Induction Machine Design

Design of a three-phase induction motor 0.25KW and 1380rev/min, 415v, 50hz three-phase and four poles. This machine is intended to be sold in a highly competitive market and in addition, insulation class F is considered for its insulation.

Main dimensions

Speed

n = N(rev/min)/60 = 1380/ 60 = 23 rev/s

output power

.25 /23 ×103 10.86= kw output/n ×103

For small motors, the specific electrical loading is usually between 8000 and 25000 conductor amperes per meter. Higher values are used for motors designed to operate in submerged conditions. Given the value of B_av, the specific magnetic loading and ac, the specific electrical loading and output are obtained:

B_{av}= .5T

ac = 22000 $(Ampere\ Conductor)\ /\ m$

Number of Poles

The number of poles can be easily expressed in terms of synchronous speed and supply frequency as follows:

$$P = {}^{2f}/_{n_s} = {}^{2*50}/_{23} = 4.34$$

$$Q[KVA] = \frac{P_0\ [KW]}{\eta\ \cos\phi} = \frac{0.25}{0.7*0.7} = 0.51\ KVA$$

To start the calculations, we can assume the distribution factor for three-phase motors to be 0.955 (equal to 3 slots per pole for each phase), and the step factor to be unity.

The winding factor will be determined when the stator (primary) winding is designed. Initial values for efficiency and power factor can be obtained from the corresponding table, which shows typical values for mains-fed motors.

The initial value for the winding factor is taken to be .955. The output factor is:

$$=\mathbf{1.11}\boldsymbol{\pi}^{\mathbf{2}}\ \boldsymbol{B_{av}}\ \boldsymbol{ac}\ \boldsymbol{K_W}\ \mathbf{10^{-3}}\ =\mathbf{1.11}\boldsymbol{\pi}^{\mathbf{2}}\ *\mathbf{0.5}\ *\mathbf{22000}\ *\mathbf{0.955}\ *\mathbf{10^{-3}}=\mathbf{115}\boldsymbol{C_0}$$

The active volume is equal to:

$$\boldsymbol{Q = c_0 D^2 L\ n_s}$$

$$\boldsymbol{D^2 L} = \frac{\boldsymbol{Q}}{\boldsymbol{c_0\ n_s}} = \frac{\mathbf{0.51}}{\mathbf{115*25}} = \mathbf{1.77} *\ \mathbf{10^{-2}}\boldsymbol{m^3}$$

Assuming that the ratio of the length to the diameter of the core is 1, we have:

D = L

D =55 mm **L =58 mm**

The average flux in each pole is equal to:

$$\emptyset = \mathbf{0.5} * \mathbf{0.0551} * \mathbf{0.043} = \mathbf{1.18}\ \mathbf{mwb}$$

The voltage induced in the armature winding is equal to:

$\boldsymbol{E_S}$= 4/ 44 f Ø $\boldsymbol{T_S K_{WS}}$

Es=0.97*415/$\sqrt{\mathbf{3}}$ =232.4

The induced voltage in each phase can be taken to be equal to the terminal phase voltage minus the product of the magnetizing current and the stator leakage reactance. Initially, it can be assumed to be 0.97 of the terminal phase voltage.

The number of turns in each stator phase is:

$$\boldsymbol{T_S} = \frac{\mathbf{232.4}}{\mathbf{4.44*50*1.18*10^{-3}*0.966}} = \mathbf{918}$$

Stator design

Due to the small diameter, we choose 2 slots for each pole in each phase. With q=2, the number of stator slots will be 24.

A single layer toroidal winding is used and the pitch of the winding is 5 slots.

Now, the number of stator turns must be corrected to give the correct number of conductors per slot:

With 230 conductors per slot, the required turns per phase will be 920.

The flux per pole becomes 1.22 mwb.

The average air gap flux density remains approximately constant at 0.4T.

The stator phase current is given by:

$$I_S = \frac{P_0 * 10^3}{3\, V_{ph}\, \cos\emptyset\, \eta} = \frac{0.51 * 10^3}{3 * 240} = \mathbf{0.7\ A}$$

We can achieve much higher current densities than those used in air-cooled motors.

The current density in the stator winding of a standard induction motor can be considered between 3 and , A/〖mm〗^26.

Assuming a stator current density of , the cross-sectional area of the conductor will be equal to:

$$a_s = \frac{I_{ZS}}{\delta_S} = \frac{0.7}{6.0} = \mathbf{0.118\ mm^2}$$

The required conductor diameter is .39 mm. Therefore, we use a standard copper wire with a diameter of 0.4 mm, whose cross-sectional area is 0.1257〖mm〗^2.

The approximate length of the average turn for a single-layer winding can be determined from the following formula:

$$L_{mts} = 2L + \frac{2}{3}\tau = 2 * 0.058 + \frac{2}{3} * 0.43 = \mathbf{0.215\ m}$$

The stator resistance is equal to:

$$r_s = \frac{\rho\, T_S\, L_{mts}}{a_s * 10^{-6}} = \frac{1.8 * 10^{-8} * 920 * 0.215}{0.1257 * 10^{-6}} = \mathbf{28.4\ \Omega}$$

The flux density of the stator teeth is equal to:

$$B_{ts} = \frac{1.22 * 10^{-2}}{6 * 0.0551 * 32.3 * 10^{-3}} = \mathbf{1.23\ T}$$

Rotor design

The rotor diameter is:

Dr = D -2Ig = 55 – 2 * 0.25 = 54.5 mm

If we consider the number of rotor slots to be 30% less than the number of stator slots, we will need 8/16 slots. So, on the basis of calculations, 17 rotor slots is perfectly acceptable. The number of 24 stator slots and 17 rotor slots fulfills the criteria discussed in Section 5.3.6 above. This slot combination is available from K & S sheets and the details of the sheet and stator are given in Table 5.3.

Therefore:

$S_s = 24$, $S_r = 17$

Details of stator and rotor sheets				
O/D (mm)	I/D (mm)	A_s (mm²)	W_t (mm)	
99/78	55/..	72/60	3/00	Stator
54/50	18/..	27/70	3/90	Rotor

The area of each rotor bar is 27.7 mm2 and the area of 17 bars is about 471 mm2. By finding the ratio of the total rotor conductor area to the stator copper area, one can comment on whether the bar area is acceptable or not. In principle, a value between 0.5 and 0.8 results in a satisfactory and acceptable design. The total stator copper area (5520 conductor cross-sectional area) is about 693 mm2. Therefore:

$$\frac{A_{ct}}{A_{cs}} = \frac{471}{693} = 0.68$$

Which is acceptable.

Next, we test the current density in the rotor bars. The rotor bar current is equal to:

$$I_b = \frac{2m_s K_{ws} T_s}{S_r}\ I_s \cos\phi = \frac{2*3*0.933*920}{17} * 0.73 * 0.7\ = 154.9\ A$$

And the current density is about 6.5 A/mm2, which is quite acceptable.

Before the final acceptance of this rotor sheet, it is necessary to test the values of the core flux density and rotor tooth. The tooth width is 3.9 mm and the tooth flux density is equal to:

$$\text{Btr} = \frac{1.22 * 10^{-3}}{17.4 * 0.0551 * 3.9 * 10^{-3}} = 1.34\ T$$

The rotor core depth is 11.8 mm and the core density is about 0.9 T. Therefore, both the core and rotor tooth densities are acceptable.

The end-loop current is calculated from equation (5-28) as follows:

$$I_{er} = \frac{154.9*17}{\pi * 4} = 209.5\ A$$

Assuming the current density in the end ring to be 6.5 mm2 / A (equal to the current density of the rod), the cross-sectional area of each end ring is 4.37 mm2. The outer diameter of the end ring must be smaller than the rotor diameter. Suppose the end ring diameter is 53 mm, its radial thickness is 8 mm, and its axial length is 10 mm. The area of the end ring will be 80 mm2, which is about twice the area required to obtain the current density of 6.5 mm2 / A. These dimensions will be more suitable for construction. The end current density will be only about 6.2 mm2 / A. The rotor will be cast using aluminum. The average diameter of the end ring is 49 mm. The end ring coefficient is obtained from Figure 5-11, which is 0.95. The cage winding resistance in each phase referred to the stator is calculated using equation (5-33) as follows:

$$\boldsymbol{r' = 12 * 920^2 * 0.933^2 * 2.7 * 10^{-2}\left[\frac{0.058}{17*27.7} + \frac{2*0.049*0.95}{\pi*16*80}\right] = 34.9\ \Omega}$$

No-load current:

The method for calculating the ampere-turns required per pole to pass flux through the magnetic circuit is given in Appendix 3. Magnetization information for the current design is given in Table 5-4.

The magnetizing current is equal to:

$$\boldsymbol{I_m = \frac{0.427*4*211.1}{920*0.933} = 0.42\ A}$$