EE568 - Selected Topics on Electrical Machines

Project - 1

Variable Reluctance Machine

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Introduction

In this project, we are required to model a simple variable reluctance machine. Variable reluctance means that, when rotor is rotated, reluctance of system changes. When reluctance is, changed, inductance is also effected and stored energy changes. Changing energy produces output power.

In this project, there is a simple C shaped core and a rectangular rotor in the gap. Stator winding is composed of 250 turns and supplied by 3A direct current.

In the first part, we are required the calculate the model via analytical methods. In the second part, the model is calculated by using FEA model and linear materials. In the third part same simulations were run with nonlinear materials. Lastly, a method is suggested in order to produce positive net torque.

Q1)

In this part, system is analytically modelled.

$$\alpha = 77.36 \; by \; using \; the \; given \; dimensions$$

- When rotatation angle is greater than 77.36 degrees, reluctance is assumed to be constant.
- Rotor is assumed to be a rectangle when calculating area.

$$Area = 15 * 10^{-3} * 20 * 10^{-3} = 300 * 10^{-6} \, m^2$$

$$R = \frac{l}{\mu_0 * Area} = \frac{0.5 * 10^{-3}}{\mu_0 * 300 * 10^{-6}}$$

There are two series connected paths, so

$$R_{tot} = 2 * R$$

$$R_{tot} = \frac{2 * 0.5 * 10^{-3}}{\mu_0 * 0.3 * 10^{-3}} \; and \; decrease \; with \; factor \left(\frac{77.36 - \theta}{77.36}\right)^{-1}$$

$$R_{tot} = 2.65 * 10^6 * \left(\frac{77.36 - \theta}{77.36}\right)^{-1}$$

$$L = \frac{N^2}{R} = \frac{250^2}{2.65 * 10^6} * \frac{77.36 - \theta}{77.36}$$

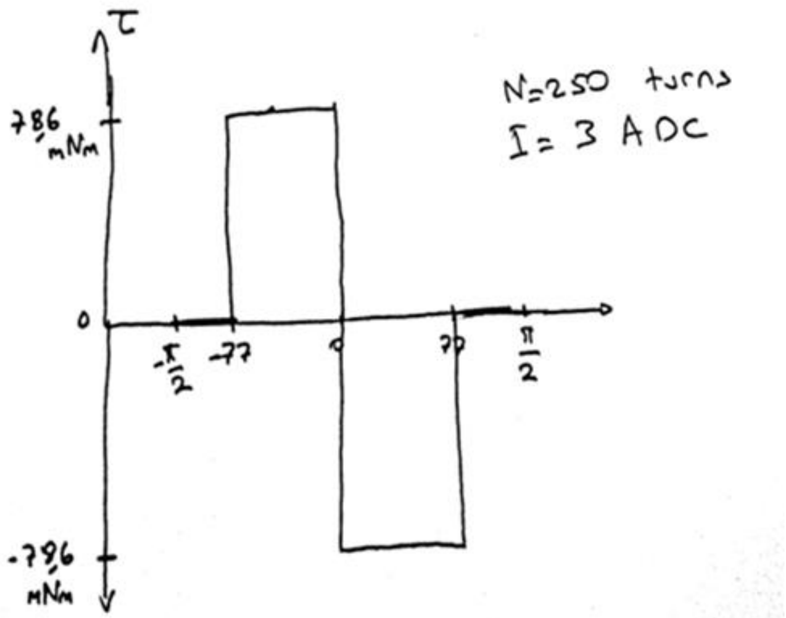
$$L = 23.58 * \frac{77.36 - \theta}{77.36}\ mH$$

b-

$$\tau = \frac{d(energy)}{d\theta} = \frac{d\left(I^2 * \frac{L}{2}\right)}{d\theta}$$

$$\tau = 3^2 * 23.58 * \frac{1}{2} * 10^{-3} * \frac{d\left(\frac{1.35 - \theta}{1.35}\right)}{d\theta}$$

$$\tau = -78.6\ mNm\ when\ 0 < \theta < 77.36$$



c)

In order to improve the model, core reluctance can be taken into account. When core reluctance is added, some points will start to saturate. As a result, permeability and inevitably reluctance will change again. Same calculation should be performed again a few times to find the exact operating point of the core.

Lastly leakage flux should be taken into account. Permeability of steel is 300-3000 times larger than air. However, since it is not infinitively large, some portion of the flux passes through air. At low currents leakage may be smaller but, when the steel starts to saturate, it will be effective and should be taken into account.

Q2)

In this part, model is simulated by using a 2D FEA software. Firstly, steels are assumed ideal in terms of magnetic properties. In other words, magnetic permeability is constant. In the simulation it is taken as 4000 u_0. 2D model is shown in figure1.

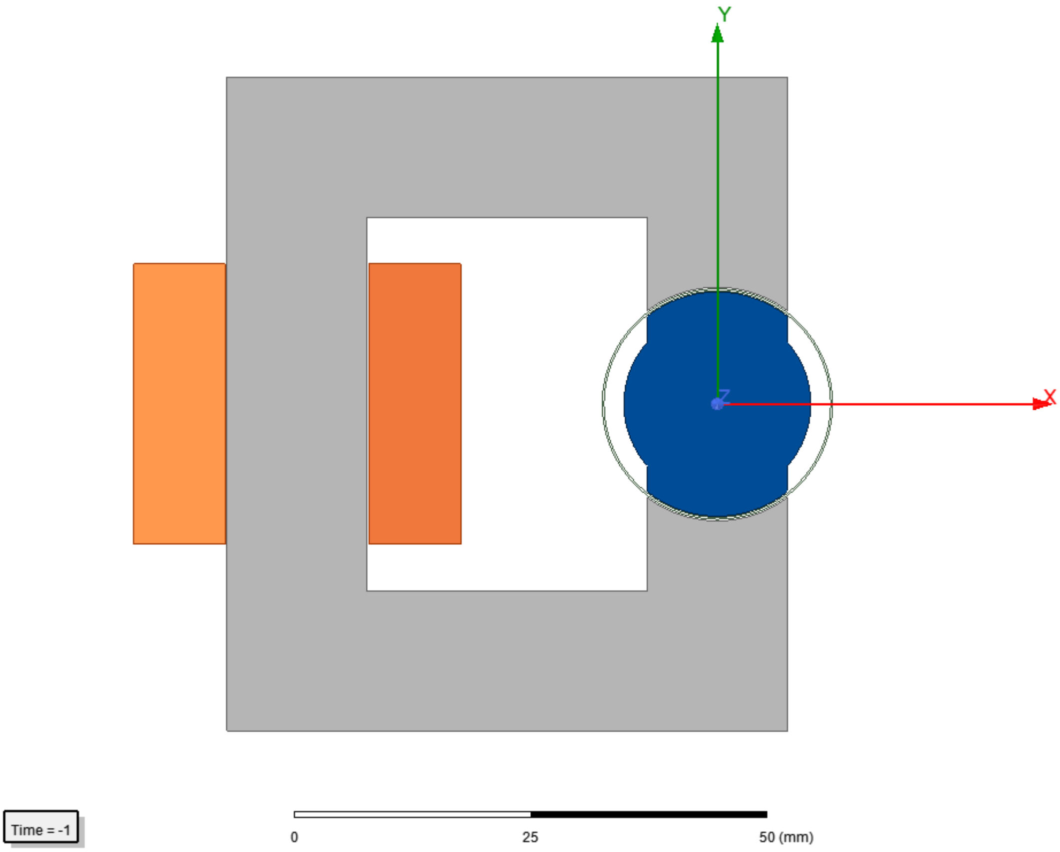


Figure 1 2D model

Copper regions are approximated as solid parts. Number of turns is 250 and current is 3 A.

a)

Flux density vectors are given in figures 2,3 and 4 for angles 0, 45 and 90 degrees.

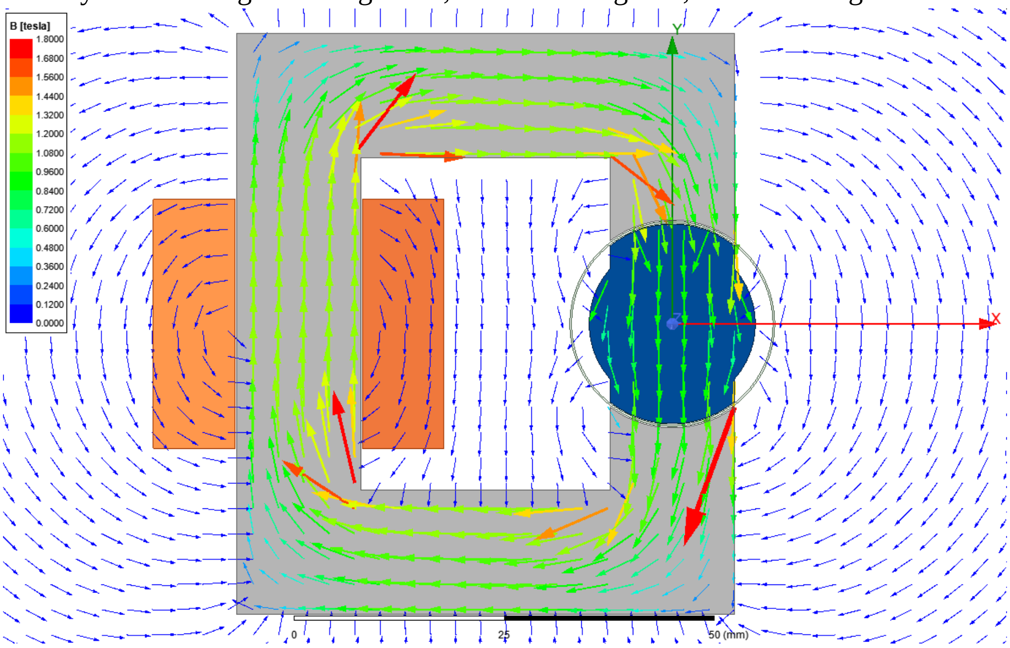


Figure 2 Flux density vectors for $\theta = 0$

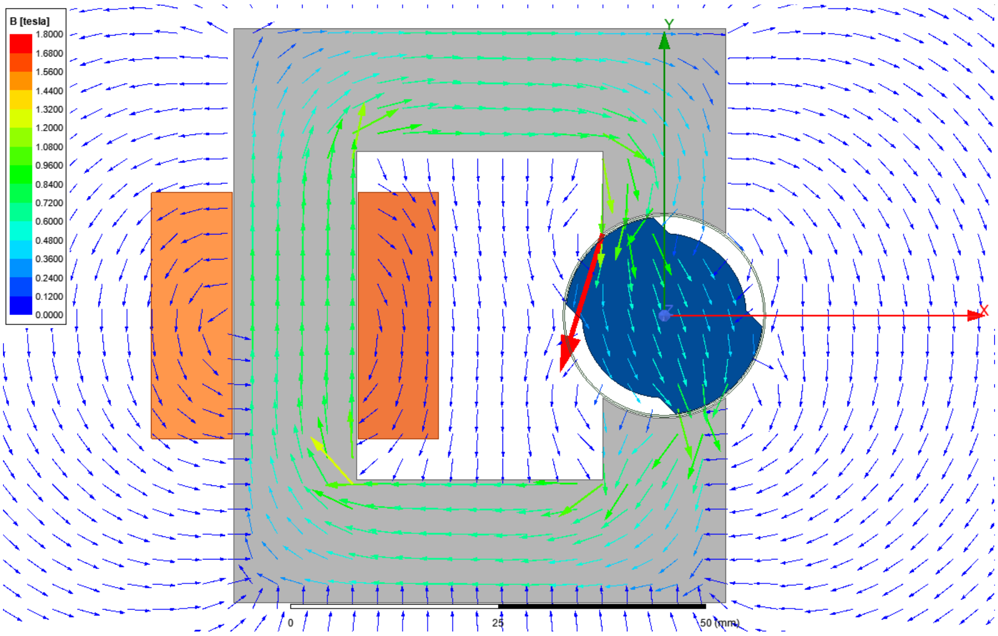


Figure 3 Flux density vectors for $\theta = 45$

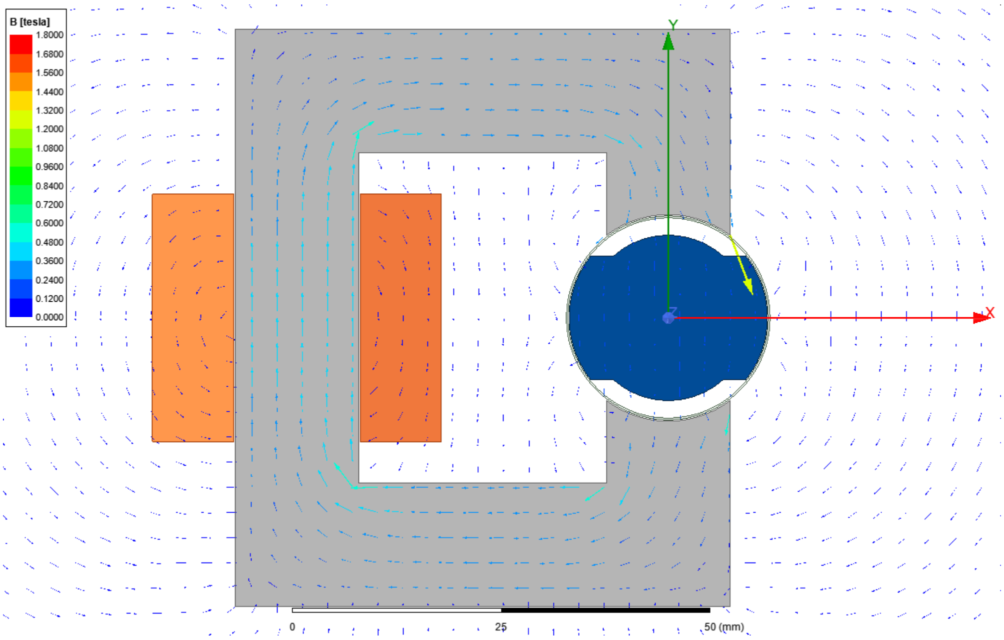


Figure 4 Flux density vectors for $\theta = 90$

b)

Inductance vs angle table is given in table1.

Table 1 Inductance vs angle

	current [A]	Matrix1.L(Current1,Current1)/50 [mH] Setup1 : LastAdaptive angle='0deg'	Matrix1.L(Current1,Current1)/50 [mH] Setup1 : LastAdaptive angle='45deg'	Matrix1.L(Current1,Current1)/50 [mH] Setup1 : LastAdaptive angle='90deg'
1	3.000000	28.353165	18.094793	9.089797

Inductance vs angle graph is given in figure 5.

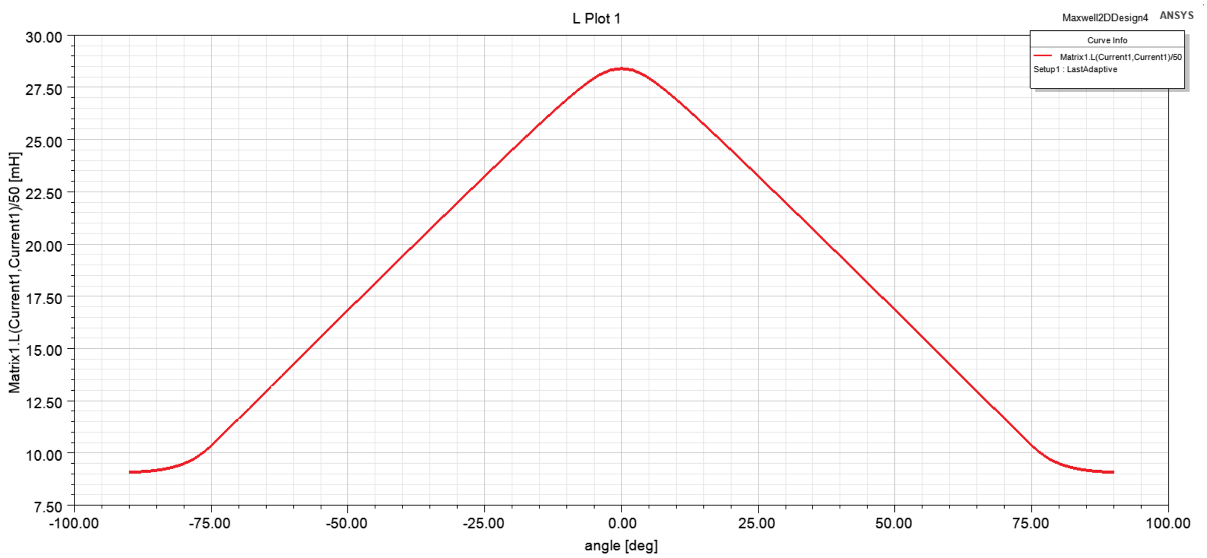


Figure 5 Inductance vs angle

Total energy vs angle is given in table 2.

Table 2 energy vs angle

	current [A]	(rotor_energy+stator_energy)/50 Setup1 : LastAdaptive angle='0deg'	(rotor_energy+stator_energy)/50 Setup1 : LastAdaptive angle='45deg'	(rotor_energy+stator_energy)/50 Setup1 : LastAdaptive angle='90deg'
1	3.000000	0.005971	0.002378	0.000490

Total coenergy vs angle is given in table 3

Table 3 co-energy vs angle

	current [A]	(rotor_coenergy+stator_coenergy)/50 Setup1 : LastAdaptive angle='0deg'	(rotor_coenergy+stator_coenergy)/50 Setup1 : LastAdaptive angle='45deg'	(rotor_coenergy+stator_coenergy)/50 Setup1 : LastAdaptive angle='90deg'
1	3.000000	0.005971	0.002378	0.000490

It can be seen that energy and coenergy is equal to each other. Since linear a material is used, this is expected.

c)

Torque vs angle is given in figure 6

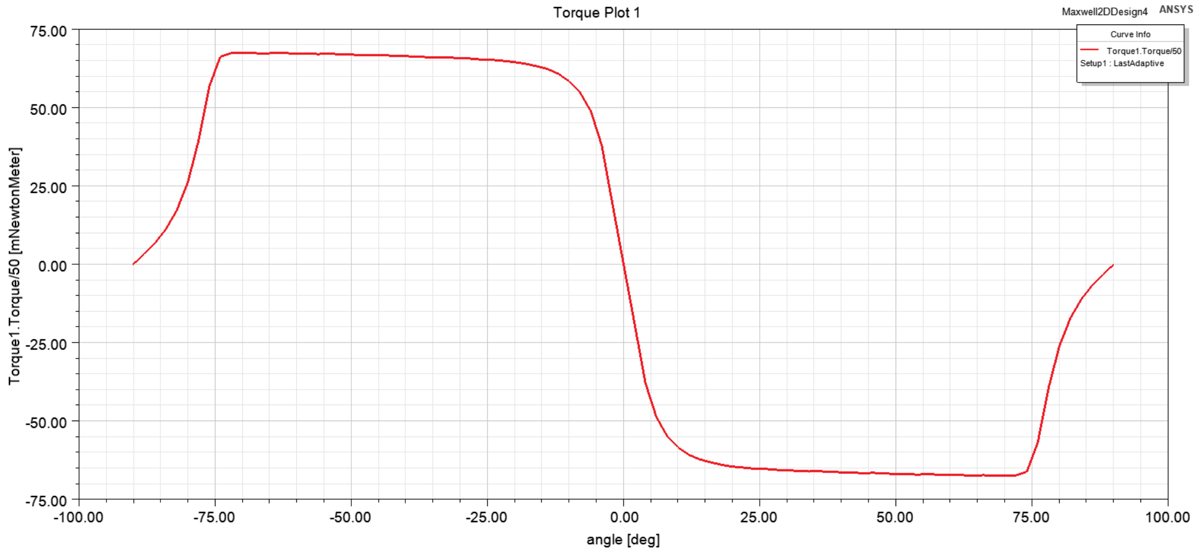


Figure 6 Torque vs angle

Q3)

In this part material is changed to a nonlinear steel. Steel type is AISI 1008

a)

Flux density vectors are given in figures 7,8 and 9 for angles 0, 45 and 90 degrees.

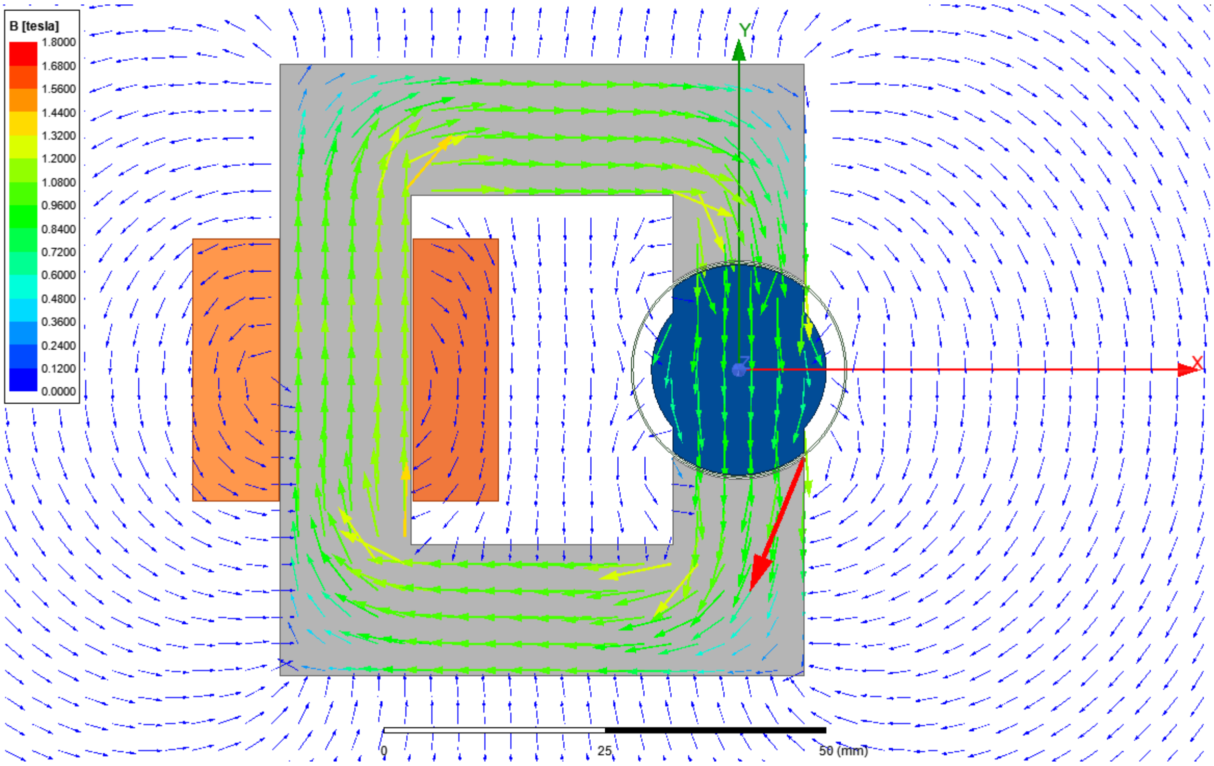


Figure 7 Flux density vectors for $\theta = 0$

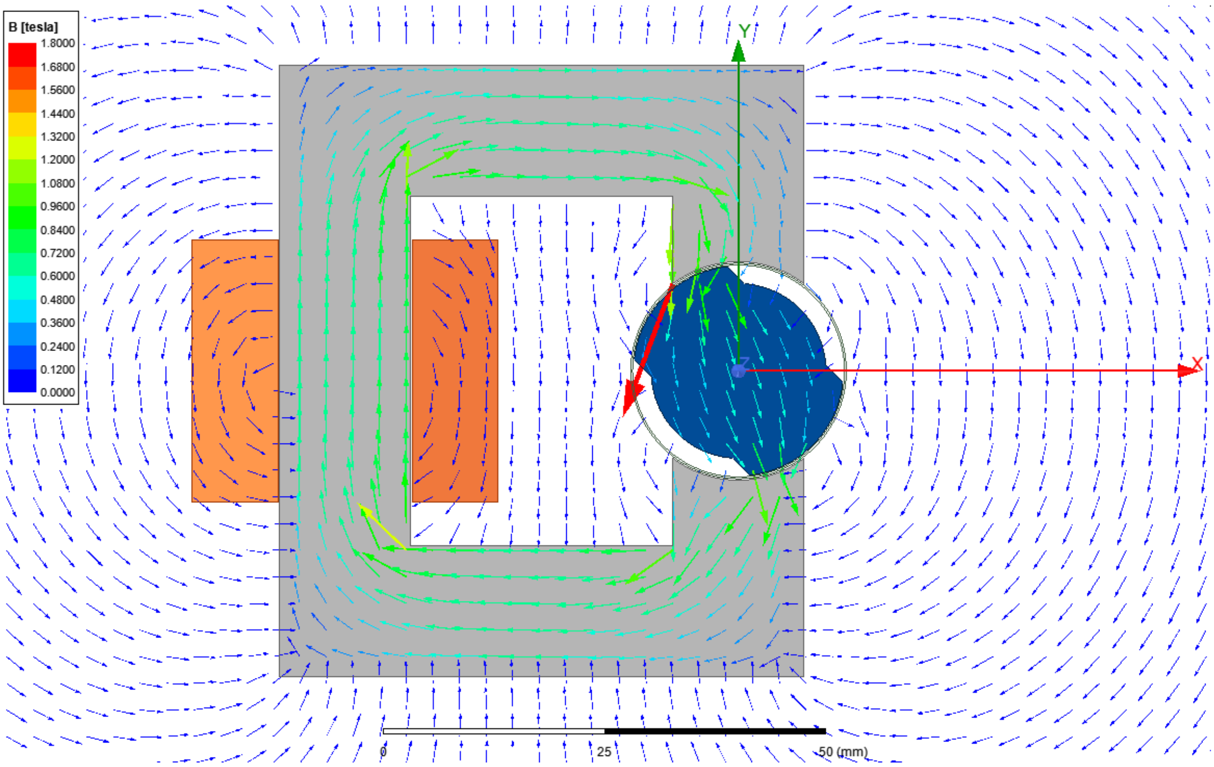


Figure 8 Flux density vectors for $\theta = 45$

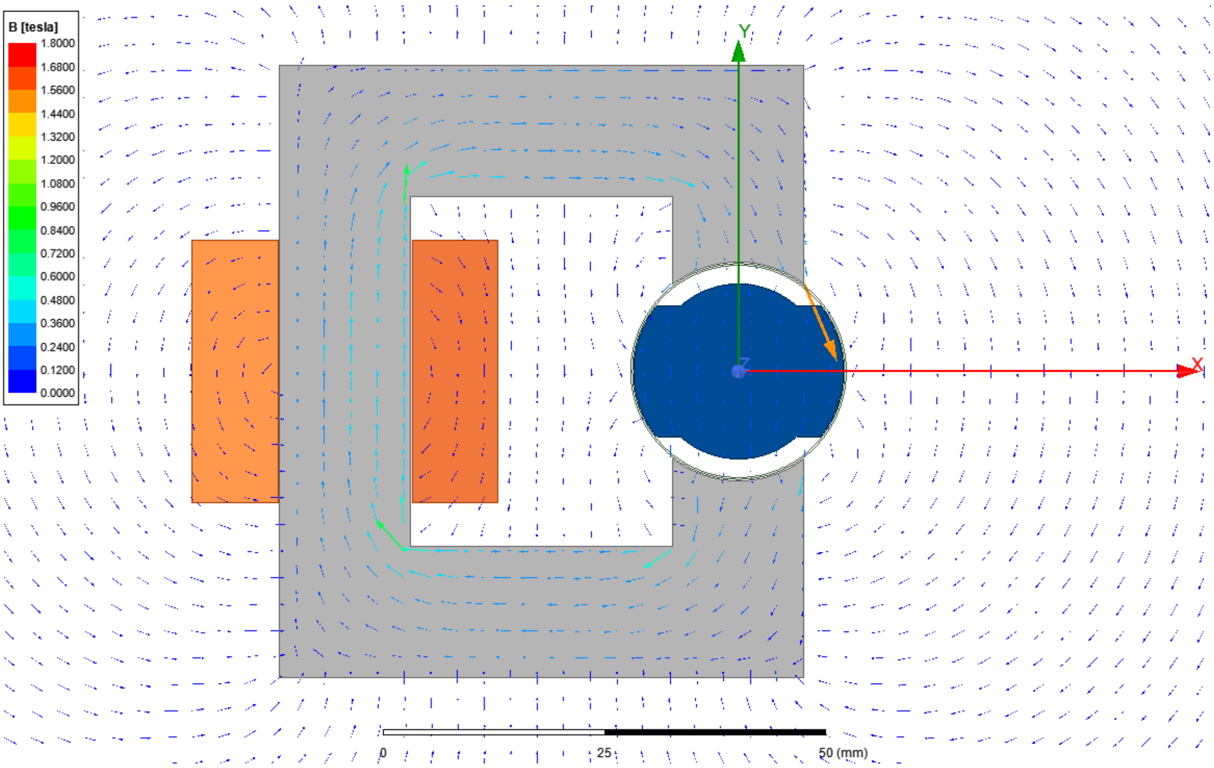


Figure 9 Flux density vectors for $\theta = 90$

b)

Inductance vs angle table is given in table4.

Table 4 Inductance vs angle

	current [A]	Matrix1.L(Current1,Current1)/50 [mH] Setup1 : LastAdaptive angle='0deg'	Matrix1.L(Current1,Current1)/50 [mH] Setup1 : LastAdaptive angle='45deg'	Matrix1.L(Current1,Current1)/50 [mH] Setup1 : LastAdaptive angle='90deg'
1	3.000000	26.809780	17.495815	8.927260

Inductance vs angle graph is given in figure 10.

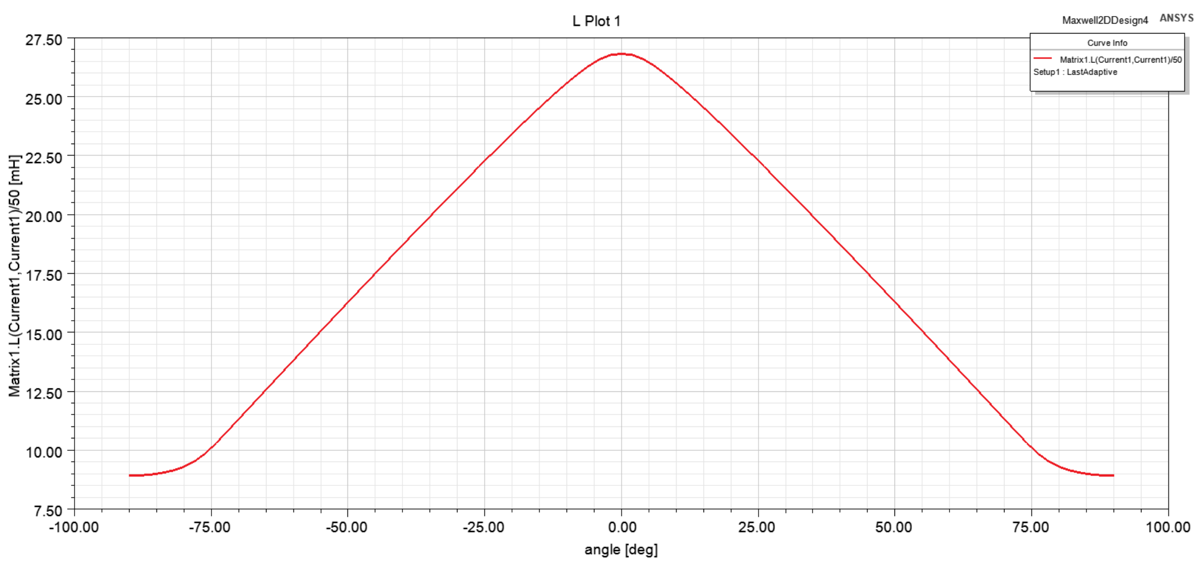


Figure 10 Inductance vs angle

Total energy vs angle is given in table 5.

Table 5 energy vs angle

	current [A]	(rotor_energy+stator_energy)/50 Setup1 : LastAdaptive angle='0deg'	(rotor_energy+stator_energy)/50 Setup1 : LastAdaptive angle='45deg'	(rotor_energy+stator_energy)/50 Setup1 : LastAdaptive angle='90deg'
1	3.000000	0.011939	0.005358	0.001364

Total coenergy vs angle is given in table 6.

Table 6 co-energy vs angle

	current [A]	(rotor_coenergy+stator_coenergy)/50 Setup1 : LastAdaptive angle='0deg'	(rotor_coenergy+stator_coenergy)/50 Setup1 : LastAdaptive angle='45deg'	(rotor_coenergy+stator_coenergy)/50 Setup1 : LastAdaptive angle='90deg'
1	3.000000	0.011897	0.004392	0.001074

c)

Torque vs angle is given in figure 11.

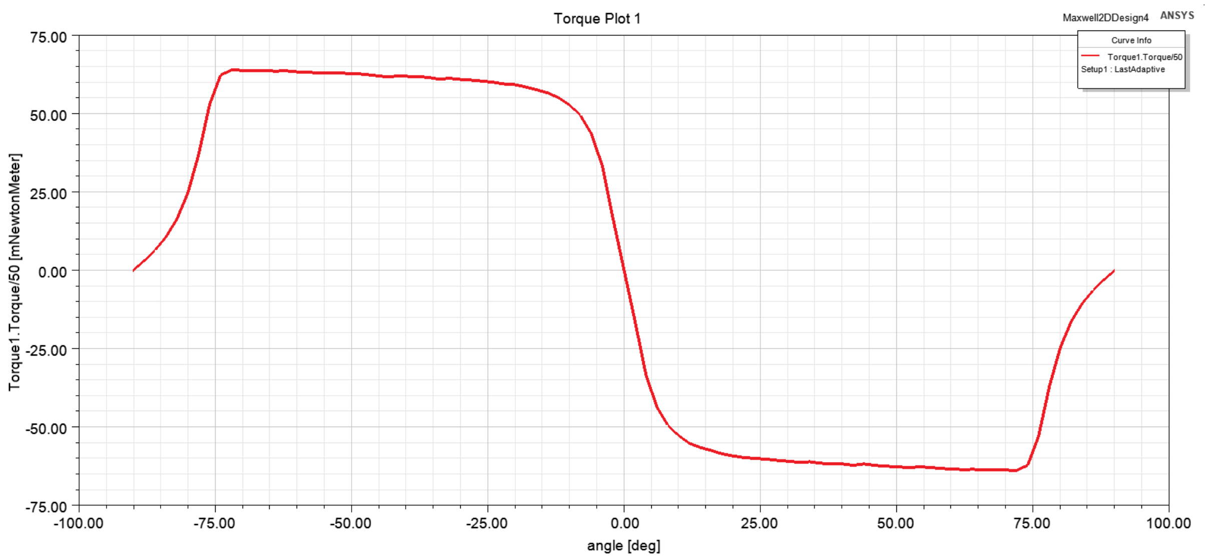


Figure 11 Torque vs angle

Q4)

In this part we are required to propose a method to run the machine continuously. The problem with DC excitation was the average torque. There were some points that torque is positive. However just after that, torque becomes negative so net torque is always zero.

Torque with transient motion is shown in figure 12.

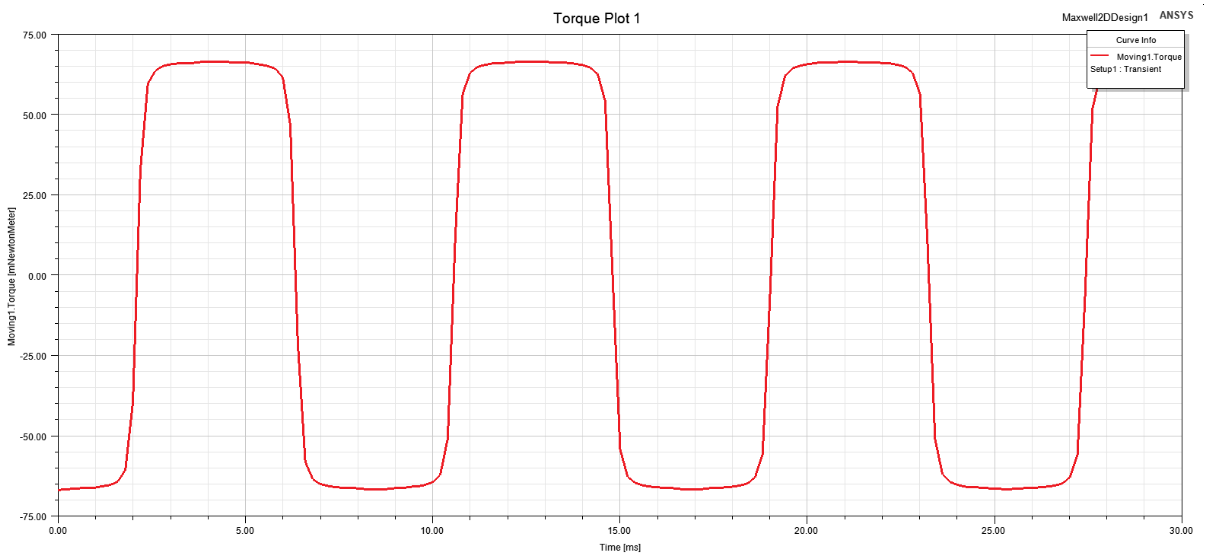


Figure 12 Torque with transient motion

In order to make average torque greater than zero, we have to eliminate the regions with negative torque. To do that, we can stop the current flow for negative torque angles and start it for positive torque angles. Resultant would be a square wave with increasing frequency with respect to rotation speed.

Q4)

Added in .avi format.