DESIGN OF ELECTRICAL APPARATUS

UNIT-3.

1. Calculate the diameter and length of armature for a 7.5kW 4 pole 1000 rpm 220V shunt motor.
Given: Full load efficiency = 0.83; Maximum gap flux density = 0.9 wb/m²; Specific electric loading = 30,000 ampere conductors per metre; field form factor = 0.7. assume that the maximum efficiency occurs at full load and the field current is 2.5 percent of rated current. The pole face is square.

Solution:-

$$\text{Power input} = \frac{P}{\eta} = \frac{7500}{0.83} = 9040\,W.$$

$$\text{Total Losses at full load} = 9040 - 7500$$
$$= 1540\,W$$

Since the maximum efficiency occurs at full load, the constant losses and armature losses are equal at full load

$$\therefore \text{Constant losses} = \frac{1540}{2} = 770\,W$$

$$\text{Motor current at full load} = \frac{7500}{0.83 \times 220} = 41.1\,A$$

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Field current $= 0.025 \times 41.1 = 1.03A$

Field I^2R loss $= 220 \times 1.03 = 227W$

~~Hence, power~~ $\therefore$ Friction and windage plus iron loss $\Big\} = 770 - 227 = 543W$

Hence, power developed by armature $P_a = 7.5 + 0.543$

$P_a = 8.1KW$

Average gap density $B_{av} = k_f B_g = 0.7 \times 0.9$

$= 0.63 \, wb/m^2$

output coefficient $C_0 = \pi^2 \times 0.63 \times 30,000 \times 10^{-3}$

$= 186.5$

Speed $\eta = \frac{1000}{60} = 16.67 \, r.p.s$

$$D^2L = \frac{P_a}{C_0 n} = \frac{8.1}{186.3 \times 16.67} = 2.6 \times 10^{-3} m^3$$

For a square pole face $\frac{L}{\psi \tau} = 1$

$$L = \frac{0.7 \times \pi D}{4} = 0.55D \, (\text{taking } \psi = k_f)$$

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$\therefore 0.55D^3 = 2.61 \times 10^{-3}$

$D = 0.17m$ and $L = 0.09m$

2. A design is required for 50kW, 4pole, 600rpm DC shunt generator, The full load Terminal voltage being 220V, if the maximum gap density is 0.83Wb/m3 and the armature ampere conductor/m = 30,000. Calculate suitable dimension of armature case to given square pole phase. Assume that full load armature voltage drop is 3% of rated terminal voltage and the field current is 1%. of rated full load current. The ratio of pole arc to pole pitch is 0.67.

Given :.

$N = 600$ rpm

$ac = 30,000$

$P = 50kw$

$\frac{\text{pole arc}}{\text{pole pitch}} = 0.67$

$B_{av} = 0.83 \text{ wb/m}^3$

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Formulae:-

$$P_a = \pi^2 B_{av}\, ac \times 10^{-3} D^2 L n_s$$

Solution:-

i) $E = V + I_a R_a$

$$= 220 + \left[\frac{3}{100} \times 220\right]$$

$$\boxed{E = 226.6V}$$

ii) $I_L = \frac{P}{V} = \frac{50 \times 10^3}{220} = 227.27A$

iii) $I_a = I_L + I_F$

$$I_F = 227 \times \left(\frac{1}{100}\right) = 2.27$$

$I_a = \cancel{227.2742}\ 227.27 + 2.27 = 229.54A$

$I_a = 229$

$P_a = E I_a \times 10^{-3}$

$$= 226.6 \times 229 \times 10^{-3}$$

$$\boxed{P_a = 51.89\,kW}$$

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$P_a = \pi^2 B_{av} ac \times 10^{-3} D^2 L n_s$

$51.89 = \pi^2 \times 0.83 \times 30{,}000 \times 10^{-3} D^2 L \times 10$

$D^2 L = 0.021$

$\frac{\text{Core length}}{\text{pole arc}} = 1$, for square pole

$\frac{L}{\psi\tau} = 1$

$L = \psi \times \frac{\pi D}{P}$

$= 0.67 \times \frac{\pi D}{4}$

$\boxed{L = 0.52625 D}$

$D^2 [0.525 D] = 0.0211$

$D^3 = 0.0211 / 0.525$

$$\boxed{\begin{array}{l} D = 0.3423 m \\ L = 0.1801 m \end{array}}$$

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3. Determine the main dimensions number of poles and length of air gap of a 1000kW 500V 300 rpm DC shunt generator. Assume average flux density in the air gap is 1.0 wb/m² and ampere conductor per meter = 40,000. the pole arc to pole pitch ratio is 0.7 and the efficiency is 92%. The mmf required for the air gap 55% armature mmf and gap contraction factor is 1.15. peripheral speed should not exceed 30 m/sec, frequency of flux reversal should not exceed 50 Hz current per brush arm should not exceed 400 A

Given:

$P = 1000\,kW$

$V = 500\,V$

$N = 300\,rpm$

$B_{av} = 1$ Tesla $= 1\,wb/m^2$

$a_c = 400$ amp. cond/cm

$= 40000$ amp. cond./m.

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Solution:-

The choice of pole depend on the following factors

1. Frequency of flux reversals should be lie between 25HZ to 50HZ.

2. The current per brush arm should be exceed 400A.

3 For reduced cost the highest possible choice of poles should be chosen.

(Refer chapter 3 section 3.5 for the guiding factor for choice of number of poles)

speed in rps, $n = 300/60 =$ rps

If $p = 10$, $f = \frac{pn}{2} = \frac{10 \times 5}{2} = 25$ HZ

If $p = 20$, $f = \frac{pn}{2} = \frac{20 \times 5}{2} = 50$ HZ

Hence, choice of poles can be 10, 12, 14, 16, 18, 20

Armature current, $I_a = \frac{1000 \times 10^3}{500} = 2000$ amps

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For $P=10$, current/brush arm $= I_a/10 = 200$ amps

For $P=20$, current/brush arm $= I_a/20 = 100$ amps

For all choice of poles the current limit is not violated. (But for minimum cost we can choose the maximum number of poles.)

Let number of poles, $P=10$

for square pole face, $L/\tau = 0.7$

$$\frac{L}{\tau} = 0.7 \quad \& \quad \tau = \pi D/P$$

$$\therefore \frac{L}{\pi D/P} = 0.7$$

$$L = \frac{\pi D}{P} 0.7$$

$$L = \frac{\pi \times 0.7}{10} D$$

$$L = 0.2199 D$$

The power development in armature,

$$P_a = C_0 D^2 L n$$

output coefficient, $C_0 = \pi^2 B_{av}\, ac \times 10^{-3}$

Let the power output, $P \simeq P_a$,

$$\therefore P = \pi^2 B_{av}\, ac \times 10^{-3} D^2 L n$$

$$\therefore D^2 L = \frac{P}{\pi^2 B_{av}\, ac \times 10^{-3} n}$$

$$= \frac{1000}{\pi^2 \times 1 \times 40000 \times 10^{-3} \times 5}$$

$$= 0.5066 m^3$$

Put $\cancel{D^2}$ $L = 0.2199D$

$$\therefore D^2 L = D^2 (0.2199D)$$

$$= 0.5066 m^3 \quad \text{(or)} \quad 0.2199 D^3 = 0.5066$$

$$D = \left(\frac{0.5066}{0.2199}\right)^{1/3}$$

$$\boxed{D = 1.32 m}$$

$$L = 0.2199D = 0.2199 \times 1.32$$

$$\boxed{L = 0.29 m}$$

Result:-

The main dimensions are D and L

The diameter of armature, $D = 1.32$ m

The length of armature $L = 0.29$ m

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4. A 5 kW, 250V, 4 core, 1500 rpm shunt generator is design to have a square pole phase. The loading are avg. flux density in air gap = 0.42 wb/m², Ampere/conductor/m +5,000. Find the main dimension of the machine. Assume full load efficiency of 0.87 and ratio of pole arc to pole pitch 0.66

Given data:-

$N = 1500\,rpm$ $\quad$ $B_{av} = 0.42\,wb/m^2$

$\eta_{full} = 0.87$ $\quad$ pole pitch, $\psi = 0.66$

$P = 5\,kW$ $\quad$ $ac = 15,000\,ac/m$

Formula:-

$$P_a = \pi^2 B_{av}\, ac \times 10^{-3} D^2 L\, n_s$$

solution:-

$$P_a = \frac{P}{\eta} = \frac{5 \times 10^3}{0.87}$$

$$P_a = 5.75\,kW$$

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$N/60 = n_s$

$$n = \frac{1500}{60} = 25 \text{ rps}$$

$$P_a = \pi^2 \times 0.42 \times 15000 \times 10^{-3} \times D^2 L \times 25$$

$$5.75 = \pi^2 \times 0.42 \times 15000 \times 10^{-3} \times 25 \times D^2 L$$

$$D^2 L = 3.7 \times 10^{-3} m^2.$$

For a square pole phase

$$\frac{\text{Core length}}{\text{pole length}} = 1$$

$$\frac{L}{\psi \tau} = 1$$

$$L = \psi \times \frac{\pi D}{P}$$

$$= 0.66 \times \frac{\pi D}{4}$$

$$L = 0.518D$$

From (1) $\Rightarrow D^2 [0.518D] = 3.7 \times 10^{-3}$

$$D = 0.1926 m$$

From (2) $\Rightarrow L = 0.0997 m$

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Result:-

$D = 0.1926m$

$L = 0.0997m$

4. Explain the design procedure for the shunt field winding of D.C machine.

Procedure for shunt field design:-

Step1:- Determine the dimension of pole

Assume a suitable value of leakage coefficient from table 3.8 and flux density in the range 1.2 to 1.7 wb/m^2

Flux in the pole body, $\phi_p = C_t \phi$.

Area of pole body, $A_p = \frac{\phi_p}{B_p}$

For cylindrical pole,

Diameter of pole body, $d_p = \sqrt{\frac{4A_p}{\pi}}$

For rectangular pole,

Length of pole $L_p = L - (0.001 \text{ to } 0.015)$

Net iron length of pole, $L_{pi} = 0.9 L_p$

width of the pole, $b_p = \frac{A_p}{L_{pi}}$

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Step2:- Determine the length of mean turn of field coil. Assume a suitable depth of field winding from table 3.9

For Rectangular field coils,

Length of mean turn, $L_{mt} = 2(L_p + b_p + 2d_f)$

For cylindrical field coils

Length of mean turn, $L_{mt} = \pi(d_p + d_f)$

Step3:- Calculate the voltage accross-section ~~of field~~ each shunt field coil

Voltage across field coil, $E_f = \frac{(0.8 \text{ to } 0.85) \times V}{P}$

Step4:- Calculate the area of cross section of field conductor

Area of cross-section of field conductor,

$$a_f = \frac{\rho L_{mt} AT_{fl}}{E_f}$$

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Step 5: calculate the diameter of field conductor and copper space factor.

Diameter of field conductor, $d_{fc} = \sqrt{\frac{4a_f}{\pi}}$

Diameter of field conductor including insulation thickness } ~~d_{fc}~~ d_{fci}

$$d_{fci} = d_{fc} + \text{Thickness of insulation}$$

Copper space factor, $S_f = 0.75 \left(\frac{d_{fc}}{d_{fci}}\right)^2$

Step 6: Determine the number of turns (T_f) and Height of field coil (h_f)

They can be determine by solving the following two equation (3.72 & 3.75)

$$2L_{mt} q_f (h_f + d_f) = \frac{E_f^2 a_f}{\rho L_{mt} T_f}$$

$$T_f a_f = S_f h_f d_f$$

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Step 7:-

Calculate the resistance of the field coil and field current.

Resistance of field coil, $R_f = \frac{T_f \rho L_{mt}}{a_f}$

Field current, $I_f = \frac{E_f}{R_f}$

Step 8:-

Check for current density in field coil

Current Density in field coil, $\delta_f = \frac{I_f}{a_f}$

The current density should not exceed $3.5\ A/mm^2$

If it exceeds $3.5\ A/mm^2$, then increase a_f by 5% and repeat step 5 to 8 until δ_f is less than $3.5\ A/mm^2$.

Step 9:

Check for desired value of mmf.

Actual value of mmf, $AT_{actual} = I_f T_f$

The desired field mmf may be either specified in the problem or it may

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be taken as 1.1 to 1.25 times the armature mmf at full load. The actual value of mmf should be equal to or higher than desired value.

If the actual mmf is less than the desired value then increases the depth of field winding by 5% and repeat step 2 to step 9 until the desired m.m.f is achieved

Step 10:-

check for temperature rise

Actual copper losses $= I_f^2 R_f$

The surface area of field coil, $S = 2L_{mt}(h_f + d_f)$

Cooling coefficient, $C = \frac{0.14 \text{ to } 0.16}{1 + 0.1 V_a}$

where,

V_a = peripheral velocity of armature.

Temperature rise, $\theta_m = \frac{\text{Actual copper loss} \times C}{S}$

If temperature rise is within limits then the design is accepted. The allowable temperature rise depend on the class of insulation. If temperature rise exceed the limit then repeat the design by increasing the depth of field winding by 5%.

5. Derive the output equation of a d.c machine and point out its salient features.

The output equation of machine can be expressed in terms of its main dimension specific magnetic and electric loading and field

The equation which relates to power output to D, L, B_{av}, ac and of the machine is known as output equation

n is called as speed measured in rps.

The induced emf in armature

$$E = \frac{\phi Z N}{60} \cdot \frac{P}{a}$$

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$n = N/60$ $\quad E = \dfrac{\phi Z n P}{a}$ volts

In the armature of DC machine the conductor are connected in parallel path.

If "a" is no. of parallel path when the q went through each conductor is

Current through each conductor, $I_z = \dfrac{I_a}{a}$

specific magnetic loading, $B_{av} = \dfrac{P\phi}{\pi D L}$

specific electric loading, $ac = \dfrac{I_z Z}{\pi D}$

In a DC generator, the electrical power generator in the armature is given by the product of induced emf and armature current

$$P = E I_a \times 10^{-10}$$

$$= \frac{\phi Z n P}{a} a I_z \times 10^{-3}$$

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$$= \phi Z_n P I_z \times 10^{-3}$$

$$= (\phi P)(Z_n I_z \times 10^{-3})$$

$$= [B_{av}][\pi D L \cdot ac \times \pi D n \times 10^{-3}]$$

$$\boxed{P_a = \pi^2 B_{av} ac \times 10^{-3} D^2 L n}$$

$\pi^2 B_{av} ac \times 10^{-3}$ is called as o/p equation coefficient of DC machine and represented by "C_0"

$$\boxed{P_a = C_0 D^2 L n}$$

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