EE568- Project 4

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1 Literature Review

2 Analytical Modeling of IPM Machine

The aim of this study is to design a 1.3 MW traction motor. The initial specs of the machine is given in Table 2

Table 1: EML System Constants

Machine Output Power	1280 kW
Rated Speed	1500 rpm
Rated Voltage	1350 V_{l-l}
Number of Poles	6
Cooling Type	Forced Air Cooled

Since this machine is a traction motor having more than 1 MW of output power, this machine is most probably used in a heavy duty load carrier truck. Since the power output of fully electric EV are around 100-150 kW. Let us start the analysis by selecting a proper machine constant(C_{mech}), a specific magnetic loading ($\hat{B}$) and specific electrical loading ($\hat{A}$). C_{mech} is selected from Figure 1 as 270 kW/sm^3. Which is right in the middle of the curve at 110$kW/pole$

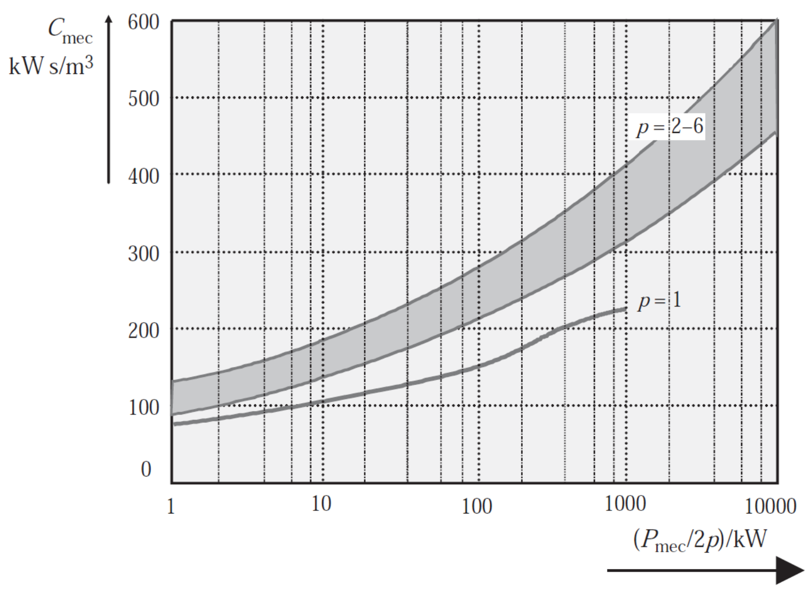

Figure 1: Machine constant-power per pole curve

Specific magnetic loading is given in Eq. 1 and was selected as 0.8 T as initial value. This selection was performed using the rule of thumbs given in the lecture slides. These values also be found in Pyronen.

$$\hat{B} = \frac{p\Phi_p}{\pi D_i L} = 0.8\ T \tag{1}$$

Therefore the specific electrical loading is found as 71.91 from the Eq. 2. k_w is taken as 0.933.

$$C_{mech} = \frac{\pi^2}{2} k_w \hat{A}\hat{B} \tag{2}$$

The next topic is to determine the rotor diameter. Using typical aspect ratio in Eq. 3, the rotor diameter can be found in Eq. 4.

$$X = \frac{\pi}{4p}\sqrt{p} = \frac{L'}{D_i} = 0.4534 \tag{3}$$

$$D_i = \sqrt[3]{\frac{P_{mech}}{XC_{mech}f}} = 490\ mm \tag{4}$$

The frequency is found to be 75 Hz, since we have 6 poles and 1500 rpm.
Hence the axial length L' can be calculated as 222 mm.
Next, is the calculation of airgap. The airgap calculation can be found in Eq. 5. The multiplication of 1.6 is due to the fact that the machine is a heavy duty machine.

$$l_{airgap} = 1.6(0.18+0.006P^{0.4}) = 1.6(0.18+0.006x1300000^{0.4}) = 2.966\ mm \tag{5}$$

The next subject, is selection of number of stator slots. According to, emetor winding calculator, 6 pole-54 slot with a double layer configuration has a $k_w = 0.945$ and the 3rd and 5th harmonics are nearly eliminated. Although, the reasoning for selection of number of stator slot is missing at this point, actually it was selected iteratively. The stator slot number selection will make more sense as the analytical design continues.
In Table 1, the rated voltage is given as $1350V_{l-l}$. A Δ configuration is used. Therefore, the number of turns per phase can be calculated as in Eq. 6.

$$V_{emf} = 1350V = 4.44fk_w N_{ph}\Phi_p \tag{6}$$

From Eq. 6, the number of turns per phase (N_{ph}) is calculated as 72 turns resulting in 8 turns per slot.
At this point we are ready to determine the slot dimensions and back core thickness. Since the airgap is known the slot inner diameter (D_{si}) is 496 mm. This machine is for a heavy duty truck and hence easy repair and manufacturing is key. Therefore, parallel slot is chosen resulting in a slot ratio$d = 0.5$. The outer diameter of the slot (D_{so})is calculated as in Eq. 7.

$$D_{so} = \frac{0.490\ mm}{0.5} = 980\ mm \tag{7}$$

Hence, the slot height can be calculated as in Eq. 8.

$$h_{slot} = \frac{D_{so} - D_{si}}{2} = 248\ mm \tag{8}$$

Now, let us find the slot thickness. Initially, take assume half of the circumference is the slot. Hence average width of trapezoidal slot can be found as in Eq. 9.

$$w_{slot,avg} = \frac{\pi(D_{si} + D_{so})}{2} \frac{1}{2x54} = 14\ mm \tag{9}$$

Hence, the slot area can be calculated as in Eq. 10.

$$A_{slot} = w_{slot,avg} h_{slot} = 14x248 = 3742\ mm^2 \tag{10}$$

The next arising question is that whether we can fit the coils in the slot. To calculate we need to choose a AWG wire.
The phase current can be found from Eq. 11.

$$P_{mech} = 3V_{phase} I_{phase} \tag{11}$$

From Eq. 11 I_{phase} can be found as 555A. By choosing a current density $J = 5A/mm^2$, the required coil area can be found as 111 mm^2. Thefore, 2 parallel strands of AWG0(53 mm^2) can carry the necessary current. Moreover, assuming a fill factor of 0.4, the slot area is bigger than the copper area. The calculation is given in Eq. 12.

$$A_{copper} = 8 * 111 = 888 mm^2 < A_{slot} * k_{fill} = 1388\ mm^2 \tag{12}$$

Therefore, the coppers can fit into the slot. We can also decrease the slot width further more in order to enhance the both the heat conduction and reduce the teeth magnetic field density. A down-side is the increases iron mass.
The final geometric unknown parameter is the back-core thickness. The back core thickness is calculated such that the maximum B is 1 T. The back-core thickness calculation can be found in Eq. 13 where $k_{stacking}$ is taken as 0.95 and the back-core thickness is denoted as h_{ys}.

$$B = \frac{\Phi_{pole}}{2k_{stacking} L' h_{ys}} = 1\ T \tag{13}$$

Using Eq. 12, h_{ys} can be found as 10 cm.
At this stage all required geometric parameters are known. The inital results are listed in Table 2.

Table 2: EML System Constants

D_{rotor}	490 mm
Air gap	2.96 mm
D_{si}	496 mm
D_{so}	980 mm
h_{slot}	248 mm
w_{slot}	14 mm
h_{ys}	100 mm
N_{ph}	54 turns
N_{slot}	8 turns
Number of Pole	6
Number of Stator Slot	54
Layer configuration	Double Layer
Coil Span	8 slots
$\hat{B}$	0.8 T
$\hat{B}$	0.8 T

3 Conclusion

References