Seventh Week.
D.C. Motors and Generators.

3.7

QUESTION #1. Who was Michael Faraday and for what discoveries is he remembered?

ANSWER #1. Michael Faraday was born in 1791 and died in 1867. He was a distinguished English physicist who made important discoveries in electrochemistry and electromagnetism. He was the first to see that a true understanding of the action of magnets could be had only by studying the empty space around them, as well as the magnets themselves. He drew what he called lines of force around a magnet and defined a line of magnetic force as a line which indicates at its every point the direction in which a north-seeking pole is urged by the attractions and repulsions of all poles in the neighborhood. But he thought of these lines of force as having a much more real meaning than this. He thought of them as actually existing throughout the space around every magnet, even when there were no filings to show them. He believed that they represent a real state of strain in the ether in which all material bodies are immersed.
About 1831 Faraday (and Henry) discovered that it is possible to transform mechanical energy directly into electrical energy. Their method of producing electric currents by means of magnets is the underlying principle of the commercial generator, which has made possible the modern age of electricity.

QUESTION #2. State Faraday's law.

ANSWER #2. Faraday's Law is as follows: Let any conducting circuit be placed in a magnetic field; then, if by a change in position or a change in the strength of field the number of magnetic lines of force passing through or interlinked with the circuit is altered, an Electromotive Force will be induced in the circuit proportional to the rate at which the number of lines is altered.

QUESTION #3. Draw sketch and explain how you would find direction of induced emf by the right hand rule.(Generator Rul

ANSWER #3. See end of seventh week's work for sketch. This righ hand rule for generators is called the Fleming Rule. It is as follows: Extend the thumb, forefinger, and center finger of the right hand so as to form right angles with each other. If the thumb points in the direction of the motion of the wire, and the forefinger in the direction of the magnetic flux, the cente finger will point in the direction of the induced current. To remember this rule, notice the corresponding initial letters in the words "fore" and "flux", "center" and "current."

QUESTION #4. State Lenz's law.

ANSWER #4. The first part of Lenz's law is: The direction of th induced e.m.f. is such that it tends to set up a

ANSWER #4. Continued.

current the magnetic field of which always opposes any change in the existing field.
The important word in this law is the word *change*. The field of the induced current does not always oppose the existing field, nor does it always aid it, but it always opposes any *change* in it. Thus if the existing field is zero, and if we send a current through the primary coil to set up a field there wil be induced in the secondary coil a current the field of which will be opposite to the growing field, and thus will tend to keep the condition of the field as near zero as possible. But if there is a field already within the coil, and we try to weaken it, say by decreasing the current in the primary, there will be induced in the secondary coil a current the field of which will aid the existing field and tend to kee it at the same strength. The induced current thus is always such that its field opposes any change in the existing magnetic field.
The second part of Lenz's law is: The amount of induced e.m.f. is equal, in volts, to one hundred-millionth of the number of cuttings per second of the magnetic field by the circuit in which the e.m.f. is induced.

QUESTION #5. Make sketches to prove Faraday's and Lenz's law.

ANSWER #5. For sketches, see end of seventh week's work.

QUESTION #6. Explain in detail and by sketch the fundamental principle of a D. C. Generator.

ANSWER #6. As has been explained before, if a wire is moved thru a magnetic field, an e.m.f will be induced in it, the direction depending on the direction of the flux and the direction of motion of the wire thru the magnetic field. This is the fundamental principle of the generator. To explain the function of a generator, we consider that we have a single turn of wire, the ends of which are connected to rings, upon which rest brushes which take the current from the wire. As the wire revolves on its axis a current is induced in one side of the wire in one direction and in the other side of the wire in the other direction. Since the wire is in series with the external circuit, the e.m.f. will flo in one direction, but as both sides of the wire pass thru the field and commence the second half of the revolution, they are moving parallel to the lines of force, and are cutting none of them, so no e.m.f. wil be induced. Then the sides of the wire commence to cu the field again, but the direction is reversed because the motion of the respective sides of the loop has been reversed. Thus we can construct a sine curve of the e.m.f. starting at zero, gaining in value unti it reaches a maximum in one direction, which we will call positive, just as the sides of the wire are cutting the maximum number of lines. Then the e.m.f. dro s to zero at the half revolution, and starts gaining again, but in the opposite direction, which we will

ANSWER #6. Continued.

call negative, until it reaches a maximum as it is cutting the maximum number of lines again. It then returns to zero again and is ready to start a second revolution. This is a complete cycle. If we remove one of the rings, split the other in half, insulate the halves from each other and from the shaft, altho securing them firmly to the latter, and connect the ends of the loop to the halves of the loop, we can prevent the direction of e.m.f in the external circuit from changing. The direction will continue to reverse within the loop, tho. As the loop revolves, the e.m.f. will be induced in a direction, depending on the direction of motion of the loop thru the field but the direction of e.m.f. will be opposite in the two sides of the loop, so it will move out thru one half of the slit ring, thru the external circuit, and in the other half. As the loop continues to revolve the direction of e.m.f in the loop changes, but the ends of the loop have changed connections with the external circuit so the e.m.f. will continue to flow in the same direction in the external circuit, altho the value will pulsate. A sine curve of this e.m.f. will start at zero, gain in one direction (positive) until it reaches a maximum, fall to zero, and start again to rise, but in the same direction, will reach maximum again, and return to zero. The first explanation, using the two rings, is the principle of an Alternating Current Generator, commonly called an alternator. The second explanation, using the split ring, or commutator, is the principle of the Direct Current Generator.

QUESTION #7. What does the value of induced emf depend on?

ANSWER #7. Since Lenz stated that the amount of e.m.f. is equal, in volts, to one hundred-millionth of the number of cuttings per second of the magnetic field by the circuit in which the e.m.f. is induced, we can state tha the value of the induced emf depends on the number of lines cut per second. This can be divided into parts. It depends on the strength of the magnetic field, the number of conductors cutting the field, and the speed with which these conductors are moving thru the field

QUESTION #8. A wire 24 inches long travels at a velocity of 300 feet per second thru a magnetic field where the flux density is 1,000,000 lines. What is the value of the induced emf?

ANSWER #8. Formula:

$$\text{Induced emf} = \frac{\Phi \times AC \times S \times l}{108}$$

Where:
Φ = lines of force.
AC = Active conductors.
S = speed in inches per second.
l = length of conductors in inches

ANSWER #8. Continued.

Substituting:

$$\text{Induced emf} = \frac{1\cancel{0}\cancel{0}\cancel{0}\cancel{0}\cancel{0}\cancel{0} \times 1 \times 3\cancel{0}\cancel{0} \times 12 \times 24}{1\cancel{0}\cancel{0}\cancel{0}\cancel{0}\cancel{0}\cancel{0}\cancel{0}\cancel{0}} =$$

864 volts.
Ans.

QUESTION #9. How compute the voltage, current and resistance of a multipole generator armature?

ANSWER #9. The voltage of a multipolar generator is the voltage across one armature path from brush to brush, since the brushes split the windings in the armature into parallel circuits, and the voltage of a parallel circuit is the voltage of one branch.

To compute the value of voltage in a multipolar generator:

Formula:

$$\text{Induced emf} = \frac{\Phi \times AC \times RPM \times Po}{10^8 \times 60 \times Pa}$$

Where: Φ = flux per pole.
AC = Active conductors.
RPM = Revolutions per minute.
Po = Number of poles.
10^8 = constant for one volt.
60 = time factor to reduce RPM to RPS
Pa = Number of armature paths.

It must be remembered that there are as many armature paths as there are brushes. There are usually as many brushes as there are poles, altho it is not necessary that there be as many brushes as there are poles, but the number of brushes never exceeds the number of poles. This induced voltage is the terminal voltage at no load. To find the terminal voltage at full load, compute the IR drop across the armature and subtract it from the terminal voltage at no load.

Since all the armature paths are in parallel and the currents in all paths are equal, the current delivered by a multipolar generator must be the current in each path multiplied by the number of paths.

The armature resistance of a multipolar generator is the resistance of a number of parallel paths all of equal resistance, and must therefore be equal to the resistance of one path divided by the number of paths.

QUESTION #10. Explain armature construction.

ANSWER #10. The prime object in the construction of a generator is to produce as many lines of force as possible with a minimum field current, so that the armature will not have to be revolved so fast. This is accomplished by winding the armature coils on lamina-

ANSWER #10. Continued.

ted annealed steel cores. Practically all of the space between the poles of the machine is filled up by these cores, thus leaving only small air gaps between the poles and the armature. This makes the reluctance very low hence a high flux density is maintained and a correspondingly high emf is induced by the conductors at a lower speed. The commonest form of armature is the drum type. It is made up of a core of thin annealed steel punchings about .014 inch thick. These punchings are built into a cylinder and keyed to a shaft. The coils are formed by winding insulated wire in the slots on the outside of the core.

QUESTION #11. What is meant by armature reaction? Explain fully.

ANSWER #11. The induced emf in the windings of an armature tend to set up a magnetic field which threads the armature at right angles to the magnetic field from the pole pieces. This magnetic field set up in the armature core is called cross-magnetization of the armature. The effect of these two fields at right angles tend to distort the field between the poles, causing the lines to crowd toward the upper tip of the north pole and down toward the lower tip of the south pole depending on the direction of rotation. This occurs only when there is a load on the machine, that is, when a current is being drawn from it. At no load there would be no field set up by the armature windings, hence no cross-magnetization. The brushes on a commutator are ordinarily set in such a position that the coils shorted out are cutting no lines of force at that instant. If this field is shifted due to cross-magnetization, it is necessary to shift the brushes forward enough so that they are again on the zero axis, that is so that they short out coils which are cutting no lines of force. It can be seen that sparking will occur if the brushes are not on zero axis. Sparking will pit the copper of the segments in the commutator, making it rough and uneven so that the brush makes uneven contact, causing more sparking and rapid deterioration. Of course, if no current is being drawn from the machine the proper position is at right angles to the pole pieces and as more and more current is drawn the brushes must be moved further forward. This is usually made unnecessary by commutating poles, or interpoles, which counteract the effect of cross-magnetization.

QUESTION #12. Why are commutation poles used?

ANSWER #12. Commutation poles are used to obviate the forward-shifting of the brushes to prevent sparking, also to build up the field weakened by increased armature current. These commutating poles are of the same polarity as the next pole ahead in the direction of rotation. In a generator the brushes are shifted forward to get the short-circuited coil into the flux of the following pole. The commutating pole acts like a projection from the following pole. By being

ANSWER #12. Continued.

separate from the following pole it has the advantage that the winding on it can be put in series with the armature. The flux produced by it is thus nearly proportional to the armature current. Thus instead of getting a weaker commutating flux when th armature current increases, we get a stronger flux which sets up a greater commutating voltage in the short-circuited coil. This is the condition which makes commutating poles produce sparkless commutatio without shifting the brushes.

QUESTION #13. A 6 pole 6 path generator had 1,000 active conductors on an armature which makes 400 RPM no load voltage is 125 volts. Area of pole is 200 square inches. What is the flux density?

ANSWER #13. Formula: $E_i = \frac{\text{lines cut per second}}{10^8} =$

$$\frac{\Phi \times AC \times RPM \times Po}{10^8 \times 60 \times Ps}$$

Φ = lines per pole.

$$\text{Flux density} = \frac{\Phi}{A}$$

$\therefore$

$$\text{Flux density} = \frac{E_i \times 10^8 \times 60 \times Ps}{AC \times RPM \times Po \times A}$$

Substituting:

$$\frac{125 \times \overset{10}{\cancel{10^8}} \times \overset{15}{\cancel{60}} \times \cancel{6}}{\cancel{1000} \times \underset{2}{\cancel{400}} \times \cancel{6} \times \cancel{200}} = \frac{18750}{2} =$$

9375 lines of force per square inch. Ans.

QUESTION #14. Explain what is meant by generator regulation and control.

ANSWER #14. Generators are classified by the method used to excite the field magnets: separately-excited and self-excited. In a separately excited machine the field coils get their current from an outside source such as a battery. A self-excited machine furnishes the current for the field coils from the armature itself. As has been explained before, the terminal voltage at no load will differ from the terminal voltage at full load. The relation between these two is called the external characteristic. The full load voltage in a separately excited machine will drop as the amount of current, drawn from the machine, is increased; due to two things: increase in voltage drop across the armature resistance, and demagnetization (that is, weakening of the field by shifting of the brushes) It is the back-ampere-turns, the ones setting up a

ANSWER #14. Continued.

field directly opposite to the main field, which weaken the main field. To find the back-ampere-turns multiply the number of turns in the double angle of brush shift (twice the angle of forward shift) by the current in these turns (which is the total armature current divided by the number of paths in the armature. Subtract this value from the ampere-turns in the field windings and the result is the resultant turns tending to send flux through the fields. This characteristic of a generator is called its "voltage regulation" and is stated in per cent. By regulation is meant a change which takes place automatically when the load change. The ratio of the amount of change in volts, to the no load terminal voltage of the generator is the per cent regulation. If the regulation is small, the separately excited machine is better suited for most purposes. Any change that is made by varying an auxiliary apparatus, such as a rheostat, is termed "control" This difference between regulation and control is important. The <u>regulation</u> is within the machine; the change takes place automatically with the change of load. <u>Control</u> is accomplished by manipulation of auxiliary apparatus whether the load is changed or not.

QUESTION #15. Why is it essential that all coils in the armature have exactly the same resistance?

ANSWER #15. It is essential that all coils in the armature have exactly the same resistance, so that the resistance through each path will be the same so that each path will carry the same current. This prevents unequal heating of the armature and unequal armature reactio and mechanical stress.

QUESTION #16. The speed of a 6 pole 6 path generator is 250 RPM when delivering 500 amperes at 120 volts. The flux per pole is 6,000,000 lines. How many active conductors are there on the armature?

ANSWER #16. Formula:

$$E = \frac{\Phi \times AC \times RPM \times Po}{10^8 \times 60 \times Pa}$$

$$\therefore \quad AC = \frac{E \times 10^8 \times 60 \times Pa}{\Phi \times RPM \times Po}$$

Substituting:

$$AC = \frac{\overset{24}{\cancel{120}} \times \overset{10}{\cancel{10}}^8 \times \overset{2}{\cancel{60}} \times \cancel{6}}{\cancel{6}\cdot\cancel{10}^{\cancel{6}} \times \cancel{250} \times \cancel{6}} = \underline{\text{480 active conductors. Ans.}}$$

QUESTION #17. Draw simple sketch of series, shunt and compound wound generators with voltage control.

ANSWER #17. For sketches see end of seventh week's log work.

QUESTION #18. Explain characteristics and use of each.

ANSWER #18. See next sheet.

ANSWER #18. Continued.

Self excited generators are divided into three classes: Series wound, shunt wound, and compound wound. In a series wound generator, the field coils are placed in series with the line supplied by the generator. The current that flows through the line thus flows through the field coils. If a series generator is not delivering current there is no current in the field coils, so the poles of the generator are made of steel, which will hold some of its magnetism, producing enough lines of force to induce a small emf, which will force enough current through the series field coils (and the line) to produce more lines, which produce more emf, and more lines, etc. The voltage will rise as the load increases, and the current in the field coils will also continue to rise until the steel pole pieces and the frame become saturated, when it becomes exceedingly difficult to set up more lines of force, therefore there is a definite limit to the amount of emf which can be economically induced. The load voltage increases until the saturation point is reached, when it commences to drop slightly altho the terminal voltage will increase slightly. Series wound generators are used whereever a constant-current is desired. They are for this reason called "constant-current" machines, not because they will automatically deliver a constant current but because they are used on constant current lines, because it is very easy to control the current by means of a rheostat shunted across th series field. Series wound generators were formerly used on arc lighting circuits but since they have gone out of date, they are sometimes used now on series tungsten lamp lighting circuits. If one of th lamps burned out the external resistance would be decreased. If the resistance of the rheostat is then decreased slightly more current is shunted around the series field . This results in a smaller generated voltage there mainting the current constant.

In a shunt wound generator, the field coils are placed in parallel with the external circuit, and across the armature. They are composed of many turns of fin wire having a high resistance, so that a small percentage of the current drawn from the machine will flow through the field coils and the main portion of the current will flow through the external circuit, since the current used by the shunt field coils, is not utilized in the external circuit. The voltage builds up the same as in a series wound generator, until it reaches a definite limit set by the resistance of the field coils, and by the saturation point of the pole pieces and frame. Three factors tend to cause the voltage to drop as the load increases. The are: armature resistance drop, armature reaction,and decrease in field current due to the drop caused by the first two factors, which causes decrease in the strength of the magnetic field, which still further decreases the terminal voltage. Shunt wound generators are not usually used where close voltage regulation is desired due to difficulty in control.

ANSWER #18. Continued.

A compound wound generator is a combination of both the series wound and the shunt wound generators. There are two sets of coils. One set is shunted across the line, the other is in series with the line Compound wound generators are divided into two classes: Long-shunt and short-shunt, depending on whether the shunt winding is across the armature or across the armature and the series windings. At no load the same current flows through both the series and the shunt windings. As a current is drawn from the machine it must also flow through the series windings. The number of series turns is regulated so that no matter what current flows through them, it will strengthen the field just enough to compensate for the armature resistance drop, and for the increase in armature reaction, if the machine has no commutating poles. In this case the terminal voltage is nearly constant from no load to full load. This is called a flat-compounded machine. If the load is at any distance from the machine, there will be a line drop to consider, so if a constant voltage is desire more series turns must be added to strengthen the field enough to produce enough additional emf to compensate for the line drop. In this case the generator is over-compounded. The percentage of over-compounding varies from 5 to 15 percent. Some machines are supplied with a rheostat shunted across the series field windings so that their value can be varied and thus the compounding adjusted. Compound wound generators are used wherever a constant potential is desired.

Shunt wound generators can be operated in parallel provided the noload voltage of each is the same and that the external characteristic-s are the same.

Compound wound generators, which are under-compounded can be operated in parallel just like shunt wound generators, because they have drooping characteristics. If they are over-compounded, they must have the same over-compounding, the resistances of the series field must be inversely proportional to the capacities of the machines, and an equalizer must be connected with the series fields.

Series wound machines are never operated in parallel, and in fact are seldom used at all any more.

Series wound machines are wound with few turns of heavy wire, since the turns must carry the whole of the current flowing in the external circuit, while shunt wound machines are wound with many turns of fine wire, having a high resistance, so that the small current naturally ensuing will produce a flux density high enough to produce the necessary emf.

B-QUESTION #1. Explain in detail and by sketch the fundamental principle of a motor.

ANSWER #1. For sketch see end of seventh week's work. A circular magnetic field is set up around a wire carrying current. Such a wire when placed in a uniform magnetic field has its flux density increased on one side of the wire and decreased on the other side. If the wire has a current flowing in, it will have a clockwise magnetic flux about it. If the wire is placed in a uniform left-to-right magnetic field, it will have two fields flowing in the same direction above it and in opposite directions below it, resulting in a bunching of the lines above it and thinning of the lines below it. These lines of force act like stretched rubber bands; that is, they have a tendency to straighten out and exert a downward push on the wire. This is the fundamental principle of a motor.

QUESTION #2. State left hand rule for motors.

ANSWER #2. The left hand rule for motors is as follows: Extend the thumb and first two fingers of the left hand at right angles to one another. If the forefinger points in the direction of the magnetic lines of force and the middle finger in the direction of the current in the wire, the thumb will point in the direction of the force on the wire.

QUESTION #3. How compute force on a current-carrying wire placed in a magnetic field.

ANSWER #3. If a loop is placed in a uniform left-to-right magnetic field, and the current is flowing in the left side of the loop and out the right side, the lines of force will bunch above the left side and below the right side thus causing a force downward on the left side and upward on the right side, causing the entire loop to turn. This force can be computed by multiplying the force on both wires by the distance of each wire from the axis of revolution; that is, the radius of the resulting circle produced by the turning of the loop. The force on each wire is computed by this formula:

$$F = \frac{22.5\ BlI}{10^8}$$

Where:
F = force on wire in pounds.
I = current in wire in amperes.
B = flux density in air in gausses.
l = length of wire in centimeters.

QUESTION #4. What force would be exerted on a loop of wire 80 CM. long carrying a current of 80 amperes if it was placed in a field of 20,000 gausses?

ANSWER #4. Formula: $F = \frac{22.5\ BlI}{10^8}$

Substituting: $F = \frac{\overset{.9}{\cancel{22.5}} \times 2\cancel{0000} \times \cancel{40} \times 8\cancel{0}}{\underset{4}{\cancel{100000000}}}$ = 14.4 lbs = force on 1 wire.

2 x 14.4 or 28.8 lbs. Ans.

QUESTION #5. What is meant by torque?

ANSWER #5. By torque is meant the tendency to revolve. It is measured in pound feet, since to compute the torque we multiply the force on the wire times the length of the arm in feet. The arm is the distance of the wire from the point around which the wire tends to revolve Torque is expressed as the number of pounds at the end of an arm of 1 foot. Thus if the armature of a motor is connected to a pulley which is 12 inches in diameter twice the force must be exerted on the rim of the pulley, since the ratio of 24 inches (the diameter of a pulley having a 1 foot arm or radius) to 12 inches is 2 to 1.

QUESTION #6. The width of loop in Question #4, is 6 inches. What is the torque?

ANSWER #6. The torque is the force on both wires, in pounds, times the distance of each wire from the point around which they tend to revolve.

The total force is 28.8 pounds. The distance is half the width of the loop. Since the loop is 6 inches wide the arm is 3 inchs. To change this to feet, we divide by twelve:

$$\text{Torque} = \frac{\overset{7.2}{\cancel{28.8}} \times \cancel{3}}{\underset{4}{\cancel{12}}} = \underline{7.2 \text{ pound feet. Ans.}}$$

QUESTION #7. The force of a wire 60 CM. long is 4.5 pounds when 15 amperes flow thru it. How strong is the magnetic field

ANSWER #7. Formula: $F = \frac{22.5\ BlI}{10^8}$

Transposing, $B = \frac{F \times 10^8}{l \times I \times 22.5}$

Substituting:

$$B = \frac{\overset{.1}{\overset{\cancel{.3}}{4.\cancel{5}}} \times \overset{200000}{\overset{\cancel{3000000}}{\cancel{100000000}}}}{\underset{\cancel{2}}{\cancel{60}} \times \cancel{15} \times \underset{.9}{\cancel{22.5}}} = \underline{22222.2 \text{ gausses.}}$$

Ans.

QUESTION #8. The force of a wire 90 CM. long is 4 pounds when placed in a magnetic field of 25,000 gausses. What current is flowing in the wire?

ANSWER #8. Formula: $F = \frac{22.5\ BlI}{10^8}$

$$\text{Transposing, } I = \frac{F \times 10^8}{22.5\ Bl} = \frac{4 \times \overset{16}{\cancel{100000000}}}{\underset{.9}{\cancel{22.5}} \times \cancel{25000} \times \cancel{90}} = \frac{64}{8.1}$$

$$= \underline{7.901 \text{ amperes. Ans.}}$$

QUESTION #9. What is meant by the generation effect of a motor? Explain fully.

ANSWER #9. As explained in Question #1, if a current is sent through a loop of wire placed in a uniform magnetic field, the loop will tend to revolve. Since it is revolving in a magnetic field, the wires of the loop are cutting magnetic lines. In the study of generators we were told that a conductor cutting lines of force will have an emf induced in it proportional to the rate of cutting. Therefore, this loop of wire in a motor, will be cutting lines of force, and an emf will be set up in the wire in a direction opposite to the emf which is forcing a current through the wire, the magnetic field of which causes the motor to turn. This opposite emf induced, is called the counter-electro-motive force. It is thus evident that there are two sources of emf in the windings of a motor that is running: first, the emf impressed from an outside source, and, second, the emf induced in the windings by cutting lines of force. Since they are in opposite directions, therefore the current through the winding must be proportional to their difference.

To find the current through a motor armature:

Find the effective emf, by subtracting the counter-emf from the impressed emf: $E_{eff} = E_x - E_c$

Divide the effective emf by the armature resistance to find the current flowing through the armature.

This may be combined into one formula:

$$I = \frac{E_{eff}}{R} = \frac{E_x - E_c}{R}$$

Where: I = current through armature.
E_{eff} = Effective emf.
E_x = Impressed emf.
E_c = Counter emf.

QUESTION #10. What would be the counter emf developed by a motor armature if it's resistance were .37 ohm? Current .04 impressed voltage 120.

ANSWER #10. $E_d = IR = .04 \times .37 = .0148$ volts.

$E_c = Ex - E_d = 120 - .0148 =$ 119.9852 volts -cemf. Ans.

QUESTION #11. The impressed voltage across a motor armature is 110 volts; current is 22 amperes; counter emf is 107 volts. What is the resistance of the armature?

ANSWER #11. $E_{eff} = E_x - E_c = 110 - 107 = 3$ volts.

$$R = \frac{E}{I} = \frac{3}{22} = .13636 \text{ ohms. Ans}$$

QUESTION #12. Explain in detail and by sketch armature reaction, how remedied.

ANSWER #12. Any wire carrying a current will have a magnetic field set up about it. If several wires are wound in the form of a loop, the loop takes the same form as a bar magnet; that is, the lines of force will leave at one end of the loop and enter at the other end. If the core of the loop is made of a magnetic material, the lines of force will be intensified. If this loop is placed in a magnetic field, so that the magnetic field of the loop and core is at right angles to the magnetic field, opposition will result and the magnetic field will be distorted. Such is the action within a motor. The turns of wire on the armature of magnetic material is the loop and core, and the field between the pole pieces of the motor, is the magnetic field. As explained before in generators the induced emf is in such a direction, that the magnetic field set up in the generator armature is such that the lines of force in the field will be concentrated at the top of one pole and at the bottom of the other, thus shifting the zero axis; that is, the point at which a conductor would cut no lines of force, thus necessitating a forward lead of the brushes to prevent sparking. In a motor it is just the opposite. Since the direction of current through the armature windings, is opposite in a motor, than in a generator, it is evident that, for the same direction of rotation, the field would be distorted in just the opposite direction, so, in order to get the conductor or conductors which are shorted by the brushes, out of a position where they are cutting lines of force and into a position where they are cutting no lines of force, it is necessary to give the brushes a backward lead; that is, shift them back of the neutral axis. This is done to prevent sparking which would result if the coil was cutting lines of force at the instant of short circuit. The disadvantage of shifting the brushes to prevent sparking at the brushes, is that when the brushes are shifted, demagnetization will result, and the field weakened as a result, so, in order to eliminate this demagnetization, and still prevent the sparking at the brushes, commutating poles are used. Commutating poles are small poles set in the space between the main poles. In a motor they have the same polarity of the pole ahead, that is, they are like a tail on the main pole, so that the short circuited coil will be in the flux of the pole ahead. By being separate from the pole ahead, it has the advantage that the winding on it can be put in series with the armature. The flux produced by it is nearly proportional to the armature current, thus, instead of getting a weaker commutating flux when the armature current increases, we get a stronger flux which sets up a greater cemf in the short circuited coil. This is the condition which makes commutating poles produce sparkless commutation without shifting the brushes. In motors compensating field windings are also used. They prevent any shift of the field by aramture cross ampere turns, thus they are equal and opposite to the armature cross armature-turns.

QUESTION #13. Explain characteristics and use of series, shunt and compound wound motors.

ANSWER #13. In a shunt wound motor the field is shunted around the armature. The speed of a shunt motor is classified by its characteristic; that is, the relation between the speed to the armature current. The speed load characteristic of a shunt motor is quite simila to the voltage characteristic of a shunt generator, altho the speed of a shunt motor does not fall off quite as rapidly as the voltage of a shunt generator A shunt motor is known as a "constant speed" machine altho the speed falls slightly. It has a low startin torque. It races when the field is broken, making necessary a no-field release connected in series with the field. The speed is controlled by varying the field strength. This can be explained by supposing field was a certain strength and that the motor was turning at a certain speed. If we had a resistor in series with the field, and we cut in some of the resistance. This would cause a decrease of current flowing through the coils, which would cause a weakening of the field. Due to the weakened field, the cemf set up in the armature windings would be less. This would allow more current to flow in the armature windings. This increase of current in the armature windings is much greater in proportion than the decrease in the strength of the magnetic field. Thus the torque of the motor is greater, and the armature speeds up until a balance is reached again.

In a series wound motor the field is in series with the armature. The speed decreases with an increase in the load, altho it has a large torque at slow speeds, thus a large starting torque. The motor races when it has no load, making it necessary to keep the load permanently attached. To explain the racing of a series motor when there is no load, we consider the behavior of the field. Since there is no opposing torque due to no load, the speed tends to increase until the cemf is equal to the impressed voltage. But the increasing cemf weakens the current in the armature and in the field, thus making necessary a greater speed to increase the cemf. The field keeps getting weaker and the speed greater and keeps on until the terrific centrifugal force causes the armature windings to fly loose from the armature. The characteristic is decidedly a falling one. The no load speed is too high to be plotted, falling rapidly as the load increases, then settling down gradually to a constant speed as the full load point is reached. Since a doubling of armature current produces a doubling of field current the torque is nearly quadrupled. In a shunt motor a doubling of current will double only the armature current, the field current remaining the same,therefore the torque is only doubled. From this it is evident that in a shunt motor the torque varies directly as the current, while in a series motor it varies directly as the square of the current. Thus a series motor is used where a fast starting, large starting torque is desired.

ANSWER #13. Continued.

A compound wound motor is one with two fields; one in series with the armature and one in shunt with the armature. If a constant speed under widely vary-loads is desired a differential compound wound motor is used. In a differential wound compound motor the series field is bucking the shunt field; that is, th current in the series field is flowing around the pole pieces in an opposite direction to the current in the shunt field. Since the series coils are in series with the armature, the field strength due to these series coils increases with the load, and, acting against the shunt coils, weakens the field enough to permit more current to flow in the armature windings. Extra current will produce extra torque since torque depends on current in the armature windings. This extra torque will overcome the extra drag on the pulley, thus the speed is kept constant. The shunt field in a differential compound wound motor is much larger than the series field, tho. The characteristic is an exaggerated shunt characteristi that is; it has a low starting torque but the speed regulation is exceptionally good.

A cumulative compound wound motor is one in which th series coils are wound so that they aid the shunt coils; that is, the current flows in the same direction around the pole pieces in both the shunt and series windings. This is because a series motor has a greater starting torque than a shunt motor, altho the shunt coils will prevent the motor from racing on no load. This kind of compound motor has the characteristics of a series motor; the speed decreasing with the load. To prevent this the series field may be shorted out after starting. In this case the motor starts as a series motor and runs as a shunt.

Series motors are used where a high starting torque is desired. Shunt motors are used where a constant speed is desired. Differential compound motors are used where constant speed at all loads within certai limits is desired. Cumulative compound motors are used where large starting torque, with a constant speed at constant load is desired.

QUESTION #14. Draw diagram of a shunt motor connected to starting box showing all external connections, shunt field windings and no load and over load releases.

ANSWER #14. For sketch, see end of seventh week's log work.

QUESTION #15. Why are no load and overload releases necessary?

ANSWER #15. A no load release is used in a series motor so that, the circuit (the line) is opened if the load is suddenly thrown off the motor, to prevent the motor attaining such a speed that the centrifugal force will tear the windings out of the armature and wreck the machine. An overload release is used to prevent to great a load from being put on a motor such that the speed is slowed down so much that the armature current becomes excessive.

QUESTION #16. How compute the efficiency of a motor?

ANSWER #16. The efficiency of a motor is the relation of the output to the input. The terms compared must be like units. If the input is measured in watts and the output in horsepower, the watts must be changed to horsepower or the horsepower to watts. The input is measured with an ammeter and a voltmeter, the watts input being the product of the amperes input times the input pressure in volts. The output is measured by means of the Prony Brake. This system is described in Fifth Week log work. Of courses the losses within the machine must be considered. Therefore the efficiency is equal to the output divided by the input, the input minus losses, divided by the input, or the output divided by the output plus the losses. This may be stated in an equation:

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{input - losses}}{\text{input}} = \frac{\text{output}}{\text{output + losses}}$$

QUESTION #17. Explain motor losses.

ANSWER #17. There are several losses in an electric motor due to forcing an electric current through the windings of the armature and field. These losses are: the copper loss in the field, the eddy-current loss in core, the hysteresis loss in core, loss due to windage , friction, etc., and a variable loss due to the copper loss in the armature. The constant loss is equal to the power input to run idle as motor minus the corresponding armature copper loss.

The copper loss is equal to the square of the current times the resistance. Thus in the field it is the square of the current in the field times the resistance of the field windings. In the armature it is the square of the armature current times the resistance in the armature windings.

The hysteresis loss in the armature core is due to the change in direction of magnetization. The field coils have no hysterisis loss because they are always magnetized in the same direction.

The eddy current loss is due to the iron or steel of the armature cutting lines of force on account of iron and steel being conductors to some extent. They flow around and around in the core and cause heating besides that, in order to set up these currents it is necessary to expend power and since these currents cannot be used they are a total loss. They are prevented by laminating the armature core and insulating them from each other. The eddy current loss is proportional to the square of the speed, to the square of the flux density, and to the square of the thickness of the laminations.

The other losses are the mechanical losses which are due to brush friction, bearing friction and the air friction. The sum of these are the mechanical losses

QUESTION #18. Explain motor regulation and control.

ANSWER #18. Motor regulation has been explained in the answer to Question #13 in the explanation of the characteristics of series, shunt, and compound wound motors, but it is important to note that motor regulation concerns itself with changes in speed inherent in the machine. Speed control signifies deliberate external adjustment to attain various desired speeds. The speed control of a shunt motor is controlled by an increase or decrease of voltage across the armature which will respectively increase or decrease the speed provided the voltage across the field remains constant. It is also controlled by an increase or decrease of field flux which will respectively decrease or increase the speed. A series motor is controlled by means of the load on the machine and great care must be exercised never to start a series motor with no load.

QUESTION #19. The drum wound armature of a motor is 30 CM. long and 15 CM in diameter and has 300 active conductors. Average flux density is 20,000 gausses. If current in each conductor is 20 amperes what would be the force exerted on 4 inch pulley?

ANSWER #19. Formula for finding the force exerted by this motor on a 4 in-ch pulley:

$$\frac{22.5 \text{ x } B \text{ x } 1 \text{ x } I \text{ x } AC \text{ x } Rs \text{ x } .3937 \text{ x } 24}{10^8 \text{ x } 2 \text{ x } 12 \text{ x } 4} =$$

$$\frac{22.5 \text{ x } \cancel{20000} \text{ x } 3\cancel{0} \text{ x } \cancel{20} \text{ x } 3\cancel{00} \text{ x } 15 \text{ x } .3937 \text{ x } \overset{2}{\cancel{24}}}{\cancel{100000000} \text{ x } \cancel{2} \text{ x } \cancel{12} \text{ x } \cancel{4}}$$

= 1195.86375 pounds. Ans.

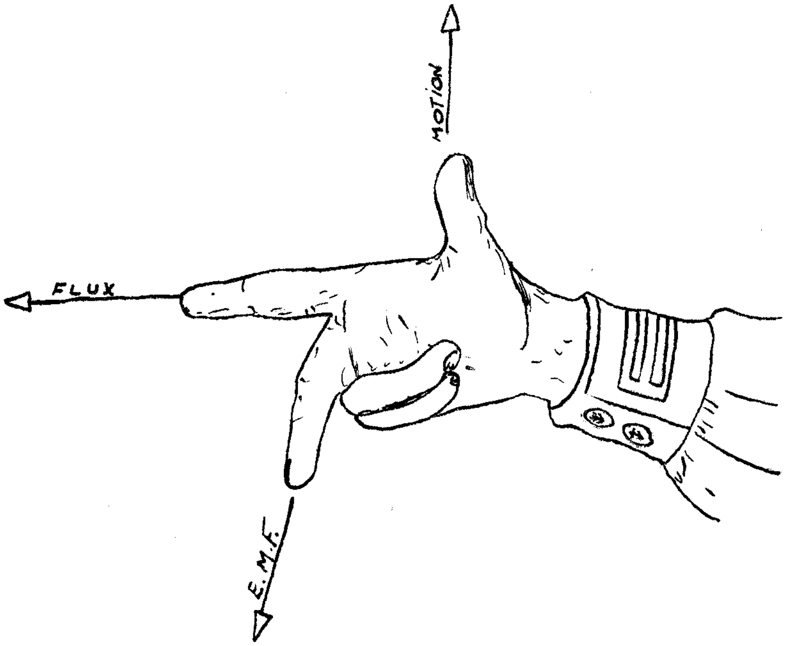
QUESTION #20. Draw TU Transmitter.

ANSWER #20. For diagram see end of seventh week's log work.

QUESTION #21. Draw three step automatic starter and give explanation.

ANSWER #21. For diagram and explanation see end of seventh week's log work.

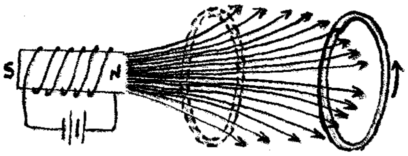
QUESTION A-3.



Right Hand Rule for Generators:

Extend the Thumb, Forefinger and Middle Finger of the right hand at right angles to one another. Let the Thumb point in the direction of the motion, the forefinger in the direction of the magnetic flux, then the Middle finger will be pointing in the direction of the induced electromotive force.

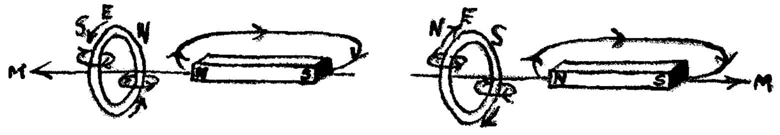
QUESTION A-5



The diagram shows how a coil of wire may have an emf induced in it by moving it without rotation in a non-uniform magnetic field. In the position of the coil shown by the solid lines, the number of lines of force through it is less than in the dotted position, consequently an emf is induced during a movement from one position to the other. The direction of the current in the coil is found by the right hand rule, and is such that if the ring be viewed from the side toward the North pole as it is being moved away from this pole the induced current flows around it clockwise, producing a South pole on this face, with resulting attraction for the North pole from which it is receding.

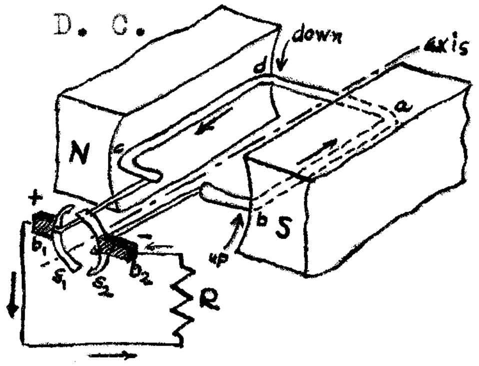
QUESTION A-5.

Illustrating Lenz's Law.



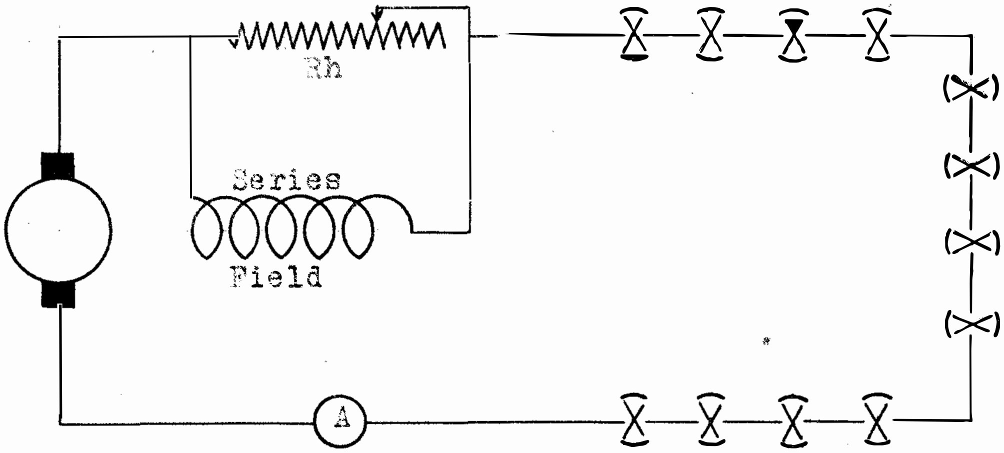
The diagram shows a closed conducting loop and a permanent bar magnet. Assume that the magnet is moving toward the loop, as shown by the arrow M. An emf will be induced in the loop in the direction shown by the arrow E. The resulting induced current will set up a magnetic field acting in the direction shown by the circles around the loop. It will be seen that the N polear face of the loop is toward the N pole of the bar magnet and therefore that a repulsion exists between the loop and the magnet and their relative motion is thus opposed. If the direction of motion of the magnet is reversed all effects are reversed. The face of the loop toward the retreating magnet then becomes S and an attraction exists which opposes their separation.

QUESTION #A-6. D. C. GENERATOR.

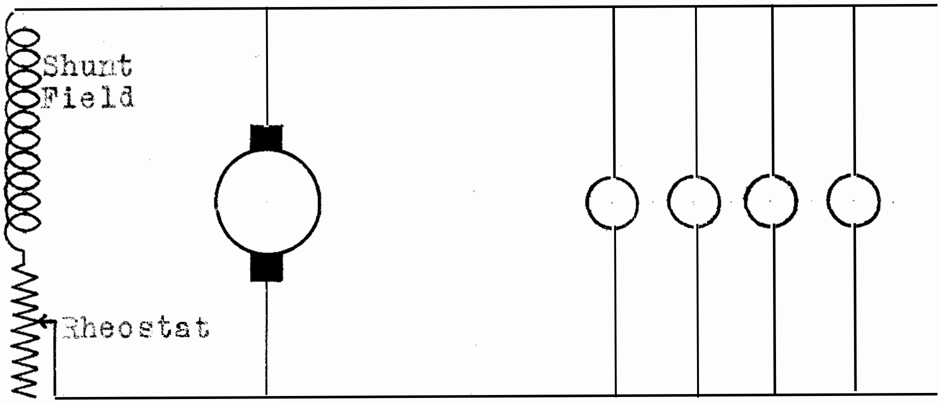


The commutator is simply one of the collector rings cut into halves, s1 and s2, which are insulated from each other and from the shaft, but securely connected to the latter. The halves are arranged on the shaft so that the line drawn between them is at right angles to the plane of the loop. The loop is supposed to be revolving in a counter-clockwise direction. At the instant shown in the diagram, the emfs induced in the loop are acting in the directions shown by the arrows; for example, the direction in side dc towards the reader, and out at segment s1 to brush b1. This is called the positive direction, and brush b1 is therefore the Positive Terminal of the machine The direction in side ab is away from the reader; that is, in at brush b2 and through the segment s2 to side ab. Brush b2 is the Negative Terminal. As the loop revolves, whichever side of the loop is moving down past N pole has an outward emf induced. Contact with this side is made with brush b1. Hence the brush b1 is always and b2 negative except at the instant when no emf is being induced. This point is the neutral position and is point where the brushes are bridging the segments and shorting the loop.

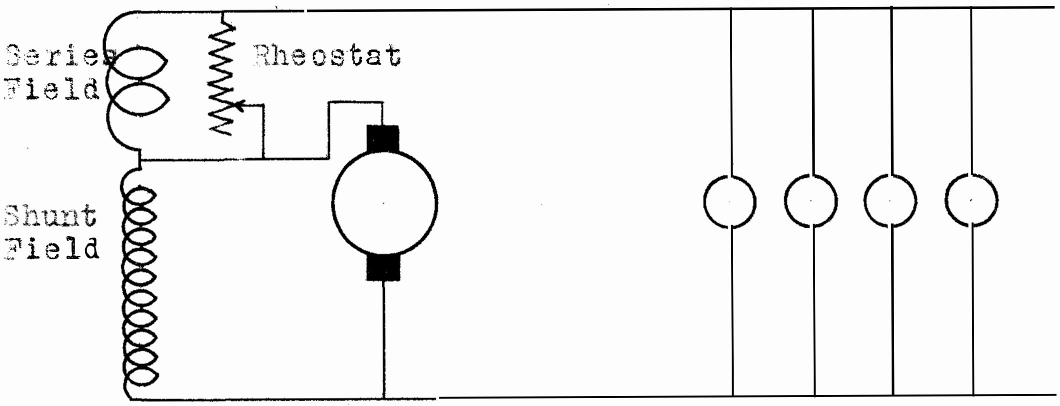
QUESTION A-17.



Series wound generator. The strength of the series field is controlled by the amount of resistance in the shunt Rh.

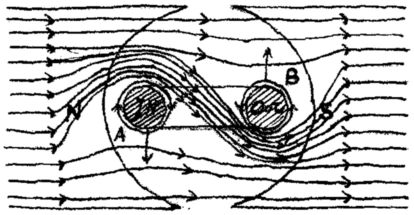


Shunt wound generator. The voltage of a shunt generator can be controlled by a resistance in series with the shunt field.



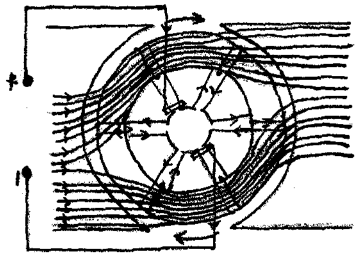
Compound wound generator. The voltage of a compound generator can be controlled by a resistance placed around the series field.

QUESTION B-1.



Illustrating the fundamental principle of a motor. The sketch shows a cross-section of single loop carrying a current in a magnetic field. The current is flowing in at A and out at B, as marked, and the flux is strengthened above A and below B. Thus there is a force pushing down on A and up on B, tending to cause the loop to rotate in a counter clockwise direction as marked.

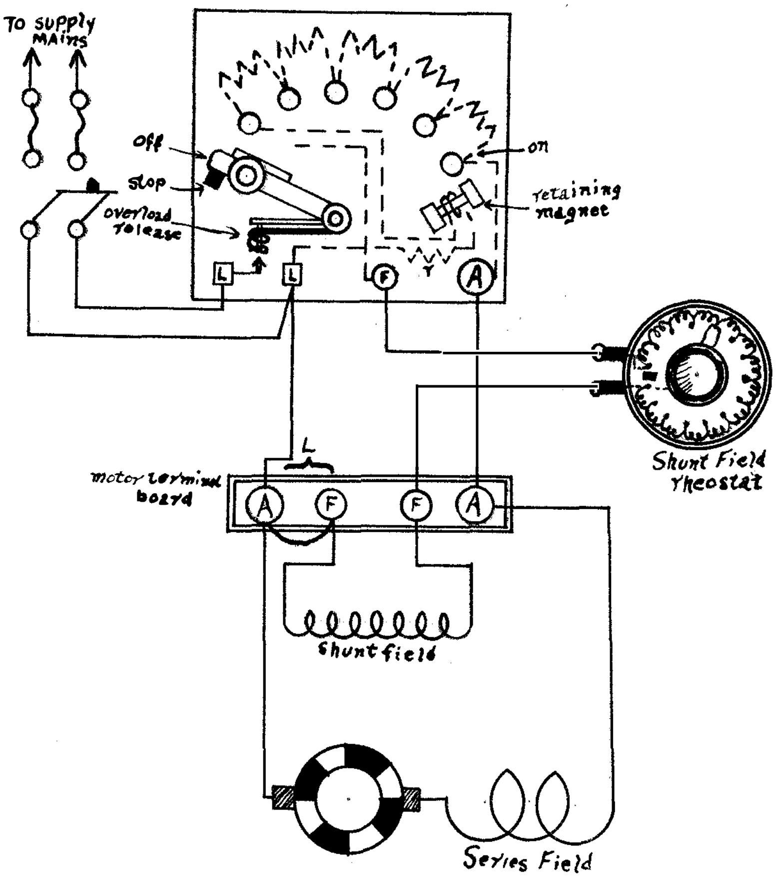
QUESTION B-12.



The current flowing in the armature windings sets up a magnetic field which opposes the main field and causes a distortion. This distortion in a motor is just the opposite to that in a generator, causing all the lines to bunch at the approaching pole tips in a motor, instead of at the trailing pole tips as in a generator. This necessitates a backward lead of the brushes in a motor so that the coils which are shorted out by the brushes will not be cutting lines of force at the time, thus preventing sparking at the brushes.

QUESTION B-14.

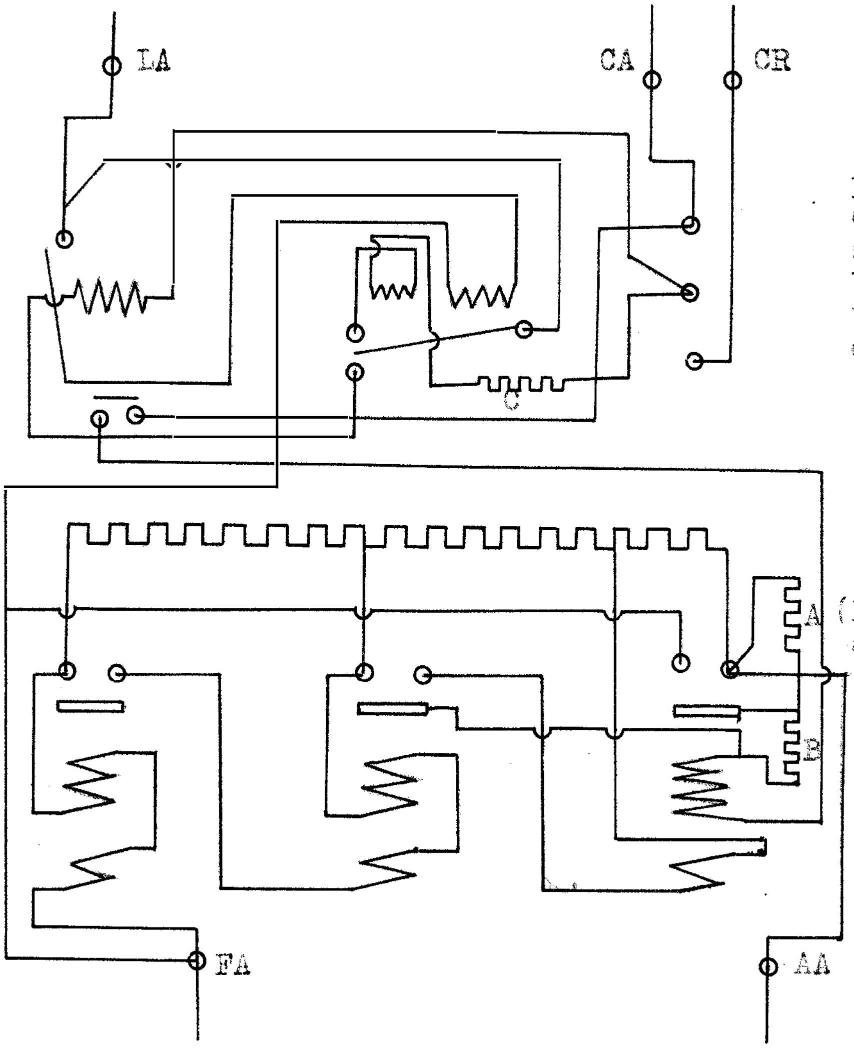
Circuit diagram of a starting box and its connections to Line and Motor.



This sketch shows the circuits included in one type of starting box used for shunt and compound wound motors, together with the connections to a compound motor and supply mains. Care must be taken to make the proper connections. The lead from the terminal F on the starting box must run to the F terminal on the board of the motor which is not connected to the armature by a jumper. The lever is shown in the off position. It will be noted that the shunt field circuit is not closed until the lever is on the first contact, and also that the retaining magnet winding, which, i series with a limiting resistance r, is also across the supply mains. The purpose of the retaining magnet is to hold the lever in the running position as long as the supply mains are alive.

QUESTION B-21.

Diagram of a D.C. Automatic Starter for use with U.S.Navy Radio Sets, 5KW, 120 or 230 V., 10 KW 230 V., with overload.



(For fine adjustmnt)

Note:-
Ov.Ld.
Coils to
be conn.
to assist
each other

Connections to be of Und. Wire.

After the starter is properly connected to the line and the motor, closing the local or remote control switch actuates the upper left magnet which closes the switch to the generator and to the field, also to the armature since it is in shunt, but all of the starting resistance is cut in. The current flowing through the magnet coils lower left actuates them in opposite polarities, the smaller keeps the clapper from going up too soon, that is, before a field has been built up, then the larger prevails, the clapper goes up, completes the circuit to the second clapper, which acts just the same, except that when it goes up and makes connection, the first clapper drops. Also when the second one goes up it completes the circuit to the third. Altho the coils in the third clapper are actuated, the clapper can not go up until the current in the smaller one (thus in the armature) has dropped sufficiently to permit the larger one to prevail. When the third one goes up, the second one drops, and a small resistor is connected in series with the retaining magnet so that it will not heat. If for any reason the load gets too heavy, thus the current too high, the overload release will draw the upper center clapper up, thus shorting the upper left magnet, which opens the circuit to the line.