2.6.3 Characteristic of Compound-wound motor

A compound-wound motor has both a series and a shunt field winding, (i.e. one winding in series and one in parallel with the armature circuit), by varying the number of turns on the series and shunt windings and the directions of the magnetic fields produced by these windings (assisting or opposing), families of (c/s) may be obtained to suit almost all applications. There are two common types of compound motor **connection**, the long-shunt connection and short-shunt connection. And there are two different types of compound motors in **common use**, they are the cumulative compound motor and the differential compound motor. In the cumulative compound motor, the field produced by the series winding **aids** the field produced by the shunt winding. The **speed** of this motor **falls** more rapidly with increasing current than does that of the shunt motor because the field increases. In the differential compound motor, the flux from the series winding **opposes** the flux from the shunt winding. The field flux, therefore, decreases with increasing load current. Because the flux decreases, the **speed** may **increases** with increasing load. Depending on the **ratio** of the **series-to-shunt field ampere-turns**, the motor speed may increases very rapidly.

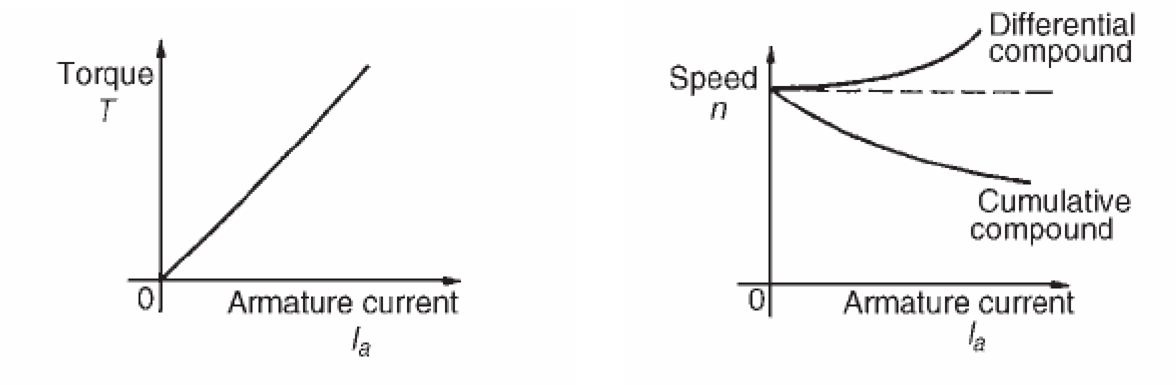


Fig.(2.15)

The torque-speed (c/s) of a cumulatively compound D.C motor

In the cumulative compounded D.C. motor, there is a component of flux which is constant and anther component which is proportional to its armature current (and thus to its load). Therefore, the cumulatively compounded motor has a higher starting torque than a shunt motor (whose flux is constant) but a lower starting torque than a series motor (whose entire flux is proportional to armature current). At light loads, the series field has a very small effect, so the motor behaves approximately as a shunt D.C. motor. As the load gets very large, the series flux becomes quite important and the torque-speed curve begins to look like a series motor's (c/s). A comparison of the torque-speed (c/s) of each of these type of machines is shown in figure (2.16).

The torque-speed (c/s) of a differentially compound D.C motor

In a differentially compound D.C. motor, the shunt magneto motive force and series magneto motive force subtract from each other. This means that as the load on the motor increases, I_a increases and the flux in the motor decreases. But as the flux decreases, the speed of the motor increases. This speed increases causes anther increases in load, which further increases I_a , further decreasing the flux, and increasing the speed again. The result is that a differentially compounded motor is unstable and tends to run away. It is so bad that a differentially compounded motor is unsuitable for any application.

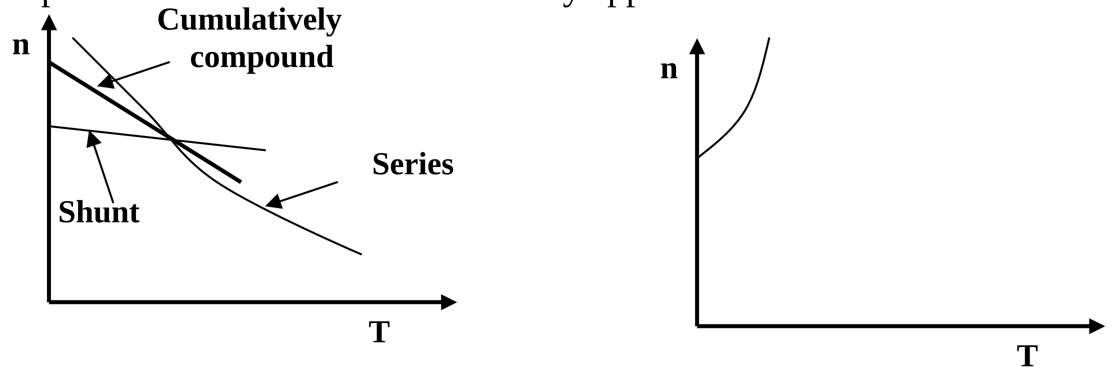


Figure (2.16

2.7 D.C Motor Starter

If a D.C motor whose armature is **stationary** is switched directly to its supply voltage, it is likely that the fuses protecting the motor will burn out. Because the **armature resistance** is **small**, frequently being less than **one ohm**. Thus, additional resistance must be added to the armature circuit at the instant of closing the switch to start the motor.

As the speed of the motor increases. The armature conductors are cutting flux and a generated voltage, acting in opposition to the applied voltage, is produced, which limits the flow of armature current. Thus the value of the additional armature resistance can then be reduced.

When at **normal running** speed, the generated e.m.f. is such that **no** additional resistance is **required** in the armature circuit. To achieve this varying resistance in the armature circuit on starting a D.C motor starter is used, as shown in fig.(2.17). The starting handle is moved slowly in a clockwise direction to start the motor. For a shunt-wound motor, the field winding is connected to stud (1) or (M) via a sliding contact on the starting handle. To give maximum field current hence maximum flux, hence maximum torque on starting, since $T \propto \phi . I_a$.

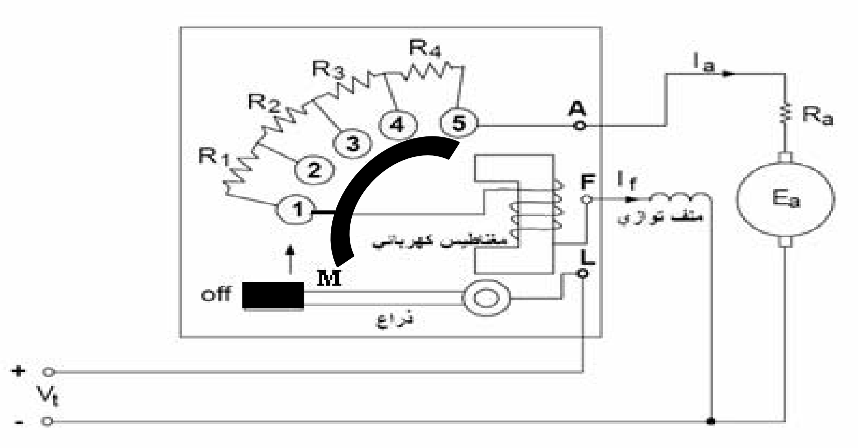


Fig.(2.17)

2.8 Speed Control of D.C Motor

2.8.1 Shunt-Wound Motor

The speed of a shunt-wound D.C motor, **n**, is proportional to $\frac{(V - I_a.R_a)}{\phi}$. The speed is varied either by varying the value of **flux**, (ϕ), or by varying the value of **(**R_a**)**. The former is achieved by using a variable resistor in **series** with the field winding, as shown in fig.(2.18) and such a resistor is called the **shunt field regulator**. As the value of resistance of the shunt field regulator is **increased**, the value of the field current, (I_f), is **decreased**. This results in a decrease in the value of **flux,** (ϕ), and hence an increase in the **speed**, since $n \propto \frac{1}{\phi}$. Thus only **speeds above** that given without a shunt field regulator can be obtained by this method.

Speeds **below** those given by $\frac{(V - I_a.R_a)}{\phi}$ are obtained by increasing the resistance in the armature circuit, as shown in fig.(2.18), where

$$n \propto \frac{V - I_a(R_a + R)}{\phi}$$

Since resistor (**R**) is in series with the armature, it carriers the full armature current and results in a large power **loss** in large motors where a considerable speed reduction is required for long periods.

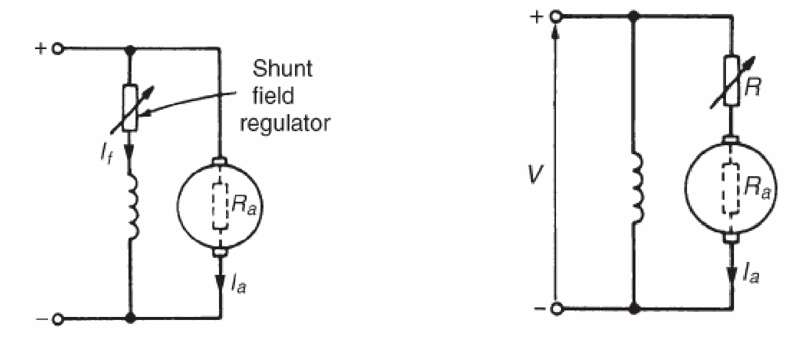


Fig.(2.18)

2.8.2 Series-Wound Motor

The speed control of series-wound motors is achieved using either (a) **field resistance**, or (b) **armature resistance** techniques.

(a) The speed of a D.C series-wound motor is given by :

$$n = K\left(\frac{V - IR}{\phi}\right)$$

Where (K) is a constant, (V) is the terminal voltage, (R) is the combined resistance of the armature and series field and (ϕ) is the flux.

Thus, a reduction in flux results in an increase in speed. This is achieved by putting a variable resistance in **parallel** with the **field winding** and reducing the field current, and hence flux, for a given value of supply current. A circuit diagram of this arrangement is shown in fig. (2.19). A variable resistor connected in **parallel** with the series-wound field to control speed is called a diverter speeds above those given with no diverter are obtained by this method.

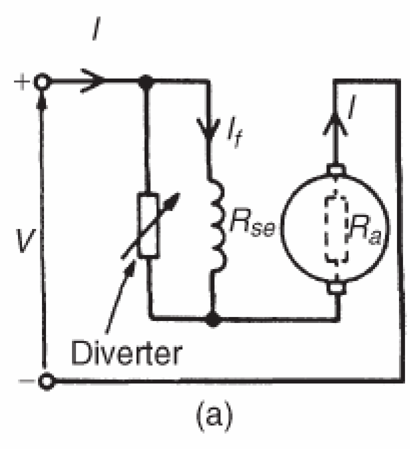


Fig.(2.19)

(b) **speed below normal** are obtained by connecting a variable resistor is **series** with the **field winding** and **armature circuit**, as shown in fig.(2.20). This effectively increases the value of (R) in the equation.

$$n = K\left(\frac{V - I.R}{\phi}\right)$$

And thus reduces the speed. Since the additional resistor carries the full supply current, a large power loss is associated with large motors in which a considerable speed reduction is required for long periods.

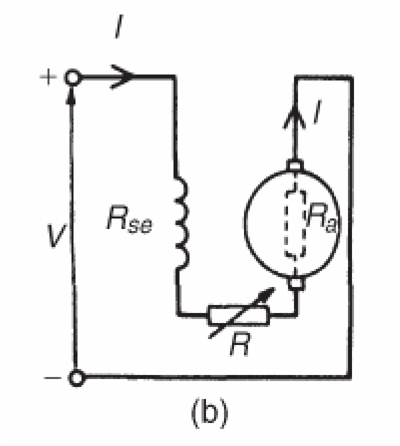


Fig.(2.20)

<u>Example (2.1)</u> A D.C motor has a speed of (**900 r.p.m**) when connected to a (**460 V**) supply. Find the approximate value of the speed of the motor when connected to a (**200 V**) supply, assuming the flux decreases by (**30%**) and neglecting the **armature volt drop**?

<u>Solution:</u>

$E_{b1} = \overline{K}\phi_1.n_1$ $\quad\quad$ $E_{b2} = \overline{K}\phi_2.n_2$

$\phi_2 = \phi_1 - \phi_1 \times 0.3$ $\quad\quad$ $\phi_2 = 0.7\phi_1$

Now

$$\frac{E_{b1}}{E_{b2}} = \frac{\phi_1 \times 900}{0.7.\phi_1 \times n_2}$$

$n_2 = 559$ r.p.m

Example (2.2): A series motor has an armature resistance of (**0.2 Ω**) and a series field resistance of (**0.3 Ω**). It is connected to a (**240 V**) supply and at a particular load runs at (**1440 r.p.m**) when drawing (**15 A**) from the supply.

(a) Determine the back e.m.f at this load.

(b) Calculate the speed of motor when the load is changed such that the current is increased to (**30 A**). Assume that this cases a **doubling of flux**.

Solution:

(a) at initial load, is given by

$$E_{b1} = V - I_a(R_a + R_f)$$

$$E_{b1} = 240 - 15(0.2+0.3)$$

$$= 232.5 \text{ Volt.}$$

(b) When the current is increased to (30 A), the back e.m.f. is given by.

$$E_{b2} = V - I_a(R_a + R_f)$$

$$=240 - 3o(0.2+0.3)$$

$$=225 \text{ volt}$$

Now back e.m.f $E_b \propto \phi.n$

Thus

$$\frac{E_{b1}}{E_{b2}} = \frac{\phi_1.n_1}{2.\phi_1.n_2}$$

i.e.

$$\frac{232.5}{225} = \frac{\phi_1 \times 1440}{2 \times \phi_1 \times n_2}$$

$$n_2 = \frac{1440 \times 225}{232.5 \times 2} = 696.77 \text{ r.p.m}$$

****

<u>Example (2.3);</u> A **series motor** runs at (**800 r.p.m**) when the voltage is (**400 V**) and the current is (**25 A**). The armature resistance is (**0.4 Ω**) and the series field resistance is (**0.2 Ω**). **Determine** the resistance to be connected in **series** to reduce the speed to (**600 r.p.m**) **with same current**.

<u>Solution:</u>

at (800 r.p.m)

$E_{b1} = V - I(R_a + R_f)$

$= 400 - 25(0.4+0.2)$

$= 385$ volt

at (600 r.p.m), since the **current is unchanged**, the **flux** is unchanged.

Thus $E_b \propto \phi \times n$, or $E_b \propto n$, and $\frac{E_{b1}}{E_{b2}} = \frac{n_1}{n_2}$

$E_{b2} = \frac{(385)(600)}{(800)} = 288.75$ volt

And

$E_{b2} = V - I(R_a + R_f + R)$

$288.75 = 400 - 25(0.4+0.2+R)$

Rearranging gives

$0.6 + R = \frac{400 - 288.75}{25} = 4.45$

From which, extra series resistance,

R=4.45-0.6

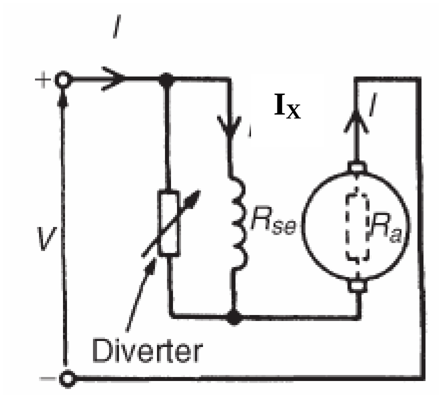
i.e. , R=3.85 Ω

thus the addition of a series resistance of (3.85 Ω) has reduced the speed from (800 r.p.m) to (600 r.p.m).

****

<u>Example (2.4):</u> On full-load a (**300 V**) series motor takes (**90 A**) and runs at (**900 r.p.m**) the armature resistance is (**0.1 Ω**) and the series winding resistance is (**50 mΩ**). **Determine** the speed when developing full load torque but with a (**0.2 Ω**) diverter in **parallel** with the field winding. (assume that the flux is proportional to the field current).

<u>Solution:</u>



at (300 V)

$$E_{b1} = V - I(R_a + R_f)$$

$$= 300 - 90(0.1 + 0.05)$$

$$=286.5 \text{ Volts}$$

With the (0.2 Ω) diverter in parallel with (R_f)

The equivalent resistant

$$R = \frac{0.2 \times 0.05}{0.2 + 0.05} = 0.04\Omega$$

By current division, current $I_X = I\left(\frac{0.2}{0.2 + 0.05}\right)$

$$I_X = 0.8I \quad , \qquad I_X = 0.8I_{a2}$$

Torque, $T \propto I_a \phi$ and for full load torque $\quad I_{a1}\phi_1 = I_{a2}\phi_2$

Since flux is proportional to field current $\phi_1 \propto I_{a1}$ and $\phi_2 \propto 0.8 I_{a2}$

Then $(90)(90) = (I_{a2})(0.8 I_{a2}) \quad , \quad I_{a2}^2 = \frac{(90)^2}{0.8}$ and $\quad I_{a2} = 100.62A$

Hence $E_{b2} = V - I_{a2}(R_a + R)$

$$= 300 - 100.62(0.1 + 0.04) = 285.9 \text{ Volts}$$

Back e.m.f. , $E_b \propto \phi.n$ from which $\dfrac{E_{b1}}{E_{b2}} = \dfrac{\phi_1 \times n_1}{\phi_2 \times n_2} = \dfrac{I_{a1} \times n_1}{0.8 \times I_{a2} \times n_2}$

new speed $\quad n_2 = \dfrac{285.9 \times 90 \times 900}{286.5 \times 0.8 \times 100.62} = 1004.4$ r.p.m

---

2.9 The efficiency of a D.C. motor

It was stated in section (1.14), that the efficiency of a D.C. machine is given by.

Efficiency, $\eta = \frac{output \cdot power}{input \cdot power} \times 100 \,\%$

Also, the total losses $= I_a^2 R_a + I_f V + C$ (for a shunt motor) and,

total losses= $I^2 R + C$ (for a series motor), where C is the sum of the iron, friction and windage losses, R is the total resistance for series motor $R = (R_a + R_f)$

for a motor, the input power=VI

and the output power=VI-losses

hence,

$$\eta = \left(\frac{VI - I_a^2 R - I_f V - C}{VI} \right) \times 100 \,\% \qquad \text{(for shunt motor)}$$

$$\eta = \left(\frac{VI - IR - C}{VI} \right) \times 100 \,\% \qquad \text{(for series motor)}$$

The efficiency of a motor is a maximum when the load is such that

$I_a^2 R_a = I_f V + C$ (for shunt motor), $I^2 R = C$ (for series motor)

Example (2.5): A 250 V series motor draws a current of 40 A. The armature resistance is 0.15 Ω and the field resistance is 0.05 Ω. Determine the maximum efficiency of the motor.

Solution:

For series motor $\eta = \left(\frac{VI - I^2 (R_a + R_f) - C}{VI} \right) \times 100$

For maximum efficiency , $\eta = \left(\frac{VI - 2I^2 (R_a + R_f)}{VI} \right) \times 100$

$$= \left(\frac{(250)(40) - 2(40)^2 (0.15 + 0.05)}{(250)(40)} \right) \times 100 = 93.6 \,\%$$

2.10 D.C Stepping Motors

D.C stepping motors are unique D.C motors that are used to **control automatic** industrial processing equipment. D.C motors of this type are fund in numerically controlled machines and **robotic** system used by industry. They are very efficient and develop a high torque the stepping motor is used primarily to change **electrical pulses** into a **rotary motion** that can be used to produce **mechanical movements**.

The shaft of a D.C stepping motor rotates a specific number of mechanical degrees with each incoming pulse of electrical energy. The amount of **rotary movement** or **angular displacement** produced by each pulse can be repeated precisely with each succeeding pulse from the drive source. The resulting output of this device is used to accurately **locate** or **position** automatic process machinery.

i_1	i_2	θ
+	0	0°
+	+	45°
0	+	90°
−	+	135°
−	0	180°
−	−	225°
0	−	270°
+	−	315°
+	0	0°

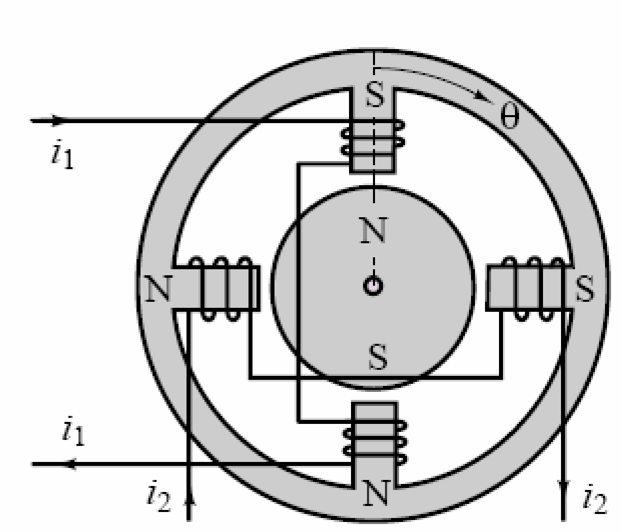


Fig.(2.20)

2.11 Electromechanical power control equipment

There are so many types of electromechanical power control equipment used today that it is almost impossible to discuss each type. However, some of the very important types will be discussed in the following paragraphs.

2.11.1 Relays

Relays represent one of the most widely used control devices available today. The electromagnet of a relay contains a **stationary core.** Mounted close to one end of the core is a **movable piece** of magnetic material called the **armature**. When the coil is activated electrically, it produces a magnetic field in the metal core. The armature is then attracted to the core, which in turn produces a mechanical motion. When the coil is de-energized, the armature is returned to its original position by spring action. Figure (2.21) shows a simplified diagram of the construction of a relay that is used to control.

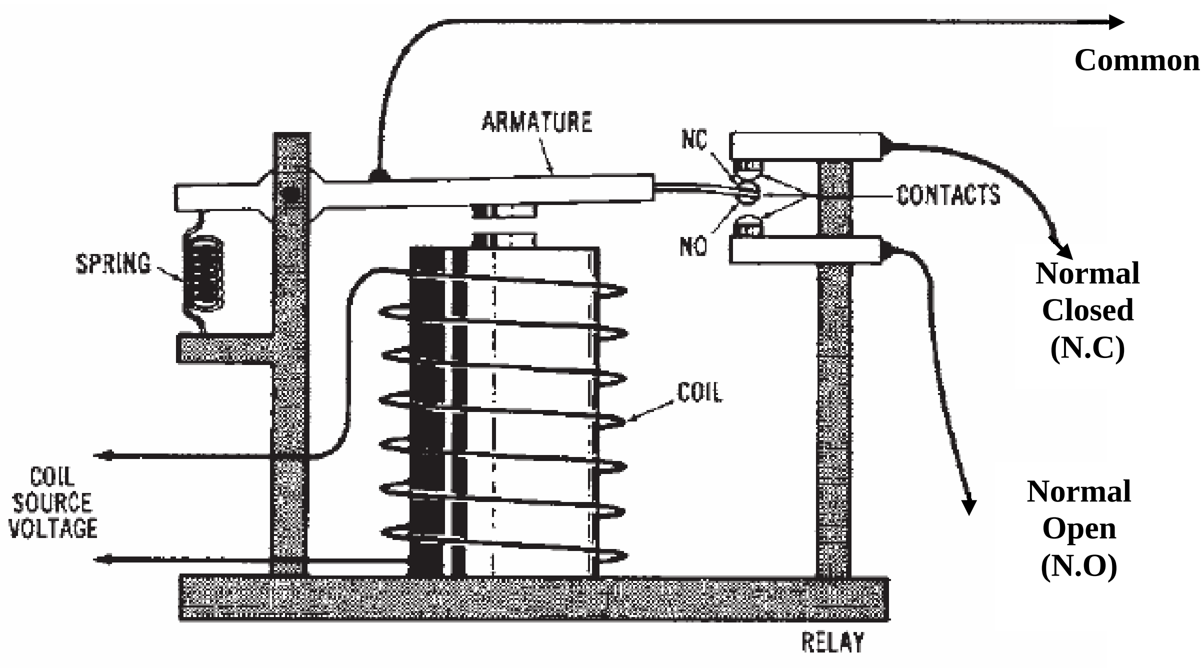


Fig.(2.21)

Relays use a **small** amount of **current** to create an electromagnetic field that is strong enough to attract the armature. When the armature is attracted, it either opens or closes the contacts. The contacts then either turn (**on**) or (**off**) circuits that are using **large** amounts of **current**.

There are **two types** of **contacts** used in conjunction with most relays. Normally open (**N.O**) and normally close **(N.C**). The (N.O) contacts remain **open** when the relay coil is **de-energized**, and are **closed** only when the relay is **energized**. The (N.C) contacts remain **closed** when the relay is **de-energized**, and are **open** only when the coil is **energized**.

Application

D.C Motor Reversing

The direction of rotation of a permanent-magnet D.C motor can be reversed by reversing the two power line as shown in fig.(2.22).

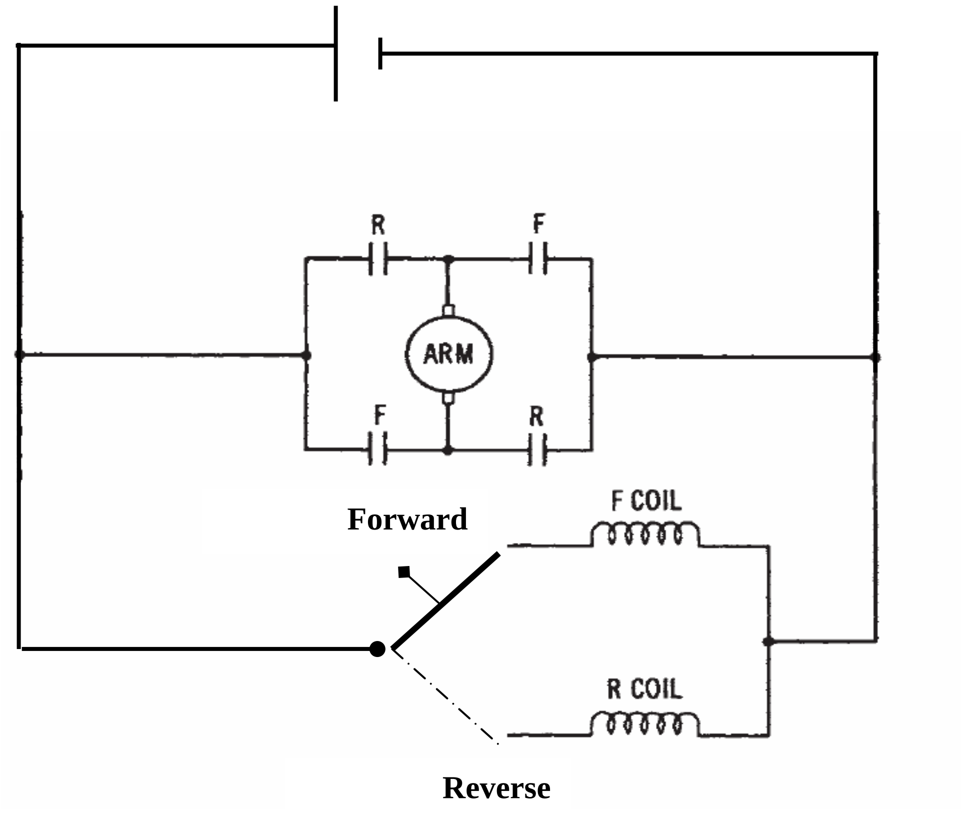


Fig.(2.22)

2.11.2 Solenoids

A solenoid, shown in fig.(2.23) is an electromagnetic coil with a **movable core** that is constructed of a magnetic. The **core**, or **plunger**, is sometimes attached to an external spring. This spring causes the plunger to remain in a fixed position until moved by the electromagnetic field that is created by current through the coil. This external spring also causes the core or plunger to return to its original position when the coil is de-energized.

Solenoid are used for a variety of control applications. Many gas and fuel oil furnaces use solenoid valves to automatically turn the fuel supply (on) or (off) upon demand. Dishwashers used one or more solenoids to control the flow of water.

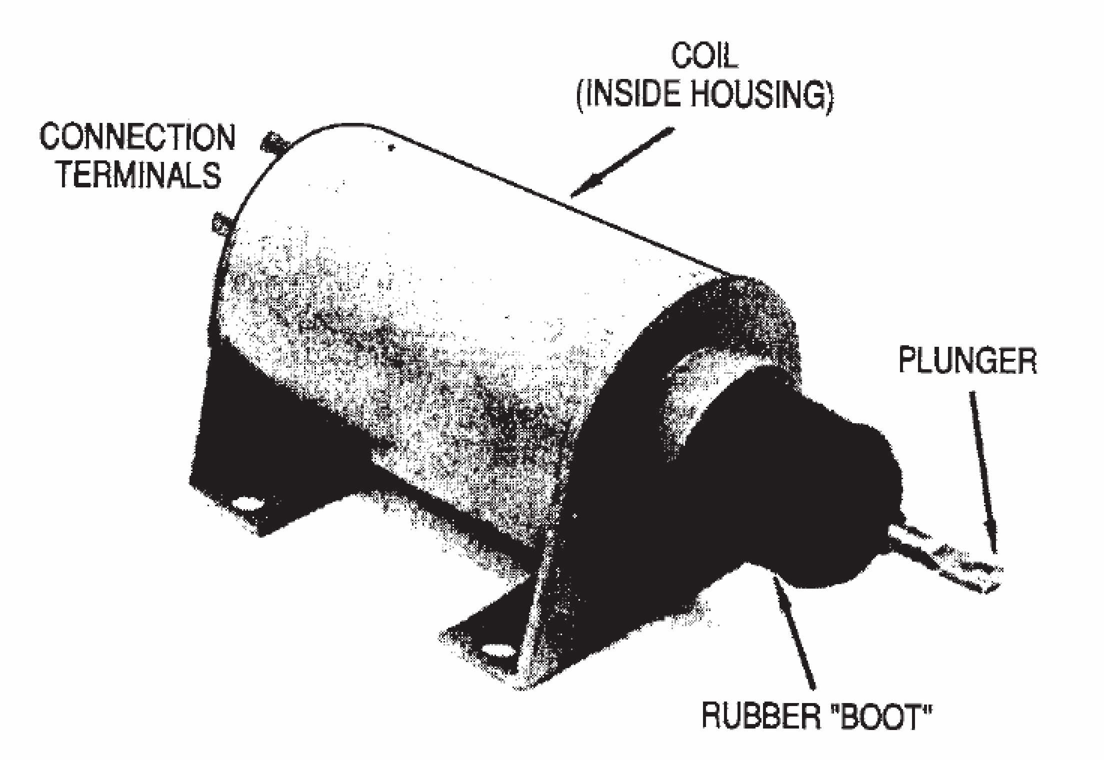


Fig.(2.23)