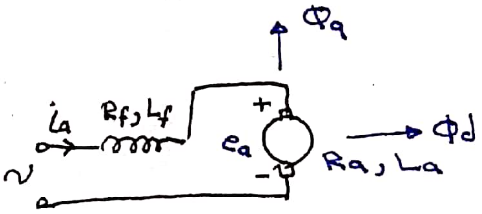
Single phase motors

Single-phase series (universal) motors

Single phase ~~ss~~ series motors can be used with either a dc source or a single-phase ac source and therefore called universal motors.

They are widely used in fractional horse power ratings in many domestic appliances such as portable tools, drills, mixers, and vacum cleaners and usually are light in weight and operate at high speed (1500–10,000 rpm). Large ac series motors in the range of 500 hp are used for traction applications.

Universal motors are mostly operated from a single phase ac source. Therefore, both the stator and rotor structures are made of laminated steel to reduce core losses and eddy current.



The armature current i_a flowing through the series field produces d-axis flux Φ_d and flowing through the armature winding produces the q-axis flux Φ_q. If eddy current is neglected both Φ_d and Φ_q are in phase with i_a.

Single phase motors

DC Excitation

$T = k_a \Phi_d I_a$

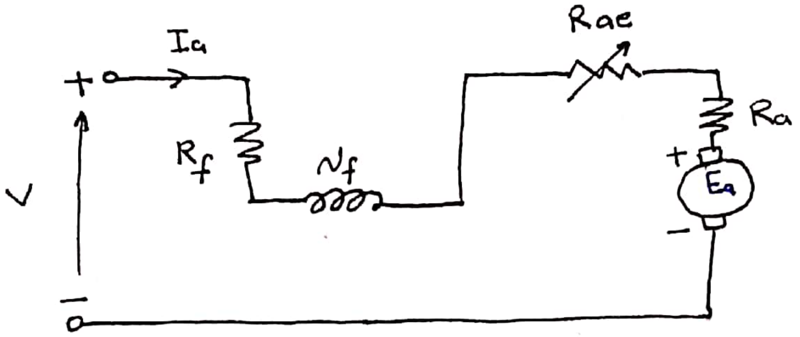
$E_a = k_a \Phi_d \omega$

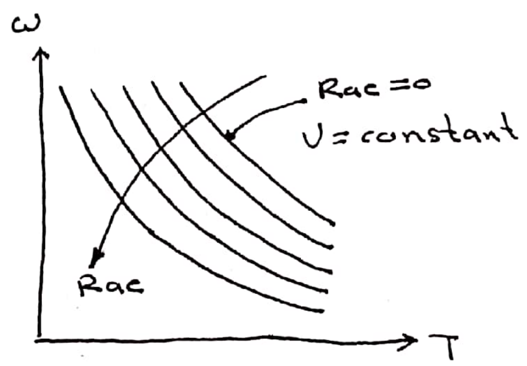
If magnetic linearity is assumed then: $k_a \Phi_d = k_{sr} I_a$

hence

$$T = k_{sr} I_a^2$$

$$E_a = k_{sr} I_a \omega$$





Single phase motors

AC Excitation

If eddy currents effect are neglected, the current i_a and the flux Φ_d are in phase

$$i_a = I_{am} \cos\omega t$$

$$\Phi_d = \Phi_{dm} \cos\omega t$$

The back emf $\quad e_a = k_a \Phi_d \omega$

$$= k_a \Phi_{dm} \omega \cos\omega t$$

The rms value of the back emf is

$$E_a = \frac{k_a \Phi_{dm}}{\sqrt{2}} \cdot \omega$$

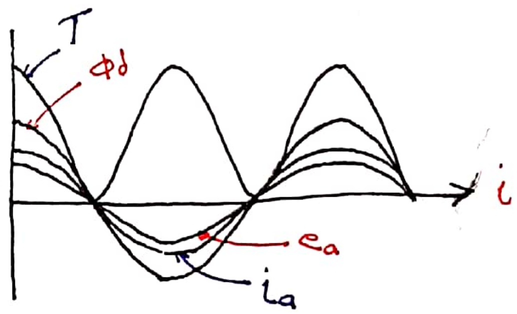
$$= k_a . \Phi_d . \omega$$ where Φ_d is rms value of d-axis flux

The instantanous torque is $T = k_a . \Phi_d . i_a$

$$= k_a \Phi_{dm} I_{am} \cos^2\omega t$$

$$= k_a \frac{\Phi_{dm} I_{am}}{2} (1 + \cos 2\omega t)$$

voltage, current, flux, and torque waveforms



average torque $= T = k_a . \frac{\Phi_{dm} . I_{am}}{2}$

$$= k_a . \Phi_d . I_a$$

If magnetic linearity is assumed : $\quad k_a . \Phi_d = k_{sr} . I_a$

hence: $\quad T = k_{sr} . I_a^2$

$$E_a = k_{sr} . I_a . \omega$$

Single phase motors

Electromagnetic or mechanical power developed is :

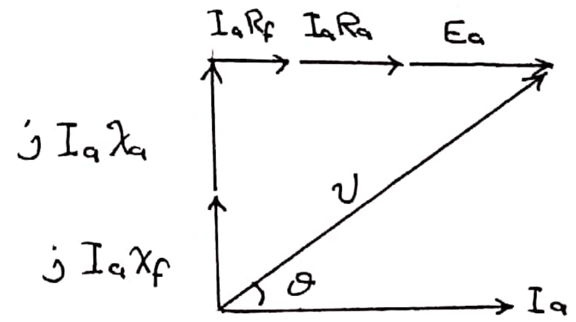
$$P_m = E_a \cdot I_a$$

The developed torque can also be obtained as:

$$T_d = \frac{E_a \cdot I_a}{\omega}$$

$$= \frac{k_{sr} \cdot I_a \cdot \omega \cdot I_a}{\omega}$$

$$= k_{sr} I_a^2$$

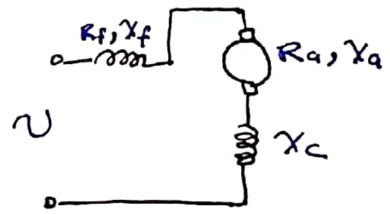


From the upper phasor diagram:

$$E_a = V\cos\theta - I_a R_f - I_a R_a$$

Compensated Motor

A compensated coil can be connected in series with the armature and will produce flux in opposition to the q-axis flux Φ_q produced by I_a flowing through the armature.



compensated series motor

The net inductance of the armature winding and the compensated winding is

$$L_{eff} = L_a + L_c - 2M$$

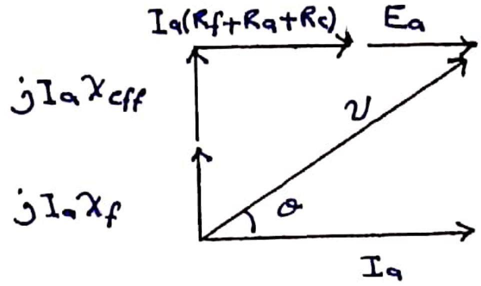
L_a = inductance of armatur winding

L_c = inductance of compensated winding.

M = mutual inductance between L_a and L_c

It is possible to make $L_{eff} << L_a$

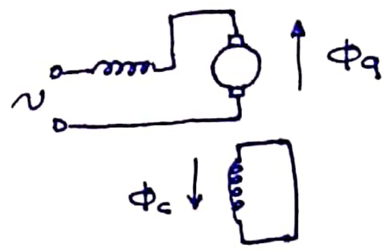
The phasor diagram is shown below



The compensated winding adds additional resistance R_c in the circuit. However, it greatly reduces the effect of the armature reactance X_a. The net result is increased E_a (hence speed), decreased power factor angle θ (hence increased power factor), and increased efficiency. The decrease in the q-axis flux due to compensated winding will improve the commutation of current

Alternative Design for compensation coil

As shown, a shorted compensation coil can be installed in the q-axis so that induced current in this coil can oppose the q-axis flux Φ_q produced by i_a.



Inductive compensation

This coil is predominantly inductive (i.e., high L/R ratio).

compensation by this arrangement is possible with a.c. excitation only.

Example 1, A 120V, 60 Hz, $\frac{1}{4}$ hp universal motor runs at 2000 rpm and takes 0.6 ampere when connected to a 120V dc source. Determine the speed, torque, and power factor of the motor when it is connected to a 120V, 60 Hz supply and is loaded to take 0.6 (rms) ampere of current. The resistance and inductance measured at the terminals of the machine are 20 Ω and 0.25 H, respectively.

Solution

$$X = 2\pi f L = 2\pi \times 60 \times 0.25 = 94.247 \ \Omega$$

$$I_a R + E = \sqrt{U^2 - (I_a X)^2}$$

$$\Rightarrow \quad E = \sqrt{U^2 - (I_a X)^2} - I_a R$$

$$= \sqrt{(120)^2 - (0.6 \times 94.247)^2} - 0.6 \times 20$$

$$= 93.84 \ \text{volt}$$

$$p.f = \cos\theta = \frac{I_a R + E}{U} = \frac{0.6 \times 20 + 93.84}{120}$$

$$= 0.882$$

$$E_{dc} = k\, \phi_{dc}\, \omega_{dc} \quad , \quad E_{ac} = k\, \phi_{ac}\, \omega_{dc}$$

$$\therefore \quad \frac{E_{dc}}{E_{ac}} = \frac{k\, \phi_{dc}\, \omega_{dc}}{k\, \phi_{ac}\, \omega_{ac}} \approx \frac{\omega_{dc}}{\omega_{ac}}$$

$$\frac{E_{dc}}{E_{ac}} \approx \frac{n_{dc}}{n_{ac}} \quad \Rightarrow n_{ac} = n_{dc} \cdot \frac{E_{ac}}{E_{dc}}$$

$$E_{dc} = U - I_a R = 120 - 0.6 \times 20 = 108 \ \text{volt}$$

$$n_{ac} = 2000 \times \frac{93.84}{108} = 1737.78 \ \text{rpm}$$

$$\text{mechanical power developed} = E_a I_a = 93.84 \times 0.6 = 56.3 \ \text{watt}$$

$$\text{Torque developed} = T = \frac{E_a I_a}{\omega} = \frac{56.3}{2\pi \times \frac{1737.78}{60}} = 0.309 \ \text{N.m}$$

Ex: A 220V, 50Hz, 1/4hp universal motor runs at 2500 rpm and takes a current of 1A when it is connected to 220V dc source. Determine the speed, developed torque (T), and power factor of the motor when it is connected to 220V, 50 Hz supply and is loaded to take 1A (rms) of current. The resistance and inductance measured at the terminals of the machine are 25 Ω and 0.4 H respectively. What is the value of starting torque in Nm? (Assume magnetic linearity).

Solution

$E_{dc} = 220 - 1 \times 25 = 195 V$

$X = 2\pi f L = 2\pi \times 50 \times 0.4 = 125.6 \Omega$

$E_{ac} + IR = \sqrt{V^2 - (IX)^2}$

$E_{ac} = \sqrt{48400 - 15775.36} - 25$

Assuming the same flux for the same current (i.e 1A dc and 1A rms)

$$\frac{E_{dc}}{E_{ac}} = \frac{2500}{N_{mac}} \Rightarrow N_{mac} = 2500 \times \frac{155.62}{195} = 1995 \text{ rpm}$$

$$p.f = \cos\theta = \frac{E_{ac} + IR}{V} = \frac{155.62 + 1 \times 25}{220} = 0.821 \text{ lagg}$$

$P_m = E_{ac} I = 155.62 \times 1$

$= 155.62 W$

$$T = \frac{P_m}{W_m}$$

$$= \frac{155.62}{2\pi \times \frac{1955}{60}}$$

At start $E = 0$

$$Z = \sqrt{(25)^2 + (125.6)^2} = 128.6\ \Omega$$

$$I_s = \frac{V}{|Z|} = \frac{220}{128.16} = 1.716\ A$$

$$T_s = k\, I_s^2$$

$k = ?$

$$E_{dc} = k\, I_a\, W_{dc}$$

$$195 = k \times 1 \times 2\pi \times 2500/60$$

$$= 0.74487$$

$$T_s = 0.74487 \times (1.716)^2$$

$$= 2.193\ Nm$$