EE568 Project 3 - PM Motor Comparison Analysis

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1 Introduction

In this project, we will examined some stuff.

2 Question 1 - Magnetic Loading

2.1 Part - a

Flux path for one pole pair is provided in Figure 1 and the corresponding equivalent magnetic circuit is provided in Figure 2. In this part, the permeability of the rotor and stator are assumed to be infinite. Therefore, the reluctance of core material becomes zero. Another assumption can be made as that there is no fringing or leakage flux and flux lines are straight as shown in Figure 1 with green lines.
The machine parameters are as follows:

- Number Of Poles: 4

- Motor Axial Length: 100 mm

- Air Gap Clearance: 1 mm

- Magnet To Pole Pitch Ratio: 0.8

- Rotor Diameter: 100 mm

- Magnet Thickness: 4 mm

- Magnet Type: NdFeB N42 grade (ur=1.05), radial shaped

With the assumptions made, the reluctance R_{m1} and R_{m2} in Figure 1 can be calculated as:

$$A_{pole} = \frac{\pi \, D_i \, L_{axial}}{P} = 0.007853 \, \text{m}^2 \tag{1}$$

where P is the number of poles.

From the magnet to pole pitch ratio value of 0.8 (shown as K in (2)), the magnet area per pole can be calculated.

$$A_{magnetperpole} = A_{pole} \cdot K = 0.006283 \, \text{m}^2 \tag{2}$$

$$A_{nonmagnetperpole} = (1 - K) \cdot A_{pole} = 0.00157 \, \text{m}^2 \tag{3}$$

$$R_{m1} = R_{m2} = \frac{H_{magnet}}{A_{magnetperpole} \cdot \mu_0 \cdot \mu_r} = 482480 \, \frac{1}{\text{Henry}} \tag{4}$$

$$R_{ag1} = R_{ag2} = \frac{H_{airgap}}{A_{magnetperpole} \cdot \mu_0} = 126650 \, \frac{1}{\text{Henry}} \tag{5}$$

$$\mathcal{F}_{permagnet} = A_{magnetperpole} \cdot B_{residual} \cdot R_{m1} = 4001.61 \, \text{Amperes} \tag{6}$$

Assuming that the core is infinitely permeable, loop equation of the equivalent circuit (see Fig.2) results in (7).

$$\phi_m = \frac{2 \cdot \mathcal{F}_{permagnet}}{R_{m1} + R_{m2} + R_{ag1} + R_{ag2}} = 6.57 \, \text{mWeber} \tag{7}$$

$$B_m = \frac{\phi_m}{A_{magnetperpole}} = 1.0455 \, \text{Tesla} \tag{8}$$

However, the FEA simulations gave a peak flux density value of 1.0174 T while the analytical calculations are 1.0455 T. The difference is due to the leakage flux.

From the values found in (8), the magnetic field strength value is provided in (9).

$$H_m = \frac{B_m - B_{residual}}{\mu_r \cdot \mu_0} = -208004.48 \; \frac{\text{A}}{\text{m}} \tag{9}$$

As stated in [1], the coercivity value for a N42 NdFeB magnet is around $\mathbf{955 \; \frac{kA}{m}}$

2.2 Part - b

The magnetic loading of the machine is given in (10)

$$\bar{B} = \frac{P \; \phi_m}{\pi \; D_i \; L_{axial}} = 0.8364 \; \text{Tesla} \tag{10}$$

2.3 Part - c

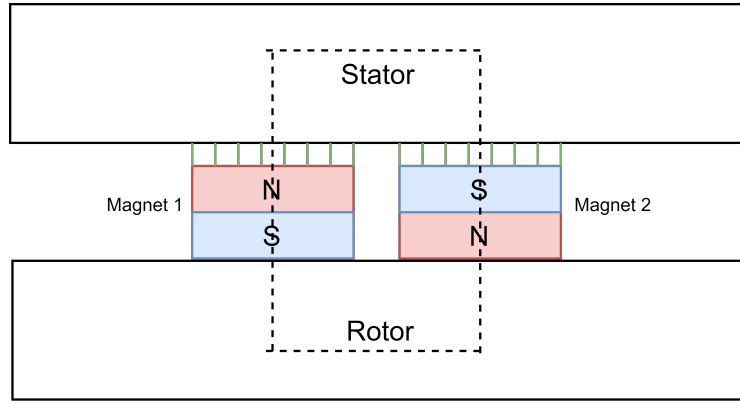The FEA results are provided in Figure 4.
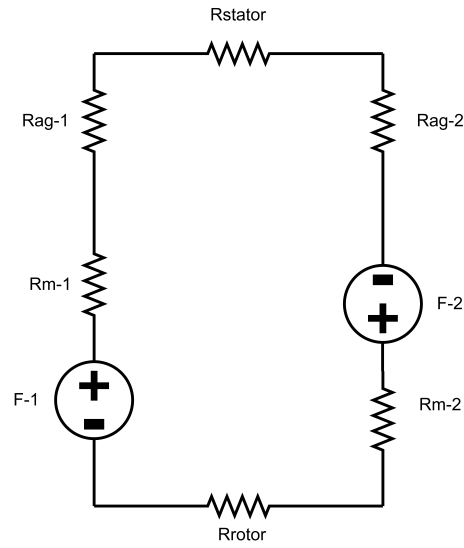

Figure 1: Flux Path Through a Pole Pair

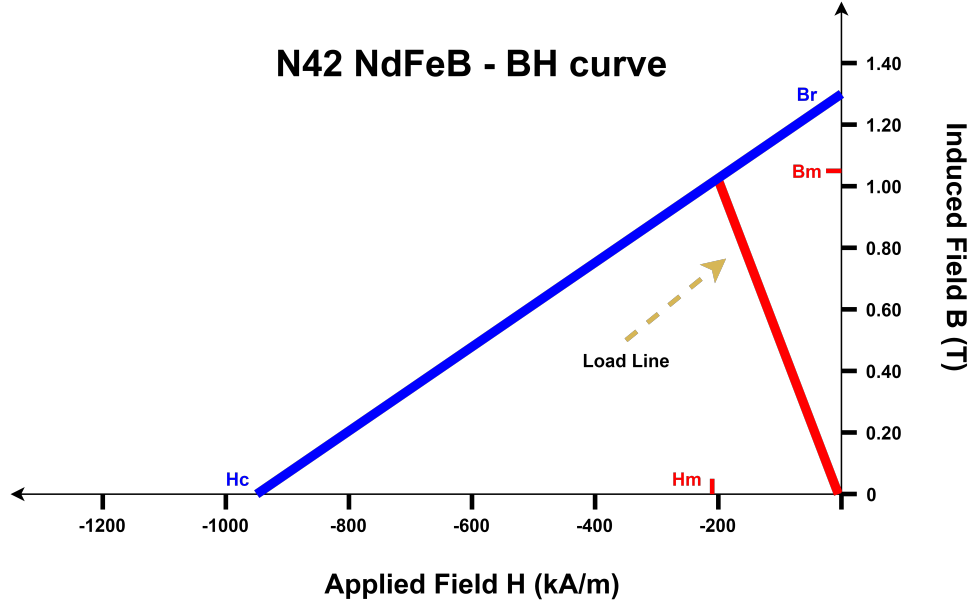Figure 2: Magnetic Equivalent Circuit

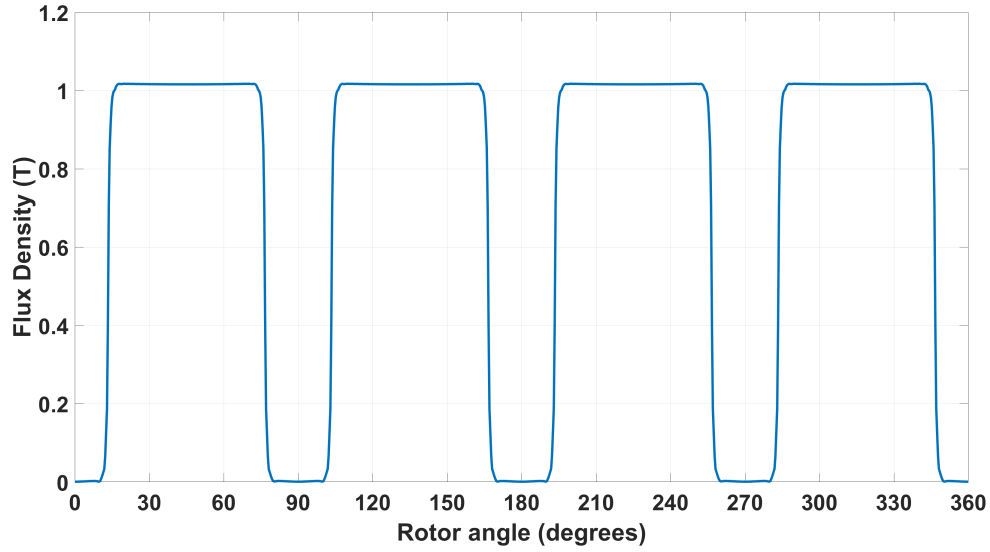Figure 3: N42 NdFeB - BH curve with load line

Figure 4: Magnetic Flux Density Magnitude

3 Question 2 - Electrical Loading and Machine Sizing

3.1 Part - a

The number of slots are chosen to be 36, which gives out a reasonable slot width value of 4.363 mm as calculated in (11). Moreover the distribution factors for the chosen number of slots are listed in Table 1. The winding factors for the harmonic could be reduced using a different number of slots, which is out of the scope of this study.

$$W_{Slot} = \frac{\pi \cdot D_i}{2 \cdot N_{slot}} = 4.363 \, \text{mm} \tag{11}$$

Table 1: Winding Factors for the chosen slots

Harmonic order:	First	Third	Fifth
kd	0.96	0.64	0.192
kp	1	−1	1
kw	0.96	−0.64	0.192

3.2 Part - b

For 2.5 A_{rms} current and 5 $\frac{A}{mm^2}$ current density, the required wire area is calculated in (12). For the calculated copper wire area, AWG20 cable is chosen whose area and diameter are 0.518 mm^2 0.406 mm respectively.

$$A_{wire} = \frac{2.5 \text{ A}_{rms}}{5 \frac{A}{mm^2}} = 0.5 \text{ mm}^2 \tag{12}$$

3.3 Part - c

It is known that the optimal torque value is obtained when slot ratio value is $\frac{1}{\sqrt{3}}$. Therefore, the slot ratio is chosen as 0.6. Considering the slot ratio, The slot-end diameter and the height of the slots are calculated in (14).

The back core thickness is chosen for a peak flux density value of 1.5 Tesla. The resultant stator outer diameter is provided in (16).

$$D_{SlotEnd} = \frac{D_i}{\text{Slot Ratio}} = 166.67 \text{ mm}; \tag{13}$$

$$H_{Slot} = \frac{D_{slotend} - D_i}{2} = 33.33 \text{ mm} \tag{14}$$

$$H_{BackCore} = \frac{\phi_{pp}}{\hat{B}_{airgap} \cdot L_{axial}} = 42.6 \text{ mm} \tag{15}$$

$$D_o = D_{slotend} + 2 \cdot H_{backcore} = 251.9 \text{ mm} \tag{16}$$

3.4 Part - d

In order to calculate the electrical loading, number of turns per slot must be calculated. To calculate the number of turns, fill factor value is chosen as **0.5**. Note that, the fill factor is chosen relatively low for thermal consideration but may need further iteration. The calculation of the number of turns is provided in 17.

$$N_{turn} = \frac{H_{slot} \cdot W_{slot} \cdot FillFactor}{A_{AWG20}} \approx 141 \frac{\text{turns}}{\text{slot}} \tag{17}$$

The electrical loading of the machine is provided in 18. The current value was stated as 2.5 A_{rms}.

$$A_{rms} = \frac{N_{turn} \cdot I_{rms} \cdot N_{slot}}{\pi \cdot D_i} = 40393.52 \frac{A}{m} \tag{18}$$

The obtained $40.4 \frac{kA}{m}$ value is in the reasonable range which is between $35 - 65 \frac{kA}{m}$.

3.5 Part - e

The peak airgap flux density is found as 1.0174 T from the FEA results. The resultant average tangential stress and total force are provided in (19) and (20) respectively.

$$\sigma_{tan} = \frac{A_{rms} \cdot \hat{B} \cdot cos(\phi)}{\sqrt{2}} = 29059.81 \text{ Pa} \tag{19}$$

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$$F = \sigma_{tan} \cdot \pi \cdot D_i \cdot \mathrm{L}_{axial} = 912.94 \, \text{Newton} \tag{20}$$

$$T = \frac{F \cdot D_i}{2} = 45.65 \, \text{Nm} \tag{21}$$

3.6   Part - f

At a rated speed of 1500 rpm, the power of the machine can be calculated in (22).

$$P = T \cdot \omega = 7.17 \, \text{kW} \tag{22}$$

References

[1] e magnetsuk. Grades of Neodymium, 2020.