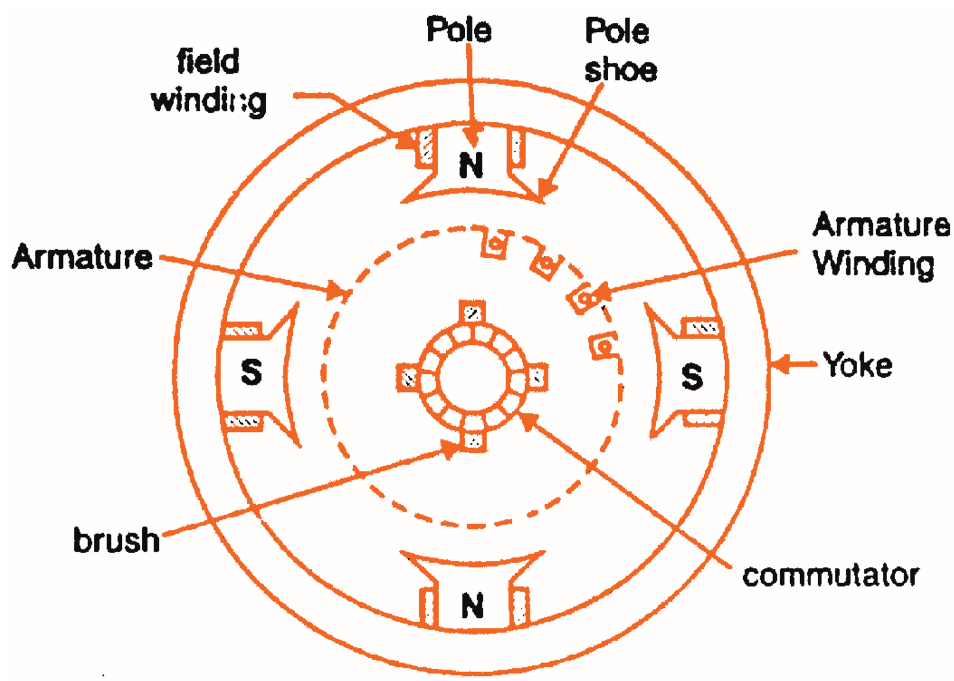
DC Generator

A dc generator is an electrical machine which converts mechanical energy into direct current electricity. This energy conversion is based on the principle of production of dynamically induced emf. This article outlines the basics of construction and working of a DC generator.

Construction of a DC generator:

Note: A DC generator can be used as a DC motor without any constructional changes. Thus, a DC generator or a DC motor can be broadly termed as a DC machine. These basic constructional details are also valid for a DC motor. Hence, let's call this point as construction of a DC machine.



Above figure shows the constructional details of a simple 4-pole DC generator. A DC generator consists two basic parts, stator and rotor. Basic constructional parts of a DC generator are described below.

1. Yoke: The outer frame of a generator or motor is called as yoke. Yoke is made up of cast iron or steel. Yoke provides mechanical strength for whole assembly of the generator (or motor). It also carries the magnetic flux produced by the poles.

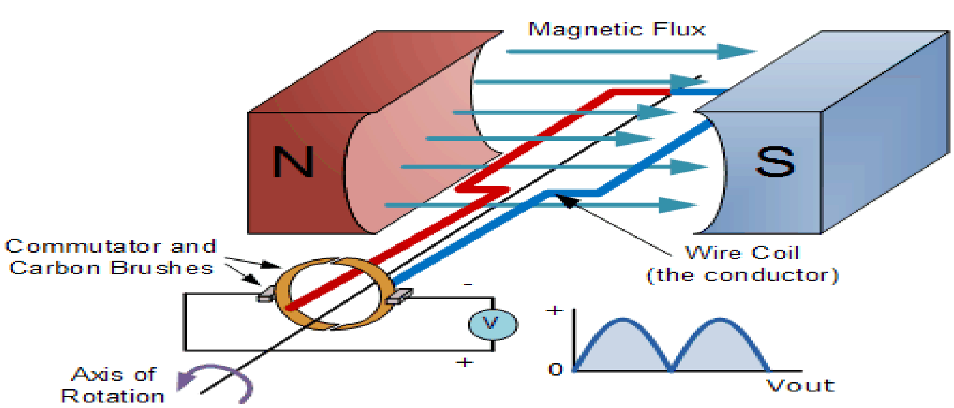
2. Poles: Poles are joined to the yoke with the help of screws or welding. Poles are to support field windings. Field winding is wound on poles and connected in series or parallel with armature winding or sometimes separately.
3. Pole shoe: Pole shoe is an extended part of the pole which serves two purposes, (i) to prevent field coils from slipping and (ii) to spread out the flux in air gap uniformly.

Armature core (rotor)

4. Armature core: Armature core is the rotor of a generator. Armature core is cylindrical in shape on which slots are provided to carry armature winding. Armature winding can be wound by one of the two methods known as lap winding and wave winging.

5. Commutator and brushes: As emf is generated in the armature conductors terminals must be taken out to make use of generated emf. But we can't directly solder wires to commutator conductors, because the commutator conductors will be rotating and the wires will get twisted and break. Thus commutator is connected to the armature conductors and mounted on the same shaft as that of armature core. Conducting brushes rest on commutator and they slides over when rotor (hence commutator) rotates. Thus brushes are physically in contact with armature conductors hence wires can be connected to the brushes. The generated emf is taken to external circuit through brushes.

Working principle:



According to Faraday's law of electromagnetic induction, 'when a conductor moves in a magnetic field (thereby cutting the magnetic flux lines), an emf gets induced in the conductor'. The magnitude of generated emf can be given by emf equation of DC generator. If a closed path is provided to the moving conductor then generated emf causes a current to flow in the circuit. One of the main functions of commutator is to convert generated AC emf into DC.

EMF equation of D.C Generator

Let**,**

	P	=	Number of poles of the generator	
	Φ	=	Flux produced by each pole in webers (Wb)	
	N	=	Speed of armature in r.p.m	
	Z	=	Total number of armature conductors	
	A	=	No. of parallel paths in which the ‘Z’ no. of conductors are Divided	
So	A	=	P	for lap type of winding
	A	=	2	for wave type of winding

Now e.m.f gets induced in the conductor according to Faraday’s law of electromagnetic induction. Hence average value of e.m.f induced in each armature conductor is,

$$e = \text{Rate of cutting the flux} = \frac{d\Phi}{dt}$$

Now consider one revolution of conductor. In one revolution, conductor will cut total flux produced by all the poles i.e. Φ x P. While time required to complete one revolution is (60 / N) seconds as speed is N r.p.m.

Therefore,

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

This is the e.m.f induced in one conductor. Now the conductors in one parallel path are always in series. There are total Z conductors with A parallel paths, hence $\frac{z}{A}$ number of conductors are always in series and e.m.f remains same across all the parallel paths.
Total e.m.f can be expressed as,

$$E = \Phi P \frac{N}{60} \times \frac{Z}{A} \quad \text{Volts}$$

This is nothing but the e.m.f equation of a d.c. generator.
So,

$$E = \frac{\Phi P N Z}{60 A} \quad \text{Volts}$$

$$E = \frac{\Phi N Z}{60} \quad \text{For lap type as } A = P$$

$$E = \frac{\Phi P N Z}{120} \quad \text{For wave type as } A = 2$$

Types of D.C. Generator

D.C generator is basically divided into two categories depending on the way of deriving the field current or exciting current as,

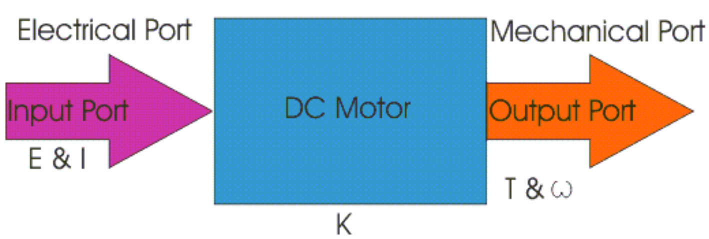
1. Separately excited generator
2. Self excited generator
   (a) Shunt generator
   (b) Series generator
   (c) Compound generator

DC Motors

Principle of DC Motor

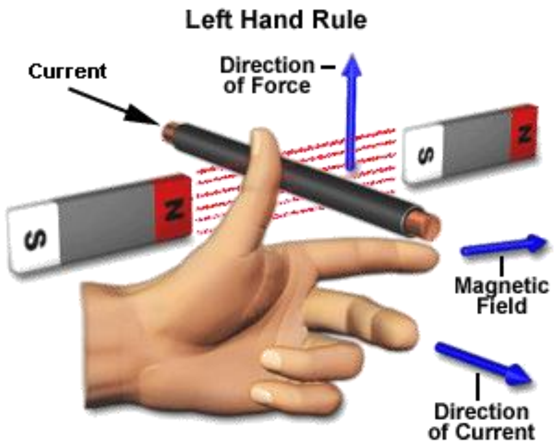
"Whenever a current carrying conductor is placed in a magnetic field, torque is developed in the conductor". In a practical d.c motor, field winding produces a required magnetic field while armature conductors play a role of current carrying conductors and hence armature conductors experience a force.

Energy Conversion Diagram



A motor is a device which converts an electrical energy into the mechanical energy. The energy conversion process is exactly opposite to that involved in a d.c generator. The construction of a d.c machine is same whether it is a motor or a generator.

Fleming's Left hand rule



The rule states that outstretch the three fingers of the left hand namely the first finger, middle finger and thumb such that they are mutually perpendicular to each other. Now point the first finger in the direction of magnetic field and the middle finger in the direction of the current then the thumb gives the direction of the force experienced by the conductor.

Whenever a current carrying conductor is placed inside a magnetic field, a force acts on the conductor, in a direction perpendicular to both the directions of the current and the magnetic field. In the figure it is shown that, a portion of a conductor of length L placed vertically in a uniform horizontal magnetic field strength H, produced by two magnetic poles N and S.

The magnitude of the force experienced by the conductor in a motor is given by,

$$F=BIL \text{ Newton (N)}$$

Where,

B = Flux density due to the flux produced by the field winding
L = Active length of the conductor
I = Magnitude of the current passing through the conductor

Back EMF

According to faraday's law of electromagnetic induction, there is an induced e.m.f in the rotating armature conductors. This induced e.m.f in the armature always acts in the opposite direction of the supply voltage.

" Lenz's law states that the direction of the induced e.m.f is always so as to oppose the cause producing it "

In a d.c motor, the supply voltage is the cause and hence this induced e.m.f opposes the supply voltage. This e.m.f tries to set up a current through the armature which is in the opposite direction to that, which supply voltage is forcing through the conductor. So as this e.m.f always opposes the supply voltage, it is called back e.m.f. and denoted as Eb.

The expression for back e.m.f is given by,

$$E_b = \frac{PN\phi Z}{60A} \quad \text{Volts}$$

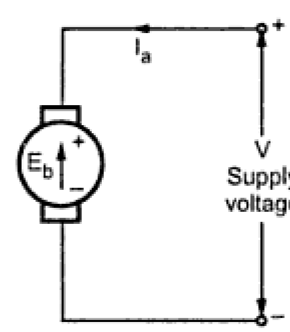


Fig : Back e.m.f in a D.C motor

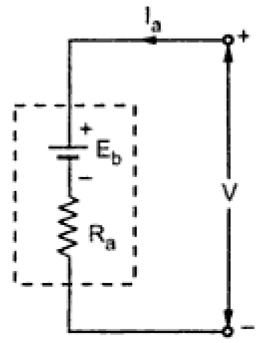


Fig: Equivalent circuit

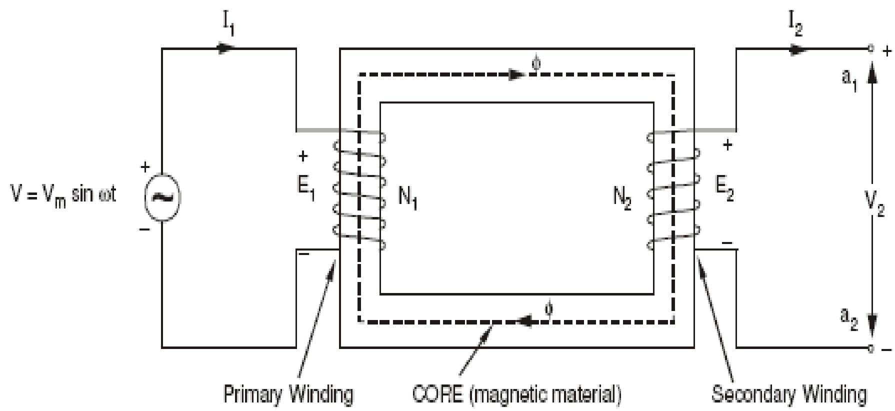
SINGLE PHASE TRANSFORMER

INTRODUCTION

The transformer is a device that transfers electrical energy from one electrical circuit toanother electrical circuit. The two circuits may be operating at different voltage levels butalways work at the same frequency. Basically transformer is an electro-magnetic energyconversion device. It is commonly used in electrical power system and distributionsystems.

Principle of operation

The single phase transformer works on the principle of mutual induction between two inductively coupled coils. A single-phase transformer consists of two windings, wound on an ironcore one of the windings is connected to an ac source of supply *f*. The source supplies acurrent to this winding (called primary winding) which in turn produces a flux in the ironcore. This flux is alternating in nature. The alternating flux linkingwith the second winding, induces a voltage *E*2 in the second winding (called secondarywinding). [Note that this alternating flux linking with primary winding will also induce avoltage in the primary winding, denoted as *E*1. Applied voltage *V*1 is very nearly equal to$E1$]. The number of turns in the primary and secondary windings is $N1$ and $N2$. The load is connected acrossthe secondary winding, between the terminals $a1$, $a2$ carries a current $I2$, called loadcurrent.The transfer of power from the primary side(or source) to the secondary side (or load) is through the mutual flux and core. There is nodirect electrical connection between the primary and secondary sides.



In an actual transformer, when the iron core carries alternating flux, there is a power loss in the core called core loss, iron loss or no load loss. Further, the primary and secondary windings have a resistance, and the currents in primary and secondary windings give rise to I^2R losses in transformer windings, also called copper losses. The losses lead to production of heat in the transformers, and a consequent temperature rise. Therefore, in transformer, cooling methods are adopted to ensure that the temperature remains within limit so that no damage is done to windings' insulation and material.

CONSTRUCTION

There are two basic parts of a transformer

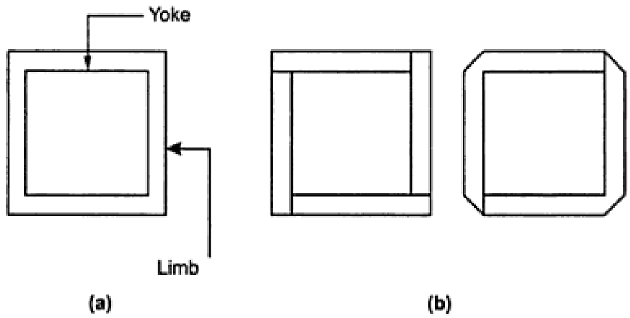
i) Magnetic core

ii) Winding or coils

i)Magnetic Core

The core of the transformer is either square or rectangular in size. It is further divided in to two parts. The vertical portion on which coils are wound is called limb while the top and bottom horizontal portion is called yoke of the core.

The core is built-up of thin steel laminations insulated from each other. This helps in reducing the eddy current losses in the core. The steel used for core is of high silicon content, sometimes heat treated to produce high permeability and low hysteresis loss. The material commonly used for core is CRGO (Cold Rolled Grain Oriented) steel.



Magnetic Core

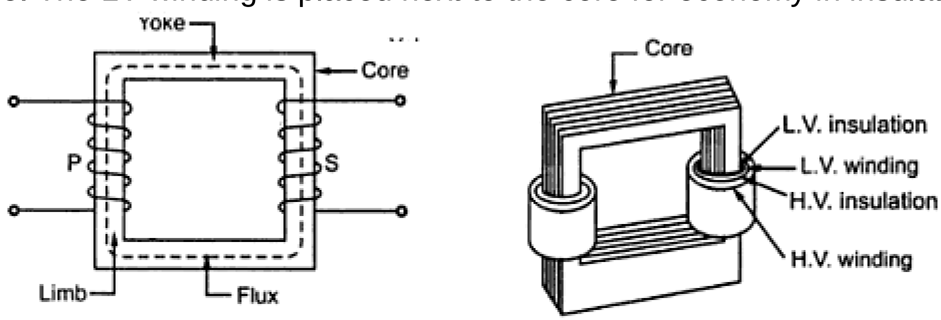
TYPES OF TRANSFORMER

Depending upon the manner in which the primary and secondary windings are placed on the core, and the shape of the core, there are two types of transformers, called

(a) Core type Transformer
(b) Shell type Transformer

(a) Core type Transformer

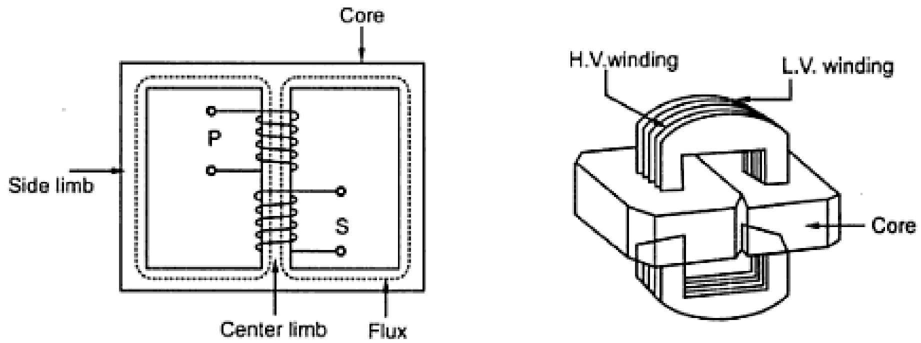
In core type transformers, the windings are placed in the form of concentric cylindrical coils placed around the vertical limbs of the core. The low-voltage (LV) as well as the high-voltage (HV) winding are made in two halves, and placed on the two limbs of core. The LV winding is placed next to the core for economy in insulation cost.



Core type Transformer

(b) Shell type Transformer

In the shell type transformer, the primary and secondary windings are wound over the central limb of a three-limb core. The HV and LV windings are split into a number of sections, and the sections are interleaved or sandwiched i.e. the sections of the HV and LV windings are placed alternately.



Shell type Transformer

Comparison of Core and Shell Type

Sr. No	Core Type	Shell Type
1	The winding encircles the core	The core encircles most part of the winding
2	It has single magnetic circuit	It has a double magnetic circuit
3	The core has two limbs	The core has three limbs
4	The cylindrical coils are used	The multilayer disc on sandwich type coils are used
5	The windings are uniformly distributed on two limbs hence natural cooling is effective	The natural cooling does not exists as the winding are surrounded by the core
6	The coils can be easily removed from maintenance	The coil cannot be removed easily
7	Preferred for low voltage transformers	Preferred for high voltage transformers

ii)Winding

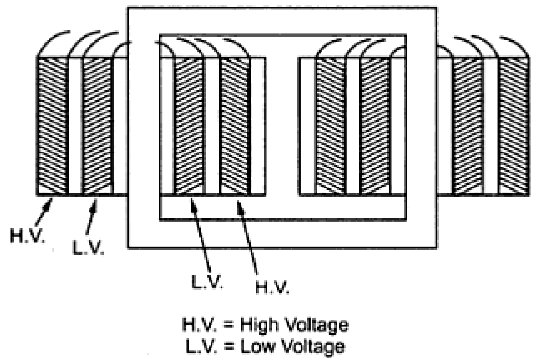
Conductor material used for windings is mostly copper. However, for small distribution transformer aluminum is also sometimes used. The conductors, core and whole windings are insulated using various insulating materials depending upon the voltage.

The different types of windings are

a) Concentric windings
b) Sandwich windings

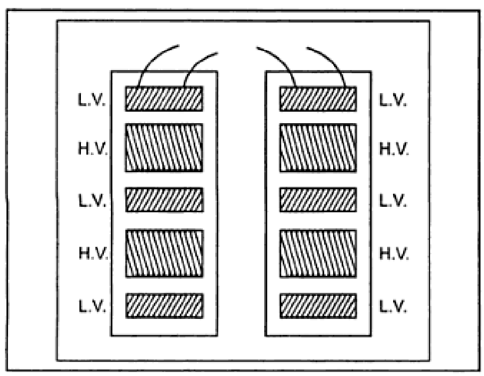
a)Concentric windings

These windings are used for core type transformers. Each limb has group of coils having both primary and secondary turns concentrically wound. The LV winding is placed next to the core and HV winding on the outside.



c) Sandwich Coils

It is used for shell type transformers. Each winding is subdivided in to sections. The LV and HV subsections are alternately put in the form of a sandwich. Each HV section lies between the LV sections.



Insulating Oil

In oil-immersed transformer, the iron core together with windings is immersed in insulating oil. The insulating oil provides better insulation, protects insulation from moisture and transfers the heat produced in core and windings to the atmosphere.
The transformer oil should possess the following qualities:
(a) High dielectric strength,
(b) Low viscosity and high purity,
(c) High flash point, and
(d) Free from sludge.
Transformer oil is generally a mineral oil obtained by fractional distillation of crudeoil.

Tank and Conservator

The transformer tank contains core wound with windings and the insulating oil. In large transformers small expansion tank is also connected with main tank is known as conservator. Conservator provides space when insulating oil expands due to heating. The transformer tank is provided with tubes on the outside, to permits circulation of oil, which aides in cooling. Some additional devices like breather and Buchholz relay are connected with main tank. Buchholz relay is placed between main tank and conservator. It protects the transformer under extreme heating of transformer winding. Breather protects the insulating oil from moisture when the cool transformer sucks air inside. The silica gel filled breather absorbs moisture when air enters the tank. Some other necessary parts are connected with main tank like, Bushings, Cable Boxes, Temperature gauge, Oil gauge, Tappings, etc.

Transformers can also be classified according to the type of cooling employed. The different types according to these classifications are:

1. Oil Filled Self-Cooled Type

Oil filled self cooled type uses small and medium-sized distribution transformers. The assembled windings and core of such transformers are mounted in a welded, oil-tight steel tanks provided with a steel cover. The tank is filled with purified, high quality insulating oil as soon as the core is put back at its proper place. The oil helps in transferring the heat from the core and the windings to the case from where it is radiated out to the surroundings. For smaller sized transformers the tanks are usually smooth surfaced, but for large size transformers a greater heat radiation area is needed, and that too without disturbing the cubical capacity of the tank. This is achieved by frequently corrugating the cases. Still larger sizes are provided with radiation or pipes.

2. Oil Filled Water Cooled Type

This type is used for much more economic construction of large transformers, as the above told self cooled method is very expensive. The same method is used here as well- the windings and the core are immersed in the oil. The only difference is that a cooling coil is mounted near the surface of the oil, through which cold water keeps circulating. This water carries the heat from the device. This design is usually implemented on transformers that are used in high voltage transmission lines. The biggest advantage of such a design is that such transformers do not require housing other than their own. This reduces the costs by a huge amount. Another advantage is that the maintenance and inspection of this type is only needed once or twice in a year.

3. Air Blast Type

This type is used for transformers that use voltages below 25,000 volts. The transformer is housed in a thin sheet metal box open at both ends through which air is blown from the bottom to the top.

STEPPER MOTORS

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

Open loop operation

One of the most significant advantages of a stepper motor is its ability to be accurately controlled in an open loop system. Open loop control means no feedback information about position is needed. This type of control eliminates the need for expensive sensing and feedback devices such as optical encoders. Your position is known simply by keeping track of the input step pulses.

Stepper motor types

There are three basic types of stepper motor types. They are:

- Variable – reluctance
- Permanent magnet
- Hybrid

Working of Stepper Motor

Stepper motors consist of a permanent magnetic rotating shaft, called the rotor, and electromagnets on the stationary portion that surrounds the motor, called the stator. Figure 1 illustrates one complete rotation of a stepper motor. At position 1, we can see that the rotor is beginning at the upper electromagnet, which is currently active (has voltage applied to it). To move the rotor clockwise (CW), the upper electromagnet is deactivated and the right electromagnet is activated, causing the rotor to move 90 degrees CW, aligning itself with the active magnet. This process is repeated in the same manner at the south and west electromagnets until we once again reach the starting position.

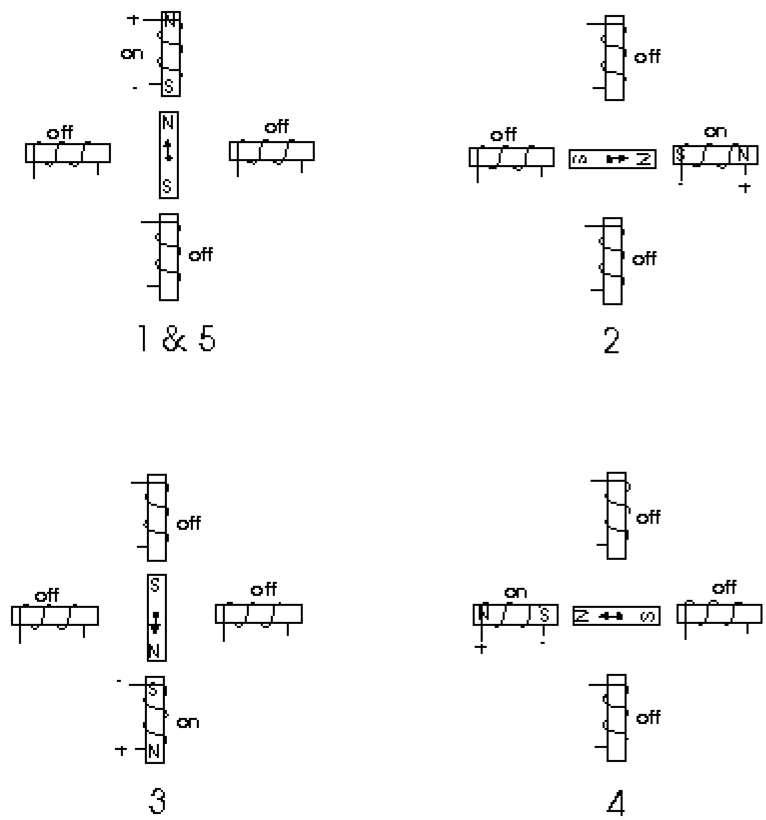


Figure 1

In the above example, we used a motor with a resolution of 90 degrees or demonstration purposes. In reality, this would not be a very practical motor for most applications. The average stepper motor's resolution -- the amount of degrees rotated per pulse -- is much higher than this. For example, a motor with a resolution of 5 degrees would move its rotor 5 degrees per step, thereby requiring 72 pulses (steps) to complete a full 360 degree rotation.

You may double the resolution of some motors by a process known as "half-stepping". Instead of switching the next electromagnet in the rotation on one at a time, with half stepping you turn on both electromagnets, causing an equal attraction between, thereby doubling the resolution. As you can see in Figure 2, in the first position only the upper electromagnet is active, and the rotor is drawn completely to it. In position 2, both the top and right electromagnets are active, causing the rotor to position itself between the two active poles. Finally, in position 3, the top magnet is deactivated and the rotor is drawn all the way right. This process can then be repeated for the entire rotation.

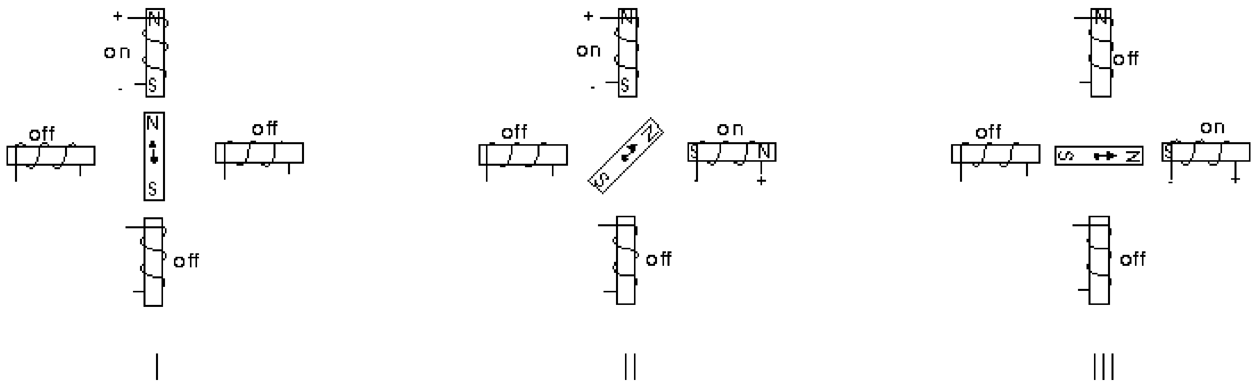


Figure 2

There are several types of stepper motors. 4-wire stepper motors contain only two electromagnets, however the operation is more complicated than those with three or four magnets, because the driving circuit must be able to reverse the current after each step. For our purposes, we will be using a 6-wire motor.

Unlike our example motors which rotated 90 degrees per step, real-world motors employ a series of mini-poles on the stator and rotor to increase resolution. Although this may seem to add more complexity to the process of driving the motors, the operation is identical to the simple 90 degree motor we used in our example. An example of a multipole motor can be seen in Figure 3. In position 1, the north pole of the rotor's permanent magnet is aligned with the south pole of the stator's electromagnet. Note that multiple positions are aligned at once. In position 2, the upper electromagnet is deactivated and the next one to its immediate left is activated, causing the rotor to rotate a precise amount of degrees. In this example, after eight steps the sequence repeats.

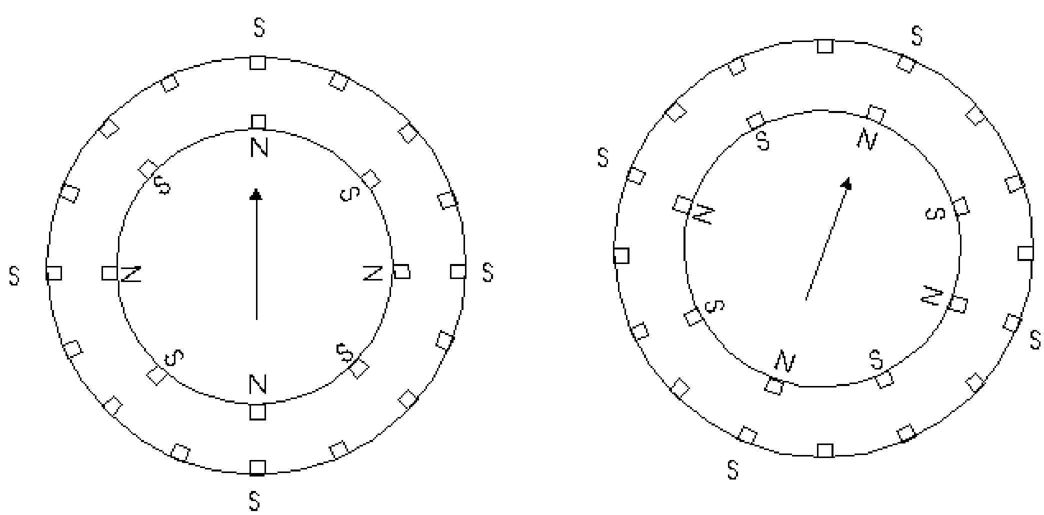


Figure 3

When to Use a Stepper Motor

A stepper motor can be a good choice whenever controlled movement is required. They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism. Stepper motors have found their place in many different applications. Some of these include printers, plotters, highend office equipment, hard disk drives, medical equipment, fax machines, automotive and many more.

Variable - reluctance motor

This type of stepper motor has been around for a long time. It is probably the easiest to understand from a structural point of view. Figure 1 shows a cross section of a typical V.R. stepper motor. This type of motor consists of a soft iron multi-toothed rotor and a wound stator. When the stator windings are energized with DC current the poles become magnetized. Rotation occurs when the rotor teeth are attracted to the energized stator poles.

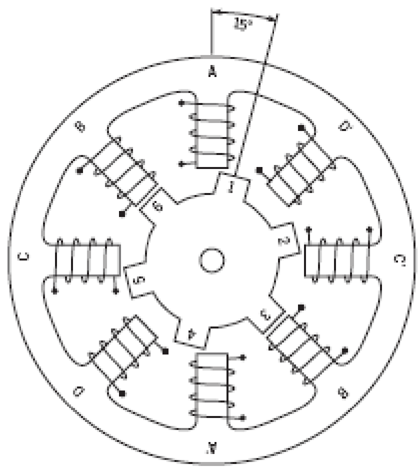


Figure 4

Permanent magnet motor

Often referred to as a “tin can” or “canstock” motor the permanent magnet step motor is a low cost and low resolution type motor with typical step angles of 7.5° to 15°. (48 – 24 steps/revolution) PM motors as the name implies have permanent magnets added to the motor structure. The rotor no longer has teeth as with the VR motor. Instead the rotor is magnetized with alternating north and south poles situated in a straight line parallel to the rotor shaft. These magnetized rotor poles provide an increased magnetic flux intensity and because of this the PM motor exhibits improved torque characteristics when compared with the VR type.

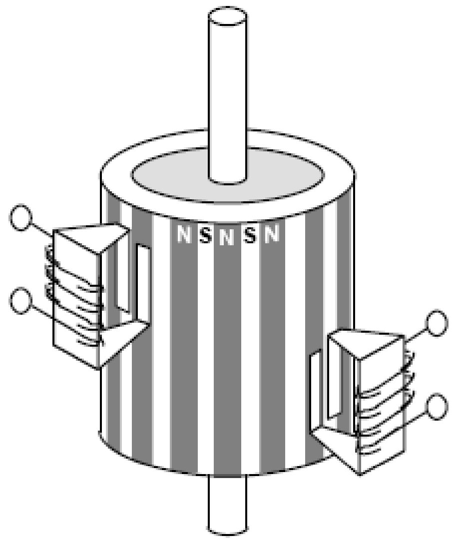


Figure 5

Hybrid Motor

The hybrid stepper motor is more expensive than the PM stepper motor but provides better performance with respect to step resolution, torque and speed. Typical step angles for the HB stepper motor range from 3.6° to 0.9° (100 – 400 steps per revolution). The hybrid stepper motor combines the best features of both the PM and VR type stepper motors. The rotor is multi-toothed like the VR motor and contains an axially magnetized concentric magnet around its shaft. The teeth on the rotor provide an even better path which helps guide the magnetic flux to preferred locations in the airgap. This further increases the detent, holding and dynamic torque characteristics of the motor when compared with both the VR and PM types.

The two most commonly used types of stepper motors are the permanent magnet and the hybrid types. If a designer is not sure which type will best fit his applications requirements he should first evaluate the PM type as it is normally several times less expensive. If not then the hybrid motor may be the right choice.

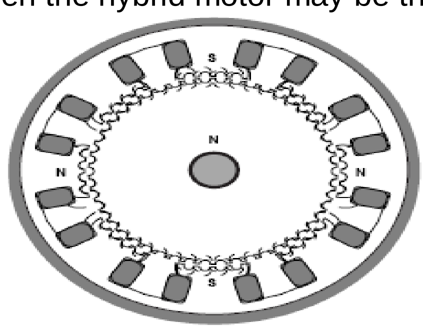


Figure 6

Advantages

1. The rotation angle of the motor is proportional to the input pulse.
2. The motor has full torque at standstill (if the windings are energized)

3. Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 – 5% of a step and this error is non cumulative from one step to the next.
4. Excellent response to starting/stopping/reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.
6. The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.
7. It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft.
8. A wide range of rotational speeds can be realized as the speed is proportional to the frequency of the input pulses.

Disadvantages

1. Resonances can occur if not properly controlled.
2. Not easy to operate at extremely high speeds.

SERVOMOTORS

Mootrs used in automatic control systems are called servomotors. They are also called control motors and have high torque capabilities. They are used for precise speed and precise position control at high torques. Two types:

1. AC Servomotors

2. DC Servomotors

AC SERVOMOTORS

Most of the ac servomotors are two phase squirrel cage induction type. AC servomotor are used for low power application. 3 phase induction motor have been modified for high power servo system. This motor run on frequency of 60 Hz or 400 Hz

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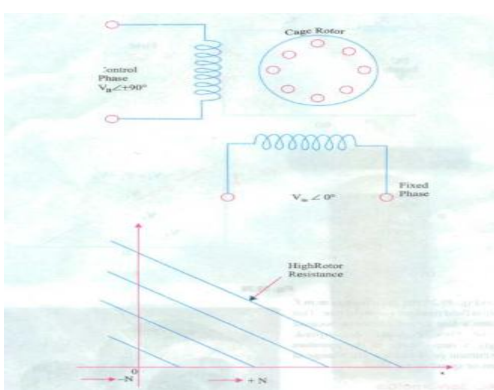


The stator has two distributed winding which are displaced from each other by 90 degree.

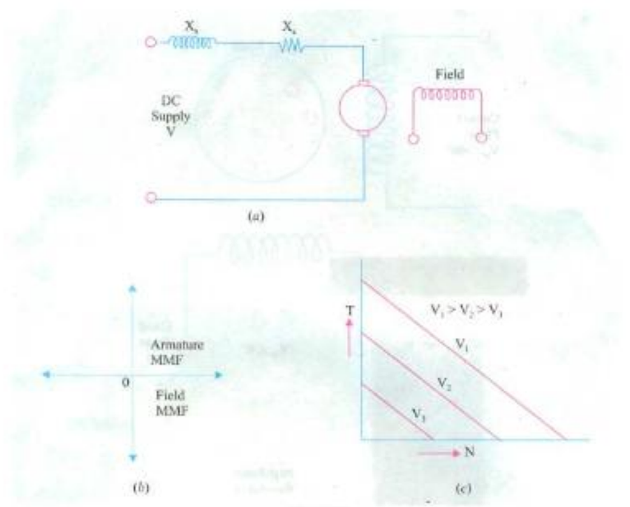
Main winding – Reference winding

Fixed phase is supplied from a constant voltage

V_{in} the other winding also control phase os supplied with variable voltage of the same frequency as the reference phase but is phase displaced by 90 degree. The control phase voltage is controlled by an electronic controller. The speed and torque are controlled by phase difference between main and control windings. Reversing the phase difference from leading to lagging reverses the motor direction.The motor operation can be controlled by varying the voltage of control phase while the reference phase voltage is kept constant.

DC SERVOMOTORS

These motors are either separately excited dc motor or permanent magnet dc motor.



The speed of dc motor is normally controlled by varying armature voltage. Their armature has large resistance so that torque –speed characteristics are linear(fig c). The armature mmf and field mmf are in quardature. This fact provide a fast torque response because torque and flux become decoupled.(fig b).A step change in armature voltage or current produces quick change in position or speed of the rotor.

Difference between AC servo motor & DC servo motor

A.C. Servo Motor	D.C. Servo Motor
Low power output of about 0.5 W to 100 W.	Deliver high power output.
Efficiency is less about 5 to 20%.	High efficiency.
Due to absence of commentator maintenance is less.	Frequent maintenance required due to commentator.
Stability problems are less	More problems of stability.
No radio frequency noise.	Brushes produce radio frequency noise.
Compare to DC servo motor it is relatively stable and smooth operation.	It is Noisy operation.