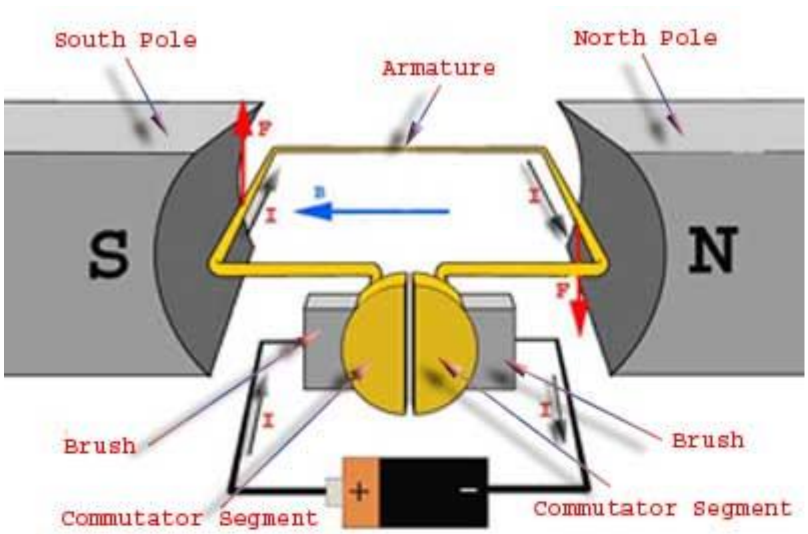
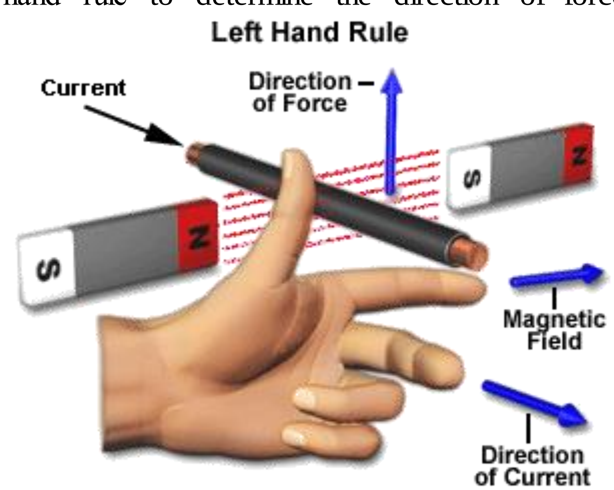
Working and Operating Principle of DC Motor

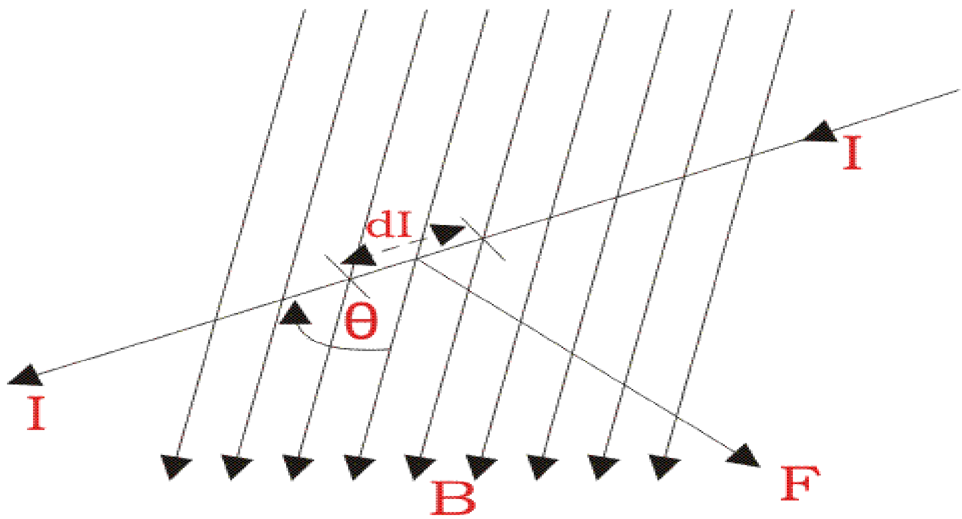
A DC motor in simple words is a device that converts direct current (electrical energy) into mechanical energy. It's of vital importance for the industry today, and is equally important for engineers to look into the **working principle of DC motor** in details that has been discussed in this article. In order to understand the **operating principle of dc motor** we need to first look into its constructional feature.



The very basic construction of a dc motor contains a current carrying armature which is connected to the supply end through commutator segments and brushes and placed within the north south poles of a permanent or an electro-magnet as shown in the diagram below. Now to go into the details of the **operating principle of DC motor** its important that we have a clear understanding of Fleming's left hand rule to determine the direction of force acting on the armature conductors of dc motor.



Fleming's left hand rule says that if we extend the index finger, middle finger and thumb of our left hand in such a way that the current carrying conductor is placed in a magnetic field (represented by the index finger) is perpendicular to the direction of current (represented by the middle finger), then the conductor experiences a force in the direction (represented by the thumb) mutually perpendicular to both the direction of field and the current in the conductor.
For clear understanding the **principle of DC motor** we have to determine the magnitude of the force, by considering the diagram below. We know that when an infinitely small charge dq is made to flow at a velocity 'v' under the influence of an electric field E, and a magnetic field B, then the Lorentz Force dF experienced by the charge is given by:-



$$dF = dq(E + vB)$$

For the **operation of dc motor**, considering E = 0

$$dF = dq \times v \times B$$

i.e. it's the cross product of dq v and magnetic field B.

$$dF = dq\frac{dL}{dt} \times B \qquad \left[V = \frac{dL}{dt}\right]$$

Where dL is the length of the conductor carrying charge q.

$$dF = dq\frac{dL}{dt} \times B$$

$$or,\ dF = IdL \times B \qquad \left[Since,\ current\ I = \frac{dq}{dt}\right]$$

$$or,\ F = IL \times B = ILB\sin\theta$$

$$or,\ F = BIL\sin\theta$$

From the 1st diagram we can see that the construction of a DC motor is such that the direction of current through the armature conductor at all instance is perpendicular to the field. Hence the force acts on the armature conductor in the direction perpendicular to the both uniform field and current is constant.

$i.e.\ \theta = 90^\circ$

So if we take the current in the left hand side of the armature conductor to be I, and current at right hand side of the armature conductor to be − I, because they are flowing in the opposite direction with respect to each other.

Then the force on the left hand side armature conductor,

$$F_i = BIL\sin 90° = BIL$$

Similarly force on the right hand side conductor

$$F_r = B(-I)L\sin 90° = -BIL$$

∴ we can see that at that position the force on either side is equal in magnitude but opposite in direction. And since the two conductors are separated by some distance w = width of the armature turn, the two opposite forces produces a rotational force or a torque that results in the rotation of the armature conductor.

Now let's examine the expression of torque when the armature turn crate an angle of α with its initial position.

The torque produced is given by,

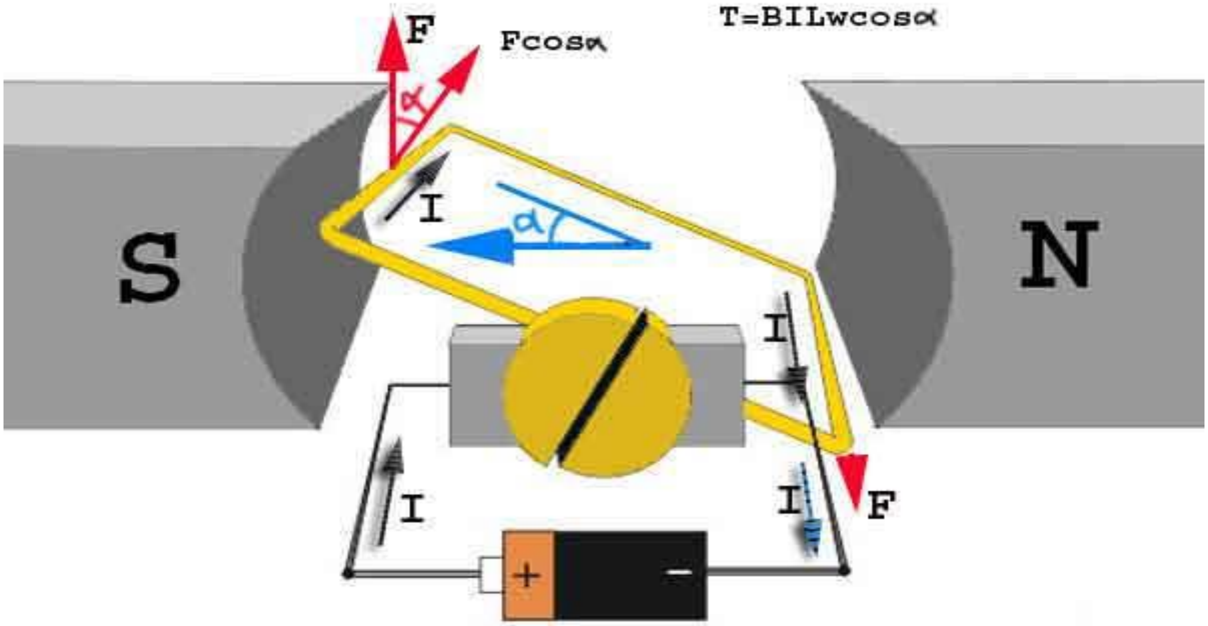
$$Torque = (force,\ tangential\ to\ the\ direction\ of\ armature\ rotation) \times (distance)$$

$$or,\ \tau = F\cos\alpha \times w$$

$$or,\ \tau = BILw\cos\alpha$$

Where α is the angle between the plane of the armature turn and the plane of reference or the initial position of the armature which is here along the direction of magnetic field.

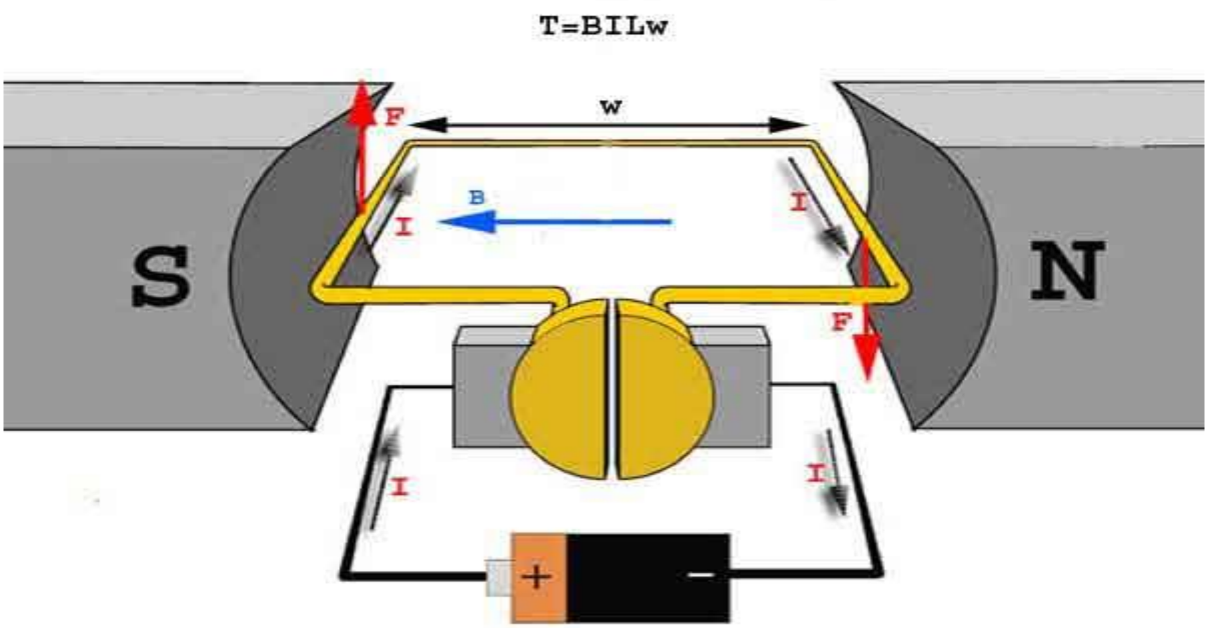
The presence of the term cosα in the torque equation very well signifies that unlike force the torque at all position is not the same. It in fact varies with the variation of the angle α. To explain the variation of torque and the principle behind rotation of the motor let us do a step wise analysis.



Step 1: Initially considering the armature is in its starting point or reference position where the angle α = 0.

$$\therefore \ \tau = BILw \times \cos 0^\circ = BILw$$

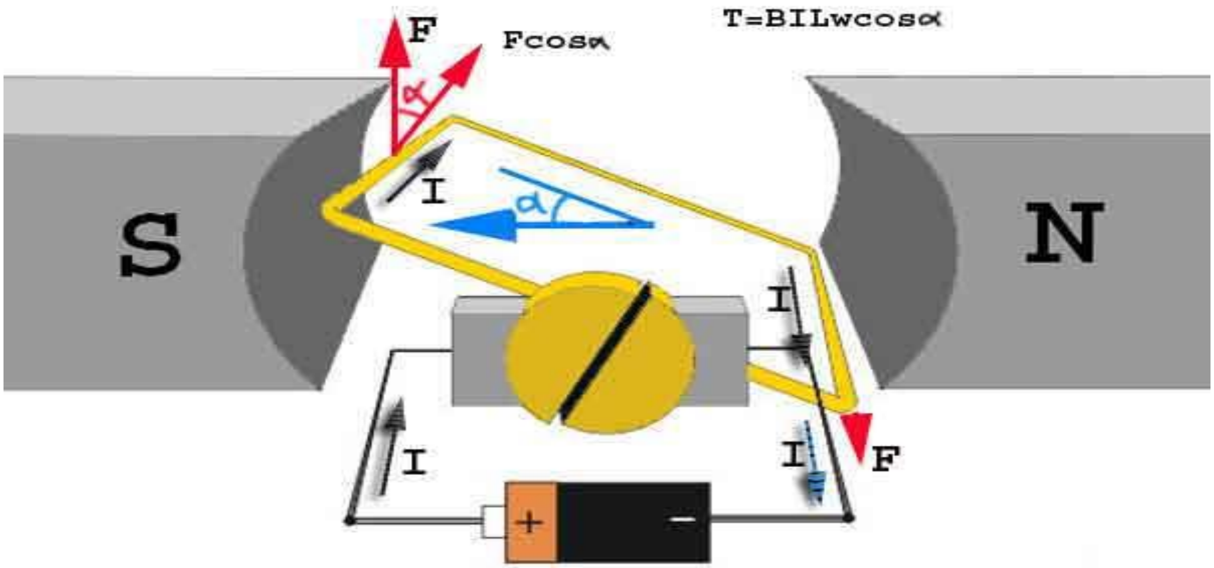
Since α = 0, the term cos α = 1, or the maximum value, hence torque at this position is maximum given by τ = BILw. This high starting torque helps in overcoming the initial inertia of rest of the armature and sets it into rotation.



Step 2: Once the armature is set in motion, the angle α between the actual position of the armature and its reference initial position goes on increasing in the path of its rotation until it

becomes 90° from its initial position. Consequently the term cosα decreases and also the value of torque.

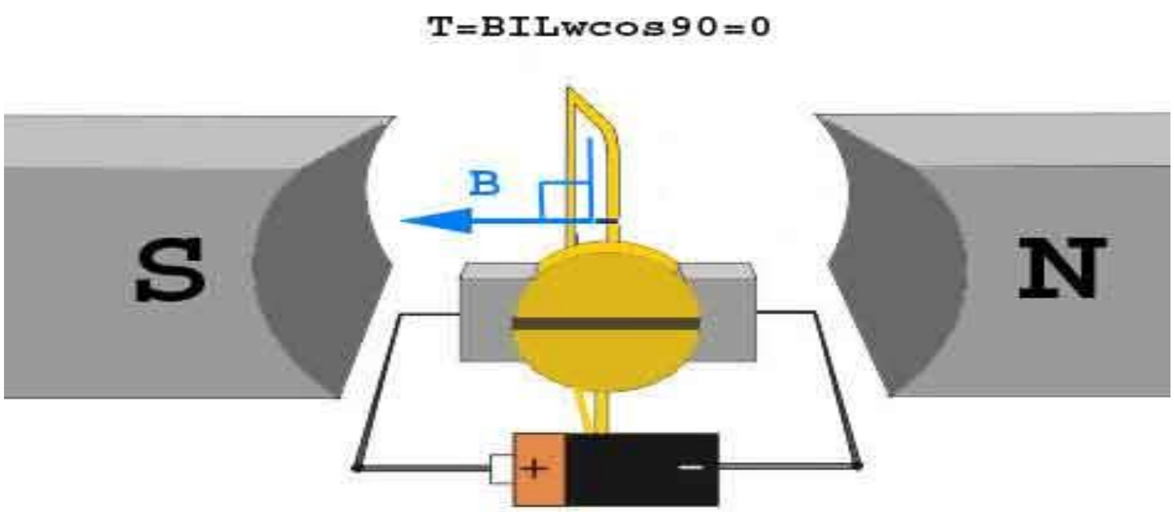
The torque in this case is given by τ = BILwcosα which is less than BIL w when α is greater than 0°.



Step 3: In the path of the rotation of the armature a point is reached where the actual position of the rotor is exactly perpendicular to its initial position, i.e. α = 90°, and as a result the term cosα = 0.

The torque acting on the conductor at this position is given by,

$$\therefore \tau = BIL\omega \times \cos 90^o = 0$$

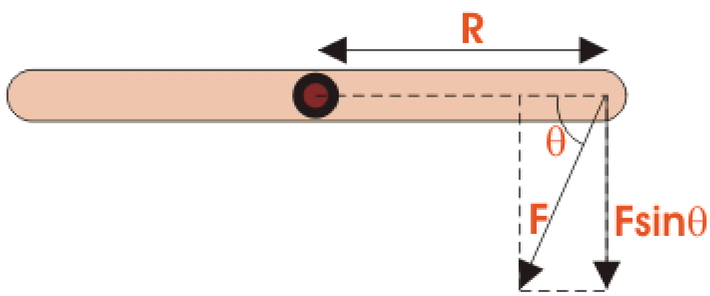


i.e. virtually no rotating torque acts on the armature at this instance. But still the armature does not come to a standstill, this is because of the fact that the operation of dc motor has been engineered in such a way that the inertia of motion at this point is just enough to overcome this point of null torque. Once the rotor crosses over this position the angle between the actual position of the armature and the initial plane again decreases and torque starts acting on it again.

The equation of torque is given by,

$$\tau = FR\sin\theta ....(1)$$

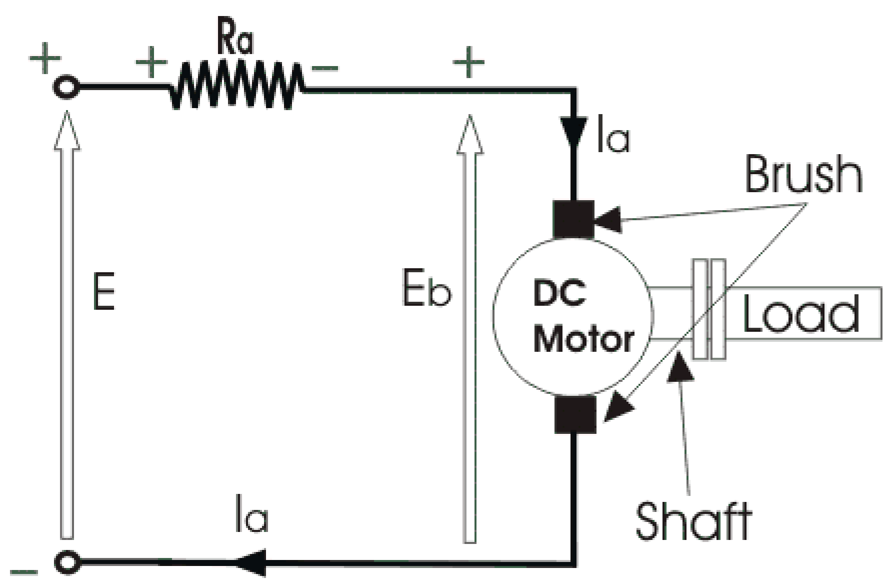
Where F is force in linear direction. R is radius of the object being rotated, and θ is the angle, the



force F is making with R vector

The dc motor as we all know is a rotational machine, and **torque of dc motor** is a very important parameter in this concern, and it's of utmost importance to understand the **torque equation of dc motor** for establishing its running characteristics.

To establish the torque equation, let us first consider the basic circuit diagram of a dc motor, and



its voltage equation.

Referring to the diagram beside, we can see, that if E is the supply voltage, E_b is the back emf produced and I_a, R_a are the armature current and armature resistance respectively then the voltage equation is given by,

$$E = E_b + I_a R_a \;\ldots\ldots\ldots\ldots\ldots\ldots\; (2)$$

But keeping in mind that our purpose is to derive the **torque equation of dc motor** we multiply both sides of equation (2) by I_a.

$$Therefore,\; EI_a = E_b I_a + I_a^2 R_a \;\ldots\ldots\ldots\ldots\ldots\ldots\; (3)$$

Now $I_a^2.R_a$ is the power loss due to heating of the armature coil, and the true effective mechanical power that is required to produce the desired torque of dc machine is given by,

$$P_m = E_b I_a \;\ldots\ldots\ldots\ldots\ldots\; (4)$$

The mechanical power P_m is related to the electromagnetic torque T_g as,

$$P_m = T_g \omega \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (5)$$

Where ω is speed in rad/sec.

Now equating equation (4) & (5) we get,

$$E_b I_a = T_g \omega$$

Now for simplifying the torque equation of dc motor we substitute.

$$E_b = \frac{P\varphi ZN}{60A} \;\ldots\ldots\ldots\ldots\ldots\ldots\; (6)$$

Where, P is no of poles, φ is flux per pole, Z is no. of conductors, A is no. of parallel paths, and N is the speed of the D.C. motor.

$$Hence,\; w = \frac{2\pi N}{60} \;\ldots\ldots\ldots\ldots\ldots\ldots\; (7)$$

Substituting equation (6) and (7) in equation (4), we get:

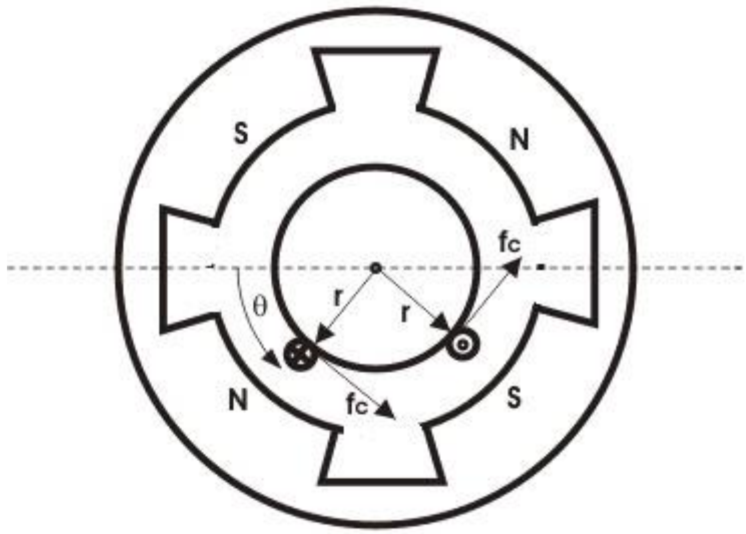
$$T_g = \frac{P.Z.\varphi.I_a}{2\pi A}$$

The torque we so obtain, is known as the electromagnetic torque of dc motor, and subtracting the mechanical and rotational losses from it we get the mechanical torque. Therefore, $T_m = T_g$ - mechanical losses. This is the torque equation of dc motor. It can be further simplified as:

$$T_g = k_a \phi I_A$$

$$Where,\; k_a = \frac{P.Z}{2\pi A}$$

Which is constant for a particular machine and therefore the torque of dc motor varies with only flux φ and armature current I_a. The Torque equation of a dc motor can also be explained considering the figure below



.

$$Here\ we\ can\ see\ Area\ per\ pole\ A_r = \frac{2\pi.r.L}{P}$$

$$B = \frac{\varphi}{A_r}$$

$$B = \frac{P.\varphi}{2\pi r L}$$

Current / conductor $I_c = I_a / A$ Therefore, force per conductor $= f_c = BLI_a/A$ Now torque $T_c = f_c.r = BLI_a.r/A$

$$\therefore\ T_c = \frac{\varphi P.I_a}{2\pi A}$$

Hence the total torque developed of a dc machine is,

$$T_g = \frac{P.Z.\varphi.I_a}{2\pi.A}$$

This torque equation of dc motor can be further simplified as:

$$T_g = k_a \phi I_a$$

$$Where,\ k_a = \frac{P.Z}{2\pi.A}$$

Which is constant for a particular machine and therefore the torque of dc motor varies with only flux φ and armature current I_a.

EMF Equation of DC Generator

The derivation of **EMF equation for DC generator** has two parts:

1. Induced EMF of one conductor
2. Induced EMF of the generator

Derivation for Induced EMF of One Armature Conductor
For one revolution of the conductor, Let Φ = Flux produced by each pole in weber (Wb) and P = number of poles in the DC generator therefore, Total flux produced by all the poles

$$= \phi \times P$$

And, Time taken to complete one revolution

$$= \frac{60}{N}$$

Where, N = speed of the armature conductor in rpm Now,according to Faraday's law of induction, the induced emf of the armature conductor is denoted by "e" which is equal to rate of cutting the flux. Therefore,

$$e = \frac{d\phi}{dt} \ and \ e = \frac{total\ flux}{time\ take}$$

Induced emf of one conductor is

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

Derivation for Induced EMF for DC Generator

Let us suppose there are Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series. Here, Z = total numbers of conductor A = number of parallel paths Then, Z/A = number of conductors connected in series We know that induced emf in each path is same across the line Therefore, Induced emf of DC generator E = emf of one conductor × number of conductor connected in series.

Induced emf of DC generator is

$$e = \phi P \frac{N}{60} X \frac{Z}{A} \ volts$$

Simple wave wound generator Numbers of parallel paths are only 2 = A Therefore, Induced emf for wave type of winding generator is

$$\frac{\phi PN}{60} X \frac{Z}{2} = \frac{\phi ZPN}{120} \ volts$$

Simple lap-wound generator Here, number of parallel paths is equal to number of conductors in one path i.e. P = A Therefore, **Induced emf for lap-wound generator is**

$$E_g = \frac{\phi ZN}{60} X \frac{P}{A} volt$$

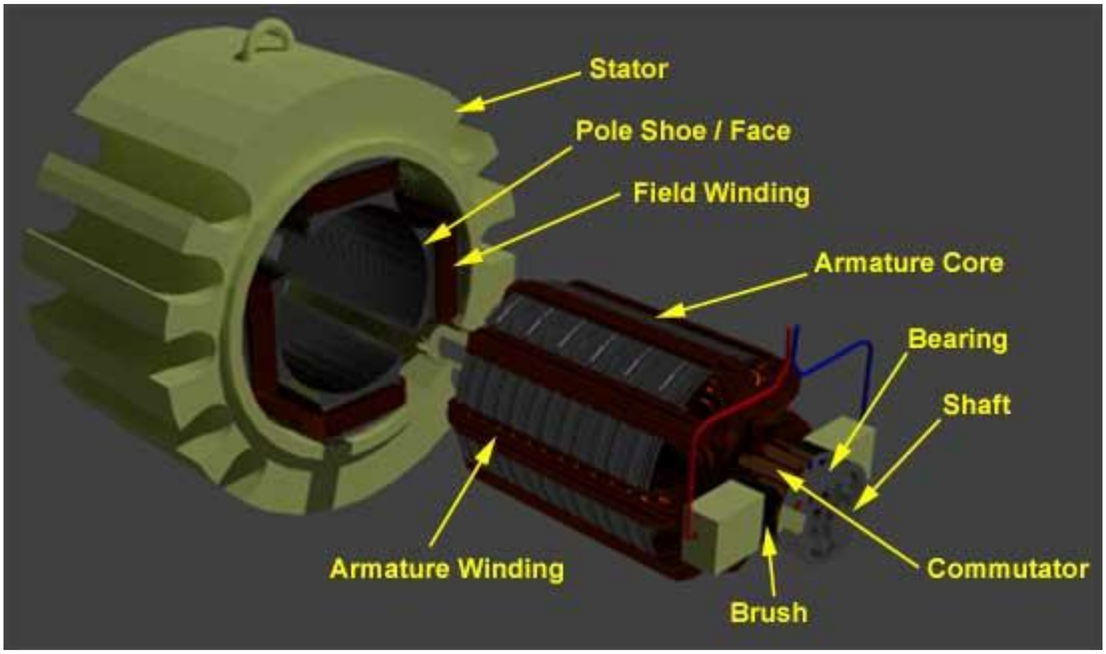
Construction of DC Motor | Yoke Poles Armature Field Winding Commutator Brushes of DC Motor

A DC motor like we all know is a device that deals in the conversion of electrical energy to mechanical energy and this is essentially brought about by two major parts required for the **construction of dc motor**, namely. 1) Stator – The static part that houses the field windings and receives the supply and,

2) Rotor – The rotating part that brings about the mechanical rotations.
Other than that there are several subsidiary parts namely the

3) **Yoke of dc motor**.
4) **Poles of dc motor**.
5) **Field winding of dc motor**.
6) **Armature winding of dc motor**.
7) **Commutator of dc motor**.
8) **Brushes of dc motor**.

All these parts put together configures the total **construction of a dc motor**. Now let's do a detailed discussion about all the essential parts of dc motor.



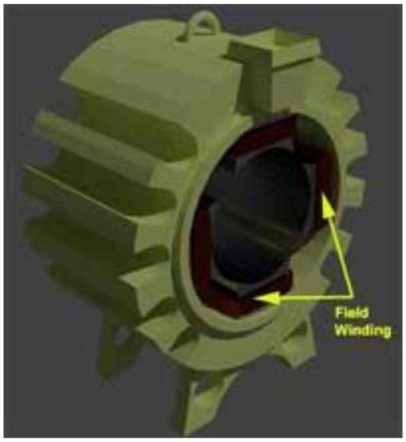
Yoke of DC Motor

The magnetic frame or the **yoke of dc motor** made up of cast iron or steel and forms an integral part of the stator or the static part of the motor. Its main function is to form a protective covering over the inner sophisticated parts of the motor and provide support to the armature. It also supports the field system by housing the magnetic poles and field winding of the dc motor.

Poles of DC Motor

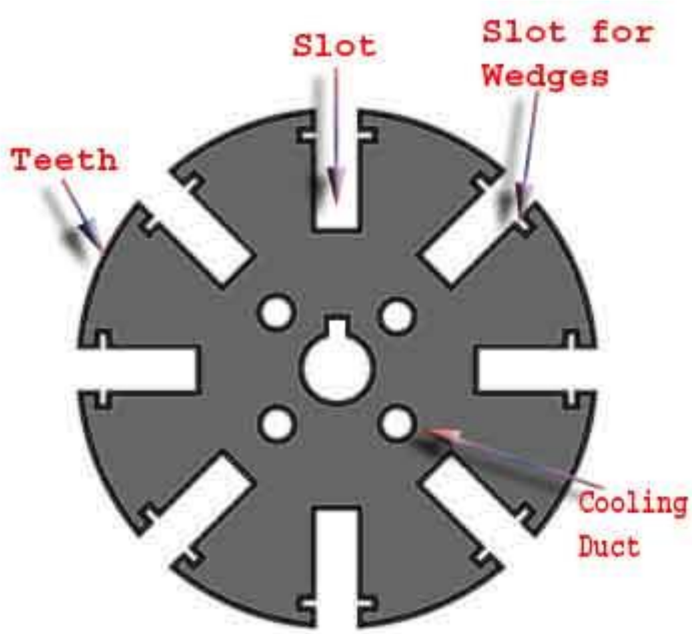
The magnetic **poles of DC motor** are structures fitted onto the inner wall of the yoke with screws. The construction of magnetic poles basically comprises of two parts namely, the pole core and the pole shoe stacked together under hydraulic pressure and then attached to the yoke. These two structures are assigned for different purposes, the pole core is of small cross sectional area and its function is to just hold the pole shoe over the yoke, whereas the pole shoe having a relatively larger cross-sectional area spreads the flux produced over the air gap between the stator and rotor to reduce the loss due to reluctance. The pole shoe also carries slots for the field windings that produce the field flux.

Field Winding of DC Motor



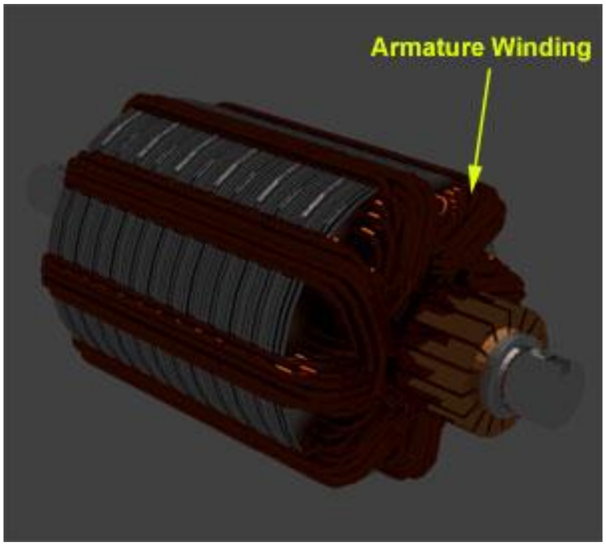
The **field winding of dc motor** are made with field coils (copper wire) wound over the slots of the pole shoes in such a manner that when field current flows through it, then adjacent poles have opposite polarity are produced. The field winding basically form an electromagnet, that produces field flux within which the rotor armature of the dc motor rotates, and results in the effective flux cutting.

Armature Winding of DC Motor



The **armature winding of dc motor** is attached to the rotor, or the rotating part of the machine, and as a result is subjected to altering magnetic field in the path of its rotation which directly results in magnetic losses. For this reason the rotor is made of armature core, that's made with several low-hysteresis silicon steel lamination, to reduce the magnetic losses like hysteresis and eddy current loss respectively. These laminated steel sheets are stacked together to form the cylindrical structure of the armature core.

The armature core are provided with slots made of the same material as the core to which the armature winding made with several turns of copper wire distributed uniformly over the entire periphery of the core. The slot openings a shut with fibrous wedges to prevent the conductor from plying out due to the high centrifugal force produced during the rotation of the armature, in presence of supply current and field.



The construction of **armature winding of dc motor** can be of two types:-

Lap Winding

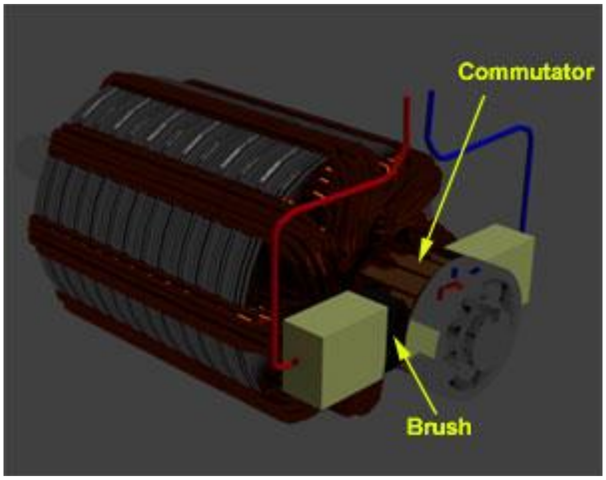
In this case the number of parallel paths between conductors A is equal to the number of poles P. i.e A = P

***An easy way of remembering it is by remembering the word LAP-----→ L A=P

Wave Winding

Here in this case, the number of parallel paths between conductors A is always equal to 2 irrespective of the number of poles. Hence the machine designs are made accordingly.

Commutator of DC Motor



The **commutator of dc motor** is a cylindrical structure made up of copper segments stacked together, but insulated from each other by mica. Its main function as far as the dc motor is concerned is to commute or relay the supply current from the mains to the armature winding housed over a rotating structure through the **brushes of dc motor**.

Brushes of DC Motor

The **brushes of dc motor** are made with carbon or graphite structures, making sliding contact over the rotating commutator. The brushes are used to relay the current from external circuit to the rotating commutator form where it flows into the armature winding. So, the commutator and brush unit of the dc motor is concerned with transmitting the power from the static electrical circuit to the mechanically rotating region or the rotor.

Armature Reaction in DC Machine

In a DC machine, the carbon brushes are always placed at the magnetic neutral axis. In no load condition, the magnetic neutral axis coincides with the geometrical neutral axis. Now, when the machine is loaded, the armature flux is directed along the inter polar axis (the axis in between the magnetic poles) and is triangular in wave shape. This results an armature current flux directed along the brush axis and causes cross magnetization of the main field. This cross magnetization effect results in the concentration of flux at the trailing pole tip in generator action and at the leading pole tip in motor action.

What is leading and trailing pole tip?

The tip of the pole from where the armature conductors come into influence is called leading tip and the other tip opposite in direction to it will be the trailing tip. For example, in the above figure if the motor rotates clockwise, then for North Pole, the lower tip is leading tip and for South Pole upper tip is leading tip. If the motion is reversed (in case of generator), the tips is interchanged. Due to cross magnetization, the magnetic neutral axis on load, shifts along the direction of rotation in DC generator and opposite to the direction of rotation in DC motor. If the brushes remain at their previous positions, then back e.m.f in case of motor or generated e.m.f in case of generator would reduce and commutation would be accompanied by heavy sparking. This is because commutation occurs at the coils located on the brushes only, and the coil undergoing commutation comes under the influence of the alternate pole(changes its location from north to south pole or vice versa). Hence, the direction of current flowing in the coil also reverses in a very short duration of time i.e., current changes from + i to – i or vice versa in a small span of time. This induces a very high magnitude of reactance voltage (L*di/dt) in the coil which emerges out in the form of heat energy along with sparking, thus damaging the brushes and commutator segment. To reduce the adverse effects mentioned above and to improve the machine’s performance, following methods are used:

Brush Shift

A natural solution to the problem appears to shift the brushes along the direction of rotation in generator action and against the direction of rotation in motor action, this would result into a reduction in air gap flux. This will reduce the induced voltage in generator and would increase the speed in motor. The demagnetizing m.m.f (magneto motive force) thus produced is given by: Where, I_a = armature current, Z = total number of conductors, P = total number of poles, β = angular shift of carbon brushes (in electrical Degrees). Brush shift has serious limitations, so the brushes have to be shifted to a new position every time the load changes or the direction of rotation changes or the mode of operation changes. In view of this, brush shift is limited only to very small machines. Here also, the brushes are fixed at a position corresponding to its normal load and the mode of operation. Due to these limitations, this method is generally not preferred.

Inter Pole

The limitation of brush shift has led to the use of inter poles in almost all the medium and large sized DC machines. Inter poles are long but narrow poles placed in the inter polar axis. They have the polarity of succeeding pole(coming next in sequence of rotation) in generator action and proceeding (which has passed behind in rotation sequence) pole in motor action. The inter pole is designed to neutralize the armature reaction mmf in the inter polar axis. This is because the direction of armature reaction m.m.f is in the inter polar axis. It also provides commutation voltage for the coil undergoing commutation such that the commutation voltage completely neutralizes the reactance voltage (L di/dt). Thus, no sparking takes place.

Inter polar windings are always kept in series with armature, so inter polar winding carries the armature current ; therefore works satisfactorily irrespective of load, the direction of rotation or the mode of operation. Inter poles are made narrower to ensure that they influence only the coil undergoing commutation and its effect does not spread to the other coils. The base of the inter poles is made wider to avoid saturation and to improve response.

Compensating Winding

Commutation problem is not the only problem in DC machines. At heavy loads, the cross magnetizing armature reaction may cause very high flux density in the trailing pole tip in generator action and leading pole tip in the motor action.

Consequently, the coil under this tip may develop induced voltage high enough to cause a flashover between the associated adjacent commutator segments particularly, because this coil is physically close to the commutation zone (at the brushes) where the air temperature might be already high due to commutation process.

This flashover may spread to the neighboring commutator segments, leading ultimately to a complete fire over the commutator surface from brush to brush. Also, when the machine is subjected to rapidly fluctuating loads, then the voltage L* di/dt, that appears across the adjacent commutator segments may reach a value high enough to cause flashover between the adjacent commutator segments. This would start from the centre of pole as the coil below it possesses the maximum inductance. This may again cause a similar fire as described above. This problem is more acute while the load is decreasing in generating action and increasing in motor action as then, the induced e.m.f and voltage L* di/dt will support each other. The above problems are solved by use of compensating winding.

Compensating winding consists of conductors embedded in the pole face that run parallel to the shaft and carry an armature current in a direction opposite to the direction of current in the armature conductors under that pole arc. With complete compensation the main field is restored. This also reduces armature circuit's inductor and improves system response.Compensating winding functions satisfactorily irrespective of the load, direction of rotation and mode of operation. Obviously it is help in commutation as the inter polar winding gets relieved from its duty to compensate for the armature m.m.f under the pole arc.

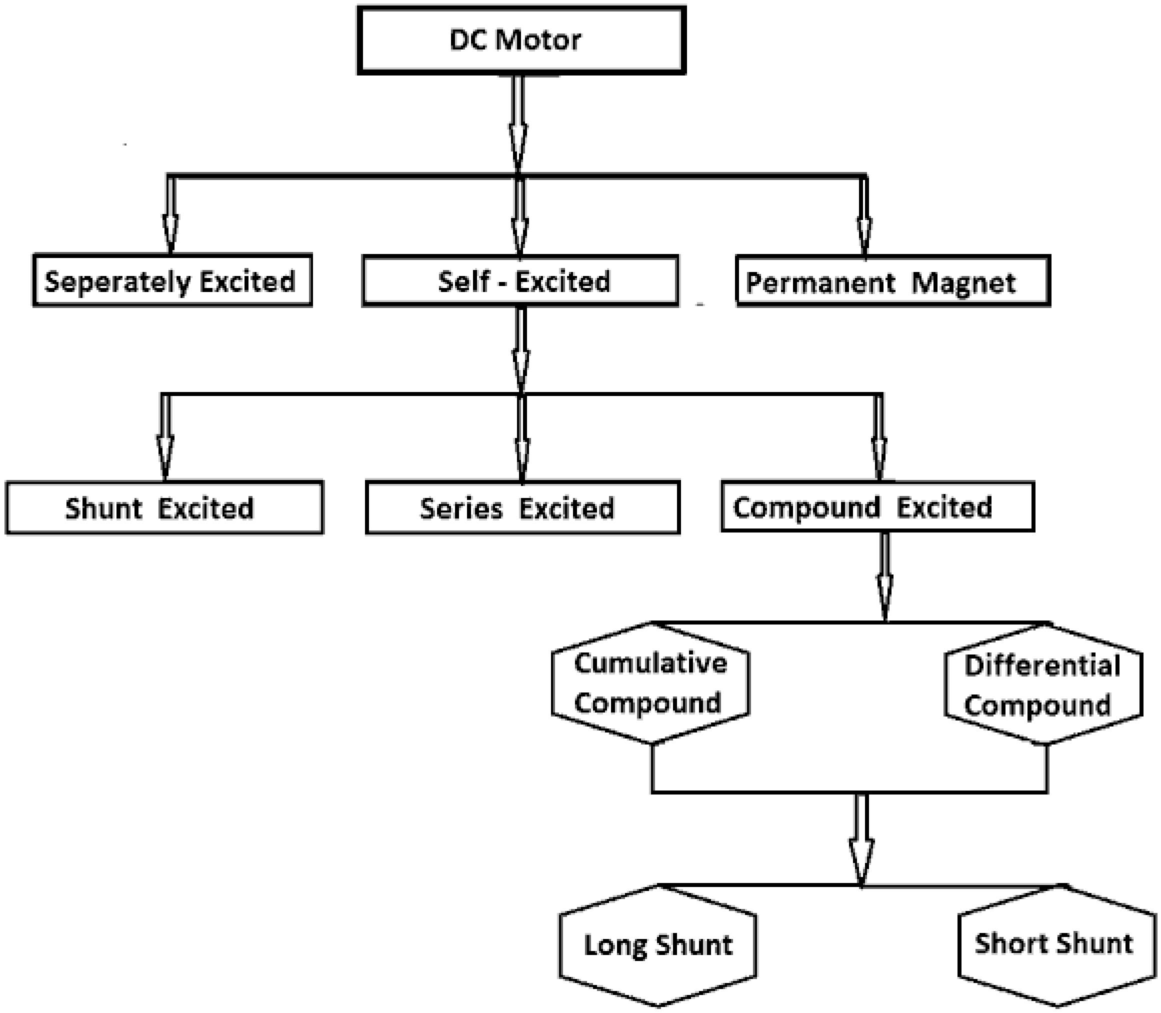
NOTE:

1. **The cross magnetizing armature reaction effect is mainly caused by armature conductors which are located under the pole arc. At high loads, this effect of armature reaction may cause excessive flux density in the trailing pole tip (in generator) and leading pole tip (in motor). Due to saturation in the pole shoe, the increase in flux density may be less than the reduction in the flux density in remaining section of the pole shoe. This would ultimately result into a net reduction in flux per pole. This phenomenon is thus known as the demagnetizing effect of cross magnetizing armature reaction, which is further compensated by the use of compensating windings.**
2. **Inter polar winding and compensating windings are connected in series with the armature winding but on the opposite sides with respect to armature.**
3. **The primary duty of inter polar winding is to improve the commutation process, and that of the compensating winding is to compensate for the increase or decrease in the net air gap flux i.e., to maintain its constant value.**

Types of DC Motor Separately Excited Shunt Series Compound DC Motor

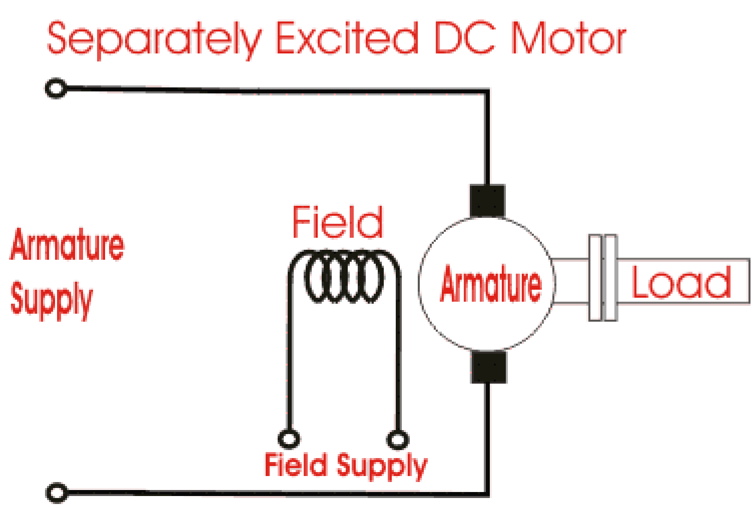
The direct current motor or the DC motor has a lot of application in today's field of engineering and technology. Starting from an electric shaver to parts of automobiles, in all small or medium sized motoring applications DC motors come handy. And because of its wide range of application different functional **types of dc motor** are available in the market for specific requirements. The **types of DC motor** can be listed as follows

- DC motor
- Permanent Magnet DC Motor
- Separately Excited DC Motor
- Self Excited DC Motor
- Shunt Wound DC Motor
- Series Wound DC Motor
- Compound Wound DC Motor
- Cumulative compound DC motor
- Short shunt DC Motor
- Long shunt DC Motor
- Differential Compound DC Motor
- Short Shunt DC Motor
- Long Shunt DC Motor



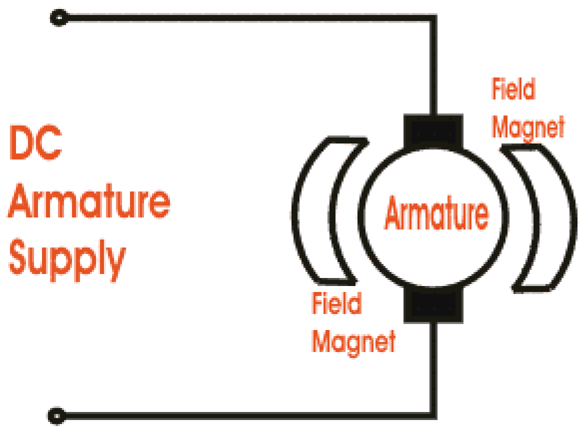
Now let's do a detailed discussion about all the essential types of dc motor.

Separately Excited DC Motor



As the name suggests, in case of a separately excited DC motor the supply is given separately to the field and armature windings. The main distinguishing fact in these types of dc motor is that, the armature current does not flow through the field windings, as the field winding is energized from a separate external source of dc current as shown in the figure beside.
From the torque equation of dc motor we know $T_g = K_a \varphi I_a$ So the torque in this case can be varied by varying field flux φ, independent of the armature current I_a.

Permanent Magnet DC Motor



Permanent Magnet DC Motor

The **permanent magnet DC motor** consists of an armature winding as in case of an usual motor, but does not necessarily contain the field windings. The construction of these types of DC motor are such that, radially magnetized permanent magnets are mounted on the inner periphery of the stator core to produce the field flux. The rotor on the other hand has a conventional dc armature with commutator segments and brushes. The diagrammatic representation of a permanent magnet dc motor is given below. The torque equation of dc motor suggests $T_g = K_a \varphi I_a$. Here φ is always constant, as permanent magnets of required flux density are chosen at the time of construction and can't be changed there after. For a permanent magnet dc motor $T_g = K_{a1} I_a$
Where $K_{a1} = K_a.\varphi$ which is another constant. In this case the torque of DC Motor can only be changed by controlling armature supply.

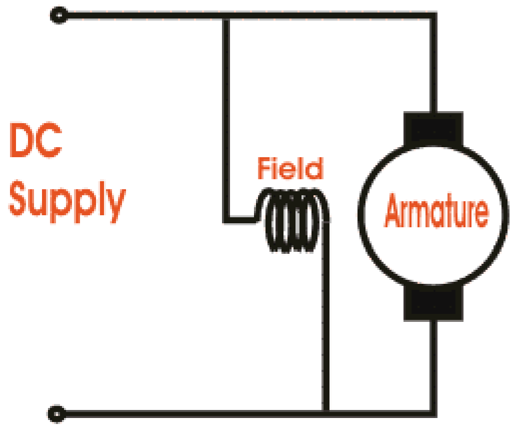
Self Excited DC Motor

In case of self excited dc motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding, and on this basis its further classified as:-

1. **Shunt wound DC motor**.
2. **Series wound DC motor**.
3. **Compound wound DC motor**.

Let's now go into the details of these types of self excited dc motor.

Shunt Wound DC Motor



Shunt Excited DC Motor

In case of a **shunt wound dc motor** or more specifically shunt wound self excited dc motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding as shown in the figure below.

To understand the characteristic of these types of DC motor, lets consider the basic voltage equation given by,

$$E = E_b + I_a R_a \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

[Where E, E_b, I_a, R_a are the supply voltage, back emf, armature current and armature resistance respectively]

$$Now,\ E_b = k_a \phi \omega \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

[since back emf increases with flux φ and angular speed ωω]

Now substituting E_b from equation (2) to equation (1) we get,

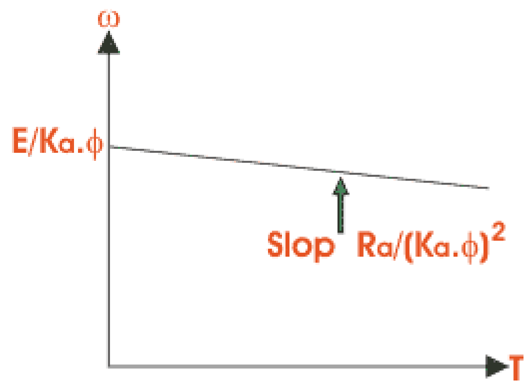
$$E = k_a \phi \omega + I_a R_a$$

$$\therefore \omega = \frac{E - I_a R_a}{k_a \varphi} \text{----------}(3)$$

The torque equation of a dc motor resembles,

$$T_g = K_a \phi I_a \cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

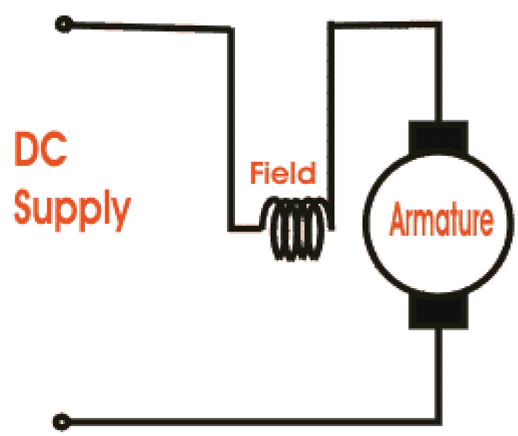
This is similar to the equation of a straight line, and we can graphically representing the torque speed characteristic of a shunt wound self excited dc motor as



The shunt wound dc motor is a constant speed motor, as the speed does not vary here with the variation of mechanical load on the output.

Series Wound DC Motor

In case of a series wound self excited dc motor or simply **series wound dc motor**, the entire armature current flows through the field winding as its connected in series to the armature winding. The series wound self excited dc motor is diagrammatically represented below for clear understanding.



Series Excited DC Motor

Now to determint the torque speed characteristic of these types of DC motor, lets get to the torque speed equation.

From the circuit diagram we can see that the voltage equation gets modified to

$$E = E_b + I_a(R_a + R_s) \cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

Where as back emf remains $E_b = k_a\varphi\omega$

Neglecting saturation we get,

$$\phi = K_1 I_f = K_1 I_a$$

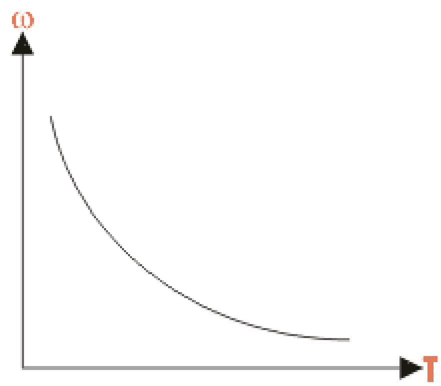
[since field current = armature current]

$$Therefore,\ E_b = k_a K_1 I_a \omega = K_s I_a \omega \cdots\cdots\cdots\cdots\cdots\cdots (6)$$

From equation (5) & (6)

$$\omega = \frac{E}{K_s I_a} - \frac{R_a + R_s}{K_s}$$

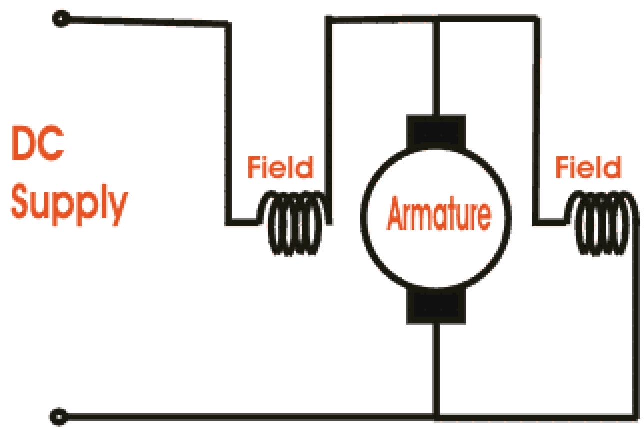
From this equation we obtain the torque speed characteristic as



In a series wound dc motor, the speed varies with load. And operation wise this is its main difference from a shunt wound dc motor.

Compound Wound DC Motor

The compound excitation characteristic in a dc motor can be obtained by combining the operational characteristic of both the shunt and series excited dc motor. The compound wound self excited dc motor or simply **compound wound dc motor** essentially contains the field winding connected both in series and in parallel to the armature winding as shown in the figure below



Cumulatively Compound Excited DC Motor

:

The excitation of compound wound dc motor can be of two types depending on the nature of compounding.

Cumulative Compound DC Motor

When the shunt field flux assists the main field flux, produced by the main field connected in series to the armature winding then its called cumulative compound dc motor.

$$\phi_{total} = \phi_{series} + \phi_{shunt}$$

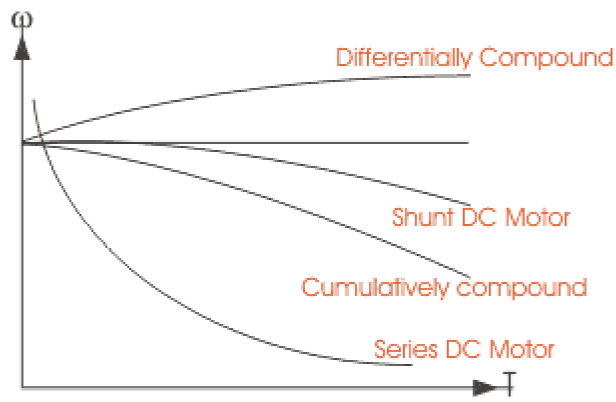
Differential Compound DC Motor

In case of a differentially compounded self excited dc motor i.e. differential compound dc motor, the arrangement of shunt and series winding is such that the field flux produced by the shunt field winding diminishes the effect of flux by the main series field winding.

$$\phi_{total} = \phi_{series} - \phi_{shunt}$$

The net flux produced in this case is lesser than the original flux and hence does not find much of a practical application.

The compounding characteristic of the self excited dc motor is shown in the figure below.



Both the cumulative compound and differential compound dc motor can either be of short shunt or long shunt type depending on the nature of arrangement.

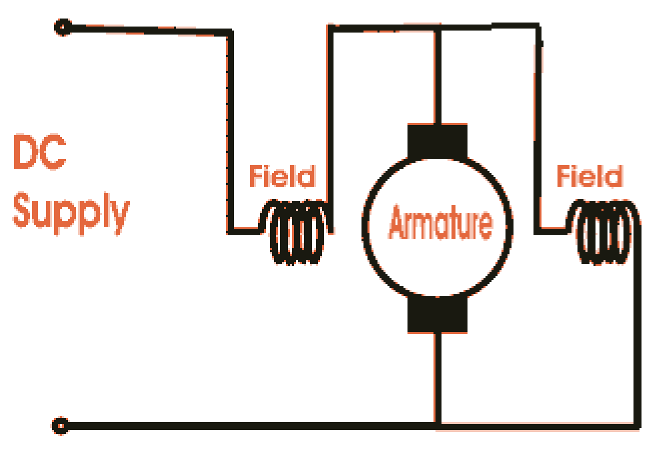
Short Shunt DC Motor

If the shunt field winding is only parallel to the armature winding and not the series field winding then its known as short shunt dc motor or more specifically short shunt type compound wound dc motor.

Long Shunt DC Motor

If the shunt field winding is parallel to both the armature winding and the series field winding then it's known as long shunt type compounded wound dc motor or simply long shunt dc motor.

Short shunt and long shunt type motors have been shown in the diagram below.



Short Shund DC Motor

Characteristics Of DC Motors

Generally, three characteristic curves are considered for DC motors which are, (i) Torque vs. armature current (Ta - Ia), (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of DC motor. These characteristics are determined by keeping following two relations in mind.
Ta α Φ.Ia and N α Eb/Φ

Characteristics Of DC Series Motors

Torque Vs. Armature Current (Ta-Ia)

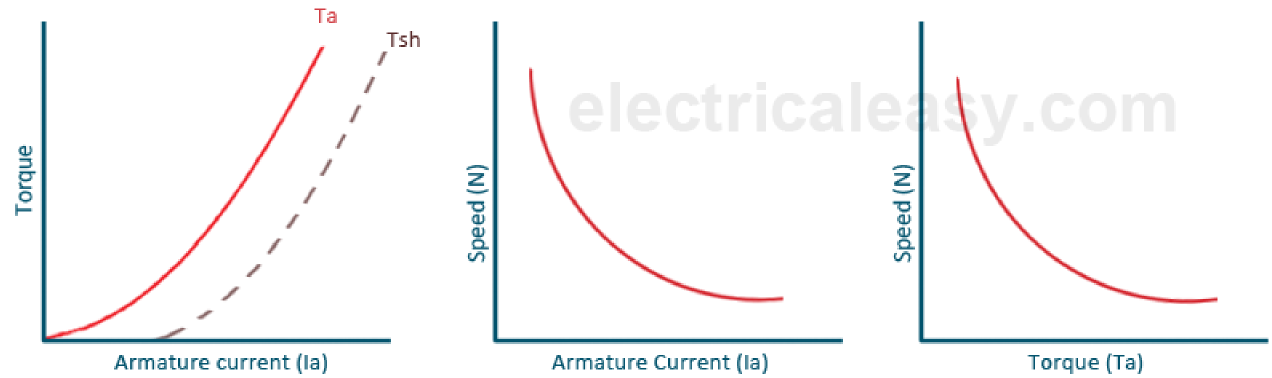
This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to armature current and flux, Ta α Φ.Ia. In DC series motors, field winding is connected in series with armature. Thus, before magnetic saturation of the field, flux Φ is directly proportional to Ia. Therefore, before magnetic saturation Ta α Ia^2. At light loads, Ia as well as Φ is small and hence the torque increases as the square of the armature current. Therefore, the Ta-Ia curve is parabola for smaller values of Ia.
After magnetic saturation of the field winding, flux Φ is independent of armature current Ia. Therefore, the torque varies proportional to Ia only, T α Ia.Therefore, after magnetic saturation, Ta-Ia curve becomes straight line.
The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses.
In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required

Speed Vs. Armature Current (N-Ia)

We know the relation, N α Eb/Φ
For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Thus, for small currents speed is inversely proportional to Φ. As we know, flux is directly proportional to Ia, speed is also inversely proportional to Ia.
When armature current is very small the speed becomes dangerously high. That is why **a series motor should never be started without some mechanical load**.
But, at heavy loads, armature current Ia is large. And hence speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.

Speed Vs. Torque (N-Ta)

This characteristic is also called as **mechanical characteristic**. From the above two characteristics of DC series motor, it can be found that when speed is high, torque is low and vice versa.



Characteristics of DC series motor

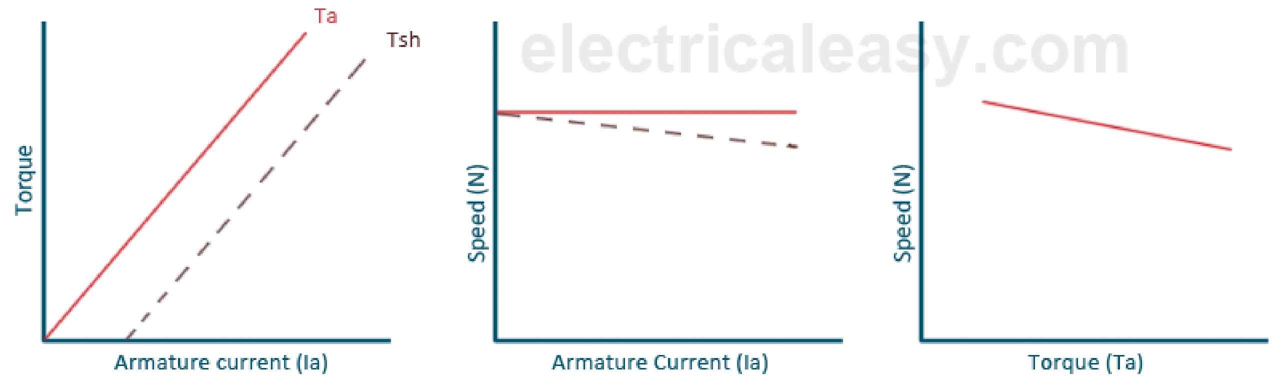
Characteristics Of DC Shunt Motors

Torque Vs. Armature Current (Ta-Ia)

In case of DC shunt motors we can assume the field flux Φ to be constant. Though at heavy loads, Φ decreases in a small amount due to increased armature reaction. But as we are neglecting the change in the flux Φ, we can say that torque is proportional to armature current. Hence the Ta-Ia characteristic for a dc shunt motor will be a straight line through origin. Since, heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load**.

Speed Vs. Armature Current (N-Ia)

As flux Φ is assumed constant, we can say N α Eb. But, back emf is also almost constant, the speed remains constant. But practically, Φ as well as Eb decreases with increase in load. But, the Eb decreases slightly more than Φ, and hence the speed decreases slightly. Generally, the speed decreases by 5 to 15% of full load speed only. And hence, **a shunt motor can be assumed as a constant speed motor**.



Characteristics of DC shunt motor

Characteristics Of DC Compound Motor

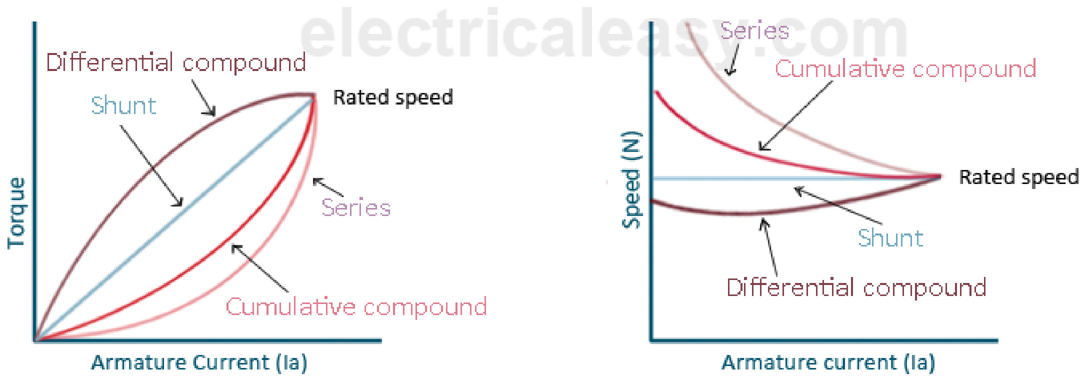
DC compound motors have both series as well as shunt windings. In a compound motor series and shunt windings are connected such that series flux is in direction with shunt flux then the motor is said to be cumulatively compounded. And if series flux is opposite direction as that of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these types are explained below.

(a) Cumulative compound motor

Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors are generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

(b) Differential compound motor

Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load. Differential compound motors are not commonly use, but they find limited applications in experimental and research work.



Characteristics of DC compound motor

Starting Methods to limit Starting Current and Torque of DC Motor

Starting of DC Motor

The **starting of DC motor** is somewhat different from the starting of all other types of electrical motors. This difference is credited to the fact that a dc motor unlike other types of motor has a very high starting current that has the potential of damaging the internal circuit of the armature winding of dc motor if not restricted to some limited value. This limitation to the **starting current of dc motor** is brought about by means of the starter. Thus the distinguishing fact about the **starting methods of dc motor** is that it is facilitated by means of a starter. Or rather a device containing a variable resistance connected in series to the armature winding so as to limit the starting current of dc motor to a desired optimum value taking into consideration the safety aspect of the motor.

Now the immediate question in **why the DC motor has such high starting current ?** To give an explanation to the above mentioned question let us take into consideration the basic operational voltage equation of the dc motor given by,

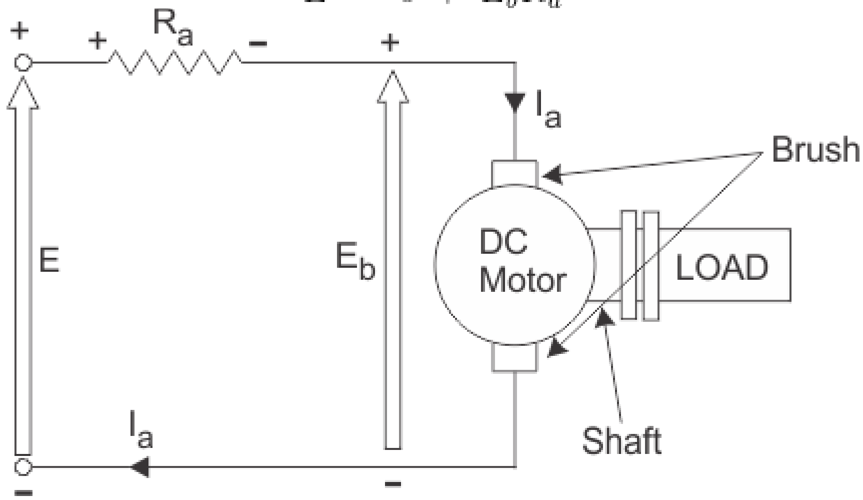
$$E = E_b + I_a R_a$$

Where E is the supply voltage, I_a is the armature current, R_a is the armature resistance. And the back emf is given by E_b. Now the back emf, in case of a dc motor, is very similar to the generated emf of a dc generator as it's produced by the rotational motion of the current carrying armature conductor in presence of the field. This back emf of dc motor is given by

$$E_b = \frac{P.\phi.Z.N}{60A}$$

and has a major role to play in case of the **starting of dc motor**. From this equation we can see that E_b is directly proportional to the speed N of the motor. Now since at starting N = 0, E_b is also zero, and under this circumstance the voltage equation is modified to

$$E = 0 + E_b R_a$$



$$Therefore,\ I_a = \frac{E}{R_a}$$

For all practical practices to obtain optimum operation of the motor the armature resistance is kept very small usually of the order of 0.5 Ω and the bare minimum supply voltage being 220 volts. Even under these circumstance the starting current, I_a is as high as 220/0.5 amp = 440 amp. Such high starting current of dc motor creates two major problems. 1) Firstly, current of the order of 400 A has the potential of damaging the internal circuit of the armature winding of dc motor at the very onset. 2) Secondly, since the torque equation of dc motor is given by

$$Therefore,\ I_a = \frac{E}{R_a}$$

Very high electromagnetic **starting torque of DC motor** is produced by virtue of the high starting current, which has the potential of producing huge centrifugal force capable of flying off the rotor winding from the slots.

Starting Methods of DC Motor

As a direct consequence of the two above mentioned facts i.e high starting current and high starting torque of DC motor, the entire motoring system can undergo a total disarray and lead towards into an engineering massacre and non-functionality. To prevent such an incidence from occurring several starting methods of dc motor has been adopted. The main principal of this being the addition of external electrical resistance R_{ext} to the armature winding, so as to increase the effective resistance to $R_a + R_{ext}$, thus limiting the armature current to the rated value. The new value of starting armature current is desirably low and is given by.

$$Therefore,\ I_a = \frac{E}{R_a + R_{ext}}$$

Now as the motor continues to run and gather speed, the back emf successively develops and increases, countering the supply voltage, resulting in the decrease of the net working voltage. Thus now,

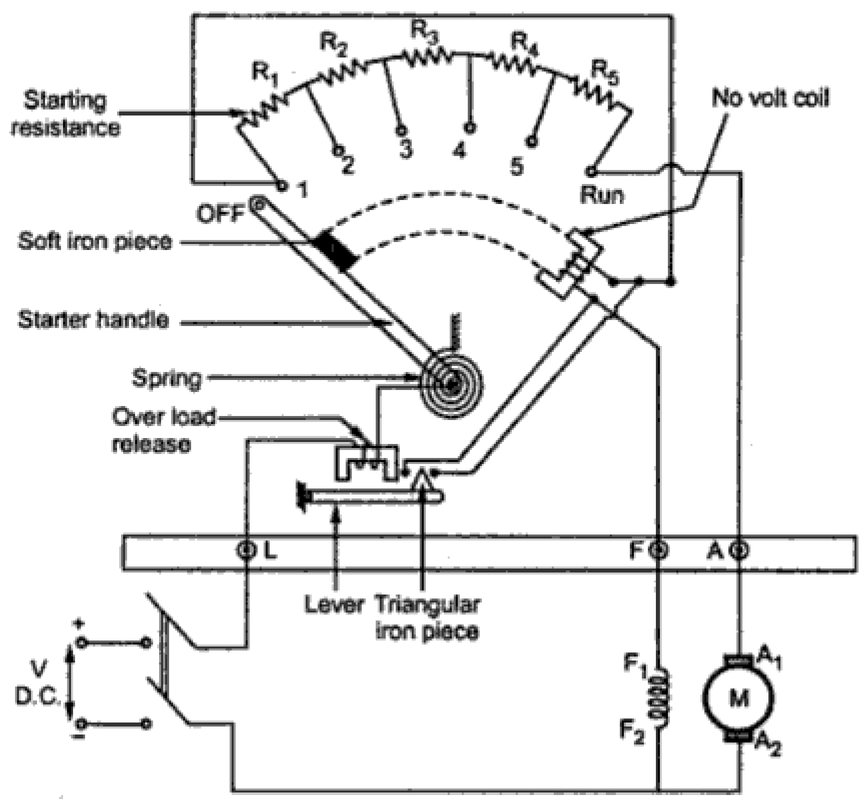
$$Therefore,\ I_a = \frac{E - E_b}{R_a + R_{ext}}$$

At this moment to maintain the armature current to its rated value, R_{ext} is progressively decreased unless its made zero, when the back emf produced is at its maximum. This regulation of the external electrical resistance in case of the starting of dc motor is facilitated by means of the starter.

Starters can be of several types and requires a great deal of explanation and some intricate level understanding. But on a brief over-view the main types of starters used in the industry today can be illustrated as:-

1) 3 point starter.
2) 4 point starter.

Used for the starting of shunt wound DC motor and compound wound DC motor.



3 point Starter

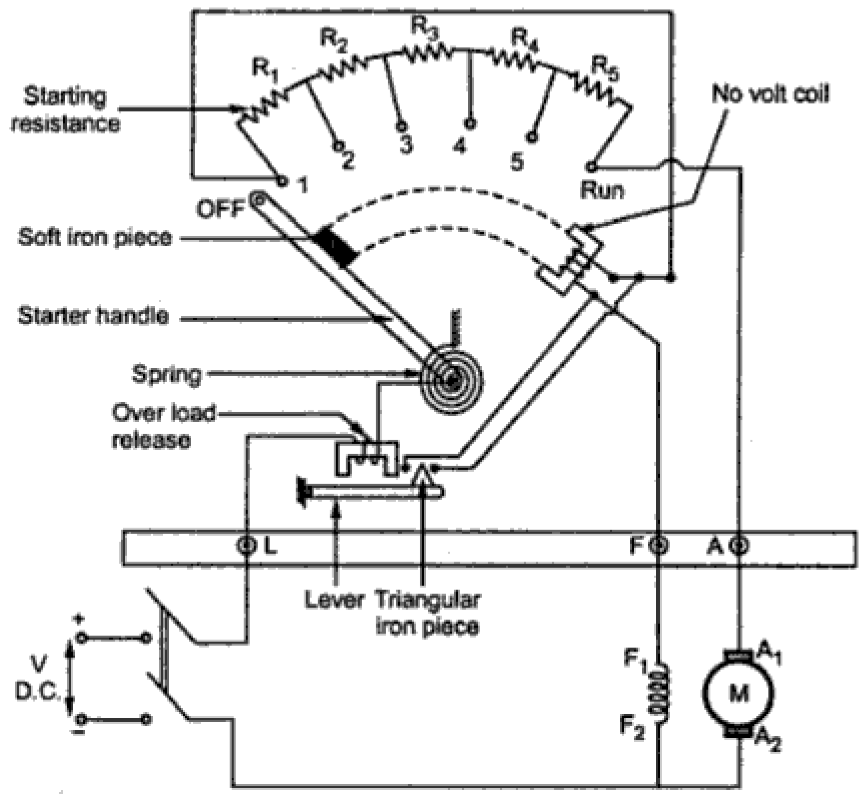
3 Point Starter | Working Principle and Construction of Three Point Starter

A **3 point starter** in simple words is a device that helps in the starting and running of a shunt wound DC motor or compound wound DC motor. Now the question is why these types of DC motors require the assistance of the starter in the first case. The only explanation to that is given by the presence of back emf E_b, which plays a critical role in governing the operation of the motor. The back emf, develops as the motor armature starts to rotate in presence of the magnetic field, by generating action and counters the supply voltage. This also essentially means, that the back emf at the starting is zero, and develops gradually as the motor gathers speed.

The general motor emf equation $E = E_b + I_a.R_a$, at starting is modified to $E = I_a.R_a$ as at starting $E_b = 0$.

$$\therefore\ I_a = \frac{E}{R_a}$$

Thus we can well understand from the above equation that the current will be dangerously high at starting (as armature resistance R_a is small) and hence its important that we make use of a device like the **3 point starter** to limit the starting current to an allowable lower value. Let us now look into the construction and **working of three point starter** to understand how the starting current is restricted to the desired value. For that let's consider the diagram given below showing all essential parts of the three point starter.



<u>3 point Starter</u>

Construction of 3 Point Starter

Construction wise a starter is a variable resistance, integrated into number of sections as shown in the figure beside. The contact points of these sections are called studs and are shown separately as **OFF, 1, 2,3,4,5, RUN**. Other than that there are 3 main points, referred to as 1. 'L' Line terminal. (Connected to positive of supply.) 2. 'A' Armature terminal. (Connected to the armature winding.) 3. 'F' Field terminal. (Connected to the field winding.) And from there it gets the name 3 point starter. Now studying the construction of 3 point starter in further details reveals that, the point 'L' is connected to an electromagnet called overload release (OLR) as shown in the figure. The other end of 'OLR' is connected to the lower end of conducting lever of starter handle where a spring is also attached with it and the starter handle contains also a soft iron piece housed on it. This handle is free to move to the other side RUN against the force of the spring. This spring brings back the handle to its original OFF position under the influence of its own force. Another parallel path is derived from the stud '1', given to the another electromagnet called No Volt Coil (NVC) which is further connected to terminal 'F'. The starting resistance at starting is entirely in series with the armature. The OLR and NVC acts as the two protecting devices of the starter.

Working of Three Point Starter

Having studied its construction, let us now go into the **working of the 3 point starter**. To start with the handle is in the OFF position when the supply to the DC motor is switched on. Then handle is slowly moved against the spring force to make a contact with stud No. 1. At this point, field winding of the shunt or the compound motor gets supply through the parallel path provided to starting resistance, through No Voltage Coil. While entire starting resistance comes in series with the armature. The high starting armature current thus gets limited as the current equation at this stage becomes $I_a = E/(R_a+R_{st})$. As the handle is moved further, it goes on making contact with studs 2, 3, 4 etc., thus gradually cutting off the series resistance from the armature circuit as the motor gathers speed. Finally when the starter handle is in 'RUN' position, the entire starting resistance is eliminated and the motor runs with normal speed. This is because back emf is developed consequently with speed to counter the supply voltage and reduce the armature current. So the external electrical resistance is not required anymore, and is removed for optimum operation. The handle is moved manually from OFF to the RUN position with development of speed. Now the obvious question is once the handle is taken to the RUN position how is it supposed to stay there, as long as motor is running ? To find the answer to this question let us look into the working of No Voltage Coil.

Working of No Voltage Coil of 3 Point Starter

The supply to the field winding is derived through no voltage coil. So when field current flows, the NVC is magnetized. Now when the handle is in the 'RUN' position, soft iron piece connected to the handle and gets attracted by the magnetic force produced by NVC, because of flow of current through it. The NVC is designed in such a way that it holds the handle in 'RUN' position against the force of the spring as long as supply is given to the motor. Thus NVC holds the handle in the 'RUN' position and hence also called **hold on coil**.
Now when there is any kind of supply failure, the current flow through NVC is affected and it immediately looses its magnetic property and is unable to keep the soft iron piece on the handle, attracted. At this point under the action of the spring force, the handle comes back to OFF position, opening the circuit and thus switching off the motor. So due to the combination of NVC and the spring, the starter handle always comes back to OFF position whenever there is any supply problems. Thus it also acts as a protective device safeguarding the motor from any kind of abnormality.

Speed Regulation of DC Motor

On application of load the speed of a dc motor decreases gradually. This is not at all desirable. So the difference between no load and full load speed should be very less. The motor capable of maintaining a nearly constant speed for varying load is said to have good speed regulation i.e the difference between no load and full load speed is quite less. The speed regulation of a permanent magnet DC motor is good ranging from 10 - 15% whereas for dc shunt motor it is somewhat less than 10 %. DC series motor has poor value of regulation. In case of compound DC motor the speed regulation for dc cumulative compound is around 25 % while differential compound has its excellent value of 5 %.

Speed of a DC Motor

The emf equation of DC motor is given by

$$E = \frac{NP\phi Z}{60A}$$

Here N = speed of rotation in rpm. P = number of poles. A = number of parallel paths. Z = total no. conductors in armature.

$$Thus,\ speed\ of\ rotation\ N = \frac{60A}{PZ} X \frac{E}{\phi}$$

$$\Rightarrow N = \frac{E}{k\phi} \quad Where\ k = \frac{PZ}{60A}\ is\ a\ constant$$

Hence, speed of a DC motor is directly proportional to emf of rotation (E) and inversely proportional to flux per pole (φ).

Speed Regulation of a DC Motor

The speed regulation is defined as the change in speed from no load to full load, expressed as a fraction or percentage of full load speed. Therefore, as per definition per unit (p.u) **speed regulation of DC motor** is given as,

$$Speed\ Regulation_{pu} = \frac{N_{no\ load} - N_{full\ load}}{N_{full\ load}}$$

Similarly, percentage (%) **speed regulation** is given as,

$$Speed\ Regulation(\%) = \frac{N_{no\ load} - N_{full\ load}}{N_{full\ load}} \times 100\%$$

Where $N_{no\ load}$ = no load speed and $N_{full\ lod}$ = full load speed of DC motor. Therefore, Percent speed regulation = Per unit (p.u) speed regulation X 100 %. A motor which has nearly constant speed at all load below full rated load, have good speed regulation.

Speed Control of DC Motor

Speed control means intentional change of the drive speed to a value required for performing the specific work process. Speed control is a different concept from speed regulation where there is natural change in speed due change in load on the shaft. Speed control is either done manually by the operator or by means of some automatic control device.

One of the important features of dc motor is that its speed can be controlled with relative ease. We know that the expression of speed control dc motor is given as,

$$E = \frac{NP\phi Z}{60A}$$

Therefore speed (N) of 3 types of dc motor – SERIES, SHUNT AND COMPOUND can be controlled by changing the quantities on RHS of the expression. So speed can be varied by changing (i) terminal voltage of the armature V , (ii) external resistance in armature circuit R and (iii) flux per pole φ . The first two cases involve change that affects armature circuit and the third one involves change in magnetic field. Therefore speed control of dc motor is classified as 1) armature control methods and 2) field control methods.

Speed Control of DC Series Motor

Speed control of dc series motor can be done either by armature control or by field control.

Armature Control of DC Series Motor

Speed adjustment of dc series motor by armature control may be done by any one of the methods that follow,

1. Armature resistance control method: This is the most common method employed. Here the controlling resistance is connected directly in series with the supply to the motor as shown in the fig. diagram The power loss in the control resistance of dc series motor can be neglected because this control method is utilized for a large portion of time for reducing the speed under light load condition. This method of speed control is most economical for constant torque. This method of speed control is employed for dc series motor driving cranes, hoists, trains etc. 2. Shunted armature control: The combination of a rheostat shunting the armature and a rheostat in series with the armature is involved in this method of speed control. The voltage applied to the armature is varies by varying series rheostat R_1. The exciting current can be varied by varying the armature shunting resistance R_2. This method of speed control is not economical due to considerable power losses in speed controlling resistances. Here speed control is obtained over wide range but below normal speed. Diagram :

3. Armature terminal voltage control: The speed control of dc series motor can be accomplished by supplying the power to the motor from a separate variable voltage supply. This method involves high cost so it rarely used.

Field Control of DC Series Motor

The speed of dc motor can be controlled by this method by any one of the following ways –

1. Field diverter method: This method uses a diverter. Here the field flux can be reduced by shunting a portion of motor current around the series field. Lesser the diverter resistance less is the field current, less flux therefore more speed. This method gives speed above normal and the method is used in electric drives in which speed should rise sharply as soon as load is decreased.
2. Tapped Field control: This is another method of increasing the speed by reducing the flux and it is done by lowering number of turns of field winding through which current flows. In this method a number of tapping from field winding are brought outside . This method is employed in electric traction.

Speed Control of DC Shunt Motor

Speed of dc shunt motor is controlled by the factors stated below

Field Control of DC Shunt Motor

By this method speed control is obtained by any one of the following means –

1. Field rheostat control of DC Shunt Motor: In this method, speed variation is accomplished by means of a variable resistance inserted in series with the shunt field. An increase in controlling resistances reduces the field current with a reduction in flux and an increase in speed. This method of speed control is independent of load on the motor. Power wasted in controlling resistance is very less as field current is a small value. This method of speed control is also used in DC compound motor.

Limitations of this method of speed control:

A. Creeping speeds cannot be obtained.

B. Top speeds only obtained at reduced torque

C. The speed is maximum at minimum value of flux, which is governed by the demagnetizing effect of armature reaction on the field.

2. Field voltage control: This method requires a variable voltage supply for the field circuit which is separated from the main power supply to which the armature is connected. Such a variable supply can be obtained by an electronic rectifier.

Armature Control of DC Shunt Motor

Speed control by this method involves two ways . These are :
1. Armature resistance control : In this method armature circuit is provided with a variable resistance. Field is directly connected across the supply so flux is not changed due to variation of series resistance. This is applied for dc shunt motor. This method is used in printing press, cranes, hoists where speeds lower than rated is used for a short period only.
2. Armature voltage control: This method of speed control needs a variable source of voltage separated from the source supplying the field current. This method avoids disadvantages of poor speed regulation and low efficiency of armature-resistance control methods. The basic adjustable armature voltage control method of speed d control is accomplished by means of an adjustable voltage generator is called Ward Leonard system. This method involves using a motor – generator (M-G) set. This method is best suited for steel rolling mills, paper machines, elevators, mine hoists, etc.

Advantages of this method –

A. Very fine speed control over whole range in both directions

B. Uniform acceleration is obtained

C. Good speed regulation

Disadvantages –

A. Costly arrangement is needed , floor space required is more

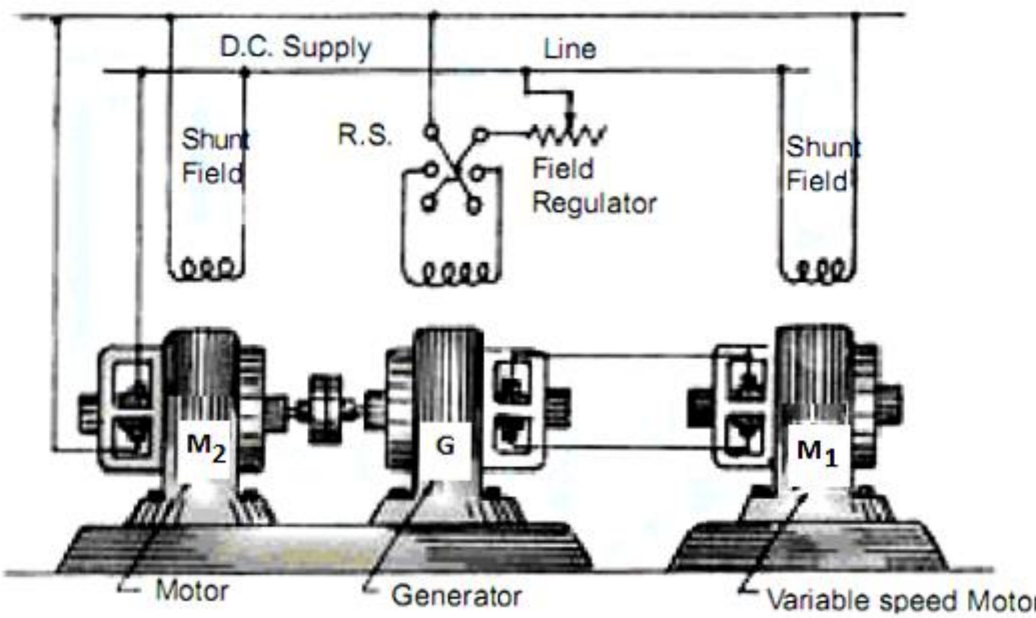
B. Low efficiency at light loads

Ward Leonard Method of Speed Control

Ward Leonard control system is introduced by Henry Ward Leonard in 1891. Ward Leonard method of speed control is used for controlling the speed of a DC motor. It is a basic armature control method. This control system is consisting of a dc motor M_1 and powered by a DC generator G. In this method the speed of the dc motor (M_1) is controlled by applying variable voltage across its armature. This variable voltage is obtained using a motor-generator set which consists of a motor M_2(either ac or dc motor) directly coupled with the generator G. It is a very widely used method of speed control of DC motor.

Principle of Ward Leonard Method

Basic connection diagram of the Ward Leonard speed control system is shown in the figure below.



WARD LEONARD SYSTEM OF SPEED CONTROL

The speed of motor M_1 is to be controlled which is powered by the generator G. The shunt field of the motor M_1 is connected across the dc supply lines. Now, generator G is driven by the motor M_2. The speed of the motor M_2 is constant. When the output voltage of the generator is fed to the motor M_1 then the motor starts to rotate. When the output voltage of the generator varies then the speed of the motor also varies. Now controlling the output voltage of the generator the speed of motor can also be controlled. For this purpose of controlling the output voltage, a field regulator is connected across the generator with the dc supply lines to control the field excitation. The direction of rotation of the motor M_1 can be reversed by excitation current of the generator and it can be done with the help of the reversing switch R.S. But the motor-generator set must run in the same direction.

Advantages of Ward Leonard System

1. It is a very smooth speed control system over a very wide range (from zero to normal speed of the motor).
2. The speed can be controlled in both the direction of rotation of the motor easily.
3. The motor can run with a uniform acceleration.
4. Speed regulation of DC motor in this ward Leonard system is very good.

Disadvantages of Ward Leonard System

1. The system is very costly because two extra machines (motor-generator set) are required.
2. Overall efficiency of the system is not sufficient especially it is lightly loaded.

Application of Ward Leonard System

This Ward Leonard method of speed control system is used where a very wide and very sensitive speed control is of a DC motor in both the direction of rotation is required. This speed control system is mainly used in colliery winders, cranes, electric excavators, mine hoists, elevators, steel rolling mills and paper machines etc.

Losses in DC Machine

As we know "Energy neither can be created nor it can be destroyed, it can only be transferred from one form to another". In DC machine, mechanical energy is converted into the electrical energy. During this process, the total input power is not transformed into output power. Some part of input power gets wasted in various forms. The foam of this loss may vary from machine to machine. These losses give in rise in temperature of machine and reduce the efficiency of the machine. In DC Machine, there are broadly four main categories of energy loss.

Copper Losses or Electrical Losses in DC Machine

The copper losses are the winding losses taking place during the current flowing through the winding. These losses occur due to the resistance in the winding. In DC machine, there are only two winding, armature and field winding. Thus copper losses categories in three parts; armature loss, field winding loss, and brush contact resistance loss. The copper losses are proportional to square of the current flowing through the winding.

Armature Copper Loss in DC Machine

Armature copper loss = $I_a^2R_a$ Where, I_a is armature current and R_a is armature resistance. These losses are about 30% of the total losses.

Field Winding Copper Loss in DC Machine

Field winding copper loss = $I_f^2R_f$ Where, I_f is field current and R_f is field resistance. These losses are about 25% theoretically, but practically it is constant.

Brush Contact Resistance Loss in DC Machine

Brush contact loss attributes to resistance between the surface of brush and commutator. It is not a loss which could be calculated separately as it is a part of variable losses. Generally, it contributes in both the types of copper losses. So, they are factor in the calculation of above losses.

Core Losses or Iron Losses in DC Machine

As iron core of the armature is rotating in magnetic field, some losses occurred in the core which is called core losses. Normally, machines are operated with constant speed, so these losses are almost constant. These losses are categorized in two form; Hysteresis loss and Eddy current loss.

Hysteresis Loss in DC Machine

Hysteresis losses occur in the armature winding due to reversal of magnetization of the core. When the core of the armature exposed to magnetic field, it undergoes one complete rotation of magnetic reversal. The portion of armature which is under S-pole, after completing half electrical revolution, the same piece will be under the N-pole, and the magnetic lines are reversed in order to overturn the magnetism within the core. The constant process of magnetic reversal in the armature, consume some amount of energy which is called hysteresis loss. The percentage of loss depends upon the quality and volume of the iron.

The Frequency of Magnetic Reversal

$f = \frac{PN}{120}$ Where, P = Number of poles N = Speed in rpm

Steinmetz Formula

The Steinmetz formula is for the calculation of hysteresis loss.

$$Hysteresis\ loss\ P_h = \eta B_{max}^{1.6} f V\ \ watts$$

Where, η = Steinmetz hysteresis co-efficient B_{max} = Maximum flux Density in armature winding F = Frequency of magnetic reversals V = Volume of armature in m^3.

Eddy Current Loss in DC Machine

According to Faraday's law of electromagnetic induction, when an iron core rotates in the magnetic field, an emf is also induced in the core. Similarly, when armature rotates in magnetic field, small amount of emf induced in the core which allows flow of charge in the body due to conductivity of the core. This current is useless for the machine. This loss of current is called eddy current. This loss is almost constant for the DC machines. It could be minimized by selecting the laminated core.

Mechanical Losses in DC Machine

The losses associated with mechanical friction of the machine are called mechanical losses. These losses occur due to friction in the moving parts of the machine like bearing, brushes etc, and windage losses occurs due to the air inside the rotating coil of the machine. These losses are usually very small about 15% of full load loss.

Stray Load Losses in DC Machine

There are some more losses other than the losses which have been discussed above. These losses are called stray-load losses. These miscellaneous losses are due to the short-circuit current in the coil undergoing commutation, distortion of flux due to armature and many more losses which are difficult to find. However, they are taken as 1 % of the whole load power output.

Introduction

Welcome to another course in the STEP series, **S**iemens **T**echnical **E**ducation **P**rogram, designed to prepare our distributors to sell Siemens Energy & Automation products more effectively. This course covers **Basics of PLCs** and related products.

Upon completion of **Basics of PLCs** you should be able to:

- Identify the major components of a PLC and describe their functions
- Convert numbers from decimal to binary, BCD, and hexadecimal
- Identify typical discrete and analog inputs and outputs
- Read a basic ladder logic diagram and statement list
- Identify operational differences between different S7-200 models
- Identify the proper manual to refer to for programming or installation of an S7-200 PLC
- Connect a simple discrete input and output to an S7-200
- Select the proper expansion module for analog inputs and outputs
- Describe the operation of timers and counters

This knowledge will help you better understand customer applications. In addition, you will be better able to describe products to customers and determine important differences between products. You should complete **Basics of Electricity** before attempting **Basics of PLCs**. An understanding of many of the concepts covered in **Basics of Electricity** is required for **Basics of PLCs**. In addition you may wish to complete **Basics of Control Components**. Devices covered in **Basics of Control Components** are used with programmable logic controllers.

If you are an employee of a Siemens Energy & Automation authorized distributor, fill out the final exam tear-out card and mail in the card. We will mail you a certificate of completion if you score a passing grade. Good luck with your efforts.

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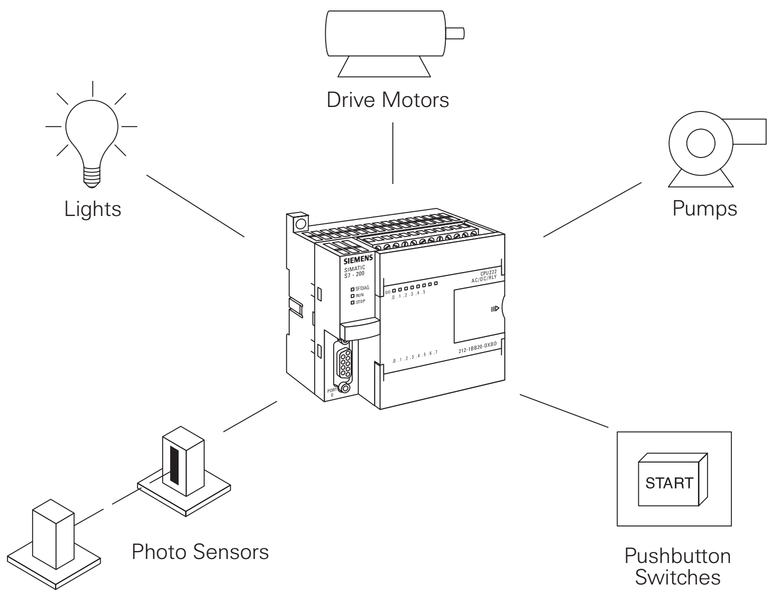
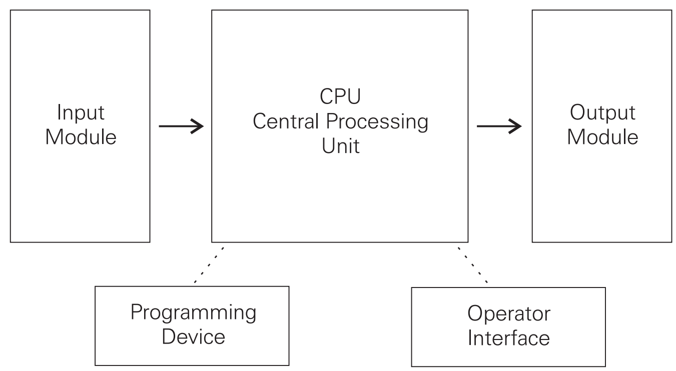
PLCs

Programmable Logic Controllers (PLCs), also referred to as programmable controllers, are in the computer family. They are used in commercial and industrial applications. A PLC monitors inputs, makes decisions based on its program, and controls outputs to automate a process or machine. This course is meant to supply you with basic information on the functions and configurations of PLCs.

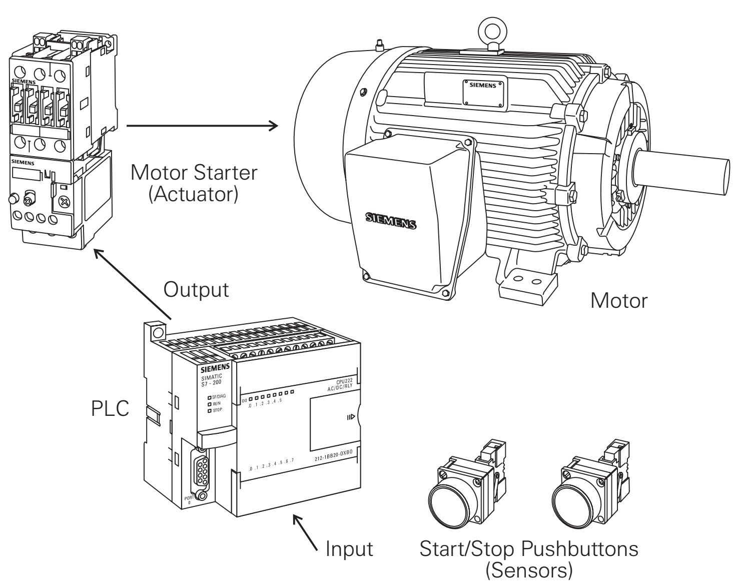


Basic PLC Operation

PLCs consist of input modules or points, a Central Processing Unit (CPU), and output modules or points. An input accepts a variety of digital or analog signals from various field devices (sensors) and converts them into a logic signal that can be used by the CPU. The CPU makes decisions and executes control instructions based on program instructions in memory. Output modules convert control instructions from the CPU into a digital or analog signal that can be used to control various field devices (actuators). A programming device is used to input the desired instructions. These instructions determine what the PLC will do for a specific input. An operator interface device allows process information to be displayed and new control parameters to be entered.

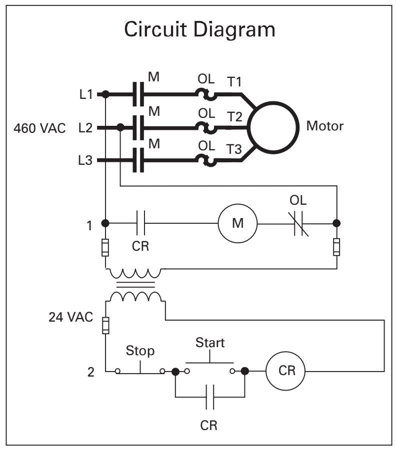


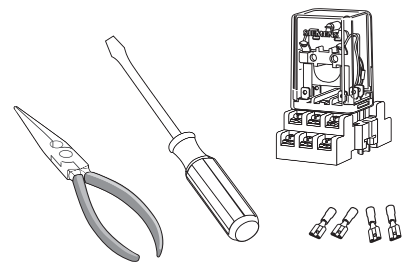
Pushbuttons (sensors), in this simple example, connected to PLC inputs, can be used to start and stop a motor connected to a PLC through a motor starter (actuator).



Hard-Wired Control

Prior to PLCs, many of these control tasks were solved with contactor or relay controls. This is often referred to as hard-wired control. Circuit diagrams had to be designed, electrical components specified and installed, and wiring lists created. Electricians would then wire the components necessary to perform a specific task. If an error was made, the wires had to be reconnected correctly. A change in function or system expansion required extensive component changes and rewiring.





Advantages of PLCs

The same, as well as more complex tasks, can be done with a PLC. Wiring between devices and relay contacts is done in the PLC program. Hard-wiring, though still required to connect field devices, is less intensive. Modifying the application and correcting errors are easier to handle. It is easier to create and change a program in a PLC than it is to wire and re-wire a circuit.

Following are just a few of the advantages of PLCs:

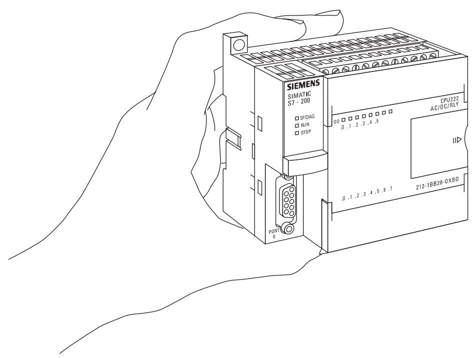
- Smaller physical size than hard-wire solutions.
- Easier and faster to make changes.
- PLCs have integrated diagnostics and override functions.
- Diagnostics are centrally available.
- Applications can be immediately documented.
- Applications can be duplicated faster and less expensively.

Siemens PLCs

Siemens makes several PLC product lines in the SIMATIC® S7 family. They are: S7-200, S7-300, and S7-400.

S7-200

The S7-200 is referred to as a micro PLC because of its small size. The S7-200 has a brick design which means that the power supply and I/O are on-board. The S7-200 can be used on smaller, stand-alone applications such as elevators, car washes, or mixing machines. It can also be used on more complex industrial applications such as bottling and packaging machines.



S7-300 and S7-400

The S7-300 and S7-400 PLCs are used in more complex applications that support a greater number of I/O points. Both PLCs are modular and expandable. The power supply and I/O consist of separate modules connected to the CPU. Choosing either the S7-300 or S7-400 depends on the complexity of the task and possible future expansion. Your Siemens sales representative can provide you with additional information on any of the Siemens PLCs.

Number Systems

Since a PLC is a computer, it stores information in the form of On or Off conditions (1 or 0), referred to as binary digits (bits). Sometimes binary digits are used individually and sometimes they are used to represent numerical values.

Decimal System

Various number systems are used by PLCs. All number systems have the same three characteristics: digits, base, weight. The decimal system, which is commonly used in everyday life, has the following characteristics:

Ten digits	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
Base	10
Weights	1, 10, 100, 1000, ...

Binary System

The binary system is used by programmable controllers. The binary system has the following characteristics:

Two digits	0, 1
Base	2
Weights	Powers of base 2 (1, 2, 4, 8, 16, ...)

In the binary system 1s and 0s are arranged into columns. Each column is weighted. The first column has a binary weight of 2^0. This is equivalent to a decimal 1. This is referred to as the least significant bit. The binary weight is doubled with each succeeding column. The next column, for example, has a weight of 2^1, which is equivalent to a decimal 2. The decimal value is doubled in each successive column. The number in the far left hand column is referred to as the most significant bit. In this example, the most significant bit has a binary weight of 2^7. This is equivalent to a decimal 128.

Most Significant Bit ↓ … ↓ Least Significant Bit

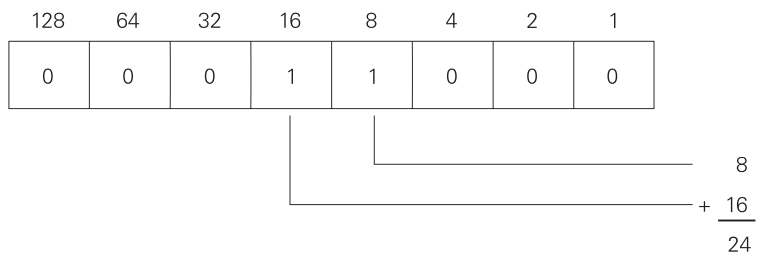
2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
128	64	32	16	8	4	2	1
0	0	0	1	1	0	0	0

Converting Binary to Decimal

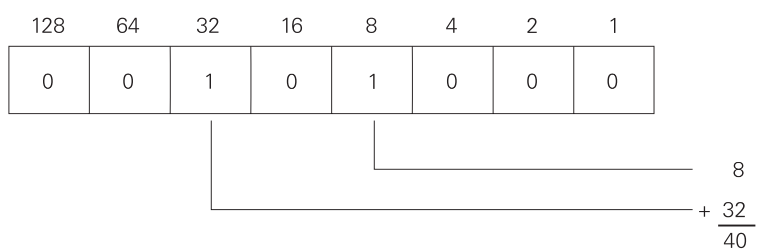
The following steps can be used to interpret a decimal number from a binary value.

1) Search from least to most significant bit for 1s.
2) Write down the decimal representation of each column containing a 1.
3) Add the column values.

In the following example, the fourth and fifth columns from the right contain a 1. The decimal value of the fourth column from the right is 8, and the decimal value of the fifth column from the right is 16. The decimal equivalent of this binary number is 24. The sum of all the weighted columns that contain a 1 is the decimal number that the PLC has stored.

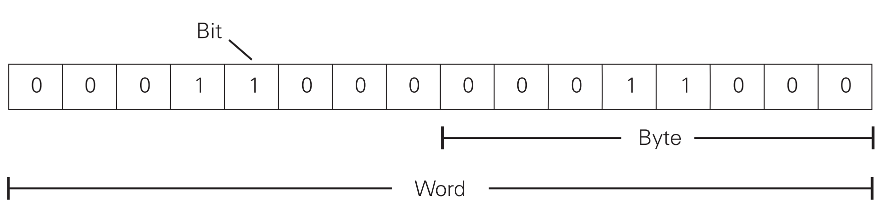


In the following example the fourth and sixth columns from the right contain a 1. The decimal value of the fourth column from the right is 8, and the decimal value of the sixth column from the right is 32. The decimal equivalent of this binary number is 40.



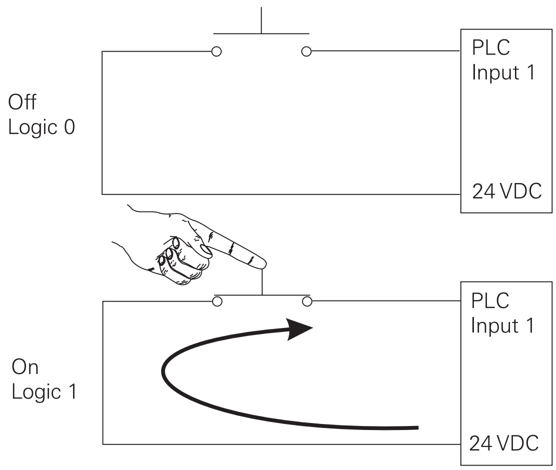
Bits, Bytes, and Words

Each binary piece of data is a bit. Eight bits make up one byte. Two bytes, or 16 bits, make up one word.



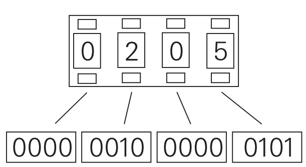
Logic 0, Logic 1

Programmable controllers can only understand a signal that is On or Off (present or not present). The binary system is a system in which there are only two numbers, 1 and 0. Binary 1 indicates that a signal is present, or the switch is On. Binary 0 indicates that the signal is not present, or the switch is Off.



BCD

Binary-Coded Decimal (BCD) are decimal numbers where each digit is represented by a four-bit binary number. BCD is commonly used with input and output devices. A thumbwheel switch is one example of an input device that uses BCD. The binary numbers are broken into groups of four bits, each group representing a decimal equivalent. A four-digit thumbwheel switch, like the one shown here, would control 16 (4 x 4) PLC inputs.



Decimal Numbers	BCD Numbers
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001

Hexadecimal

Hexadecimal is another system used in PLCs. The hexadecimal system has the following characteristics:

16 digits	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F
Base	16
Weights	Powers of base 16 (1, 16, 256, 4096 ...)

The ten digits of the decimal system are used for the first ten digits of the hexadecimal system. The first six letters of the alphabet are used for the remaining six digits.

A = 10	D = 13
B = 11	E = 14
C = 12	F = 15

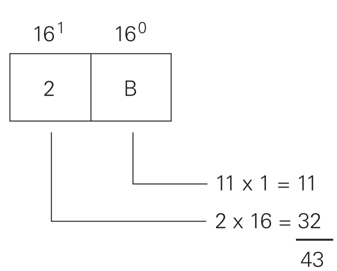
The hexadecimal system is used in PLCs because it allows the status of a large number of binary bits to be represented in a small space such as on a computer screen or programming device display. Each hexadecimal digit represents the exact status of four binary bits. To convert a decimal number to a hexadecimal number the decimal number is divided by the base of 16. To convert decimal 28, for example, to hexadecimal:

$$16\overline{)\,28\,}\quad 1 \text{ r } 12$$

Decimal 28 divided by 16 is 1 with a remainder of 12. Twelve is equivalent to C in hexadecimal. The hexadecimal equivalent of decimal 28 is 1C.

The decimal value of a hexadecimal number is obtained by multiplying the individual hexadecimal digits by the base 16 weight and then adding the results. In the following example the hexadecimal number 2B is converted to its decimal equivalent of 43.

$16^0 = 1$
$16^1 = 16$
B = 11



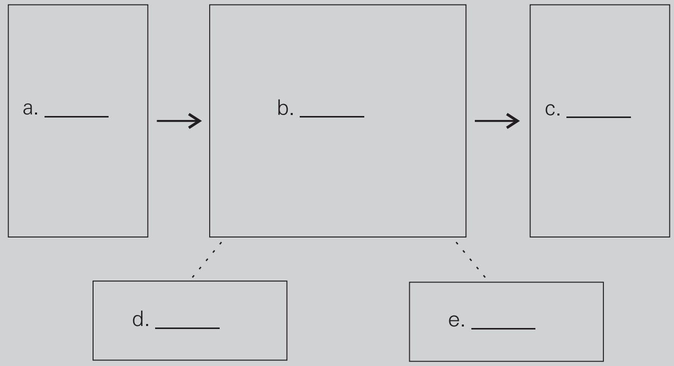
Conversion of Numbers

The following chart shows a few numeric values in decimal, binary, BCD, and hexadecimal representation.

Decimal	Binary	BCD	Hexadecimal
0	0	0000	0
1	1	0001	1
2	1	0010	2
3	11	0011	3
4	100	0100	4
5	101	0101	5
6	110	0110	6
7	111	0111	7
8	1000	1000	8
9	1001	1001	9
10	1010	0001 0000	A
11	1011	0001 0001	B
12	1100	0001 0010	C
13	1101	0001 0011	D
14	1110	0001 0100	E
15	1111	0001 0101	F
16	1 0000	0001 0110	10
17	1 0001	0001 0111	11
18	1 0010	0001 1000	12
19	1 0011	0001 1001	13
20	1 0100	0010 0000	14
.	.	.	.
.	.	.	.
126	111 1110	0001 0010 0110	7E
127	111 1111	0001 0010 0111	7F
128	1000 0000	0001 0010 1000	80
.	.	.	.
.	.	.	.
510	1 1111 1110	0101 0001 0000	1FE
511	1 1111 1111	0101 0001 0001	1FF
512	10 0000 0000	0101 0001 0010	200

Review 1

1. Identify the following:



2. The binary number system has a base ____________ .

3. The hexadecimal number system has a base ____________ .

4. Convert a decimal 10 to the following:

   Binary ____________

   BCD ____________

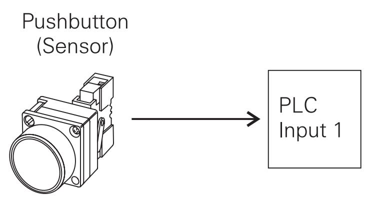
   Hexadecimal ____________

Terminology

The language of PLCs consists of a commonly used set of terms; many of which are unique to PLCs. In order to understand the ideas and concepts of PLCs, an understanding of these terms is necessary.

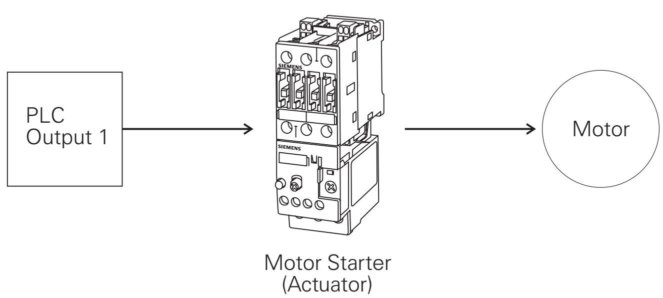
Sensor

A sensor is a device that converts a physical condition into an electrical signal for use by the PLC. Sensors are connected to the input of a PLC. A pushbutton is one example of a sensor that is connected to the PLC input. An electrical signal is sent from the pushbutton to the PLC indicating the condition (open/closed) of the pushbutton contacts.



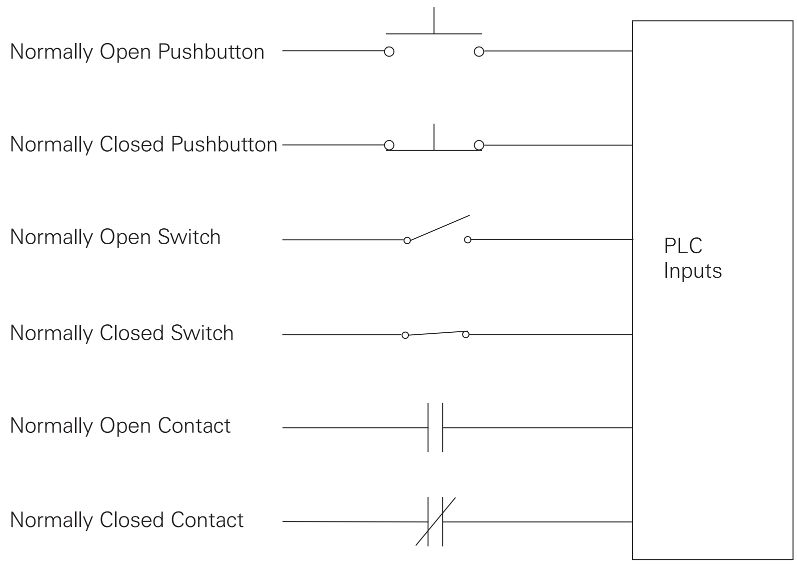
Actuators

Actuators convert an electrical signal from the PLC into a physical condition. Actuators are connected to the PLC output. A motor starter is one example of an actuator that is connected to the PLC output. Depending on the output PLC signal the motor starter will either start or stop the motor.

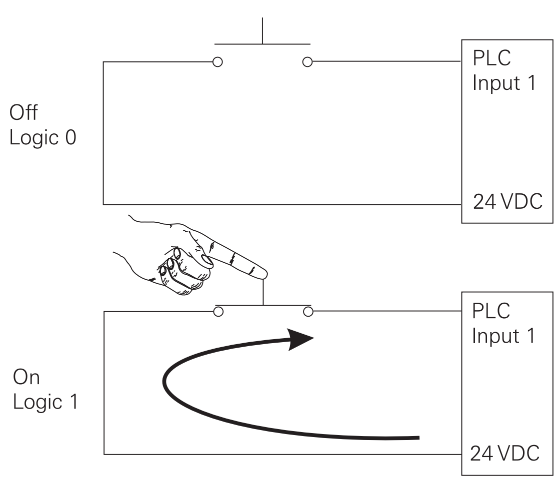


Discrete Input

A discrete input, also referred to as a digital input, is an input that is either in an ON or OFF condition. Pushbuttons, toggle switches, limit switches, proximity switches, and contact closures are examples of discrete sensors which are connected to the PLCs discrete or digital inputs. In the ON condition a discrete input may be referred to as a logic 1 or a logic high. In the OFF condition a discrete input may be referred to as a logic 0 or a logic low.

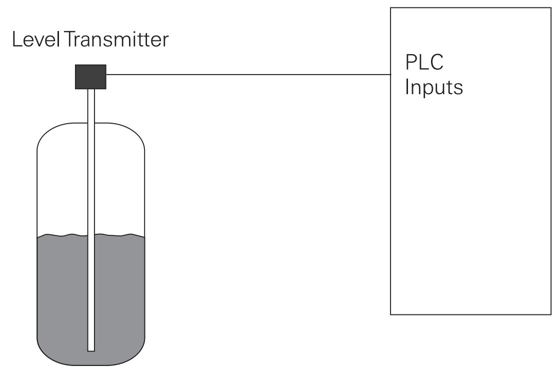


A Normally Open (NO) pushbutton is used in the following example. One side of the pushbutton is connected to the first PLC input. The other side of the pushbutton is connected to an internal 24 VDC power supply. Many PLCs require a separate power supply to power the inputs. In the open state, no voltage is present at the PLC input. This is the OFF condition. When the pushbutton is depressed, 24 VDC is applied to the PLC input. This is the ON condition.



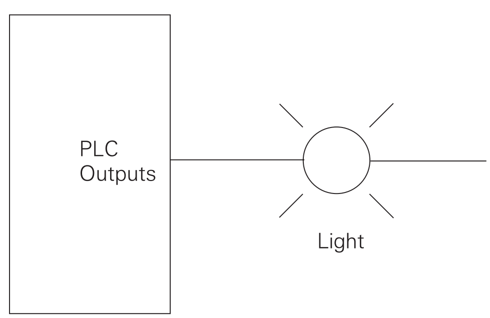
Analog Inputs

An analog input is a continuous, variable signal. Typical analog inputs may vary from 0 to 20 milliamps, 4 to 20 milliamps, or 0 to 10 volts. In the following example, a level transmitter monitors the level of liquid in a tank. Depending on the level transmitter, the signal to the PLC can either increase or decrease as the level increases or decreases.



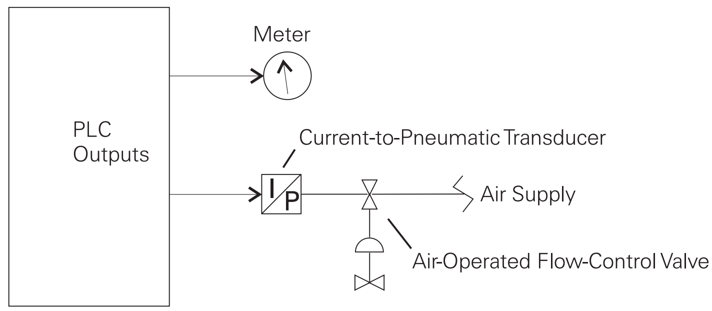
Discrete Outputs

A discrete output is an output that is either in an ON or OFF condition. Solenoids, contactor coils, and lamps are examples of actuator devices connected to discrete outputs. Discrete outputs may also be referred to as digital outputs. In the following example, a lamp can be turned on or off by the PLC output it is connected to.



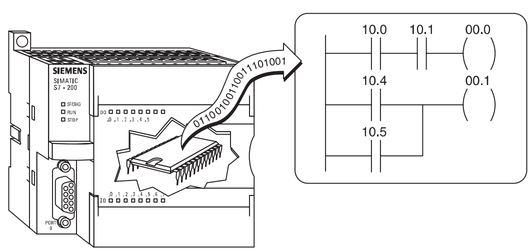
Analog Outputs

An analog output is a continuous, variable signal. The output may be as simple as a 0-10 VDC level that drives an analog meter. Examples of analog meter outputs are speed, weight, and temperature. The output signal may also be used on more complex applications such as a current-to-pneumatic transducer that controls an air-operated flow-control valve.



CPU

The central processor unit (CPU) is a microprocessor system that contains the system memory and is the PLC decision-making unit. The CPU monitors the inputs and makes decisions based on instructions held in the program memory. The CPU performs relay, counting, timing, data comparison, and sequential operations.

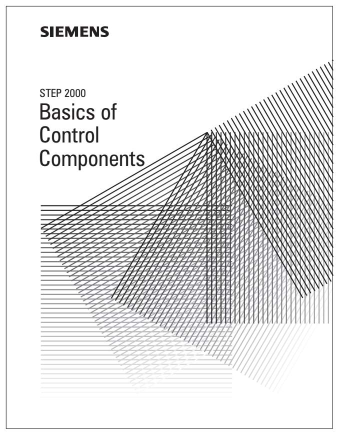


Programming

A program consists of one or more instructions that accomplish a task. Programming a PLC is simply constructing a set of instructions. There are several ways to look at a program such as ladder logic, statement lists, or function block diagrams.

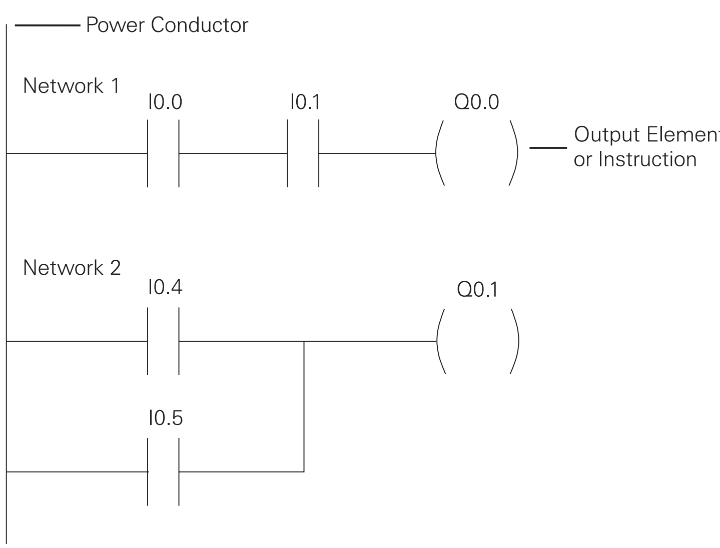
Ladder Logic

Ladder logic (LAD) is one programming language used with PLCs. Ladder logic uses components that resemble elements used in a line diagram format to describe hard-wired control. Refer to the STEP course **Basics of Control Components** for more information on line diagrams.



Ladder Logic Diagram

The left vertical line of a ladder logic diagram represents the power or energized conductor. The output element or instruction represents the neutral or return path of the circuit. The right vertical line, which represents the return path on a hard-wired control line diagram, is omitted. Ladder logic diagrams are read from left-to-right, top-to-bottom. Rungs are sometimes referred to as networks. A network may have several control elements, but only one output coil.



In the example program shown example I0.0, I0.1 and Q0.0 represent the first instruction combination. If inputs I0.0 and I0.1 are energized, output relay Q0.0 energizes. The inputs could be switches, pushbuttons, or contact closures. I0.4, I0.5, and Q1.1 represent the second instruction combination. If either input I0.4 or I0.5 are energized, output relay Q0.1 energizes.

Statement list

A statement list (STL) provides another view of a set of instructions. The operation, what is to be done, is shown on the left. The operand, the item to be operated on by the operation, is shown on the right. A comparison between the statement list shown below, and the ladder logic shown on the previous page, reveals a similar structure. The set of instructions in this statement list perform the same task as the ladder diagram.

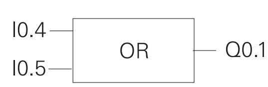
```
NETWORK 1
            LD          I0.0
            A           I0.1
            =           Q0.0
NETWORK 2
            LD          I0.4
            O           I0.5
            =           Q0.1
```

Function Block Diagrams

Function Block Diagrams (FBD) provide another view of a set of instructions. Each function has a name to designate its specific task. Functions are indicated by a rectangle. Inputs are shown on the left-hand side of the rectangle and outputs are shown on the right-hand side. The function block diagram shown below performs the same function as shown by the ladder diagram and statement list.

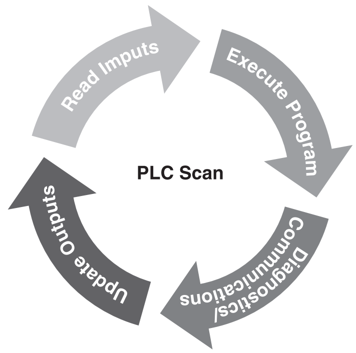
NETWORK 1

NETWORK 2



PLC Scan

The PLC program is executed as part of a repetitive process referred to as a scan. A PLC scan starts with the CPU reading the status of inputs. The application program is executed using the status of the inputs. Once the program is completed, the CPU performs internal diagnostics and communication tasks. The scan cycle ends by updating the outputs, then starts over. The cycle time depends on the size of the program, the number of I/Os, and the amount of communication required.

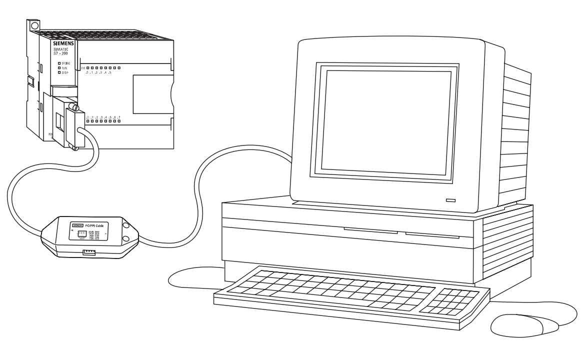


Software

Software is any information in a form that a computer or PLC can use. Software includes the instructions or programs that direct hardware.

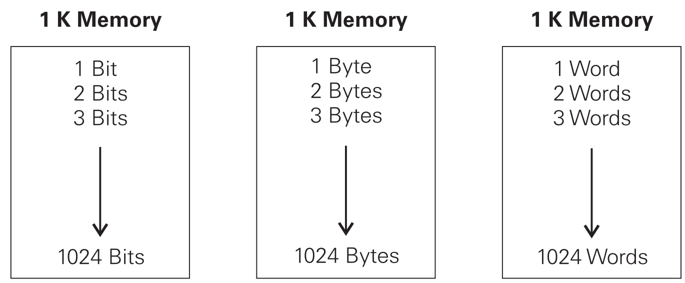
Hardware

Hardware is the actual equipment. The PLC, the programming device, and the connecting cable are examples of hardware.



Memory Size

Kilo, abbreviated K, normally refers to 1000 units. When talking about computer or PLC memory, however, 1K means 1024. This is because of the binary number system ($2^{10}=1024$). This can be 1024 bits, 1024 bytes, or 1024 words, depending on memory type.



RAM

Random Access Memory (RAM) is memory where data can be directly accessed at any address. Data can be written to and read from RAM. RAM is used as a temporary storage area. RAM is volatile, meaning that the data stored in RAM will be lost if power is lost. A battery backup is required to avoid losing data in the event of a power loss.

ROM

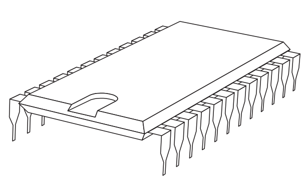
Read Only Memory (ROM) is a type of memory that data can be read from but not written to. This type of memory is used to protect data or programs from accidental erasure. ROM memory is nonvolatile. This means a user program will not lose data during a loss of electrical power. ROM is normally used to store the programs that define the capabilities of the PLC.

EPROM

Erasable Programmable Read Only Memory (EPROM) provides some level of security against unauthorized or unwanted changes in a program. EPROMs are designed so that data stored in them can be read, but not easily altered. Changing EPROM data requires a special effort. UVEPROMs (ultraviolet erasable programmable read only memory) can only be erased with an ultraviolet light. EEPROM (electronically erasable programmable read only memory), can only be erased electronically.

Firmware

Firmware is user or application specific software burned into EPROM and delivered as part of the hardware. Firmware gives the PLC its basic functionality.



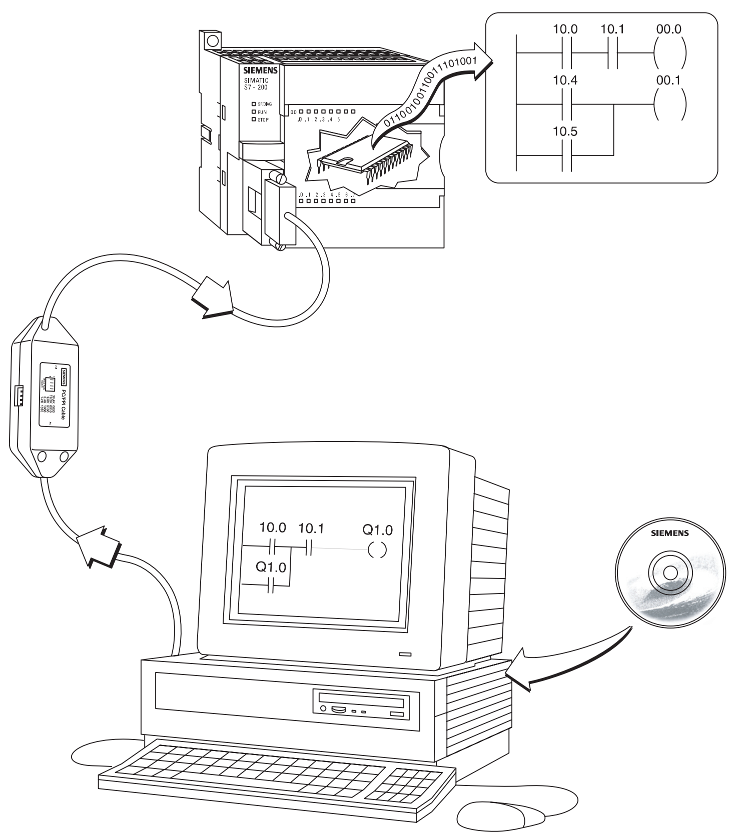
Putting it Together

The memory of the S7-200 is divided into three areas: program space, data space, and configurable parameter space.

- Program space stores the ladder logic (LAD) or statement list (STL) program instructions. This area of memory controls the way data space and I/O points are used. LAD or STL instructions are written using a programming device such as a PC, then loaded into program memory of the PLC.

- Data space is used as a working area, and includes memory locations for calculations, temporary storage of intermediate results and constants. Data space includes memory locations for devices such as timers, counters, high-speed counters, and analog inputs and outputs. Data space can be accessed under program control.

- Configurable parameter space, or memory, stores either the default or modified configuration parameters.



PLC selection criteria

PLC selection criteria consists of:

* System (task) requirements.
* Application requirements.
* What input/output capacity is required?
* What type of inputs/outputs are required?
* What size of memory is required?
* What speed is required of the CPU?
* Electrical requirements.
* Speed of operation.
* Communication requirements.
* Software.
* Operator interface.
* Physical environments.

System requirements
* The starting point in determining any solution must be to understand what is to be achieved.
* The program design starts with breaking down the task into a number of simple understandable elements, each of which can be easily described.

Application requirements
* Input and output device requirements. After determining the operation of the system, the next step is to determine what input and output devices the system requires.
* List the function required and identify a specific type of device.
* The need for special operations in addition to discrete (On/Off) logic.
* List the advanced functions required beside simple discrete logic.

Electrical Requirements
The electrical requirements for inputs, outputs, and system power; When determining the electrical requirements of a system, consider three items:

- Incoming power (power for the control system);
- Input device voltage; and
- Output voltage and current.

Speed of Operation
How fast the control system must operate (speed of operation).
When determining speed of operation, consider these points:
– How fast does the process occur or machine operate?
– Are there “time critical” operations or events that must be detected?
– In what time frame must the fastest action occur (input device detection to output device activation)?

– Does the control system need to count pulses from an encoder or flow-meter and respond quickly?

Communication
If the application requires sharing data outside the process, i.e. communication. Communication involves sharing application data or status with another electronic device, such as a computer or a monitor in an operator's station. Communication can take place locally through a twisted-pair wire, or remotely via telephone or radio modem.

Operator Interface
If the system needs operator control or interaction. In order to convey information about machine or process status, or to allow an operator to input data, many applications require operator interfaces. Traditional operator interfaces include pushbuttons, pilot lights and LED numeric display. Electronic operator interface devices display messages about machine status in descriptive text, display part count and track alarms. Also, they can be used for data input.

Physical Environment
The physical environment in which the control system will be located. Consider the environment where the control system will be located. In harsh environments, house the control system in an appropriate IP-rated enclosure. Remember to consider accessibility for maintenance, troubleshooting or reprogramming.

What are the Applications of PLC in Daily Life and in Industry?

1.Industrial Applications of PLC

In industrial automation, PLC performs a wide variety of manufacturing production, monitoring machine tool or equipment, building the system, and process control functions.

Here are some of the example where PLC has been used.

PLCs are used in,

1. Transportation System likes Conveyor Belt System.
2. Packing and Labeling System in Food & Beverage.
3. Automatic Bottle or Liquid Filling System.
4. Packaging and Labelling System in Pharma Industries.
5. Transportation System like Escalator and Elevator.
6. Industrial Crane Control System for Operation of Overhead Traveling Crane.

7. Glass Industries for glass production and recording data.
8. Paper Industries for the production of Pages, Books or Newspapers, etc.
9. Cement Industries for manufacturing or mixing the right quality and quantities of raw materials, and accuracy of data regarding.
10. Automatic Drainage Water Pump Monitoring and Controlling System.
11. Time and Count-based Control System for an Industrial Machine.
12. Temperature Controller or Humidity by using the Sensors Input to the PLC system.
13. Fault Detection and Protection of Industrial Machines like an Induction Motor.
14. Wind Turbine System for Maximum Efficiency, Recording Data, and Safety Purposes.
15. Conveyor Belt System controls the Sequence of Conveyors and Interlocking procedure.
16. Energy Management System like Boiler, Ball Milling, Coal Kiln, Shaft Kiln, etc.
17. Oil and Gas Industries for controlling the Purging Procedure.

2. Power Station Applications of PLC

For the electrical power system analysis, PLC plays operation for maintenance and other main roles in the power plants and the smart grid system.

18. PLC uses for the Smart Grid System to Monitor and Detect fault conditions.
19. It is used in the Power Generation, Transmission, and Distribution System.
20. In the Power Substation, PLC can use the Auto Assembly Line System.
21. Some Electrical Equipment (like Circuit Breaker Tripping, Capacitor Switching) can be automatically operated with PLC.
22. A Single-Phase or Three-Phase Sequence Detect by using the PLC.
23. In Oil, and Gas an Automation Power Plant, PLC needs for Valve Switching for Changeover of Fuels, Pilot Light ON or OFF, Flame Safety Checking, Oil Filtering procedure, and more things.
24. Real-time PLC uses in Underground Coal Mine or Water Level Sensing and Data Survey.

3. Commercial Applications of PLC

We can see the growth of PLC in commercial control applications. With the use of PLC, applications can easily operate without or with very minimal manpower or physical hard work.

Here are some basic commercial application uses PLC.

25. Smart Traffic Control Signal System.
26. Smart Elevator Control System.
27. Fire Detection and Alarm System.
28. Automatic Machine Handling System.
29. Automatic Vehicle Washer System
30. Automated Guided Vehicle System.
31. In the Roller Coasters Machine.
32. Automation System for Well Drainage System.
33. Luggage Handling System. For example, at the Airport.
34. Pressure Controller in Multi-Motor Pump Applications.
35. Sequence or Numerical Counting and Packing System.
36. Mining Equipment Line Detection and Remote Control System.
37. For Wind Turbine Operation, PLCs convert signals from the Wind Speed and Direction Sensors to better control the Wind Turbines.

4. Domestic Applications of PLC

For the domestic purpose, PLC act as a remote operating device or automatic sensing device. We can automate some day-to-day activities with PLC.

Here are some useful domestic applications we can automate with PLC.

38. Water Tank Level Control System
39. Car Washing and Parking System.
40. Flashing Light Controlling System.
41. Automatic Door Opening/Closing System.
42. Remote Monitoring Application like Air compressor (AC), Fan.
43. ON/OFF Switching Application like Light, Motor, and More daily life applications of PLC.

5. Education Applications of PLC

Engineering students mostly prefer the automation system for doing their academic or research projects. It is a big trend.

As part of the automation projects, you can automate any commercial or domestic applications using PLC.

Your project should be designed to automate a specific task. It should work under real-time and with superior reliability and best performance.

What are the major areas of Application of PLC?

PLC works in an industrial automation environment where PLC replaces the relay system. Now, we will see the top automation companies list where PLC is needed.

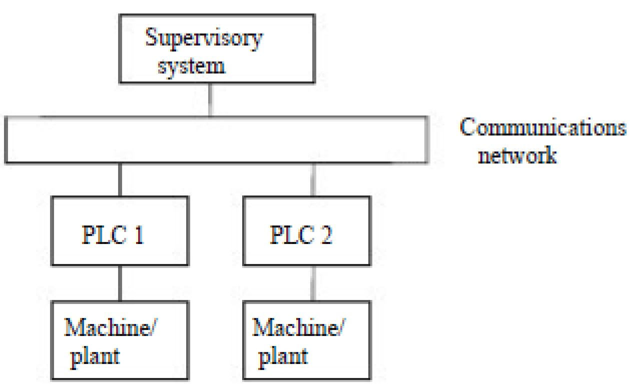
Automation Industries:

- Steel Industry
- Glass Industry
- Paper industry
- Textile industry
- Cement Industry
- Chemical industry
- Automobile industry
- Food Processing System
- Oil and Gas Power Plant
- Wind Turbine System
- Robotic Automation System
- Underground Coal Mine and many more industries.

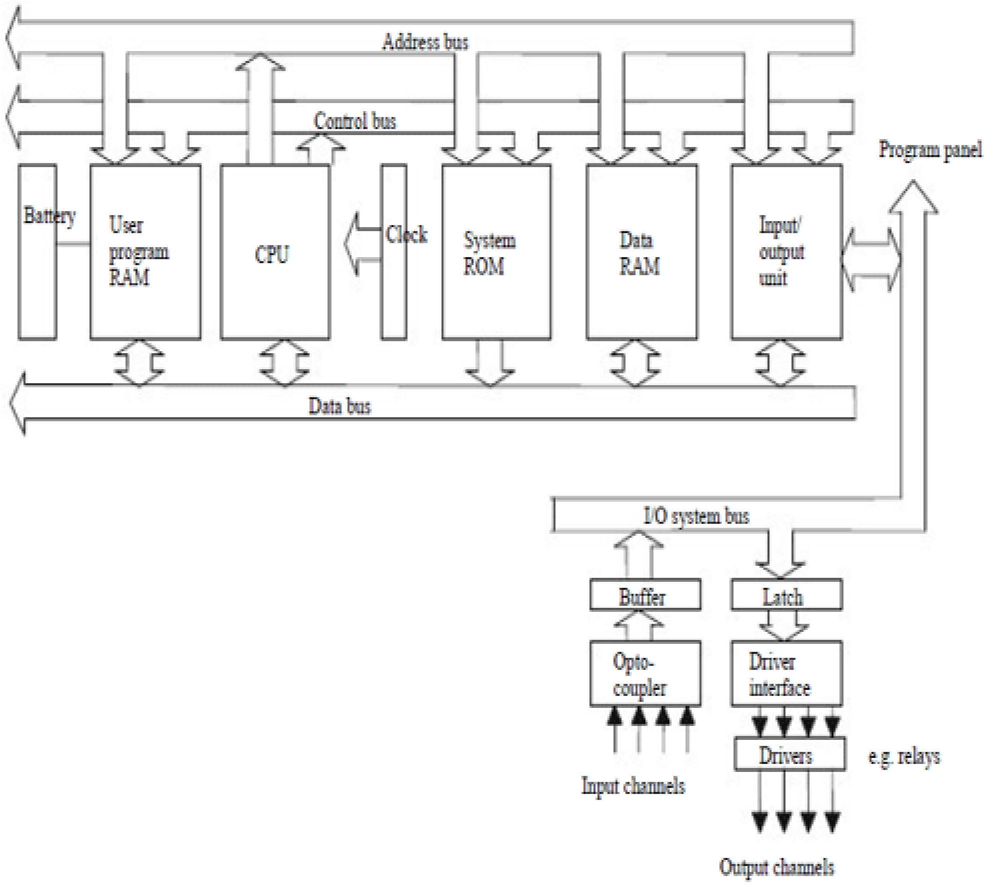
In the above automation industrial area, PLC helps to monitor input and output and makes the logic-based decision, automatic sequential count, time-based control system for the automated process.

Architecture And Basic Internal Structure Of PLC

Figure shows the basic internal architecture of a PLC. It consists of a central processing unit (CPU) containing the system microprocessor, memory, and input/output circuitry. The CPU controls and processes all the operations within the PLC. It is supplied with a clock that has a frequency of typically between 1 and 8 MHz. This frequency determines the operating speed of the PLC and provides the timing and synchronization for all elements in the system. The information within the PLC is carried by means of digital signals. The internal paths along which digital signals flow are called buses. In the physical sense, a bus is just a number of conductors along which electrical signals can flow. It might be tracks on a printed circuit board or wires in a ribbon cable. The CPU uses the data bus for sending data between the constituent elements, the address bus to send the addresses of locations for accessing stored data, and the control bus for signals relating to internal control actions. The system bus is used for communications between the input/output ports and the input/output unit.



Basic communications model.



Architecture of a PLC.

The CPU

The internal structure of the CPU depends on the microprocessor concerned. In general, CPUs have the following:

- An arithmetic and logic unit (ALU) that is responsible for data manipulation and carrying out arithmetic operations of addition and subtraction and logic operations of AND, OR, NOT, and EXCLUSIVE-OR.
- Memory, termed registers, located within the microprocessor and used to store information involved in program execution.
- A control unit that is used to control the timing • of operations.

The Buses

The buses are the paths used for communication within the PLC. The information is transmitted in binary form, that is, as a group of bits, with a bit being a binary digit of 1 or 0, indicating on/off states. The term word is used for the group of bits constituting some information. Thus an 8-bit word might be the binary number 00100110. Each of the bits is communicated simultaneously along its own parallel wire. The system has four buses:

- The data bus carries the data used in the processing done by the CPU. A microprocessor termed as being 8-bit has an internal data bus that can handle 8-bit numbers. It can thus perform operations between 8-bit numbers and deliver results as 8-bit values.
- The address bus is used to carry the addresses of memory locations. So that each word can be located in memory, every memory location is given a unique address. Just like houses in a town are each given a distinct address so that they can be located, so each word location is given an address so that data stored at a particular location can be accessed by the CPU, either to read data located there or put, that is, write, data there. It is the address bus that carries the information indicating which address is to be accessed. If the address bus consists of eight lines, the number of 8-bit words, and hence number of distinct addresses, is 28 ¼ 256. With 16 address lines, 65,536 addresses are possible.
- The control bus carries the signals used by the CPU for control, such as to inform memory devices whether they are to receive data from an input or output data and to carry timing signals used to synchronize actions.

The system bus is used for communications between the input/output ports and the input/ output unit.

Memory

To operate the PLC system there is a need for it to access the data to be processed and instructions, that is, the program, which informs it how the data is to be processed. Both are stored in the PLC memory for access during processing. There are several memory elements in a PLC system:

- System read-only-memory (ROM) gives permanent storage for the operating system and fixed data used by the CPU.
- Random-access memory (RAM) is used for the user’s program.
- Random-access memory (RAM) is used for data. This is where information is stored on the status of input and output devices and the values of timers and counters and other internal devices. The data RAM is sometimes referred to as a data table or register table. Part of this memory, that is, a block of addresses, will be set aside for input and output addresses and the states of those inputs and outputs. Part will be set aside for preset data and part for storing counter values, timer values, and the like.
- Possibly, as a bolt-on extra module, erasable and programmable read-only-memory (EPROM) is used to store programs permanently.

The programs and data in RAM can be changed by the user. All PLCs will have some amount of RAM to store programs that have been developed by the user and program data. However, to prevent the loss of programs when the power supply is switched off, a battery is used in the PLC to maintain the RAM contents for a period of time. After a program has been developed in RAM it may be loaded into an EPROM memory chip, often a bolt-on module to the PLC, and so made permanent. In addition, there are temporary buffer stores for the input/output channels.

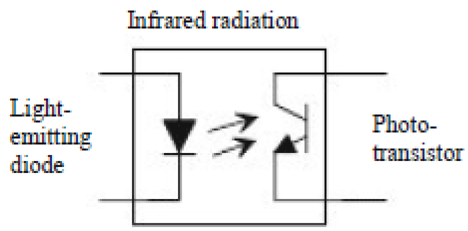
The storage capacity of a memory unit is determined by the number of binary words that it can store. Thus, if a memory size is 256 words, it can store 256 Â 8 ¼ 2048 bits if 8-bit words are used and 256 Â 16 ¼ 4096 bits if 16-bit words are used. Memory sizes are often specified in terms of the number of storage locations available, with 1K representing the number 210, that is, 1024. Manufacturers supply memory chips with the storage locations grouped in groups of 1, 4, and 8 bits. A 4K Â 1 memory has 4 Â 1 Â 1024 bit locations.

A 4K Â 8 memory has 4 Â 8 Â 1024 bit locations. The term byte is used for a word of length 8 bits. Thus the 4K Â 8 memory can store 4096 bytes. With a 16-bit address bus we can have 216 different addresses, and so, with 8-bit words stored at each address, we can have 216 Â 8 storage locations and so use a memory of size 216 Â 8/210 ¼ 64K Â 8, which might be in the form of four 16K Â 8-bit memory chips.

Input/Output Unit

The input/output unit provides the interface between the system and the outside world, allowing for connections to be made through input/output channels to input devices such as sensors and output devices such as motors and solenoids. It is also through the input/output unit that programs are entered from a program panel. Every input/output point has a unique address that can be used by the CPU. It is like a row of houses along a road; number 10 might be the “house” used for an input from a particular sensor, whereas number 45 might be the “house” used for the output to a particular motor.

The input/output channels provide isolation and signal conditioning functions so that sensors and actuators can often be directly connected to them without the need for other circuitry.



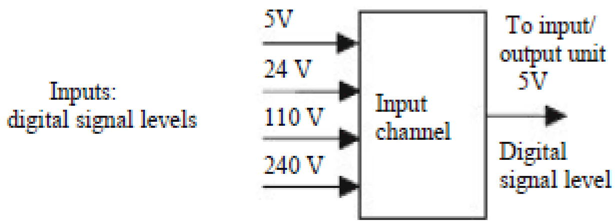
An optoisolator.

Electrical isolation from the external world is usually by means of optoisolators (the term optocoupler is also often used) shows the principle of an optoisolator. When a digital pulse passes through the light-emitting diode, a pulse of infrared radiation is produced.

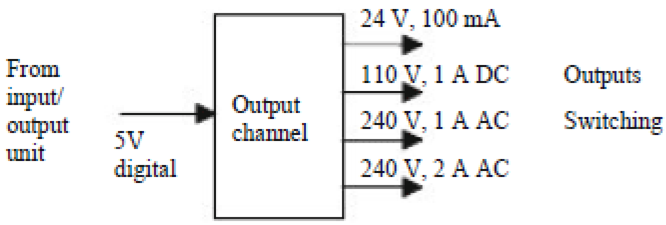
This pulse is detected by the photo transistor and gives rise to a voltage in that circuit. The gap between the light-emitting diode and the photo transistor gives electrical isolation, but the arrangement still allows for a digital pulse in one circuit to give rise to a digital pulse in another circuit.

The digital signal that is generally compatible with the microprocessor in the PLC is 5 V DC. However, signal conditioning in the input channel, with isolation, enables a wide range of input signals to be supplied to it (see Chapter 3 for more details). A range of inputs might be available with a larger PLC, such as 5 V, 24 V, 110 V, and 240 V digital/discrete, that is, on/ off, signals. A small PLC is likely to have just one form of input, such as 24 V.

The output from the input/output unit will be digital with a level of 5 V. However, after signal conditioning with relays, transistors, or triacs, the output from the output channel might be a 24 V, 100 mA switching signal; a DC voltage of 110 V, 1 A; or perhaps 240 V, 1 A AC or 240 V, 2 A AC, from a triac output channel. With a small PLC, all the outputs might be of one type, such as 240 V, 1 A AC. With modular PLCs, however, a range of outputs can be accommodated by selection of the modules to be used.



Input levels.



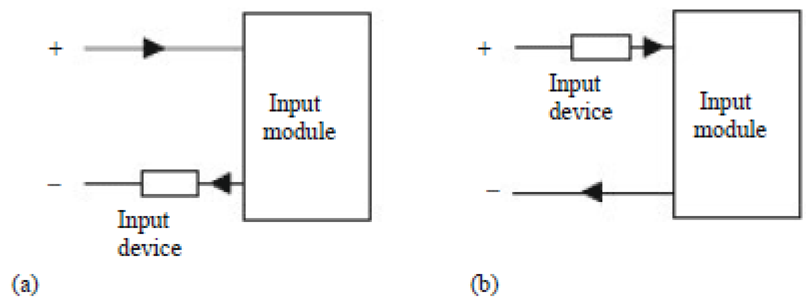
Output levels.

Outputs are specified as being of relay type, transistor type, or triac type:

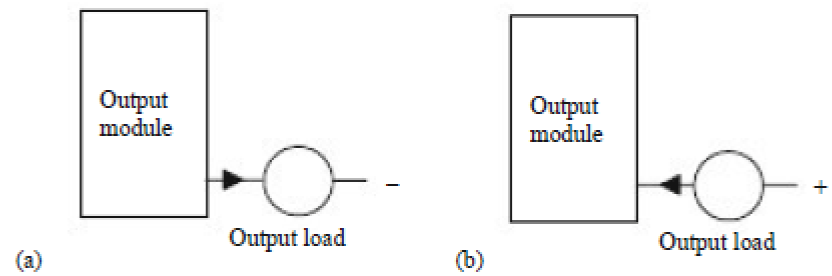
- With the relay type, the signal from the PLC output is used to operate a relay and is able to switch currents of the order of a few amperes in an external circuit. The relay not only allows small currents to switch much larger currents but also isolates the PLC from the external circuit. Relays are, however, relatively slow to operate. Relay outputs are suitable for AC and DC switching. They can withstand high surge currents and voltage transients.
- The transistor type of output uses a transistor to switch current through the external circuit. This gives a considerably faster switching action. It is, however, strictly for DC switching and is destroyed by over current and high reverse voltage. For protection, either a fuse or built-in electronic protection is used. Optoisolators are used to provide isolation.
- Triac outputs, with optoisolators for isolation, can be used to control external loads that are connected to the AC power supply. It is strictly for AC operation and is very easily destroyed by over current. Fuses are virtually always included to protect such outputs.

Sourcing and Sinking

The terms sourcing and sinking are used to describe the way in which DC devices are connected to a PLC. With sourcing, using the conventional current flow direction as from positive to negative, an input device receives current from the input module, that is, the input module is the source of the current. With sinking, using the conventional current flow direction, an input device supplies current to the input module, that is, the input module is the sink for the current. If the current flows from the output module to an output load, the output module is referred to as sourcing. If the current flows to the output module from an output load, the output module is referred to as sinking



Inputs: (a) sourcing; (b) sinking.



Outputs: (a) sourcing; (b) sinking.

It is important know the type of input or output concerned so that it can be correctly connected to the PLC. Thus, sensors with sourcing outputs should be connected to sinking PLC inputs and sensors with sinking outputs should be connected to sourcing PLC inputs. The interface with the PLC will not function and damage may occur if this guideline is not followed.

Input/Output processing and PLC Programming Concept

Programmable Logic Controllers (PLCs) are the major components in industrial automation and control systems. The controlling nature of PLC is ranging from simple- push button switching to a single motor to several complex control structures. The PLC programming is an important task of designing and implementing control application depending on customers need. A PLC program consists of a set of instructions either in textual or graphical form, which represents the logic to be implemented for specific industrial realtime applications.

A dedicated PLC programming software comes from a PLC hardware of specific manufacturer that allows entry and development of user application code, which can be finally download to the PLC hardware. This software also ensures Human Machine Interface (HMI) as a graphical representation of variables. Once this program gets downloaded to the PLC and if the PLC is placed in Run mode, then the PLC continuously works according to the program. Before going to the program of the PLC, let us know the basics of the PLC programming tutorial and its basic concepts.

PLC Programming Basics

A CPU of the PLC executes two different programs:

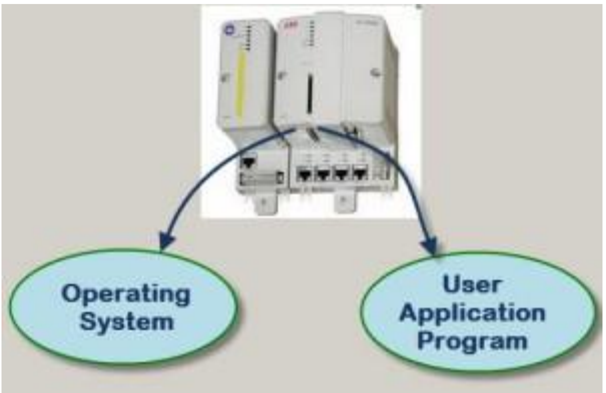
1. The Operating System
2. The User Program

The Operating System

The operating system organizes all the functions, operations and sequences of the CPU that are not associated with a control task. The OS tasks include

- Handling a hot restart and warm restart

- Updating and outputting the process image tables of input and outputs
- Executing the user program
- Detecting and calling the interrupts
- Managing the memory areas
- Establishing communication with programmable devices



PLC programming Basics

The User Program

It is a combination of various functions which are required to process an automated task. This must be created by the users and need to be downloaded to the CPU of the PLC. Some of the tasks of the user program include:

- Initiating all the conditions for starting the specified task
- Reading and evaluating all binary and analog input signals
- Specifying output signals to all binary and analog output signals
- Executing interrupts and handling errors

In present industrial automation sector, there are several leading PLC manufactures that develop typical PLC's ranging from small to high-end PLC's. Each and every PLC manufacturer has its own dedicated software to program and configure the PLC hardware. But the PLC programming language is varied depending on the manufacturers. Some manufacturers have common programming languages and some others have dissimilar. Some of the standard programming languages of PLC are basically of two types, which are further sub-divided into several types, which are as follows:

1.Textual language

- Instructions List (IL)
- Structured Text (ST)

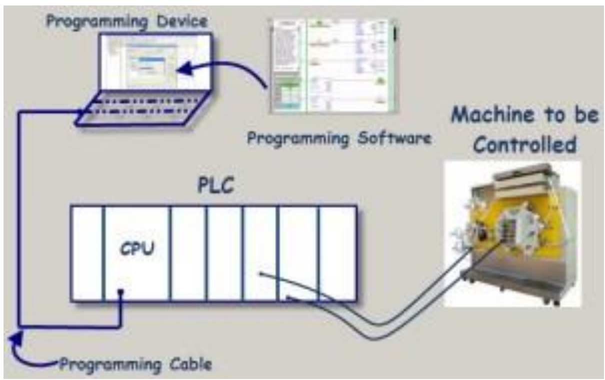
2. Graphical language

- Ladder Diagrams (LD)
- Function Block Diagram (FBD)
- Sequential Function Chart (SFC)

Compared with text based languages, graphical languages are preferred by many users to program a PLC due to their simple and convenient programming features. All the necessary functions and functional blocks are available in the standard library of each PLC software. These function blocks include timers, counters, strings, comparators, numeric, arithmetic, bit-shift, calling functions, and so on.

PLC Programming Devices

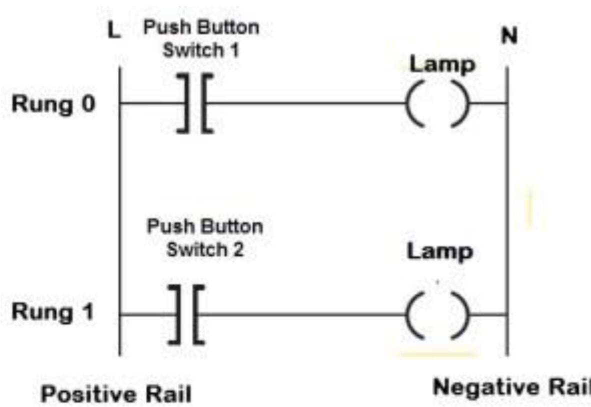
Various types of programming devices are used to enter, modify and troubleshoot a PLC program. These programming terminal devices include handheld and PC based devices. In the handheld programming device method, a proprietary device is connected to PLC through a connecting cable. This device consists of a set of keys that allows to enter, edit and dump the code into the PLC. These handheld devices consist of small display to make the instruction that has been programmed visible. These are compact and easy to use devices, but these handheld devices have limited capabilities.



PLC Programming Devices

Most popularly a Personal Computer (PC) is used for programming the PLC in conjunction with the software given by the manufacturer. By using this PC we can run the program in either online or offline mode, and can also edit, monitor, diagnose and troubleshoot the program of the PLC. The way of transferring the program to the PLC is shown in the above figure wherein the PC consists of program code corresponding to control application which is transferred to the PLC CPU via programming cable.

Ladder Logic PLC Programming



Ladder Logic PLC Programming

Among several programming languages ladder logic diagram is the most basic and simplest form of programming the PLC. Before going to program the PLC with this language, one should know some basic information about it. The below figure shows the hardwired-ladder diagram wherein the same lamp load is controlled by two push button switches, In case if any one of the switches gets closed, the lamp glows. Here two horizontal lines are called rungs which are connected between two vertical lines called rails. Each rung establishes the electrical continuity between positive (L) and negative rails (N) so that the current flows from the input to output devices. Some of the symbols used in ladder logic programming are shown in the figure.

Input switches are types include normally closed and normally opened as shown above. In addition to above given functional symbols, there are several functions like timer, counter, PID, etc., which are stored in the standard library to program complex tasks.

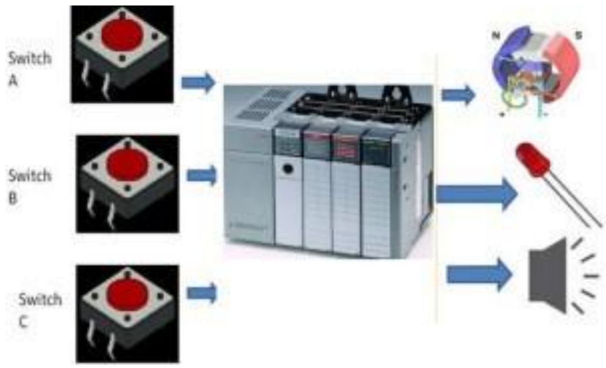
Step-By-Step Procedure for Programming PLC Using Ladder Logic

Step By Step Procedure for Programming PLC using Ladder Logic

The procedure for programming a PLC for a certain application depends on the type of standard manufacturer software tool and the type of control application. But in order to give a basic guidance to the students, this atrticle provides a simple approach of designing control application in PLC programming software, as given below But this way of programming doesn’t exactly fit into all the types of programming tools and control applications.

Step 1: Analyze and Get the Idea of Control Application

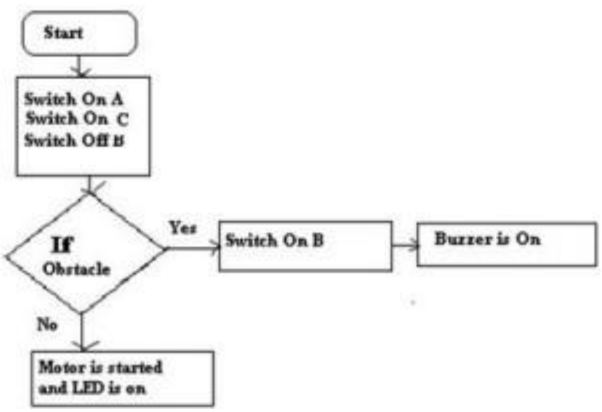
The primary step to program the PLC is to get the idea for which you are going to develop an application-based program. If you are driving a line follower robot by the use of DC motor when the push button is pressed. This status must be displayed by the LED light when the motor gets turn on. The motor is also attached with a sensor (Here it is considered as another switch) that detects obstacles, so when this turned on, the motor should be turned off. And correspondingly, if the motor switched off, the buzzer should be turned on.



PLC Control Application

Step 2: List All the Conditions and Get the Design using Flowchart

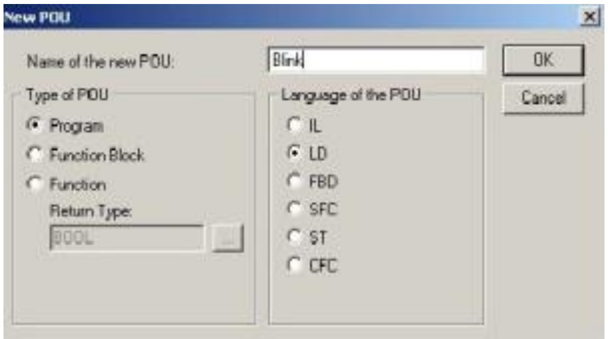
The variables of the above project are M: Motor, A: Input Switch 1, B: Input Switch 2, L:LED and Bu: Buzzer, and the designing of the logic is easy with the implementation of flow chart, which is given below for the above application.



Flowchart of PLC Programming

Step3: Open and Configure the PLC Programming Software

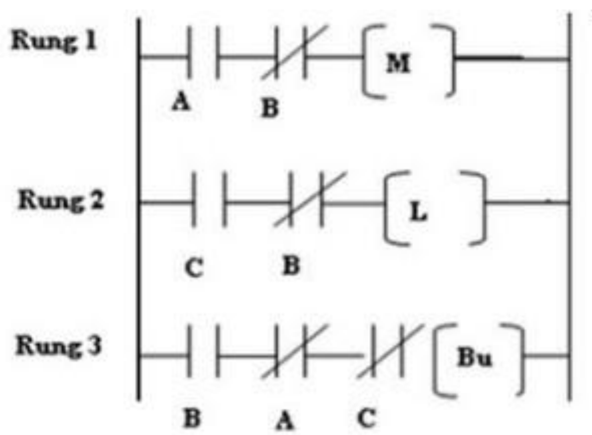
Open the programming software installed in the PC that comes with PLC hardware. Select the hardware model of the PLC in the software and configure it with appropriate input and output modules. Select the ladder language (LD) from the list of the programming languages, and choose the hardware processor and give a name for the program.



PLC Programming Software

Step 4: Add the Required Rungs and Address Them

Add the required rungs based on the control application logic and give the address to the each and every input and outputs. The ladder logic diagram of the above discussed example is given below.



Example of Ladder Logic Program

Step 5: Check the Errors and Simulate It

Locate the Online section in the menu bar and select Online. Check for the errors and make necessary changes after selecting Offline. Again, go online and select the Run option to simulate it.

Step6: Download the Program to PLC CPU Memory

After the successful simulation of the program, download the program to CPU by selecting the Download option through a network or communication cable.

This is about the PLC programming basics and its procedural steps. We hope that the given content is clear and easy for understanding. It is also possible to know and understand it better with specified software of particular PLC like RSLogix 500, Codesys, step 7, etc. You can share your views, suggestions on PLC programming or if you want any help pertaining to the examples , then write to us in the comment section below.

What is Numerical Control Machine?

Numerical control, popularly known as the NC is very commonly used in the machine tools. Numerical control is defined as the form of programmable automation, in which the process is controlled by the number, letters, and symbols. In case of the machine tools this programmable automation is used for the operation of the machines.

In other words, the numerical control machine is defined as the machined that is controlled by the set of instructions called as the program. In numerical control method the numbers form the basic program instructions for different types of jobs; hence the name numerical control is given to this type of programming. When the type of job changes, the program instructions of the job also change. It is easier to write the new instructions for each job, hence NC provides lots of flexibility in its use.

The NC technology can be applied to wide variety of operations like drafting, assembly, inspection, sheet metal working, etc. But it is more prominently used for various metal machining processes like turning, drilling, milling, shaping etc. Due to NC all the machining operations can be performed at the fast rate resulting in bulk manufacturing becoming quite cheaper.

Brief History of the NC

The invention of numerical control has been due to the pioneering works of John T. Parsons in the year 1940, when he tried to generate a curve automatically by milling cutters by providing coordinate motions. In the late 1940s Parsons conceived the method of using punched cards containing coordinate position system to control a machine tool. The machine directed to move in small increments and generate the desired finish. In the year, 1948, Parons demonstrated this concept to the US Air Force, who sponsored the series of project at laboratories of Massachusetts Institute of Technology (MIT). After lots of research MIT was able to demonstrate first NC prototype in the year 1952 and in the next year they were able to prove the potential applications of the NC.

Soon the machine tool manufacturers began their own efforts to introduce commercial NC units in the market. Meanwhile, the research continued as MIT, who were able to discover Automatically Programmed Tools, known as APT language that could be used for programming the NC machines. The main aim of APT language was to provide the means to the programmer by which they can communicate the machining instructions to the machine tools in easier manner using English like statements. The APT language is still used in widely in the manufacturing industry and a number of modern programming languages are based on the concepts of APT.

Advent of the CNC Machines

In the initial years of NC, punched tapes were for feeding the instructions to the machine tools via the control unit. The APT language also marked the arrival of the computer numerical controlled machines, popularly known as the CNC machines. Another language, PRONTO, was discovered by Parick Hanratty, who carried out various experiments at GE and released the language in the year 1958.

In CNC machines programs are fed in the computer was used to control the operations of the machines. Thus the control unit used that would read the punched cards in the NC machines was replaced by the microcomputer in the CNC machines. The CNC brought major revolution in the manufacturing industry. The next development has been the combination of computer aided manufacturing (CAM) and computer aided designing (CAD) called as CAD/CAM.

Components of the Numerical Control System

There are three important components of the numerical control or NC system. These are:

1. Program of instructions
2. Controller unit, also called as the machine control unit (MCU) and
3. Machine tool

All these have been shown in the figure below and also described in the subsequent sections.

Parts of the Numerical Control Machine

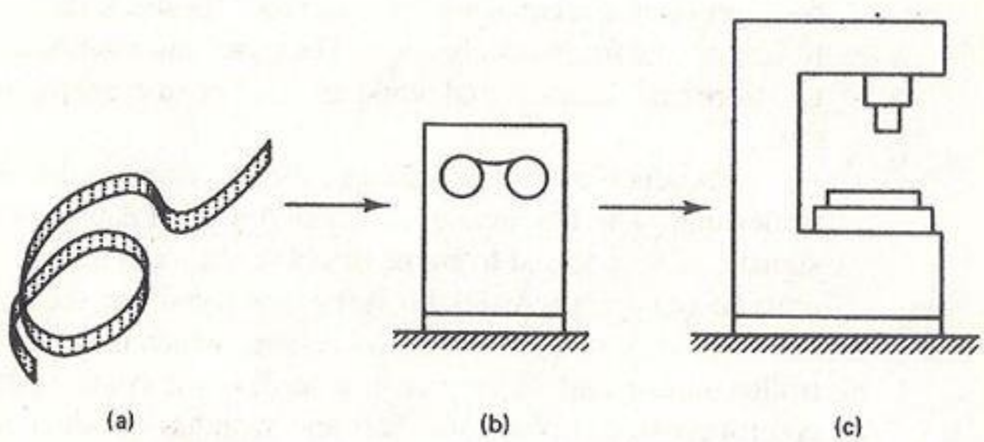


FIGURE 7.1 Three basic components of a numerical control system: (a) program of instruction; (b) controller unit; (c) machine tool.

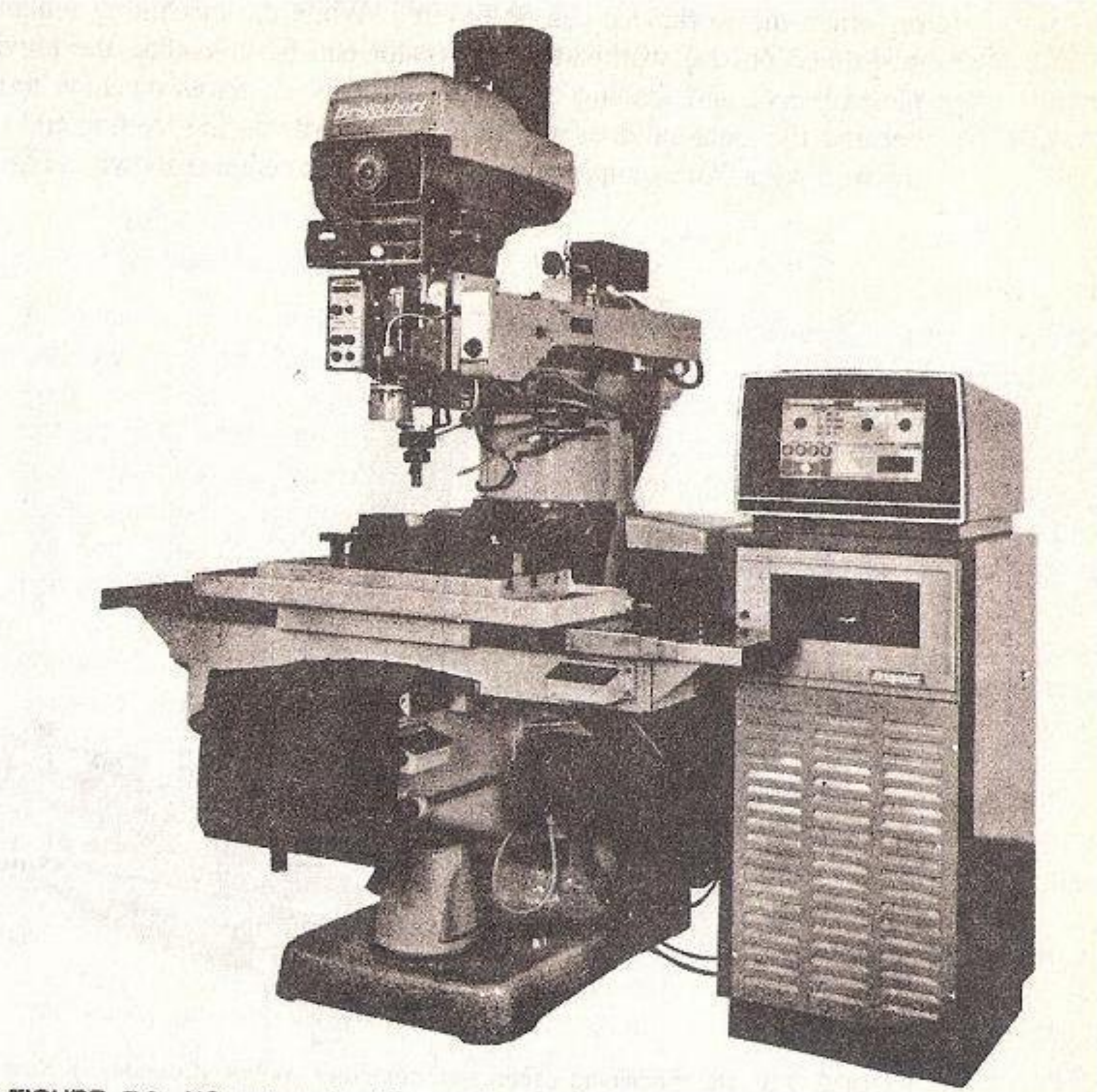


FIGURE 7.2 NC system showing machine tool and controller. (Courtesy of Bridgeport Machines Division of Textron Inc.)

1. Program of Instructions

The typical desktop program gives the instructions to the computers to perform certain functions. The program of instructions of the NC machine is the step-by-step set of instructions that tells the machines what it has to do. These instructions can tell the machine to turn the piece of metal to certain diameter, drill the hole of certain diameter up to certain length, form certain shape etc. The set of instructions are coded in numerical or symbolic form and written on certain medium that can be interpreted by the controller unit of the NC machine. The mediums commonly used earlier for writing the instructions were punched cards, magnetic tapes and 35mm motion picture film, but now 1 inch wide punched tape is used more commonly.

The program instructions are written by the expert who has programming knowledge as well the machining knowledge. The person should know the various steps of the machining required to manufacture a particular product and should be able to write these steps in the form of the program that can be understood by the control unit of the NC machine, which would eventually direct the machine tool to perform the required machining operations.

One can also input the instructions directly into the controller unit manually, this method is called as manual data input (MDI), which is used for very simple jobs. Then there is direct numerical control method (DNC) in which the machines are controlled by the computers by direct link omitting the tape reader.

2. Controller Unit or Machine Controller Unit (MCU)

The controller unit is most vital parts part of the NC and CNC machines. The controller unit is made of the electronics components. It reads and interprets the program of instructions and converts them in the mechanical actions of the machine tool. Thus the controller unit forms an important link between the program and the machine tool. The control unit operates the machines as per the set of instructions given to it.

The typical control unit comprises of tape reader, a date buffer, signal output channels to the machine tools, feedback channel from the machine tool, and the sequence control to coordinate the overall machining operation.

Initially, the set of instructions from the punched tape are read by the tape reader, which is sort of the electromechanical devise. The data from the tape is stored into the data buffer in form of logical blocks of instructions with each block resulting in certain sequence of operations.

The controller sends the instructions to the machine tool via signal output channels that are connected to the servomotors and other controls of the machines. The feedback channels ensure that the instructions have been executed by the machine correctly. The sequence control part of the controller unit ensures that all the operations are executed in the proper sequence.

One important thing to note about the controller unit here is that all the modern NC machines are equipped with the microcomputer that acts as the controller unit. The program is fed into the computer directly and the computer controls the working the machine tool. Such machines are called as Computer Controller Machines (CNC) machines.

3. Machine Tool

It is the machine tool that performs the actual machining operations. The machine tool can be any machine like lathe, drilling machine, milling machine etc. The machine tool is the controlled part of the NC system. In case of the CNC machines, the microcomputer operates the machine as per the set of instructions or the program.

The NC machine also have the control panel or control console that contains the dials and switches using which the operator runs the NC machine. There are also displays to display information to the user. Most of the modern NC machines are now called as the CNC machines.

What is the CNC Machine?

Now that we have seen **what the NC machine is** and its **various parts**, it is easier to understand what the CNC machine is. CNC is the short form for Computer Numerical control. We have seen that the NC machine works as per the program of instructions fed into the controller unit of the machine. The CNC machine comprises of the mini computer or the microcomputer that acts as the controller unit of the machine. While in the NC machine the program is fed into the punch cards, in CNC machines the program of instructions is fed directly into the computer via a small board similar to the traditional keyboard.

In CNC machine the program is stored in the memory of the computer. The programmer can easily write the codes, and edit the programs as per the requirements. These programs can be used for different parts, and they don’t have to be repeated again and again.

Compared to the NC machine, the CNC machine offers greater additional flexibility and computational capability. New systems can be incorporated into the CNC controller simply by reprogramming the unit. Because of its capacity and the flexibility the CNC machines are called as “soft-wired” NC.

CNC Machine

How the CNC Machine Works?

The CNC machine comprises of the computer in which the program is fed for cutting of the metal of the job as per the requirements. All the cutting processes that are to be carried out and all the final dimensions are fed into the computer via the program. The computer thus knows what exactly is to be done and carries out all the cutting processes. CNC machine works like the Robot, which has to be fed with the program and it follows all your instructions.

Some of the common machine tools that can run on the CNC are: Lathe, Milling machines, Drilling Machine etc. The main purpose of these machines is to remove some of the metal so as to give it proper shape such as round, rectangular, etc. In the traditional methods these machines are operated by the operators who are experts in the operation of these machines. Most of the jobs need to be machined accurately, and the operator should be expert enough to make the precision jobs. In the CNC machines the role of the operators is minimized. The operator has to merely feed the program of instructions in the computer, load the required tools in the machine, and rest of the work is done by the computer automatically. The computer directs the machine tool to perform various machining operations as per the program of instructions fed by the operator.

You don’t have to worry about the accuracy of the job; all the CNC machines are designed to meet very close accuracies. In fact, these days for most of the precision jobs CNC machine is compulsory. When your job is finished, you don’t even have to remove it, the machine does that for you and it picks up the next job on its own. This way your machine can keep on doing the fabrication works all the 24 hours of the day without the need of much monitoring, of course you will have to feed it with the program initially and supply the required raw material.

Most of the manufacturing companies are now equipped with the CNC machines as the markets have got very competitive; however, getting the expert labors for operating these machines is becoming quite difficult. Even the machine operators of these days prefer to operate the machine by programming instead of operating it manually. In most of the machine tools training institutes the new operators are taught manual machining as well as CNC machining and programming.

Though the NC machines worked automatically as per the program fed in the punched tape and though they increased the productivity, a number of problems were associated with them. These problems posed a major obstacle in the further development of the NC machines. With the introduction of the computers in the NC machines their further developments were enabled and these automatic machines came to be popularly known as the CNC (computer numerical control) machines.

Problems Associated with the Conventional NC Machines

Here are some of the problems associated with the conventional NC machines:

1) Mistakes related with part programming (programming for the parts to be manufactured): When the programs of instructions related to the particular part to be manufactured are written on the punched tape, the syntax or numerical mistakes are quite common. The NC tape is not completed correctly in a single pass and at least three passes are required to get the correct program written. Another major problem with the part programming is achieving the best sequence of steps required for the machining the part.

2) Nonoptimal speed and feeds: For most economic manufacturing of the object from the raw material it should be given optimum speed and feeds during manufacturing. The conventional numerical control does not provide opportunity to change the speeds and feeds during the cutting operations, so the programmer is compelled to set the speeds and feeds for the worst-case conditions that can result in highly expensive manufacturing due to wastages, and low quality jobs. This also results in manufacturing of the jobs at lower than optimum productivity.

3) Punched tape: The punched, which is made up of paper and on which the program is written is the problem in itself. This tape is fragile and susceptible to wear and tear so it has short life and cannot be reliable enough for the repeated use. Instead of paper, other media like Mylar can be used for writing the program of instructions, but these materials are quite expensive.

4) Unreliable tape reader: The tape reader reads the program of instructions from the punched tape, but it is considered to be highly unreliable hardware component of the NC machine. When the NC machine breaks down the first thing the maintenance personnel checks is the tape reader.

5) The inflexible controller: The conventional NC machine has the controller unit which is hard wired and the making the changes in the controls of the machines is a tough task. The controller used in the CNC machines is the computer, which is highly flexible.

6) Important information: The conventional NC machine cannot provide crucial information to the operator and the supervisor like the number of pieces manufactured, tools changes and others.

The problems associated with the NC machines have been solved over the time with the improvement in the NC technology mostly due to advancement in the electronics. The major change obviously came when mini or microcomputers were introduced in the NC system. The computers have had major impact on the NC system and with their introduction the whole technology has come to be known as the CNC (computer numerical control) technology. For the common man and also to the engineers the automatic machine tools are now known by the name CNC machines and not the NC machines.

Advantages of the CNC Machines

There are various valid reasons for the popularity of the CNC machines over the NC machines, let us see some of them.

1) Part program tape and tape reader: In the older CNC machines the part program tape and the tape reader is still required, but they are used only for feeding the program into the memory of the computer. Once the program is saved into the memory, the tape is no more required and the program stored in the memory can be used repeatedly. Thus the tape and the tape reader that poses the major maintenance problems are done away with. In fact the latest CNC machine don’t even require the tape and tape reader, for the program of instructions are fed directly into the mini or microcomputer via the control panel of the computer.

2) Editing the program: Since the program of instructions is saved in the computer memory, they can be edited and changed as per the requirements. Thus the CNC system is highly flexible. One can also make necessary changes in the program for providing variable speeds and feeds for the manufacture of the jobs resulting in economic manufacturing. Even the NC tape used for the programming in CNC machines can be corrected and optimized since it allows changes in the tool path, speed, feed etc.

3) Metric conversion: The CNC machine allows the conversion of tapes prepared in the metric system into the SI system of measurements. Thus programmer does not have to re-enter the whole program of instructions merely because of the different units of measurements used in the program.

4) Highly flexible: The CNC machines are highly flexible. One can easily make the changes in the program and store them as the new program. One can also introduce new control options like the new interpolation scheme quite easily. It is easier to make updates in the CNC machines with lesser cost; hence risk of the obsolescence of the CNC machine is reduced.

5) Easier programming: The programs are written in the CNC machine using language which has statements similar to the ordinary English language statements. The programmer can easily master the CNC programming language and use it for the wide range of the machining operations of the job. The programmer can set the various dimension of the job, the machining operations to be carried out and their sequence, the amount of metal to be removed in each cutting operation, the speed of cutting, etc. The program of instructions is written as per the available size of the raw materials and also the surface finish required for the final finished job. Some of the programs take the form of the macro subroutines stored in the memory of the CNC machine and the programmer can use them frequently whenever required. Some of the programs are stored in the library and they can be used wherever required completely or as a small part of the big program.

These days the CNC machines are found in almost all industries, from a small scale industry to big companies. There is hardly any facet of manufacturing that is not touched by the automated CNC machining center. Everyone involved in the manufacturing should know what a CNC machine can do for their company. Due to extensive applications of CNC machines in various industries, there is a great surge in the demand of the CNC programmers. To meet these demands a number of schools have come up that teach the operation and programming of the CNC machines.

CNC Machine Tools


Bridgeport
412X
Bridgeport
INTERACT
412X


LINE
3
CNC 15
FANUC
AFTER
CNC
BEFORE
CNC
AFTER

Some Industries where CNC Machining Centers are used

Here are some of the many industries where the CNC machining centers are used.

Industries for removing metal: The metal removing industries remove the metal from the raw material to give it the desired as per the requirements. These can be the automotive industries for making the shafts, gears, and many other parts. It can be manufacturing industries for making the various rounded, square, rectangular, threaded and other jobs. There are many other industries where the metal removal works are performed. All these metal removal works are performed by different machine tools like lathe, milling machine, drilling machine, boring machine, shaping machine, reamer, etc. Traditionally these machines are operated by the operators, but the CNC versions of all these machines are now used extensively. You can carryout almost all machining operations with the CNC machining centers. You can also carry out all the turning operations such as facing, boring, turning, grooving, knurling, and threading on your CNC turning centers. On your CNC grinders you can carry out the grinding of the internal diameter, outer diameter, and also the flat surfaces. The Contour Grinding technology enables you to grind surfaces of all shapes.

Industries for Fabricating Metals: In many industries thin plates like steel plates are required for various purposes, in fabrications industry the machining operations are performed on such plates. In these industries the CNC machines are used for various machining operations like shearing, flame or plasma cutting, punching, laser cutting, forming, and welding and many other applications. To bring the plates to their final shape CNC lasers and CNC plasma cutters are used commonly. To punch the holes in the plates of all sizes CNC turret punch presses are used. And if you want to bend the plate so as to give it a final shape, you can use CNC press brakes. In some cases the CNC back gages are coupled with the shearing machines, this enables controlling the length of the plate to be sheared as for different applications.

Electrical Discharge Machining (EDM) Industry: The EDM machines remove the metal by creating the sparks that burn the metal. There are two types of EDM with the CNC automation – Vertical EDM and Wire EDM. The Vertical EDM needs an electrode of the shape and size of the cavity that is be made in the job. Wire EDM is used to make the punch and die combinations for the dies set that are used in the industries where fabrication is done.

Other Industries where CNC machines are used: CNC machines are also used extensively in the wood working industries to perform various operations like routing (similar to milling) and drilling. CNC technology is also used in number of lettering and engraving systems. There are also

CNC machines for the electrical industry such as CNC coil winders, and CNC terminal location and soldering machines.

In whichever the industry you go you are sure to find some or the other type of the CNC machine. The progress made by the manufacturing sector is mainly due to the advancements in the CNC technology.