EEEE3114 – Design Exercise

Introduction

The aim of this exercise is to use 2D electromagnetic FEA (finite element analysis) to design and characterise the behaviour of a surface-mount permanent magnet synchronous machine (PMSM). Finite element analysis modelling tools are able to characterise most of the machine performance properties taking into account the magnetic material's non-linear behaviour and the geometrical details of the stator and rotor structure together with their respective material properties. The 2D nature of this modelling tool will naturally not account for any 3D effects such as skew and end-winding leakage fields. As a first approximation, the latter can be neglected if the diameter to length aspect ratio is small, in other cases these can be accounted for through analytical relations or through 3D FEA which is considerably more computationally demanding. Within this design exercise we will neglect any 3D effects.

Using an existing design of a sinusoidal PMSM you will first need to characterise its performance and torque producing properties, and calculate an equivalent circuit and nameplate representation of the machine. You will also look at the magnet span and slot opening and their effect on performance. A permanent magnet machine for a high-speed turbine is shown in Fig.1. The magnets are mounted on the rotor surface and retained using a non-magnetic sleeve. The 4-pole machine has a distributed, single-layer winding arranged with 2slots per pole per phase (S/P/P) in 24 slots. The stator core is made from silicon-steel laminations and has an effective length of 100 mm. The machine is designed to have a rated RMS phase current of 14.142A aligned with the peak torque (90˚ load angle) and a base speed of 1500 rpm.

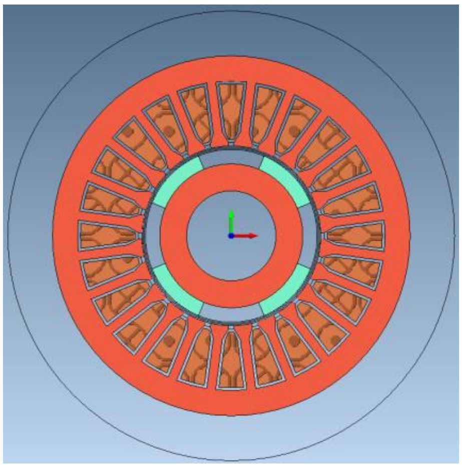

Fig.1 PMSM model

You are requested to submit an individual report briefly detailing the results obtained from the exercises below with any relevant observations.

Performance Evaluation

Using the given geometry, evaluate the performance of this machine with respect to the tasks below. Appendix 1 give information on the initial values of the model of the PMSM.

Task 1: Find the maximum magnitude of the cogging torque and its frequency (pulsations per mechanical revolution). Note, cogging torque is defined as the torque ripple which is developed as a result of the preferred rotor alignment at certain angular positions at no load, or in other words when the stator is not excited. In your report include a waveform of the torque pulsations against rotor position.

Task 2: Plot the phase back-emf of the machine at rated speed, and find the constant relating EMF to speed and the magnitude of the fundamental component.

Task 3: What is the rated torque developed by the machine and what is the frequency and magnitude of the torque ripple?

Task 4: Compare (using a table or graph) the flux density in various important parts of the machine such as the magnets, the centre of the stator teeth and the stator yoke for values of current from 0 to 10 times the rated current in steps of one times the rated current. Note that no load condition is when the phase current is at 0A.

Task 5: Plot the mean torque developed by the machine as a function of load current for values of current from 0 to 10 times the rated current in steps of one times the rated current. Comment on the linearity of the torque-current characteristic of this machine. How is this related to Task 4?

Task 6: Create a nameplate for the electrical machine, listing key parameters valid to the end user.

Task 7: Find the equivalent circuit parameters of the synchronous machine, and use the equivalent circuit to calculate machine performance at rated conditions, commenting on any significant variation from the FEA results.

Task 8: Plot motor output torque as a function of the load angle (both from the equivalent circuit and FEA) and comment on any differences between the two.

Task 9: Vary the magnet pitch factor (the amount of each pole actually covered by a magnet), and plot & discuss the effects on both overall performance and airgap flux density.

Task 10: Vary the slot opening factor (the variation between slot width and slot opening width), and plot & discuss the effects on the magnitude of overall torque, cogging torque and torque ripple.

Appendix 1: Machine geometry and initial values

Fig.2 shows the general geometry and terminology of a PMSM (note below is 12 slot, 1 S/P/P so slightly different to your model).

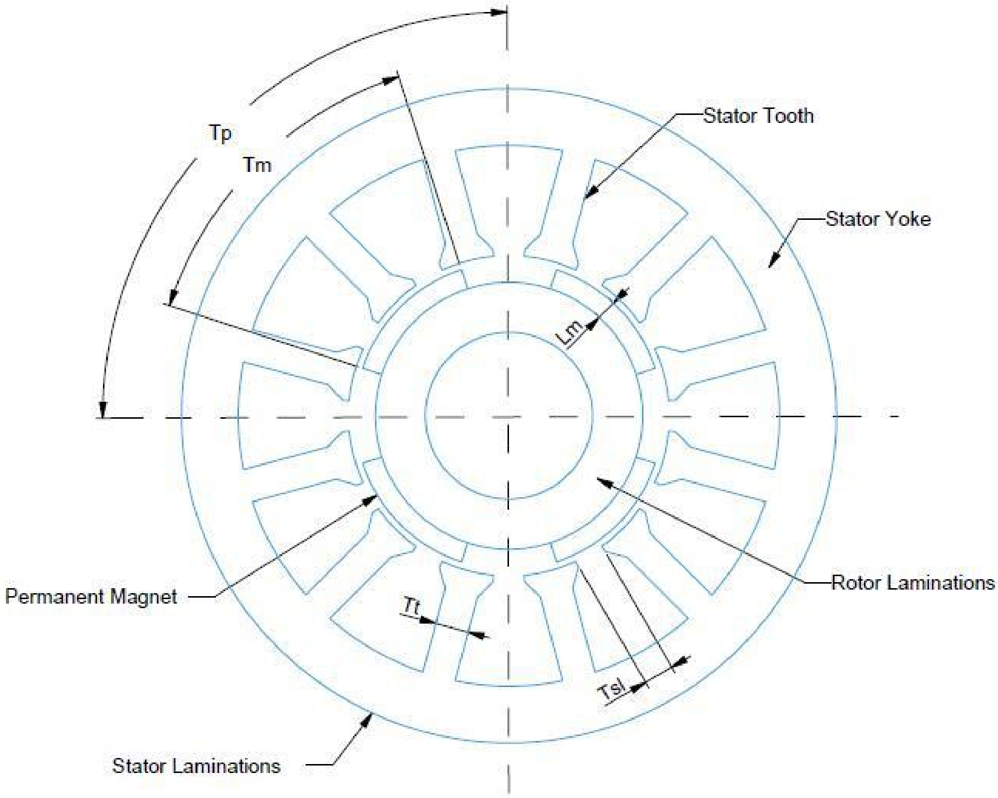

Fig.2 PMSM Geometry

For your initial model use the following:

1) Rotor Speed = 1500 rpm
2) Phase current value (I_{pk}) = 20A
3) Turns/slot = 40, of 10AWG Copper AWG Magnet Wire
4) Relative magnet span = 0.5 .... where Relative Magnet Span = (T_m/T_p)
5) Slot opening factor = 0.4 .... where Slot Opening Factor = T_{sl}/slot width
6) Load angle = 90 (peak torque point)

Table 1: Dimensions and materials of PMSM.

Attribute	Value [mm]	Material
Axial length	100	
Rotor Inner Radius	12.5	Low Carbon Steel 1018
Rotor Outer Radius	20	Silicon Iron M-19
Magnet thickness	4	Neodymium Iron Boron (NdFeB) N42
Airgap length	1	Air!
Stator Radius	50	Silicon Iron M-19, Lamination fill 98%
Outer Cage Radius	62.5	Pure Iron
Stator back iron thickness	7	Slot dimensions
Tooth Width	1.25	
External shoe height (thickness)	1.4	
Internal shoe height	4	