**METU – EEE**

Middle East Technical University – Electrical Electronics Engineering Department

**PROJECT REPORT**

*by* Serhat ÖZKÜÇÜK

within the scope of the course

**EE568**

**SELECTED TOPICS ON ELECTRICAL MACHINES**

*by* Dr. Ozan KEYSAN

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**PROJECT NAME** : PM Motor Comparison Analysis

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Introduction

In this report, we examine the PM motor design. In the design process there are several design parameters that can be determined by designer with respect to some limitations such as machine dimensions, magnetic and electrical loading, cooling etc. The purpose of this project is design with considering these trades off and obtain the optimum design with respect to given specifications.

Constant specifications:

Number of phases: 3

Number of poles: 4

Motor Axial Length: 100 mm

Air-gap clearance: 1 mm

Magnet to Pole Pitch Ratio: 0.8

1. Magnetic Loading

In this part we are going to design a NdFeB magnet machine with the following parameters:

* Magnet Type: NdFeB N42 grade (ur=1.05), radial shaped
* Rotor Diameter: 100 mm
* Magnet Radial Thickness: 4 mm

**a) Magnetic equivalent circuit, load line and operating point on the B-H characteristics, peak air-gap flux density.**

The machine has 4 pole so it contains 2 permanent magnet as shown in fig.1. Also, equivalent magnetic circuit is given in fig.2.

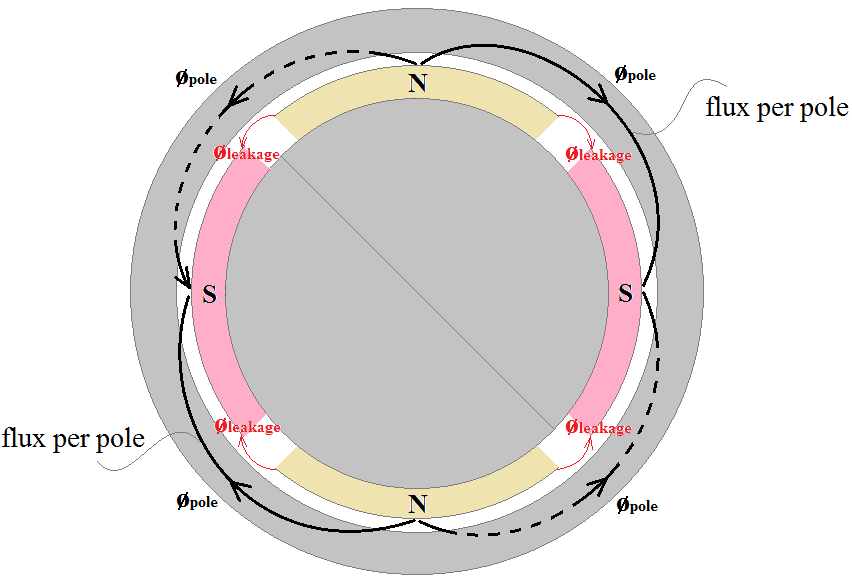


Fig.1: Solid stator machine representation

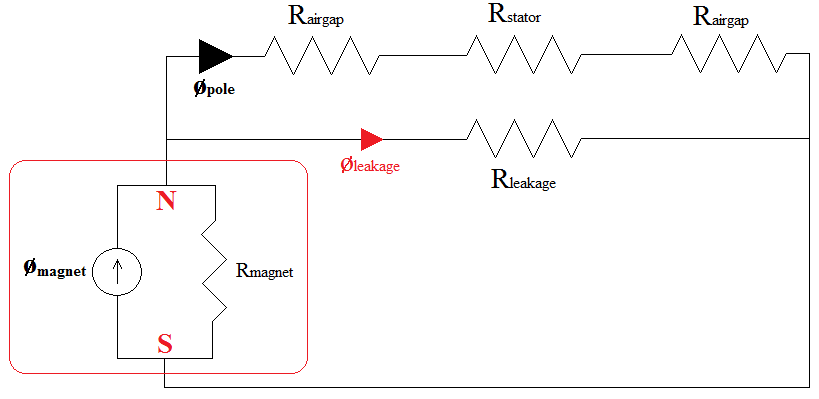


Fig.2: Equivalent magnetic circuit for one pole pairs

To calculate the peak air-gap flux density we have to know the load line and magnet operating point on the B-H characteristic. For this calculation, we determine the magnet geometry on the rotor as shown in figure 3.

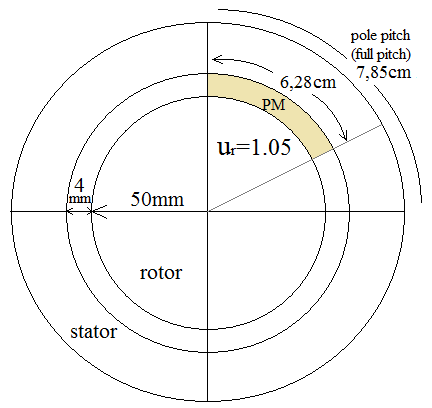


Fig.3: Magnet physical geometry on the rotor with respect to given specifications

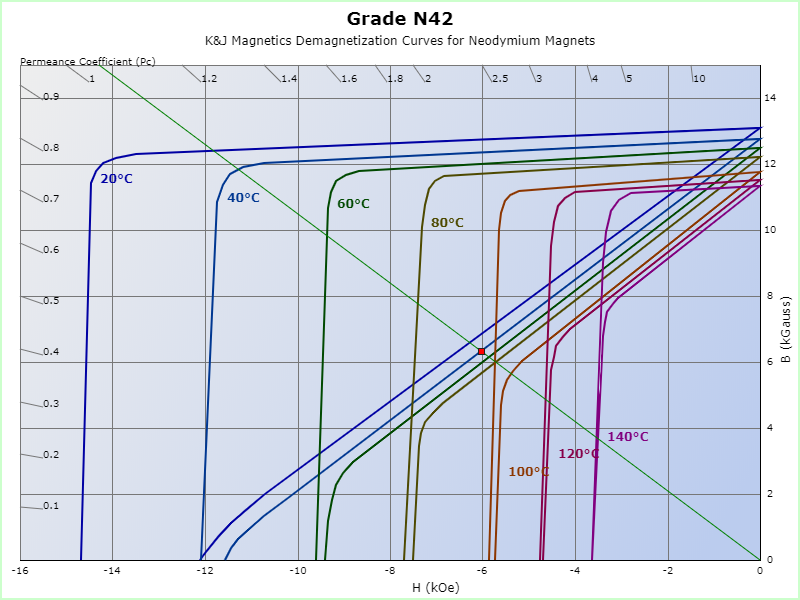


Fig. 4: Load line on the B-H characteristic of the given Neodymium magnet, Permeance Coefficient (Pc): 1.05, B: 6.34 kilogauss, H: -6.03 kilooersted, |BH|: 38.23 mega-gauss-oersted

According to specifications of the magnet, N42 grade magnet load line can obtained as shown in figure 4. If we select the operating temperature as 40’C, we can calculate the max. flux density in air gap using dimensions as shown in below equations:

Where is average magnet magnetic flux, is magnet surface area. If we assume, rotor is surface mount permanent magnet machine, when we calculate the air gap flux density we can use the above equation.

Where, we assume that the magnet has a cylindrical shape in area calculation. 0.05m is radius of rotor, 0.004m is magnet thickness, 0.1m is axial length of the machine, 0.8 is magnet to pole pitch ratio.

**b) Calculate the magnetic loading of the machine for this condition**

Magnetic loading can be calculated as mean flux density over the air gap surface:

Where, pole number =4,=110mm is the stator bore diameter as 100mm rotor dia. + 4+4mm magnets + 1+1mm air gap.

**c) Draw the radial air-gap flux density distribution in the middle of air-gap clearance for a one pole-pair using an FEA tool and compare it with your analytical calculations.**

2. Electrical Loading & Machine Sizing

In this part, we are going to improve the machine design and to analyze the machine electrical loading and sizing.

***a) Choose a suitable number of slots for this machine. Discuss and justify your choice. Please assume open slot shape for the analysis.***

If we define , total number of slots , where p: pole number, m: number of phases. Since harmonic flux components are not desirable, the MMF waveform should approximate a sinusoidal shape as much as possible. Generally, is sufficient.

After this determination, we need to check mechanical strength of tooth. The stator bore diameter is 110mm.

If we select the , the tooth pitch is .

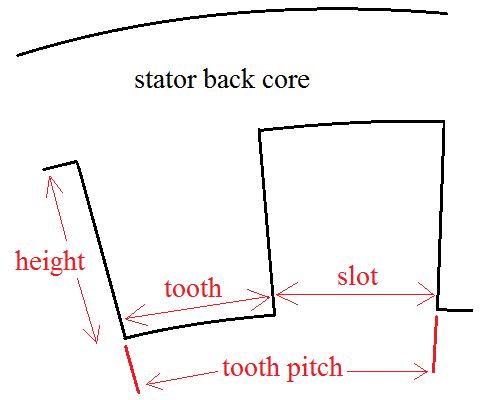


Fig. 5: Stator structure and dimensions

According to figure 5, if we select q=3 instead of q=2, the fluxes concentrate in the tooth and back core dimensions will increase because of sloth height.

***b) Assume the coil current is 2.5 A. If the maximum current density is 5 A/mm^2 and maximum fill factor is 0.6, choose a suitable AWG cable.***

According to 5 A/mm2 maximum current density of the copper, we can select the **number 8 in the AWG** table as shown in figure 6. We assume that the tooth pitch and slot pitch is equal to each other for preventing the saturation level at tooth region. The fill factor of the slot is 0.6, so this is mean that copper amount in the slot is 60% of the total slot area. When we calculate the areas with respect to given fill factor limitation, possible options of the structure is given in table 1.

Table 1: Possible conductor-slot structures

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  | Possibility |
| 1 | 4mm | 8.37mm2 | 28mm2 | No (over dsn.) |
| 2 | 4mm | 16.74mm2 | 28mm2 | YES |
| 3 | 6mm | 25.11mm2 | 42mm2 | YES |
| 4 | 7mm | 33.48mm2 | 49mm2 | No (0.68 fill f.) |
| 5 | 10mm | 41.85mm2 | 70mm2 | YES |
| 6 | 10mm | 50.22mm2 | 70mm2 | No (0.71 fill f.) |

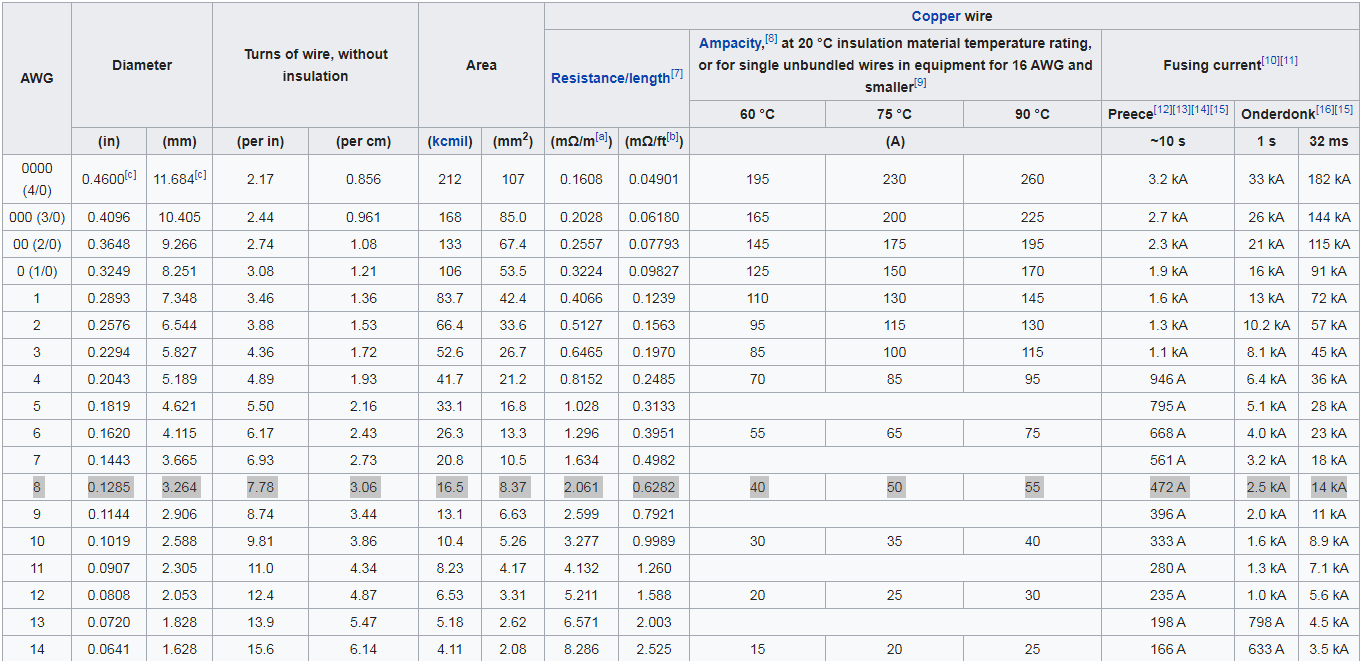


Fig. 6: AWG table

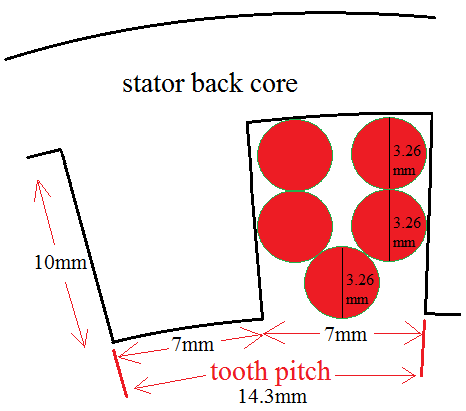


Fig. 7: One of the designed slot with coppers and dimensions for q=2, 24 slots

***c) Choose a reasonable slot height, number of coils per slot and a back-core thickness that does not saturate the core. You can use the rule-of-thumbs presented in the lecture and verify your decisions.***

If the assume slots gets wider with diameter slots (rectangular teeth), the d ratio (see fig. 8) can be assume as 0.7. This means that the slot height is:

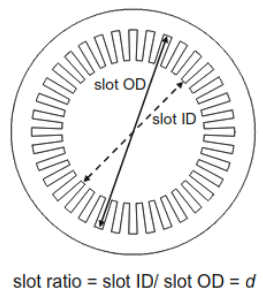


Fig. 8: d ratio on the machine

According to design table of T.Miller (fig. 9), the outer diameter Do is:

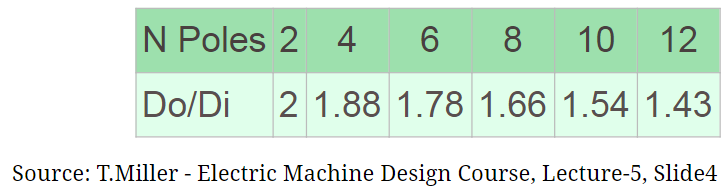
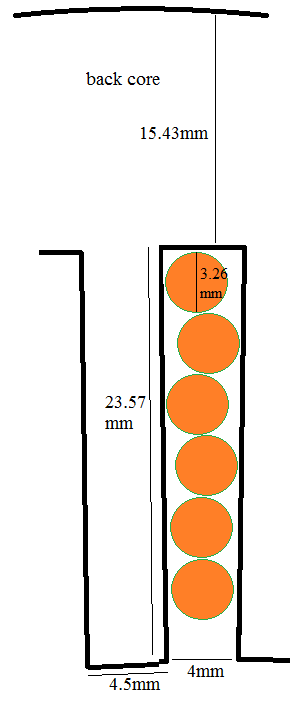


Fig. 9: Design table of Do/Di with respect to pole number

***d) Calculate the electrical loading for your design and compare with the usual values presented in the lecture.***

According to slot height calculations, we can select the q=3, 36 slots. The tooth pitch is 9.5mm, that can divided as 4mm slot width, 4.5mm tooth width (section 2, part a). Our conductor type was number 8 in AWG (section 2 part b). Slot height was 23.57mm, back core was 15.43mm (section 2, part c). According to these calculations from previous part, we can determine the number of conductor in a slot (fill factor was 0.6).



Where, N is turns per phase which is equal to 6x12=72, 2 comes from conductor number in one turn, m is phase number, I is the rms phase current.

***e) Calculate the average tangential stress in the rotor surface, total force that your design can produce.***

***f) Assuming a rotor speed of 1500 rpm, calculate the expected power output of your machine.***

3. FEA Modelling (2d) – fractional winding

In FEA (2d) model, we selected the 24 slots, 20 poles machine, which was analyzed in section 2. For the model, “Study of a Permanent Magnet Motor with MAXWELL 2D: Example of the 2004 Prius IPM Motor” document is used with some modifications (Optimizing is neglected, only suitable geometry considered). So, the designed geometry of FEA model is given in figure 9.

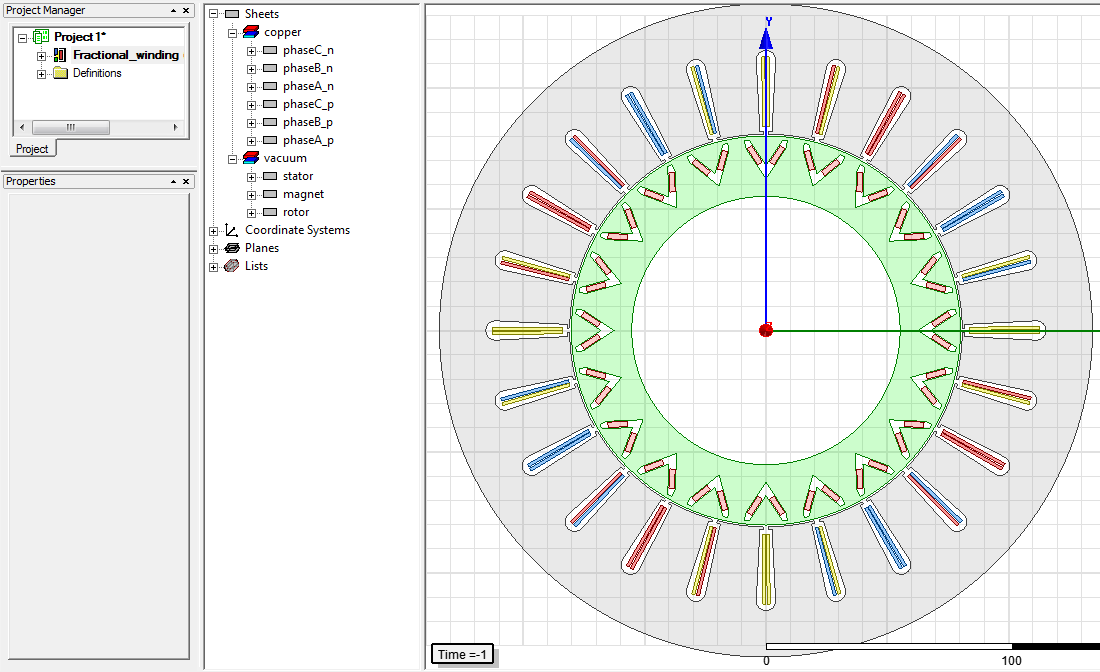
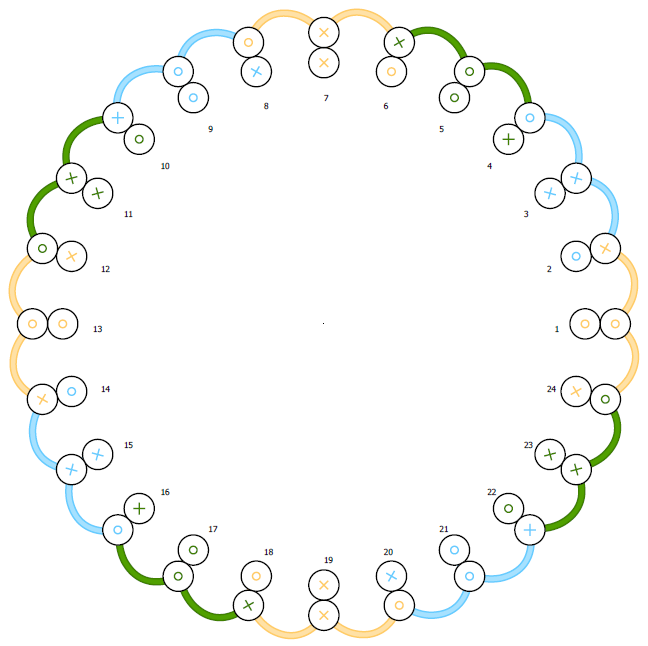


Fig. 9: Maxwell 2d FEA model of the 24 slots, 20 poles fractional winding machine.

After that, I created 1/4 model of the design (in figure 10) but I got mesh error that I can not found the solution of Maxwell error (I spent my 4.5-5h for handle it but I can not. (I selected coil pitch 0.4 but in Maxwell, I think it must set 5/2 instead of 2/5)).

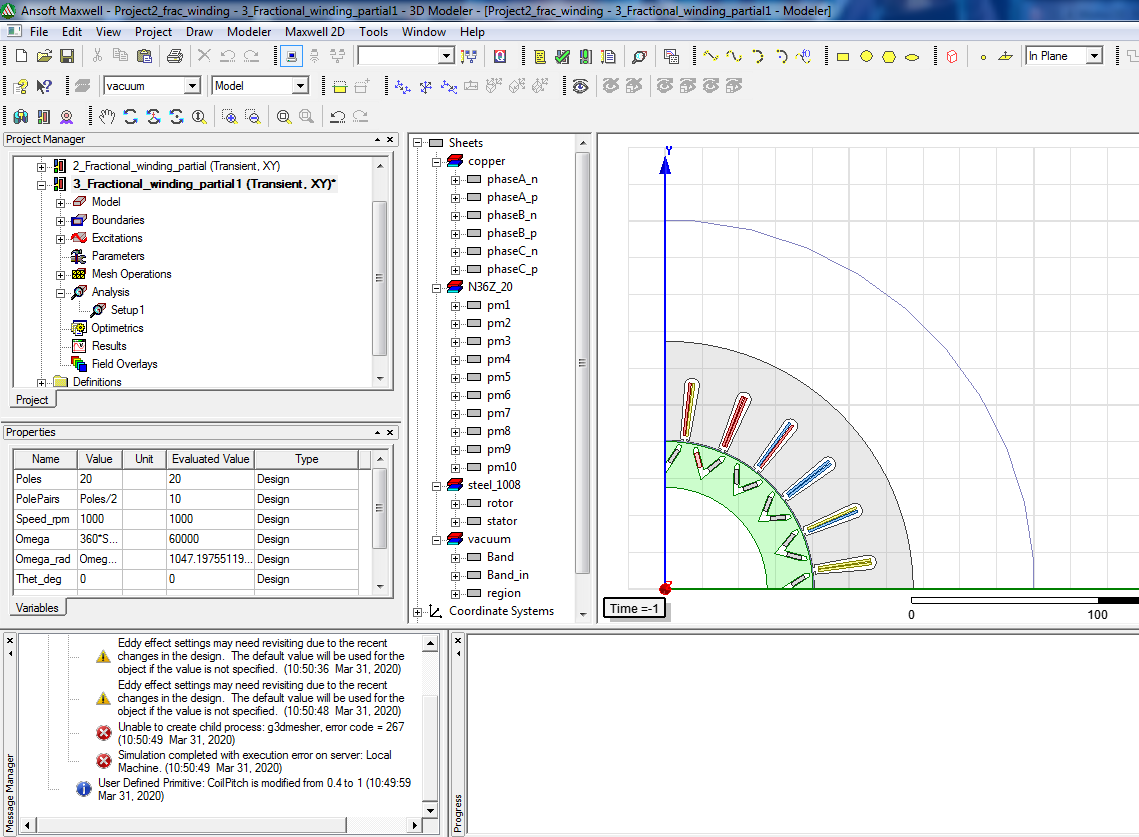


Fig. 10: Maxwell error

# REFERENCES

1. <https://github.com/odtu/ee568>

2. <http://keysan.me/ee568/>

3. ANSYS Maxwell 2D Field Simulator v15 User’s Guide 11.4, Study of a Permanent Magnet Motor with MAXWELL 2D: Example of the 2004 Prius IPM Motor

4. <https://www.kjmagnetics.com/bhcurves.asp>

5.