5 Universal Motor

An electric motor which can be operated either on DC or AC supply is called a universal motor. It has almost same performance characteristics for both AC and DC supplies. These motors are of series-compensated type. Universal motors are available in the voltage range from 1.5 V to 250 V with speed range from 2500 rpm to 35000 rpm. They find applications ranging from small driving hand tool to electric locomotives. High-speed operation, small size, light weight and high starting torque make universal motors very popular and their use can be seen from kitchen to very large industries.

5.1 Types and Construction

Universal motors are classified into non-compensated concentrated field type and compensated distributed field type. The first type is used for low-power applications and second type finds applications requiring high power.

The non-compensated concentrated universal motor has two salient poles on its stator. The whole magnetic path is laminated. The armature core (rotor) is mounted on the shaft. The rotor is made up of laminations. Slots are provided on the outer periphery of the rotor and armature conductors are housed in these slots. The slots are usually skewed. Constructionally, the armatures of DC motor and universal motor are similar. The armature coils are connected to commutator segments.

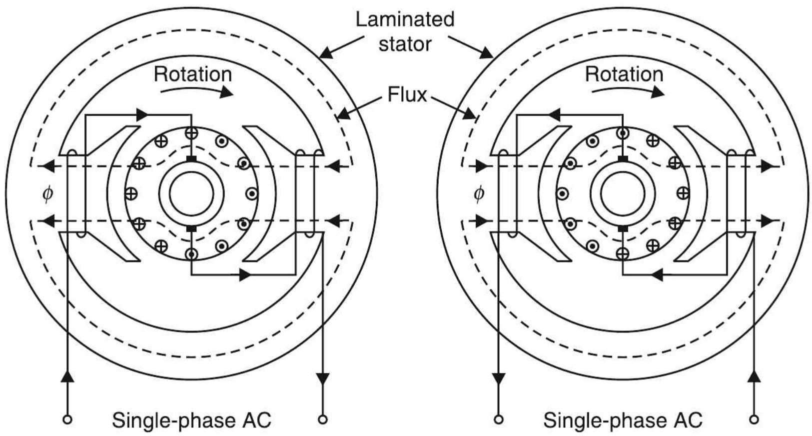
Segments of the commutator are insulated from each other and from the shaft. The commutator rotates together with armature. Current flows to the armature through the brushes.

The compensated distributed field type universal motor has a stator core similar to that of a split phase single-phase induction motor. The armature with slots and winding is similar to that of a conventional DC motor. The reactance voltage is induced when the motor operated by AC supply is reduced by using compensating winding.

5.2 Principle of Operation

With DC supply, the current directions in stator and rotor windings are same throughout the operation. The magnetic field also has the same direction. The torque developed by interaction of current and magnetic flux at all instants has same direction, or in other words, the motor develops unidirectional torque.

For explaining the operation of universal motor with AC supply, a simple two-pole motor is considered. During positive half cycle, the current drawn from the supply flows through the stator winding and the armature winding through brushes, and has the direction as shown in Fig.1.a . The flux produced by the current has the direction shown. During the negative half cycle, the current is reversed and its direction is shown in Fig.1.b . The direction of flux is also shown.



(a) Positive half cycle (b) Negative half cycle

Fig.1 Universal motor

With directions of current and flux shown in Fig.1.a and 1.b the torques developed have directions as shown. Directions of torque for both positive and negauve half cycles are clockwise. Thus, the torque is unidirectional irrespective of the polarity of supply voltage. The rotor rotates in the clockwise direction.

The circuit diagram of a universal motor is shown in Fig.2

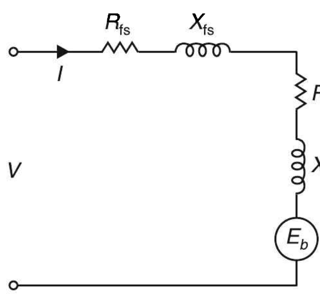


Fig. 2 Circuit diagram of a universal motor

In Fig.

R_s = resistance of stator field winding

X_s = leakage reactance of stator field winding

R_r = armature resistance (rotor resistance)

X_r = armature leakage reactance

E_b = back emf

V = terminal voltage

I = current drawn from the supply

Back emf represented in the circuit diagram is composed of three parts: transformer and rotational emfs induced in the armature and transformer emf induced in the stator field winding.

The flux produced by the stator field ϕ_s is along the direct axis and induces rotational emf in armature given by,

$$E_r = \frac{1}{\sqrt{2}} \frac{\Phi_{sm} ZN}{60} \frac{P}{A}$$

where

Φ_{sm} = maximum stator field flux/pole

Z = number of armature conductors

A = number of parallel paths

N = speed in rpm

P = number of poles

When the armature carries current, it produces a magnetic field ϕ_r. It has direct axis component ϕ_{dr} and quadrature axis component ϕ_{qr}. The quadrature axis component induces transformer emf in rotor winding. It is in quadrature with current. The transformer emf induced in armature winding is given by

$$E_{tr} = 4.44\, f k_b\, \phi_{qr} \frac{Z}{2A}$$

where

k_b = breadth factor

f = supply frequency

$$\therefore \qquad E_{tr} = 4.44 \times \frac{2}{\pi} \times f\phi_{qr} \frac{Z}{2A} \qquad \left(k_b = \frac{2}{t}\right)$$

i.e.

$$E_{tr} = 1.414\; f\phi_{qr} \frac{Z}{A}$$

Transformer emf in the stator is given by,

$$E_{ts} = 4.44\, f\, \Phi_{sm}\, T_s$$

where T_s = number of turns in the stator field winding, E_{ts} is also in quadrature with the current. The phasor diagram of the universal motor is shown in Fig. 3

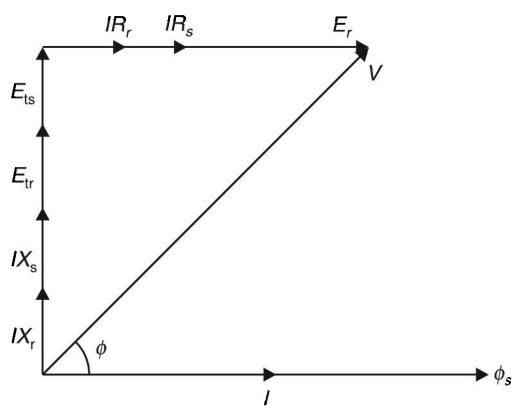
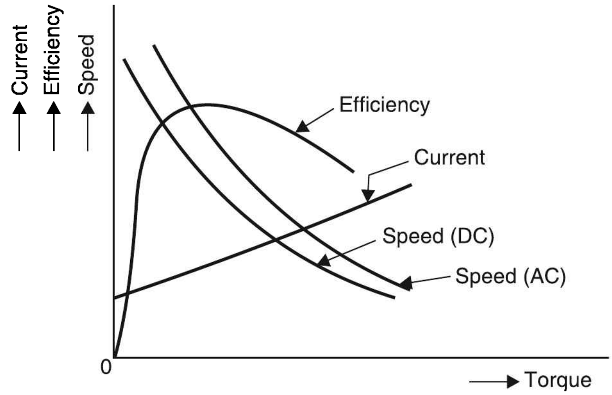
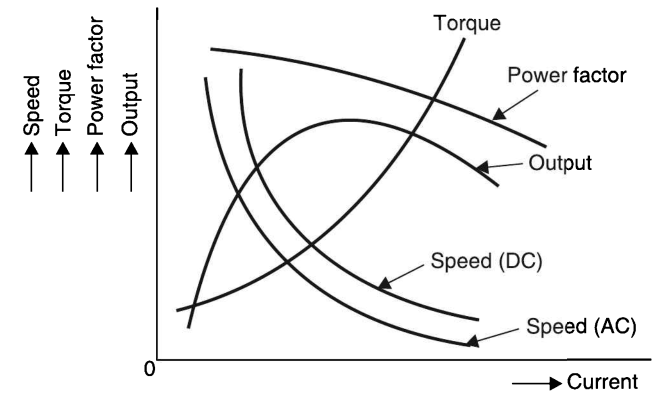


Fig. 3 **Phasor diagram of universal motor**

The performance characteristics of a typical universal motor are shown in Fig. 4



(a) Performance with torque as indepenent variable



(b) Performance with current as independent variable

Fig. 4 **Performance characteristics of universal motor**

Advantages and limitations of universal motor

Advantages

- Able to produce more power in small size
- High starting torque
- High-speed operation is possible
- Can be operated from AC and DC
- Speed control is easy

Limitations

- Regular maintenance is required
- High noise at high speeds
- Brush sparking causes radio and TV interference
- Perfect balancing is required to avoid vibrations
- Gear mechanism is required for portable tool applications

5.3 Speed Control of Universal Motor

In this section, various methods of speed control of universal motor are described.

(a) ***Resistance method***

In this method, a variable resistance is connected in series with the motor. The resistance in the circuit decides the speed of the motor. This method of speed control is adopted in sewing machines. The amount of resistance is controlled by the force applied by the foot on the foot pedal. The circuit is shown in Fig. 5

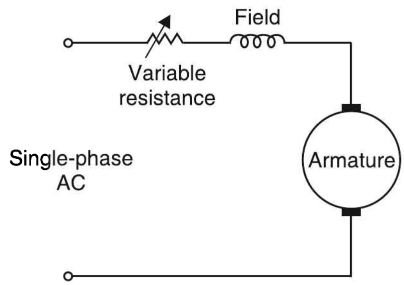
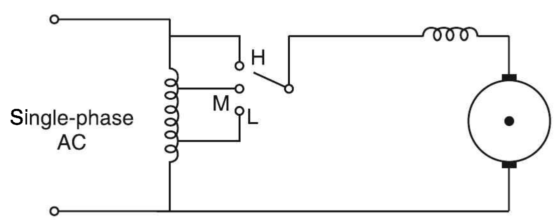


Fig. 5 **Resistance method of speed control of universal motor**

(b) ***Auto-transformer method***

An auto-transformer is used across the supply. The auto-transformer has tapping points as shown in Fig. 6 . Depending on the speed requirement, supply from different tappings is given to the motor.



L = low, M = medium, H = high speeds

Fig. 6 **Auto-transformer method of speed control**

(c) ***Tapping-field method***

In this method, the field winding is tapped (for one pole) at different points. By using this technique, the flux is controlled. The scheme is shown in Fig. 7

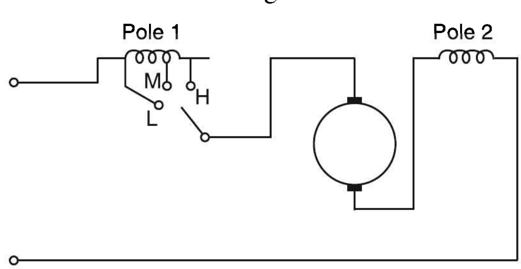


Fig. 7 **Tapping-field method of speed control**

(d) ***Centrifugal device mechanism***

This mechanism is employed in universal motors used in home food and drink mixers. They have a number speed selection facility. An external liver (knob) is used to set the required speed. A centrifugal device as shown in Fig. 8 is placed inside the motor. The switch is adjustable. If the motor speed exceeds the set speed, the switch opens and the resistance is excluded in the motor circuit, so that speed decreases. If speed decreases, the switch closes and remove the resistance from the circuit, so that speed increases. This process is very fast and hence motor runs at almost the set speed. The capacitor is to avoid sparking due to the switching operations.

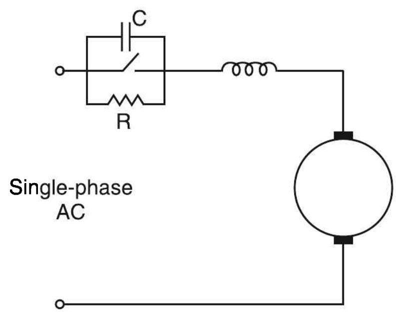


Fig. 8 Speed control of universal motor with centrifugal mechanism

In addition to the above methods, a variety of control techniques are developed using semiconductor devices.

Applications of universal motors

Universal motors are used in the following applications:

1. Centrifugal blowers in vacuum cleaners
2. For driving portable tools like electric saw and drills
3. Electric locomotives
4. Food mixers and blenders
5. Motion picture projectors
6. Cameras
7. Adding and calculating machines
8. Electronic type writers
9. Hair dryers and electric shavers

1. A universal motor takes 1 A from 220 V DC supply while running at 2000 rpm. Find the speed and power factor when it is connected to 230 V, 50 Hz supply drawing the same current. The total resistance and inductance are 20 Ω and 0.4 H, respectively.

Solution

Given:

$$I = 1\text{ A}$$
$$V_{DC} = 220\text{ V}$$
$$R = 20\ \Omega$$
$$L = 0.4\text{ H}$$
$$f = 50\text{ Hz}$$
$$N_{DC} = 2000\text{ rpm}$$

Reactance, $X = 2\pi f L = 125.6\ \Omega$ emf developed.

$$E_{DC} = 220 - I \times 20$$
$$= 200\text{ V}$$
$$E_{AC} = \sqrt{V^2 - (IX)^2} - IR$$
$$= 192.7 - IR = 172.7$$
$$\text{Power factor} = \frac{E_{AC}}{V} = 0.84\text{ (lagging)}$$

We have

$$\frac{N_{AC}}{N_{DC}} = \frac{E_{AC}}{E_{DC}}$$

∴

$$N_{AC} = N_{DC} \times \frac{E_{AC}}{E_{DC}} = 2000 \times \frac{172.7}{200}$$
$$= 1727\text{ rpm}$$

2. A 230 V, 50 Hz, 2-pole universal motor has 1200 armature turns and 400 field turns. It takes 1 A at 7000 rpm when the flux is 0.8 mWb. Find (i) quadrature flux (ii) transformer induced emf (iii) hp output and (iv) speed if it is connected to DC supply and takes 1 A. The total resistance and leakage reactances are 20 Ω and 30 Ω, respectively. The armature is wave wound.

Solution

Given:

Number of poles, $P = 2$

Speed $N_{AC} = 7000$

Number of turns in the armature = 1200

Number of parallel paths, $A = 2$

Flux, $\Phi_{sm} = 0.0008$ Wb

The rotational emf,

$$E_r = \sqrt{2}\,\Phi_{sm} Z \frac{N_{AC} P}{60 A}$$

$$= \sqrt{2} \times 0.0008 \times \frac{1200 \times 2}{2} \times \frac{7000}{60}$$

$$= 158.37 \text{ V}$$

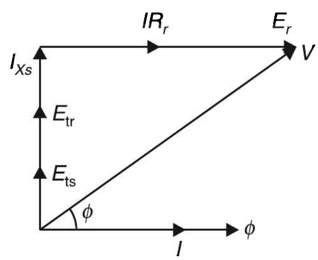
Transformer emf in the field,

$$E_{ts} = \sqrt{2}\,\pi f T_s \Phi_{sm}$$

$$= \sqrt{2} \times 3.14 \times 50 \times 400 \times 0.0008$$

$$= 71 \text{ V}$$

The phasor diagram is shown below.



From the phasor diagram

$$V^2 = (E_{ts} + E_{tr} + I_X)^2 + (IR_r + E_r)^2$$

$$230^2 = (71 + E_{tr} + 30)^2 + (20 + 158.37)^2$$

∴ $E_{tr} = 44.2$ V

Also, $E_{tr} = 2\sqrt{2} f \frac{Z}{A} \phi_{qr}$

$$44.2 = 2\sqrt{2} \times 50 \times \frac{2400}{2 \times 2} \times \phi_{qr}$$

∴ $\phi_{qr} = 0.00052$ Wb

From the phasor diagram

$$\text{power factor} = \cos\phi = \frac{E_r + IR_r}{V}$$

$$= \frac{158.37}{230}$$

$$= 0.776 \text{ (lagging)}$$

$$\text{Input power} = VI\cos\phi$$

$$= 230 \times 1 \times 0.776$$

$$= 178.48 \text{ W}$$

$$\text{copper loss} = I^2R_r = 20 \text{ W}$$

Neglecting other losses

$$\text{output} = 178.48 - 20 = 158.48 \text{ W}$$

$$= \frac{158.48}{735.5}$$

$$= 0.215 \text{ hp (metric)}$$

When connected to DC supply

$$V_{dc} = 230,\ I_{dc} = 1 \text{ A}$$

$$E_{rdc} = 230 - I_{dc}R_r$$

$$= 210$$

$$\frac{N_{DC}}{N_{AC}} = \frac{210}{158.37}$$

$$N_{DC} = \frac{210}{158.37} \times 7000 = 9282 \text{ rpm}$$