Three Phase Induction Motors

Output Equation of Induction Motor

The output equation of a.c. machines is:

KVA input $Q = C_0 D^2 L n_s$ …………. (1)

Where,

$C_0 = 1.1\ K_w\ B_{av}\ ac \times 10^{-3}$ ………… (2)

(Where, K_w = Winding factor = $K_c \times K_d$, B_{av} = Specific magnetic loading, ac = Specific electric loading)

D = Diameter of core

L = Length of core

n_s = speed in r.p.s. (rotation per second) =N/60

From equation (1), $D^2L = \frac{Q}{C_0\ n_s}$ …………(3)

KVA input (Q) = KW/ (η cosØ)

The KVA input (Q) in terms of horse power is given by:

$Q = \frac{\text{h.p.} \times 0.746}{\eta \cos\phi}$ ……………(4)

Choice of Average Flux Density (B_{av}) in Air gap

I. Power factor: The value of flux density in air gap should be small as otherwise the machine will draw a large magnetizing current giving a poor power factor. In induction motors, flux density in air gap should be such that there is no saturation in any part of the magnetic circuit.

II. Iron loss: If gap density (↑), iron losses (↑) and efficiency (↓).

III. Overload capacity: If flux density (↑), overload capacity (↑). A high value of flux density means flux per pole is large. Thus for the same voltage, the winding requires less turns per phase. If the number of turns is less, the leakage reactance becomes small. With small leakage reactance the circle diagram of machine has a large diameter which means that the maximum output which means the machine has large overload capacity. Thus, with the assumption of a higher value of B_{av}, we get higher value of overload capacity.

- For 50Hz machine of small design,
  B_{av} = 0.3 to 0.6 Wb/m^2

- For machines where a large overload capacity is required,
  B_{av} = 0.65 Wb/m^2

Choice of Ampere Conductors (ac) per Meter

I. Copper loss and temperature rise: If ac (↑), copper loss (↑) and Temperature (↑). A large value of ac means a greater amount of copper is employed in the machine. This results in higher copper losses and large temperature rise of embedded conductors.

II. Voltage: A small value of ac should be taken for high voltage machines as in their case the space required for insulation is large.

III. Overload capacity: If ac (↑), overload capacity (↓). A large value of ampere conductors would result in large number of turns per phase. This would mean that the leakage reactance of the machine becomes high. Due to this, diameter of circle diagram reduces resulting in reduced value of overload capacity. Therefore, the higher value of ac, the lower would be the overload capacity.

- The value of 'ac' varies between 5000 to 45000 ampere conductors per metre depending upon the factors listed above.

Main Dimensions

The product D^2L obtained from equation (3) is split up into its two components D and L. This separation can be done by using ratio L/τ. The ratio of core length to pole pitch (L/τ) for various design feature is:

- Minimum cost – 1.5 to 2
- Good power factor – 1.0 to 1.25
- Good efficiency – 1.5
- Good overall design – 1
- For best power factor,

$$\tau = \sqrt{0.18L}$$

(Note: The relationship is valid for values of τ and L expressed in metre.)

- The value of L/τ lies between 0.6 and 2 depending upon the size of machine.

Peripheral speed:

- Standard construction – up to 60m/s
- Special rotor construction – up to 75m/s

For a normal design, the diameter should be so chosen that the peripheral speed does not exceed about 30m/s.

Ventilating Ducts: The stator is provided with radial ventilating ducts if the core length exceeds 100 to 125 mm. The width of each duct is about 8 to 10 mm.

Turns per Phase

Flux per pole $\varnothing_m = B_{av} \times A/p$

$= B_{av} \times (\pi DL/p)$

$= B_{av} \times \tau L$ (Because, $\tau = \pi D/P$)

Where, B_{av} = specific magnetic loading

A = area = πDL

P = no. of poles

τ = pole pitch

Stator voltage per phase $E_{ph} = 4.44\, f\, \varnothing_m\, T_{ph}\, K_w$

Where, f = frequency inn Hz

$\varnothing_m$ = flux per pole

T_{ph} = no. of turns per phase in stator

K_w = winding factor = $K_c \times K_d$ = 0.955 (assumed)

$$\therefore \text{ Stator turns per phase } T_{ph} = \frac{E_{ph}}{4.44\, f\, \varnothing_m\, K_w}$$

Stator Conductors

(The current density (δ) in the stator winding is usually between 3 to 5 A/m^2).

Stator current per phase $I_{ph} = Q / (3 \times E_{ph})$

Therefore, area of each stator conductor $a = I_{ph} \times \delta$

Where, δ = current density in stator conductors

Shape of Stator Slots

The slots may be,

I. Completely open slots (slot opening = width of slot)
II. Semi-enclosed

In open slot, winding coils can be formed and insulated completely before they are inserted in the slots. Where in case of semi-enclosed slots, windings must be taped and insulated after placed in the slots.

If size of motor (↓), then diameter (↓), therefore semi-enclosed slots are used to provide more no. of slots.

If size of motor (↑), then diameter (↑), therefore open slots can be used.

Number of Stator Slots

Following factors should be considered while selecting the number of stator slots:

I. <u>Tooth pulsation loss:</u> In motors with open type slots, slot opening effects on air gap reluctance. The slots should be so proportioned that minimum variations in the air gap reluctance are produced which results in tooth pulsation losses and noise. This effects can be minimized by using large no. of narrow slots.

II. <u>Leakage Reactance:</u> If No. of slots (↑), Leakage reactance (↓). If no. of slots are more, then large no. of slots are required to insulate and therefore width of the insulation becomes more. This means that, leakage reactance has longer path through air and due to this leakage flux reduces. Due to the reduction of leakage flux, leakage reactance also reduces.

III. <u>Overload capacity:</u> If no. of slots (↑), overload capacity (↑). If no. of slots are more, then leakage reactance reduces. With small values of leakage reactance the diameter of circle diagram is large and hence the overload capacity increases.

IV. <u>Ventilation:</u> If no. of slots are larger for a given diameter, the smaller will be the slot pitch. If the slot pitch is small, the tooth width is also small. Due to this thickness of teeth becomes smaller and the teeth may become mechanically weak and they may have to be supported by radial ventilating ducts.

V. <u>Magnetizing current and iron loss:</u> If no. of slots (↑), magnetizing current and iron loss (↑). If no. of slots is larger than teeth section is reduced. Therefore the use of larger no. of slots may result in excessive flux density in teeth giving rise to higher magnetizing current and higher iron loss.

VI. <u>Cost:</u> (↑). With larger no. of slots there are larger no. of coils to wind, insulate and install involving higher costs.

(Note: It is good to use as many slots as economically possible. No. of slots per pole per phase q, should not be less than 2 otherwise the leakage reactance becomes high.)

Stator Slot Pitch

The stator slot pitch is, $Y_{sg} = \dfrac{\text{gap surface}}{\text{Total no. of stator slots}}$

$$\therefore \quad Y_{sg} = \pi D / S_g$$

Where, S = total number of stator slots

(Slots/ pole/ phase should be an integral number.)

- Slot pitch for open type slots = 15 to 20 m
- Slot pitch for Semi-enclosed type slots = < 15mm

Total number of conductors

Total no. of stator conductors = $3 \times 2T_g = 6T_g$

$\therefore$ Conductors per stator slot $Z_{sg} = 6T_g / S_g$

(The no. of conductors per slot must be an even integer for double layer winding.)

Area of Stator Slots

When the no, of conductors per slot has been obtained, an approximate area of slot can be calculated.

$$\text{Approximate area of each slot} = \frac{\text{copper area per slot}}{\text{Space factor}}$$

$$= \frac{Z_{sg} \times a_g}{\text{Space factor}} \qquad \text{................(5)}$$

Space factor = 0.25 to 0.4

From area of slot, dimensions of slots can be adjusted.

Slot width = tooth width (approximately)

(The width of the slots should be so adjusted such that mean flux density in tooth lies between 1.3 to 1.7 Wb/m^2. Ratio of slot depth to slot width = 3 to 6.)

Length of Mean Turn

Length of mean turn of stator $L_{mt} = 2L + 2.3\tau + 0.24$ ....(6)

(Note: Values of L and τ should be expressed in metre (m).)

Stator Teeth

The dimensions of the slot determines the value of flux density in the teeth. A high value of flux density is not desirable as it leads to higher iron loss and greater magnetizing mmf.

The mean flux density in stator teeth should not exceed 1.7 Wb/m^2.

$$\therefore \quad \text{Minimum tooth area per pole} = \text{Ø}_m / 1.7$$

Tooth area per pole = no. of slots per pole × net iron length × width of tooth

$$= (S_s / P) \times Li \times W_{ts}$$

Or minimum width of stator tooth

$$(W_{ts})_{min} = \frac{\text{Ø}_m}{1.7 \times (S_s / P) \times L_i} \qquad \text{...................(7)}$$

Stator Core

- The flux density in core should not exceed about 1.5 Wb/m^2.
- Flux density in core = 1.2 to 1.4 Wb/m^2

Flux in the stator core = $\phi_m / 2$

$$\therefore \text{ Area of stator core} = \frac{\text{flux through core}}{\text{Flux density in stator core}} = \frac{\phi_m}{2 \times B_{cs}}$$

Area of stator core = $L_i \times d_{cs}$

Where, L_i = net iron length

d_{cs} = depth of stator core

Thus, $$L_i \times d_{cs} = \frac{\phi_m}{2 \times B_{cs}}$$

$$d_{cs} = \frac{\phi_m}{2B_{cs} \times L_i} \qquad \text{………………(8)}$$

The outside diameter of stator laminations

D_o = D + 2(depth of stator slots + depth of core)

$= D + 2d_{ss} + 2d_{cs}$ ………………(9)