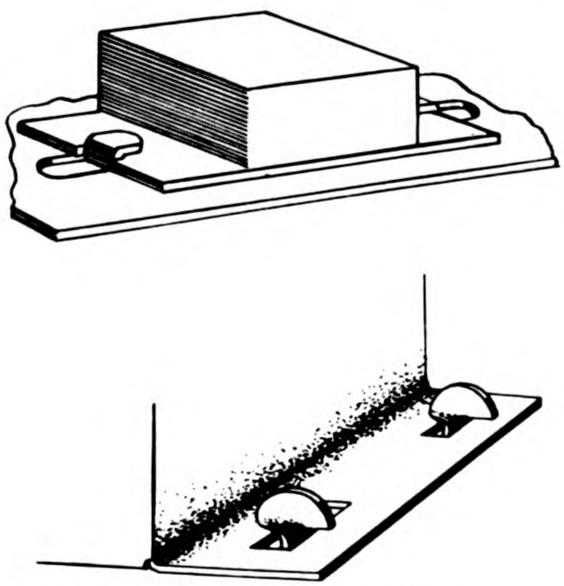
Where holes are greatly oversized, or mating surfaces are irregular, the bearing surface may not withstand the forces exerted by the screws. In such cases, larger washers may be used. Parts should have smooth, rigid clamping surfaces. In bolting soft plastic and similar materials which may cold-flow under stress, ample bearing areas should be provided.

Mounting two items by one screw makes disassembly difficult. A part held by one small screw will usually loosen, and such mounting does not have an adequate safety factor. See chapter 4 for design of threaded fasteners, and chapter 2 for additional mounting practices.

6.4.2.4 Special Mountings. Twist lugs, tabs, or ears should not be used for mounting parts except in expendable equipment. Such projections are easily broken during replacement of parts.

Sheet metal nuts and self-tapping screws are apt to loosen easily, and should not be used in military equipment.

Rivets are excellent fasteners, but should not be used to fasten parts likely to require replacement.



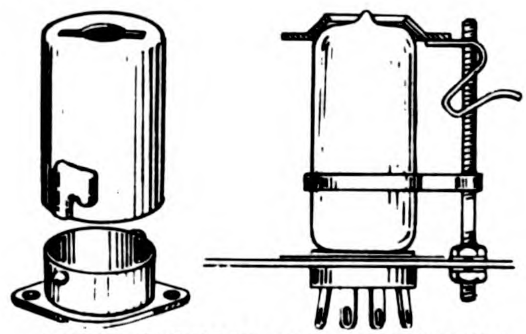
AVOID TAB OR TWIST-LUG MOUNTS

6.4.3 Plug-In Mounting

Plug-in parts include vacuum tubes, electrolytic capacitors, and relays. Modular units, plug-in amplifiers, and similar devices containing subminiature tubes are finding increased use because they are easy to replace. To allow for manufacturing deviations, some "float", or looseness in plugs and sockets, must be provided.

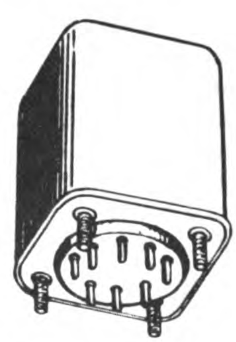
Plug-in items should have auxiliary supports to reduce lateral stresses in plugs and sockets, which keep them in place during shock and vibration. Large pins and sockets are preferable. The parts, components, and supports should be readily accessible for removal. Piloting guides or pins are required to aid in proper positioning.

JAN tube shields provide adequate retainers for miniature tubes. Unless closely fitted, tube shields have a tendency to increase the envelope temperature. Post and "top-hat" types of retainers allow free dissipation of heat and a more positive retention of tube.

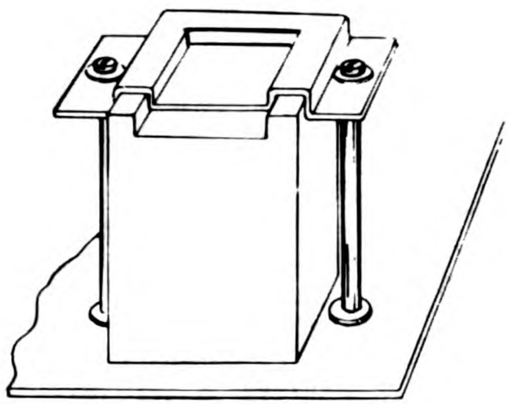


TUBE SHIELD AND RETAINER

The comparatively large mass of hermetically sealed plug-in units necessitates the use of mounting studs or posts and top-hat clamps.

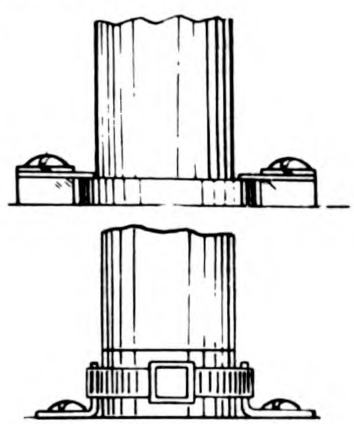


PLUG-IN UNIT WITH STUDS



PLUG-IN UNIT WITH CLAMP

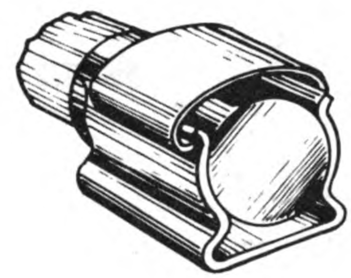
Base-gripping clamps may be used for cylindrical items, such as capacitors, vibrators, and crystal holders, if the center of gravity is located near the chassis. The positive clamp holds securely, but the spring type should engage a shoulder or rib on the component.



POSITIVE CLAMPS

UNACCEPTABLE

Parts having ferrule or threaded ends, such as fuses and resistors, require clamps similar to fuse clips. Such mountings should be carefully evaluated for behavior under shock loads. Large parts having ferrule ends should be secured by auxiliary locking devices.

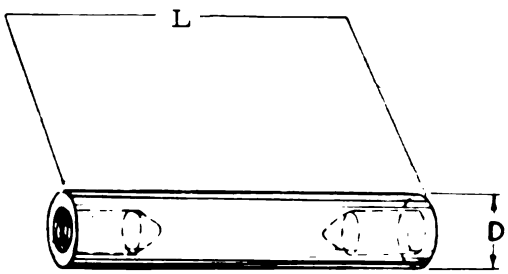


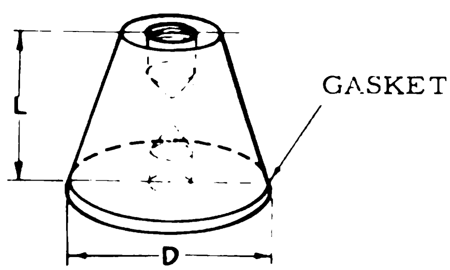
APPROVED FUSE MOUNTINGS

6.4.4 Standoff Mountings

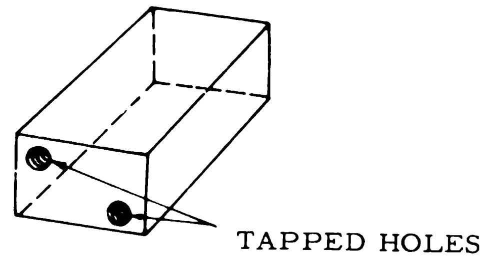
Standoff mountings provide clearance between chassis and circuit elements. Such mountings are used in high-voltage circuits to reduce undesired capacitance and to minimize magnetic coupling. Standoffs are base mounted and usually have low mechanical resonant frequencies. Mechanical resonance can be raised above 100 cps by using short pillars and broad base mounts.

Conical standoffs of relatively large base diameter are preferred. The larger base distributes stresses over a greater area and raises the resonant frequency. Various shapes and sizes are described in applicable military standards.





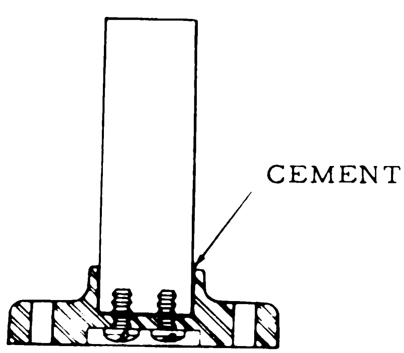
CYLINDRICAL AND CONICAL STANDOFFS



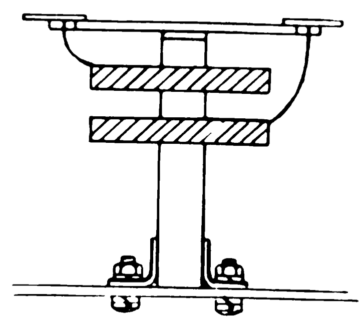
MULTIPLE-HOLE STANDOFF

Pillars for coil mounts should be as short as possible for reliable performance since their mechanical strength is low. In most applications, the coil-to-chassis distance need not exceed the radius of the coil. Unless quite short, pillars should be mounted horizontally and supported at both ends.

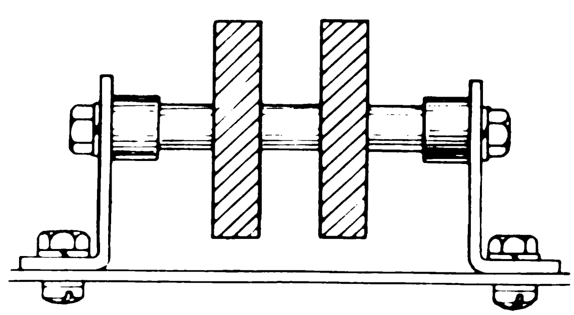
Standoffs having multiple hole mountings resist torsional loosening better than do single-hole mountings.



MULTIPLE-HOLE STANDOFF MOUNTING

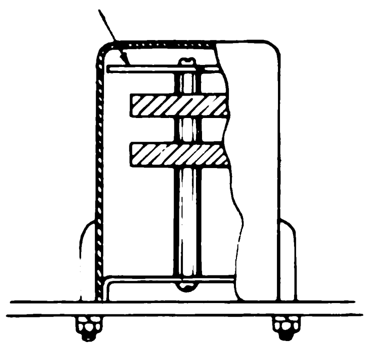


AVOID



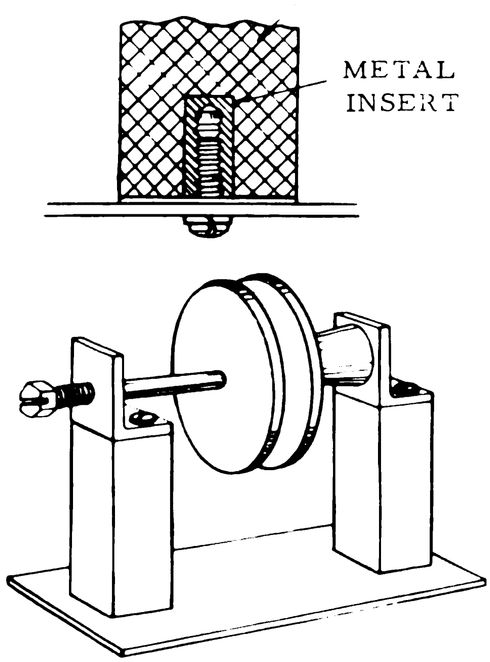
PREFERRED

When vertical standoff is required, as for a shield-can application, a wafer, fitting closely inside the shield-can, should be used for stiffening. Pillars made of inorganic materials, such as mica-filled phenolics, should have metallic mounting bushings molded into the ends.



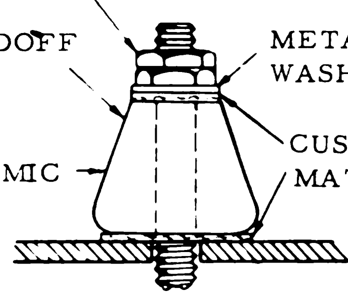
STIFFENED VERTICAL STANDOFF

Ceramic posts are used extensively as supports for electronic parts.



CERAMIC POSTS

In mounting materials such as ceramic and glass, stress-relief washers of such materials as soft copper, mica, or treated fiber, are required to prevent rupture. Lead washers must not be used because cold-flow may cause loosening of the part. Appreciable bending stresses should be avoided.



MOUNTING CERAMIC MATERIALS

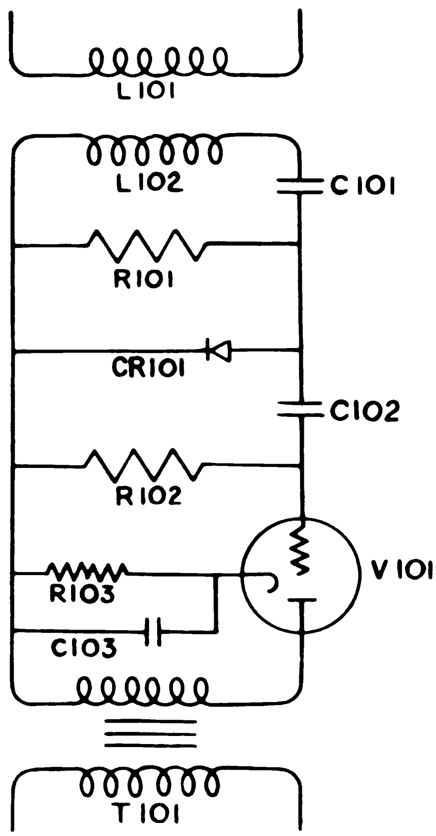
6.5 MARKING OF PARTS

6.5.1 Reference Designations and Part Identification

For maintenance purposes, it is necessary that all parts in an equipment be identified so they may be readily located.

Each part shown on a schematic diagram should be identified by a designation referring to parts descriptions given elsewhere on the diagram. The wiring diagram prepared in accordance with the schematic diagram, should carry designations for wires, sockets, plugs, receptacles and similar parts.

Standard designations given in military standards consist of various combinations of letters and numbers.



SCHEMATIC DIAGRAM
REFERENCE DESIGNATIONS

On semifixed items like fuses and resistors that are ferrule-clip mounted, the electrical rating should be shown in addition to the standard designation. On items having critical polarity or impedance ratings, these ratings should also be shown.

Large components separately mounted should be identified by manufacturer's catalog and serial number or code, or by a stock number. Where individual terminals of an enclosed assembly are marked, and complexity of the assembly warrants, a concise wiring diagram affixed to the unit is desirable in servicing.

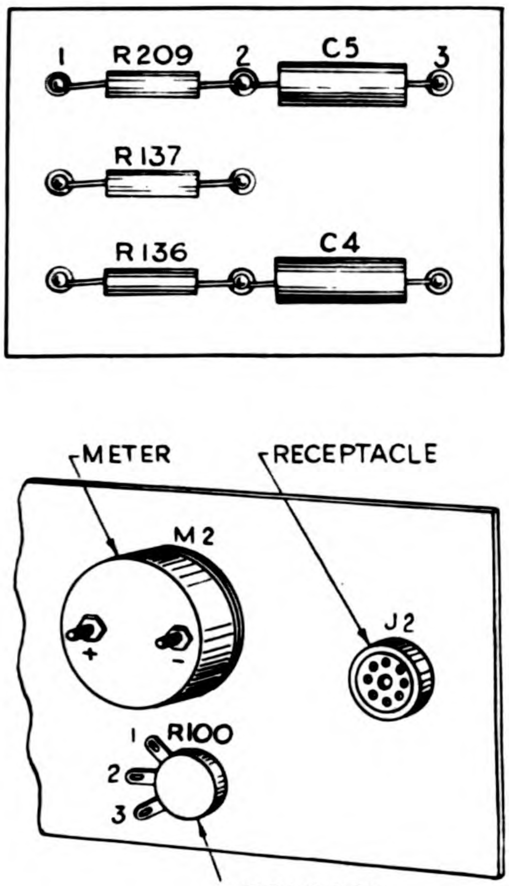
Terminals on all apparatus and parts, except those for which connections are self-evident, should be suitably marked. The wiring diagram should include all terminal markings.

Mechanical parts which may require replacement should carry standard designations. Frames, brackets, levers, bearings, pulleys, and similar parts may be marked by molding or stamping during manufacture. Fastenings are seldom marked.

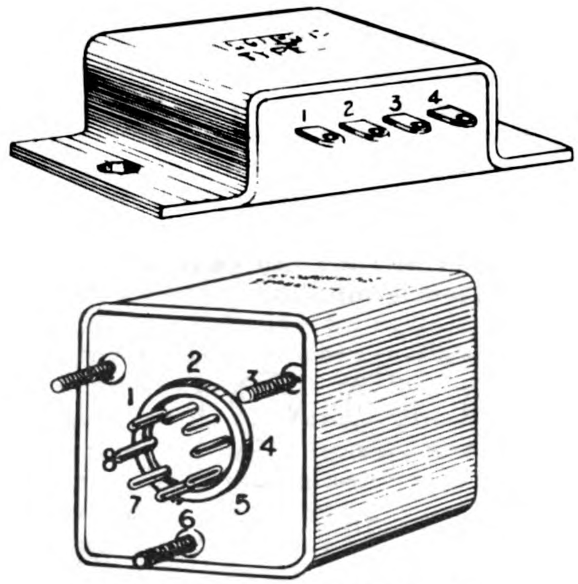
6.5.2 Location of Markings

Designation marks on equipment are placed immediately adjacent to the parts, with markings indicating the location of the part. This is important when the part is removed since many parts are not marked with full identification. Ease of identification consistent with servicing requirements determines the best location.

Small parts such as resistors, capacitors, and terminals, affixed to mounting boards or terminal strips, should be identified by markings on the boards. Items which are not board-mounted should be identified by markings on the chassis. Multiple terminals should be identified by markings on the component or adjacent chassis.



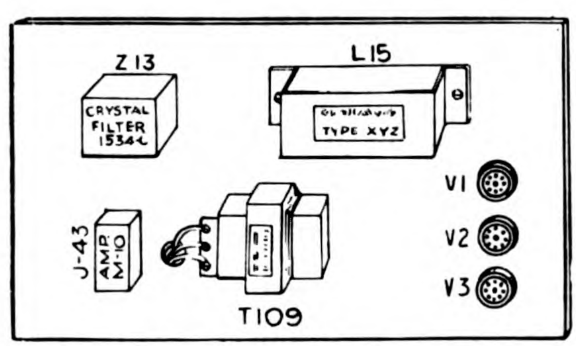
DESIGNATION OF PARTS



MARKING OF TERMINALS

Above-chassis apparatus with wiring cabled through to the underside should be marked on the top, adjacent to the wiring. Receptacles for plugs, modular units, and similar parts, operable from the top side should have both bottom- and top-side identification. Large enclosed assemblies are usually identified by a nameplate or case marking.

Where a part projects through the chassis, the marking should be made on the wiring side. Terminals of transformers, relays, capacitors, and all socket-mounted items except standard vacuum tubes require marking adjacent to each terminal. If terminal markings on parts are too small for ready identification, additional markings may be placed on the chassis.

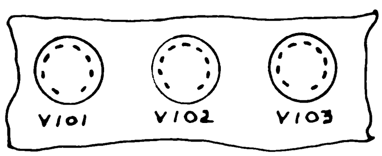


PANEL AND PART MAKING

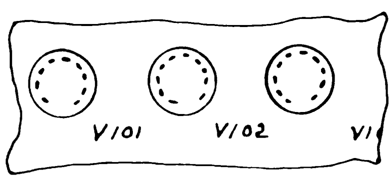
The following criteria should be followed in the marking of part designators:

a. Make markings legible, correct, and sufficient to identify the referenced part

b. Locate markings adjacent to referenced parts, in a consistent manner which will eliminate any possibility of confusion



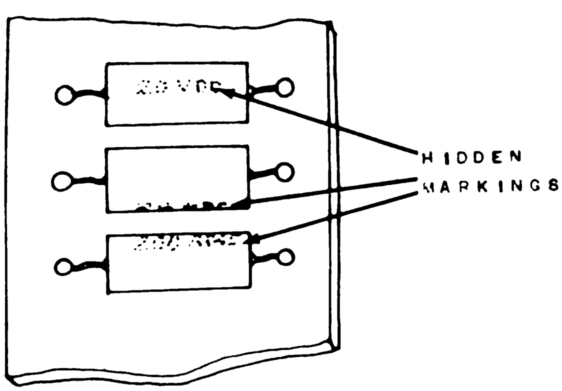
GOOD



POOR

c. Make markings permanent enough to last the life of the equipment

d. Place markings so that they are visible without moving other parts

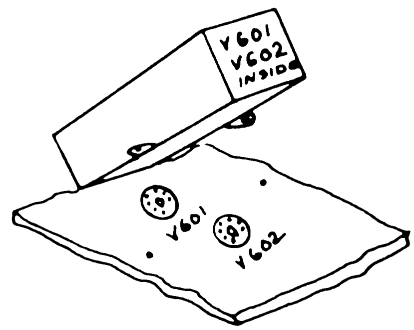


AVOID

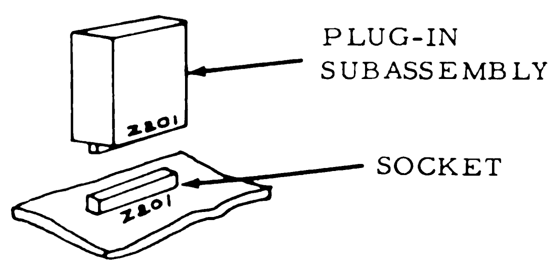
e. Orient markings so that they can be read with the chassis in the installed position

f. Mark stacked parts and modules so that they can be individually recognized

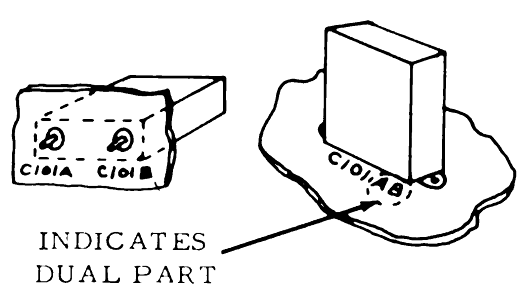
g. Identify individually enclosed or shielded parts on the outside of the enclosure



h. Place identical markings on both the chassis and the removable part of a plug-in subassembly



i. Identify clearly individual sections of dual parts



6.5.3 Marking Processes

A marking process should be selected after consideration of type of surface, legibility of characters, location, accuracy, engineering change requirements, visibility, water resistance, and fungus resistance.

Several processes are available, including photoetching, silk screening, rubber stamping, engraving, steel stamping, molding, and use of decals.

6.5.3.1 Photoetching. The photoetching process is often employed for nameplates, flat panels, or circuit diagrams. Either the characters or the background may be raised by means of a photosensitized acid etching process. Raised characters on an aluminum plate are preferred.

6.5.3.2 Silk Screening. Silk screening involves the use of a stencil or screen from which certain areas have been removed to allow passage of colored paints or inks. With such screens, it is possible to secure good detail. Characters are usually raised, but the same process can be used for raised background. The screens tend to become clogged with usage and eventually produce imperfect characters. Viscosity of the paint or ink affects the depth of color and perfection of characters. Lettering should be as large as practicable. Durability can be improved by improving adhesion (chapter 5). Location of characters can be controlled by using multiple screens for larger areas. The screens are easily made at low cost and any necessary changes are easily made.

Silk screens which have uniformity of weave, freedom from flaws, full mesh count, and unusual fiber strength are currently available. Wire cloth screens made of copper, brass, phosphor bronze, monel metal, and stainless steel are particularly useful for printing on metals and for precision work. These improved materials permit longer use of screens without cleaning or replacement, and afford better character definition. Vinyl inks, enamels, and lacquers especially prepared for silk screening have also improved the results of this process.

Some of the advantages of screen process printing for marking part locations are:

a. The equipment for silk screening is relatively inexpensive to install and maintain
b. A wide variety of materials and items can be marked
c. Almost any size object can be marked
d. This process is particularly suitable and economical for small and medium size production runs
e. No skilled labor is required (for simple chassis and panel marking).

6.5.3.3 Rubber Stamping. Rubber stamps are widely used for markings, but legibility may be affected by smudging.

The application of lettering is awkward when the length of the stamp is greater than eight times the height. Low viscosity inks, carefully rolled out on a smooth surface, provide a thin film that may be transferred without extensive squeezing or smudging. This type of marking does not have the durability of screening. Water soluble inks should not be used.

6.5.3.4 Engraving. Precision apparatus is usually engraved. Durability is excellent. The characters may be filled with colors to improve legibility. Small characters are costly and difficult to produce accurately.

6.5.3.5 Steel Stamping. Stamping dies providing depressed characters may also be used for marking. This method provides identification of mechanical parts at low cost. Care must be exercised in hand stamping to avoid deformation of parts. Letters may be filled to secure contrast.

6.5.3.6 Molding. Molded-in markings may be depressed or raised. This method may be used on all types of molded materials, including glass.

6.5.3.7 Decalcomanias. Decalcomanias are undesirable unless lacquered after application. They should be of the water-resistant type.

6.6 BIBLIOGRAPHY

Reference books to aid designers, who may require additional authoritative information on the subjects covered in this chapter, are listed below.

Design Manual of Methods of Forced Air Cooling Electronic Parts. Cornell Aeronautical Laboratory, Inc. 1958.

Electronic Components Handbook. K. Henny and C. Walsh, editors. 3 vol. McGraw-Hill, 1957, 1958, 1959. (Originally issued as WADC Report 57-1, Vols, I, II, and III).

Electronic Designers Handbook. R. W. Landee, A. P. Albrecht, and D. C. Davis. McGraw-Hill, 1957.

Electronic Engineers Master. Technical Publishers, Inc. Published annually.

General Electric Rectifier Manual. General Electric, 1961.

Industrial Electronics Handbook. R. Kretzmann. Philips' Technical Library, 1956.

Mechanical Design for Electronics Production. J. M. Carroll. McGraw-Hill, 1956.

NEL Reliability Design Handbook. Naval Electronics Laboratory, San Diego, Calif. 1961. (This handbook is distributed by U. S. Department of Commerce, Office of Technical Services and kept current through loose-leaf revisions).

Reliability Factors for Ground Electronic Equipment. K. Henny and others. McGraw-Hill, 1956. (Originally issued as WADC Report 56-148).

The designer should also refer to current issues of applicable technical serial publications to obtain up-to-date information on the subjects covered in this chapter.

Chapter 7

WIRING AND CABLING

7.0 GENERAL

Interconnecting conductors in military equipment are subject to severe conditions of usage and therefore the standards of workmanship and design must be correspondingly high. Test and inspection procedures used are intended to determine the adequacy of equipment for its potential service use.

Mechanical design problems include resistance to shock and vibration, placement of wires, making of connections, servicing, marking, replacement of parts, climatic protection, separation, and insulation. Environmental factors to be considered are temperature, humidity, abrasion, fungus, wind velocity, shock, and vibration.

Electrical problems include current-carrying capacity, impedance, voltage, rf interference, personnel protection, and placement of components. These problems are best solved by cooperative efforts of both the electronic and mechanical engineers.

7.1 SELECTION OF CONDUCTORS

Conductors play a vital role in reliable electronic equipment. With advances in equipment design, conductor variations have become as complex as the electronic components they serve, and requirements have become correspondingly exacting.

Conductors are generally selected for their current-carrying capacity, mechanical strength, and properties of their insulation. However, unique conditions may require the use of wires having special characteristics, and several types of special purpose conductors may be needed for a single electronic assembly.

7.1.1 Types and Uses

Electrical conductors are commercially available as solid or stranded, bare or insulated, individual or cabled wires.

Soft, annealed copper is most commonly used in making wire because of its high conductivity and ductility, resistance to corrosion and mechanical fatigue, and ease of soldering. Aluminum is sometimes used where weight is a primary consideration, and various other materials are used for specific purposes.

Solid wire of round, square, or rectangular cross section is commercially available to suit particular applications. Advantages of solid wire include rigidity and efficiency at the higher frequencies. Solid wire, when permitted, may be used for jumpers up to 3 inches long, and for longer lengths where leads are securely mounted and not subject to vibration. When used, bare wire can be insulated by covering with external sleeving. Untinned, solid copper wire is most efficient at high frequencies, since tinned or stranded wires exhibit greater losses. A disadvantage of solid wire is its susceptibility to stress concentrations. A slight nick on the conductor, which may result when insulation is stripped, can become a breaking point when subjected to flexing.

Stranded wire should be used in preference to solid wire because of its greater flexibility. It can be easily bent and formed into wire assemblies. Also, stranded wire is less apt to break if unsoldered and unwrapped during servicing. Most frequently used is wire consisting of seven strands twisted together.

Multiconductor cables are selected according to the same factors governing selection of individual conductors, with special attention given to interwire insulation. Cables may take countless forms. Special wires and insulation are formed into cables to be used for low-, medium-, or high-frequency applications.

A variant of the multiconductor is the coaxial cable used where distributed capacity must be held constant over the length of the line. Here one conductor follows a precise concentric path through another and the space between is filled by an insulating material. It is important that concentricity be maintained; if the space relation between outer shielding and inner wire is permitted to vary, circuit efficiency will be affected. When coaxial cable is bent, minimum bend radius should be no less than ten times the outside diameter of the cable; otherwise, cold flow of the dielectric can cause creeping of the inner conductor at the bend. Coaxial cables should be selected with regard to impedance and attenuation at design frequencies. Various forms are available. Typical is the cable consisting of a solid or stranded inner conductor, dielectric other than air, outer conductor of braided shielding, and protective, insulating material covering the braid.

In the coaxial low-capacity line, air is used as the dielectric. Inner and outer conductors are separated by means of widely spaced insulators. Effect of this construction is to lower effective capacitance. RG-62/U is an example of an air-dielectric cable.

In the coaxial delay line, high impedance is achieved by spiraling the inner conductor. A foot of this cable may have an impedance equivalent to 15 feet of standard coaxial cable.

7.1.2 Size

Wire size is most commonly designated by American Wire Gage (AWG), by circular mils, or by diameter of the wire in mils. Size to be selected depends on current to be carried, permissible temperature rise, power loss, and physical requirements such as space limitations and mechanical strength.

Hook-up wire for military equipment should be no less than AWG No. 26 to minimize the danger of wire breakage. AWG Nos. 22 through 24 are suitable for general chassis wiring. Filament wiring, particularly where heaters are wired in parallel, should consist of AWG

No. 20 wire or larger, depending upon current consumption. Conductors intended to carry only audio-frequency or direct currents are chosen primarily with voltage and current ratings in mind. In choosing conductors for rf applications, the size also depends somewhat on their impedance.

7.1.3 Insulation

A wide variety of insulating materials, each characterized by individual properties, may be used to cover conductors. Electrically, insulating materials are rated according to dielectric strength, dielectric constant, resistance, and capacity-to-"Q" ratio. Physically, insulating materials are rated according to permissible operating temperatures, mechanical strength, ease of stripping, effects of aging, and resistance to abrasion, vibration, moisture, flame, oils, alkalies, and fungi.

Thermal properties, to a great extent, determine the applicability of insulation. Some materials deteriorate rapidly at high temperatures; others soften and tend to lose their shape. At low temperatures, insulation tends to become brittle and easily damaged by flexing. Temperature limitations must be carefully considered, especially where leads must be dressed close to heat-generating components. Particular requirements are usually governed by the detail specification. In general, conductors in military electronic equipment are required to withstand storage or nonoperating temperatures ranging from -62° to $+85^{\circ}C$. Operating temperature limits are determined by the application.

Voltage breakdown requirements depend upon application, operating temperatures, altitude, and humidity. When voltage is low, insulation resistance is not usually an important factor, nor is capacity-to-Q ratio; however, capacity changes can appreciably affect performance of high-frequency circuits.

Insulation usually consists of a solid waterproof material which may be covered with a braid. The primary solid insulation can be made of such materials as rubber, vinyl, polyethylene, or fluorocarbon. The braid affords additional protection against abrasion and may carry the color code or identification. Polyethylene and similar materials are used extensively without braided coverings. Outstanding properties of insulation commonly used for wiring military equipment are listed in the table on page 7-4.

7.2 CODING OF CONDUCTORS

Color coding not only facilitates wiring, testing, and localizing faults in manufacture, but also greatly aids servicing in the field.

7.2.1 Color Codes

A single color code must be used continuously throughout a series of equipment models. Solid colors should be used wherever possible, as these facilitate tracing leads. However, if the number of circuits required to be coded exceeds ten, multiple tracer colors may be used.

Colors should be readily distinguishable under incandescent light and should resist fading, running or discoloring due to heat. Violet is usually omitted, since it is difficult to distinguish under certain adverse lighting conditions.

PROPERTIES OF INSULATION MATERIAL

Insulation	Notes	Applications
Cellulose Acetate	Moisture and abrasion resistant. Combustible, poor flexibility.	Solid insulation
Cotton	Low resistivity in humid environments.	Cable interwire filler
Cotton, Impregnated	Relatively high dielectric strength	Braided insulation
Fluorocarbon (Teflon, Kel-F)	High melting point, no appreciable moisture absorption; excellent flexibility despite low temperatures.	Solid insulation for use up to 200°C (Teflon) and 135°C (Kel-F)
Glass Fiber	Non-inflammable, fungi and heat resistant. Tendency to fray and absorb moisture at ends; subject to abrasion.	Braided insulation
Nylon	Excellent abrasion, flame, solvent resistance. High surface resistivity.	Braided insulation
Polyethylene	Low loss at high frequencies, chemically stable, moisture resistant, excellent flexibility. Subject to abrasion, softens at comparatively low temperatures.	Solid insulation
Rubber, High Temperature	Good dielectric strength, moisture and abrasion resistant. Subject to aging; impairment upon contact with oils.	Cable jacket; primary solid insulation
Vinyl	Chemically stable, moisture and abrasion resistant, flameproof. Fair dielectric.	General purpose solid insulation for use up to 100°C.

7.2.2 Identification Tags

Interconnecting cable leads are easily identified by means of adhesive wire markers. Pre-printed, self-sticking markers offer a simple solution to identification. Markers may be used permanently or can be detached when no longer needed. Also available are permanent thermosetting adhesive tapes for coding heat-generating components. These are resistant to any changes in environmental conditions over the ranges specified for military equipment.

7.2.3 Coding of Noninsulated Leads

Noninsulated solid wire leads can be color coded by means of colored lacquer spotted on the wire near connecting terminals. No coding is required if terminals are otherwise identified, if leads are less than 4 inches in length, or if placement permits obvious identification.

7.3 WIRING PROCEDURE

Whether an assembly is a single unit or a composite of subassemblies, the basic steps of wiring are essentially the same. These include routing and dressing, harnessing and cabling, and preparing wire ends for connection. Proper procedure insures wiring which will withstand severe conditions and facilitate any maintenance required.

7.3.1 Routing and Dressing

Routing is the layout of wiring to secure the most efficient and direct order throughout an assembly.

Dressing is the arrangement of wiring within a localized area to secure neat and orderly appearance.

In contrast to the point-to-point routing used in most commercial equipment, wires in military equipment are usually run either parallel or at right angles to each other, thus presenting a more orderly appearance. The manner of routing and dressing wires is determined by the nature of the circuit, anticipated service life, and cost. However, it is important that critical dressing of leads or cables should not be required to maintain circuit stability.

Proper routing and dressing should accomplish the following: Wiring and cabling should be neat, sturdy, and as short as is practicable; arranged to permit easy inspection and test of the final unit; and arranged to prevent damage to assembled parts by additional wiring and cabling operations.

Wiring and cabling should not cross sockets or those openings which permit access to adjustments, nor interfere with normal operation of equipment or replacement of electronic components.

Lugs and terminals should be arranged for easy access during assembly and service operations and to prevent damage to components during wiring and soldering. Proper application of all connectors should be considered in the final wiring layout.

General practice in dressing is to place insulated wires flat against the chassis or base to provide compactness. Bare or bus-bar wiring is usually dressed high to prevent short circuits to the chassis. Resistors, capacitors, and similar components are usually mounted flat against insulated terminal boards to limit movement during shock or vibration.

In making a layout for the placement of wires and cables, the following factors should be considered:

a. Size, type, and number of wires routed between various components.
b. Location of runs with respect to framework and clamping.
c. Isolation of critical wiring to reduce inter-circuit interference.
d. Protection of personnel against radio frequency or high voltages.

Proper placement of wire connections facilitates fabrication and replacement of components. Removable subassemblies, such as component mounting boards, should be interconnected with the main assembly after sub-assembly components have been mounted; interconnecting wire ends should be wrapped onto terminals above component leads. However, when the harness or cable is an integral part of the subassembly, interconnecting wire ends should be wrapped on terminals below component leads to facilitate subsequent wiring and maintenance.

Wires and cables should be located to minimize inductive and capacitive effects. Improper placement of wires or cables may cause serious operating difficulty due to spurious oscillations or other electrical interference. Clearance for movement of mechanical parts must also be provided. Wiring should be firmly supported to prevent undue strain on the conductor or terminal and to eliminate possible changes in equipment performance resulting from any shifting of conductors.

Conductor pairs carrying alternating current should be twisted wherever possible to minimize undesired magnetic flux.

To prevent deterioration of wire insulation due to heat, care must be taken to provide sufficient clearance between conductors and heat-radiating components such as vacuum tubes, resistors, and transformers as shown on the following page.

All wiring must be protected against abrasion. Wires and cables should not be routed over sharp edges, screws, nuts, lugs, or terminals and should not be routed or bent around sharp details that may cause abrasion under normal service conditions.

When it is necessary to pass wiring through holes in thin metal, the conductors should be protected by grommets.

To protect and isolate conductors carrying radio-frequency or high voltages, it may be necessary to cover the entire length of the conductor with insulating beads; thus avoiding a sharp bend and assuring adequate clearance between conductor and metal parts.

Ceramic, nylon, Teflon or similar grommets should be employed to protect conductors carrying radio-frequency potentials unless coaxial cables are used. The cables are already provided with outer sheathing, and rubber or metal grommets furnish sufficient additional protection. If the metal is more than 1/8 inch thick,

DRESSING OF LEADS

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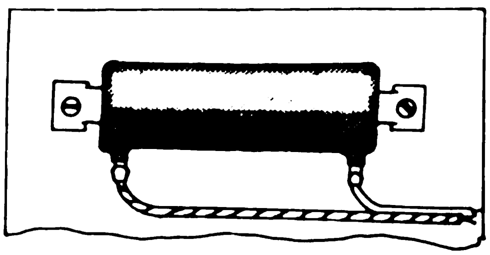
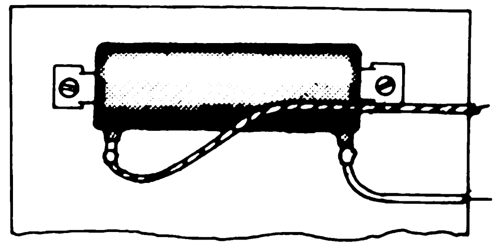


Lead dressed away from hot component (preferrably 1/2 inch or more)

AVOID



Lead near hot component

and electrical requirements permit, the edges of holes may be rounded to a radius of one-half the metal thickness as shown on the following page.

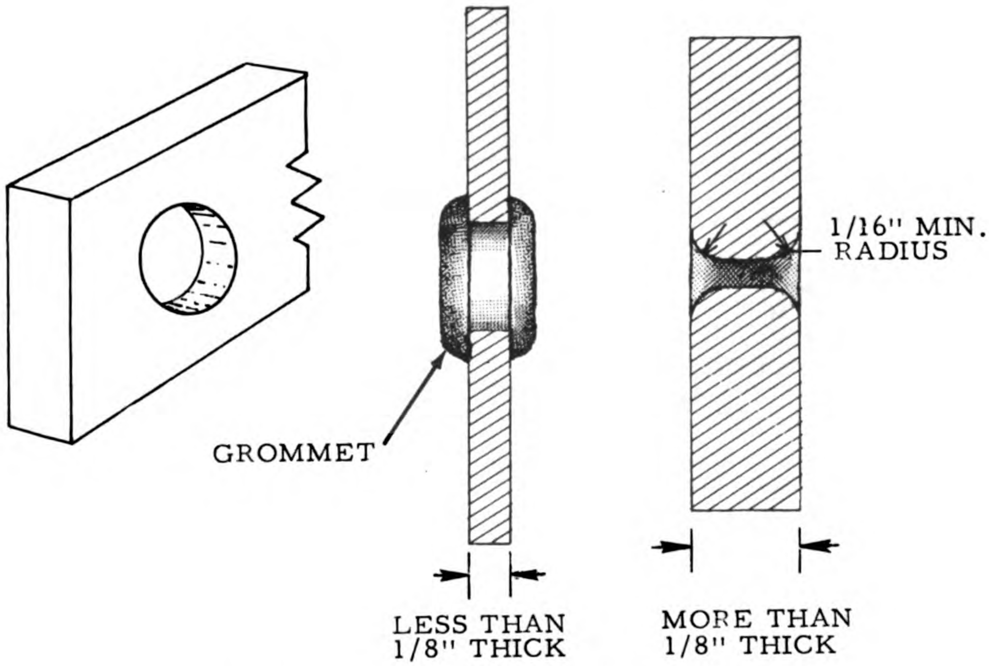
Synthetic rubber tape or varnished cambric sleeving (spagetti) must not be used to protect wires. Fiberglass or high temperature vinyl sleeving is recommended.

Wiring should be performed in the following sequence: select wire, cut to proper length, strip insulation, tin ends, place in position, wrap, crimp, solder, and dress. Terminals should be wired in a definite order. First all wiring required between adjacent terminals should be connected, then nonadjacent terminals should be wired, and last, small components.

Sufficient slack equal to at least the length of the stripped and tinned portion of the wire should be left to permit limited movement of parts and subassemblies during inspection and maintenance.

7.3.1.1 Inspection of Routing and Dressing. The following are considered to be major defects:

a. Broken strands likely to result in nonfunction or malfunction.
b. Space between conducting movable elements and fixed bare conductors less than 1/16 inch.
c. Improper placement of wiring which may result in shortened service life of equipment or interfere with normal operation.
d. Wire pinched, frayed, or burned to the extent that a break or short circuit could result.
e. Improper termination which could result in an eventual loose connection.



USE OF GROMMETS OR ROUNDED EDGES

f. Improper support which may result in breakage of conductor due to fatigue.

The following are considered to be minor defects:

a. Broken strands not likely to result in nonfunction or malfunction.
b. Spacing between conducting movable elements and fixed bare conductors greater than 1/16 inch, but less than 1/8 inch.
c. Improper placement of wire or cable which could result in reduced efficiency but will not render equipment inoperative.
d. Wire insulation chafed but unlikely to cause short circuit.
e. Wire drawn taut, introducing excessive stress on wire, components or terminals.
f. Insulation back more than 1/8 inch from a connection but cannot result in a short circuit.

7.3.2 Harnessing and Cabling

Grouped wires are usually harnessed or cabled to form a sturdy compact unit which can be dressed more neatly than individual conductors and installed as a single assembly.

Chassis wiring is usually laced to form what is commonly termed a "wiring harness", or "harness". These are usually fabricated by the equipment manufacturer to suit the particular wiring layout.

Harnesses should be located so that circuit tracing can be readily accomplished, and accessibility to parts or components which may require replacement is not limited.

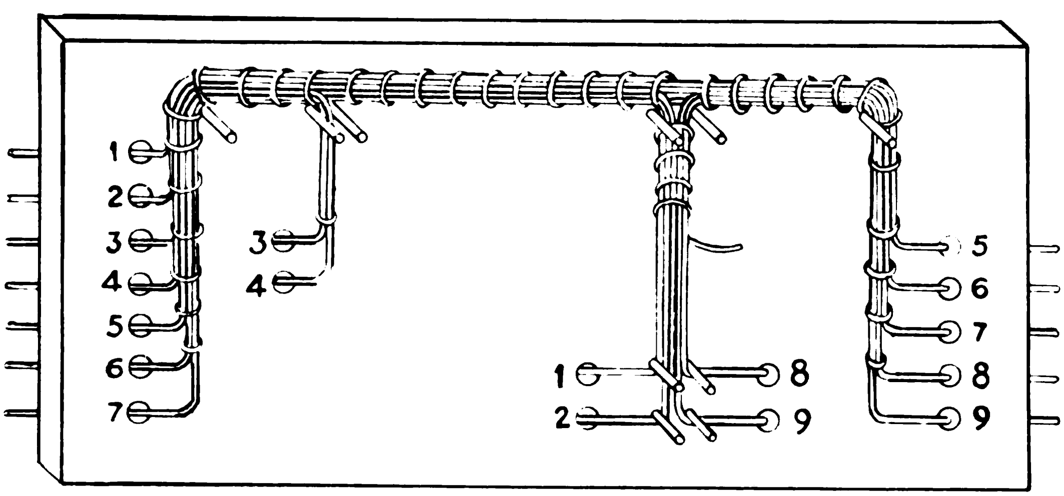
Individual wires of a harness should be arranged to run parallel or at right angles to each other wherever possible. Sharp bends which may damage conductors or insulation are to be avoided.

Harnesses are usually fabricated on a "harness jig" or "forming board". The board may be marked with numbers and symbols to indicate wire sizes, color coding, routing, terminations, and wiring sequence. Pegs or nails, placed in a pattern which follows a pictorial wiring diagram, serve to locate wire runs.

Conductor ends may be anchored to the board by wrapping them about nails or pegs, or may be fanned out for easier dressing if holes to accommodate wire ends are provided.

A typical application for a forming board is shown below.

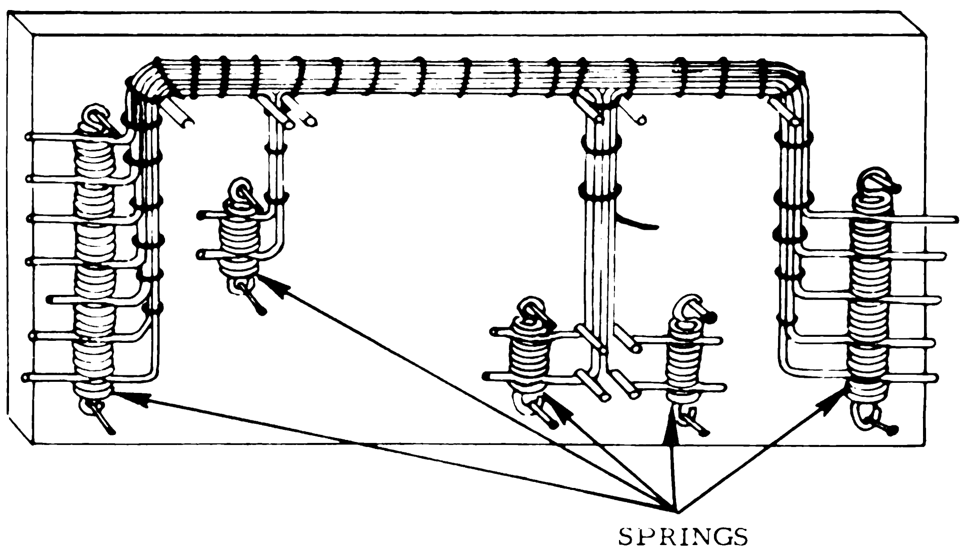
Another method of anchoring conductor ends on a harness jig is to attach springs on the board near the termination point of the wire. The pitch of the spring should be determined by the size of the wires to be held in place. The wire may be pushed into the spring, where it will be held firmly. This method is rapid and minimizes drilling



HARNESS FORMING BOARD

of holes and placing of pegs or nails in the board. Harness jigs may thus be reused many times. A typical application of a forming board utilizing springs is shown below.

Harnesses may be laid out on a jig bottom-side-up for ease of lacing. When this is done and the harness is installed in a given unit, the lacing knots and splices will not be visible from above and the harness will have a neat, workmanlike appearance.



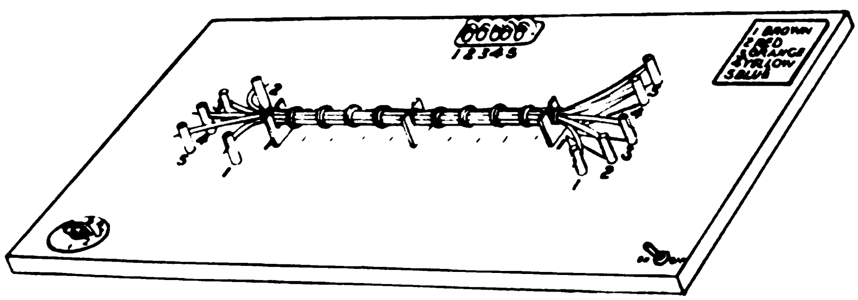
HARNESS FORMING BOARD WITH SPRINGS

Forming boards are sometimes equipped with electrical checking devices to speed harness testing, as shown below.

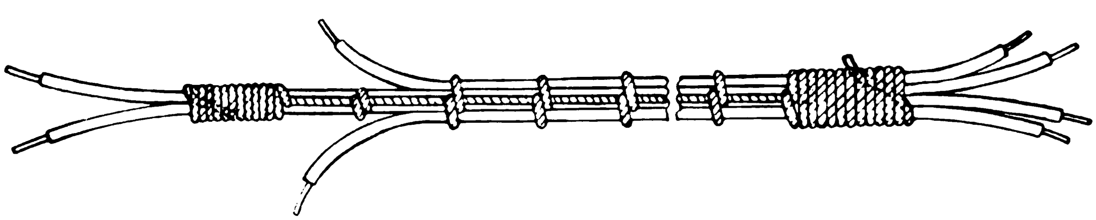
Ribbon-type lacing cord should be used in preference to round cord to reduce the possibility of cutting into wire insulation. One-eighth inch nylon or similar ribbon is best suited for this purpose.

If round cord is used, sizes should be as follows:

PRINCIPAL CABLE DIAMETER	CORD SIZE
Up to 3/8"	# 4
5/16 to 3/4"	# 6
5/8 to 1"	# 9
7/8" and over	# 12

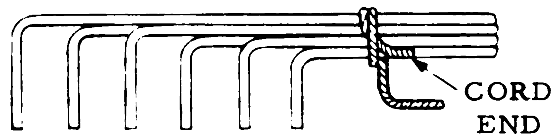


HARNESS FORMING BOARD WITH ELECTRICAL CHECKING DEVICES

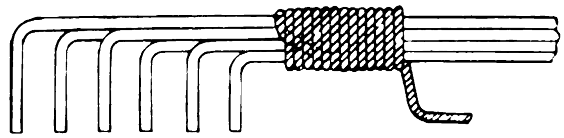


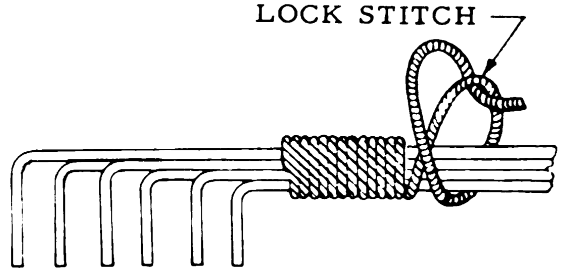
THE HARNESS IS LACED AFTER ALL WIRES HAVE BEEN CUT TO LENGTH, STRIPPED, TINNED, AND PLACED IN POSITION

The process of lacing or binding a harness can be started at one end with a "starting tie". Alternatively, lacing can be started at the center with a "lock stitch," and a terminating wrap can be used at each end.

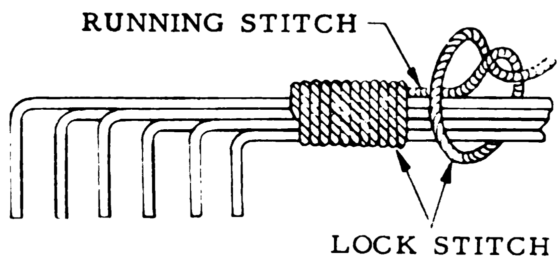


Lacing is started by cutting a length of cord two and one-half times the length of the proposed harness. One end of the cord is laid alongside the principal cable pointing into the harness. The cord end is secured as approximately four turns of cord are wound over it, and wrapping is continued until a total of twelve turns is wound about the principal cable.

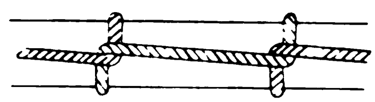




The wrap is secured by a lock stitch. This is made by forming a loop, passing the cord over the loop, then through the loop, and finally pulling the cord tight.

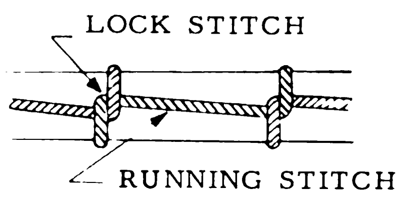


Secure stitches can be formed only by lacing the cord over the loop, never under, to form the so-called lock stitch. The cord is thus locked under each loop.



WRONG

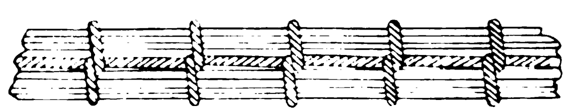
Lock stitches at approximately 1/2-inch intervals thereafter secure other loops in the same fashion.



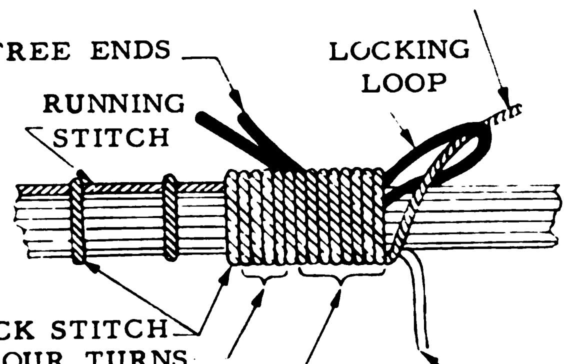
RIGHT

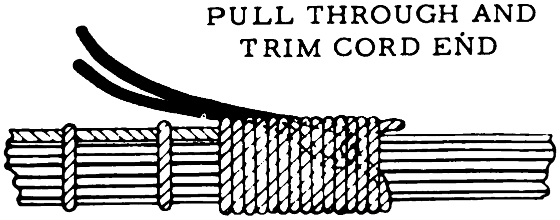
The foregoing describes the "regulation cableman's knot", which is self locking.

As lacing is advanced, the wires should be re-formed to insure a neat and firmly bound cable; conductors should be arranged to lie parallel without crossovers except when twisting is required.

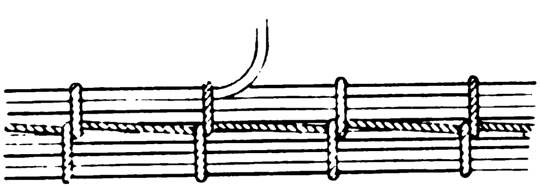


Lacing is terminated by the following procedure. Four turns of cord are wrapped adjacent to the last lock stitch. A separate piece of cord is formed into a 2 inch-loop and laid alongside the cable as shown. Eight turns of lacing are wrapped about the loop and the end of the lacing cord is then drawn through the loop.

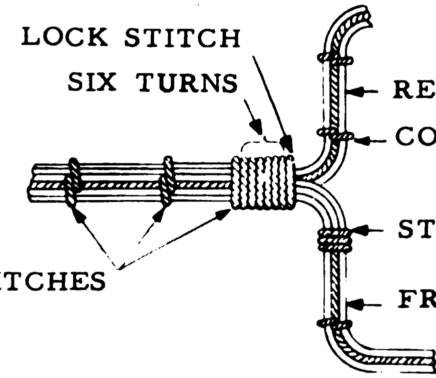




Both ends of the loop are then pulled to carefully draw the cord end underneath and out of the wrap. The cord end is then pulled tight, locking the wrap, and finally the end is cut to approximately 1/8 or 1/4 inch.



Branches and sub-branches, including single leads, are usually referred to as "breakouts". Single-lead breakouts should be preceeded by a lock stitch without variation in the distance between stitches.

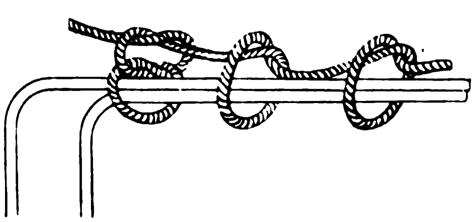


Any breakout of two or more wires should be laced. When a group of wires is branched from a cable, a lock stitch is made; six turns are wrapped firmly about the principle cable adjacent to the new stitch, and finally, another lock stitch is made adjacent to the new turns. After a branch is thus secured, the running stitches are continued along the main cable.

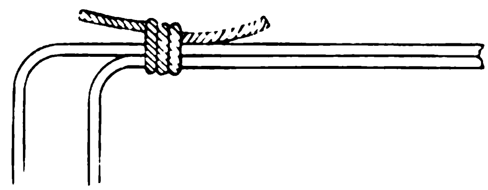
All lacing should follow the top of the harness. All knots, splices, or other irregularities should be hidden from view when the cable is installed in the equipment.

When laced, the cord should be sufficiently tight to minimize slippage but should not cut into the insulation.

Lacing may also be started with a square knot, followed by two lock stitches.

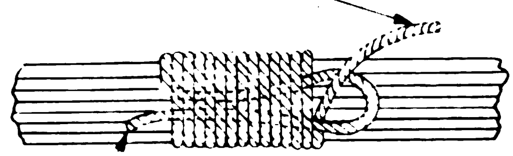


Lacing is then performed as previously described, and terminated by a lock stitch and a square knot.

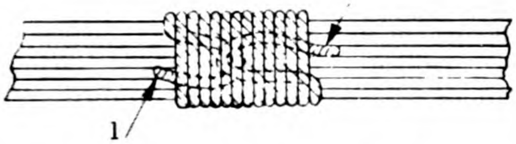


Another procedure for lacing consists of making a series of individually bound wraps at points along the equidistant points along the cable, as required. Lacing cord, 2 inches longer than the length required to make twelve turns about the harness, is cut. One end of the cord is formed into a 1-inch loop which is placed flat on the harness, parallel to the wiring.

Twelve turns are wound tightly over this loop and, at the last turn, the cord end is pushed through the loop which extends from under the wrap.



The end of the looped cord is then pulled until the loop is under the wrap, but only so far that the two loops intersect at the approximate center of the wrap. Loose cord ends are then trimmed.



A carpet needle or shuttle facilitates feeding of the cord end and may be used to speed lacing.

Should lacing break or require splicing, a square knot should be used to connect the ends.

Any of the following defects should be noted during harness and cable inspection.

a. Frequent cord splices indicate that the cord was pulled too tight or that the cord size was too small for the diameter of the cable.

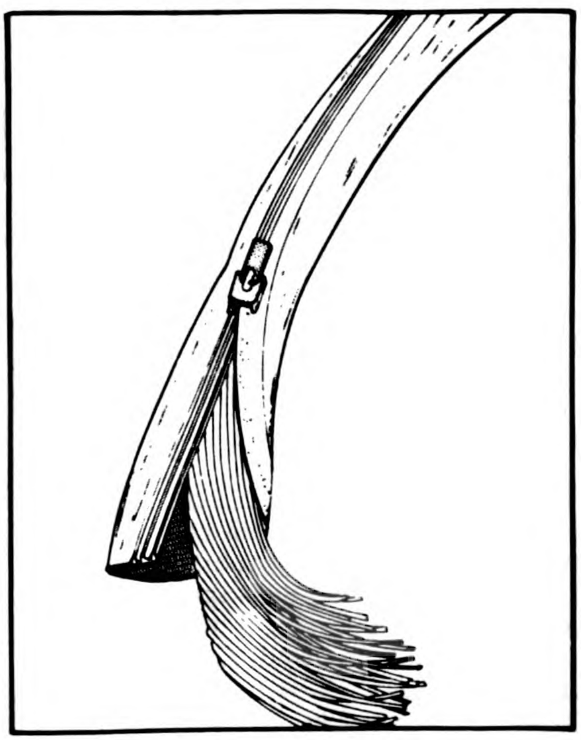
b. Lacing cord should not become frayed. If fraying occurs, the original length of cord was excessive.

c. Knots and splices should be concealed from top view.

d. Wire insulation should not be broken, split, or frayed at its ends.

e. Lacing should not be spattered by solder or scorched as a result of a soldering operation.

7.3.2.1 Zippered Tubing. Another method for forming a wiring harness is to twist, bunch, or interlace the wires and enclose them in a commercially available zippered plastic tubing. This method is especially useful for custom cabling or in applications where a replaceable cable jacket is desirable. The principal advantages of using the zippered tubing are that it is much less time-consuming than lacing and tying, permits repeated access to work points, and allows the rapid addition or extraction of circuits. The jacket may be easily removed, the necessary changes made in the wiring, and the tubing rezipped in a matter of minutes. In contrast, if it is necessary to make changes in a conventional wiring harness which has been laced and tied, the cable may have to be replaced or extensively reworked. Zippered tubing also presents definite advantages in external wiring applications, where cables between equipment are too stiff when laced and tied, and where protection against abrasion is required. A typical use of zippered plastic tubing is illustrated below.

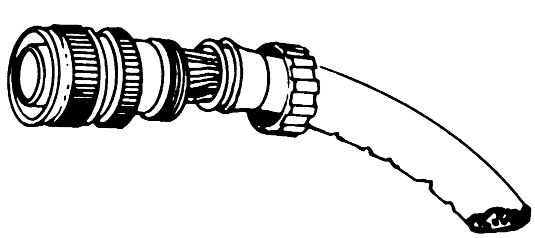


ZIPPERED TUBING

Zippered tubing is very useful when wires are to be soldered to a connector. The tubing can be unzipped and folded back of the connector to expose the work area, then zipped shut to cover the soldered area and sealed. The tubing can be easily and effectively terminated by using one of the following:

a. AN or other type connectors in conjunction with two matching ferrules
b. Pressure-sensitive tapes
c. Potting

Termination of the tubing by method "a" is illustrated below.



TERMINATION WITH CONNECTOR

Zippered tubing is available which will shield cables and harnesses from electrostatic and electromagnetic radiation. Its installation is a one-step operation which eliminates the laborious hand wrapping or expensive braiding necessary to shield conventional types of cables and wiring harnesses. The tubing can be terminated and grounded by:

a. Grounding adapters which fit the back of a connector or plug
b. Grounding wires or tabs.

Perforated zippered tubing is available for use where wire branchouts are necessary or where localized moisture condensation must be avoided.

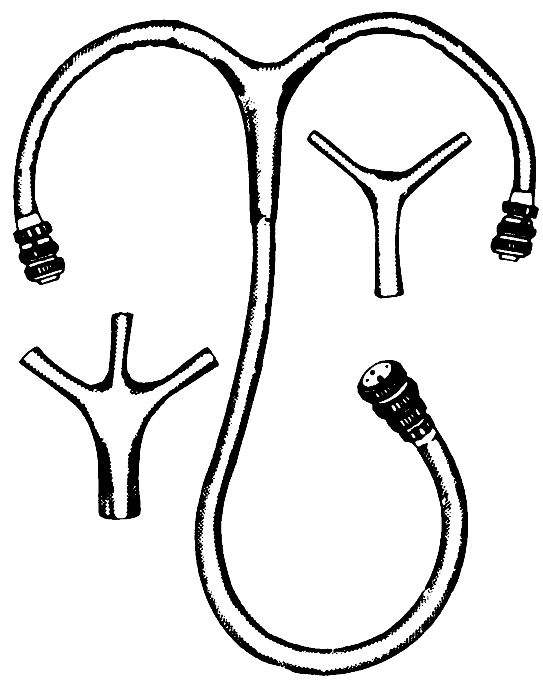
Zippered tubing is generally available in the following compositions:

a. Vinyl
b. Vinyl-coated fiberglass
c. Vinyl-saturated fiberglass laminated to aluminum foil
d. Vinyl-backed butyl rubber
e. Lead-saturated vinyl
f. Mylar
g. Polyethylene
h. Aluminized asbestos fiber.

Zippered tubing is available in compositions which can be used at temperatures ranging from those normal for electronic equipment up to approximately 2000^{o}F.

Zippered tubing is made in a variety of shapes to meet special needs. Two of the more commonly used shapes, the "Y" and the "T", are illustrated below.

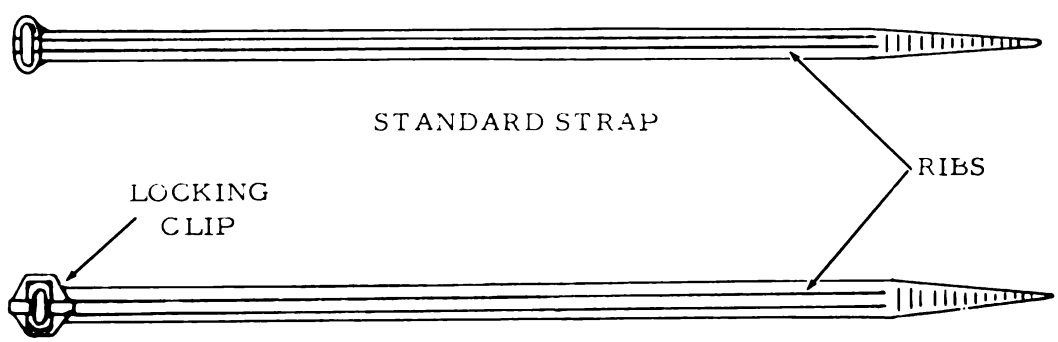
Compounds are available which will effectively seal the zippers of zippered tubing in applications where a high degree of waterproofing is essential.

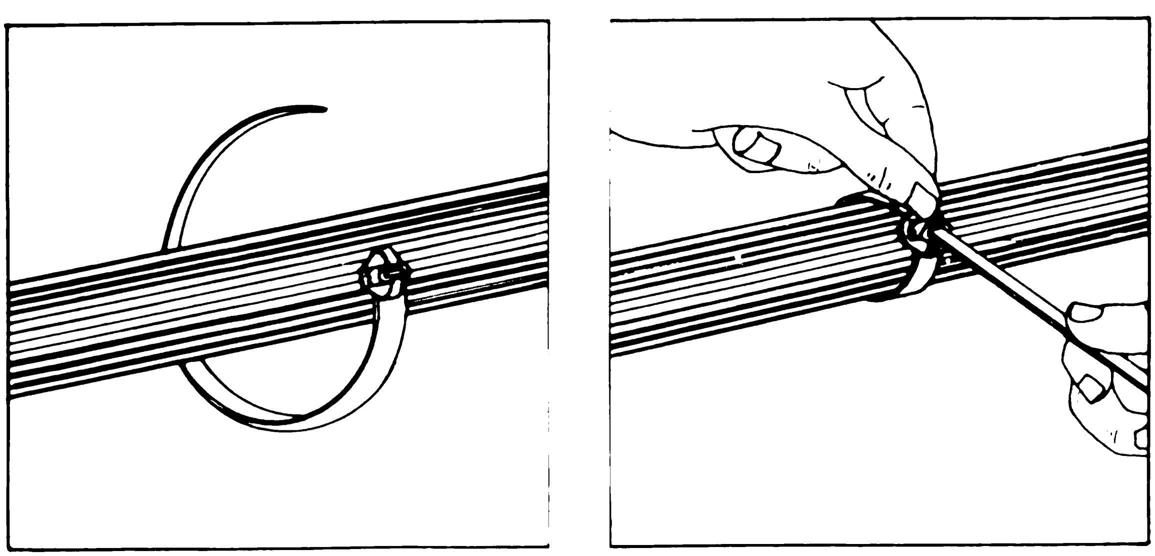


Y- AND T-SHAPED ZIPPERED TUBING

7.3.2.2 Tie Straps. A recently developed method of binding wires to form a cable or harness involves the use of plastic tie straps, such as those illustrated below.

The tie straps are made of one-piece molded nylon, and are able to withstand temperatures between -65° and 350°F. They permit lightweight, rapid, and effective lacing of wire bundles and harnesses, and are available in sizes from 1/16 inch to 1-3/4 inches in diameter. These straps resist fungus and corrosion, do not support combustion, and have good dielectric characteristics. Each strap has two ribs running lengthwise along the inside surface to prevent lateral movement of the strap along the harness.

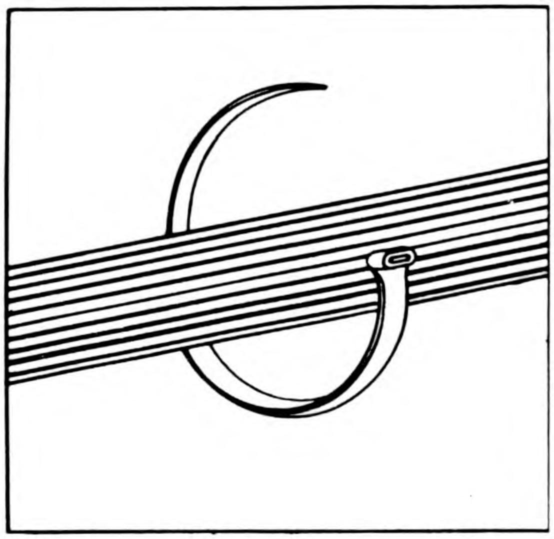




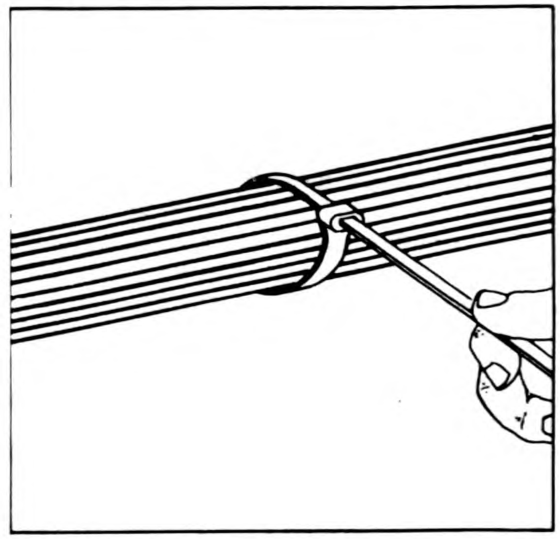
1. Slip strap around wire bundle, rib side inside

2. Pull tight and clip off excess

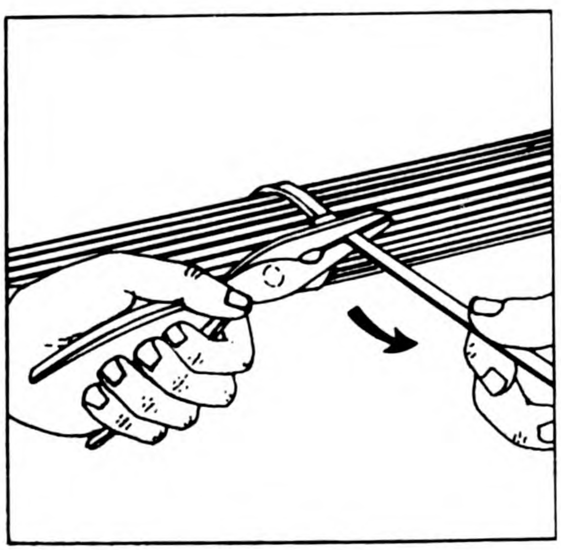
INSTALLATION OF SELF-CLINCHING STRAPS



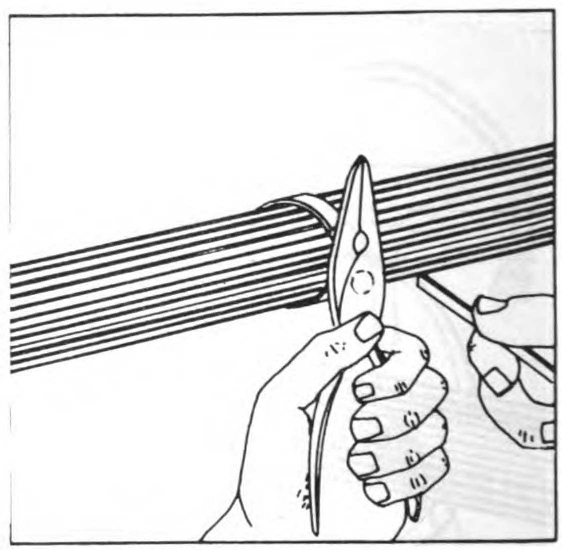
1. Slip strap around wire bundle, rib side inside



2. Thread tip through eye and draw up tight



3. Apply pliers; twist 120°



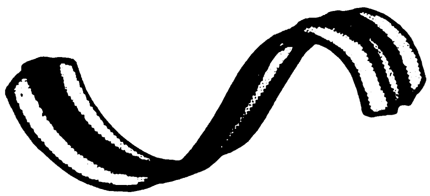
4. Clip off excess

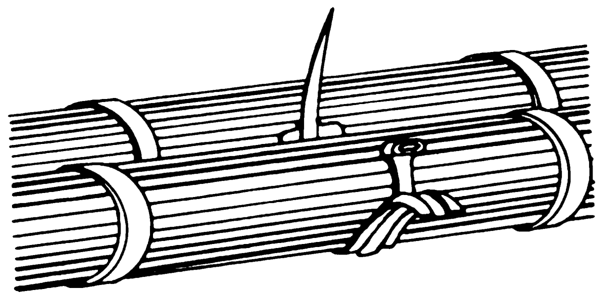
Larger bundles may be tied by using two straps together, inserting the tip of one strap through the eye of the other, and locking both straps.

The shoehorn-type tool shown below may be used for installing the tie straps in close quarters.

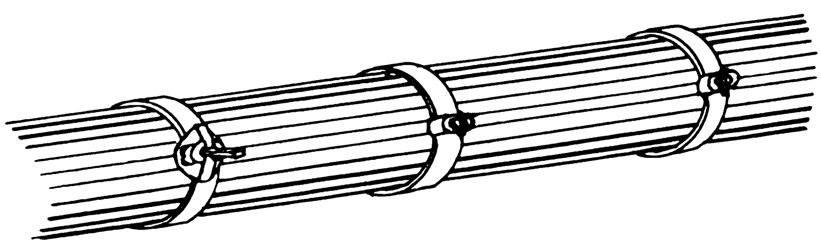
The use of tie straps in service is also illustrated below.

Tie straps may also be used for clamping bundles of wire and harnesses as discussed in 7.3.8.5.





SHOEHORN-TYPE TOOL



USE OF TIE STRAPS IN SERVICE

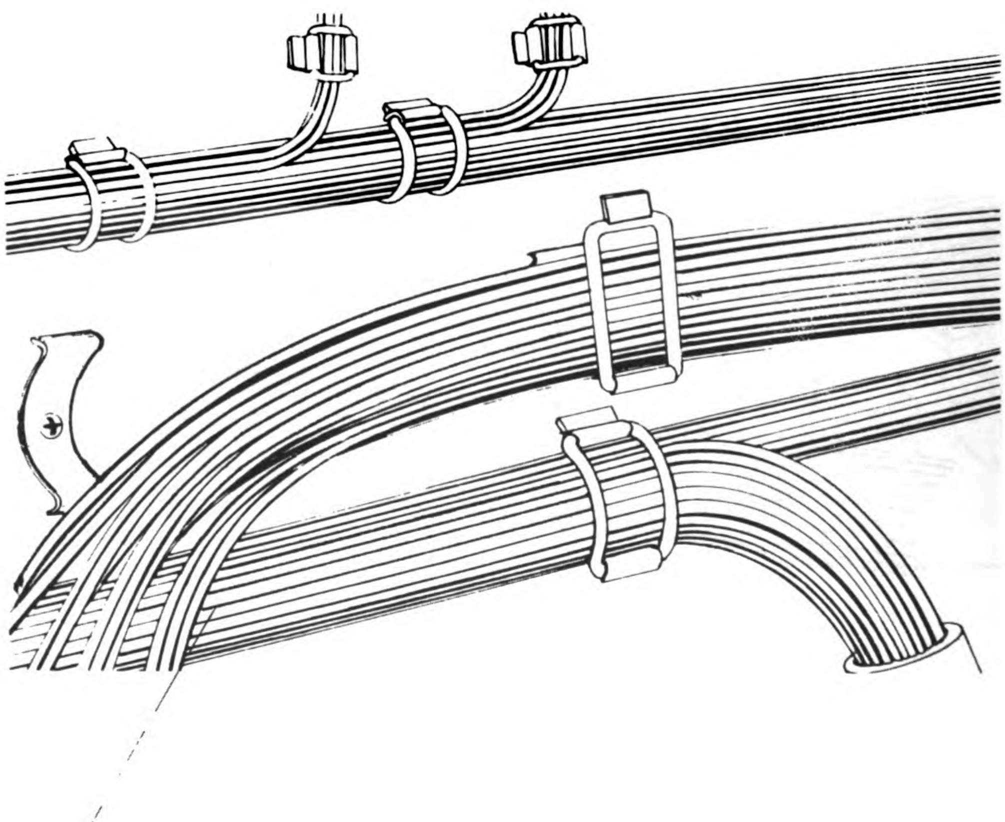
7.3.2.3 Cable Clips. Another recently developed method of harnessing or strapping wires involves the use of two-piece cable clips which are quickly and easily installed either by hand or with a special tool. Each clip consists of a flat or U-shaped base and a flexible strap which cinches across the open end of the base and locks under inverted lips.

The straps are made of neoprene which is flexible, tough, and relatively inexpensive. They are also available in certain molded fluorine-base elastomers for high-temperature (above 400°F) and other special applications. The base is molded of nylon. The neoprene straps and nylon bases are usable in the temperature range of -76° to 212°F.

The bases and flexible straps are available in several sizes and can accommodate cable or wire bundles from 3/16 inch to 2-1/4 inches in diameter. Larger diameter cables can be strapped by using two or more bases and clips together.

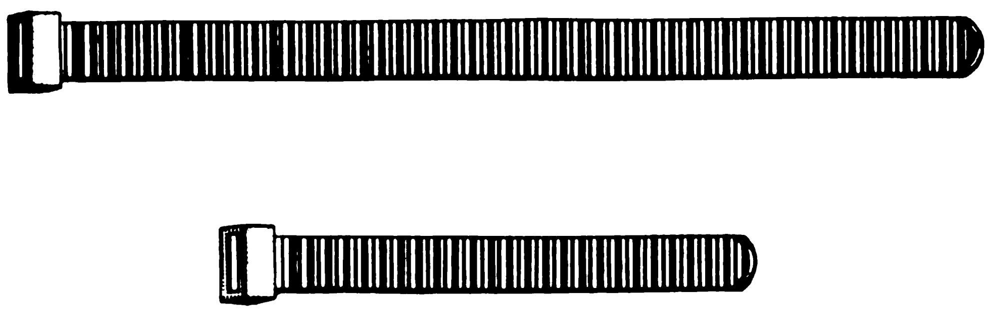
These cable clips are quicker to install, neater, and easier to disassemble than standard lacing methods. An example of the use of the clips in service is illustrated below.

The cable clips may also be used to clamp cables and bundles of wire, as discussed in 7.3.8.5.

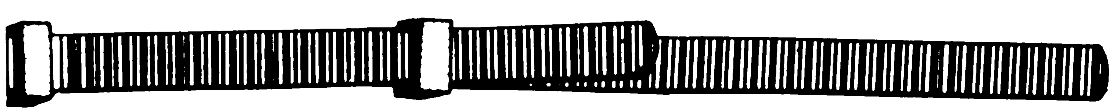


7.3.2.4 Band Clamps. The band clamps illustrated below are similar to the tie straps discussed in 7.3.2.2, and are used for the same purposes. They are available for cable sizes from 5/16 to 1-1/4 inches in diameter.

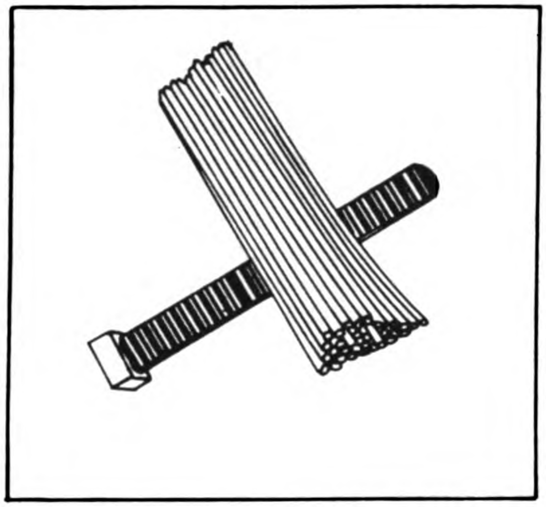
The band clamps are non-conducting, corrosion resistant, one-piece molded nylon. The ratchet-like teeth across the inside of the flexible band engage the teeth of the loop when installed to form a tight bond around the cable or wire bundle. Two or more clamps can be used together, as shown, if bundles of wire larger than 1-1/4 inches in diameter are involved.



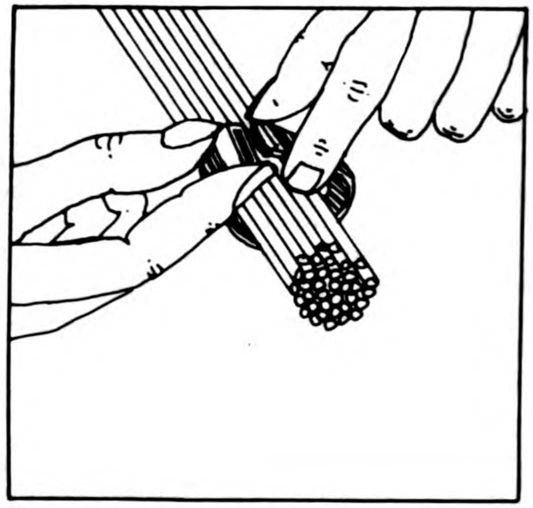
BAND CLAMPS



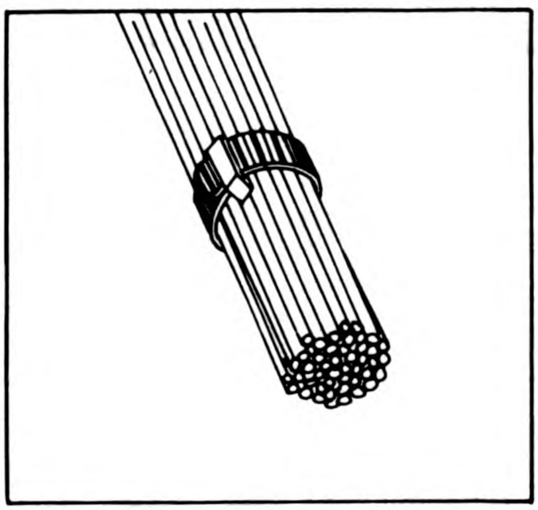
USE OF BAND CLAMPS
FOR LARGE WIRE BUNDLES



1. Select right length band clamp



2. Insert tab through loop so tab is between wires and clamp



3. Push clamp together until it fits snugly around the wires and the ratchet teeth engage

INSTALLATION OF BAND CLAMPS

A special tool is available for installing the band clamps if more than hand-tightness is required.

The clamps can be removed by inserting a hard flat strip through the loop to force the ratchet teeth apart. The clamps can also be mounted on a chassis or panel with standard fasteners.

7.3.3 Preparing Connections

7.3.3.1 Stripping of Insulation. Insulation may be stripped from wire ends by means of either hand tools or automatic machinery.

In short production runs, a hand stripper is usually employed. It bares conductors more easily than does a knife, and is less likely to damage wires.

STRIPPING TOOL

Automatic machinery, performing cutting and stripping separately or combining these in a single operation, is often used for high production runs.

Care must be exercised in either manual or automatic stripping to prevent cutting, nicking, scraping, or otherwise damaging conductors. Ends should be stripped clean of all foreign materials to prevent insulation particles or frayed ends from becoming twisted among wire strands.

In general, insulation should be stripped back about 3/4 inch from each wire end. This length is sufficient to wrap most turret or flat terminals.

RIGHT

WRONG

To insure uniform wire ends, insulation can be stripped back further than required; wire ends may then be grouped together, aligned, and cut to a single length.

Broken or nicked strands should not project beyond wire insulation unless strands are long enough to be secured by proper tinning. The number of short, untinned strands should not exceed the following:

No. Strands in Conductor	Allowable Clipped Strands
7 - 15	1
16- 18	2
19-25	3
26-36	4
37-40	5
41 or more	6

7.3.3.2 Cleaning of Wire. In the routine of preparing connections for soldering, some wires may require additional cleaning. The methods used are also employed for initial removal of some insulation. They are alternately called stripping methods.

Insulation may stick to bared wire after the stripping operation, or perspiration may contaminate metal surfaces, if overhandled, and impair or slow the soldering operation. Before soldering enamel-covered wire, all enamel must be removed from the portion of wire to be soldered.

There are four widely used methods of cleaning wire.

a. Mechanical scraping. A knife can be used to restore the conductor surface to a bright appearance but is least effective and care must be taken not to cut, nick, or abrade the wire. Sandpaper is more effective especially for cleaning stranded wire. Strands should be spread apart and cleaned individually.

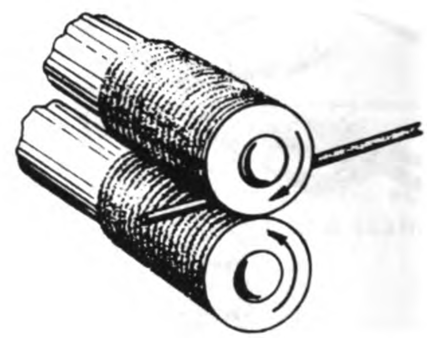
b. Heating. Insulation and foreign material can be burned off and the wire then easily cleaned of the residue by chemical or mechanical means. Care must be taken to avoid burning of the wire especially in the case of small diameter wires.

c. Chemically dissolving. Most effective cleaning method for magnetic and resistance wire is to dip the wire end into a solvent and then wipe off the foreign deposit.

Practically any type of wire insulation can be removed by means of chemical solutions. They will remove enamel, fiberglass, Formvar, chrome oxide, silicones and hardbaked varnish insulations. Dissolution times range from 2 seconds to 2 minutes. Precautions must be observed when employing the caustic solvents.

Often when chemical solvents are employed, the wire will be cleaned sufficiently to permit soldering without the use of flux.

d. Abrading. Effective for high production runs is an arrangement of two abrasive wheels, usually fiberglass, which serve to scrape off enamel or other insulating material. The wire end is inserted between the wheels which rotate at high speeds. This method works well on either stranded or solid wire.



ROTATING BRUSHES

7.3.3.3 Tinning. Tinning, the process of coating metal surfaces with a uniform layer of solder, is necessary for several reasons which include ease of soldering, strengthening of stranded wire, cleaning, and retarding of oxidation.

Although conventional hook-up wire after stripping is usually clean enough to be soldered, stripped ends can be retinned to insure quicker, more thorough bonding.

Stranded conductors should be twisted before tinning to keep individual strands from spreading when the wire is crimped to a terminal.

To quickly tin a large number of conductors, a handful of stripped wires are evened up and dipped into a dish of liquid flux. Excess flux is then shaken off and leads are immediately immersed in a solder pot heated to a temperature between 420° and 460°F. A stranded conductor when tinned is equivalent in rigidity to a single, solid wire.

Suggested tinning length is as follows.

AWG Wire Size	Maximum Tinning Length
#18 wire and smaller	2/3 of stripped length
#16 wire and larger	1/3 of stripped length
Coaxial cables and shielded conductors	3/16 inch

7.3.4 Permanent Wire Connections. Permanent wire connections are those unlikely to be disassembled during equipment life.

7.3.4.1 Mechanical Connections. No connection should depend upon the strength of soft solder alone for security. All electrical connections should be mechanically supported and secured prior to soldering by wrapping or crimping the wire tightly around the terminal. This helps to prevent disturbing the joint while the solder is "setting". A good mechanical joint is also necessary because solder, although solidified, is relatively soft, and if subjected to continual tension may "cold flow" and increase the electrical resistance.

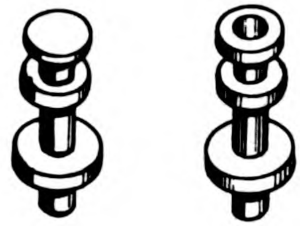
A desirable connection to a terminal is made by wrapping the stripped end of the wire around the terminal 3/4 to one turn. Wrapping the wire more than 3/4 turns does not add materially to the strength of the joint and makes subsequent removal of the connection difficult. Care should be taken to bring the end of the insulation as close to the terminal as possible without allowing insulation to interfere with the soldering operation. The wire should be wrapped around the terminal so that tension on the wire will be transmitted to the terminal and not to the solder.

A good mechanical joint sometimes requires crimping. This may be accomplished by using pliers to squeeze the wire wrap tightly against the terminal. In many cases, particularly with stranded wire, crimping is not necessary if sufficient pull is exerted upon the wire while making the wrap.

When wrapping more than one wire on a terminal, the proper wrapping procedure is generally the same as for one wire. If the terminal size or shape does not permit proper connections, an auxiliary terminal should be used.

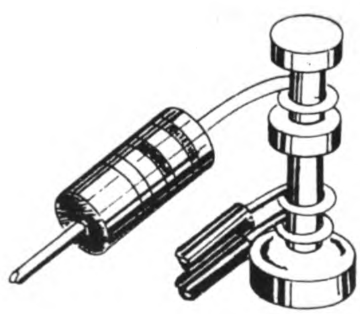
7.3.4.2 Terminals. There are four basic types of terminals to which mechanical connections can be made. The best wrapping technique varies with each type of terminal.

Type 1, the turret or stud terminal, is used primarily on component mounting boards (see 6.4.1.4).

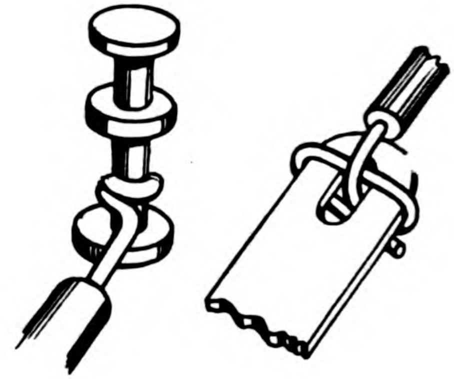


TURRET OR STUD TERMINALS

The wire is led directly to one side of the terminal, wrapped and crimped if necessary. On this type of terminal, the component lead is preferably wrapped on the upper portion and the connecting wire on the lower portion. To facilitate maintenance, it is best to wrap the wire over the terminal post from the bottom up and to be consistent in either clockwise or counterclockwise wrapping. However, clockwise wrapping is preferred because of the natural tendency to attempt unwinding in a counterclockwise direction.



CORRECT WRAP

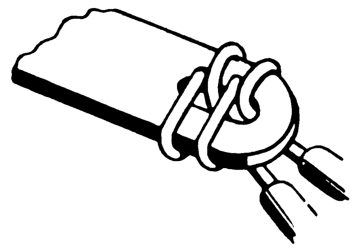


INCORRECT WRAP
(Wire pulls against solder)

Type 2, the flat, perforated terminal, is used on most tube sockets, variable resistors, wafer switches, etc.

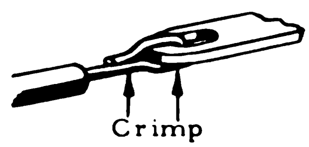
FLAT PERFORATED TERMINALS

The wire is secured by inserting through the hole and wrapping around the body.



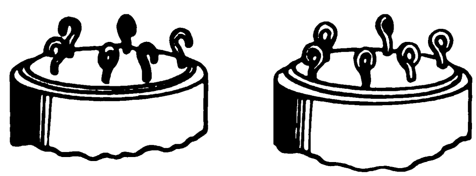
CORRECT WRAPS

When using heavy wire or where space does not permit proper wrap (such as with most miniature tube sockets), a mechanical connection may be made by feeding the wire through the hole in the lug, bending around the lug 180° and firmly crimping.



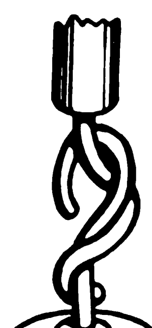
MINIMUM WRAP
(For limited space only)

Type 3, the hook or eyelet terminal, is used on most relays.

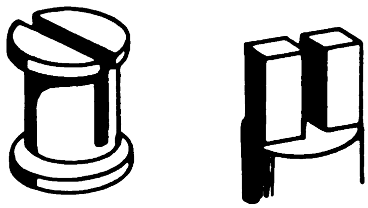


HOOK OR EYELET TERMINALS

A recommended mechanical connection may be made by feeding the wire through the loop and wrapping one full turn on the shank.

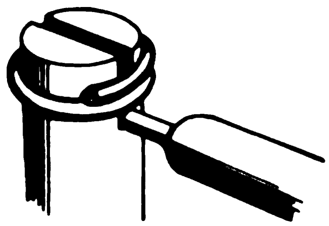


CORRECT WRAP



SPLIT TERMINALS

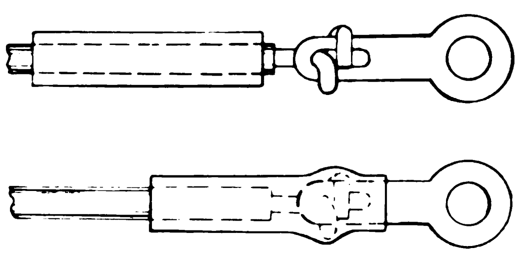
Type 4, the split terminal, is used on transformers and heavy components.

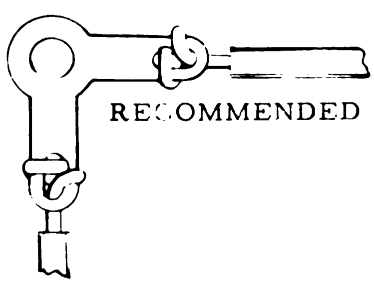


CORRECT WRAP

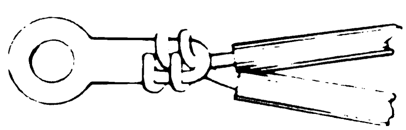
The wire is laid in the slot and wrapped around the body.

7.3.4.3 Soldering Lugs. Small, lightweight soldering lugs, available in many types and sizes, are extensively used for terminating conductors. The principal types used are flat-perforated and crimped-tab lugs. The important difference between these are the provisions for supporting the wire insulation.





RECOMMENDED



TO BE AVOIDED

(These lugs not to be used on terminal boards)

To connect flat-perforated lugs, the insulation is stripped approximately 1/2 inch from the wire end. The bared end is inserted through the hole and wrapped around the lug, clipped and crimped. In production, the wire is usually previously cut to the right length for wrapping and soldering. Insulated sleeving should be used to mechanically support the wire insulation as shown. The sleeve may carry lead identification marking.

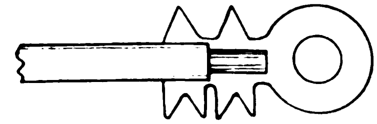
When multiple connections are required, all conductors should be wrapped prior to soldering.

To wire crimped-tab lugs, the stripped end is positioned on the lugs so that when crimped, one tab grips the bared wire and the other grips the insulation.

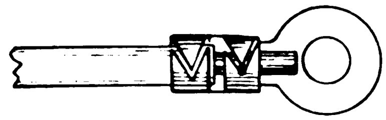
The wire should be clipped close to the inner tab so as not to interfere with proper seating of the eye when secured.

Insulating sleeving is then drawn over the barrel of the lug previously shown.

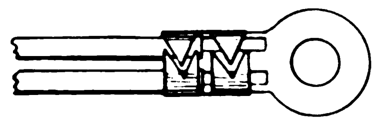
PREFERRED LUGS



RIGHT



WRONG



TO BE AVOIDED

7.3.4.4 Braided Shielding. This section discusses shielded wire, other than the coaxial type, which is described in 7.3.9.1.

Wires covered by bare metallic shielding must be mounted securely in position to prevent contact with other exposed conductors or terminals. All shielding must be terminated a safe distance from the exposed inner wire ends and secured by an approved method of grounding.

Any one of several methods can be employed to terminate the shielding. Of these methods, unbraiding and twisting together shielding strands, although widely used, is least desirable. Some shielding strands are likely to be broken, thus resulting in sharp disconnected strands and possible short circuits.

When the shielding can be slipped over the length of the inner conductor, the following procedure is recommended.

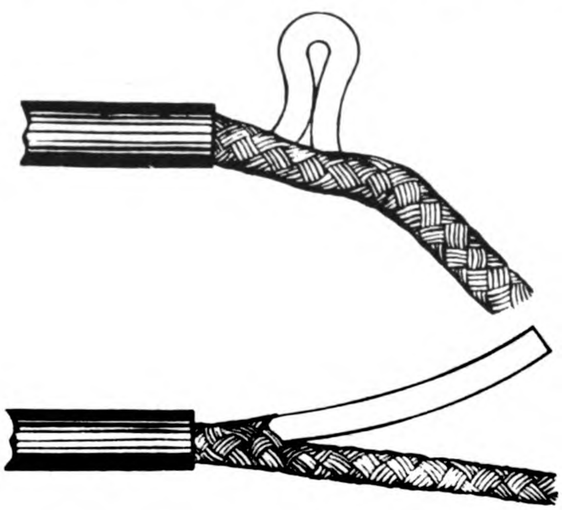
The shielding is slipped over the inner conductor until the point through which wire will protrude is positioned just beyond the end of the inner conductor as shown. A pointed tool is used to carefully separate the shielding strands and form the opening.

The wire end is pushed through this opening and then stripped.

After each end of the shielded wire has been processed in this manner, the shielding is held at its extreme ends and stretched lengthwise. This last operation draws the shielding tightly about the wire, binding it, and preventing slippage.

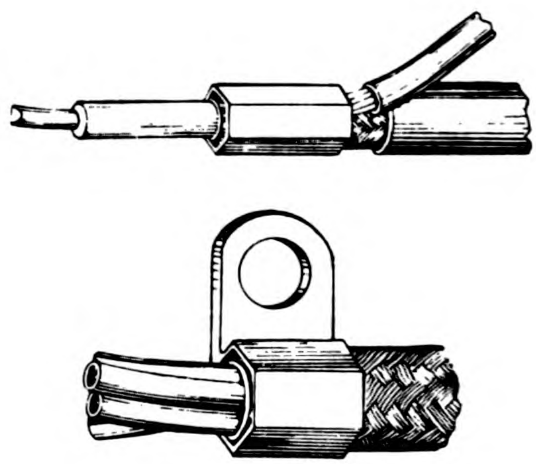
The following procedure for terminating the ends of shielded wire is an alternate method used when the shielding cannot be slipped over the inner conductor.

A pointed tool is used to form an opening in the shielding. Then the tool is inserted underneath the exposed inner conductor. The conductor is flexed as its end is carefully drawn through the opening.



A satisfactory method of terminating shielded wire and coaxial cable is to cut shielding back and then solder a separate length of conductor onto the cut end. This method is sometimes applied to production runs for which special dies are improvised. The following figure illustrates a braided, shielded conductor prepared in this manner. A lead collar is formed which securely bonds both original and terminating conductors.

A preferred method of terminating shielded wire and coaxial cable makes use of a two-piece compression type of solderless connection. When crimped, inner and outer tubular sleeves connect the braided shield to the grounding wire or terminating lug. Special hand and production tools are available for pressure forming the connections.

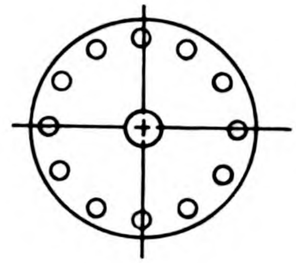


In certain applications at higher frequencies, it may be necessary to ground comparatively long cables at points along their lengths. Ground wires can be satisfactorily soldered to shielding if great care is taken to minimize soldering time in order to avoid overheating the cable dielectric. Another method of satisfactorily grounding shielding is by means of mechanically firm grounding clamps.

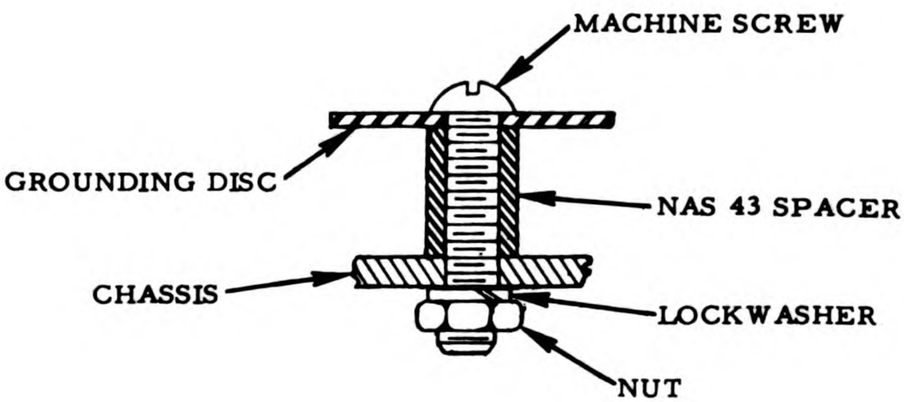
7.3.4.4.1 Grounding Shielded Conductors. A grounding disc, illustrated here, may be used to ground two or more conductors.

A recommended method of securing this disc to the chassis is illustrated below.

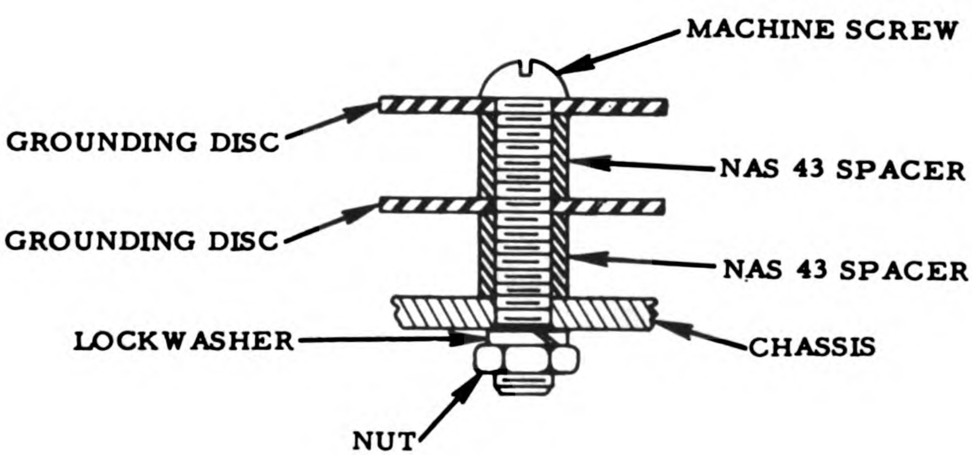
Additional discs may be used as illustrated below, if one disc is not sufficient.



HOT TIN DIPPED
BRASS GROUNDING DISC



ATTACHING GROUNDING DISC



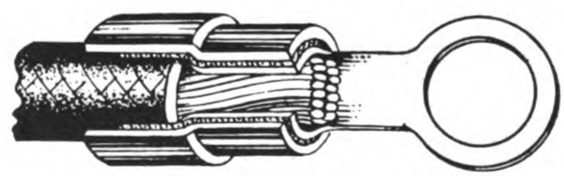
ATTACHING GROUNDING DISCS

7.3.4.5 Solderless Connections. Solderless connections depend on mechanical pressure rather than the fusion of metal.

Advantages of solderless connections include high operating temperatures, ease of fabrication, relatively great mechanical strength, and resistance to mechanical fatigue.

However, solderless connections should not be used unless approved for the particular application by the government bureau or agency concerned.

Solderless lugs and terminals are manufactured within necessarily close tolerances. "Barrel" design depends upon wire size, type, insulation, space limitations, operating temperature, vibration, and corrosion resistance.

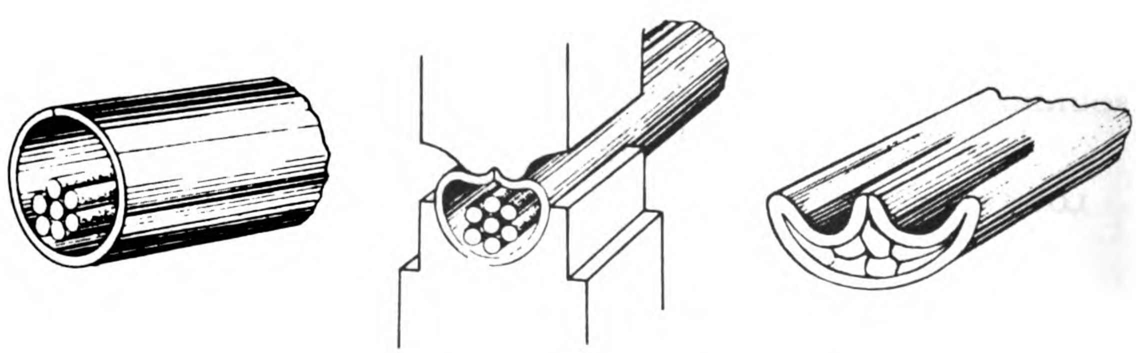


Strict tolerances are observed in dimensions of barrel length, inside and outside diameters. The inside diameter of the barrel is considerably larger than the diameter of the wire to allow for deformation of the barrel when subjected to forming pressure.

"Tongue", or mounting end design is available in closed, perforated types as shown or in open spade-tip configurations. Design should be selected to suit the particular application.

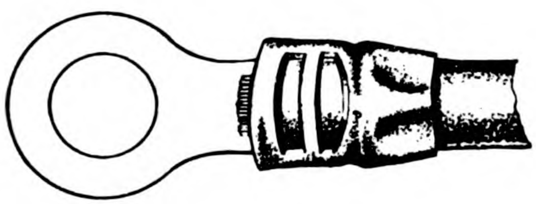
Size and type of crimping tool, terminal, and wire must conform to the manufacturer's recommendations or weakened and defective connections are almost certain to result.

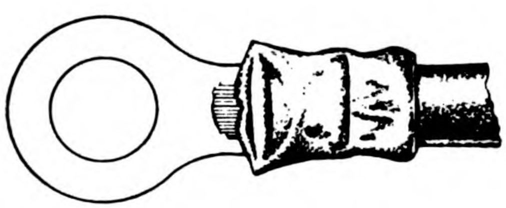
The condition of the tool should be periodically checked by careful examination of several completed connections. Care must be taken when crimping to insure that the solderless terminal or lug is fitted properly into the socket of the crimping device, that the stripped wire end is fully inserted into the barrel of the terminal or lug, and that jaws of the crimping device are completely closed. If the terminal or wire is misaligned, a poor joint will result.



CRIMPING SOLDERLESS CONNECTIONS

When released from compression wire expands slightly. Expansions are additive in stranded conductors, each strand contributing its own expansion. Total expansion of all strands exceeds expansion of the barrel. When external pressure is removed, wires continue to exert pressure against the inner wall of the barrel.





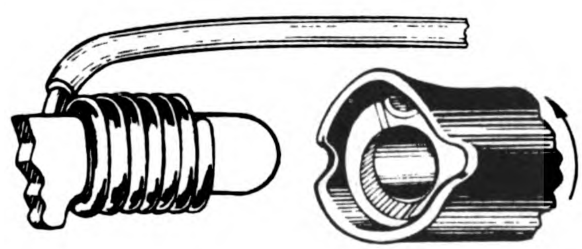
The type of barrel depends on whether the wire is solid or stranded. Solderless connectors are specifically designed for either solid or stranded wire and are not interchangeable.

Crimped, solid conductors, when released, do not expand as much as stranded conductors. If the same type of barrel were to be used for both solid and stranded wires, pressure between the inner wall of the barrel and solid wire would be lost. A different type of barrel is therefore used for solid wires.

Crimping of the barrel mechanically supports insulated wire connections by gripping the end of wire insulation. Strength can be increased further by using commercially available terminals equipped with vinyl sleeving covering the barrel. After crimping, vinyl sleeving is secured to the barrel, and provides protection against possible contact with a bare wire.

In a recently developed type of solderless connection, solid wire is tightly wound about a terminal. Sufficient tension is exerted on the wire, when wrapped, to assure a lasting electrical and mechanical bond.

Both wire and terminal are inserted into a special drill-like tool which automatically wraps the wire about the terminal.



Tests show that joints fabricated in this manner are reliable in some applications.

7.3.5 Solders and Fluxes

The solders and fluxes treated in the following sections are in the main intended for use in fabricating electrical connections. Soldering, as applied to structural assembling techniques, is discussed in 4.4.2.

7.3.5.1 Fluxes. Wire connections are "fluxed" to remove oxide films and to prevent further oxidation due to heating. Often invisible, these films form on most metal surfaces exposed to the atmosphere and prevent molten solder from fusing with the metal. Thickness of the oxide film increases with time of exposure, and formation is accelerated by increased heat or moisture.

Fluxes are classed as corrosive or noncorrosive. Noncorrosive fluxes, having a rosin base, are commercially available in powder, paste, liquid, or solid form. Often flux is incorporated in the core of wire solder, and is made available to the joint when the solder is melted. Sometimes, as in resistance or induction soldering, it is convenient to use flux in paste form or mixed with powdered solder for application directly to a connection. Since rosin flux minimizes metal corrosion, it is well suited for removing oxides from electrical connections. Rosin residue is characterized by high insulation properties in contrast to corrosive fluxes and their by-products. Corrosive fluxes, including muriatic acid, zinc chloride, ammonium chloride, and sal-ammoniac, should never be used in making electrical connections. These are only used when soldering metals which are otherwise difficult to bond. When using corrosive fluxes, it is absolutely necessary to remove the residue after soldering. Mechanical and chemical cleaners are employed successfully for this purpose.

No "all-purpose" flux exists. Fluxes should be chosen for the type of metal to be soldered and for the characteristics of the flux residue. They may be judged according to their activity, melting point, liability to corrosion, permanency, odor, and physical consistency. Soldering in electronic work requires a flux which will not leave a corrosive residue. Rosin flux intended for wiring leaves a residue which is relatively inert, noncorrosive, nonconductive, and nonhygroscopic.

The rosin content of core solder may be specified as a percentage of solder weight, in three ranges: 1 to 3%, 3 to 6%, and 6 to 12%. Solder core flux must completely fill the solder wire leaving no voids. Special flux configurations in some solder cores are intended by the manufacturer to furnish more uniform flux distribution.

Fluxes vary in their degree of corrosion. Types available range from plain or activated rosin to strong acid. Products are sometimes vaguely identified as "neutral" or "nonacid" flux, but if truly neutral, a solder flux could not perform its intended function. Nonacid does not mean that such a flux is noncorrosive. Soldering salts are nonacid, yet their residues are strongly corrosive. These residues absorb moisture and will corrode electronic equipment by setting up a galvanic action which generates a voltage and eats away the connected metals. If any doubt exists, a flux, even if termed noncorrosive, should first be tested.

7.3.5.2 Solders. Used to join metals (and nonmetals) at comparatively low temperatures, solder alloys include various combinations of tin-lead, tin-lead-bismuth, lead-silver, and indium with tin, lead, and silver.

"Soft" solders melt at temperatures below 700°F. These include the widely used tin-lead mixtures and special purpose additives such as bismuth and antimony. Soft solders are used to bond metals having low melting points and are almost exclusively used when soldering electrical connections.

They are easily applied and can withstand considerable bending without fracture.

Principal disadvantage of soft solder connections is their low mechanical strength as compared to that of the metals joined. Soft solder joints cannot be employed at greatly elevated operating temperatures, since at 212°F they will have lost 50% of their strength at room temperature, and at 300°F, will have lost 70%. Special consideration must be given to the mechanical strength of soldered connections when subjected to service at extremely low temperatures.

"Hard" solders are used where greater mechanical strength or exposure to high temperature is required. These include common brazing rod and silver solders melting at temperatures above 700°F.

Reliability, ease of application, and wetting properties are of major importance when selecting tin-lead solders for soldering electrical connections. Maximum joint strength and maximum wetting action is obtained with tin contents from 40% to 60%. As the tin content increases to 60%, the melting point is lowered and the plastic or cooling range of the solder becomes shorter.

If economy is the prime consideration, a solder of low tin content (40%) may be desirable. When a solder is required for joints which should not be overheated, a 60% tin solder is commonly used.

The higher tin content alloys set up faster, are easier to use, and are particularly recommended for maximum reliability in high-speed, low-temperature soldering applications.

Solder alloys do not immediately liquify as their temperature is raised, but first become plastic, then semi-liquid, and finally completely liquid. Upon heating, most tin-lead solders undergo transformation to the plastic state at 358°F, but become wholly liquid at various temperatures, depending on individual composition.

A tin-lead solder containing 63% tin and 37% lead changes from solid to liquid at a single temperature point, without an intervening plastic state. This single temperature is the "eutectic" point and the solder is known as the eutectic alloy. Completely eutectic solders are not generally desirable because of their lack of any plastic range and consequent susceptibility to fracture from even slight vibrations while solidifying.

The user should make certain that only the best materials are incorporated in solder utilized for military electronic equipment. There is no substitute for virgin

Percent Composition		Melting Range (°F Approximate)	Typical Use
Tin	Lead		
4	96	560 to 600	Coating metals and
10	90	515 to 575	differential soldering
15	85	435 to 515	Coating and joining metals
30	70	360 to 495	
33	67	360 to 485	
38	62	360 to 465	
40	60	360 to 460	General use
45	55	360 to 440	
50	50	360 to 415	Special applications
60	40	360 to 370	Low-temperature soldering
63	37	360	Eutectic solder of fixed melting point
72	25	360 to 380	Special applications

metals, since tin-lead mixtures progressively lose strength with repeated heatings.

Soft solder should not be used to resist unusual stresses. Prior to soldering, wiring must always be firmly secured to provide needed mechanical strength. Tin-lead solders, over the course of time, suffer loss of joint strength which reaches its maximum after one year and may amount to as much as 25%.

The ability of solder to resist fracture is defined in terms of tensile and shear strength measured in pounds per square inch; and in terms of strength to resist impact, measured in foot-pounds. Forces acting on a soldered joint are not usually pure tensile or shear stresses, but a combination of both.

Impact strength is the ability of solder to resist fracture and indicates its ability to withstand sudden shock ranging from 12 foot-pounds per square inch for solders of low tin content to about 15 foot-pounds per square inch for eutectic compositions.

The following table lists composite strength of a copper lap joint when bonded by solders of various compositions.

Composition		Joint Strength
Tin	Lead	Lbs/inch
5	95	3730
15	85	5300
25	75	5700
35	65	6100
45	55	6420
50	50	6510
62	38	6850

Rosin-core solders are usually available in diameters ranging from 1/32 to 1/8 inch. The thinner diameter can be applied at a slower rate and affords closer control over the amount of solder applied, particularly on smaller terminals.

Special forms of solder are

sometimes used for particular applications. Paste-alloy solders consist of finely powdered solder mixed with flux, which are applied to the work in a single operation and then heated by any convenient means. For high production runs, solder is sometimes preformed into washers, rings, or slugs, for placement on junctions before heat is applied.

Most commercial soft solders contain a small percentage of one or more special purpose elements. Antimony is often added to strengthen the solder; bismuth and silver are used to facilitate spreading. For solder pots, about 1 percent of indium added to the solder reduces dross.

For aluminum and its alloys which tend to corrode rapidly when heated, solders containing from 50% tin-50% zinc to 75% tin-25% zinc are suitable, although an alloy composed of 60% tin and 40% zinc is most frequently used.

When silver-coated ceramic terminals are to be soldered, 2 to 3 percent of silver added to a tin-lead alloy improves bonding, and prevents the tin-lead mixture from absorbing the silver coating.

So-called "liquid" or "cold" solders are in reality glues or cements which bear little or no relation to solder alloys and the fusion of metals.

When antimony is added to common tin-lead solders to improve the strength of the solder, the ratio of antimony to tin must not be greater than 0.075:1, or the solder will be too hard and brittle for use. Antimonial solder should not be used on zinc or brass, because the formation of antimony-zinc compounds may embrittle the joint. The presence of antimony, even in a minute quantity, reduces the galvanic stability (corrosion resistance) of tin-lead solder.

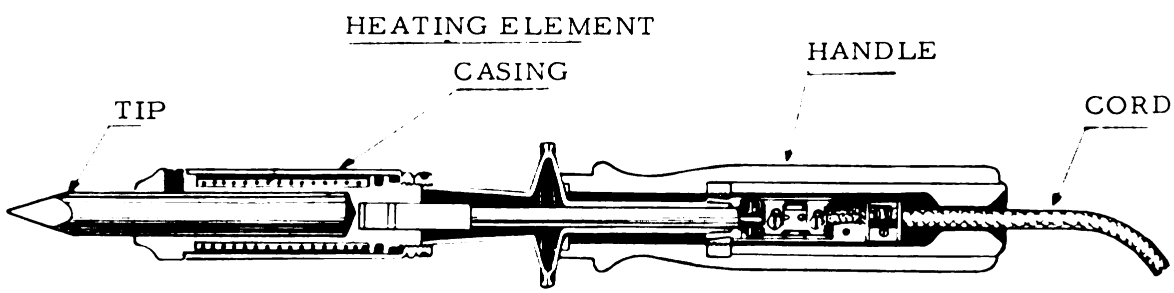
Cadmium, zinc, or aluminum should not be present in tin-lead solder unless aluminum is being soldered. These metals, even in minute quantities, increase the working temperature of the solder, making it sluggish and porous. Their presence in tin-lead alloys is evidenced by a frosty appearance of the solidified alloy.

7.3.6 Soldering Methods

7.3.6.1 Hand Soldering Irons. Hand soldering, using the conventional electrically heated iron, is the most widely used method of joining electrical conductors.

Soldering irons should be chosen with regard to the size of the work being soldered, production rate, and worker fatigue. In addition, selection of the soldering iron tip is a crucial point of consideration and demands a detailed study with respect to its application with the type of iron to be used in performance of the soldering operation. Specifically, five related parameters must be considered. These are: wattage rating of the iron; amount of voltage to be applied to a particular operation; resistance of the heat transfer unit in the iron; cross sectional area of the tip; and the metal used in tip construction. For example, the wattage rating of the iron determines the power that will be generated with a constant current. This, coupled with the resistance of the iron heat transfer unit, governs the amount of heat that will be transferred to the tip. In turn, the tip cross sectional area and the metal used will determine whether the heat will be effectively retained (heat storage) or rapidly dissipated. From this relationship it can be seen that the tip temperature and its retention time are directly proportional to the tip cross sectional area and the metal used in tip construction.

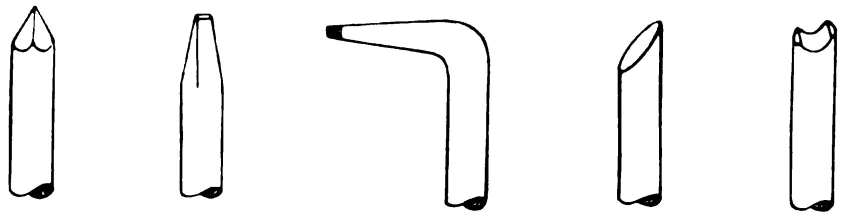
Tip diameter and length should be large enough to conduct adequate heat to the joint, yet small enough to reach connections in congested layouts. Physical size and weight of an iron, which depend in part on the manufacturer's design, should permit easy handling. The soldering iron shape, for example, a straight or right-angle barrel should be selected according to the work being done. Selection of a soldering iron must of necessity be a logical compromise of tip diameter and length, heating capacity, and ease of handling.



COMPONENTS OF THE SOLDERING IRON

The diameter, length, metal used, and shape of the tip should be suitable for the application involved. They determine the amount of heat available and rate of heat flow to the work. The copper mass acts as a heat reservoir when the soldering iron is idle, and serves to dissipate excess heat to the surrounding air. The temperature of the tip is usually maintained approximately 200°F above the melting point of the solder.

Tips, generally made of solid copper or special copper alloy, can be obtained in various shapes including pointed, chisel, bent, blunt, and concave shapes for general or specific use. The pointed or chisel shape serves for general-purpose soldering where a large variety of work is handled. The flat, narrow tip is particularly suited for soldering the terminals of multipin connectors; the bent tip for soldering connections difficult to reach with a straight tip. For rapid heating a long, small-diameter tip will not conduct heat as rapidly or maintain its temperature as evenly as will a short, thick tip.



TYPES OF IRON TIPS

The soldering iron wattage rating determines the rate at which heat is generated by the element. Production soldering depends to a large degree on wattage rating and the efficiency of heat transfer. A heating element of proper rating will deliver a steady and sufficient flow of heat to the tip without overheating or rapid corrosion. When a soldering iron is applied to a connection, outgoing heat reduces temperature of the tip. The heating element tip size and metal used in tip construction determines the length of time taken to restore the tip to the temperature required.

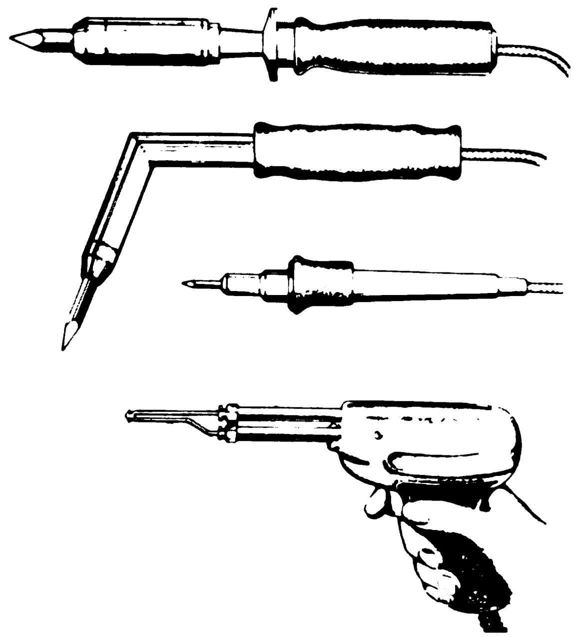
Soldering irons in general use are rated from 20 to 500 watts and have tip diameters ranging from 1/8 to 2 inches. For general electronic work, irons rated from 75 to 150 watts and having 1/4 to 3/8 inch diameter tips are popular.

Size, weight, and shape of the soldering iron must be chosen with a view toward minimizing worker fatigue. Where a high production rate is desired, one or more small irons may be used to replace or supplement a larger iron. Soldering irons of special shapes sometimes permit easier access to connections.

The soldering iron should be properly prepared before use. The working surface of the tip should be cleaned thoroughly, then heated and tinned. Tinning consists of applying solder to the tip until its working surface is completely covered and bright; then wiping off excess solder. A clean, tinned surface assures rapid heat transfer from the tip to the work being soldered, and assures well-bonded, smooth-appearing solder connections.

Ferrous plating is sometimes used to protect copper tips from rapid oxidation. The manufacturer's instructions should be observed when these "armored" tips require cleaning. Such tips must never be filed or forged as either operation will ruin the thin protective coating. Dull spots can usually be restored to brightness by applying flux and solder, then wiping off any excess solder with a clean cloth.

Plain copper tips oxidize quickly, and therefore, must be frequently cleaned and retinned. A fresh working surface can be obtained by filing or sanding the working faces of the tip and then tinning. If the tip has been



TYPES OF HAND SOLDERING IRONS

permitted to deteriorate, it may be necessary to repeat the tinning process until an even, shining, solder-coated surface is obtained.

The soldering iron should be properly maintained during use. A clean cloth or wiping pad used at intervals will remove excess solder and slag which otherwise speed erosion of the tip. Whenever the working surface becomes dull or tarnished, the tip should be retinned. Any small spots on the tip should be lightly scraped in compliance with the manufacturer's instructions, then covered with rosin core solder.

If abused, an iron will require greater effort on the part of the operator to produce good work. If permitted to overheat, a pitted and burned soldering tip will result. Overheating may occur when a tip which is too short to provide sufficient radiating surface area is used. Such a tip must be replaced. A hot soldering iron left idle will gradually overheat, since heat is generated too quickly to be dissipated through radiation alone. Various measures may be employed to avoid overheating. An idle soldering iron can be disconnected from the line or a metal-flanged stand may be used which will dissipate heat at a rate which is roughly the same as that due to usage of the iron. Alternately, a soldering iron or a stand equipped with a thermostat or variable resistor which controls line voltage will greatly increase the life of the iron.

Poor heat transfer from the heating element to the tip may cause the heating element and casing to retain excessive heat. Oxides are formed which cause "freezing" or improper seating of the tip, and may necessitate replacement of the complete soldering iron. The soldering iron tip should always be inserted to the full depth of the casing, and should be seated firmly against the heating element. The tip should occassionally be removed and cleaned of oxides. An anti-seize lubricant may be applied to the seated end of the tip before inserting to prevent sticking and to increase heat conductivity.

Besides the conventional hand soldering iron, other soldering tools include the pencil iron and soldering gun. The pencil iron is recommended for precision soldering of small electrical units, intricate instruments, and subminiature assemblies. Except for their small size, pencil irons are similar to conventional hand irons. Threaded tips are available in a variety of shapes which are easily interchangeable. These irons are available with low wattage ratings and cannot therefore be used in applications where a considerable, steady heat flow is required. The quick-heating soldering gun is excellent for intermittent use and diverse applications, but is unsuited for high-speed production work; a 4- to 5-second warmup period being required each time the trigger is depressed. The soldering gun usually contains a transformer built into the pistol handle. Its tip must be kept clean and well tinned, although oxidation and erosion are minimized by the high proportion of OFF time for the unit.

7.3.6.2 Dip Soldering. Dip soldering, the process of immersing connections in molten solder, has gained wide acceptance in the manufacture of electronic equipment. This method usually results in only a fraction of the number of rejects normally occurrent in conventional hand soldering.

In dip soldering, one or more connections can be bonded in a single operation. It is often practicable to carry a group of terminals, as on a connector or tube socket, to the solder. Special machinery has been developed for multiple-connection, mass production dip soldering.

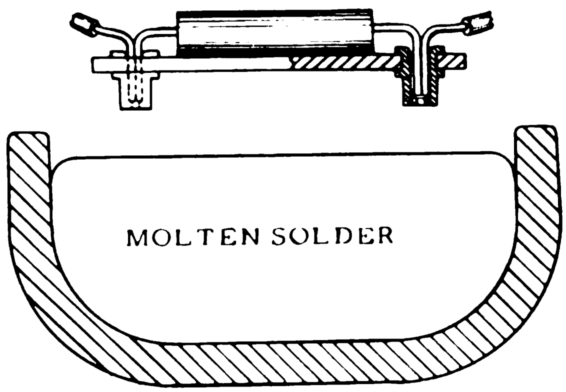
The process is well adapted to soldering printed circuits, where all conductors and terminals are mounted on one side of a terminal board, and all components are mounted on the other. The wired terminal side may be immersed in the solder pot, thereby soldering all terminals in a single operation.

In this process, all joints are secured mechanically in position, dipped in liquid flux, and then immersed in liquid solder. Square mounting eyelets are often used since these tend to draw more solder into openings than the conventional, round types. Where removal of flux is desired, terminals may be dipped into a suitable cleaner after soldering.

A "drossy" surface will form on molten solder which has been heated for a considerable length of time. To reduce this dross, terminals are sometimes pretinned, and also, one or two percent of indium added to the solder.

For simultaneous application of flux and solder, some fluxes, usually fats, may be floated on the molten solder surface. This also serves to reduce formation of dross.

If properly controlled, dip soldering produces connections at least equal in appearance and workmanship to those formed by individual operations with a hand soldering iron.



DIP SOLDERING

To maintain good quality in dip soldering, it is imperative to control solder temperature and amount of contamination.

Solder pot temperature is an important factor in producing good soldered connections and maintaining a clean solder pot. For most dip soldering applications, the pot should be approximately 100° to 150°F above the liquefaction point of the particular solder used. It is advantageous to use higher temperatures for some applications, such as printed wiring boards and tube sockets. At higher temperatures solder dross forms rapidly and must be removed frequently to insure a clean dip. If the temperature is too high, a bluish film forms very quickly over a freshly skimmed surface. If the temperature is too low, the solder does not flow properly and a cold solder dip results.

To maintain the proper temperature, the power source for the heating element should be able to supply sufficient power at a voltage recommended by the manufacturer. Under the varying temperatures usually found in a shop, solder temperature differences as great as 40°F may be caused by a supply voltage drop of 10 volts.

The solder pot must be large enough to accommodate the work and hold enough solder to maintain a uniform temperature. The thermal capacity of the solder should be sufficient so that there is immediate wetting of the work and no measurable temperature drop when the work is dipped into the solder. Congealing of the solder as the work piece is lowered into the pot is evidence that the solder capacity of the pot is too small, that the solder is not hot enough, or that the heat source is not adequate for the rate of soldering.

During initial heating, the solder should be completely melted and then stirred before any dipping is started. Dipping too soon robs the soldering pot of its tin-rich portion unbalancing the alloy and resulting in a lower tin content solder for later work.

To assure a clean dip, remove the film of oxide and burnt flux frequently from the top of the molten solder with a dry shingle, a piece of cardboard, or some other similar material. Never use a solderable material.

Alloying of the solder and the metal being soldered contaminates the solder bath. To minimize this contamination and to delay renewal of the solder bath, avoid prolonged immersion of the work pieces in the solder pot by preheating the work pieces, using a hot flux, and selecting the proper solder pot size and operating temperature.

Tin-lead solder 60/40 or 63/37 should be used for dip soldering printed wiring boards. The temperature of the solder bath should determine the dip time. A minimum dip time of 8 to 10 seconds is required for solder bath temperatures of approximately 475°F. At higher temperatures, the dip time should be shorter to avoid warping the boards.

The printed wiring boards must be clean prior to soldering. When a board has been handled or stored under normal room conditions, the areas to be soldered should be cleaned by burnishing. A suitable material for burnishing is a pencil-style typewriter eraser. In extreme cases, 4/0 steel wool may be used, but it is important to remove all particles of the steel wool that may become embedded under eyelets, fasteners, or pads. The board should be washed and dried thoroughly after abrasion cleaning to remove any foreign materials.

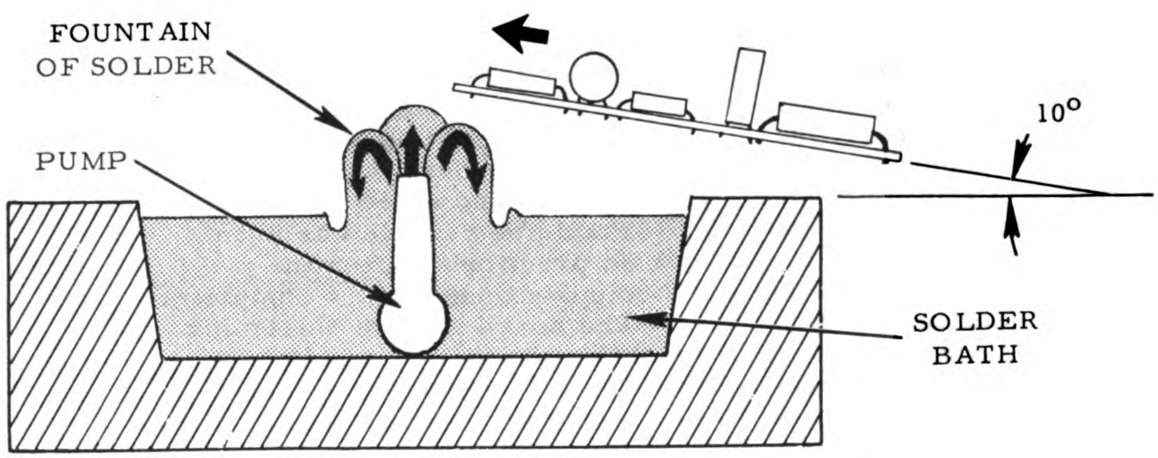
Flux may be applied by dipping the board into a container of a liquid flux. Before the board is dipped into the solder, excess flux must be drained off. Sufficient time should be allowed for the flux to thoroughly wet the surface to be soldered.

The board should be dipped into the solder bath at such an angle that only one edge touches the solder. The angle is then decreased until the flat face is in contact with the solder. This method permits vaporized solvents to escape, helps remove decomposed flux, maintains the surface of the solder at an appropriate temperature, and makes the solder flow smoothly onto the circuit pattern. Vibrating the board may be used to remove excess solder.

Flux and other residues should be removed as soon as practicable after the dipping operation is complete. The board may be placed for about 20 to 30 seconds in a shallow container of flux remover, such as toluol, ethyl alcohol, or trichloroethylene to soften and loosen the residues. The board should be brushed and redipped into the solvent to complete the cleaning, then dried with filtered compressed air. Inadequate cleaning is evidenced by streaks on the board after drying. Vapor degreasing with chlorinated hydrocarbon solvents may also be used to remove flux, but care must be exercised to prevent component markings from being defaced or dissolved by the solvent vapors.

Solder may be applied to printed circuit boards by the fountain or wave method, as shown in the illustration. Instead of dipping the board into the solder pot, the level of the solder is raised to that of the board by pumping it up in a wave. This method permits more favorable angles of insertion, better control of the duration of contact, and a reduction in the amount of heat applied to other parts of the board.

Masking tape or solder-resistant varnishes are used to keep the solder from adhering to component mountings and other areas where the presence of solder is not desired.



WAVE OR FOUNTAIN METHOD OF DIP SOLDERING

7.3.6.3 Induction Soldering. Induction soldering utilizes eddy currents generated in connecting elements to heat junctions to soldering temperature. When placed in a strong high-frequency electromagnetic field, a metallic material is heated by induced currents which follow closed-loop paths within the metal. These paths are generally predictable and depend upon the shape of the energizing coil and the geometry of the metal.

For induction soldering, as in all other methods, surfaces must be relatively free of oxides. Solder is usually applied in preformed rings, washers, and similar shapes which fit about the junction to be soldered. Alternately, parts may be coated with solder prior to joining.

Induction coils should be designed to heat joints as evenly and uniformly as possible without affecting nearby components. The comparatively large size of the induction soldering device and its coil requires that work be brought to the machine and that sufficient space be left around the work to permit proper coil placement.

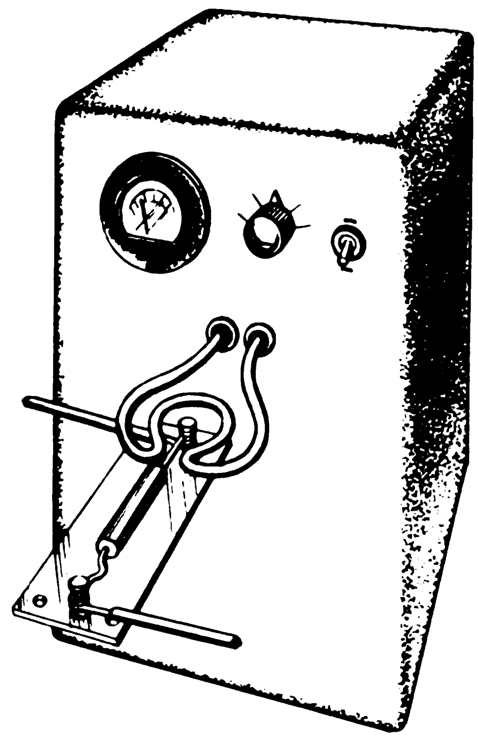
As a general rule, each type of work piece to be soldered by induction heating requires its own specially shaped coil. The shape of the work piece and the heat pattern required determine the shape of the coil. A number of coils are shown in the illustrations on pages 7-46 and 7-47.

The effectiveness of the coil varies inversely as its distance from the work piece, but the coil must be insulated or the distance great enough to prevent arcing to the work.

With small parts made of magnetic material, a coil designed with a close coupling should not be used because the strong magnetic field may prevent the proper seating of the parts. A coil that has a loose coil coupling and a large turn pitch should be used to minimize this magnetic pull on the parts.

Merits of induction soldering include precise control of temperature and rate of heating. This reduces the risk of over-heating connections. Essentially, there is no practical limitation to the size of connection, large or small, which can be soldered by this method. It is readily adaptable to automatic and mass production process. A typical induction soldering set-up is shown below.

Induction heating is very efficient in the soldering of light and heavy gage assemblies of regular shape. The clearance between parts to be soldered should be small enough to become completely filled with molten solder which is drawn in by capillary force as the solder wets the metal. Where practicable, maintain a clearance of 0.003 inch. Insufficient clearances which may prevent the solder from penetrating properly should be avoided. Even temperatures should be maintained throughout the work piece. Hot spots which will tend to make the solder flow away from the joint should be avoided.



INDUCTION SOLDERING

Too short a heating cycle should be avoided. The induction energy can destroy the soldering flux before it has had time to dissolve the metallic oxides on the surfaces to be joined. Gradual build-up to the fastest satisfactory soldering cycle is highly recommended.

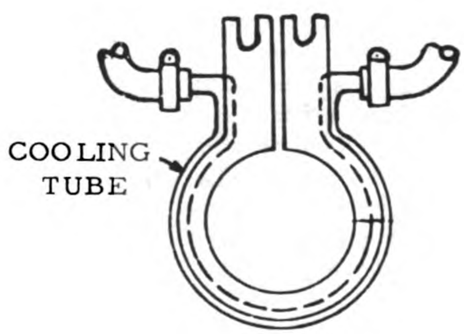
Nonconductors, such as wood, slate, plastic laminates, porcelain, glass, asbestos, or mica, should be used for building jig fixtures to hold the work pieces. Metal fasteners used on the jig should be at least 1/2 inch from the coil so as not to heat up or interfere with removal of work pieces from the coil.

ROUND MULTI-TURN TYPE

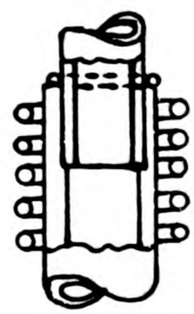
FORMED HELICAL
MULTI-TURN COIL

RECTANGULAR MULTI-TURN COIL

SPIRAL HELICAL
MULTI-TURN COIL



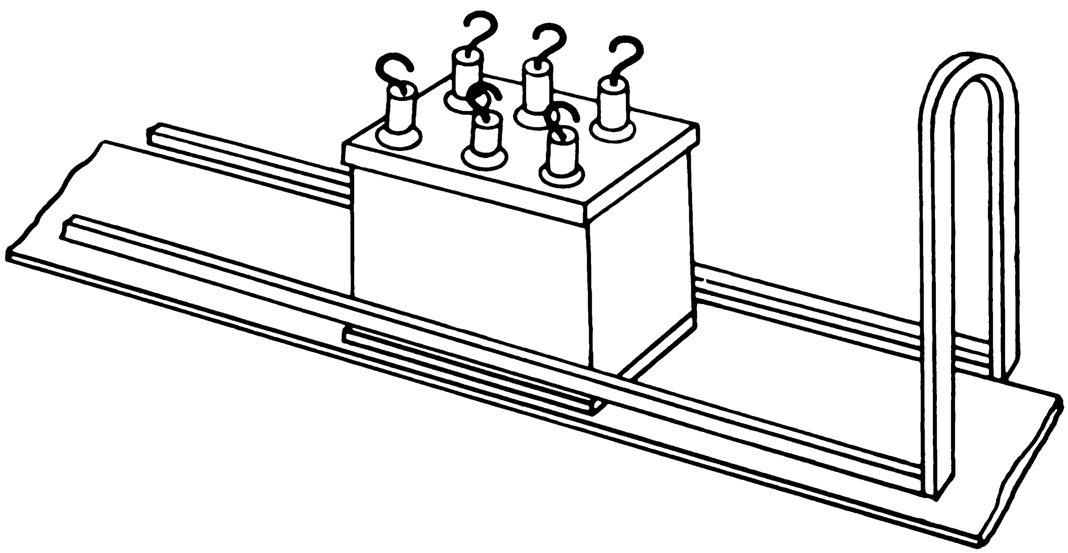
SINGLE INDUCTOR TYPE

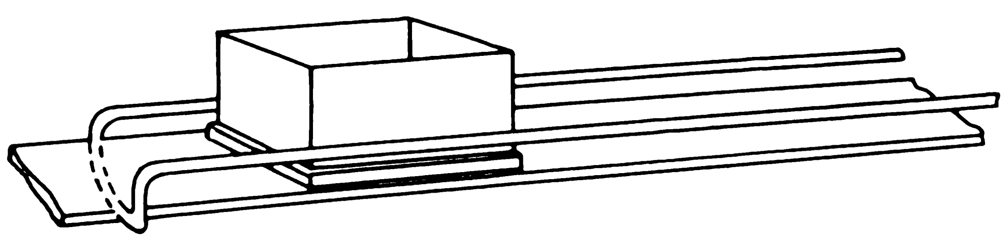


EXTERNAL COIL
(FOR HEATING TUBULAR MEMBERS)

PANCAKE COIL

INTERNAL COIL





CONVEYOR TYPE COILS

7.3.6.4 Resistance Soldering. In resistance soldering, heat is generated when a low-voltage electrical circuit is completed through contacting electrodes and the junction to be soldered. Heat is concentrated only at the junction since this is the circuit element of greatest resistance.

Two electrodes, which may also serve as clamps, are used to make electrical contact with the junction. Solder is applied directly to the work and as the junction is heated, melts and flows onto the cleaned surfaces.

Equipment consists of a low-voltage, high-current source of power such as a transformer, and contacting electrodes. Hand-held and bench-mounted types are available. Selection of the correct size of the tool is as important for this process as for conventional hand-iron soldering.

The variety of designs available makes this method adaptable to either small lot or mass production runs. Resistance soldering is well adapted to bonding connections in limited spaces, for example, multiconductor, miniature cable connectors. Other designs permit soldering of large terminals and lugs. No warmup period of the tool is required.

Certain faults apt to occur during conventional hand soldering operations are averted when resistance soldering is employed. "Cold" solder joints are minimized since solder must be applied directly to the heated connection. The danger of overheating nearby parts with resultant resistance or capacitance changes is reduced by the localized heat and soldering speed.

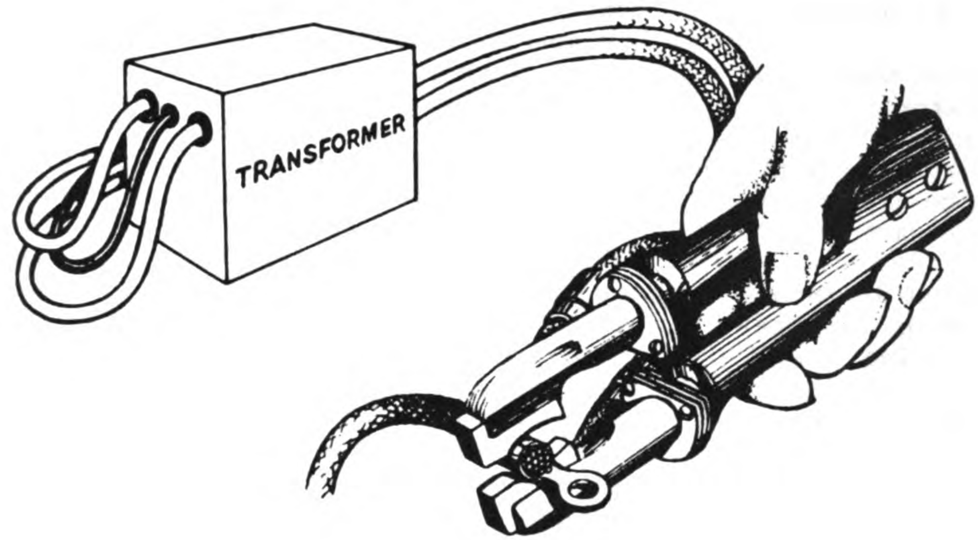
Resistance soldering is illustrated on the following page.

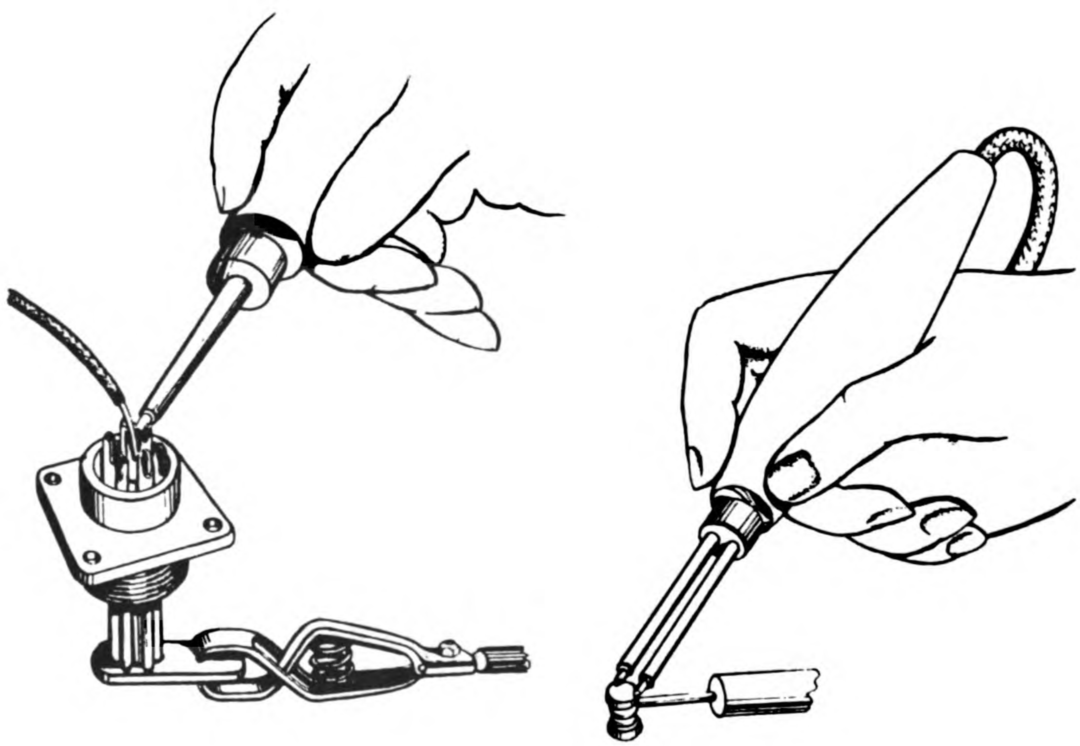
7.3.6.5 Ultrasonic Soldering. Although the equipment required is rather complex, ultrasonic soldering is especially applicable to aluminum and other hard-to-solder metals. The oxide skin normally present on aluminum and its alloys is not easily dissolved, but by ultrasonic methods, it can be readily removed while solder is applied without the use of flux. In general, this method may be applied to advantage wherever the use of flux presents difficulties.

Ultrasonic soldering equipment operates on the principle that a high-energy sound wave passing through liquefied solder sets up voids which rapidly collapse. This action produces local pressure differences thousands of times greater than atmospheric pressure eroding away surface oxides and promoting "wetting" of the surfaces by the molten solder.

The junction is caused to vibrate at the same time that heat and solder are applied. Vibration and heat must be applied and terminated simultaneously. This is usually achieved by employing a specialized vibrating-soldering iron.

One variation of ultrasonic soldering is related to the dip soldering process. A special type of soldering pot is vibrated while the connection is immersed





RESISTANCE SOLDERING

in the molten solder. No fluxing operation is required with this method.

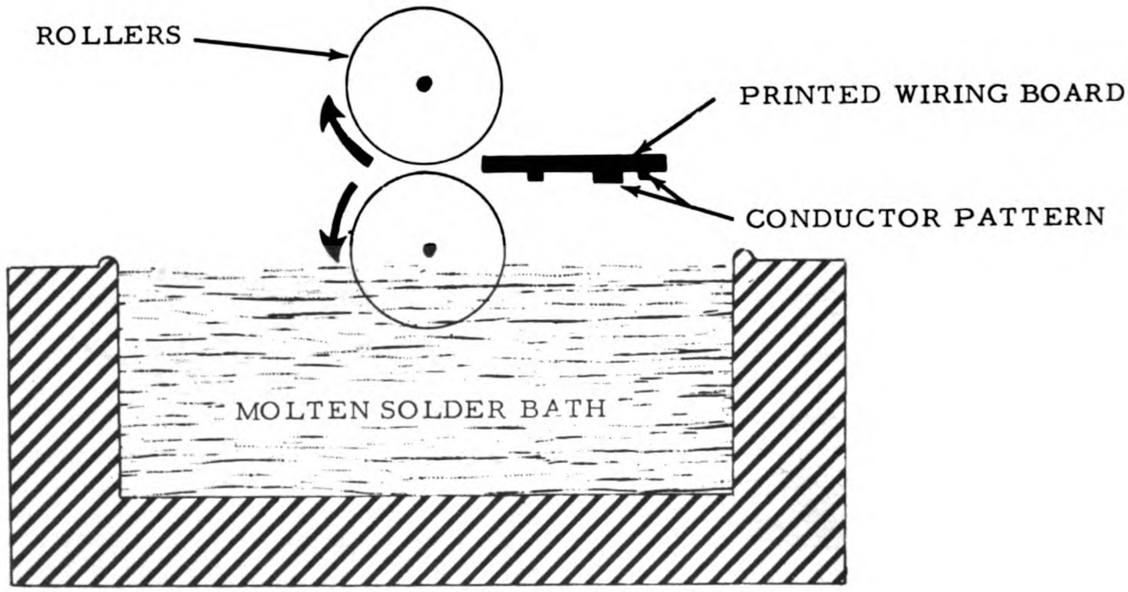
Although useful in many applications, ultrasonic soldering is not applicable to fragile materials such as thin wires or foils which are easily ruptured under such action.

7.3.6.6 Roller-Coat Soldering. Roller-coat soldering, a process similar to dip soldering, was developed primarily for solder-coating printed wiring prior to mounting of hardware and component parts.

This soldering technique, as shown in the accompanying illustration, employs two counter-rotating rollers. The lower roller is made of copper and revolves in a molten tin-lead solder bath which is thoroughly mixed and thermostatically maintained at an appropriate temperature (usually 500°F ± 10°). The upper roller is adjustable to compensate for variations in board thicknesses. A thin coating of flux is applied to the conductor pattern of the printed wiring board, and the board is inserted between the rollers. The solder coat is deposited by the lower roller on the board in the conductor pattern. Pressure of the upper roller and roller speed are adjusted to give optimum performance. A pressure of 5 to 10 lbs per inch of board width usually results in an adequate deposit without damage to the conductor pattern. After solder coating, the board is cleaned to remove flux residue and dried.

7.3 .7 Hand Soldering.

The importance of establishing and maintaining a high standard of workmanship for all soldering



ROLLER-COAT SOLDERING

operations cannot be over-emphasized. Faulty solder joints are a major cause of equipment failures despite considerable effort expended by the Armed Forces to improve soldering techniques.

Quality rather than quantity should be the principal objective. Military reliability can be achieved only by strict conformance to correct soldering techniques. Whenever over-emphasis is placed on accelerated production, the percentage of rejects rises rapidly, and a high percentage of poor connections escapes detection. Statistics show that when the percentage of plant rejects is low, the number of failures in the field is correspondingly low.

Arrangement of the production line is an important factor. Highest rate of production, as well as greatest equipment reliability, has resulted when each worker performed only one operation such as wrapping or soldering, when the number of repetitive operations per unit was reasonably limited, and when work was drawn from a stationary "pileup"

Notable difficulty has been experienced when work was moved continuously on an assembly line or when workers were obliged to follow other workers rate for each unit operation.

Despite its seeming simplicity, correct soldering entails care, experience, and a knowledge of fundamentals. Each operator should be thoroughly trained before being assigned to production of military equipment.

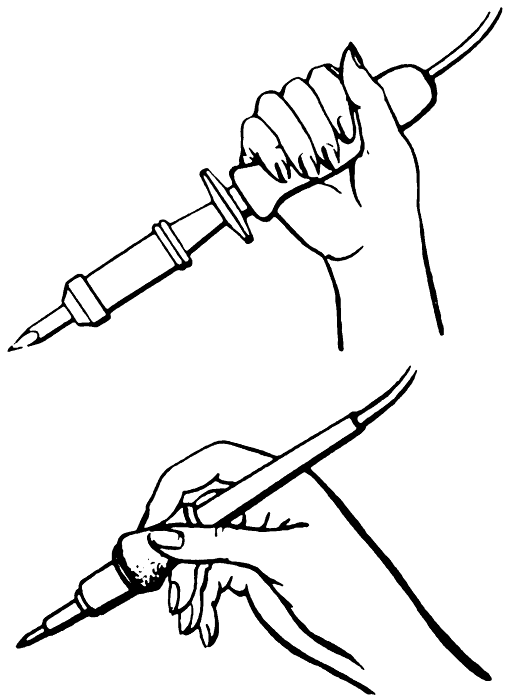
Operators who have already acquired agility in handling soldering equipment should be recruited from experienced, competent soldering personnel, and retrained to concentrate on precision rather than production speed. The production line for military equipment is not the place to indoctrinate new soldering operators since such workers cannot consistently produce joints which will serve reliably throughout the life of the equipment. Every item produced, whether first or last "off-the-line" must be equally reliable.

When best practices are observed, connections are produced wherein the solder actually alloys with the metals of mating surfaces.

7.3.7.1 Procedure. This section discusses hand soldering procedure and covers recommended practices as well as difficulties which may be encountered.

Many factors contribute to a well-bonded solder joint. Operations preparatory to actual soldering (See 7.3.3 and 7.3.4) include selection and care of the soldering iron, selection of solder and flux, and proper assembly of connections.

Applying the iron: The soldering iron should be held properly to avoid fatigue. Two widely used methods of clasping the iron for production soldering are shown on the following page.

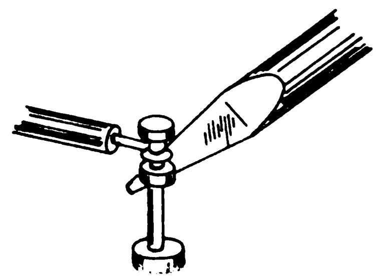


HOLDING THE SOLDERING IRON

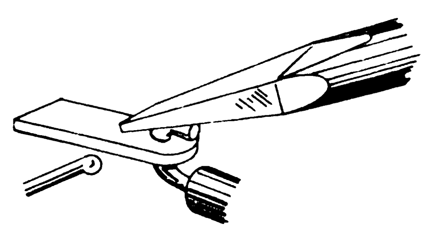
Where components on small assemblies must be soldered, it is sometimes advantageous to mount the soldering iron in a jig and move the part by hand to make contact with the iron. By using a jig, the operator has both hands free, one to hold the assembly and the other to hold the solder. By touching the terminals to the fixed soldering iron, one at a time, and simultaneously feeding solder to the joint, the operator can work more rapidly with less fatigue. The illustration on the opposite page shows this method of soldering.

The iron should be applied to contact maximum surface area of both the wire wrap and the terminal. All members of the connection should be quickly raised to soldering temperature in a single operation.

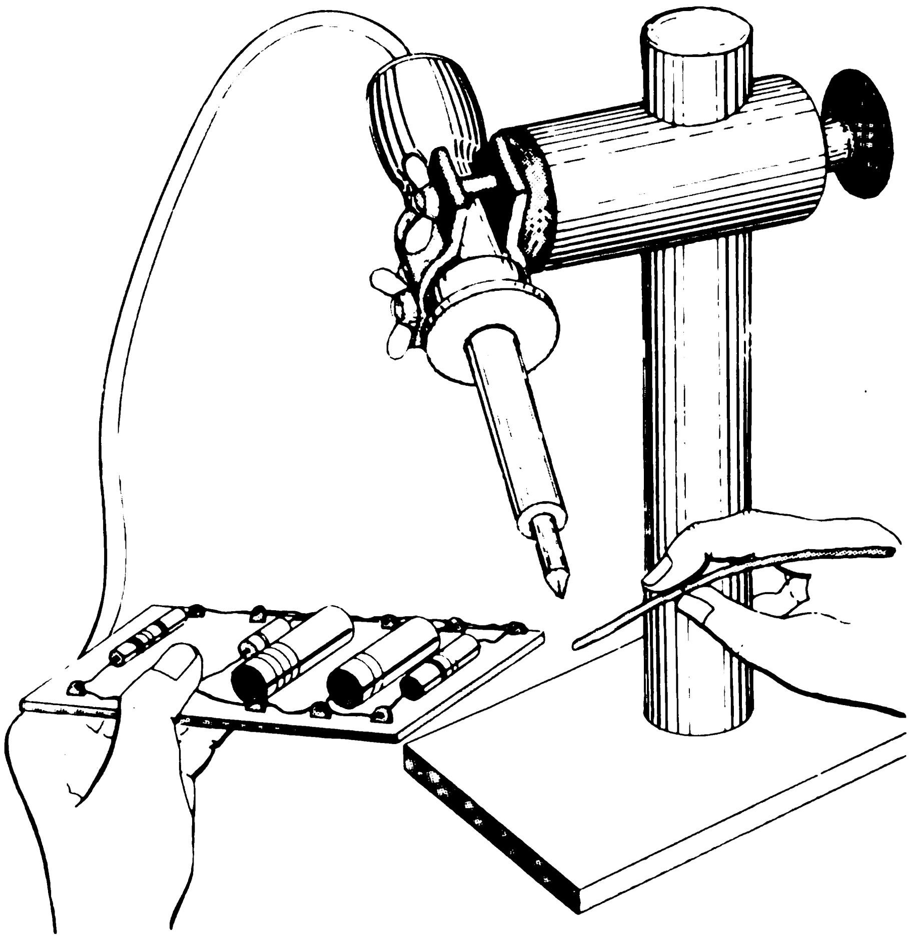
On flat terminals, the tip of the soldering iron is usually applied to the flat portion of the wire wrap; on turret terminals it is applied to both the wire wrap and the terminal.



IRON APPLIED TO TURRET TERMINAL



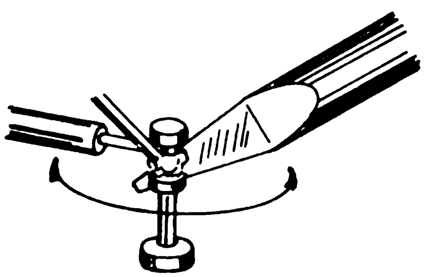
IRON APPLIED TO FLAT TERMINAL



SOLDERING BOARD-MOUNTED PARTS

The soldering iron tip should be lightly placed against the junction. If it is found necessary to exert greater pressure, heat flow to the junction is inadequate, indicating that the soldering iron is either too small or in poor working condition.

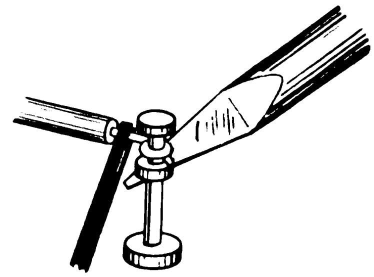
The iron must be correctly tinned to produce a sufficient heat-conducting area. Heat conduction can be further increased by lightly touching solder to the intersection of soldering iron and junction. However, solder thus applied to promote heat transfer, should not be used for bonding the connection.



TINNED IRON
CONTACTING TERMINAL

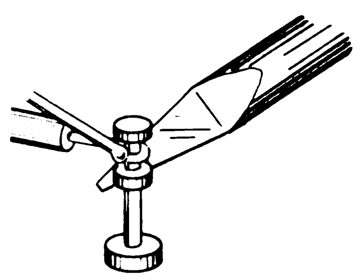
The joint should be rapidly raised to temperature and solder applied quickly to avoid prolonged heating which may interfere with proper fluxing and cause damage to surrounding components and insulation.

Damage to temperature-critical components can be prevented by gripping connecting leads between component and terminal with pliers or improvised, spring-loaded, aluminum clips. Excess heat is then conducted away from the component by the relatively large mass of the pliers or clips.

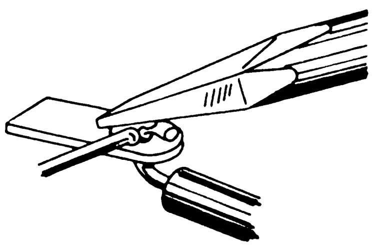


HEAT CONDUCTING CLIP

Applying the solder and flux: After all connecting parts have been heated to proper temperature, the junction should be coated with flux, and solder should be touched to the upper part of the junction, on the side opposite the soldering iron.



SOLDER APPLIED TO
TURRET TERMINAL



SOLDER APPLIED TO FLAT TERMINAL

When flux-core solder is applied to the heated joint, flux melts and coats the joint, cleaning the metals and preventing further oxidation. Flux-core solder, for bonding, is applied directly to the joint, never to the iron. If applied to the iron, the flux decomposes before it can remove oxides from the base metal surfaces.

When all connecting parts are clean and heated to proper temperature, the solder melts rapidly, instantly flowing and "wetting" all members of the junction. Solder spreads over the surface cleaned by the flux, boils flux out of the joint, and forms alloys with connecting metals.

Concave fillets form at boundaries of the junction and "feathered", thin, tapered edges blend into a continuous metal surface.

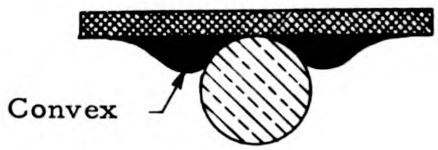
Solder should melt and flow smoothly upon contact with the heated junction. If solder fails to melt rapidly, it should be withdrawn until the junction has reached correct soldering temperature. If solder sputters excessively or a black residue appears, the soldering iron should be removed from the overheated junction.

Optimum amount of solder will have been applied when concave fillets form in the recesses between wire wrap and terminal while the outline of the wire wrap remains evident.

Application of excessive solder is wasteful and results in joints difficult to inspect. It is relatively difficult to recognize a poor solder joint obscured by excessive solder. Extreme excesses of course may cause short circuits between adjacent terminals.

Flux should be completely boiled out of solder and forced to the surface, where it will float and harden. If the iron is removed before all rosin has been forced to the surface, flux trapped in the solder will form a "rosin" joint. Such a connection may prove to be a high-resistance, poor mechanical bond.

Clean parts free of dirt and oxides should be used. Dirty or oxidized terminals may result in lack of a good bond as evidenced by the solder not flowing properly. This is known as a "cold" solder joint; it can be caused by

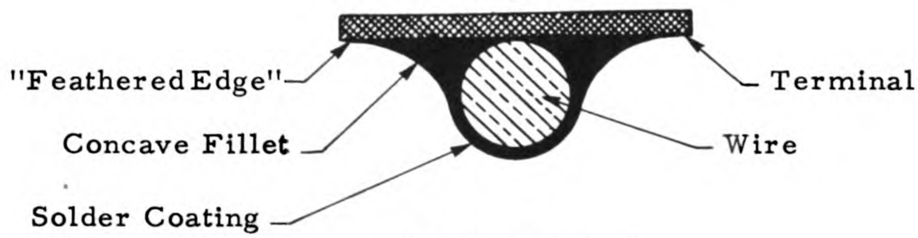


"COLD" JOINT

WIRE INSUFFICIENTLY CLEANED OR HEATED

"COLD" JOINT

TERMINAL INSUFFICIENTLY CLEANED OR HEATED



(Cross Section)
GOOD SOLDER JOINT

insufficient heat or absence of flux as well.

Flux applied when using a rosin-core solder is generally sufficient to clean oxides formed on metal surfaces, but additional flux may be required if the oxide film coating is unusually heavy. If necessary, a separate, noncorrosive flux may be used. However, best practice is to thoroughly clean the joint prior to soldering.

The joint should be warmed slightly before applying such flux. Flux should be applied sparingly, using only a quantity sufficient to cover the entire surface of the joint. It should not be permitted to seep onto insulation, since excessive flux may result in insulation breakdowns and leakage.

When contaminated terminals are encountered and solder does not readily flow after the joint has reached proper temperature and flux has been applied, the connecting wire should be removed and the terminal cleaned by lightly scraping with a small knife or piece of fine sandpaper. The terminal can then be retinned, rewired, and resoldered.

Removing the Iron: The soldering iron should be removed as soon as solder has coated the connection and the solder permitted to cool, solidify, and "set". If disturbed while

EXCESSIVE SOLDER JOINT

ROSIN SOLDER JOINT

COLD SOLDER JOINT

DISTURBED JOINT

UNACCEPTABLE SOLDER JOINTS

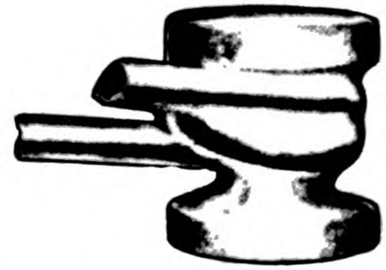
cooling, solder will crystallize and exhibit a dull, granular appearance.

It is important to solder the joint correctly the first time. If a joint must be reheated more than once, the solder should be removed, the joint completely disassembled, and the soldering procedure repeated.

Residues of rosin fluxes are usually considered to be noncorrosive and nonconductive. Removal is unnecessary except where such residue might affect equipment performance, as in high-frequency circuits.

Reliable solder joints are the product of precise workmanship and good materials, not the result of chance. They are neat in appearance, electrically stable, and mechanically sound.

WELL-SOLDERED FLAT LUG



WELL-SOLDERED TURRET LUG

7.3.8 Wiring Protection

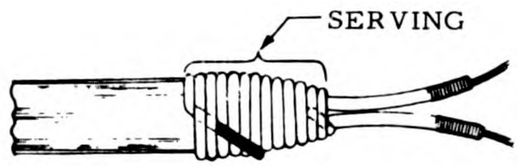
Connections and wiring should be so supported and protected as to obviate breakage and minimize any changes in performance due to vibration, inclination, shock, or environment under severe service conditions.

7.3.8.1 Sleeving. Insulated sleeving or "spaghetti" is utilized for added wire protection, such as, preventing short circuits at the terminals of multiconductor connectors and stress relief at the solder lug barrels.

When used, sleeving is slipped back over each wire prior to the soldering operation. Its length must be sufficient to cover the terminal, and to extend at least 1/2 inch over the wire insulation. After the soldering operation, sleeving should be fitted tightly over the terminal. If required the ends may be sealed to prevent moisture or other contaminant from entering and accumulating within the sleeving.

Glass braid or plastic sleeving such as vinyl or nylon should be used. Although glass braid ends may fray, this material is not adversely affected by elevated temperatures. Where high temperatures are encountered and certain electrical properties are desired fluorocarbon sleeving may be used.

7.3.8.2 Serving. Serving is the process of binding loose ends of insulation to prevent unraveling. Serving is usually accomplished by wrapping a cord about cable ends then applying a coat of nonhygroscopic lacquer or equivalent.

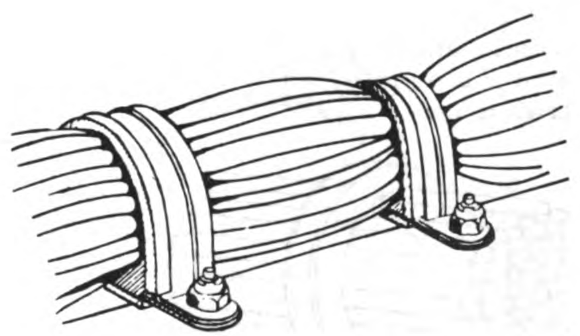


Serving of a cable end is started by laying one end of the wrapping cord alongside the wire insulation and binding it by wrapping with at least two turns. Wrapping is continued as desired, pulling each turn tightly, and slightly compressing the insulation. It is terminated by loosening the last two turns, slipping the cord end through, and pulling up tightly. The end of the cord is cut close to the wrap and a light coat of lacquer is applied to the serving.

7.3.8.3 Lacing. Grouped individual wires are often laced together to form neat, easily supported assemblies. A discussion of the lacing operation is included in 7.3.2. Lacing should not be used to fasten harness or components to a chassis in lieu of a clamp.

7.3.8.4 Taping. Electrical tape should not be used to insulate soldered joints, to bind wires, or to secure a harness in lieu of a clamp. Where specifications permit the use of tape, only vinyl electrical tape should be used.

7.3.8.5 Clamping. Long wires or cables should be securely anchored to the chassis by means of clamps which distribute pressure over a wide area of the wire or cable surface. Clamps must not cut, pinch, or abrade the wire or cable.

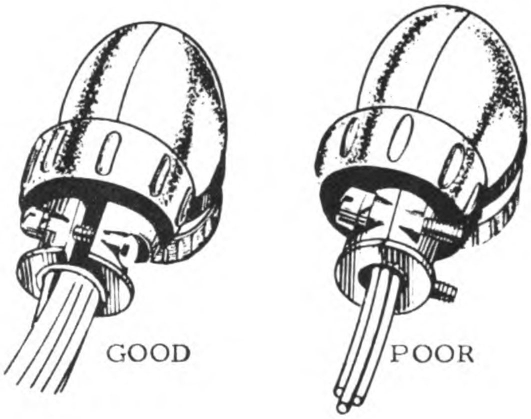


GOOD POOR

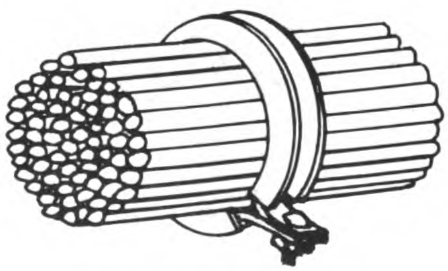
The size of the clamp must be selected to fit the diameter of the cable or wire group. Correct size centers the conductors and prevents stressing individual wires or soldered connections.

Clamps should also be employed to support cables or wires at plugs or receptacles.

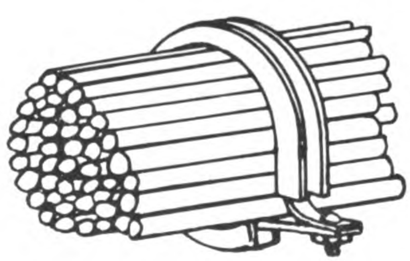
Clamps are used to secure harness assemblies where there is any possibility of damage due to shock or vibration. The harness is usually clamped at every branch or breakout and at intervals along the cable.



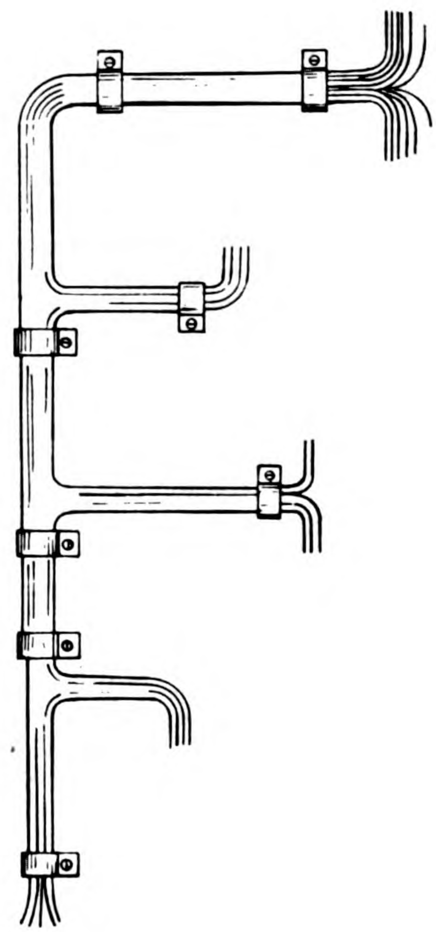
Clamps should be tightened until they cannot be twisted by hand so that they will hold cables tightly enough to prevent them from being pulled loose. When a rubber cushion is supplied with the clamp, it should completely enclose all the wires in the bundle, as illustrated .



GOOD

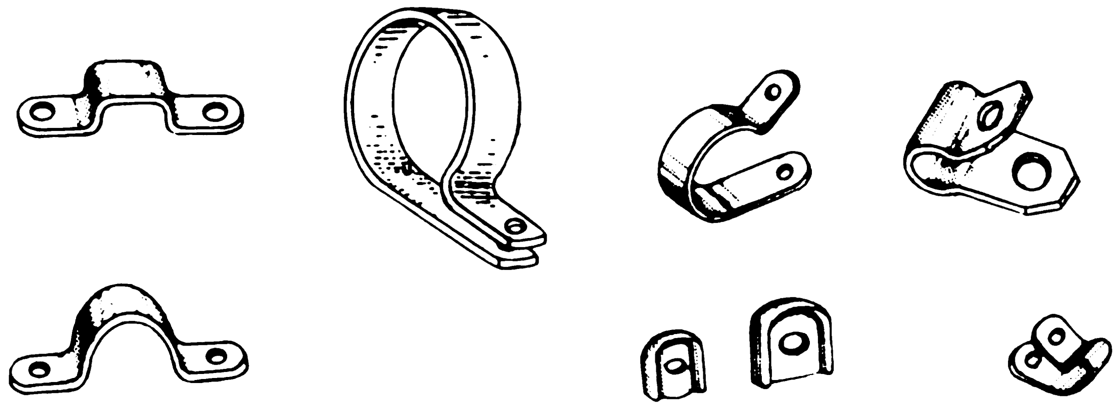


POOR

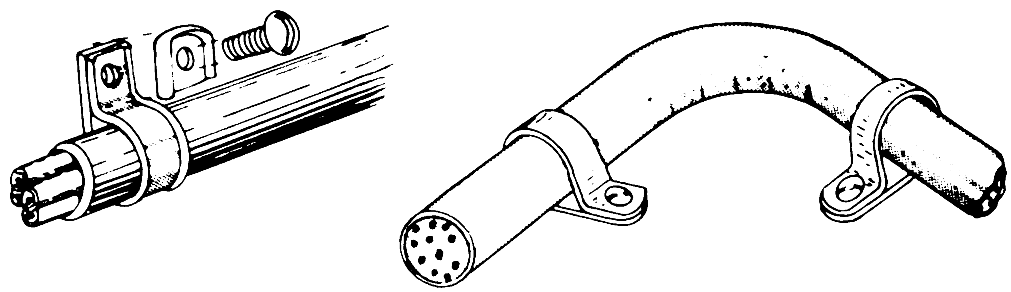


CLAMPING HARNESS ASSEMBLY

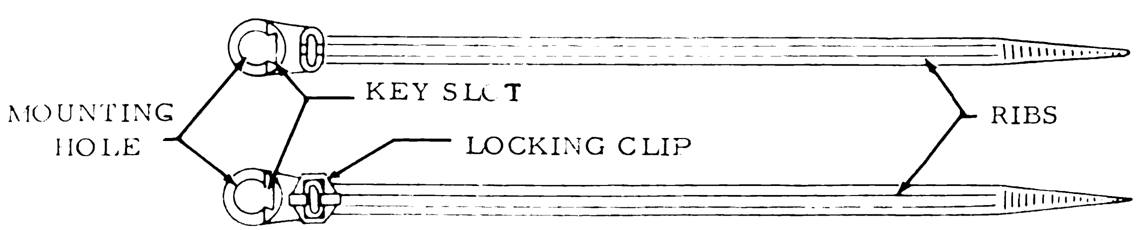
Various types and sizes of plastic clamps for cables are illustrated on the opposite page.



CABLE CLAMPS



USE OF CABLE CLAMPS



MOUNTABLE TIE STRAPS

These cable clamps are available in a number of materials which have good dielectric properties, do not support combustion, and are resistant to rust, moisture, fungus, and corrosion. The openings vary from 1/8 inch to 3.0 inches in diameter. Choice of the proper material allows use of these clamps at temperatures ranging from -60° to 275°F.

Examples of the use of these clamps in service are shown on the preceding page.

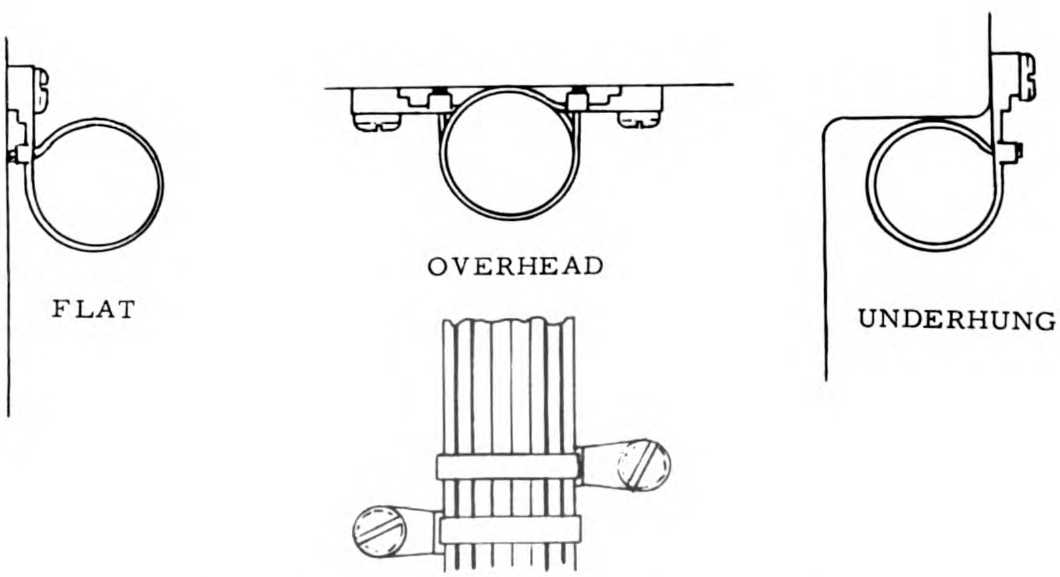
Certain of the tie straps and cable clips discussed in 7.3.2.2 and 7.3.2.3 can also be used to clamp cables and bundles of wire. The mounting straps illustrated on the following page have the same features as the tie straps discussed previously.

Mounting straps may be mounted with standard threaded fasteners in any of the positions shown below.

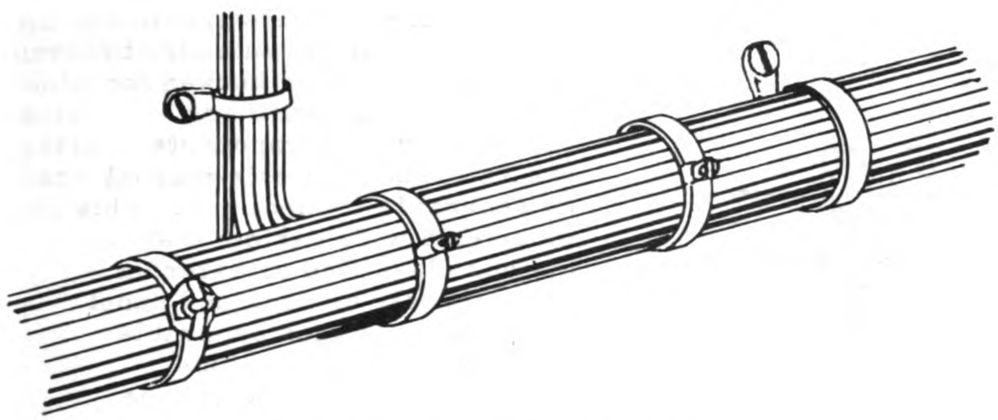
The mounting straps may be reused if the strap is installed so that the tip of the strap is threaded through the eye and then returned through the key slot of the mounting hole. The head of the screw prevents the free end from slipping back, but the strap is easily disassembled when the mounting bolt is removed.

REUSABLE MOUNTING STRAPS

An example of the use of these mounting straps in service is shown on the following page.



INSTALLATION OF MOUNTING STRAPS

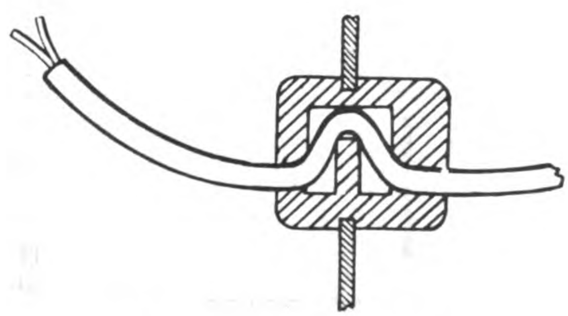


USE OF MOUNTING STRAPS

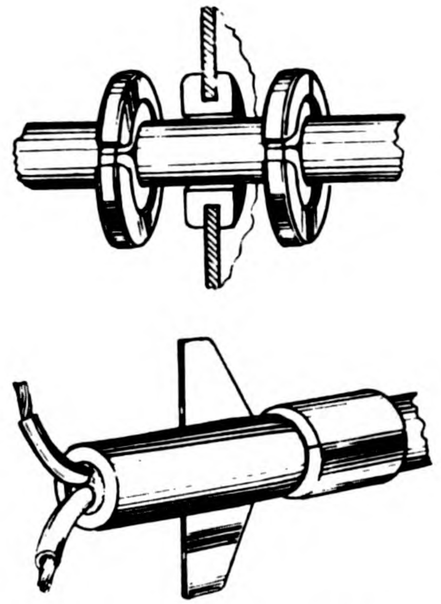
The cable clips discussed in 7.3.2.3 are also made with a recessed hole to permit mounting of a cable or wire bundle. These mountable cable clips possess the same features as the cable clips discussed previously, and can be used with a wide variety of fasteners.

These clips may also be mounted back-to-back, to support two or more parallel cables. In addition, large-diameter cables and wire bundles (over 2-1/4 inches) may be clamped by using two or more clips and bases together.

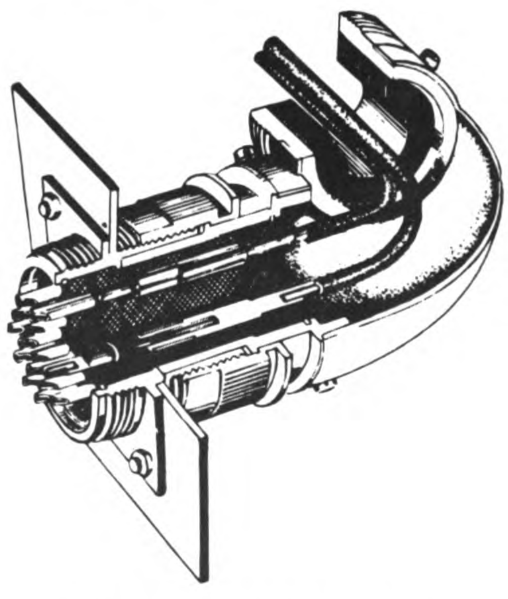
7.3.8.6 Strain Relief. Strain relief provisions are required where mechanical stresses would otherwise be transmitted to terminals by taut wires or cables. Sufficient slack should be allowed in the length of wires and cables to prevent undue stress upon terminals. Where flexible cords feed through the overall enclosure, stops should be provided. The surface against which each stop rests should be free of projections or other sharp edges which might abrade the coverings of conductors. Various devices such as the feed-through and U-types of clamps are available to suit given applications such as standard Navy terminal tubes. The degree of enclosure required by the specifications will govern the type of tube or clamp to be used.



STRAIN RELIEF DEVICE



STRAIN RELIEF DEVICES



TYPICAL CONNECTOR
(THREAD-COUPLING RING TYPE)

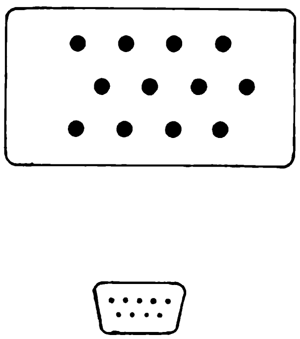
7.3.9 Separable Connectors

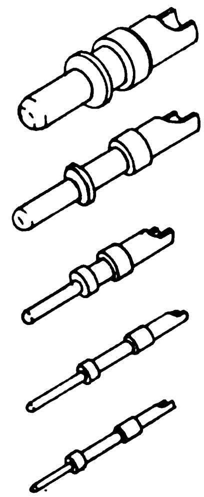
Connections in electronic equipment that are intended to be readily made or broken for testing, maintenance, or replacement of components are referred to in this manual as separable connections. This includes a wide variety that is further classified as external and internal, or rack and panel connectors. Other separable connections, such as tube sockets, tip jacks, telephone jacks, etc., are grouped as miscellaneous connections.

In selecting a connector, first determine if the connector must meet Military Specifications and second, determine the most critical or important considerations or limitations that tend to restrict selection such as: number of contacts, size of contacts (amperage rating), style of contacts, arrangement of contacts, shape of plug (round or rectangular), type of plug (cord, printed circuit, etc.), mounting space (ampule, restricted), coupling methods, insulation qualities, and environmental conditions.

One of the major restricting elements of a connector is the number of circuits it must handle. Where a large number of leads are to be accommodated, several separate connectors may prove more satisfactory than a single connector.

Except for power supply connectors, spare terminals in a quantity of ten percent should be provided. Care must be taken to avoid use of identical connectors at any one location to prevent accidental misconnecting. However, due to development in miniaturization in recent years, the number of contacts is not as restrictive as it might first seem. Many miniature connectors of current design carry an unusually large number of contacts. To illustrate, a comparison of miniature and standard plug insert sizes is shown.





Size of contacts and the resultant spacing is important. The controlling factor in this case is the amperage a particular contact must carry. The illustrations below show a typical relative increase in contact size as amperage ratings and wire sizes are increased. Be sure to note, in the selection of a connector, not only the number of contacts, but also the amperage and wire size each contact is to carry.

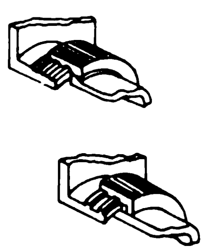
In determining the minimum spacing between contacts and contact shell, allowance must be made for possible accumulation of dirt, humidity effects, or reduced pressure at high altitude.

The voltage drop across mating contacts and contact resistance which will probably increase with time must also be carefully considered for possible effects.

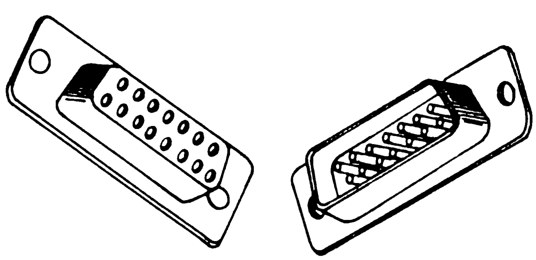
The following table lists the average current carrying capacity of connector contacts.

Contact Size or Wire Gage	Max. Allowable Current (Amps)
1/0	160-200
2	115-120
4	80-87
6	60-65
8	40-48
10	30-35
12	22-26
14	15-20
16	10-15
18	8-11
20	5-7

Connectors are primarily distinguished by the method of coupling connector halves. You will find standard MS coupling threads, easy-operating Acme coupling threads, reverse Acme threads, bayonet type, latchlock, quick-disconnect, and contact-friction couplings. Application and operation determine which is usable or desirable.

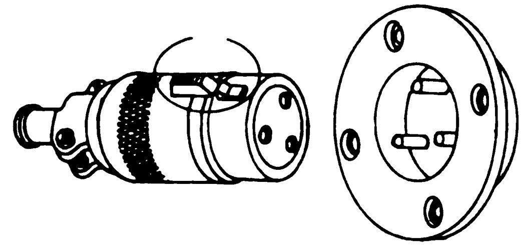


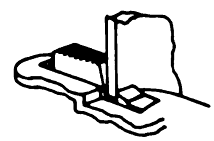
MS AND ACME COUPLING THREADS



FRICTION TYPE

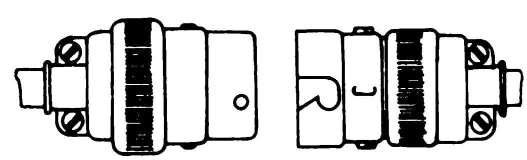
Connector halves are secured by friction of the spring contacts.





LATCH TYPE

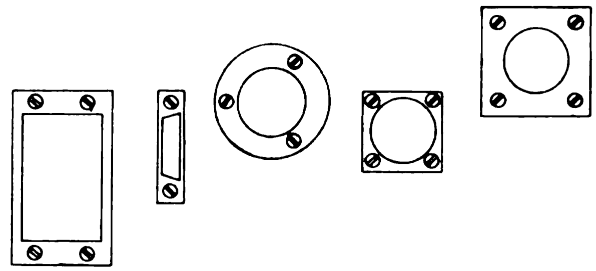
Mating halves are secured by a suitable latch incorporated in the shell.

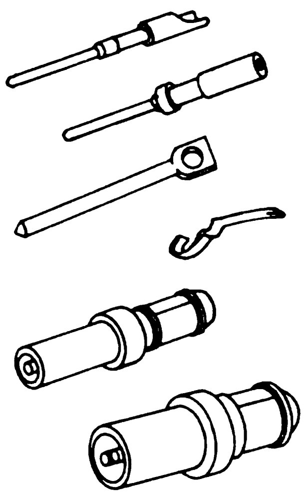


TWIST LOCK OR BAYONET TYPE

Lugs on the plug side of the fitting fit into grooves on the receptacle. A 20 degree twist locks or unlocks the connector.

Another factor in selecting plugs is a consideration pertinent to the type of contact for a specific requirement. In the figure, from top to bottom, are examples of various contacts: a solder pot terminal pin contact, a crimp type terminal, an eyelet terminal, a leaf type spring contact, a coaxial, and a twinax. Besides these, there are thermocouple types, high voltage types, and taper pin terminal types.





Dimensional limitations are often the basic factor in the type of plug selected. Normally, the receptacle is the mounted portion, although in some lines the plug may be the mounted portion, and in some types of rack-panel-chassis installations, both the plug and receptacle will be mounted on a structure. The shape and the type and size of the mounting flange are the factors to be considered. Typical configurations and sizes are shown in the figure.

In many instances, a critical item for consideration is the insulation material separating the contacts. A wide variety of insulators have been developed and each has a long list of electrical and mechanical properties any one of which might be the dominant characteristic for the application. Some of the common materials used for insulators are: melamine, phenolic, diallylphthalate, nylon, synthetic rubber, ceramics, or glass. Each is particularly adaptable to certain environmental operating conditions such as moisture, heat, vibration, pressure, humidity, corrosive atmosphere, stray electric and magnetic fields, low and high frequency noise, and oil resistance.

Not all of the above factors to be considered in selecting connectors are necessarily important in each instance, but one or more can easily be critical items.

Soldering Procedure. - Soldering of wires to connector terminals is an exacting procedure because of limited working space. Procedures used will depend upon the condition of the parts to be joined. Commonly used methods are described.

When soldering wires to a captive connector, in a jig or in a panel, the starting point should be at the side away from the iron. The start can be made at the top if the cable enters from that direction and there is no interference with subsequent operations. If soldering proceeds from the bottom, a heat resistant shield should be used to prevent contact of the iron with previously soldered wires. When the connector is held vertical or at an angle, the start is best made at the center.

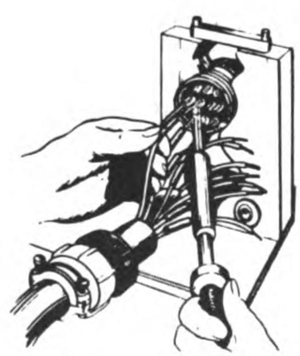
When the connector is held in the hand and can be moved, it is advantageous to solder with a stationary iron with the captive iron tip facing the operator. Soldering can then proceed by holding the terminal and wire against the tip. When this method is used, it is advantageous to start at the center, since the connector can be rotated as the work proceeds.

Regardless of the method used, wires which have been previously soldered should not interfere with the soldering iron or the operator's view. The operator must be able to place the iron in firm contact with the terminal without touching other wires. A bent soldering tip is advantageous for some operations.

Pretinned wire and terminals should be used. Additional solder is not usually required. Soldering must be performed rapidly to prevent damage to insulation, and therefore, a large tapered tip is required. Lack of flux or sufficient heat will produce a cold solder joint.

AN connectors of the multipin type are equipped with cable clamps. The cable is often smaller than the size for which the clamp was designed. To provide a more suitable means of anchoring cables of small diameter, adapters should be used. The adapter should center the cable and insure anchorage without padding.

Sleeving is slipped over the wires before soldering, and when



all joints have cooled and have been cleaned, the sleeving is slipped over each joint. The sleeving should fit snugly over each soldered terminal and wire to adequately support the wire and prevent sharp bends.

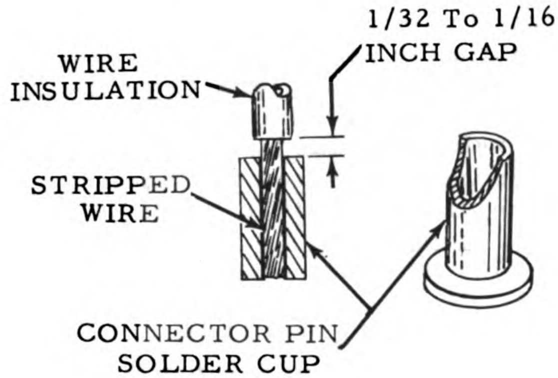
The use of high-temperature wire presents special problems, and the following procedures should be used for soldering high-temperature wire to connector terminal cups:

a. Fill the connector pin solder cup with enough solder so that the solder will be level with the top of the cup when the wire is inserted.
b. Hold the hot soldering iron on the back of the cup until the desired temperature is obtained. This will be evidenced by the solder turning a bluish, lustrous color.
c. When the desired solder temperature is obtained, insert the wire all the way to the bottom of the cup.
d. Remove the iron immediately to prevent overheating of the solder. If the solder is overheated, it will expand upward toward the gap and result in a stiff joint.

PRECAUTION - Do not allow solder to make contact with the gap portion of the wire.

The insulation of high-temperature wire should be stripped back a distance equal to the depth of the connector pin cup plus an allowance for a 1/16 to 1/32 inch gap between the stripped end of the insulation and the top of the cup, as shown.

The stripped end of high-temperature wire should be initially tinned for 1/32 inch. The wire will later become completely tinned to the top of the connector pin cup when the wire is inserted into the cup.

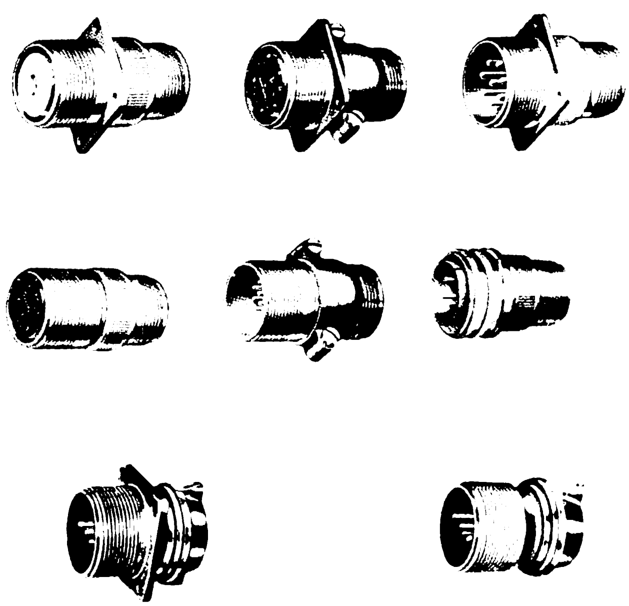


High-temperature wire should be soldered with a solder consisting of 95% tin and 5% antimony. This solder will provide a good electrical and mechanical connection and withstand temperatures up to 300°F.

7.3.9.1 External Connectors. External connectors are generally used for interconnection of cabling and electronic equipment, or joining cables external to electronic equipment. These connectors have a strong outer shell, usually metallic, which houses the dielectric or insulating material. These shells are designed for maximum protection of the enclosed dielectric and electrical contacts and usually feature some means of locking members together.

AN Connectors - AN connectors are widely used on electronic equipment designed for use in severe environmental conditions. Military Specification MIL-C-5015 and Military Standard Drawings MS 3100 through MS 3108 cover the basic design of this type connector.

AN connectors feature sturdy aluminum shells which are locked together by a threaded coupling ring either resilient or hard plastic dielectric inserts and various sizes and arrangements of individual electric contacts. The following six standard styles of aluminum shells are available: wall receptacles MS 3100, cable receptacles MS 3101, box receptacles MS 3102, straight plug MS 3106, quick disconnect plug MS 3107, and angle plugs MS 3108. Examples of these are illustrated below.



The suffix letters appearing on the illustration identify the shell construction as follows:

1. Standard purpose connectors
   - A solid shell construction
   - B split back shell construction
2. Special purpose connectors
   - C pressurized construction
   - E environmental resistant
   - R lightweight environmental resistant

In addition to the standard styles of connectors, a number of special connectors designed to mate with the standard AN connectors are also available. AN connectors are manufactured in 16 shell sizes. A number of standard dielectric insert arrangements can be obtained for each standard shell size. They differ in the number, size, arrangement, and spacing of electrical contacts. Five sizes of contacts are made with current capacities between 20 and 245 amps. Contact spacing is divided into six groups with minimum creepage distances varying from 1/16 to 1 inch.

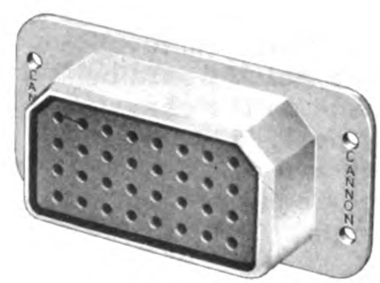
The major disadvantage of AN connectors is their inadaptability to crowded or miniaturized units. Only a fraction of the current capacity provided in the smallest socket contact is required by most electronic circuits. As a result of this newly designed miniature connector, AN connectors have been made available to the electronic industry. These miniature connectors will be discussed later in this chapter.

Rectangular Connectors - Rectangular connectors suitable for external are so numerous in design characteristics that the description of any one distinct type would be difficult if not impossible.

The outer shell of these connectors are either stamped sheet metal or die cast aluminum. Due to the wide variety in design, the weight of these shells varies considerably. Mating members of the connector are locked together by screws located at the center, ends, corners, or other appropriate positions. Wing nuts or knurled knobs are frequently used for tightening. Dielectric inserts are manufactured from any of the common plastic materials. Electrical contacts are of the pin and socket type. However, other specially designed contacts are available.

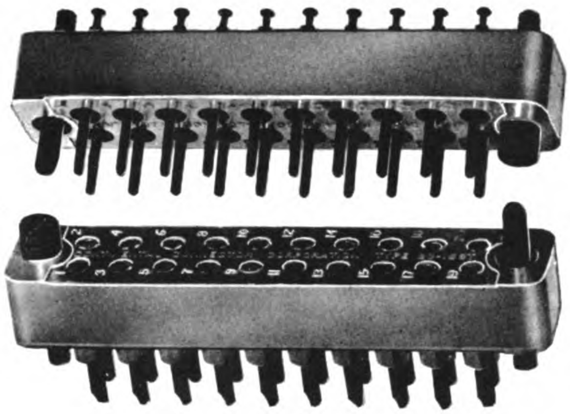
This type connector is suitable for a wide range of applications although it is less suitable for severe environments than the previously described AN connector. Prior to selecting rectangular connectors for external use, consideration should be given to the environment and the ability of this type of connector to give continued satisfactory service in the environment. The shell or hood must have the ability to withstand any mechanical service conditions that may be encountered.

A typical connector of this type is illustrated below.



7.3.9.2 Internal Connectors. Internal connectors are those connectors used entirely within electronic equipment. They differ from external connectors in that they do not have an outer metal shell and, frequently, no provisions are made for locking plug and receptacle together. Mounting holes or mounting screws are provided in each dielectric and the plugs are held in their receptacles by the lugs and fasteners that support the respective chassis units. Some typical internal connectors are described in the following paragraphs.

Rectangular Connectors - Rectangular connectors suitable for internal use, unlike those for external use, are somewhat consistent in their design characteristics. In some cases the plugs of one manufacturer will mate with the receptacle of another. Mounting holes or studs are provided in either end of the dielectric. Positive polarization is accomplished by reverse male and female guide pins. Internal rectangular connectors are available with 5 to 104 contacts. Current rating of contacts vary from 10 to 20 amperes.



Rectangular internal, or rack and panel connectors, are used extensively in electronic equipment. In a typical installation, the receptacle would be mounted with the mating face up on a chassis. The plug would be mounted at the bottom of a small removable plug-in unit which would be held in place on the chassis. For many designs, these connectors are available with metal hoods equipped with cable clamps.

Circular and Hexagon Connectors - These connectors are made with electrical contacts and dielectrics that are similar to those of rectangular rack and panel connectors. This type of connector is mounted in a circular chassis hole by means of a jam nut or rubber grommet. It is occasionally used as a termination for small internal cables.

Ribbon Connectors - Ribbon connectors of the internal or rack and panel type are popular with some manufacturers of electronic equipment for service under severe environmental conditions. The mating dielectric units of these connectors have a distinct plug and socket shape and the electrical contact ribbons are mounted axially on the mating surfaces of each.

Miscellaneous Connections - Many of the separable connections commonly used in electronic equipment are not usually classified as connectors. Some of these are tube sockets, test points, and terminal boards. Tube sockets are used to provide both physical support and electrical contact with the tubes. Tube sockets incorporating a molded phenolic dielectric are generally preferred for use in electronic equipment for industry and the military. Design and performance characteristics of molded tube sockets are found in Military Specification MIL-S-12883.

Test points, tip jacks, and banna jacks might be described as single connectors of the internal type. These are circular in construction and are mounted in circular holes in the chassis by means of jam nuts. Styles and qualities of these units vary a great deal and therefore should be selected for a specific application.

Terminal boards consist of a row or rows of terminal posts, usually screw lugs, mounted on a strip of molded insulation material. Military Drawing MS 25123 can be used as a guide in selecting terminal boards. Design consideration should be given to such factors as insulation barriers, voltage breakdown, creepage distance, warpage, terminal material and plating, mounting provisions, etc.

7.3.9.3 Miniature Connectors. Miniaturization in electronics, often a result of increasing circuit complexity, has introduced miniature, subminiature, and micro-miniature connectors as new electronic hardware. These newly designed connectors are widely used in guided missiles, telemetering equipment computers, aircraft instrumentation, and precision instruments for radar tracking.

These three classifications of connectors are similar in most respects to their larger prototypes but usually incorporate only small electrical contacts (5 or 10 amp capacity) and feature only smaller contact spacing. Because of this smaller contact spacing, the majority of miniature connectors have an average flashover voltage of 1700 volt at 60 cps ac rms at sea level. For high altitudes, flashover values will average even lower. More detailed comparisons between the three sizes of miniature connectors and standard connectors will be made in the description of specific types of connectors.

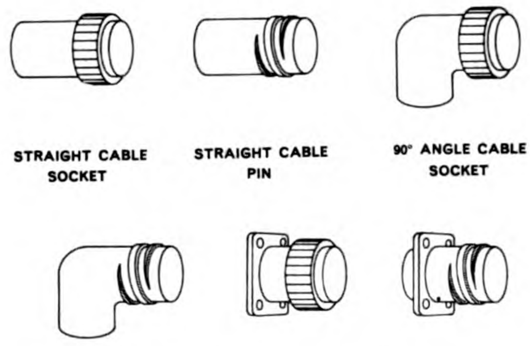
Miniature AN Connectors - Miniature AN connectors are similar to the standard connectors. They were developed to meet the unusual demands of the aircraft and missile industry for connectors that would withstand the rigors of high altitudes and increased speeds while at the same time contributing to the decrease in instrumentation space and weight requirements. These connectors are available as plugs, cable and panel receptacles, and single hole mounting receptacles.

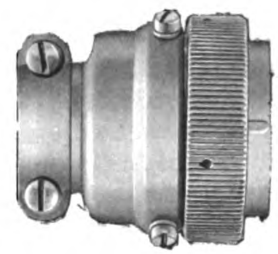
Novel shell styles, such as receptacles for mounting in a single large hole by means of a jam nut rather than by the square flange and four mounting screws of the military AN 3102, are popular with those who use miniature AN connectors.

To date, standardization of AN type miniature connectors has not been completely accomplished by any recognized military specification or other industry-wide standardizing activity. Each connector manufacturer's shell sizes and styles, insert arrangements and locking means are different, and interchangeability is limited. Conformance to electrical and environmental requirements of MIL-C-5015 is claimed for most miniature designs, but some manufacturers of electrical equipment require that back shells of these connectors be filled with sealing compound (MIL-C-8516) as added protection against low resistance in the presence of moisture.

One AN type miniature connector has been designed for use in extremes of humidity and barometric pressure.

Design characteristics of the dielectric insert to be considered are voltage breakdown, creepage distance, and corners in which foreign matter might collect. In addition, contacts should be examined for size, ruggedness of design, actual contact area, suitability of finish, etc.

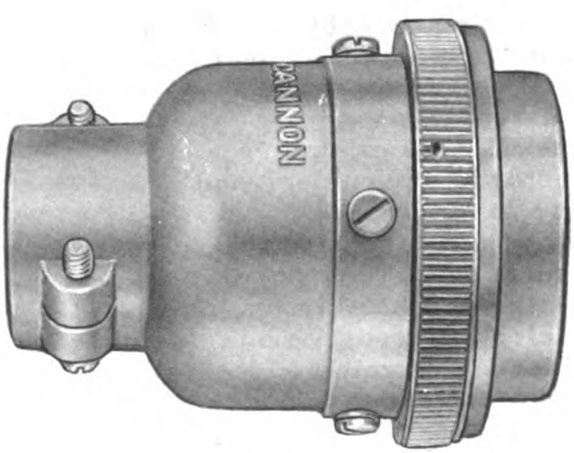




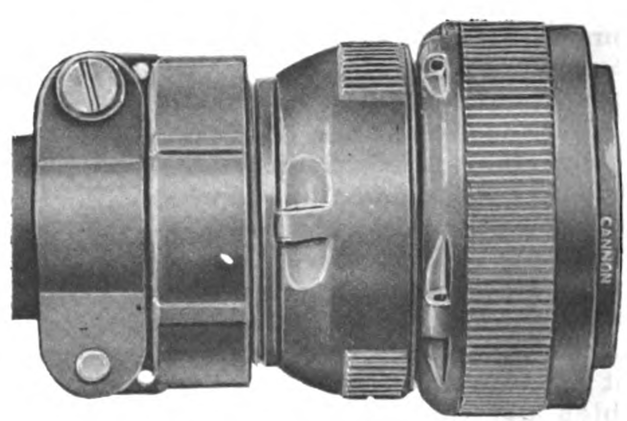
MINIATURE AN CONNECTOR

The shells of these miniature connectors usually incorporate either a bayonet lock, a single acme thread, or a snap-lock coupling ring to facilitate rapid connection and disconnection. Shell sizes are approximately half those of comparable AN connectors.

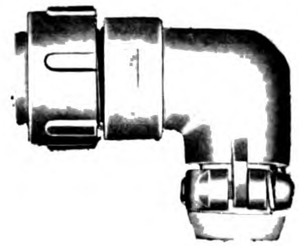
Subminiature Metal Shell Connectors - These connectors are similar in appearance and construction to standard and miniature AN connectors. To illustrate relative size, a comparison is made below between a standard connector and a subminiature connector.



STANDARD AN CONNECTOR



STANDARD SIZE CONNECTOR



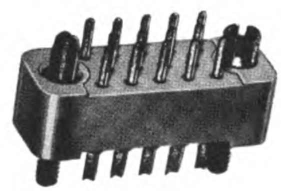
SUBMINIATURE CONNECTOR

These connectors are designed to withstand moderately severe handling and environmental conditions, and to incorporate a shell which has maximum strength within its volume limits. Sealing has been accomplished by interfacial compression of the resilient insert which provides a high degree of vibration resistance. The strong coupling nuts utilize a rugged Acme thread to permit fast and simple engagement and disengagement.

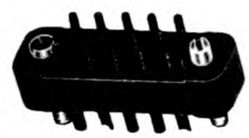
Two connector sizes are available; inserts are interchangeable for a given connector size; two alternate insert positions are provided; and a total of eight receptacles and plugs can be furnished at this time. Other layouts and shell sizes are still in the design phase of development.

Miniature, Subminiature, and Microminiature Rectangular Connectors - These connectors are used in guidance systems, radar equipment, transmitters, amplifiers, instrument panels, memory drawers, control instruments, and a wide variety of other electrical and electronic devices which require plug-in type subassemblies or chassis. They can be used as either external or internal connectors. For external use, the connector is usually equipped with aluminum hoods with a cable clamp or protective shells to prevent physical damage to molded dielectric and protruding contacts. These connectors are similar in construction to the standard rectangular connector. The major difference is lower electrical and mechanical ratings of the miniaturized connectors. A comparison of electrical and mechanical ratings of these three miniaturized connectors is given in the table on the following page.

A comparison of the actual physical size of these miniaturized connectors is illustrated below.



MINIATURE



SUBMINIATURE

MICROMINIATURE

CHARACTERISTIC	MINIATURE	SUB-MINIATURE	MICRO-MINIATURE
Breakdown voltage at sea level	3700v rms	1900v rms	2400v rms
Breakdown voltage at 70,000 feet	750v rms	*700v rms	650v rms
Recommended test voltage at sea level	2450v rms		1600v rms
Recommended test voltage at 70,000 feet	500v rms		425v rms
Continuous current rating	7.5 amps	7.5 amps	3 amps
Minimum creepage between contacts	0.125 in	0.078 in	0.063 in
Minimum air space between contacts	0.070 in	0.047 in	0.040 in
Contacts center-to-center	0.150 in	0.125 in	0.094 in
Pin diameter	0.040 in	0.040 in	0.030 in
Solder cups	#20 AWG wire	#20 AWG wire	#22 AWG wire

*60,000 feet

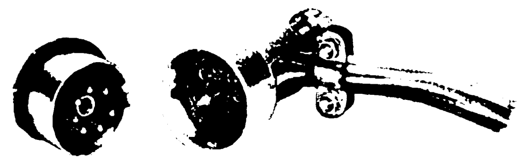
These connectors are available with 5 to 104 contacts. Contacts are precision machined spring temper phospher bronzes with gold plate over silver plate for low contact resistance. Some manufacturers incorporate a floating contact design to insure positive alignment of each contact. These connectors can be obtained with either solder cup terminals or turret and taper pin solderless terminals.

Positive polarization is assured with reverse male and female guide pins and guide sockets on the plug and receptacle. Polarizing screwlock guide pins and guide sockets provide a positive means of locking the plug and receptacle against accidental disconnection due to vibration. It is also a mechanical method of separating the plug and receptacle without prying or forcing. This feature eliminates the need to "rock" the connector during the disconnect procedure and avoids the possibility of damage to contacts and body molding.

..niature Circular and Hexagon Connectors - These connectors are designed for panel or chassis mounting and are inserted in round holes in the chassis or panel and secured with nuts or rubber grommets. They are available with 4 to 10 contacts. Contact material is brass for pin contacts and phosphor bronze for socket contacts. Some connectors in this category have the same pin size and spacing as standard seven and nine pin miniature tubes.

These connectors have locking rings which prohibit rotation and also prevent disconnection under severe vibration.

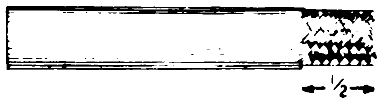
Another type of miniature round connector consists of an insert enclosed in an aluminum shell. A center jackscrew is used for engagement and disengagement. Contact material is brass for pin contacts and phosphor bronze for socket contacts. Polarization is accomplished through contact arrangement and by a key slot in the shell.



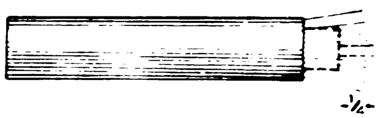
Keystone Connectors - This type of connector features a stamped sheet metal shell in the shape of an isoceles trapezoid. This shell serves as a substitute for the guide pin as well as protection for the contacts and dielectric. Miniature connectors of this type are used where environmental conditions are severe. They are occasionally used as external connectors on miniaturized equipment, but consideration must be given to the possible entry of moisture.

7.3.9.4 Coaxial-Cable Connectors. A variety of coaxial cable connectors, each characterized by low-loss properties, is available to meet the diverse requirements for radio-frequency. Specific instructions for assembling each type of connector are usually furnished by the manufacturer. A few of these connectors are shown on the following pages.

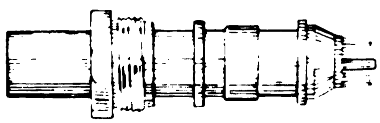
Type UG-23B/U



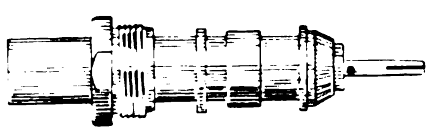
Remove 1/2 inch of vinyl jacket. When using double-shielded cable, remove 9/16 inch.



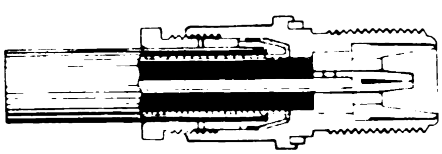
Comb out braid as shown. Cut off dielectric 1/4 inch from end. Tin center conductor.



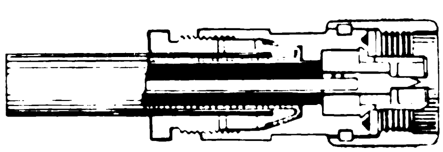
Taper braid as shown. Slide nut, washer and gasket over vinyl jacket. Slide clamp over braid with internal shoulder of clamp flush against end of vinyl jacket. When assembling connectors with gland, be sure knife-edge is toward end of cable and groove in gasket is toward the gland.



Smooth braid back over clamp and trim. Soft solder contact to center conductor. Avoid use of excessive heat and solder. See that end of dielectric is clean. Contact must be flush against dielectric. Outside of contact must be free of solder.

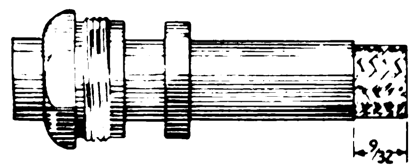


Slide body into place carefully so that contact enters hole in insulator. Face of dielectric must be flush against insulator. Slide completed assembly into body by pushing nut. When nut is in place, tighten with wrenches, In connectors with gland, knife-edge should cut gasket in half by tightening sufficiently.

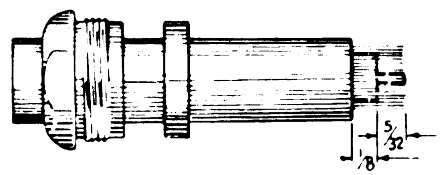


Type UG-23D/U

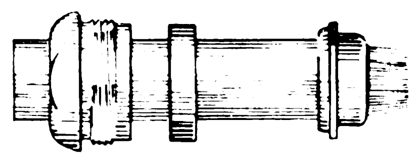
Place nut and gasket over cable and cut off jacket 9/32 inch from end.



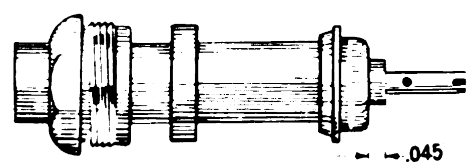
Comb out braid and fold out. Cut off cable dielectric flush 1/8 inch from end of jacket.

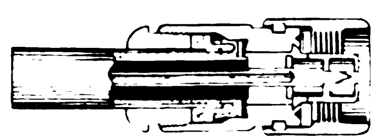


Pull braid wires forward and taper center conductor. Place clamp over braid and push back against cable jacket.

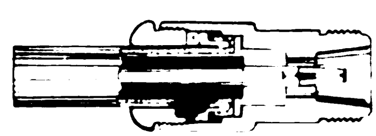


Fold back braid wires as shown, trim to proper length and form over clamp as shown. Solder contact to center conductor.

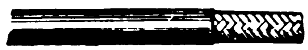




Insert cable and parts into connector body. Make sure sharp edge of clamp seats properly in gasket. Tighten nut.

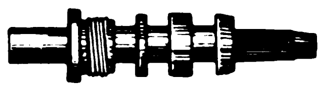


"BNC" Types

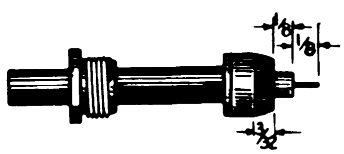


Trim jacket 1/4 inch for RG-58/U, 5/16 inch for RG-59/U, or 7/16 inch for RG-71/U cable.

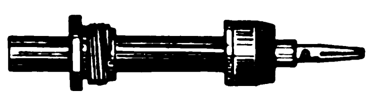
Fray shield and strip inner dielectric 1/8 inch. Tin center conductor.



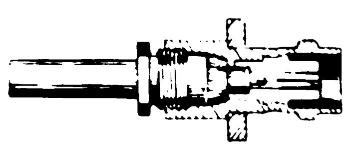
Taper braid. Slide nut, washer, gasket, and clamp over braid. Insert clamp so that its inner shoulder fits squarely against end of cable jacket.



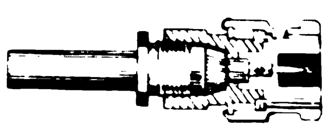
With clamp in place, comb out braid, fold back smoothly as shown, and trim 3/32 inch from end.



Slip contact in place flush against dielectric and solder. Remove any excess solder from outside surface of contact. Do not overheat dielectric.



FEMALE



MALE

Push connector onto cable as far as it will go. Slide nut into connector and tighten in position with wrench. During this operation, hold cable and shell rigid while turning nut.

Where a connector is not required, terminate cables as shown in 7.3.4.3.

Chapter 8

MATERIALS

8.0 GENERAL

In this chapter, the general methods of selecting and specifying materials are discussed. For detailed information on particular materials and processes, refer to the discussions in previous chapters, especially chapters 3 to 7. Federal and military specifications cover practically all available materials, They are listed in the Index of Specifications and Standards used by the Department of the Navy, Military Index, Volume III. These specifications supply sufficient data on the properties of materials for many design purposes. Further information is available in various handbooks, manuals, engineering society publications, journal articles, and from individual manufacturers.

8.1 PROPERTIES AND USES

Materials can be divided into two main types: metals and nonmetals.

8.1.1 Metals

Metals are much better conductors of electricity and heat than nonmetals. Ferrous metals are customarily used for structural parts requiring high strength, although aluminum alloys are often used where weight reduction is necessary. Copper and its alloys are used for good electrical conductivity and resistance to corrosion. Certain alloys containing both iron and nonferrous metals are used in magnetic materials. Cadmium, zinc, copper, chromium, nickel, silver, gold, and platinum are used singly, or in various combinations, as protective platings for ferrous metals; or to improve electrical properties, corrosion resistance, or appearance of nonferrous metals, Specifications for the various metals mentioned are listed in Military Index, Vol. III under the name of the metal or alloy, e.g., aluminum, brass, bronze, steel. Other listings are given under such titles as magnet materials, forgings, castings, bars, pipe, solder, tubing, and wire.

8.1.2 Nonmetals

Nonmetallic materials include such materials as oils, mica, rubber, plastics, ceramics, resins, and various compounds of metals, such as paint pigments. Nonmetals in electronic equipment serve as insulators, shock-mounts, lubricants, and ingredients of cleaning materials and protective coatings. Specifications for the various nonmetallic materials are listed in Military Index, Vol. III under titles such as insulation, grease, lubricating oil, molding plastic, plastic material, rubber, gasket material, packing, coating, paint, lacquer, primers, and varnish. Related processes are listed under titles such as anodizing, chemical films, cleaning, and preservation.

8.2 SELECTION OF MATERIALS

8.2.1 General

In selecting materials for use in electronic equipment, the following recommendations should be followed:

a. Critical and strategic materials such as nickel, tin, asbestos, and cobalt should be used in the smallest amounts possible.
b. The materials selected should be of a kind and quality widely available in commercial supply channels, and should not be proprietary.
c. Material specifications should permit the use of suitable alternates.
d. Select materials which give, or may be treated for, maximum protection against moisture, corrosion, and fungus (see 8.2.2).
e. Do not use cast iron without specific approval of the procuring activity. Cast iron may fail under shock loading, endangering personnel.
f. Magnesium and its alloys should not be used unless specifically approved by the procuring activity. Magnesium and magnesium alloys, especially in thin sections, are a fire hazard.
g. Materials should be selected on the basis of least cost, taking into consideration formability, machinability, weldability, corrosion resistance, and absence of toxic ingredients.

8.2.2 Moisture, Fungus, and Corrosion Resistance

The various methods used to protect metals against corrosion have been discussed in chapter 5. Nonmetals should be selected for maximum resistance to deterioration by moisture and fungus. Materials most susceptible to such deterioration are natural fats, proteins, cellulose, and carbohydrates. Unless protected, these materials may absorb water, swell, decay, mildew, or be nutrient to fungi, with consequent deterioration of electrical and mechanical properties. Note that materials of this type are often used as fillers or plasticizers in plastics and rubber, or as main constituents of insulation, spacers, cushioning material, packings and gaskets.

Examples of materials containing substances described above, which should not be used unless protected by approved methods are:

Animal and vegetable oils and fats
Carbohydrates: starch, sugar
Cellulose products: cardboard, cellophane, cork, "fiber", paper, rayon, wood
Leather
Natural fibers: cotton, felt, jute, hair, hemp, linen, sisal, silk, wool
Natural rubber

Such materials which are not protected against moisture or deterioration by potting, immersion in oil, hermetic enclosure, heat, etc., should be treated before assembly into equipment by approved mildew-proofing treatment, moisture- and fungus-resistant varnish, or preservative, such as those covered by the following specifications:

O-L-164, Leather Dressing, Mildew Preventive
TT-W-571, Wood Preservative;

Recommended Treating Practice
MIL-V-173, Varnish, Moisture- and Fungus-Resistant
MIL-T-3530, Treatment, Mildew-Resistant, for Thread and Twine
MIL-T-20168, Treatment; Fire-, Laundry-, Dry-Cleaning-, and Mildew-Resistant (for Cotton Fabrics)

8.3 SPECIFYING MATERIALS

Materials for electronic equipment should be specified by reference to documents in the following order of preference:

a. Federal or military specifications.
b. Description of mechanical or chemical properties, performance requirements, or tests.
c. Commercial quality specifications, or standards of trade or technical organizations. Include alternate materials of equivalent quality covered by Government.
d. Commercial designations. Include an equivalent Government designation.
e. Proprietary material, if a suitable nonproprietary material is not available. Data on such material should be obtained and a specification prepared.

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