EMAG Recuitment

Task 2

DC Machines

Powertrain Department

1 Introduction

In this task you are meant to understand the basics about rotating electric machinery. For this purpose, nothing is better than start by the DC machine, since it is simple to understand, easy to simulate, and it is also a good starting point to understand how more complex machines work.

2 The DC Machine

A DC machine is the simpler way to convert electrical energy into mechanical. One can see a representation of a basic DC motor in figure 1.

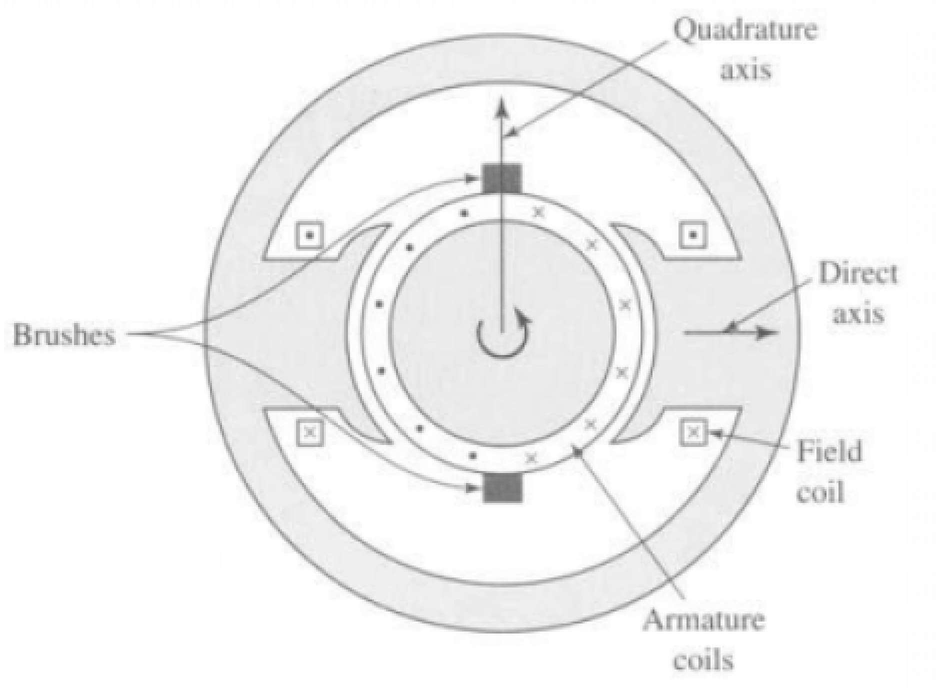

Figure 1: Schematic of a 2 pole DC machine

Usually the electric machines are composed by two main physical parts, the stator and the rotor. It is easy to understand that they are named like that because one of them rotates and the other does not. Also, usually, the stator is the outer part and the rotor is the inner cylinder, figure 2 is no exception. Let us now take a look at how the torque is produced in this machine. Most electric machines use the Lorentz Force principle to produce torque, thus, check the equation 1.

$$\overrightarrow{f} = \overrightarrow{J} \times \overrightarrow{B} \tag{1}$$

From Ampere's Law you also know that currents produce magnetic fields, and so, one can conclude that force, and therefore torque, arise from the interaction between two distinct magnetic fields. Equation 2 and figure 2 are a representation of that.

$$\vec{T} \sim \vec{\phi_1} \times \vec{\phi_2} \tag{2}$$

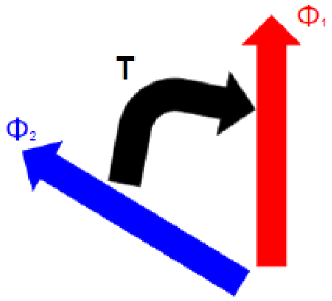

Figure 2: Interaction between magnetic fields.

One can now understand that, in order to create torque, two magnetic fields must exist and must be phase shifted. In the DC machine there are two sources of magnetic field, the field coils, and the armature coils. The field coils produce a constant magnetic field which magnetises the core, this can be seen as an auxiliary circuit with very low power input. Note that this could be accomplished using permanent magnets. On the other hand there is the armature coils. These are responsible for regulating the torque, using a variable current input. These are also the high power input to the machine.

It is also important to explain why to use brushes connected to the armature coils. On one hand the armature coils are mounted in the rotor of the machine and hence they will not be steady. On the the other hand, one can see by the equation 2 that the torque is maximum if the phase shift between the two interacting fields are 90°. If we join both facts, we conclude that it is needed some part that feeds the armature coils keeping its magnetic field at 90º degrees from the core's magnetic field. We advice you to read the book in order to make this clearer.

Finally, in the figure 1 are represented two axes, the direct, and the quadrature axis. The direct axis represent the direction of the magnetising field, the one that, in this case, is produced by the field coils. The quadrature axis is the one which is normal to the direct axis. Normally we force the armature field to be parallel to the quadrature axis in order to maximise the torque produced.

3 Report

Similarly to the last task you will have to write a report about the subject. In the report you will have to focus on the following topics:

1. When working with electric machines, one often uses the so called equivalent circuit of the machine. For a DC machine, the equivalent circuit can be seen in the figure 3.

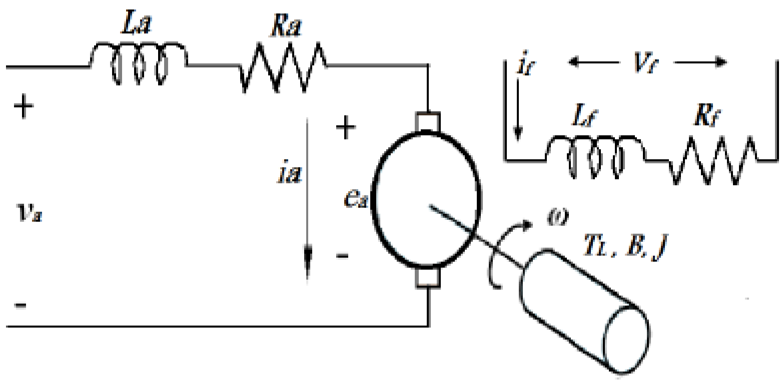

Figure 3: Equivalent circuit for a separately excited DC Machine.

Also the equations for this equivalent circuit are:

$$\begin{cases} V_a = R_a i_a + L_a \frac{di_a}{dt} + E_a \\ V_f = R_f i_f + L_f \frac{di_f}{dt} \\ E_a = k_f i_f \omega \\ T = k_f i_f i_a \\ T_{el} - T_{load} = J\frac{d\omega}{dt} + B\omega \end{cases} . \tag{3}$$

Describe what is the physical meaning of each component in the equivalent circuit, and explain the equations in 3. Also explain the conditions in which one can use the equivalent circuit.

2. Every industrial electric machine has something called the nameplate data. This is some set of important data about the motor which tells the nominal operating point/region of the machine. You should know that the nominal operating region of the machine is characterised by having the maximum efficiency. Having said so, consider the DC machine with the following nameplate data.

DC Machines Nameplate Data	
Field Voltage	180 V
Field Current	1.6 A
Armature Voltage	180 V
Armature Current	17.7 V
Speed	1740 RPM
Power	2.5 kW

Table 1: DC Machine Nameplate Data.

For this machine, compute the field resistance, the armature resistance, the nominal torque, the field constant and efficiency at the nominal point. Consider steady state operation: $\frac{d}{dt} = 0$.

3. A separately excited as a torque vs. speed curve like the one in figure 4.

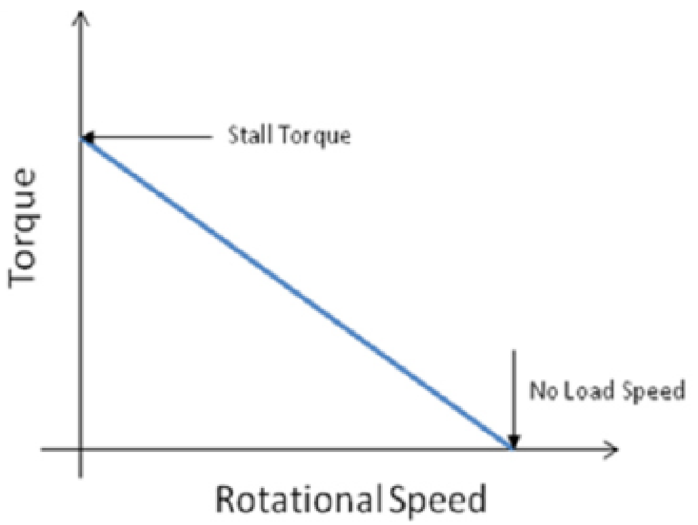

Figure 4: Torque vs. Speed

For the motor in the last point plot the torque vs. speed curve for different field currents, for example, you can consider $I_f = 1A$, $I_f = 1.6A$ and $I_f = 2A$. Also, justify the differences. Again, you can consider that the motor is in steady state conditions.

4. Up to now we have not been considering transient operations, thus, the inductance and the inertia have been neglected. For a linear B-H relation, one can use equation 4 to determine the inductance.

$$L = \frac{\psi}{I} \tag{4}$$

Consider that the DC motor of the previous questions has the geometry in the appendix drawing. Using Comsol determine the inductance of the machine. Also considering the data for the motor in table 2.

Motor parameters	
Armature number of turns	321
Field number of turns	500
Machine length	20 cm
Coils material	Copper
Core material	Soft Iron

Table 2: COMSOL parameters.

5. An important parameter for a motor is its mechanical time constant. The mechanical time constant is defined as the time that the motor takes to reach 63 percent of its steady state speed. Now that you know the inductance of the motor, you can use Matlab Simulink to simulate the full transient mechanical and electrical model of the motor.

   Consider that the combined moment of inertia of the motor's rotating parts is $J = 2 \times 10^{-3} m^4$ and that its friction coefficient is $B = 0.0028 Ns/m$. Consider that the motor is operating at no load, and that the field circuit is being supplied by a constant current of 1.6A.

6. Using the Simulink model you just implemented, consider now that the motor is driving a load of 15 Nm. In this conditions compute the new mechanical time constant. Also compute its efficiency in steady state for different field current inputs, you can consider again $I_f = 1A$, $I_f = 1.6A$ and $I_f = 2A$.

   Include plots and images of the simulations you made, for example the distribution of B in the motor from Comsol, or the evolution of the speed and current from Simulink.

4 Final Notes

Feel free to include in the report more information that you may find interesting about the subject, you are not restricted to the questions in the last section.

This is probably the most difficult task you are meant to do so far, having said so, do not hesitate to ask any doubt that you may have. As always, you can e-mail to make any question, or you can show up in team's Discord.

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