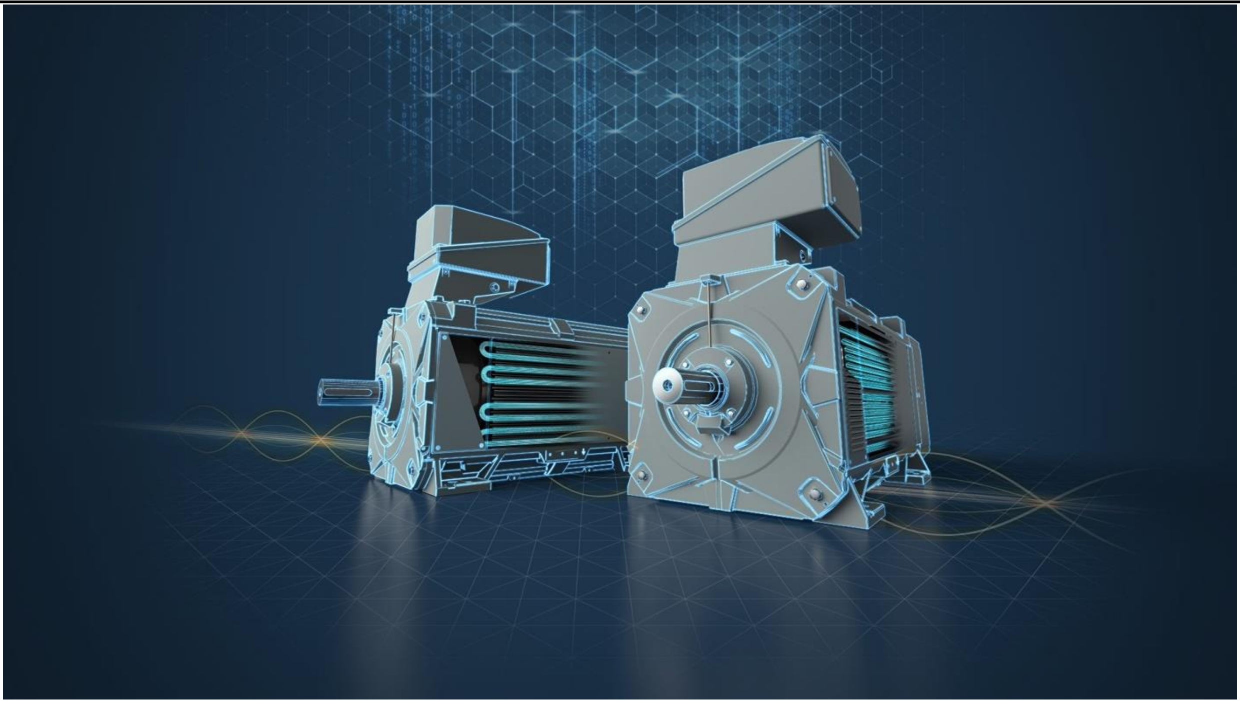

MODULE 4

I. **Title : DC MOTORS**

II. **Topics** :

Lesson 1 – Introduction to Direct Current Motor & Construction
Lesson 2 – Types of DC Motors, Connection, Operation and Reversing
Lesson 3 – Generating Factors of DC Motors
Lesson 4 – Armature Windings

III. **Time Frame** : 20 hours

IV. **Introduction** :

When a voltage is applied to a motor, current will flow through the field winding, establishing a magnetic field. Current will also flow through the armature winding, from the negative brush to the positive brush as shown in Figure 5. Since the armature is a current-carrying conductor in a magnetic field, the conductor has a force exerted on it, tending to move it at right angles to that field.

V. **Objectives : Upon completion of this course you will be able to…**

- Define Direct Current Motor & Construction
- Categorize types of DC Motors, Connection, Operation and Reversing
- Formulate the Generating Factors of DC Motors and Armature Windings

VI. Learning Activities :

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Lesson 1: INTRODUCTION TO DC MOTOR

Using the left-hand rule for current-carrying conductors, you will see that the magnetic field on one side is strengthened at the bottom, while it is weakened on the other side. Using the right- hand rule for motors, we can see that there is a force exerted on the armature which tends to turn the armature in the counter-clockwise direction.

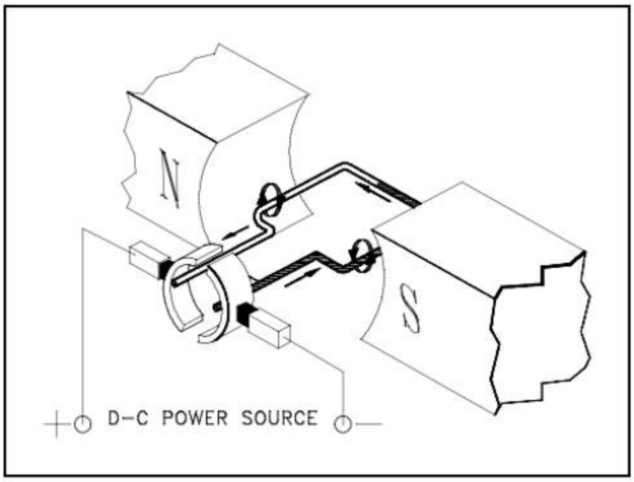
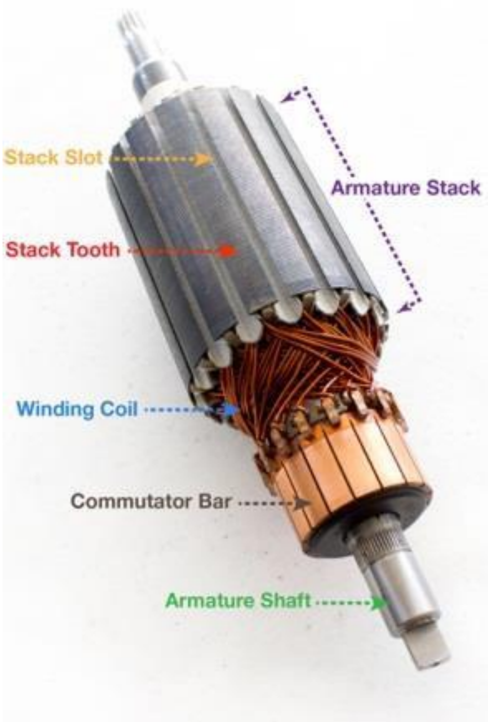


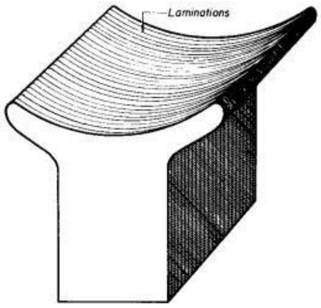
Figure 5 Armature Current in a Basic DC Motor

A DC Motor is a machine which, when supplied with electric current, can be used for such mechanical work as driving pumps, running machine tools, and so on. DC Motors are also widely used in applications that require control of speed. Most trolleys, electric railways, and elevators are driven by DC motors for this reason. They are made in sizes varying from 1/100 hp. to thousands of horsepower.

CONSTRUCTION

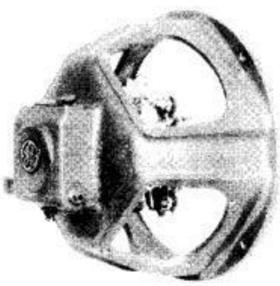
The main parts of the DC motor are the armature, field poles and frame, end plates or brackets, and brush rigging. The armature is the rotating part of the motor and consists of a laminated iron core with slots in which coils of wire are placed. The core is pressed on a steel shaft that also holds the commutator. This latter conducts current from carbon brush to the coils in the slots. The figure below shows an armature with straight slots.

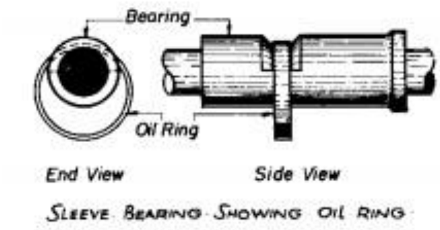




The frame of the DC motor is usually made of cast or wrought iron, generally circular in form and machined so that the field pole can be mounted inside it as shown below. Many motors are also made with laminated iron frame. The field pole is usually fastened inside the frame with screws or bolts, but on some small motors the field poles are cast with the frame. On large motors, the poles are laminated as also shown below and bolted to the frame. The field pole holds the field coils or windings. These consist of coils insulated wire that are taped before being placed on

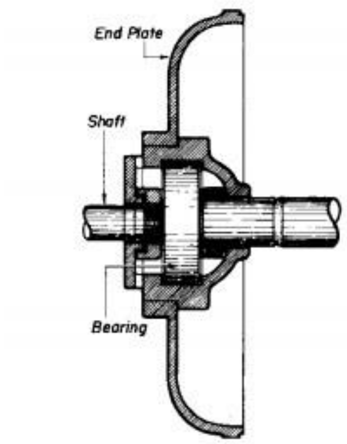
Two end plates, fastened to the frame with bolts, bear the weight of the armature and keep it equidistant from the pole pieces. The end plates contain the bearings in which the shaft of the armature revolves. These may be either (a) sleeve bearings and or (b) ball bearings as shown below.

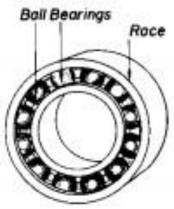




END PLATE

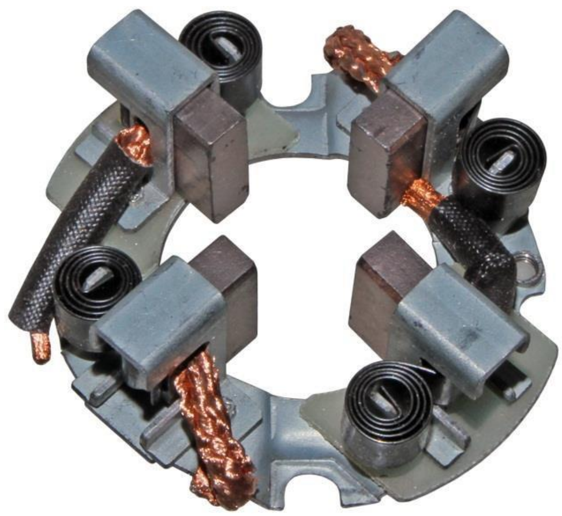
Sleeve bearing Sleeve bearing assembled on an end Plates





- **Ball Bearing at right mounted in the end plate.**

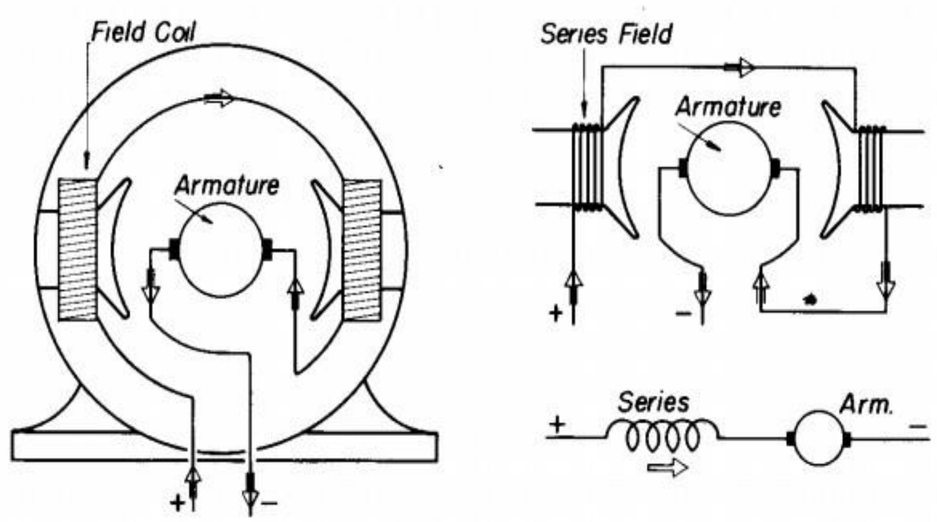
On all DC motors, current must be conducted to the armature winding. This is accomplished by connecting leads from the winding to the commutator, and in turn feeding the commutator with the current. The commutator can be supplied with the current by allowing carbon brushes to ride on it and contact it while it is turning. The brush are held in a stationary position by brush holders, which are generally mounted on the brush rigging. The rigging is usually mounted on the front plate and so constructed that the brush position may be changed. The brush holders on all motors are insulated from the end plate to prevent grounds and to prevent short- circuiting the brushes.



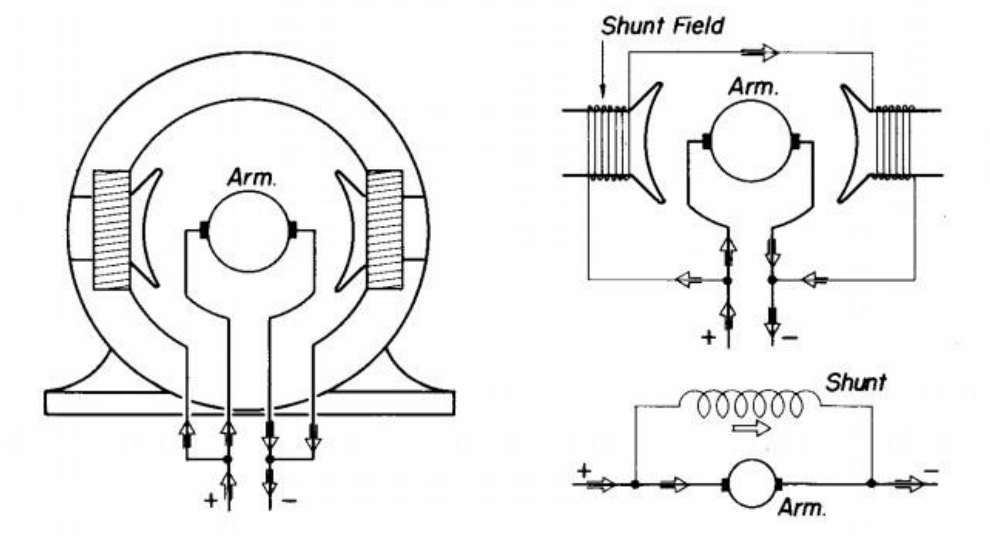
Lesson 2 : TYPES OF DC MOTORS, CONNECTION, OPERATION AND REVERSING

There are 3 types of DC Motors; The series motor, the shunt motor and the compound motor. These types are alike externally. They differ in the construction of the field coils and in the connections between the field coils and the armature.

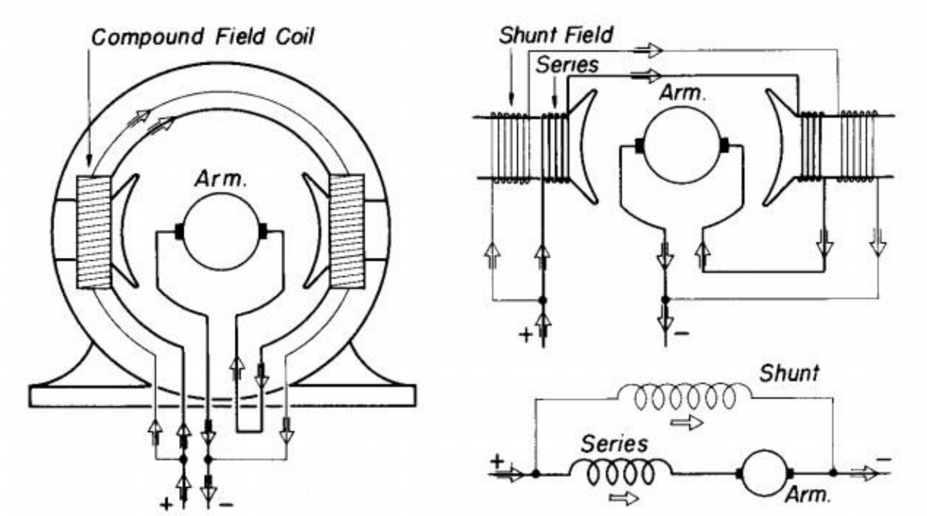
SERIES MOTOR. Contains field coils composed of few turns of heavy wire connected in series with the armature shown below. This motor has a high starting torque and a variable-speed characteristic. The greater the load, the lower the speed.



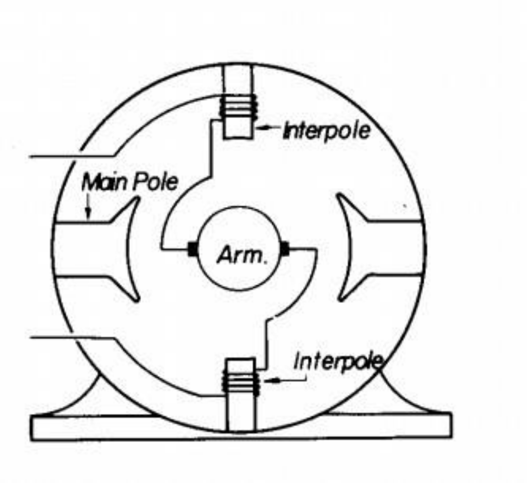
SHUNT MOTOR. Contains a field composed of many turns of fine wires. This is connected in parallel with the armature as shown below. The motor has a medium torque and constant speed characteristic and is used on applications that require constant sped.



COMPOUND MOTOR. In this type of motor, each field coil is a combination of the series and shunt fields and is made in two sections. One section (series field) is connected in series with the armature, and the other section (shunt field) is connected in the shunt circuit. This motor combines the characteristics of the series and the shunt motor.

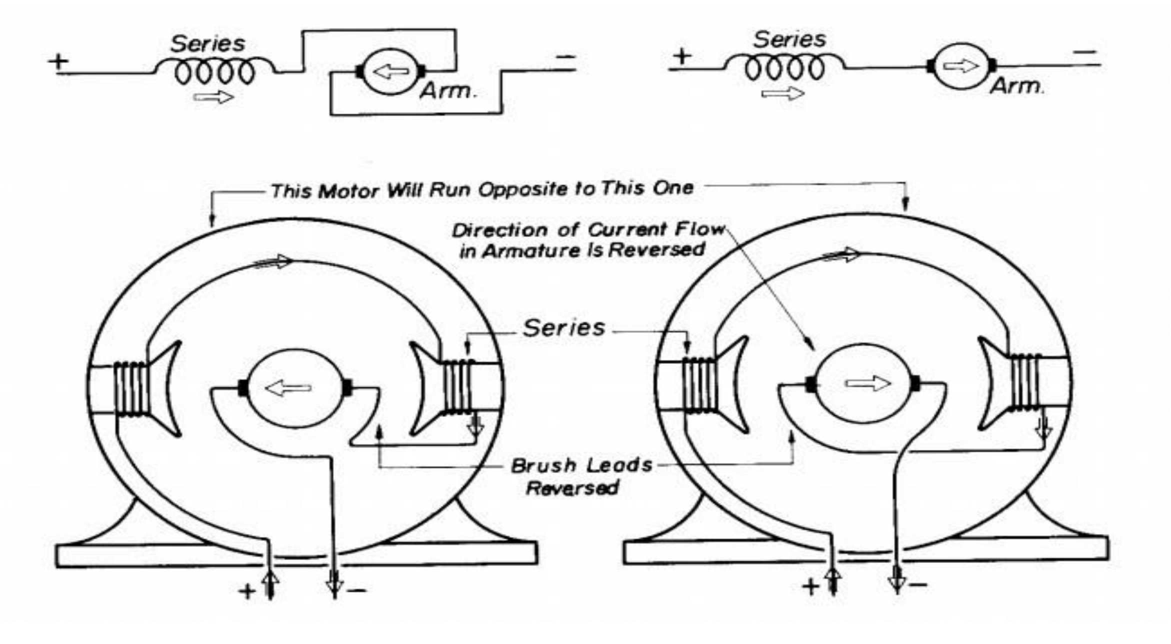


INTERPOLES. Nearly all shunt and compound motors of ½ hp. or more have commutating poles or interpoles located between the main poles. These interpoles have on winding of heavy wire and are connected in series with the armature as shown below. The purpose of the Interpoles is to prevent sparking at the brushes.

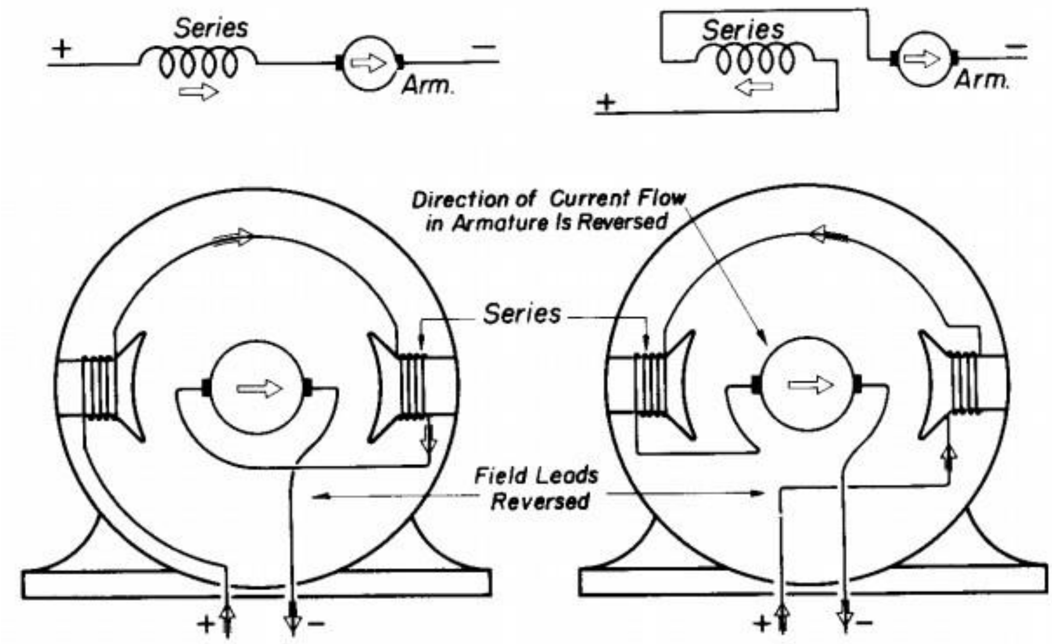


There are usually as many interpoles as main poles, although half as many may be used without causing inefficient operation. Although the interpoles are connected for alternate polarity with respect to the main poles. The polarity of the interpoles depends on the polarity of the main poles and the direction of rotation of the motor.

REVERSING DC MOTORS. Direct Current motors are reversed by changing the direction of current flow through the armature or through the field. In series motors the usual procedure is to reverse the current through the armature.

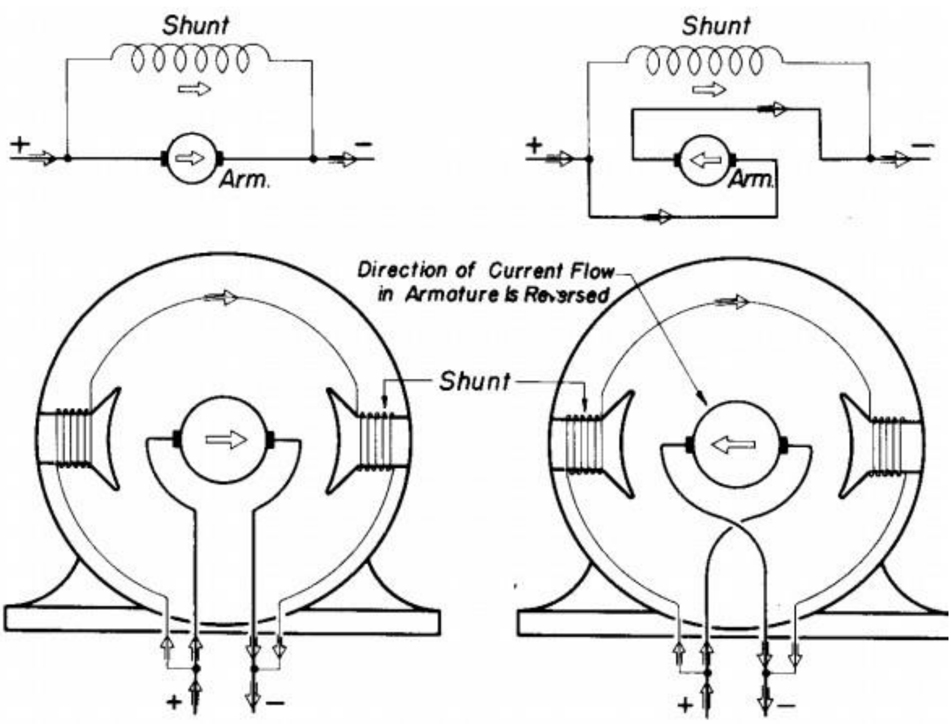


The direction of a two-pole series motor changed by reversing the current flow in the armature.

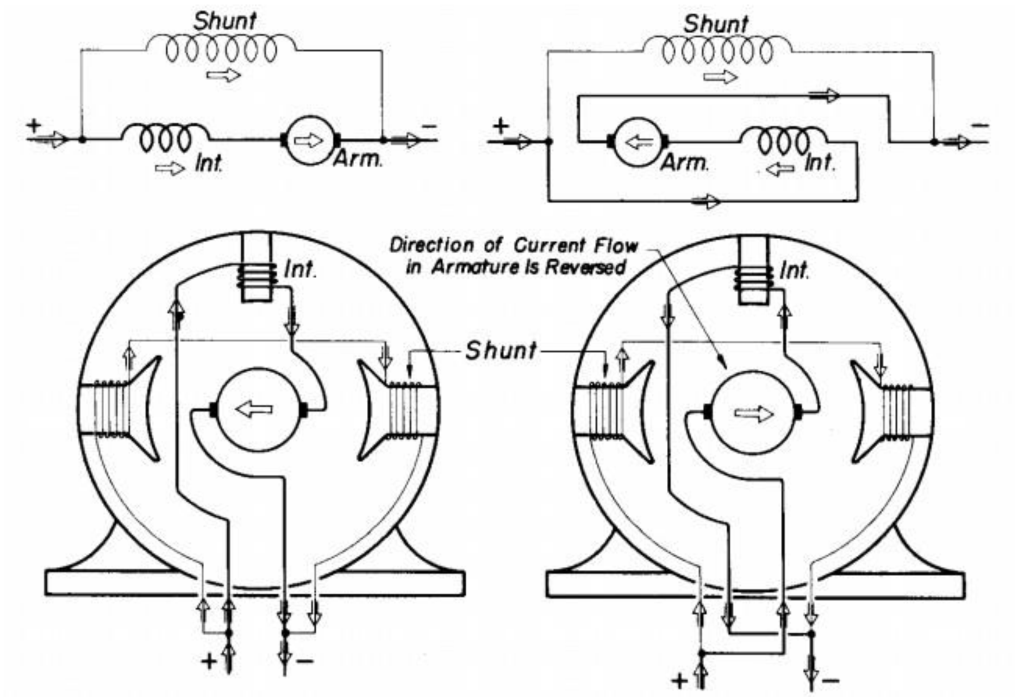


The direction of a two-pole series motor changed by reversing the current flow in the field poles.

A shunt motor has the direction of rotation changed in the same manner as a series motor. The figure below shows a two-pole shunt motor which is reversed by interchanging the armature leads.



To reverse a shunt interpole motor, it is necessary to reverse the current flow through both the armature and the interpoles as a unit. Reversing the armature leads without interpole will cause the motor to have incorrect interpole polarity, which will make the motor run excessively hot and will produce sparking at the brushes.



A two-pole, compound-interpole motor with six leads brought out the motor.

The interpoles are connected in series with the armature and two wires A1 and A2 are brought out from this as a unit. In the diagram figure A, the armature is connected between the interpoles. To reverse this motor, it is necessary to reverse the interpole and armature circuit as a unit. Wires A1 and A2 must be reversed.

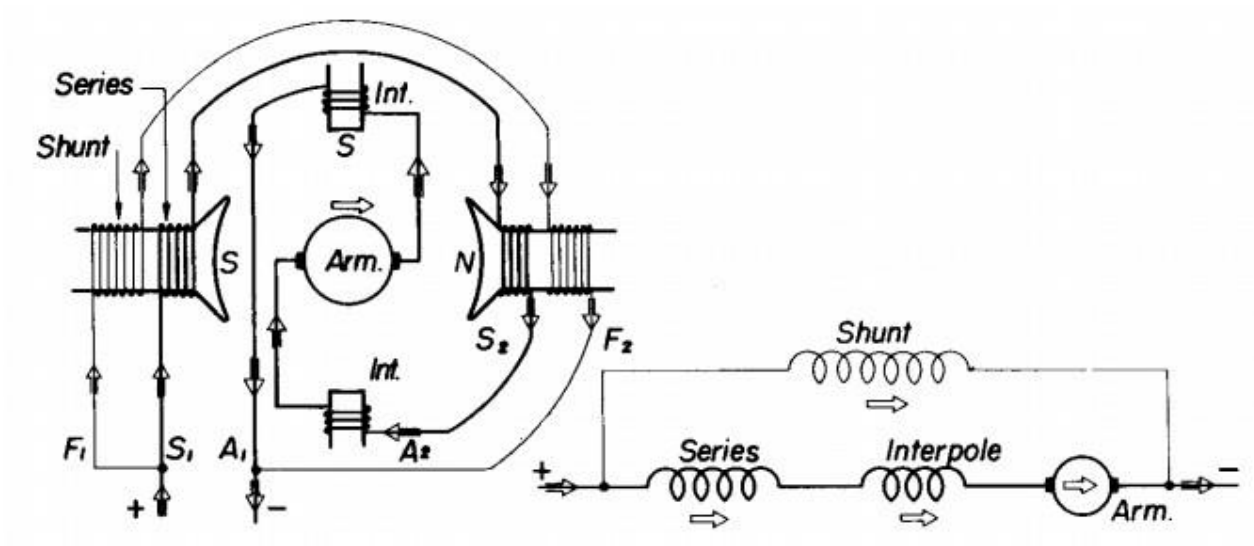
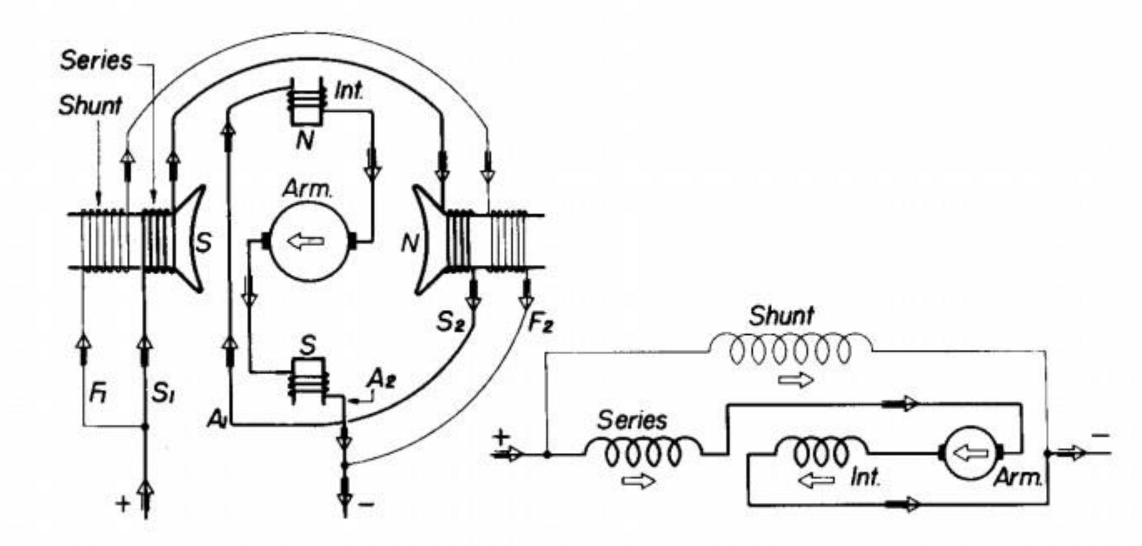


Figure A - The interpoles are sometimes connected in series and then connected to the armature.



A two-pole compound-interpole motor with the armature circuit reversed for opposite rotation from Figure A.

Lesson 3 – GENERATING FACTOR OF DIRECT CURRENT MOTOR

A generator action is developed in every motor. When a conductor cuts lines of force, an EMF is induced in that conductor. Current to start the armature turning will flow in the direction determined by the applied DC power source. After rotation starts, the conductor cuts lines of force. By applying the left-hand rule for generators, the EMF that is induced in the armature will produce a current in the opposite direction. The induced EMF, as a result of motor operation, is called counter electromotive force, or CEMF, as illustrated in Figure 6. Figure 6 Counter electromotive Force (CEMF)

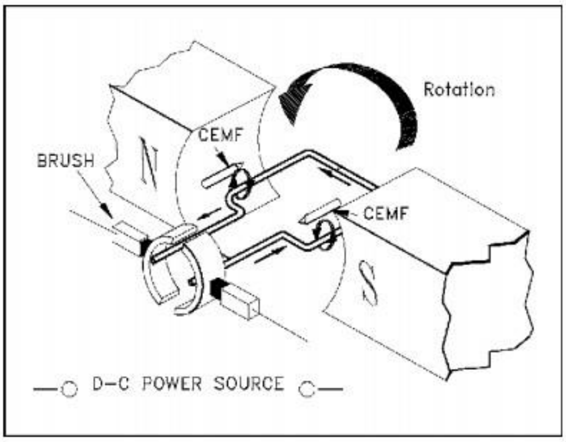


Figure 6 Counterelectromotive Force (CEMF)

Since the CEMF is generated by the action of the armature cutting lines of force, the value of CEMF will depend on field strength and armature speed, as shown in Equation below:

$$E_{CEMF} = K\Phi N$$

where

ECEMF = counter EMF K

= constant

Φ = field flux strength

N = speed of the armature

The CEMF opposes the applied voltage and functions to lower armature current. The effective voltage acting in the armature of a motor is the applied voltage, minus the counter EMF. Armature current can be found by using Ohm's law, as shown in below:

$$I_a = \frac{E_t - E_{CEMF}}{R_a}$$

where

Ia = armature current Et

= terminal voltage

ECEMF = counter EMF

Ra = armature resistance

DC MOTOR SPEED

The field of a DC motor is varied external devices, usually field resistors. For a constant applied voltage to the field (E), as the resistance of the field (Rf) is lowered, the amount of current flow through the field (If) increase as shown by Ohm’s law.

$$\uparrow I_f = \frac{\overset{\leftrightarrow}{E}}{\downarrow R_f}$$

An increase in field current will cause flux (Φf) to increase. Conversely, if the resistance of the field is increased, field flux will decrease. If the field flux of a DC motor is decreased, the motor speed will increase. The reduction of field strength reduces the CEMF of the motor, since fewer lines of flux are being cut by the armature conductors, as shown in Equation below:

$$\downarrow E_{CEMF} = \vec{K}\,\overset{\downarrow}{\Phi_F}\,\vec{N}$$

A reduction of counter EMF allows an increase in armature current as shown below:

$$\uparrow I_a = \frac{\overset{\rightarrow}{E_t} - \overset{\downarrow}{E_{CEMF}}}{\overset{\rightarrow}{R_a}}$$

This increase an armature current cause a larger torque to be developed; the increase in armature current more than offsets the decrease in field flux as shown below:

$$\uparrow T = \vec{K}\,\overset{\downarrow}{\Phi_F}\,\overset{\uparrow}{I_a}$$

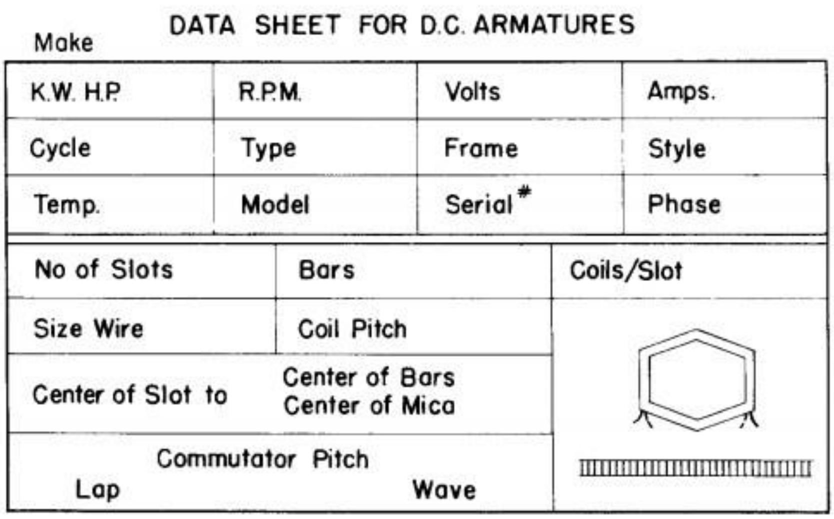
This increased torque causes the motor to increase in speed.

$$\uparrow T \propto N \uparrow$$

This increase in speed will then proportionately increase the CEMF. The speed and CEMF will continue to increase until the armature current and torque are reduced to values just large enough to supply the load at a new constant speed.

Lesson 4 – DIRECT CURRENT ARMATURE WINDING

The complete process of armature winding involves a number of operations that are performed in sequence. These are taking data while stripping the armature; insulating the core; making and taping coils; placing the coils in the slots; connecting the coil leads to the commutator; soldering the leads to the commutator; testing; turning the commutator in the lathe; baking and varnishing.



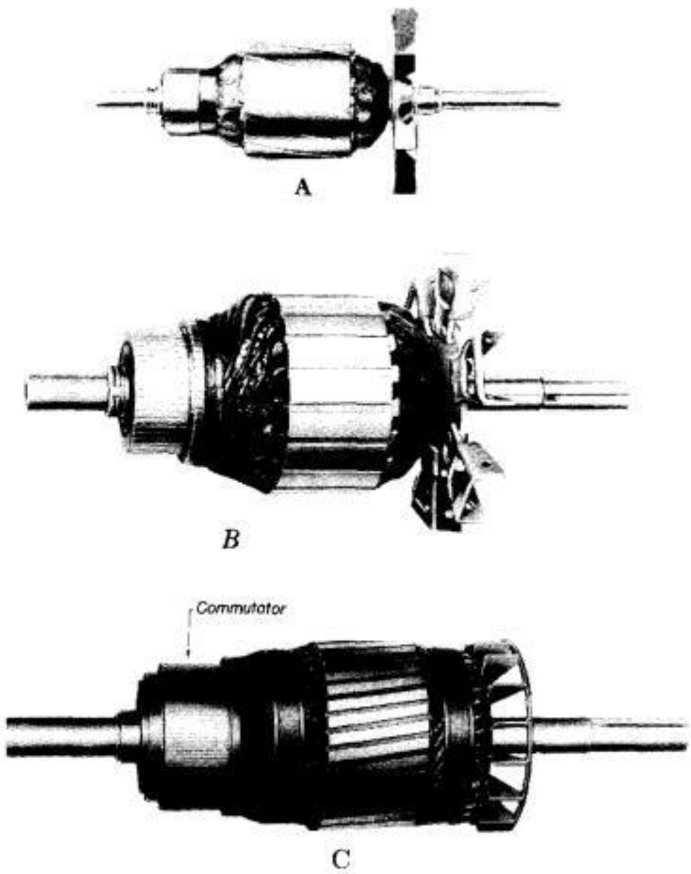
DATA SHEET FOR D.C. ARMATURES

Make

K.W. H.P.	R.P.M.	Volts	Amps.
Cycle	Type	Frame	Style
Temp.	Model	Serial #	Phase

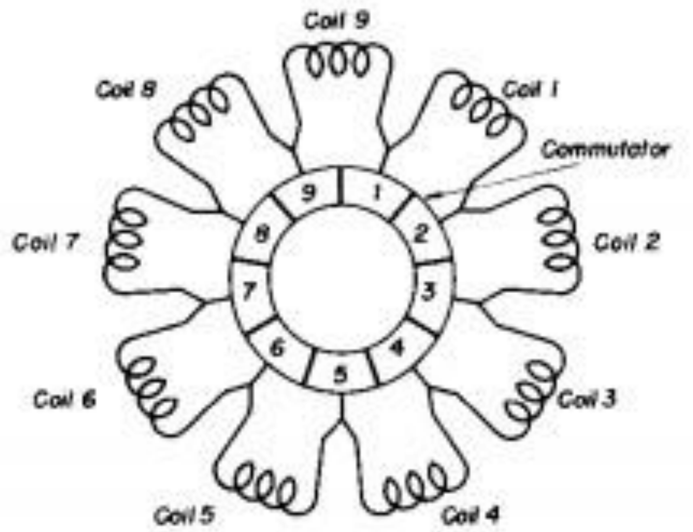
No of Slots	Bars	Coils/Slot
Size Wire	Coil Pitch	
Center of Slot to	Center of Bars Center of Mica	
Commutator Pitch Lap	Wave	

When armature such as shown below require rewinding, sufficient information must be gathered in the process of stripping to enable the mechanic to rewind it exactly as it was wound originally. Unless the different types of windings and connections are familiar to the mechanic, it will be almost impossible to record the necessary data. The different types of windings and connections will be described, and directions given for rewinding the more important ones.



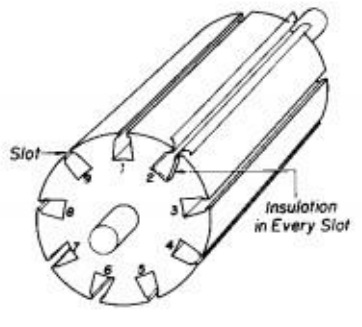
Different type of DC Armatures

TYPICAL WINDING FOR SMALL ARMATURES. The simplest type of winding consists of a series of coils wound into the slots of an armature and connected in succession to the commutator. The figure below shows a diagram of this winding. The commutator bar is shown flattened for simplicity.

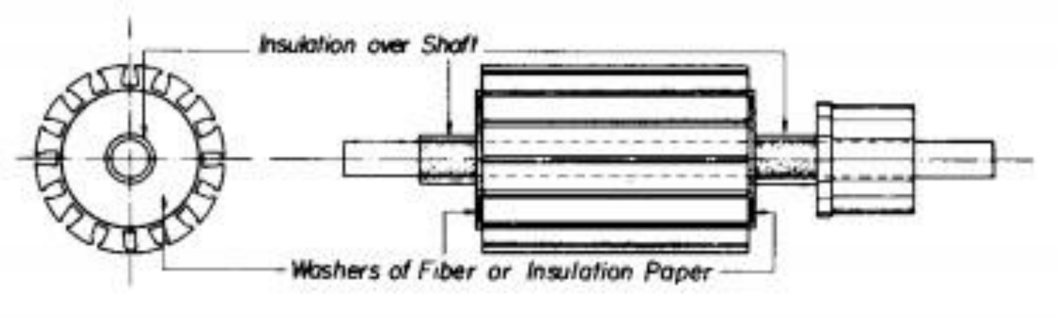


A circular schematic diagram showing all the coils of a nine-coil armature connected to the commutator bars.

Before the armature is wound, however, the slots must be insulated to prevent the wires from touching the iron core and causing grounds. As in the other types of motors, the same kind and thickness of insulation is inserted as was removed. On small armature, the insulation is cut so that it protrudes approximately 1/8 in. on both ends of the armature slot about ¼ in. above the slot. It is also necessary to insulate the shaft of the armature by placing several turns of insulating tape around it.

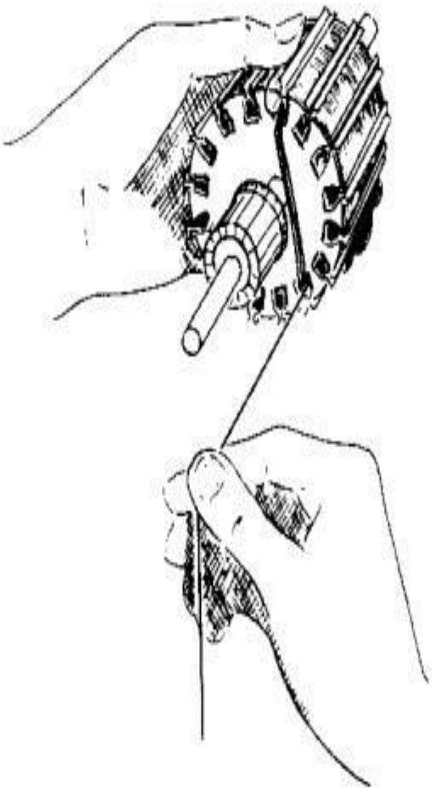


Slots in the armature into which the coils are wound.

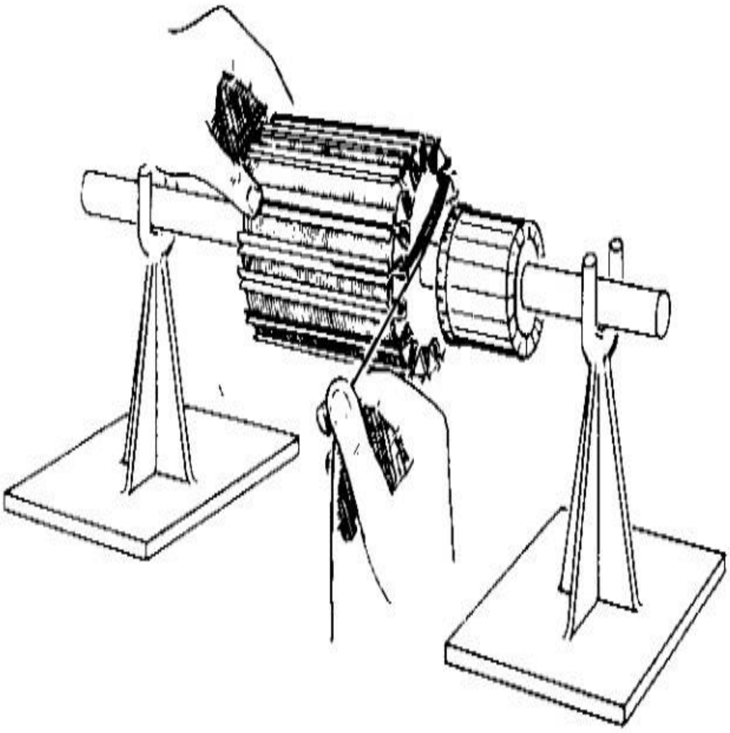


The insulation at the shaft is necessary to protect the winding from ground.

WINDING PROCEDURE. Small armatures, such as those used in vacuum cleaners and drills, can be held in one hand as shown below. Large armatures are mounted between horses also shown below.

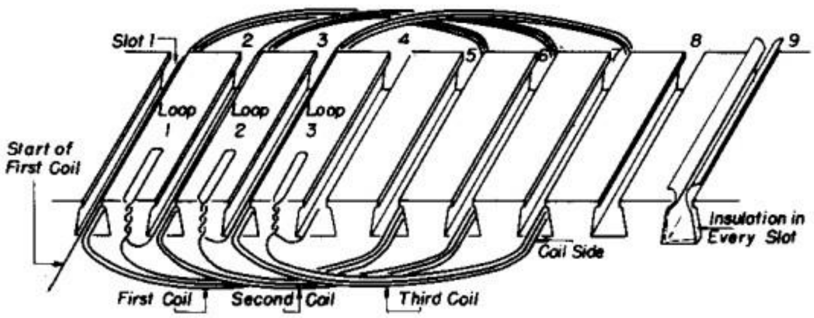


Small armatures can be held in one hand during winding.

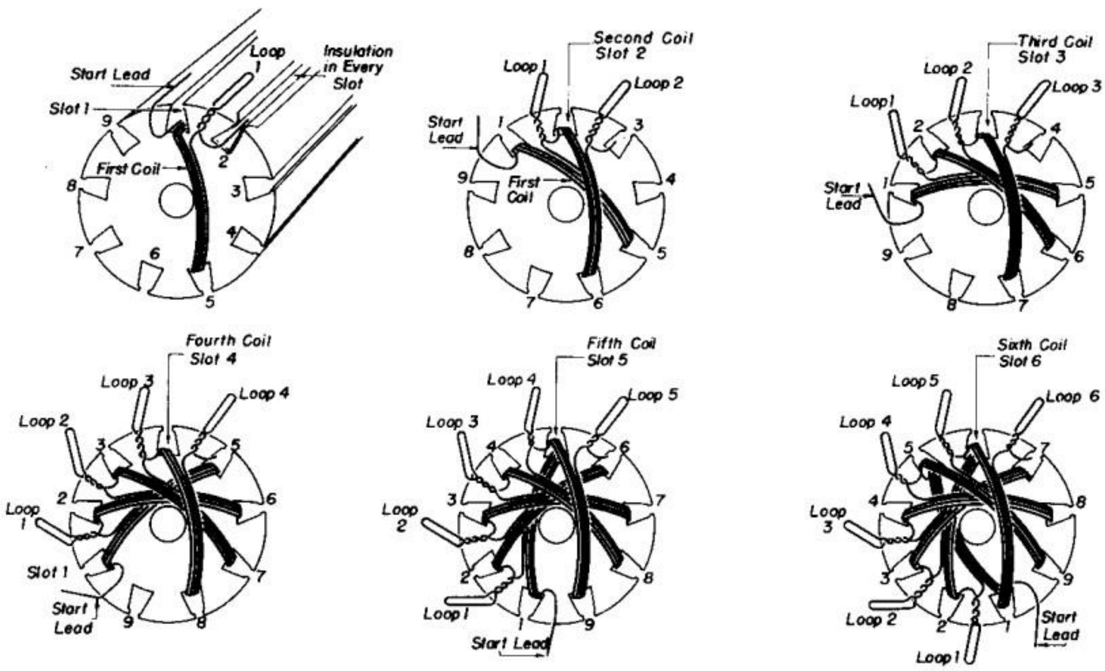


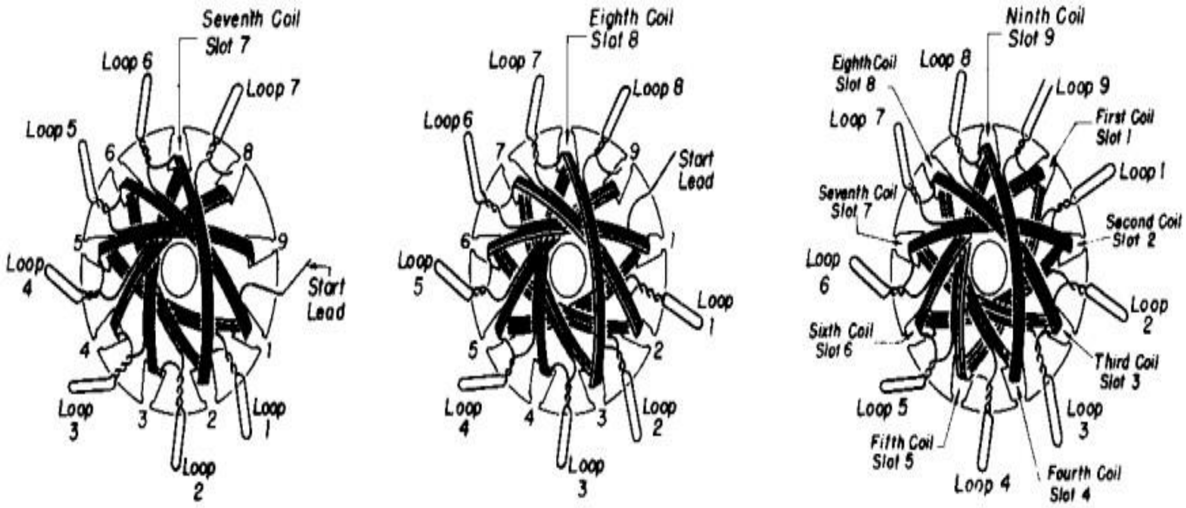
Large armatures are supported by horses during winding.

Assuming a nine-slot armature, the winding procedure is as follows: Insert insulation in the slots. Choose any slot and call it slot 1. Wind the required number of turns into the slots of proper pitch or span and then make a loop, as shown below. Use enough tension on the wire to make a tight winding without breaking the wire. Make the loop at the end of the first coil and the beginning of the second coil. Start the second coil in slot 2 and wind the coils with the same number of turns in coil 1. Be sure that the coil span is the same as coil 1.

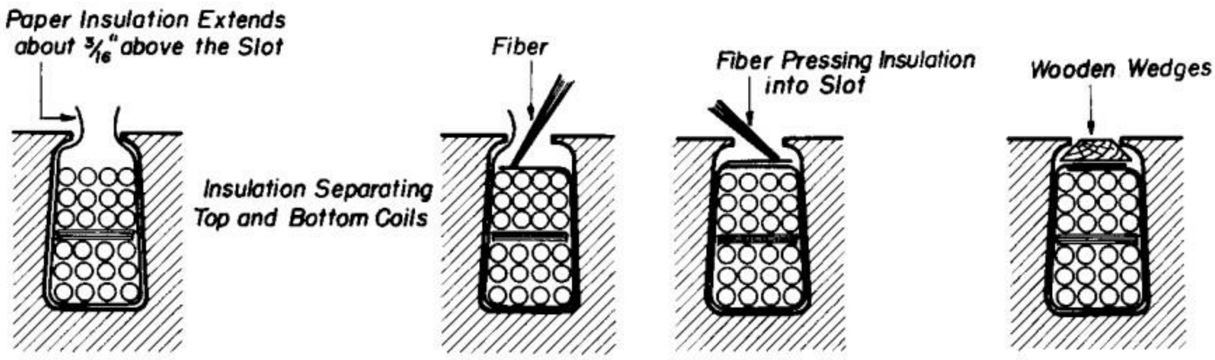


Make a loop when the second coil is finished, and then start winding in slot 3. Continue in this manner until nine coils have been wound. Connect the end lead of the last coil to the beginning lead of the first coil. After the entire armature is wound. There will be two coil sides in each slot. The figure below show the step by step winding of an armature having nine slots. This type of winding, in which a loop is made of the end of each coil, is called a loop winding.





PLACING WEDGES IN THE SLOTS. After the armature has been wound, the next operation is to close the slots so that the wires will not fly out while the armature is rotating at full speed. The procedure is illustrated below:

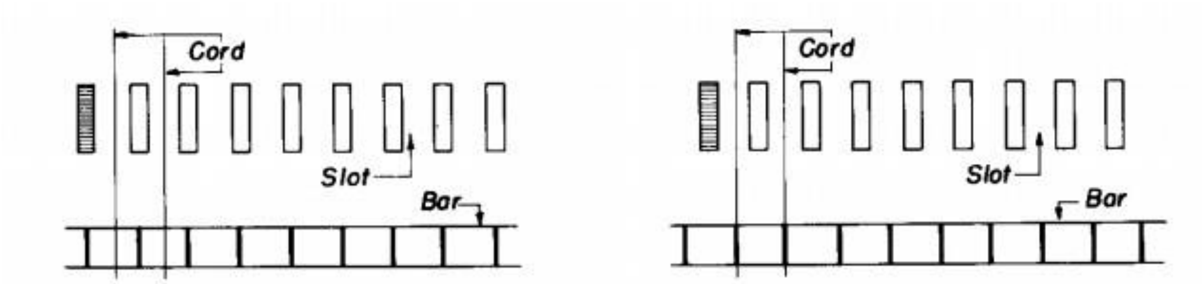


Cut the insulation so that it extends out of the slot about 3/16 in. Use a piece of fiber to press one side of the insulation into the slot and then the other side of the insulating strip into the slot. Slide a wooden (or fiber) wedge of the proper size into the slot over the insulation. On large armatures, the insulation is cut flush with the top of the slot and then banded.

LEAD SWING. One of the most important operations in the rewinding of an armature is placing the coil leads in the proper commutator bars. Lead may be placed in the bars in any one of three different positions, depending on the original location. If a slot in the armature is viewed from the commutator end, the leads to the commutator may swing to the right of the slot or to the left, or they may be aligned with it.

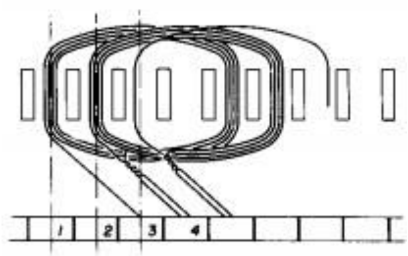
The following method is used in determining the position of the leads in the commutator.

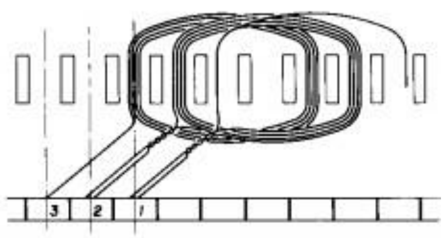
Stretch a piece of cord or string through the center of a slot as shown below.

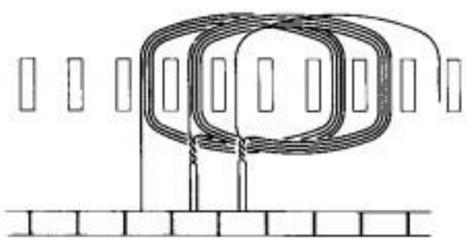


Note whether it is alignment with a commutator bar or with the mica between bars. If the data call for a lead swing of three bars to the right, place the lead of the first coil three bars to the right, counting the bar that lines up with the slot as No. 1.

All other leads follow succession in figure below. If the center of the slot is in line with the mica, consider the bar to the right of the mica as bar No. 1



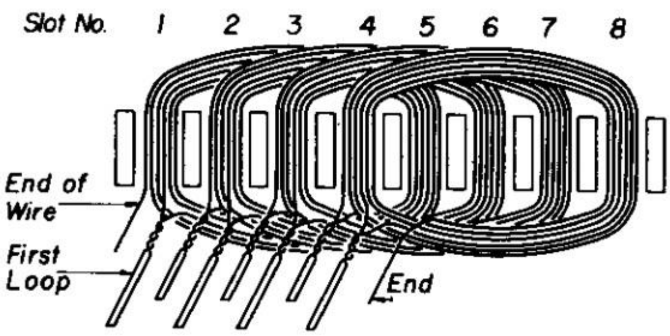




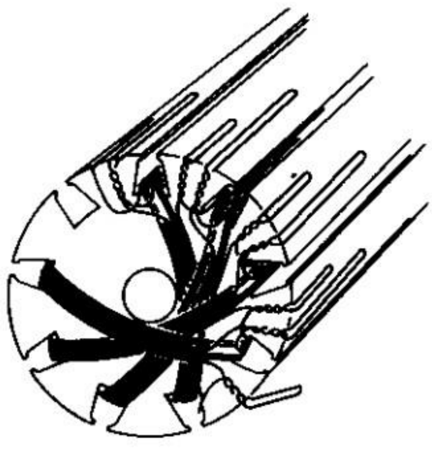
WINDINGS WITH MORE THAN ONE COIL PER SLOT. In the armature so far discussed the number of slots equal to the number of commutator bars. This is not true of all armatures. Some have twice as many bars as slots, and it is not unusual for them to have three times as many bars as slots. In an armature of this type, the number of coils is always equal to the number of bars; therefore, an armature that has nine slots and eighteen bars has eighteen coils. The procedure in winding an armature of this type is exactly the same as for the simple loop winding, except that each slot has two loops.

WINDING A LOOP ARMATURE WITH TWICE AS MANY COMMUTATOR BARS AS SLOT.

Assume a nine-slot, eighteen bar armature. The procedure for winding this two-coil-per slot armature is as follows: Wind the first coil into slot 1 and 5 in the same manner as in the simple loop winding. Make a loop and wind the second coil into the same slots. Make a loop and start the third coil in the slot 2. Continue in this manner winding two coils before going to the next slot. The windings should appear like those shown below. There should be two loops for each slot, sleeving of different colors may be put on the loops, or the second loop of each slot may be made longer than the first. This procedure enables the winder to place the leads in the proper commutator bars without testing each lead.

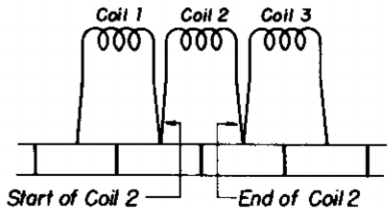


A two-coil-per-slot winding short and long loops for identification.

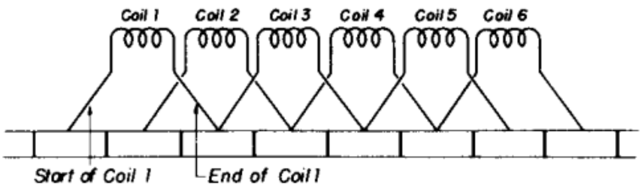


A loop armature having twice as many loops as slots after four coils have been wound.

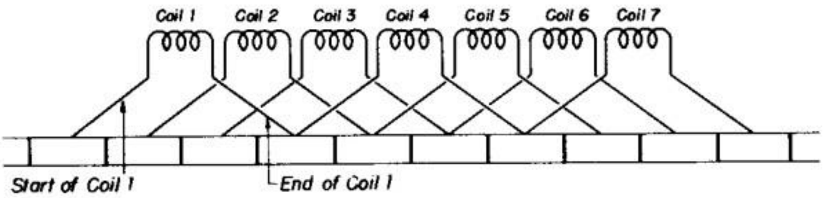
The simplex lap winding is one in which the beginning and the end leads of a coil are connected to adjacent commutator bars, as shown below. Thus the end lead of the first coil connects to the same commutator bar as the beginning lead of the second coil, and so on.



The duplex lap winding is one in which the end lead of a coil is connected two bars away from the beginning lead as shown below. Thus, the end lead of the first coil is placed in the same commutator bar as the beginning lead of the third coil; the end of the third in the same bar as the beginning of the fifth; and so on.



The triplex lap winding is one in which the end lead of a coil is connected three bars away from the beginning lead, as shown below. Thus the end of the first coil is connected to the same commutator bar as that of the fourth coil; the end of the fourth to the beginning of the seventh; and so on.

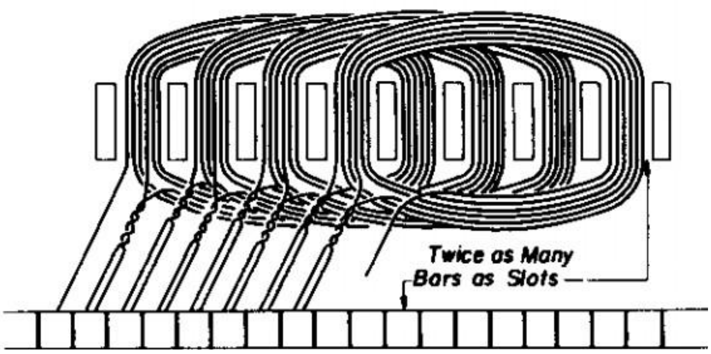


The simplex winding is most frequently used on small and medium-sized armatures. Duplex and triplex windings are not employed to any great extent, but simplex winding can generally be reconnected as duplex or triplex windings when it is desired to run a motor on a lower voltage.

LAP WINDING WITH LOOPS. A simple lap winding having one coil for each slot is shown below. This nine-slot armature has nine coils, one for each slot. In this armature, the number of slots and commutator bars must be the same.

A lap winding with one coil per slot has the beginning and end of the same coil connected to adjoining bars. The loops are connected to the commutator bars in succession.

A lap winding with two coils for each slot is shown below. A nine slot armature in this case has eighteen coils. There must be twice as many commutator bars as slots, because there are eighteen loops, and each loop requires one commutator bar. A illustrated below, one loop is made short and the next one long, so that the leads may be put in the bars in the proper rotation.

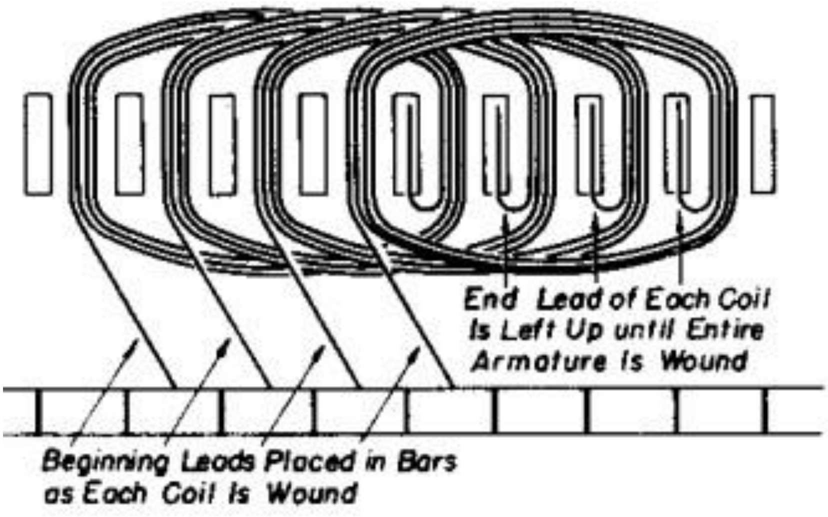


A lap winding with two coils per slot. The beginning and end of the each coil is connected to adjoining bars.

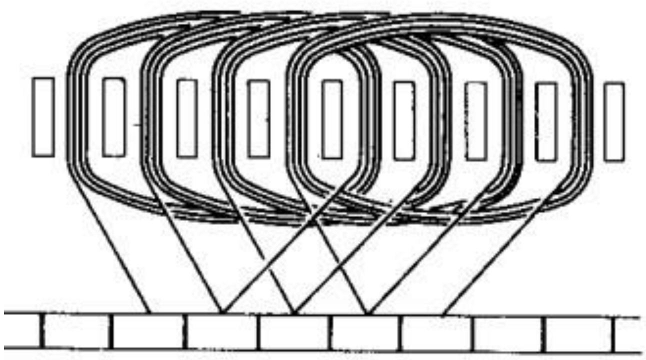
LAP WINDING WITHOUT LOOPS. In a lap winding, it is possible to place the beginning lead in the proper commutator bar as each coil is wound and to connect all the end leads to the proper bars after the entire armature is wound. This requires the end lead of each coil to be left free until all the coils are wound.

ARMATURE WITH ONE COIL PER SLOT. The procedure for winding and connecting an armature having one coil per slot follows:

Start in any slot and wind one complete coil in the slots of proper pitch. Place the beginning of coil 1 into the proper commutator bar, and leave the end lead free for connection after the armature is wound. Wind the entire armature in this manner, leaving all the end leads disconnected as shown below.



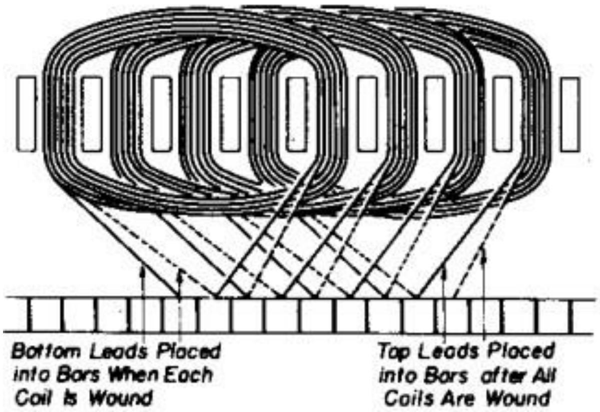
After all oils are wound, connect all the top or end leads to the commutator. Place each top lead in the bar adjacent to the bottom lead of the same coil to produce a simplex lap winding like that given figure below.



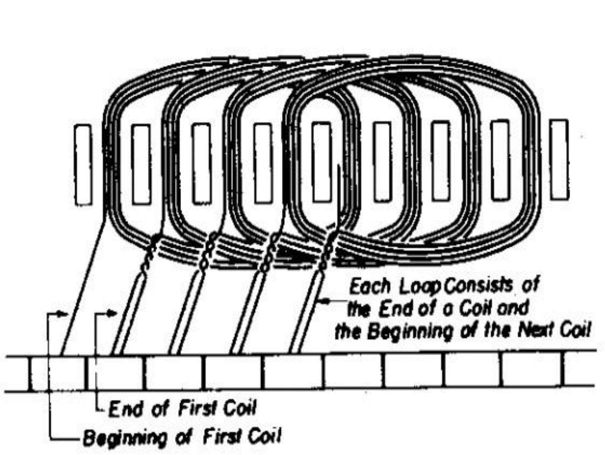
A lap winding of one coil per slot after the end leads are placed in the commutator bars.

ARMATURE WITH TWO COILS PER SLOT. A simplex lap-wound armature having two coils per slot are more common than those having one coil per slot. The procedure for winding this type of armature is as follows:

Start winding with two wires and place the beginning leads in the commutator bars according to the data taken. Cut the wires when the proper number of turns have been wound into the slots, and leave the end leads free as shown in Figure A. Start the next coil one slot to



the right of the first coil as viewed from the commutator end, (When the coils proceed to the left, the winding is called left-handed, and to the right, right handed. Follow this procedure until all coils have been wound. Then place the top, or end, leads in the commutator bars in the proper succession shows in Figure B.



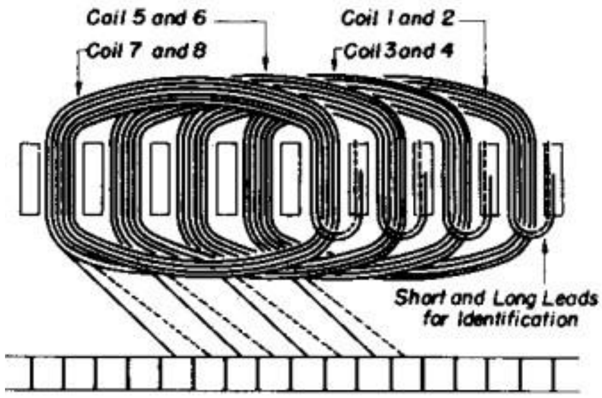
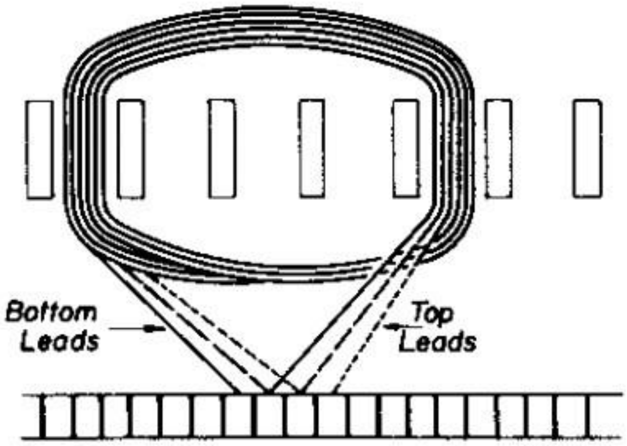


Figure A

ARMATURE WITH THREE COILS PER SLOT. Lap-wound armatures with three coils per slot are wound in the same manner as armature with two coils. Three bottom leas and three top leads are connected from each slot. These leads are place in consecutive commutator bars, as was done in the case of the two-coil-per-slot windings, and the leads are similarly identified. The figure below show three coils in one slot.

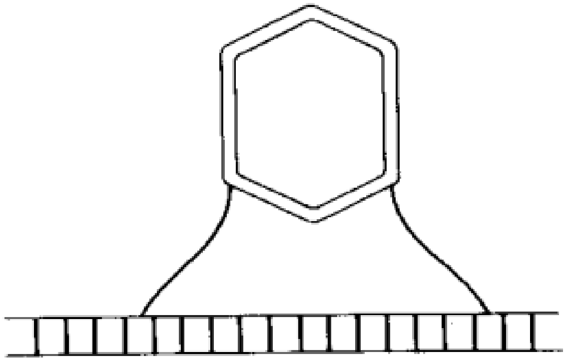


WAVE WINDINGS. There are three groups of wave windings, namely, simplex wave winding, duplex wave winding and triplex wave winding.

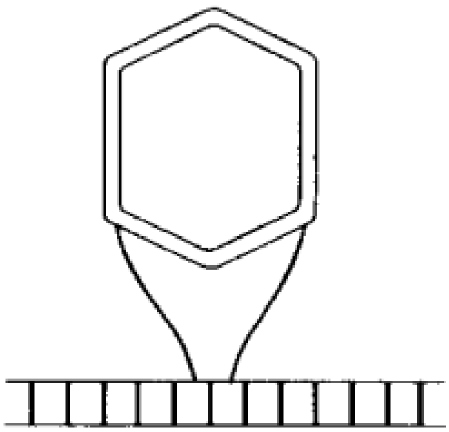
The difference between a wave winding and lap winding in the position of the armature leads on the commutator. In the simplex lap winding, the beginning and end leads of the same coil are connected to adjacent bars. In the wave winding, the beginning and end leads of a coil are connected to commutator bars quite far apart.

Thus, on a four-pole motor they are connected on opposite sides of the commutator.

A wave winding is one in which the beginning and end leads of a coil are connected a definite number of commutator bars apart, depending on the number of poles in the motor and the number of bars on the commutator. In a lap winding the leads face each other, while in wave winding the leads are face away from each other, as shown below.



Lap winding, leads face each other and are connected to adjacent bars.



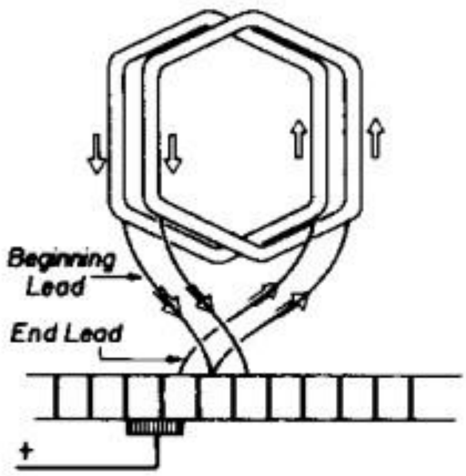
Wave winding, leads face away from one another and must be definite number of commutator bars apart.

In a wave winding for a four-pole motor the current must travel through at least two coils before reaching a bar adjacent to the starting point. For a six-pole motor the current will travel through three coils before reaching an adjacent bar. Two-pole motors cannot be wave wound.

RETROGRESSIVE AND PROGRESSIVE WINDINGS. According to the formula, the commutator pitch may be either of two figures. If the smaller number is used, the motor will run in one direction; and if the larger number is used, the armature will rotate in the opposite direction. These connections are known as retrogressive and progressive windings, and they are used in both lap and wave windings. A simplex progressive lap winding is one in which the current flowing in a coil terminates one bar beyond the starting point.

A simplex progressive lap winding. Current flow in a clockwise direction.

A simplex retrogressive lap winding is one in which the current flowing in a coil terminates one bar before the starting point.



A simplex retrogressive lap winding. The leads cross one another even though they are connected to adjacent bars. The current flows in a counterclockwise direction.

VII. Self-evaluation :

Answer the following questions concerning about the construction and operation of DC Motors.

1. How to form an alternate polarity in the field coils ?
2. How the current flows in a long shunt cumulative motor ?
3. Defined as one in which the shunt field is connected across the line so that the series and the shunt fields have opposite polarity in the same pole.
4. When the shunt field of a compound motor is connected to the armature terminals instead of across the line. ____
5. How to reverse the direction of rotation of the DC series motor ?
6. What are the uncommon procedures in rewinding between AC motor and Armature winding ?
7. Before an armature is wound. To prevent the wires from touching the iron core and causing grounds. What must it be ? ________________________________
8. Describe the simplex lap winding.
9. If the smaller number is used, the motor will run in one direction; and if the larger number is used, the armature will rotate in the opposite direction.
10. Give the three groups of wave windings.

VIII. Review of Concepts :

There are 3 types of DC Motors; The series motor, the shunt motor and the compound motor.

SERIES MOTOR.

Contains field coils composed of few turns of heavy wire connected in series with the armature

SHUNT MOTOR.

Contains a field composed of many turns of fine wires. This is connected in parallel with the armature

COMPOUND MOTOR.

In this type of motor, each field coil is a combination of the series and shunt fields and is made in two sections

GENERATING FACTOR OF DIRECT CURRENT MOTOR

A generator action is developed in every motor. When a conductor cuts lines of force, an EMF is induced in that conductor. Current to start the armature turning will flow in the direction determined by the applied DC power source. After rotation starts, the conductor cuts lines of force. By applying the left-hand rule for generators, the EMF that is induced in the armature will produce a current in the opposite direction. The induced EMF, as a result of motor operation, is called counter electromotive force, or CEMF

IX. References :

Robert Rosenberg, B.S., (1951) Electric Motor Repair, Practical book on the winding, repair and troubleshooting of AC and DC motors and controllers

EET 311 – ELECTRICAL MACHINES

LEARNING MODULE 4

DC MOTORS

Name: ____ Date: _________________

Year / Course and Section: __________________________

PRE TEST: Answer the following questions.

1. The rotating part of a DC Motor that consists of laminated core with slots in which coils of wire are placed.
2. Another purpose that the two endplates, fastened to the frame with bolts, bear the weight of the armature.
3. Two types of bearings that contains the endplates in which shaft of the armature revolves.
4. Explain how DC motor works.
5. DC Motor contains of field composed of many turns of fine wire.
6. Describe the connection of DC Series motor.
7. This motor has a high starting torque and a variable speed characteristic.
8. Describe the connection of a Compound DC Motor
9. Series field coils are wound with comparatively few turns of heavy wire whose diameter depends on the____________and________________of the motor.
10. What is the purpose Interpole Field?

COLLEGE OF TECHNOLOGY

First Semester, AY 2020-2021

EET 311 – ELECTRICAL MACHINES

LEARNING MODULE 4

DC MOTORS

Name: ____ Date: _________________

Year / Course and Section: ___________________________

POST TEST: Answer the following questions.

1. The rotating part of a DC Motor that consists of laminated core with slots in which coils of wire are placed.
2. Another purpose that the two endplates, fastened to the frame with bolts, bear the weight of the armature.
3. Two types of bearings that contains the endplates in which shaft of the armature revolves.
4. Explain how DC motor works.
5. DC Motor contains of field composed of many turns of fine wire.
6. Describe the connection of DC Series motor.
7. This motor has a high starting torque and a variable speed characteristic.
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9. Series field coils are wound with comparatively few turns of heavy wire whose diameter depends on the____________and________________of the motor.
10. What is the purpose Interpole Field?