Salahaddin University – Erbil

College of Engineering

Electrical engineering Department

Forth year power

Special Machine

Part One

UNIVERSAL MOTOR

This commutator series – wound type motor has the convenient ability to run on either alternating or direct current source with similar output performance characteristics, provided both stator and rotor cores are laminated ,such a single phase series motor; therefore is commonly called a UNIVERSAL MOTOR. Fig (1.1) .

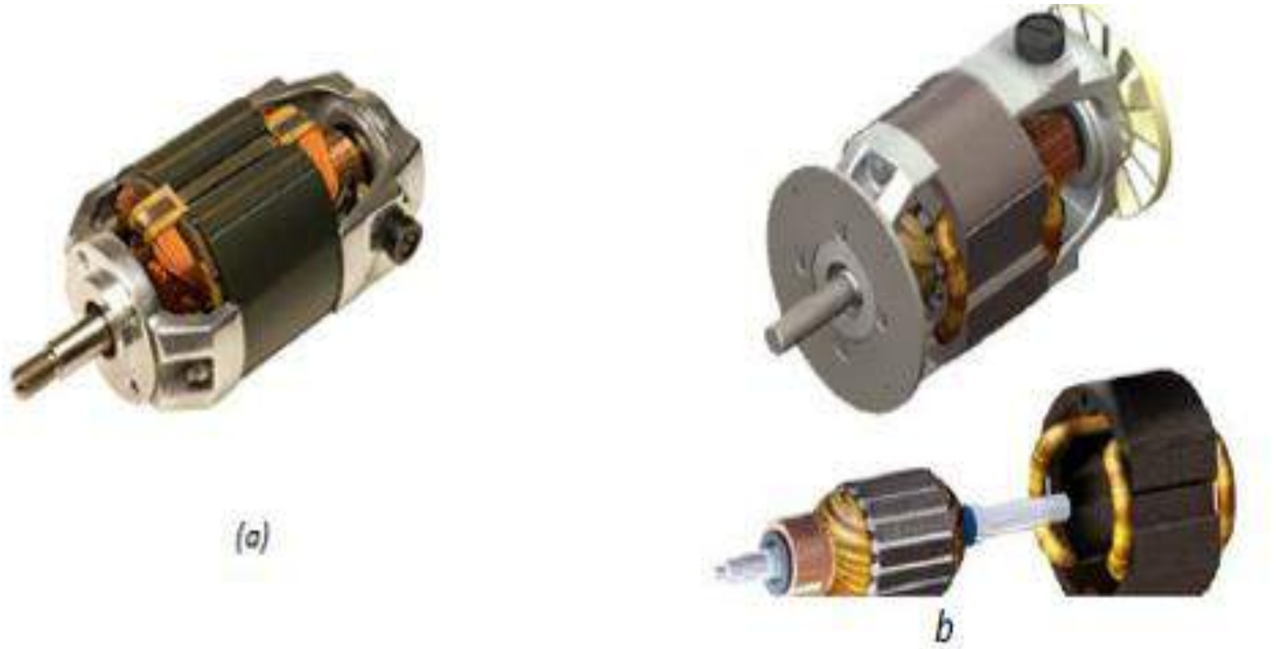


Figure (1.1) Universal Motor

The two parts of this motor, stator and armature (rotor) are both wound on stacks of stampings, each stamping being (0.5- 0.7) m.m thick. The armature coils which start and finish on two adjacent commutator bars are connected in series and uniformly distributed around the armature.

Stator winding surrounds salient stator poles, which extend out to (0.3-0.5) mm-wide airgap. Pole-pair number is normally p= 1. Airgap is constant over the greater part of its arc but it may be almost doubled towards edges of the pole shoes for the sake of an improved on-load flux distribution and reduced noise. Commutating poles and compensating winding are normally exist in the larger series machines ,But they are not designed into smaller machines. Fig (1.2) show cross-sections and details of universal motor.

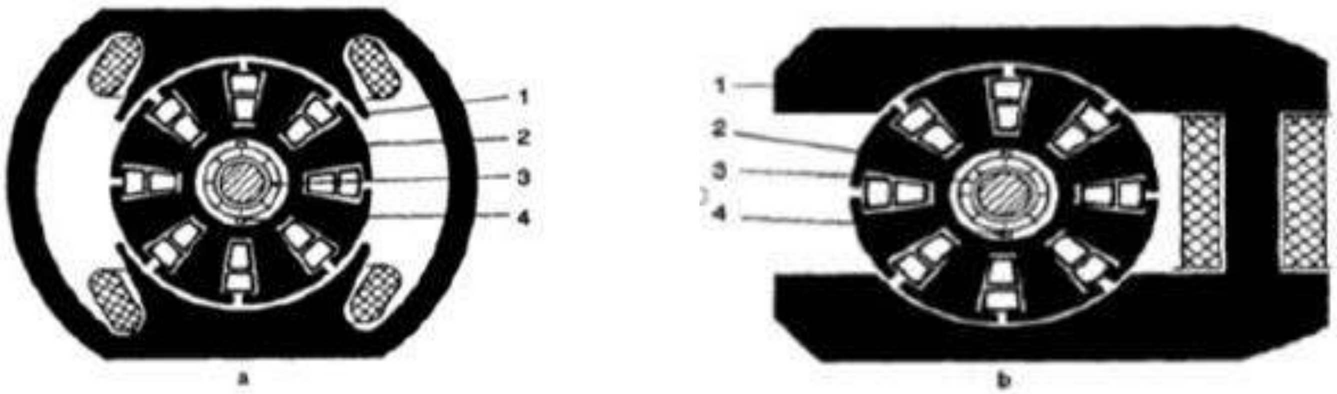
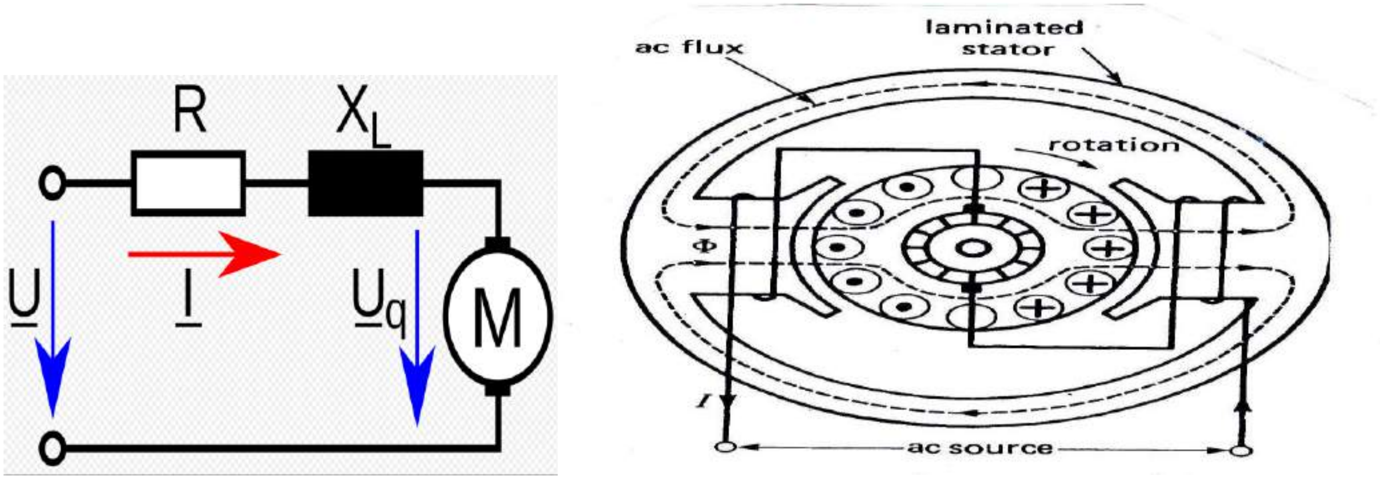


Figure (1.2) cross- section through (a) symmetrical (P > 200 W) and (b) unsymmetrical (P < 200 W) Universal motor: 1-stator pole: 2-armature: 3- commutator:4-brush

However, the commutator has brushes that wear, so the universal motors are much less used for equipment that is in continuous run. In addition, partly because of the commutator, universal motors are typically very noisy.

Electrical Equivalent Circuit

Electrical equivalent circuit of universal motor is shown in Fig (1.3a), the field and armature windings are connected in series, both winding are energized at the same time when voltage is applied to the motor. Simple design of universal motor is similar to a D.C series motor in construction, Fig (1.3b), but is modified slightly to allow the motor to operate properly on (A.C) power source.



(a) Equivalent circuit

(b) Electrical connection

Fig(1,3) universal motor

This motor type can operate well on A.C power, if polarity of applied voltage to D.C motor is reversed , both direction of field flux and direction of current will alternate (reverse polarity) synchronously with the supply, fig (1.4). But direction of developed torque will remain positive, and direction of rotation not changed. The torque will be pulsating, and frequency will be twice that of line frequency.

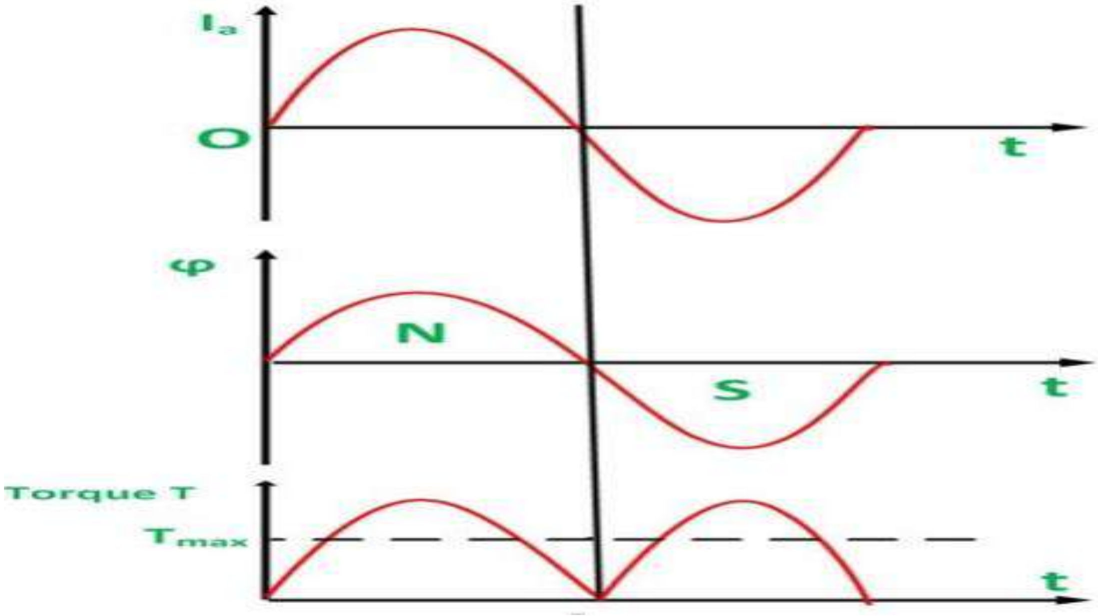


Fig (1.4) Current, Flux, and Torque Wave form

For the (D.C) universal motor the armature current and the field current in the machine must be reversed exactly at the same time.

Method of Operation

The universal motor run on either (D.C) power or single- phase (A.C) supply source. when the motor is fed from a(D.C) supply, it works as a series field (D.C) motor ,the same current flows in the field and armature winding , this current produces an electromagnetic field ,The interaction of the airgap field between the stator and armature, which is developed by the field winding, and the current in the armature winding produces a torque ,can be explain as following ;

When a conductor carrying current is placed in an electromagnetic field, resulting a mechanical force, due to this force ,or torque ,the rotor starts to rotate .The direction of this force is given by Flemings left hand rule, Fig(1.5).

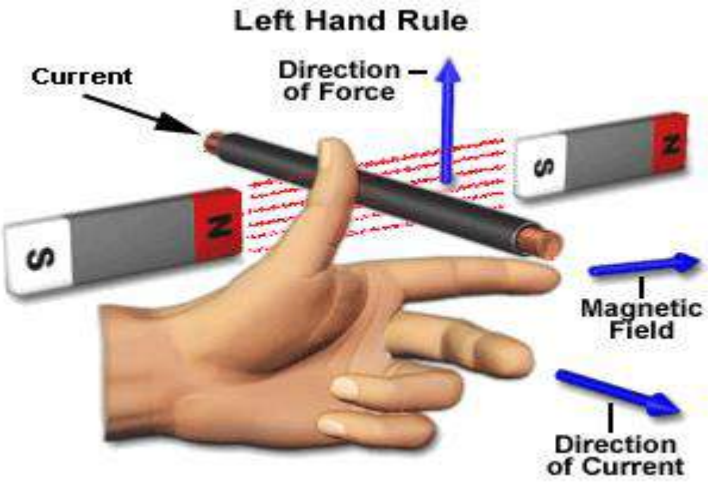


Fig (1,5) left hand rule

With (A.C) supply, the armature and the field winding are connected in SERIES, they are in the same phase. Hence, as polarity of the (A.C) power supply changes periodically, the direction of both the field and armature current winding revers at same time, to produces an unidirectional torque, see fig (1.4), that means the resulting mechanical force will occur in a consistent direction of rotation which is independent of the applied voltage polarity, but determined by the commutator and polarity of the field coils. And the motor will continue to run in the same direction.

Torque Speed Characteristics

The torque – speed curve of a universal motor is similar to that of (D.C) series field motor. The speed of a universal motor is low at full load and very high at no load. Usually, gearing system with appropriate transformations ratio are used to get the required speed for desired load. Fig (1.6).

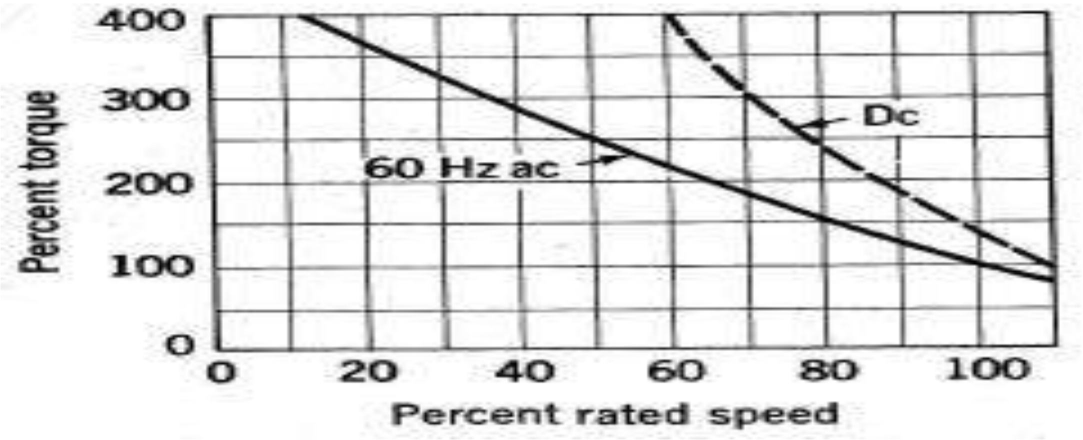


Fig (1.6) The torque – speed curve of a universal

The (A.C) Torque speed characteristic differs from the Torque speed characteristic for same machine operating on a (D.C) voltage source for two reasons:

1) The armature and field winding, have a large reactance at (50 or 60) HZ frequency, a significant part of input power voltage is dropped a cross these reactance's ,and therefore (**Ea**) is smaller since:

$$E_a = K \phi \omega \qquad \text{..........} \quad (1.1)$$

K-constant = (P × Z)/2 π a **P**-Number of pole

Z-Number of conductors **a** - Number of current parallel path

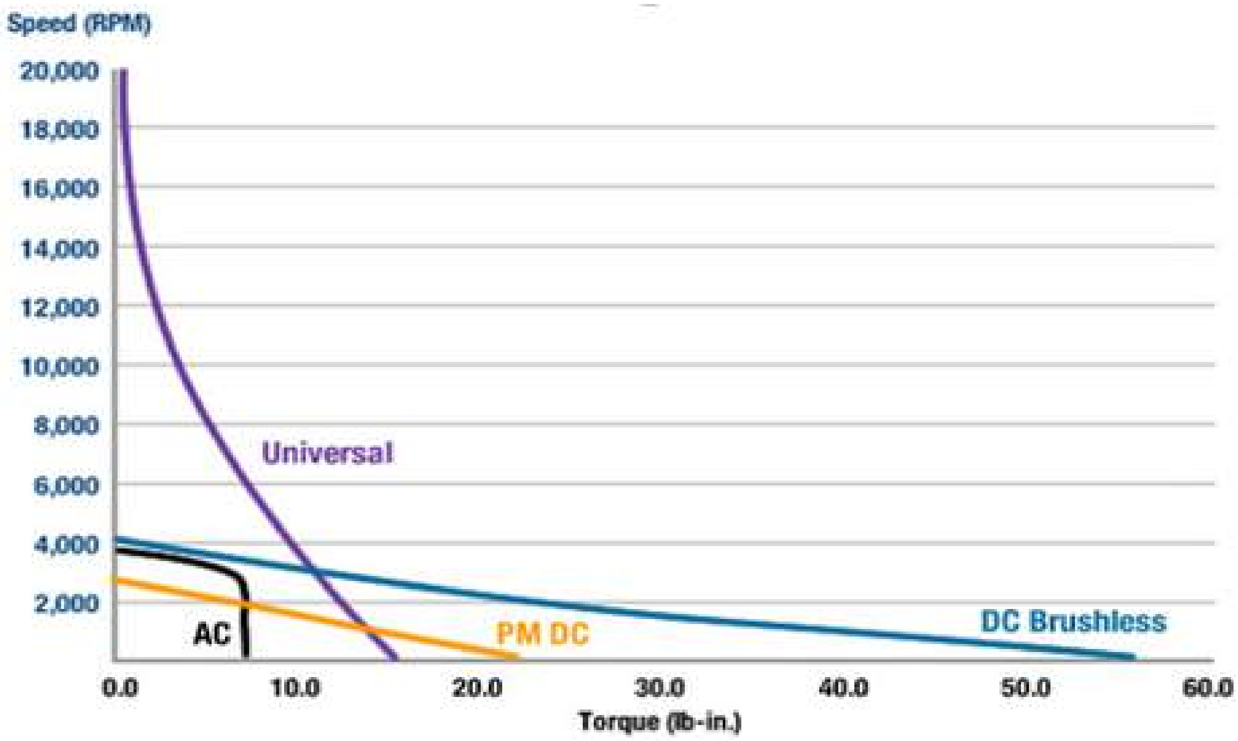
ϕ – Flux per pole (weber) **ω**- angular speed (rad. per. sec.)

The motor is slower for a given armature current with alternating supply voltage.

2) $V_{max} = \sqrt{2} \times V_{r.m.s.}$ .... (1.2)

So the magnetic saturation occur near (I_{max}) in the machine. This saturation could significantly lower **r.m.s** flux of the motor, tending to reduce the induced torque

Fig(1.7) compares universal motor torque-speed to other widely used motors.



Fig(1.7) Torque speed curves of widely used motor compared with universal motor.

The speed-torque curve is essentially a straight line between stall torque (zero speed) and no-load speed (zero torque), meaning that as the load (torque) increases, the speed decreases. In fact, like a series-wound DC motor, running a universal motor with no load (zero torque) could lead to a runaway condition, where the speed increases until the motor begins to break apart. The converse of this phenomenon is that universal motors produce very good starting torque (high torque at low speeds).

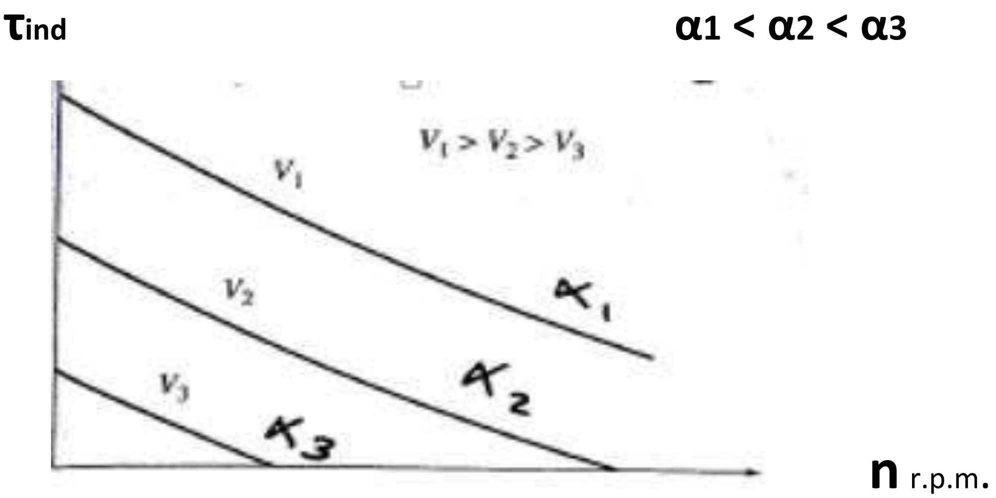
Speed Control of Universal Motor

The universal motor can achieve high speed and this speed can be adjusted by changing the motor voltage, the best way to speed control of the universal motor is to vary its input voltage.

The higher (r.m.s) input voltage, the greater resulting speed:

V input voltage **α** **n** speed

The torque – speed curve as a function of voltage is shown in Fig (1.8).

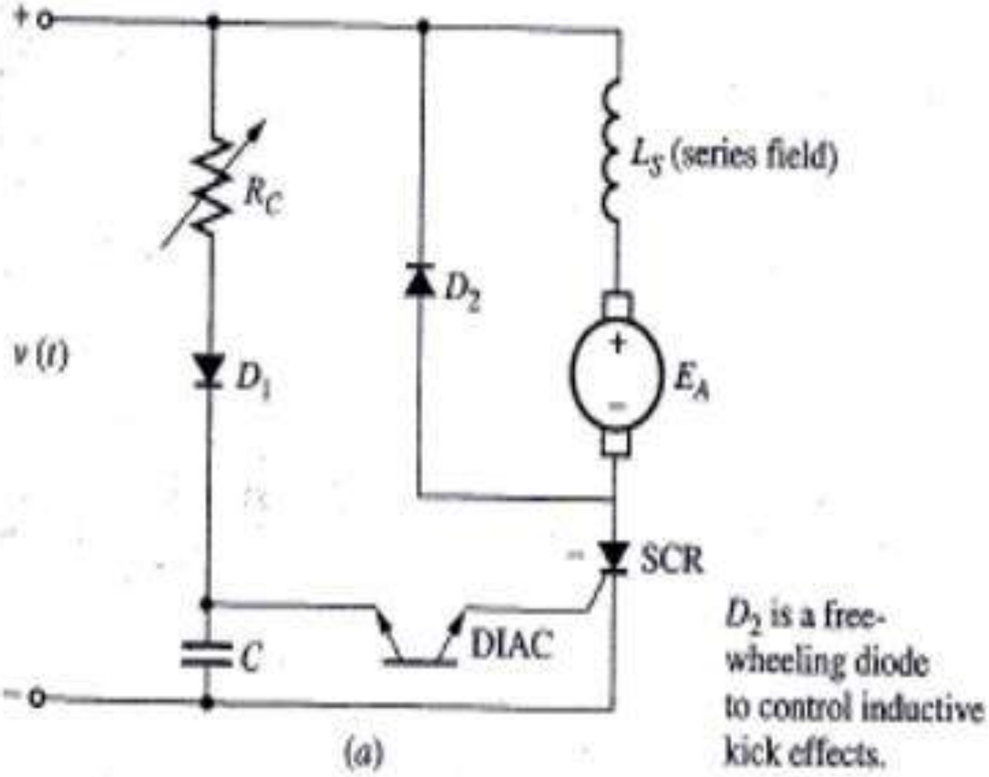


Fig(1.8) the effect of changing input voltage on the torque speed characteristic

α -Firing angle .

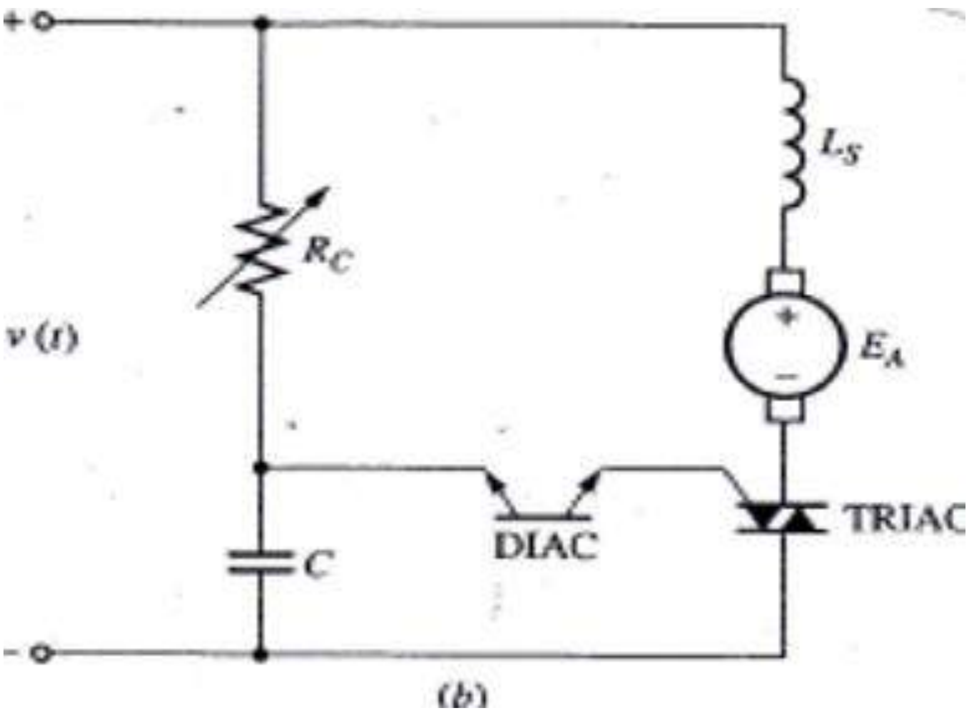
Two speed control circuit are shown in Fig (1.9):

1) Thyristor (SCR) can control alternate half- cycles of the voltage.
2) A bi-directional switch (TRIAC) control both half- cycles.



D_2 is a free-wheeling diode to control inductive kick effects.

(a) SCR control circuit



(b) **TRIAC control circuit**

Fig(1.9) Sample speed control (a- Half wave : b- Full wave)

* The firing angle (**α**) can be adjusted with a trigger control circuit.

Speed control models of Universal DC Motor

Speed control of Universal Motors typically employs two schemes:

1. Phase angle Control (varying the firing angle).
2. PWM Chopper control

Phase angle Control

The simplest method to control speed of a universal motor achieved by varying the firing angle of the TRIAC. Fig (1.10) shows Phase Angle Control mechanism typically employed for speed control of the TRIAC. A phase shift of TRIAC gate's pulses allows the effective voltage seen by the motor to be varied and hence motor speed varied also. A Zero Crossing Detection circuit is used to establish a timing reference for delaying the gate pulses firing.

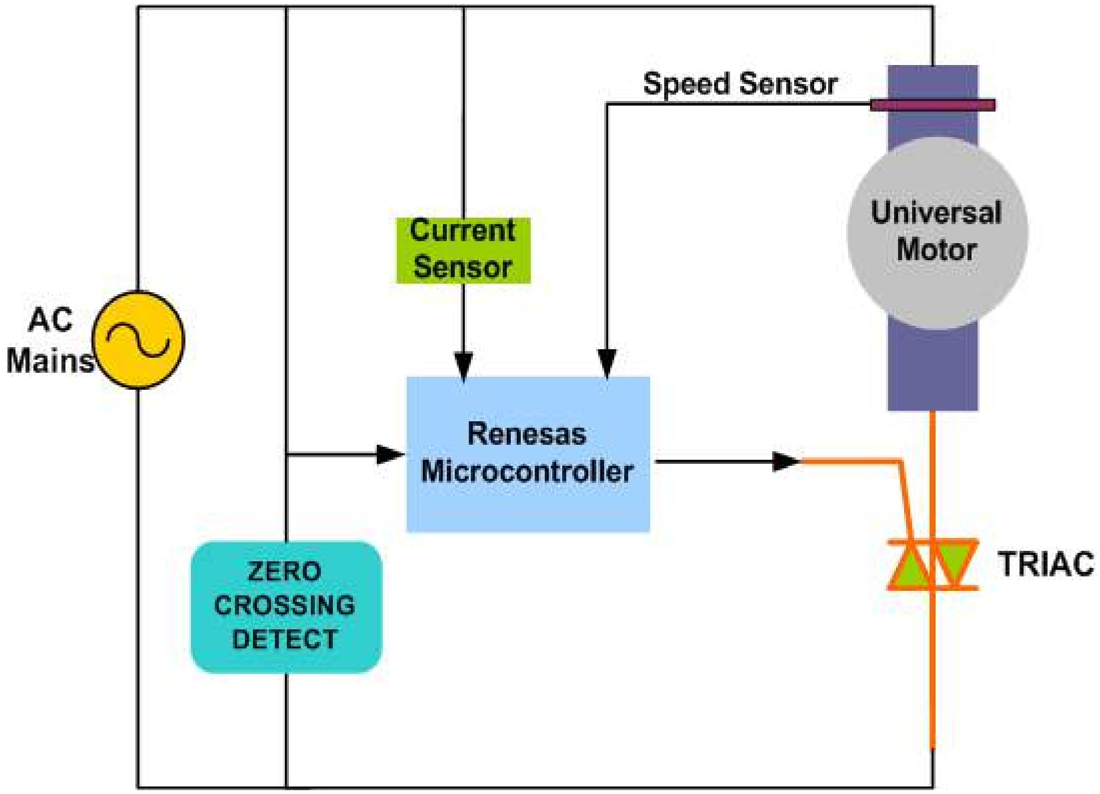


Fig (1.10) Phase Angle Control of a Universal Motor

PWM Chopper control

PWM control is a more advanced solution for controlling universal motor speed. In this method rectified AC line voltage is switched at a high frequency by a Power MOFSET or IGBT device to generate time varying voltage for the motor. Fig (1.11).

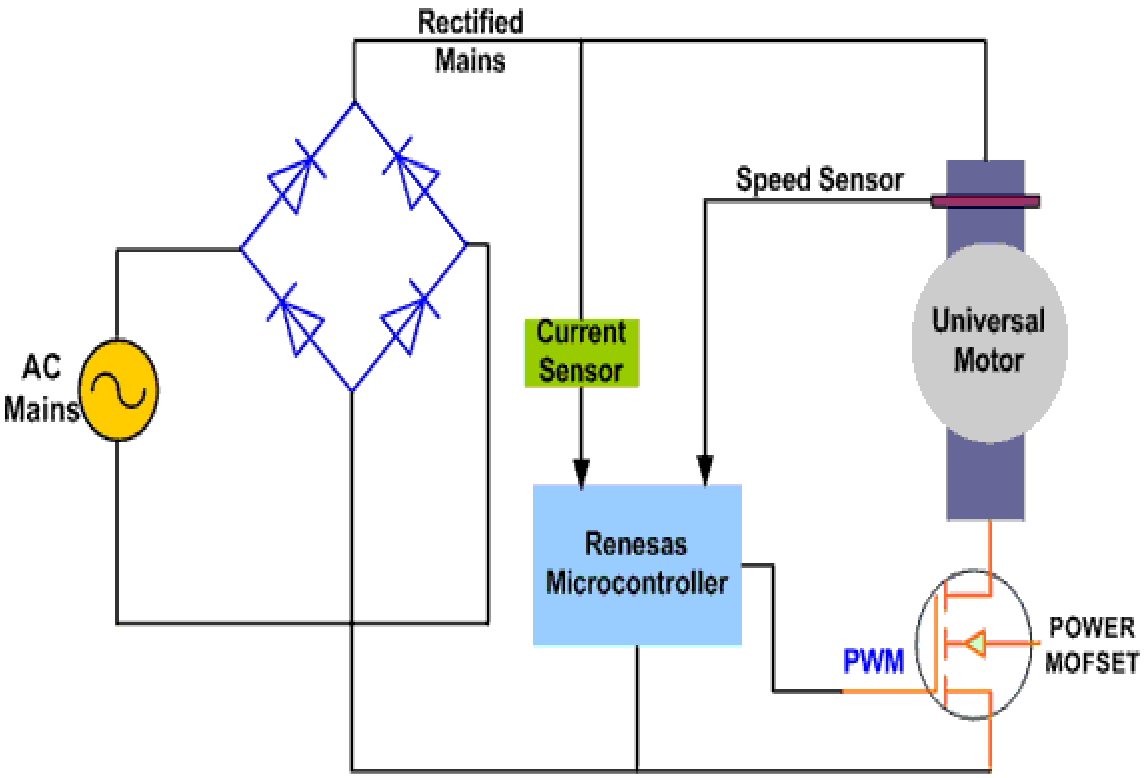


Fig (1.11) PWM Chopper Control of a Universal Motor

Switching frequency is usually in range of 10 to 20 KHz so as to eliminate acoustic noise. This method of universal motor control can achieve better current control.

Universal motors are classified into two types which include the following:

* Non-Compensated Type. * Compensated Type through Distributed Field.

Non-Compensated Type:

When the motor runs on AC voltage, the alternating flux causes a reactance voltage, which limits the current to a much lower level than would be produced with DC voltage:

* Low efficiency because of hysteresis and eddy current losses.

* Low power factor due to the large reactance of field and armature windings.

*The excess sparking at the brushes.

In order to overcome above drawbacks, certain modifications are made in a DC series motor to work even on AC current. They are as follows:-

* The field core is made up of laminated material to reduce eddy current loss.

*The area of field poles is increased to reduce the flux density. As a result, iron loss and the reactive voltage drop are reduced.

To get required torque the number of conductors in the armature is increased.

To limit effects of armature reaction, universal motor uses a compensation winding .

Compensated Type through Distributed Field:

A compensating winding is used for reducing armature reaction effect and improving the commutation process. The winding is placed in stator slots as shown in fig (1.12).

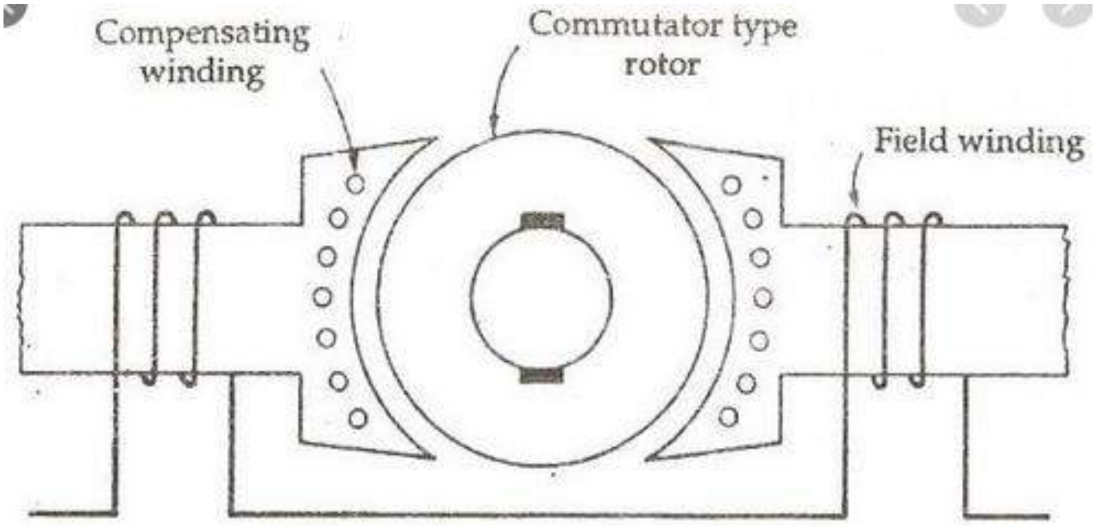
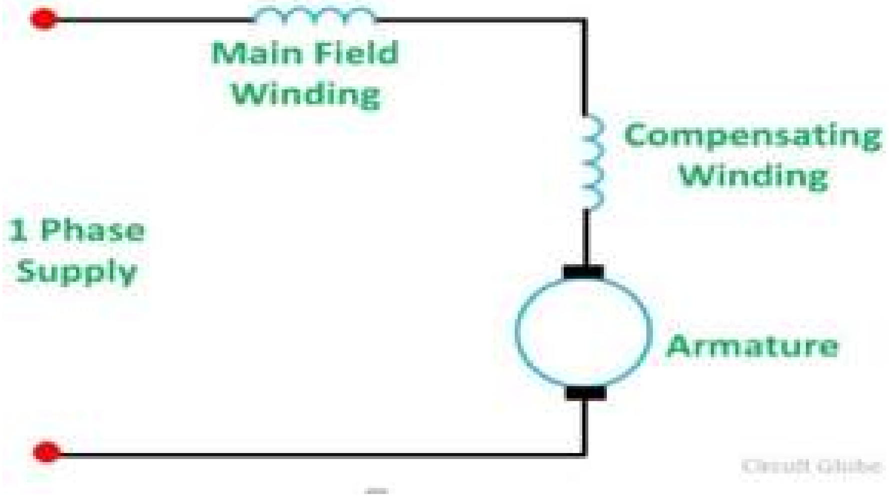


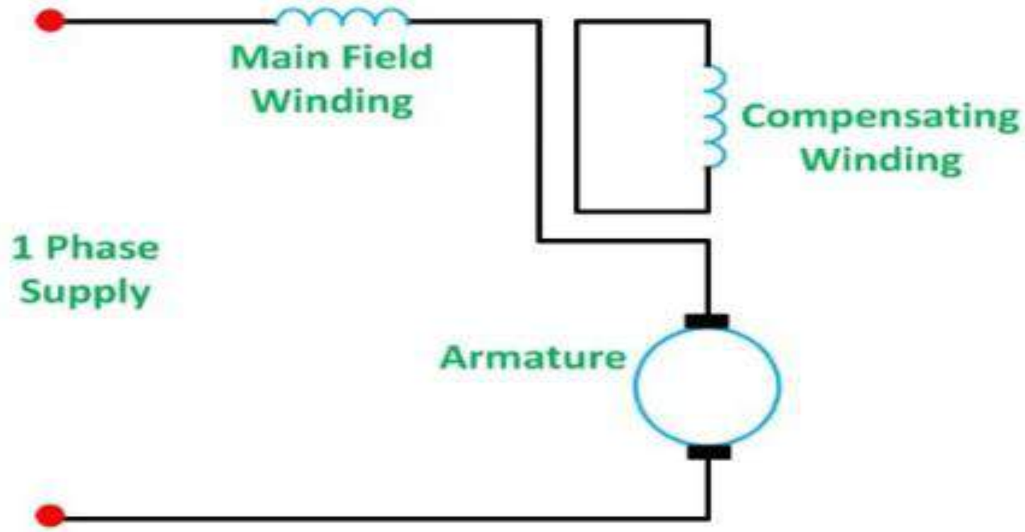
Fig (1.12) universal motor with compensating winding

The series motor with compensated winding is shown in the figure below.



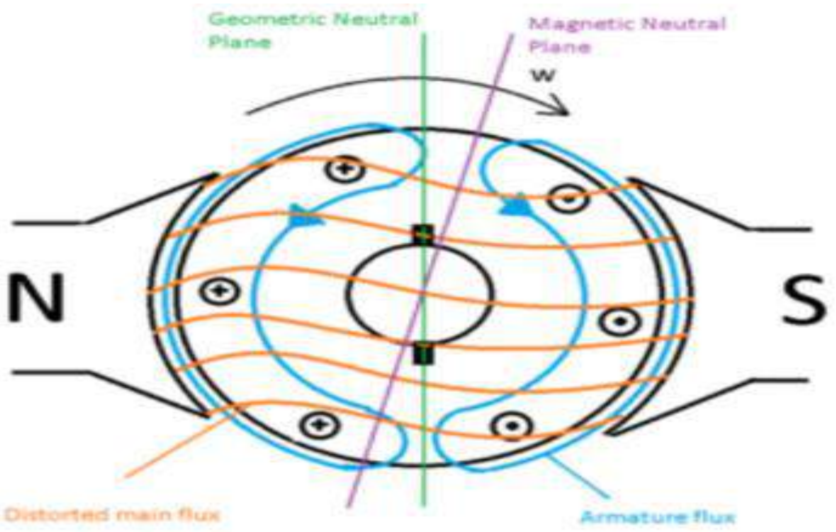
The winding is put in the stator slot. Axis of compensating winding is 90 degrees with the main field axis. Compensating winding is connected in series with both armature and the field winding, hence, it is called conductively compensated.

If compensating winding is short circuited, the motor is said to be inductively compensated. The connection diagram is shown below.



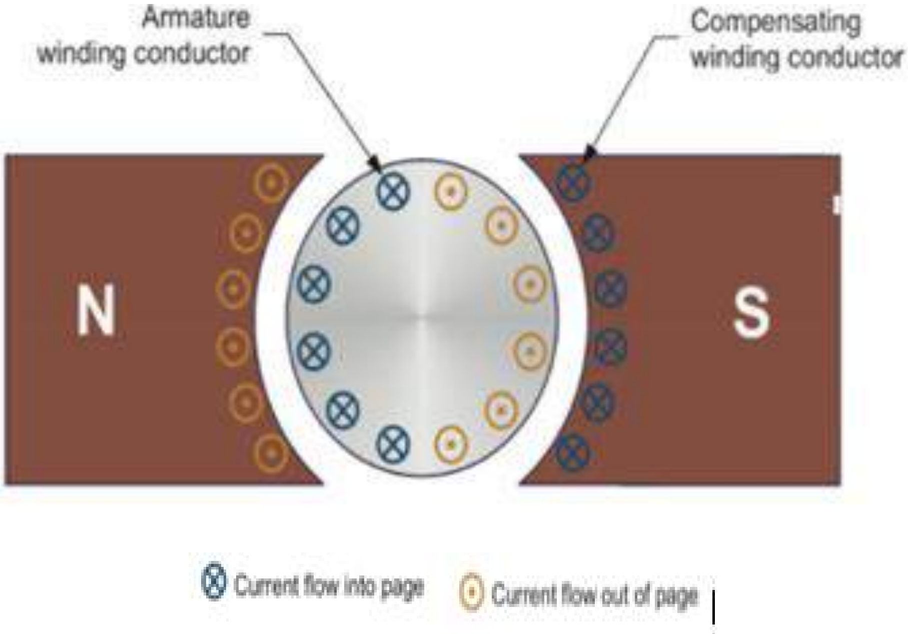
Armature reaction:

Is the interference of main field flux caused by the armature flux. This distortion and weakening of the main field flux changes the location of magnetic neutral plane, which is the axis along which the brushes should be placed, Fig (1.13).



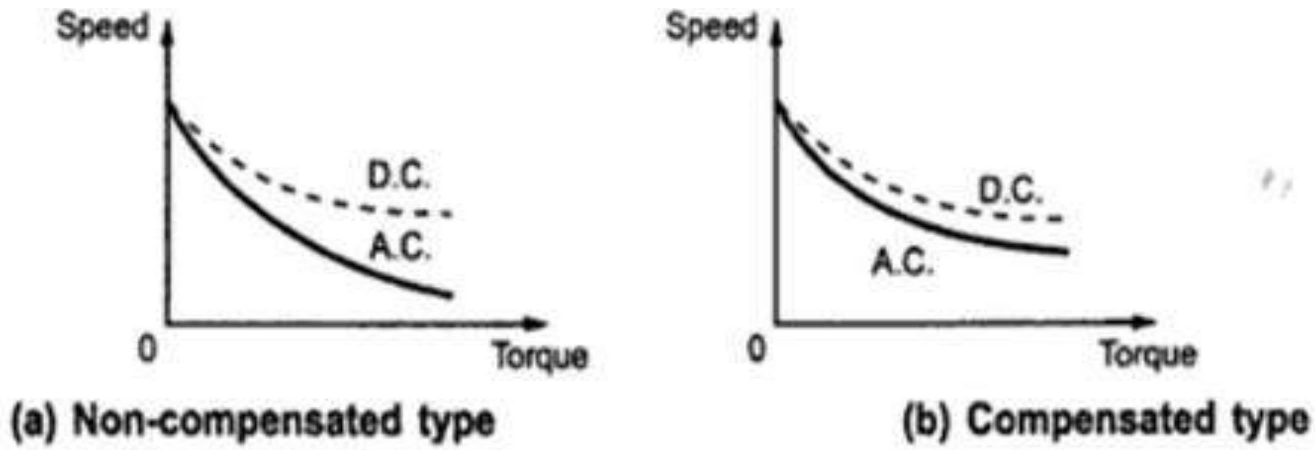
Fig(1.13) Armature reaction changes the location of the magnetic neutral plan, which is the axis along which the brushes should be mounted.

To reduce the armature inductance, the current flowing in each coil of the compensating winding is in a direction opposite to the current in the corresponding armature loop near it as shown in fig(1.14).



Fig(1.14) The current flow direction in the armature conductor.

The effect of compensating winding on the Torque Speed Characteristics is shown in Fig (1. 15)



(a) Non-compensated type

(b) Compensated type

Fig(1.15)Torque speed of Non – Compensated and Compensated type of Universal Motor

Applications of Universal Motor

Universal motors have high starting torque, can run at high speed, and are lightweight and compact. Equipment they're also relatively easy to control, electromechanically using tapped coils. However, commutator has brushes that wear, so they are much less used in equipment need continuous use. In addition, partly because of commutator, universal motors are typically very noisy

The various applications of the Universal Motor are as follows:-

* Higher rating universal motors are used in portable drills machine Fig(1.16).

* Used in hair dryers, grinders and table fans.

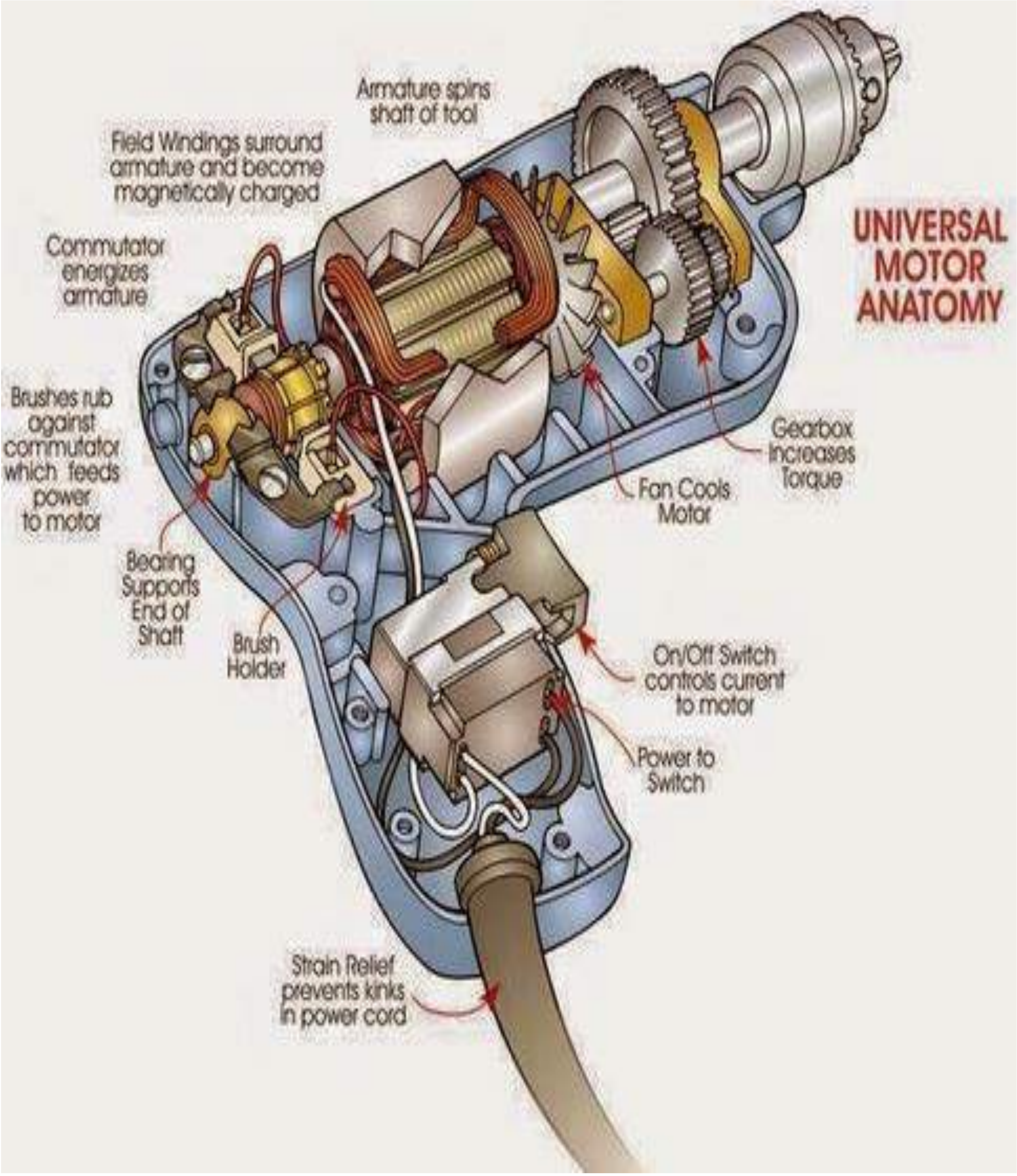
* Universal motors find their use in various home appliances like vacuum cleaners, drink and food mixers, domestic sewing machine etc.

Advantage and disadvantage of Universal Motor:

1) It is compact and gives more torque per ampere than any single Phase motor.
2) Have High starting torque throughout the start- up.
3) Can achieve high speed about 25,000 rpm compared with asynchronous motors.
4) Like a DC motor, speed can be adjusted by changing the motor voltage.

The main disadvantages of universal motor its poor speed regulation. Also:

1) The machines using universal motor needs regular protection.
2) Because pair of pulses this motor generates vibrations and a lot of noise.



Fig(1.16) Electrical Drill.

RELUCTANCE MOTOR

A reluctance motor is a type of electric motor that induces non-permanent magnetic poles on the ferromagnetic rotor. The rotor does not have any windings. It generates torque through magnetic reluctance.

The stator consists of multiple salient electromagnet poles, similar to a wound field brushed DC motor. It is may be either of single or 3 phase construction.

The rotor consists of soft magnetic material, such as laminated silicon steel, which has multiple projections acting as salient magnetic poles through magnetic reluctance. It is operates at synchronous speeds without current-conducting parts. Rotor losses are minimal compared to those of an induction motor. When a stator pole is energized, rotor torque is in direction that reduces reluctance.

Inductance of each phase winding in the motor varies with position, because reluctance itself varies with position. Speed control requires a variable-frequency drive . A simple 2- pole reluctance motor is shown in Fig(1.17).

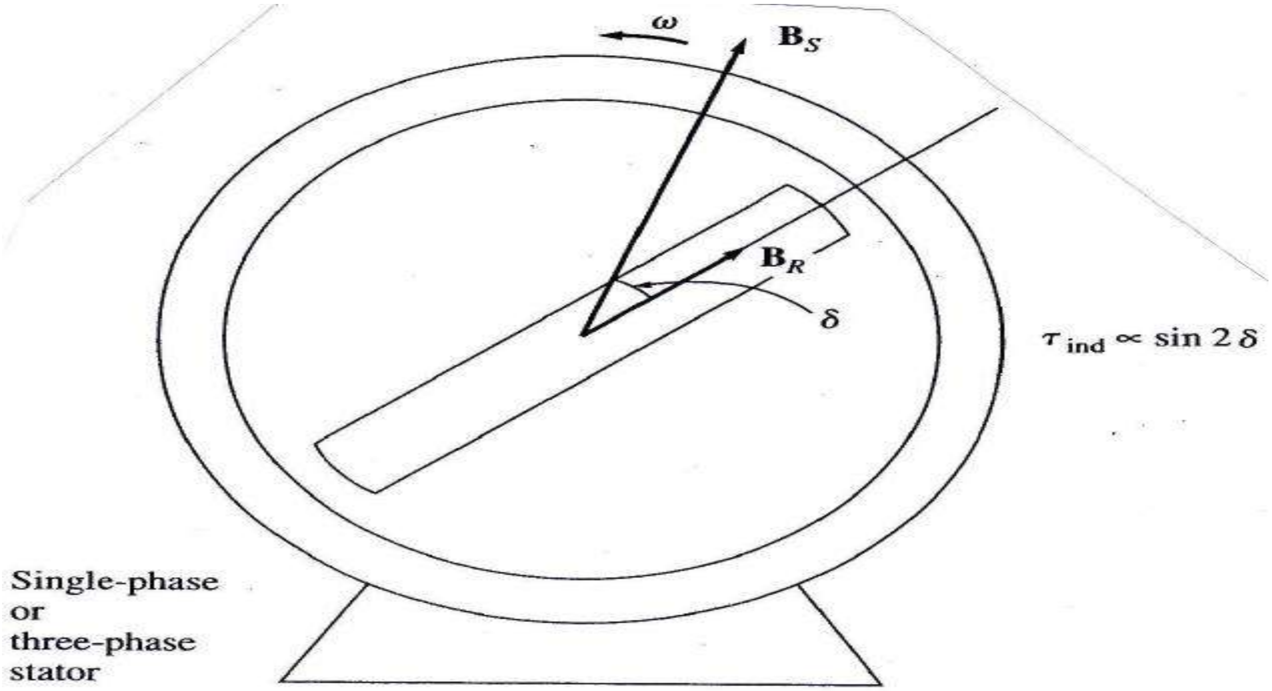


Fig (1. 17) Basic concept of 2- pole reluctance motor.

- The torque applied to the rotor is proportional to Sin **2 δ**.
- **δ** = electrical angle between the rotor and the stator magnetic field.

$\tau_{ind} = \tau_{max}$ when $\delta = 45^{o}$

Method of operation

A reluctance motor depends on reluctance torque for its operation, reluctance torque is induced in an iron object (rotor) in presence of an external magnetic field, which causes the rotor to line- up with external magnetic field.

The torque occurs because the external field induces an internal magnetic field in the (rotor), this torque twisting the object around to line up with the external magnetic field and the torque appears between the two fields.

A single phase Reluctance Motor, like a normal synchronous motor, since the rotor will be locked into the stator magnetic field, it has no starting torque and will not start by itself.

A self –starting can be built by modifying the rotor of an induction motor, as shown in Fig (1. 18).The figure shows 4 pole reluctance synchronous motor.

The rotor of a reluctance motor is a squirrel cage with some rotor teeth removed in the certain places to provide the desired number of salient rotor poles (4 pole), the two end rings are short circuited.

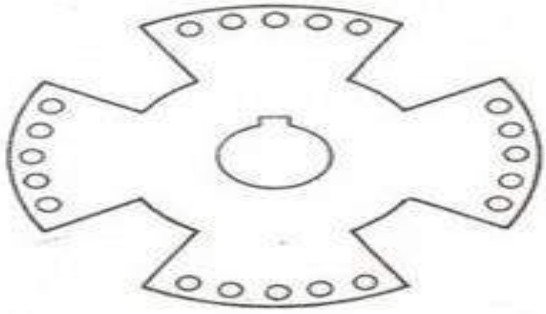


Fig (1.18) rotor design of (synchronous induction) self starting motor.

The rotor has salient poles for steady state operation as reluctance motor, and also has squirrel-cage winding for starting, therefore the reluctance motor in sometimes called a SYNCHRONOUS INDUCTION MOTOR.

Torque Speed Characteristic

When the stator is connected to a single phase supply, the motor starts as a single phase (I.M). A centrifugal switch disconnects the auxiliary winding as soon as the motor speed reaches about 75% of synchronous speed. The motor continues to speed up as a single phase motor with only the main winding in operation.

A reluctance motor torque is produced due to the rotor tendency to align itself in the minimum reluctance position, when the motor speed is close to synchronous speed. Thus, the rotor pulls in synchronism. The load inertia should be within the limits, for proper effectiveness. At synchronism, induction torque disappears, but rotor remains in synchronism due to synchronous reluctance torque.

The Torque Speed Characteristic of a Reluctance Motor is shown below in Fig (1.19).

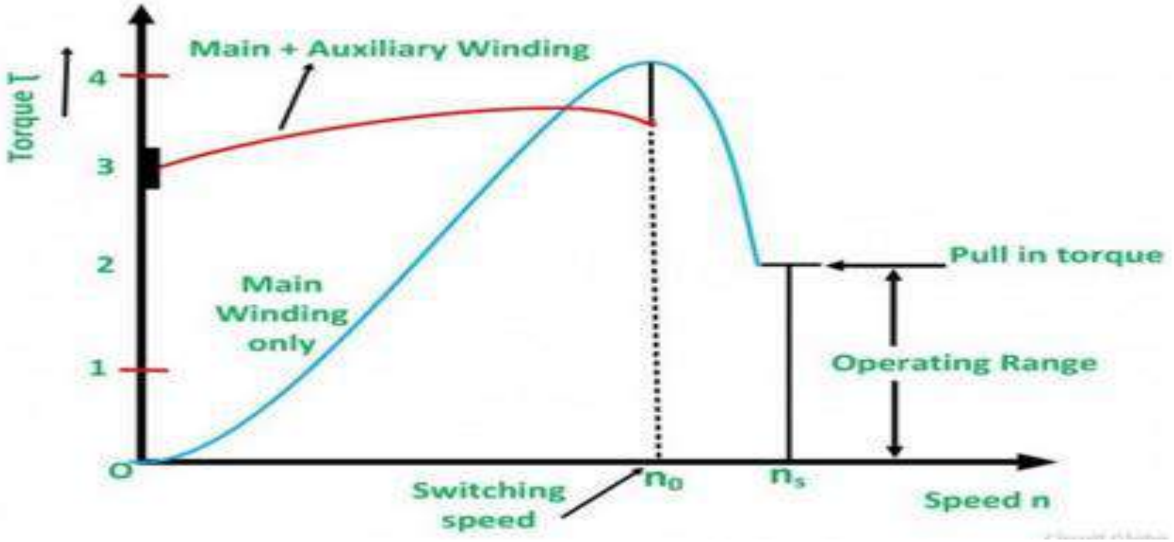


Fig (1.19) The torque speed curve of Reluctance motor.

The Starting torque depends upon rotor position. As motor reaches nearly a synchronous speed the auxiliary winding is disconnected and the rotor continues to rotate at synchronous speed.

The motor operates at a constant speed up to a little over than 200% of its full load torque. If the loading of motor is increased above pull out torque value, the motor loose synchronism but continues to run as a single phase induction motor up to over 500% of its rated torque. The rotor of a Reluctance Motor is unexcited, therefore, the power factor is low as compared to the induction motor. As motor has no DC field excitation so the output of a reluctance motor is reduced. Hence, motor size is large as compared to synchronous motor.

Torque equation of Reluctance Motor

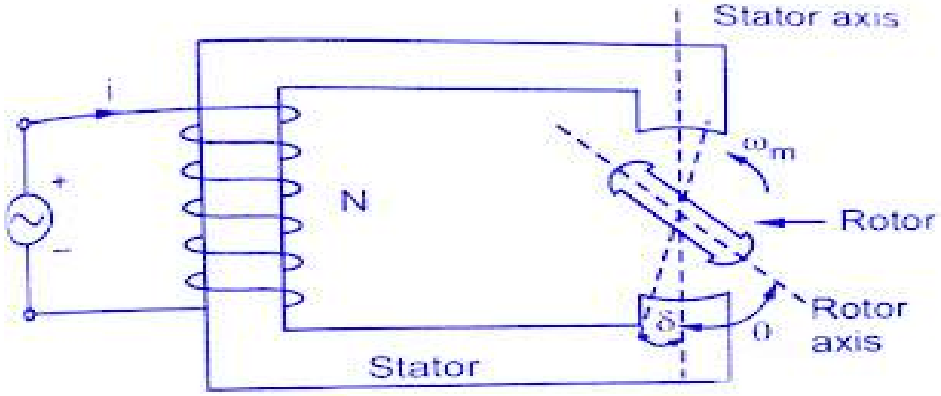


Fig (1.20) Elementary reluctance motor

Consider an elementary reluctance motor shown in fig(1.20) .The variation of windings inductance is sinusoidal with respect to rotor position .The variation of the inductance with respect to **θ** is of double frequency and is given by,

$$L(\theta) = L'' + L' \cos 2\theta \qquad (1.3)$$

The stator winding is excited by **a.c** supply hence:

$$i = I_m \sin \omega t \qquad (1.4)$$

The energy stored is a function of Inductance and given by:

$$W = (1/2) \times L(\theta) \times i^2 \qquad (1.5)$$

The flux linkage is given by,

$$\lambda(\theta) = L(\theta) \times I \qquad (1.6)$$

Then the torque is given by

$$T = -(\partial w / \partial \theta) + i\,(\partial \lambda/\partial \theta) \quad = -(1/2)\, i^2(\partial L/\partial \theta) + i^2\,(\partial L/\partial \theta)$$

$$= -(1/2) \times i^2(\partial L/\partial \theta)$$

Substituting the values of **i** and **L**

$$T = -I^2{}_m \times L' \times \text{Sin } 2\theta \times \text{Sin}^2\omega t \qquad (1.7)$$

If the rotor is rotating at an angular velocity **ωm** then finally the torque equation can be expressed in terms of **ω** and **ωm** as,

$$T = -(1/2)\, I^2{}_m\, L' \{\text{Sin } 2(\omega_m t - \delta) - (1/2)\{\text{Sin } 2(\omega_m t + \omega t - \delta) + \text{Sin } 2(\omega_m t - \omega t - \delta)\}\}$$

Where: $\theta = \omega_m t - \delta$: and δ = Rotor position at $t = 0$

Above equation gives instantaneous torque produced. The average torque is zero as the average of each term in above equation is zero. But torque value is not zero when **ω = ωm,** at this condition the magnitude of average torque is,

$$T_{av} = \tfrac{1}{4}\, I^2{}_m\, L' \,\text{Sin } 2\,\delta \qquad \text{………… } (1.8)$$

The speed corresponding to frequency **ω = ωm** is the synchronous speed. The **δ** is a torque angle .The max. (pull-out) torque occurs at **δ = 45°**

Types of reluctance motors

There are two main designs:

1) Synchronous reluctance motor. **2) Switched reluctance motor.**

1) **Synchronous reluctance motor**.

Synchronous reluctance motors have an equal number of stator and rotor poles. The projections on the rotor are arranged to introduce internal flux “barriers“, holes that direct the magnetic flux along the d- axis. Typical pole numbers are 4 and 6. Rotor losses are minimal compared to those of an induction motor. Once started at synchronous speed, the motor can operate with sinusoidal voltage. Speed control requires a variable-frequency drive.

Synchronous reluctance motors are designed to run at exact “synchronous” speeds without current-conducting parts. They accomplish this by using a 3-Ph stator winding and a rotor which implements salient rotor poles and internal magnetic flux barriers (usually notches or air gaps within the rotor, Fig (1 .21). The rotor implements a modified squirrel cage around these salient poles, so that it can benefit from induction effect to become self-starting. As the motor starts, it is pushed close to synchronous speeds via induction and then locks into synchronism via reluctance torque generated by the rotor flux barriers.

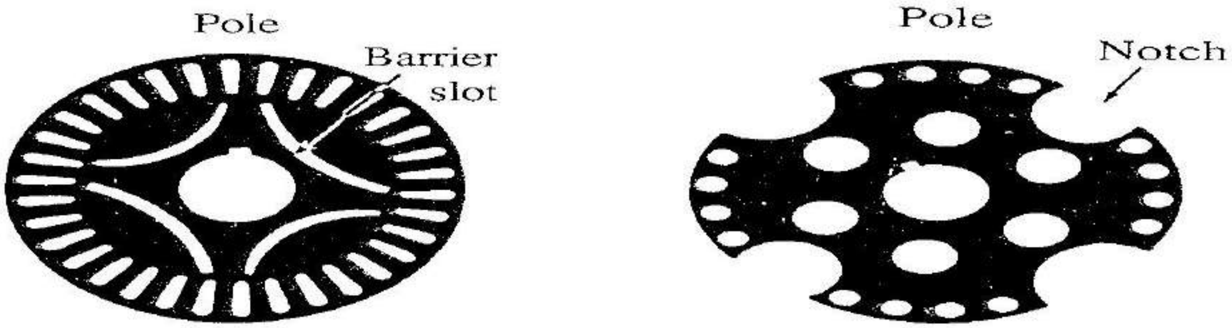


Fig (1.21). Typical designs for synchronous reluctance motors. Notice the spaces of low reluctance (poles) and high reluctance (air gaps/notches)

2) **Switched reluctance motor**

For switched reluctance motors, the number of rotor poles is typically less than number of stator poles, which minimizes torque ripple and prevents the poles from all aligning simultaneously—a position that cannot generate torque.

Switched reluctance motors are a type of stepper motor, but they are unique in that they have an inverted winding set up, the field windings are found in stator, see Fig (1.22). The rotor is a ferromagnetic core of permanent poles and notches that are acted upon by the stator electromagnetic poles.

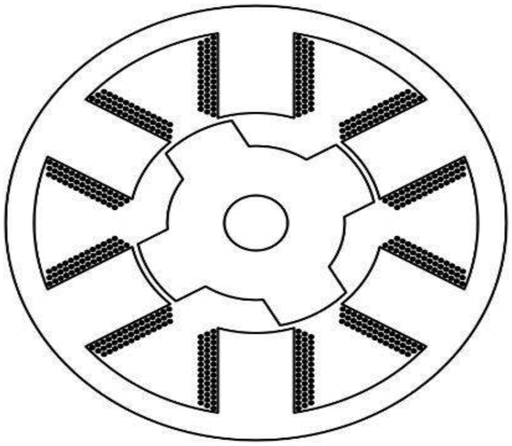


Fig (1.22). Typical design for switched reluctance motor. Notice the unequal ratio of rotor-to-stator poles, and the coils surrounding the salient stator poles.

A switched reluctance motor is also known as a variable reluctance motor. The reluctance of rotor to the stator flux path varies with rotor position Fig (1.23).

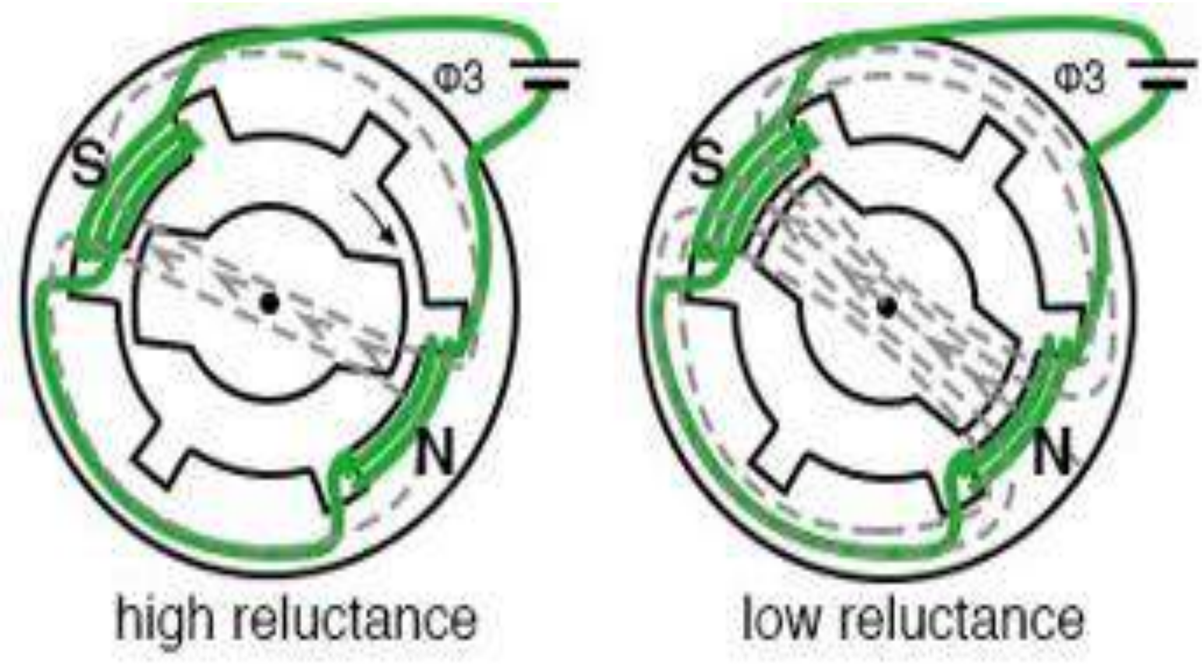


Fig (1.23) Reluctance as a function of rotor position

Applications of a Reluctance Motor

The various applications of the Reluctance Motor are as follows:-

- Signaling Devices
- Control Apparatus
- Automatic regulators
- Recording Instruments
- All timing devices and Clocks
- Tele printers

Reluctance Motor Advantages:

* Simple and robust construction.No (brushes, commutator, or permanent magnets), no copper or aluminum in the rotor.

* High efficiency and reliability compared to conventional AC or DC motors.

* High starting torque.

*Cost-effective compared to brushless DC motor in high volumes.

*Adaptable to very high ambient temperature

* Less maintenance.

Reluctance Motor Disadvantages:

The reluctance motor has following limitations:

*Current versus torque is highly nonlinear *low efficiency

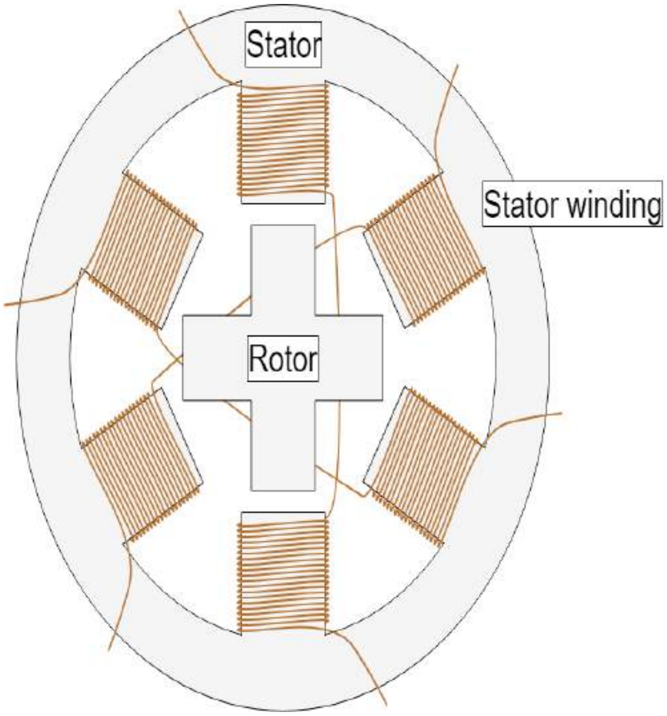
*Poor power factor *Need of very low inertia rotor

*Less capacity to drive the loads

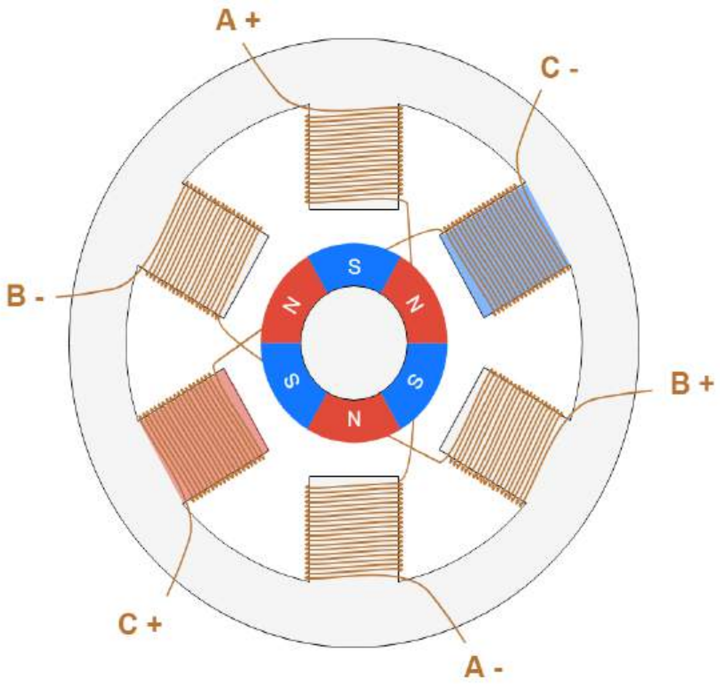
THE STEPPER MOTOR (SM)

A stepper- motor is a special type of synchronous motor have multiple coils that are in groups called "phases " , which is designed to rotate a specific number of degrees for every electric pulse received by its control unit .and by energizing each phase in sequence, the motor will rotate, one step at a time.

Stepper motors have a stationary part (stator) and a moving part (rotor). On stator, there are teeth on which coils are wired, while the rotor is either a permanent magnet or a variable reluctance iron core. Fig (1.24) shows a drawing representing of the motor section.



Fig(1.24a) : variable-reluctance Stepper Motor.



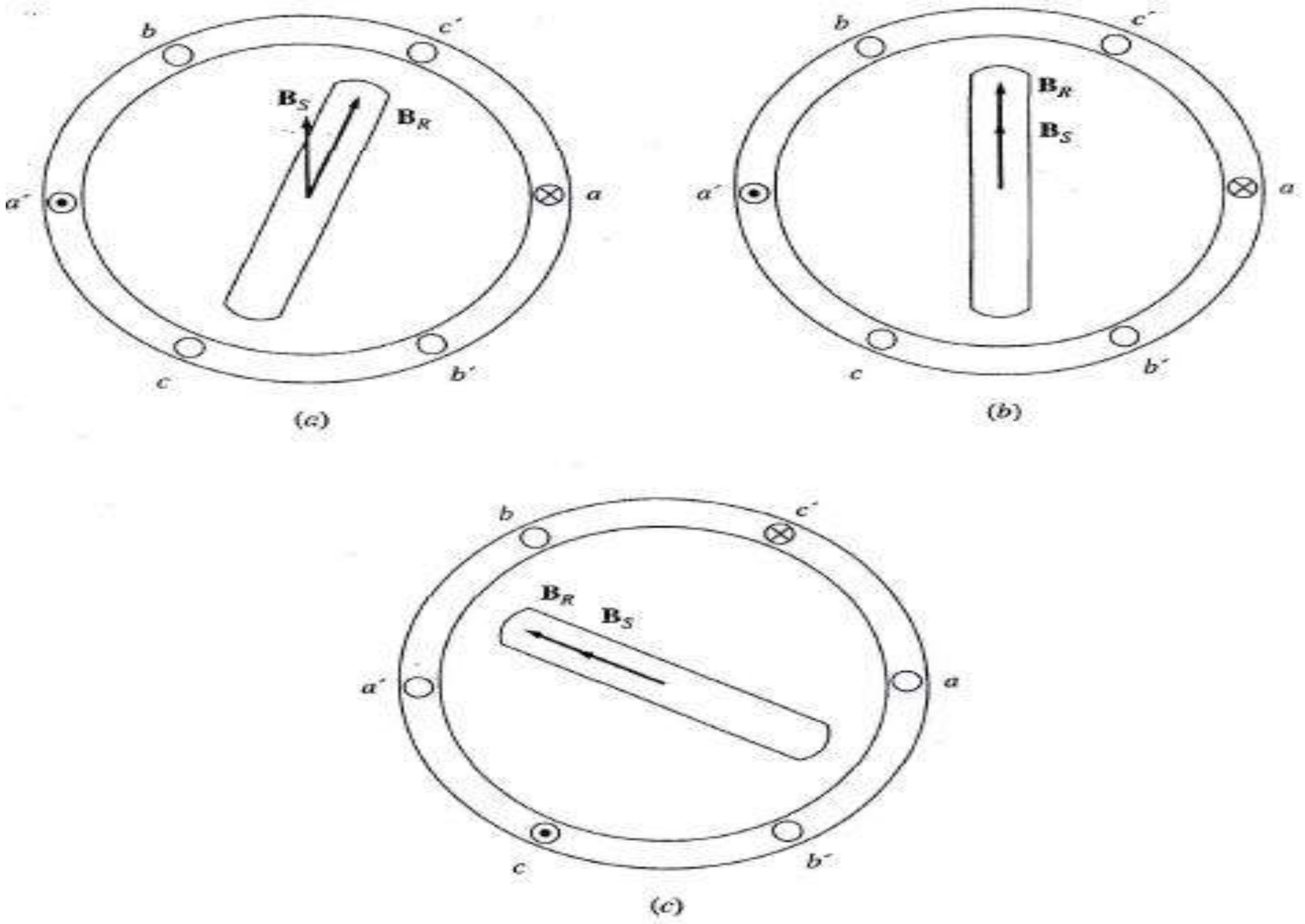
Fig(1.24b) permanent magnet stepper motor.

Fig (1.24) shows a representation of a section of a stepper motor.

* Typical steps are (7.5 or 15) degrees per pulse. The position of shaft is made to stop accurately in any number of positions in a complete revolution.

*A step according to the design, corresponds to a rotor angle can achieved by energizing the stator windings with unidirectional current pulses, by suitably timing the pulse sequence.

To understand the operation of the stepper motor, see Fig(1.25),this figure shows a two pole(2P),three phase stator (3PH) with permanent magnet rotor.



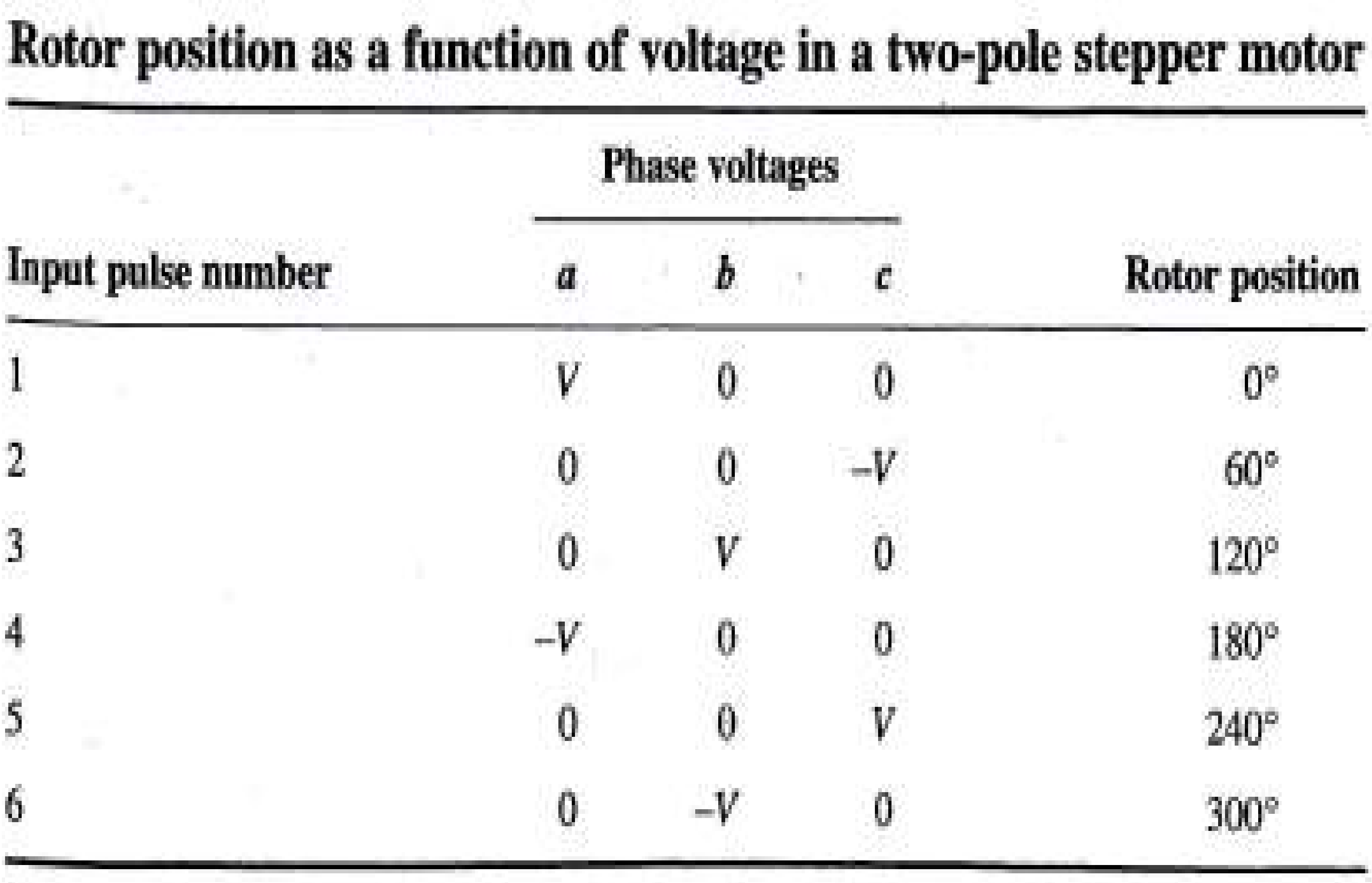
Fig(1.25) operation of stepper motor

- The interaction of **Bs** and **Br** produces a counter clock wise torque on rotor.

If a D.C voltage is applied to phase (**a**), causing a current to flow in phase (**a**) of the stator and NO voltage is applied to phases (**b&c**), then a torque will be induced in the rotor which causes it to line-up with stator magnetic field **Bs**, as shown in Fig (1.25b).

*N0W: turned off phase (**a**), & a negative D.C voltage (**-Vd.c**) is applied to phase (**c**).

The new stator magnetic field (**Bs**) is rotated 60° with respect to the previous magnetic field, and the motor follows it around .By continuing this pattern its possible to construct a table of the rotor position shown in table (1.1), then if the voltage produced by the control unit changes with each input pulse, the stepper motor will advance by (60°) degree with each input pulse.

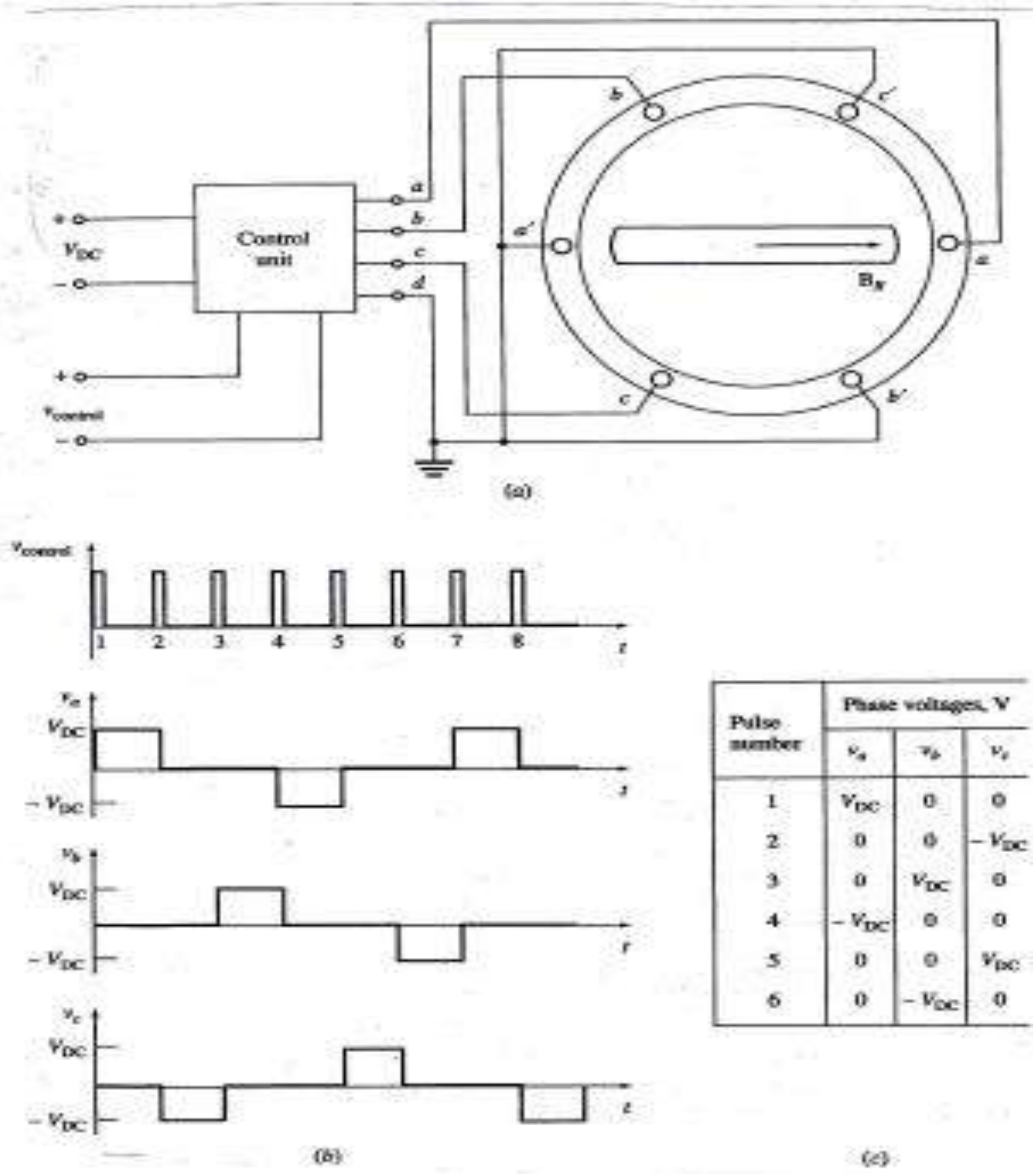


Rotor position as a function of voltage in a two-pole stepper motor

	Phase voltages			
Input pulse number	*a*	*b*	*c*	Rotor position
1	*V*	0	0	0°
2	0	0	–*V*	60°
3	0	*V*	0	120°
4	–*V*	0	0	180°
5	0	0	*V*	240°
6	0	–*V*	0	300°

Table (1.1) rotor position as a function of voltage in 3-ph 2- pole stepper motor

- A simple stepper motor with its control unit is shown in Fig (1.26).
- The input to control unit consists of a D.C power source and a control signal consisting a train of pulse.
- The output voltage from the control unit is a series of control pulses.



Pulse number	Phase voltages, V		
	v_a	v_b	v_c
1	V_{DC}	0	0
2	0	0	$-V_{DC}$
3	0	V_{DC}	0
4	$-V_{DC}$	0	0
5	0	0	V_{DC}
6	0	$-V_{DC}$	0

Fig(1.26) Three phase two pole stepper motor.

It is easy to build a stepper motor with final step size by increasing the number of poles on the motor.

*The number of mechanical degree is:

$$\theta_{mech.} = (2/P)\ \theta_{elec.} \qquad (1.9)$$

θ mech. – mechanical degree.

θ elec. -electrical angle

P- Number of poles.

Example 1:-

If the stepper motor has 8 poles, find the mechanical angle corresponds to 60^o electrical degrees.

$\theta_{mech.} = (2/P)\ \theta_{elec.}$ $\qquad$ $\theta_{mech.} = (2/8) \times 60^o = 15^o$

Therefore the motor's shaft will change 15^o per step.

- Equation (1.9) gives the mechanical angle as a function of electrical angle.
- Differentiated both sides of this equation (1.9),then a relation between the electrical and mechanical rotational speed can achieved as:

$$\omega_m = (2/P) \times \omega_e \qquad (1.10\ a)$$

OR

$$n_m = (2/P) \times n_e \qquad (1.10\ b)$$

- Equation (1.10 b) can generalized to apply to all stepper motor, regardless of the number of phases on their stator windings.

IN GENERAL:

If **N**=Number of phases & **2N**=N_o of pulses per one electrical revolution

Therefore the relationship between the motor speed in revolution per minute and the number of pulses per minute becomes:

$$n_m = (1/NP) \times n_{pulses} \qquad (1.10c)$$

Example 2:

Find the speed of the motor, if the control system sends 1200 pulses per minute to the 2- pole stepper motor shown in Fig (1.26).

Solution:-

N pulses= 1200 pulses per phases.

P=2 poles

N= 3 number of phases.

n_m =(1/3×2 pole) × (1200 pulses per min)

= 200 r.p.m.

If the initial position of the shaft is known then the computer can determine the exact angle of the rotor shaft at any time by counting the total number of pulses.

Example 3:-

A 3-phase permanent magnet stepper motor required for one particular application must be capable of controlling the position of a shaft in steps 7.5^o degree and it must be capable of running at speeds of up to 300 revolution/minute:

a) How many poles must this motor have.

b) At what rate must control pulses be received in the control unit if it is to be driven at 300 revolution/ minute.

Solution:-

a) $\theta_{mech.} = (2/P)\ \theta_{elec.}$ P= 2 ($\theta_{elec.} / \theta_{mech.}$)

Since we have;

N = 3 phases

2N = Number of pulses

= 6 pulses

Therefore:

One pulse advances the rotor 60^o electrical degree

Elec. = 60^o elec. Deg. Correspond to:

$\theta_{mech.} = 7.5$ mech. Deg.

Therefore:

$P = 2\times (60^o / 7.5^o) = 16$ poles

b) Recalling equation (1.10 c)

$n_m = (1/NP) \times n_{pulses}$

N = 3 phases : P = 16 pole : n_m = 300 r.p.m.

$n_{pulses} = N\times P \times n_m = 3\times16\times300 = 240$ pulses per sec.

Torque/ Speed characteristics:

One weakness with the(SM)is the limit torque abilities at high speeds, since the torque of a (SM) will falls with rising speed above the cutoff speed (i.e. in resonant speed), as shown in fig(1.27).

When the motor is operating below its cutoff speed, the rise and fall times of the current through the motor windings occupy an insignificant fraction of each step, while at the cutoff speed, the step duration is comparable to the sum of the rise and fall times.

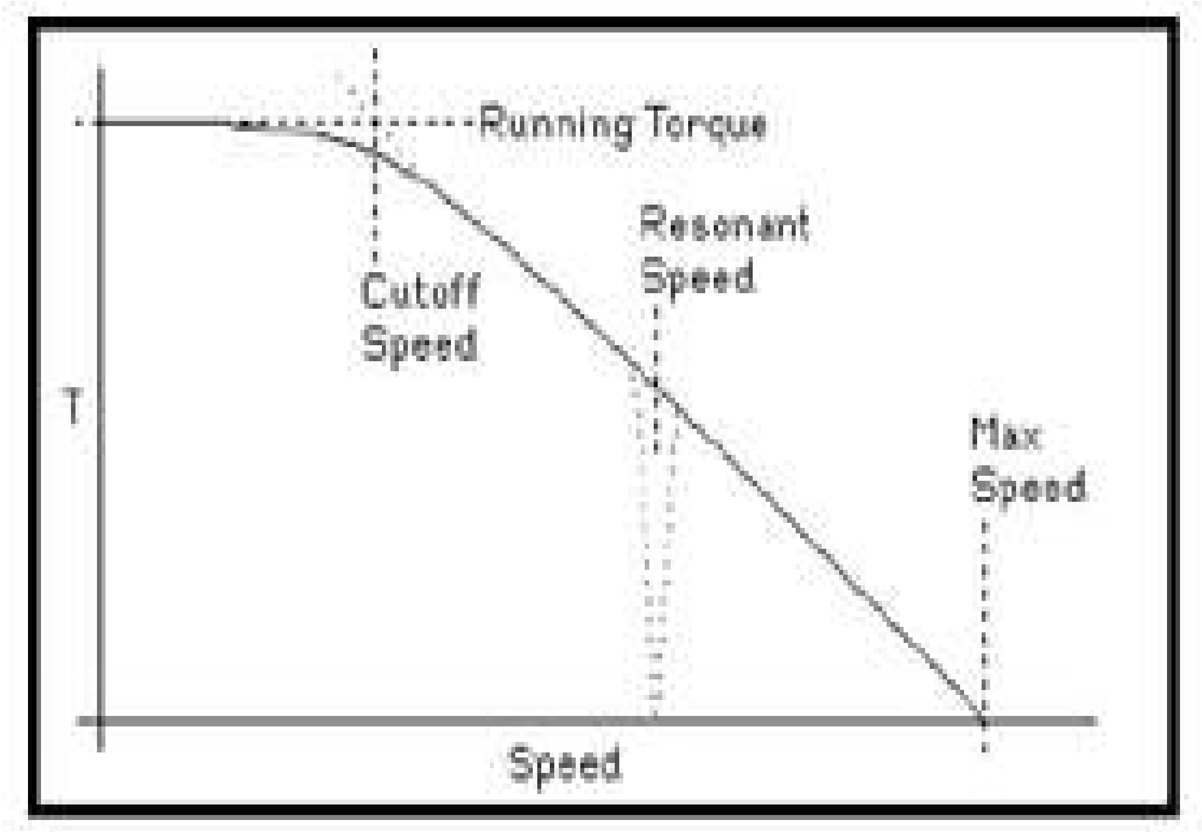


Fig (1.27) Torque vs. Speed Curve of stepper motor

Limitation of stepper motor

The main limitation of stepper motor is as the stepping rate is increased the motor can provide less torque, because the rotor has less time to drive the load from one position to the next.

The characteristic of a stepper motor are frequently presented as the torque against stepping rate in Fig (1.28) .

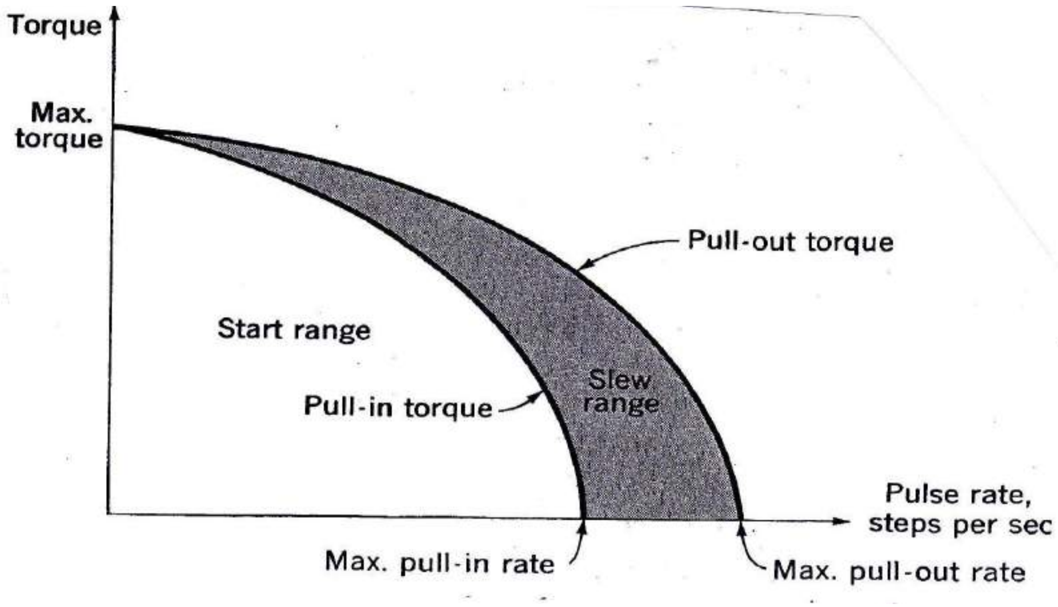


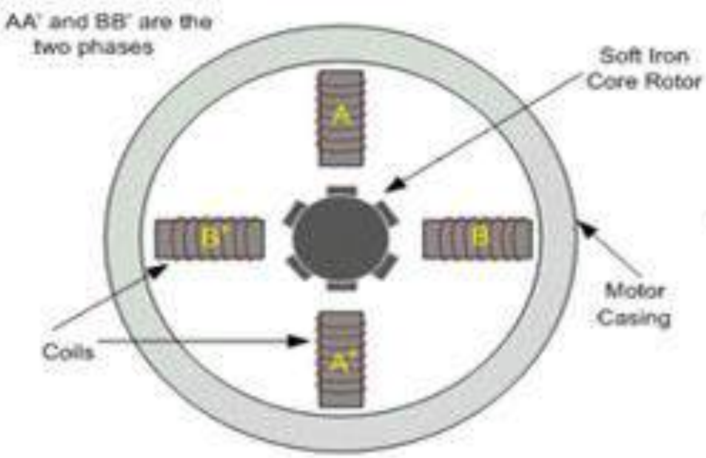
Fig (1.28) stepper motor characteristic of torque Vs pulse rate.

Stepper Motor – Types

There are three main types of stepper motors, they are:

1. Permanent magnet stepper
2. Variable reluctance stepper
3. Hybrid synchronous stepper

1. Permanent Magnet Stepper Motor: use a permanent magnet (PM) in the rotor and operate on the attraction or repulsion between the rotor PM and the stator electromagnets .Fig(1.29a).



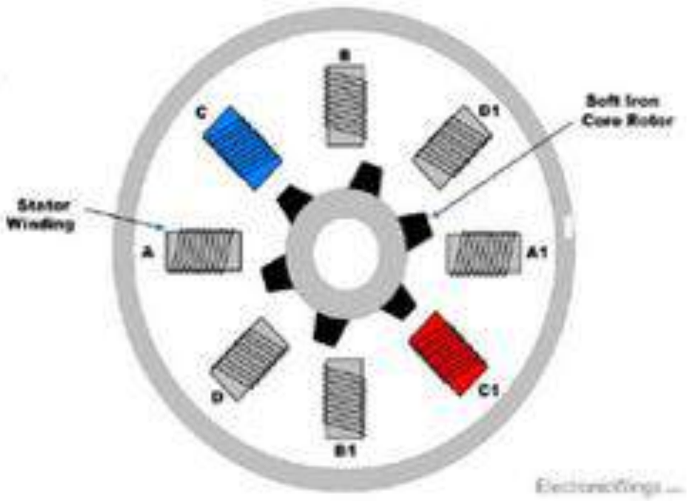


Fig (1.29a) Permanent Magnet Stepper Motor.   Fig(1.29b)Variable Reluctance Stepper Motor.

2. Variable Reluctance Stepper Motor: Variable reluctance (VR) motors have a plain iron rotor and operate based on the principle that minimum reluctance occurs with minimum gap, hence the rotor points are attracted toward the stator magnet poles. Fig (1.29b).

3. Hybrid Synchronous Stepper Motor: they use a combination of permanent magnet and variable reluctance techniques to achieve max, power in small package size. Fig(1.29c).

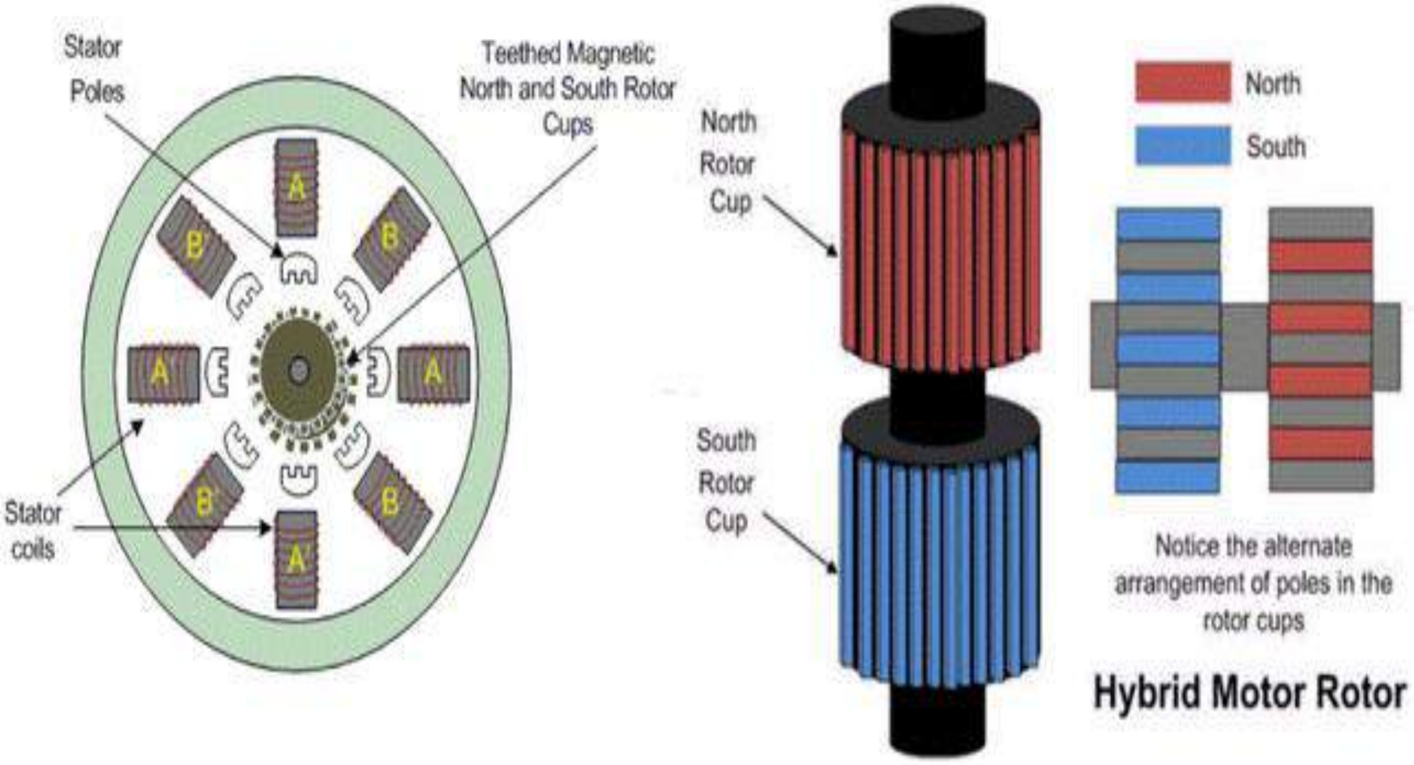


Fig (1.29c) Hybrid Synchronous Stepper Motor

Advantages & Applications

Advantages of Stepper Motor:

1. Small, lower cost compared with corresponding motor – derive unit package .
2. The motor has full torque at standstill.
3. Precise positioning and repeatability of movement since stepper motors have an accuracy of 3 – 5% of a step and this error is noncumulative from one step to the next.
4. Excellent response to starting, stopping, and reversing.
5. Very reliable since there are no contact brushes in the motor. Therefore the motor life is simply dependent on the bearing life.
6. The motor's 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.

Applications:

1. Table positioning for machine Tools.
2. Table drives.
3. Recorder pen drives.
4. X – Y plotters.

BRUSHLEES DC MOTORS (BLDC)

A brushless DC motor is a permanent magnet synchronous electric motor which is driven by direct current (DC) source and it accomplishes electronically controlled commutation system (defined as the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanically commutation system .that's mean the brushless DC motors run from a D.C power supply but do not have commutator and brushes.

The conventional D .C motors have a number of disadvantage ,the principal disadvantage is excessive sparking and brush wear .Such motors have been developed by combining a small motor much like a permanent magnetic stepper motor with a rotor position sensor and a soiled state electronic switching circuit these motors are called (BRUSHLEES DC MOTORS).

A small brushless D.C motor with 4- phases in the stator is shown in Fig (1.30).

The rotor of Brushless D.C motor is similar to that of a permanent motor, except that it is non-salient.

The principal of operation based on energizing one stator coil at a time with a constant D.C voltage , when (a) coil turned on , it produces a stator magnetic field Bs ,and a torque ($\tau_{ind.}$) is produced on the rotor given by :

$$\tau_{ind} = K \times B_s \times B_r \qquad \ldots\ldots\ldots\ldots\ldots(1.11)$$

Bs- stator magnetic field.

Br – rotor magnetic field.

K- constant. →→ $K = (Z \times P)/(2\pi a)$

Z –Number of conductors: a- Number of current parallel paths

P- Number of pole

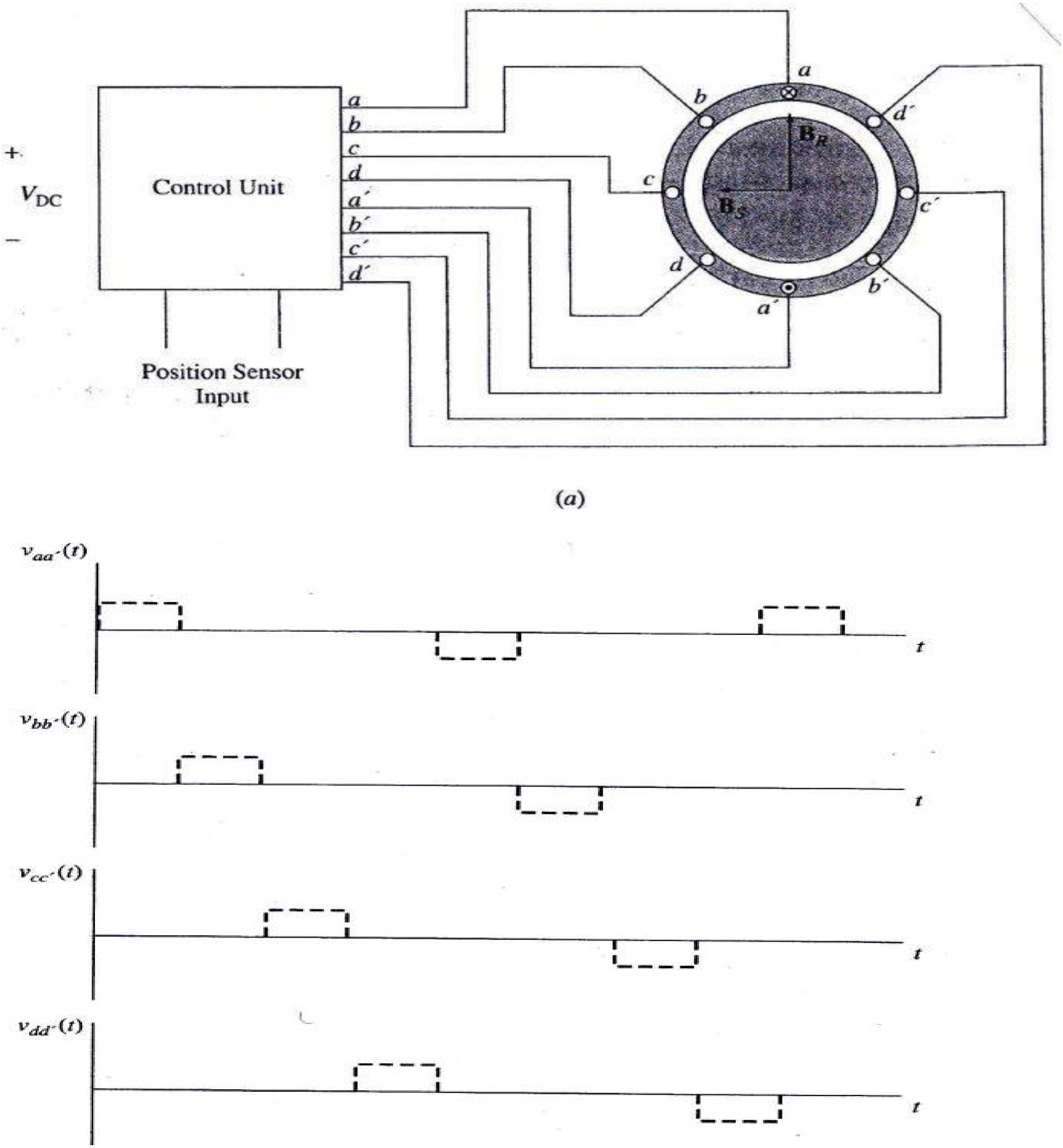


Fig (1.30) 4-phase Brushless dc motor (b)

This tends the rotor to a line with stator magnetic field **Bs**, in Fig(1.30 a), **Bs** points to the left while rotor field **Br** points up, producing an ant-clock wise torque on the rotor .

As a result the rotor will turn to the left and if coil (**a**) remained energized all of time. The rotor would turn until the two magnetic field are a lined, and then it would stop, (like a stepper motor).

Thus, operation of Brushless D.C motor must be includes a position sensor ,so control circuit will know when the rotor is almost a lined with the stator magnetic field **Bs**.

NOW:-

Turn –off the coil (**a**)

Turn – on the coil (**b**), causing the rotor to again experience , a anti-clock wise torque produced, and to continue rotating.

This process continues indefinitely with the coils turned –on in the order:-

a, **b** , **c** , **d** , **- a** ,**-b** , **-c** ,**-d** , …..Etc.

So that the motor turns continuously. The control circuit can be used to control both:- **a)** The motor speed. **b)** The direction of the speed.

The stator can have three or more phases.

Three phase BLDC Motor operation

When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap through the DC source supply, switching makes to generate an AC voltage waveform with trapezoidal shape, See Fig (1.31). Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.

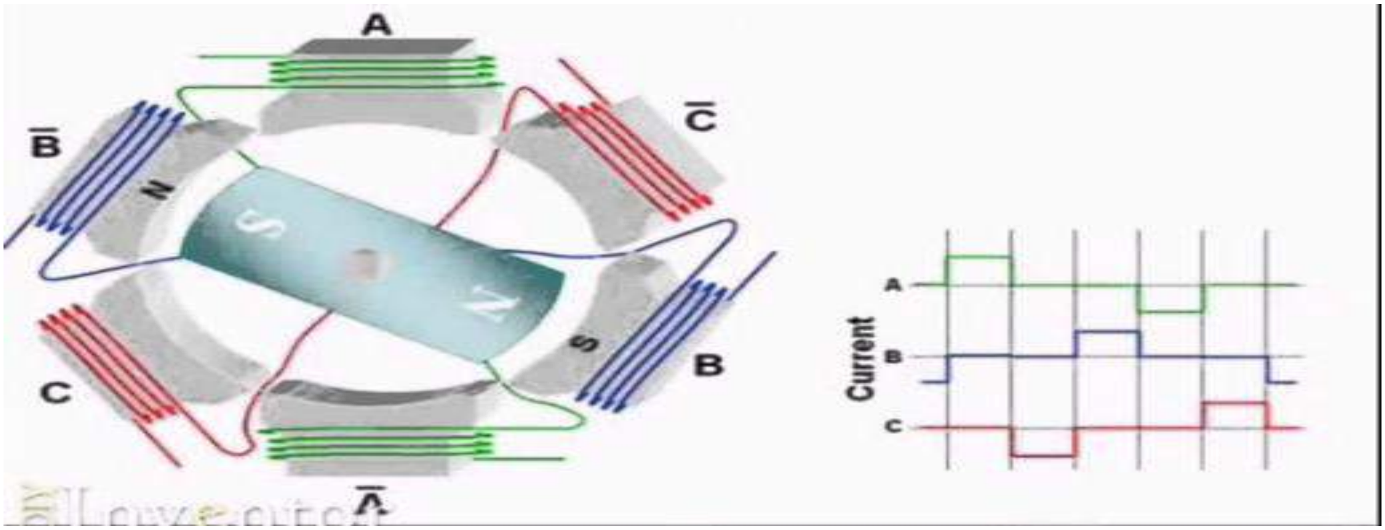


Fig (1.31) 3-phase permanent magnet Brushless dc motor

A question here, how can we know which stator coil should be energized and when to do .This is because; the continuous rotation of motor depends on switching sequence around the coils. Hall-effect sensors generate Low and High level signals whenever rotor poles pass near to it. These signals determine the shaft position.

Torque speed characteristic of Brushless dc motor

The linear graph with negative slope indicates a constant power mode; if the power input is constant and the motor efficiency is not dependent on speed, then the linear equation can be obtained. Fig(1.32).

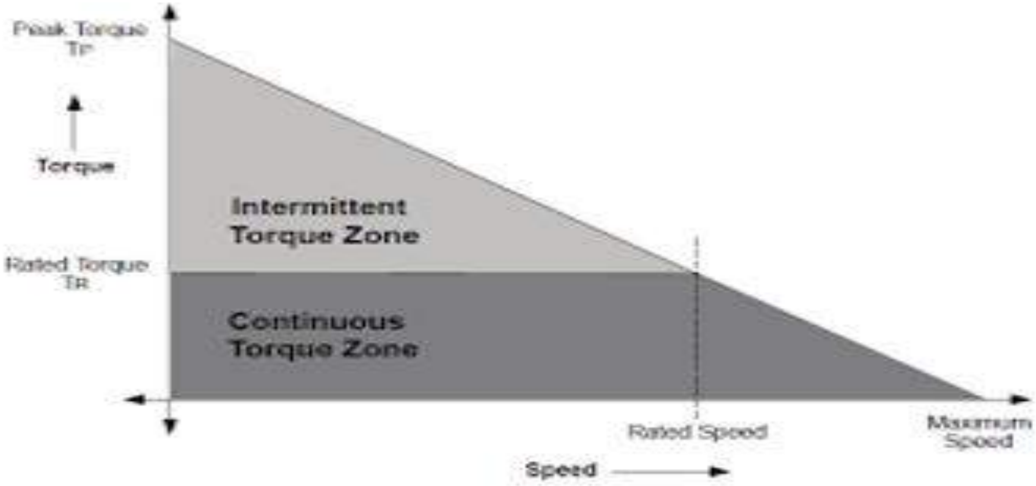


Fig (1.32) Torque speed characteristic of Brushless dc motor

Observe that motor produces torque because of the attraction forces development (when North-South or South-North alignment) and repulsion forces (when North-North or South-South alignment.

Construction of Brushless D.C Motors

The basic components of Brushless D.C Motors:-

1) A permanent magnet rotor.   2) A stator with 3, 4, or more phase winding.

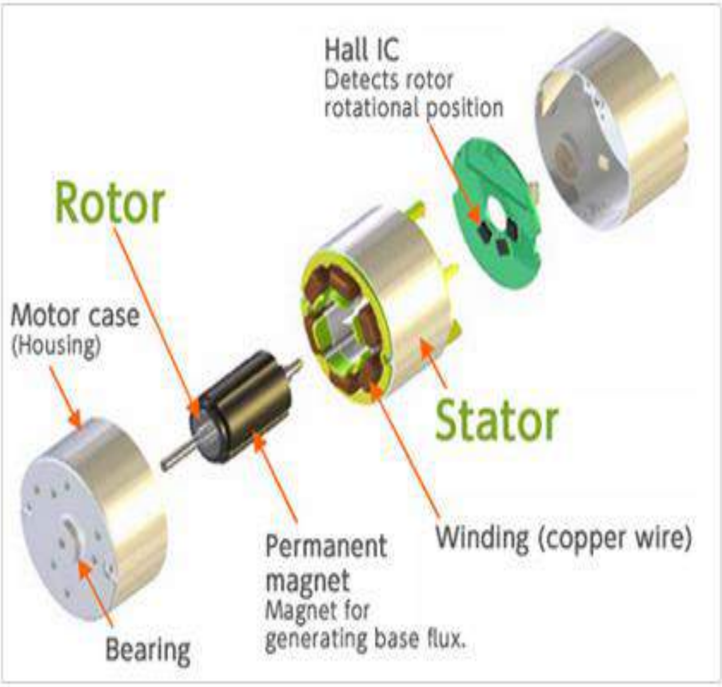
3) A rotor position sensor.   4) An electronic circuit to control motor winding phases

Construction type of Brushless D.C Motors

According to the rotor location with respect to stator the brushless D.C motors can be classified as two types:

1) Outer rotor: the rotor is outside the stator .Fig (1.33).
2) Inner rotor: like almost motor kinds the rotor is inside the stator .Fig (1.34).

Fig (1.33) Outer rotor type.



Fig(1.34) Inner rotor type.

In both types, the rotor, made of magnet, is rotated by magnetic fields that are generated by the current flowing through the stator windings. The current is switched by sensor and electronic circuit.

	Outer Rotor type	Inner Rotor type
<u>Advantages</u>	1.Easy to obtain large torque. 2.Speed is stable during constant rotation.	1.The rotor is small and can respond quickly. 2.The coil is located on the outside and the level of heat dissipation is high.
<u>Disadvantages</u>	1.Rotor is large (the motion is slow). 2.Outside rotor requires appropriate safety measures.	1.Difficult to obtain large torque. 2.Magnets can be damaged by centrifugal force.

Brushless DC Motor Drive

A single phase Brushless D.C motor electric driver circuit is shown in Fig (1.35).

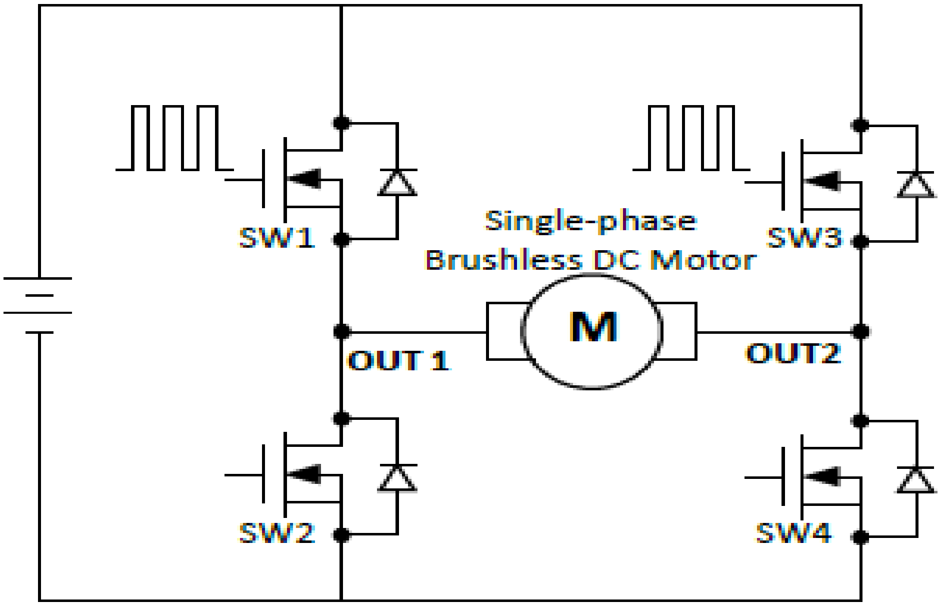
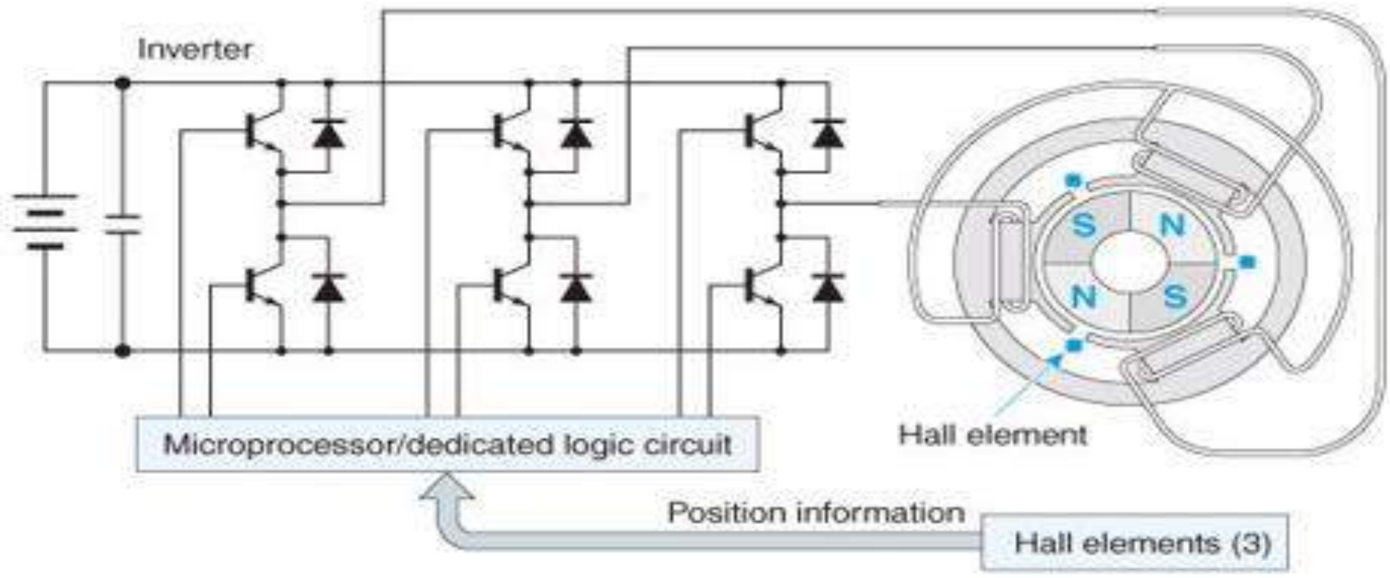


Fig (1.35) single phase driver circuit (H-bridge)

A 3 - phase electric drivers are the most common type used as electronic controller system to run with BLDC motor. Some BLDC motors use Hall-effect sensors for detecting the position of the motor's rotor with respect to the motor's stator. see Fig(1.36).



Fig(1.36) BLDC motor using Hall-effect sensor

Other motors don't have sensors; they're referred to as sensorless BLDC motors. In place of using Hall-effect sensors for determining the rotor's position and/or speed, a phenomenon called back EMF is employed, see Fig (1.37).

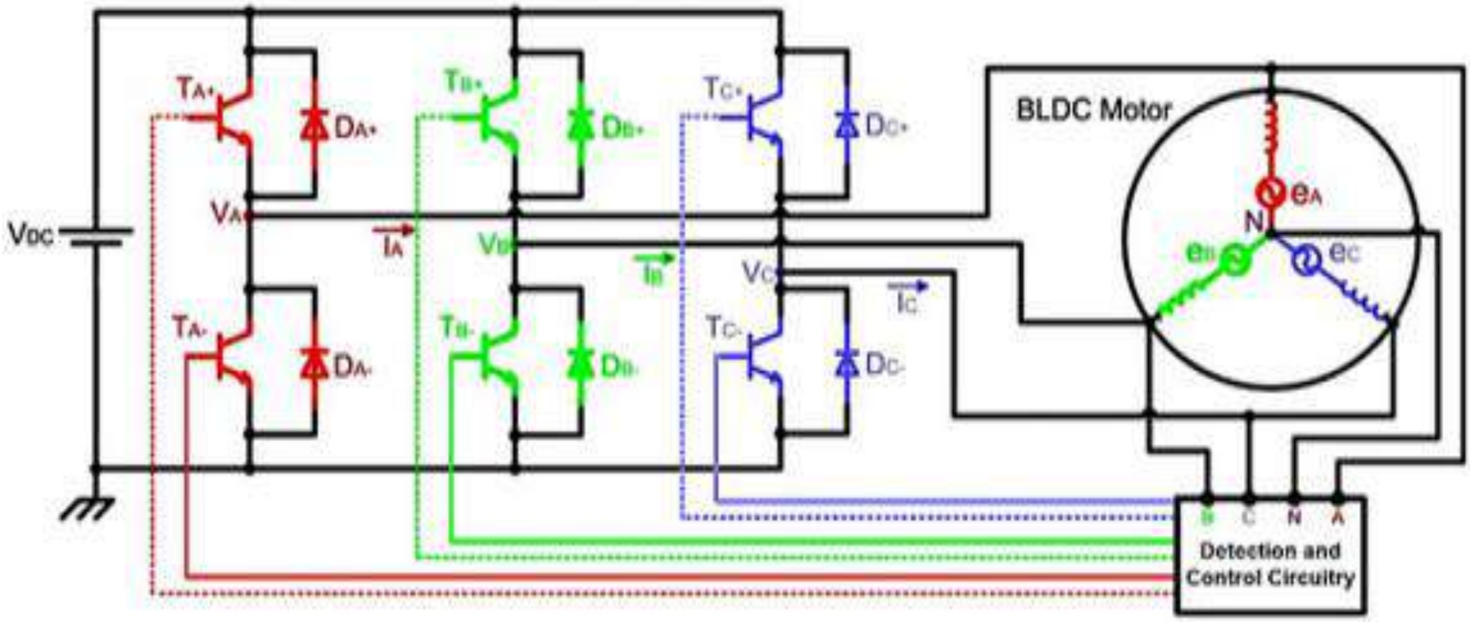


Fig (1.37) Sensorless BLDC motor control

Sensorless BLDC Motor Control

Sensorless BLDC control sometimes called sensorless trapezoidal control uses back EMF for determining location of motor's rotor with respect to stator.

A voltage applied to motor forces the rotor to turn. The rotor movement through the motor's magnetic field, however, is analogous to the behavior of a generator, and consequently the motor not only receives an applied voltage but also generates its own voltage. This voltage is referred to as back electromotive force EMF, and it is proportional to the rotational speed. Back EMF can be used to determine a motor's rotor speed and position,no sensors are required. Controlling a motor by means of back EMF is not a simple task; most sensor less BLDC motors are controlled using a microcontroller, a digital signal processor.

The electronic controller circuit energizes appropriate motor winding by turning transistor or other solid state switches to rotate the motor continuously. The figure shows simple BLDC motor drive circuit which consists of bridge (also called as inverter bridge).

Hall-effect sensors are used for position and speed feedback. The electronic controller can be a microcontroller unit or microprocessor.

Advantages of BLDC Motor

BLDC motor has several advantages over conventional DC motors:

1) No mechanical commutator and associated problems.
2) Relatively high efficiency due to the use of permanent magnet rotor.
3) Long life as little or no maintenance is required like commutator system.
4) Very high speeds and higher dynamic response due to low inertia.
5) Less electromagnetic interference and quite operation (or low noise).

Disadvantages of BLDC Motor

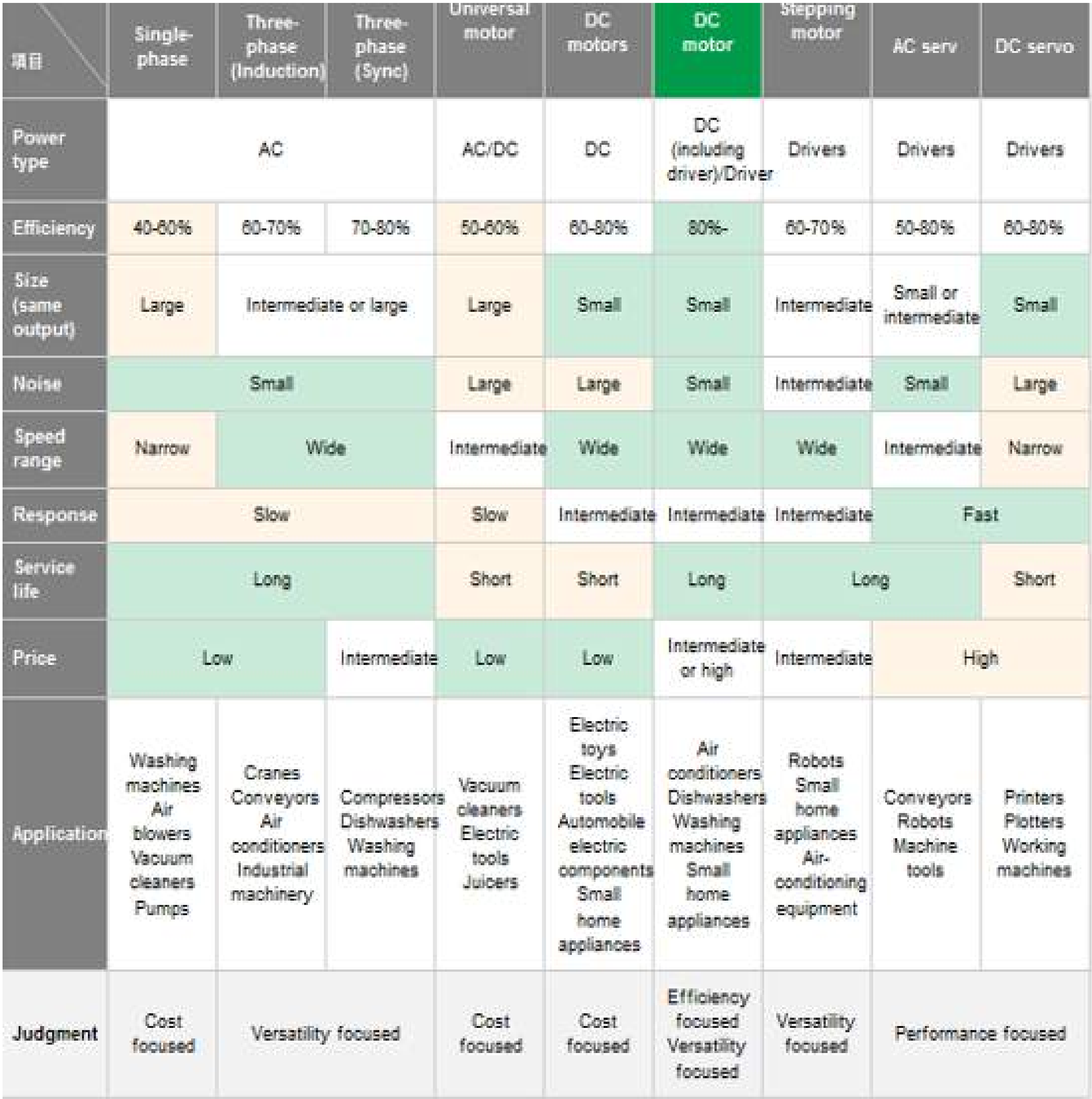
1) The main disadvantage is that a Brushless D.C Motors are more expensive and Electronic controller required complex drive circuitry.
2) Need of additional sensors.

Applications of BLDC Motors

Some specific applications of BLDC motors are Computer hard drives and DVD/CD players Electric vehicles, hybrid vehicles, and electric bicycles,Industrial robots, CNC machine tools, and simple belt driven systems, Washing machines, compressors and dryers Fans, pumps and blowers.

Motor Type Comparison Table

BLDC motors have many advantages (in particular area of efficiency).When compared to other types of motor, these advantages are compact size, high output, low vibration, low noise, and long life.



項目	Single-phase	Three-phase (Induction)	Three-phase (Sync)	Universal motor	DC motors	DC motor	Stepping motor	AC serv	DC servo
Power type	AC			AC/DC	DC	DC (including driver)/Driver	Drivers	Drivers	Drivers
Efficiency	40-60%	60-70%	70-80%	50-60%	60-80%	80%-	60-70%	50-80%	60-80%
Size (same output)	Large	Intermediate or large		Large	Small	Small	Intermediate	Small or intermediate	Small
Noise	Small			Large	Large	Small	Intermediate	Small	Large
Speed range	Narrow	Wide		Intermediate	Wide	Wide	Wide	Intermediate	Narrow
Response	Slow			Slow	Intermediate	Intermediate	Intermediate	Fast	
Service life	Long			Short	Short	Long	Long		Short
Price	Low		Intermediate	Low	Low	Intermediate or high	Intermediate	High	
Application	Washing machines Air blowers Vacuum cleaners Pumps	Cranes Conveyors Air conditioners Industrial machinery	Compressors Dishwashers Washing machines	Vacuum cleaners Electric tools Juicers	Electric toys Electric tools Automobile electric components Small home appliances	Air conditioners Dishwashers Washing machines Small home appliances	Robots Small home appliances Air-conditioning equipment	Conveyors Robots Machine tools	Printers Plotters Working machines
Judgment	Cost focused	Versatility focused		Cost focused	Cost focused	Efficiency focused Versatility focused	Versatility focused	Performance focused	