**METU – EEE**

Middle East Technical University – Electrical Electronics Engineering Department

**PROJECT REPORT**

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within the scope of the course

**EE568**

**SELECTED TOPICS ON ELECTRICAL MACHINES**

*by* Dr. Ozan KEYSAN

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**PROJECT REPORT NO** : 01

**PROJECT NAME** : Torque in a Variable Reluctance Machine

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Introduction

In this report, a basic model of variable reluctance machine in fig.1 is examined. Analytical expression of torque, reluctance and inductance of the system is derived as a function of rotation of the variable reluctance rotor. 2D FEA model is created in ANSYS/Maxwell 2D and system is analyzed. Linear (constant µ) and non-linear (considering saturation) steel lamination effect is simulated. Also a XX control method is purposed to the model for acceleration with a certain torque.

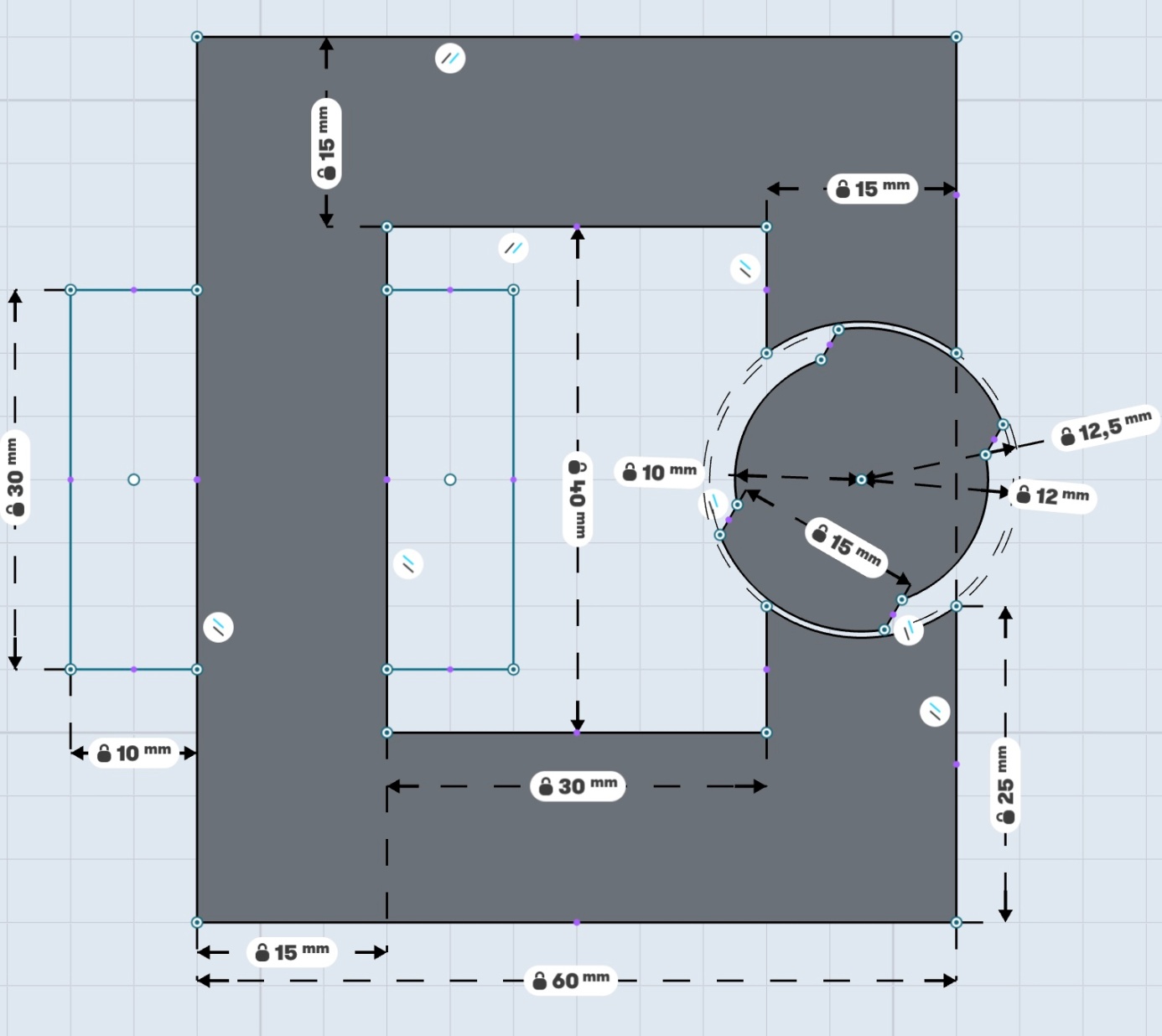


Fig. 1: Physical properties of the variable reluctance machine project model (*Coils are wound within 30mmx10mm rectangle areas, each airgap clearance is 0.5mm, depth of the core is 20mm, number of turns = 250, coil Current = 3 A DC*)

1. Analytical Modelling

There are two air-gaps in series in fig. 1 and these air gap lengths change with an angle (θ), which is between rotary part’s direct axis and stable part’s flux axis.

The maximum reluctance is observed when the angle is π/2 or 3π/2 radians (air gap is maximum). The minimum reluctance is observed when the angle is 0 or π radians (air gap is minimum).

So, total reluctance (and inductance) changes with respect to the angle θ. The maximum reluctance (minimum inductance) is calculated as () when the angle θ is equal to π/2 or 3π/2 shown in fig. 2. Steel permeability is assumed as infinite and fringing is neglected.

Where are air gap lengths, is permeability of air, are effective core areas that flux linking, is turn ratio.

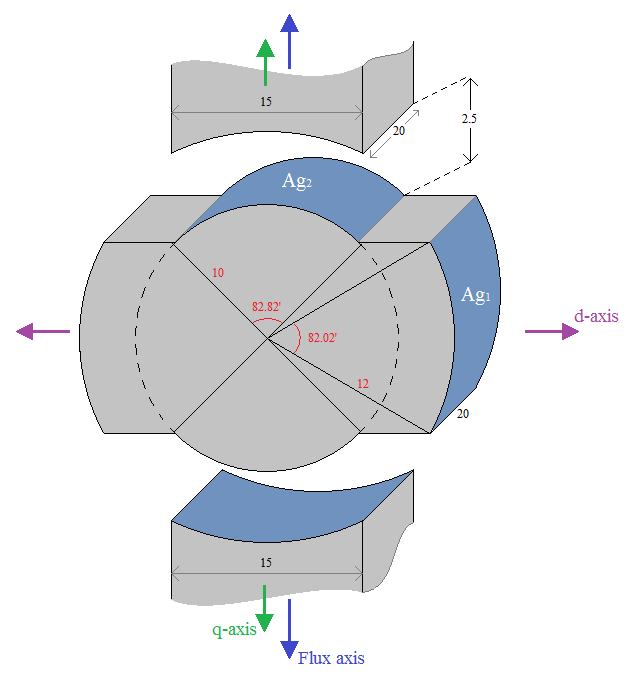


Fig. 2: Maximum reluctance case (The angle between d-axis and Flux axis is π/2, all lengths are in mm and angles are in degree)

Calculation of the max-min reluctances (or inductances) are done with respect to their effective core area that the flux is linking. So, the analyzed geometry is given in fig.3.

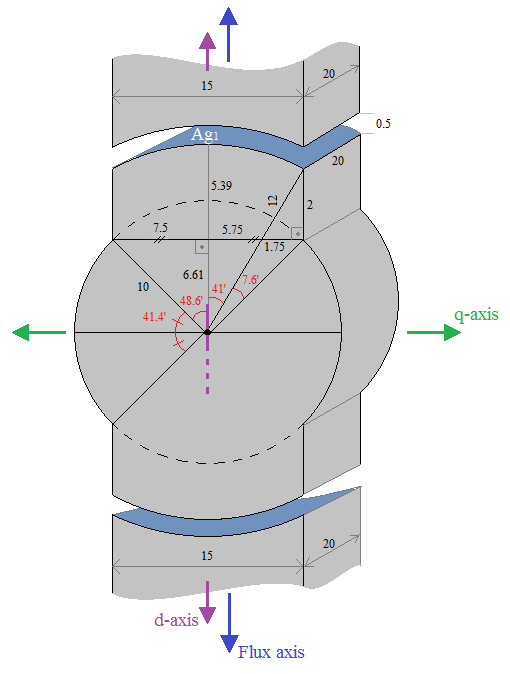


Fig. 3: Minimum reluctance case and geometry analysis (The angle between d-axis and Flux axis is 0 or π, all lengths are in mm and angles are in degree)

The minimum reluctance (maximum inductance) is calculated as () when the angle θ is equal to 0 or π shown in fig. 3. Steel permeability is assumed as infinite and fringing is neglected.

The total Reluctance and Inductance values are change with cos(2θ) character, because of mechanical symmetry, and they are multiplicative inverse each other with factor turn ratio square (N2), as shown in fig. 4.

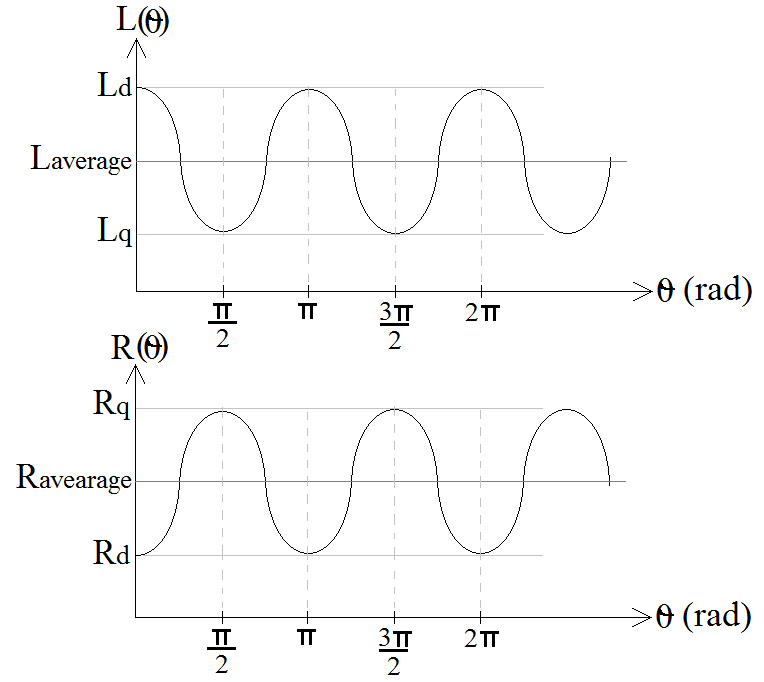


Fig. 4: Reluctance and Inductance changes with respect to the angle .

From the graphs in Fig. 4,

When we calculate the effective core areas () that are indicated in fig.2 as piece of cylinder surface,

For the case that shown in fig. 3, we can calculate and as shown below,

For the case that shown in fig. 2, we can calculate and as shown below,

The average and half of difference values of Inductances are calculated as shown below,

,

The Reluctance and Inductance as a function of are calculated as shown below,

2. FEA Modelling (2d Linear Materials)

For the given geometry, the FEA model is constructed in Ansys/Maxwell (see fig.xx). Stator and rotor materials are selected as steel\_1008 in Ansys/Maxwell library. The material property is set as constant permeability as µ=902.6.

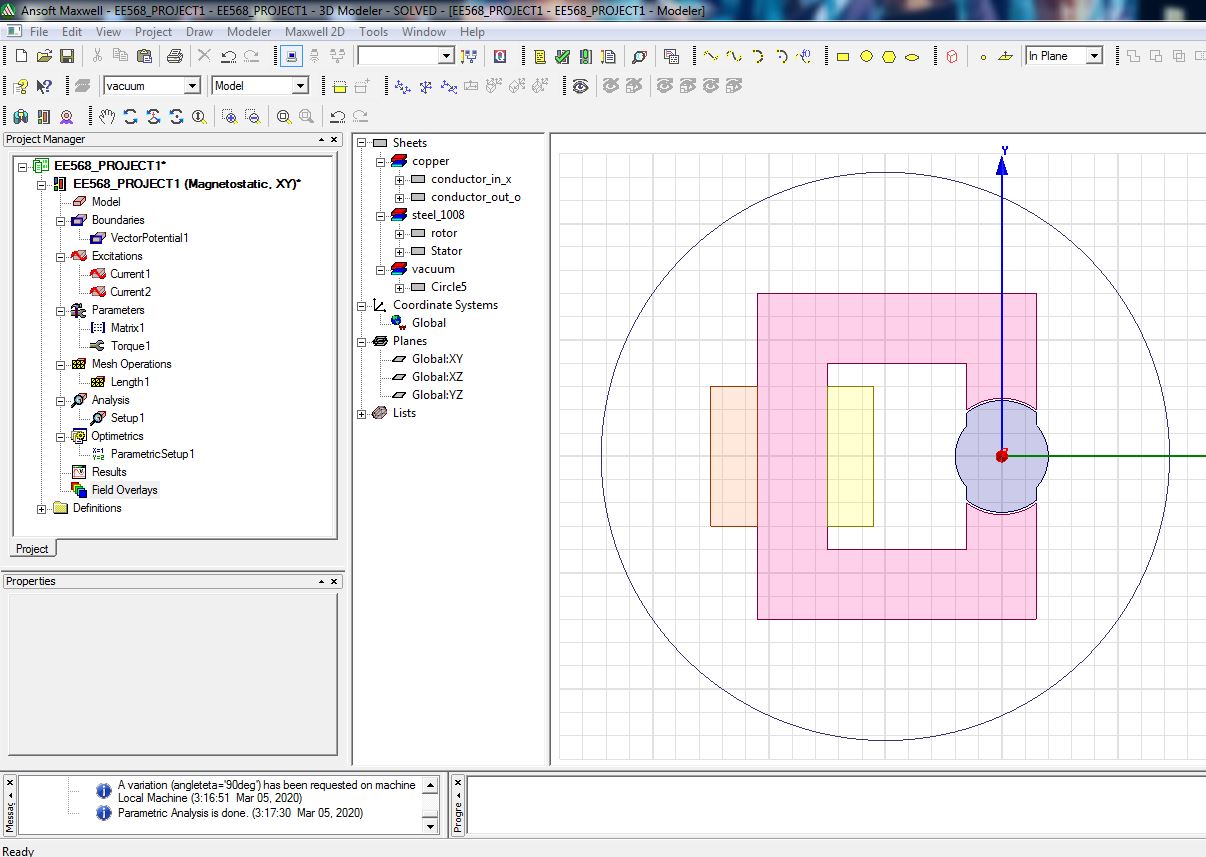
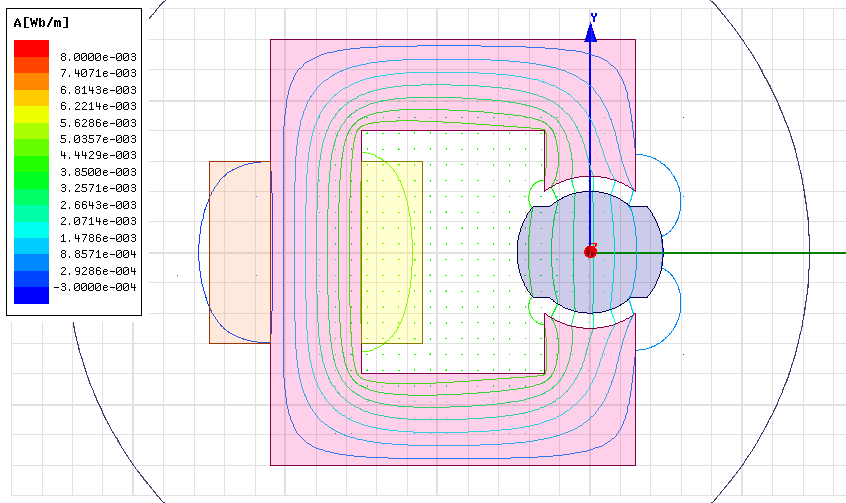
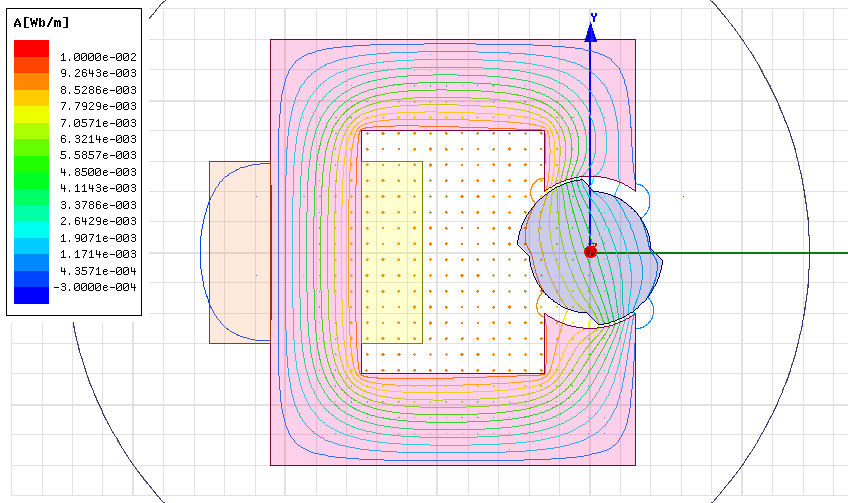
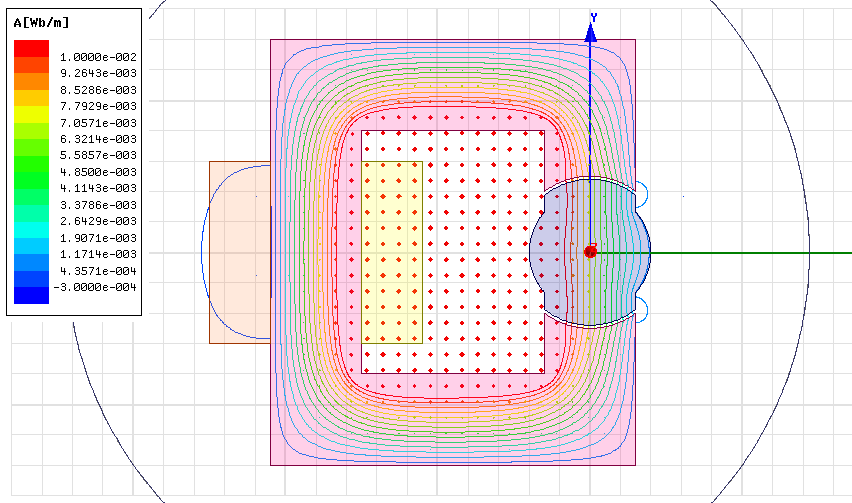
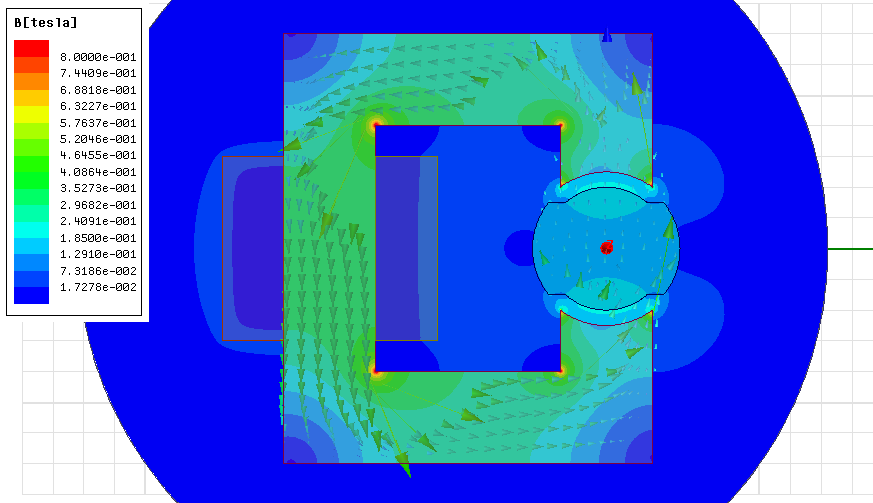
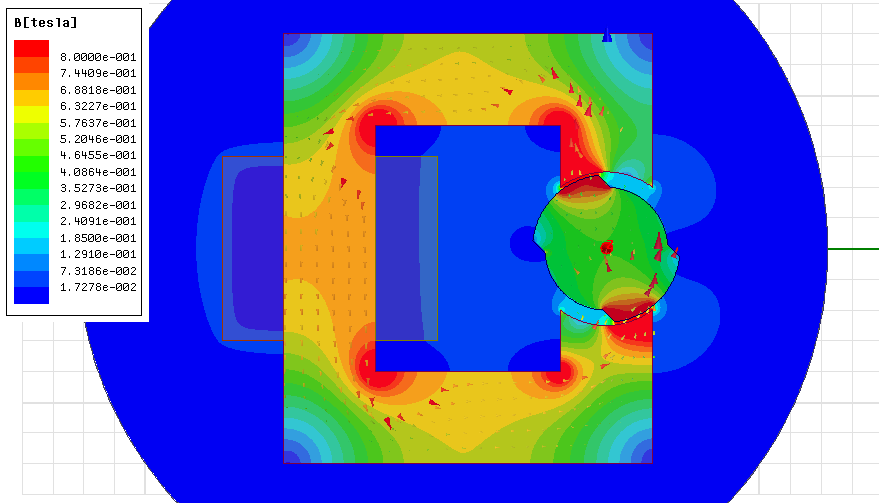
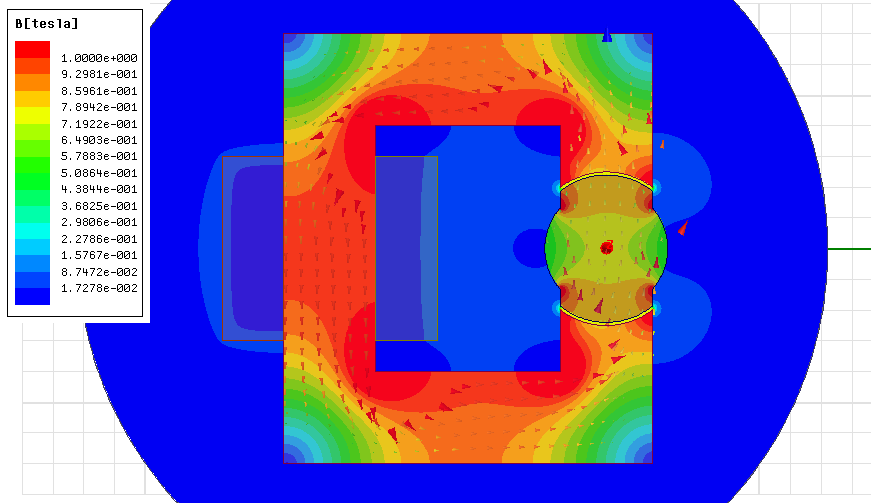


Fig. XX: FEA model of the given geometry in Ansys/Maxwell

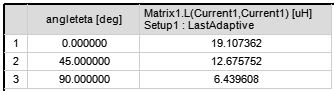
System analysis is done for three positions as rotor angles are 0o, 45o and 90o. For these three position, the flux vectors, magnetic loading, inductances and energies are calculated.

**a) Flux Density Vectors for Linear Materials (0, 45, 90 degree rotor)**



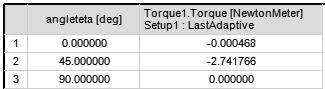
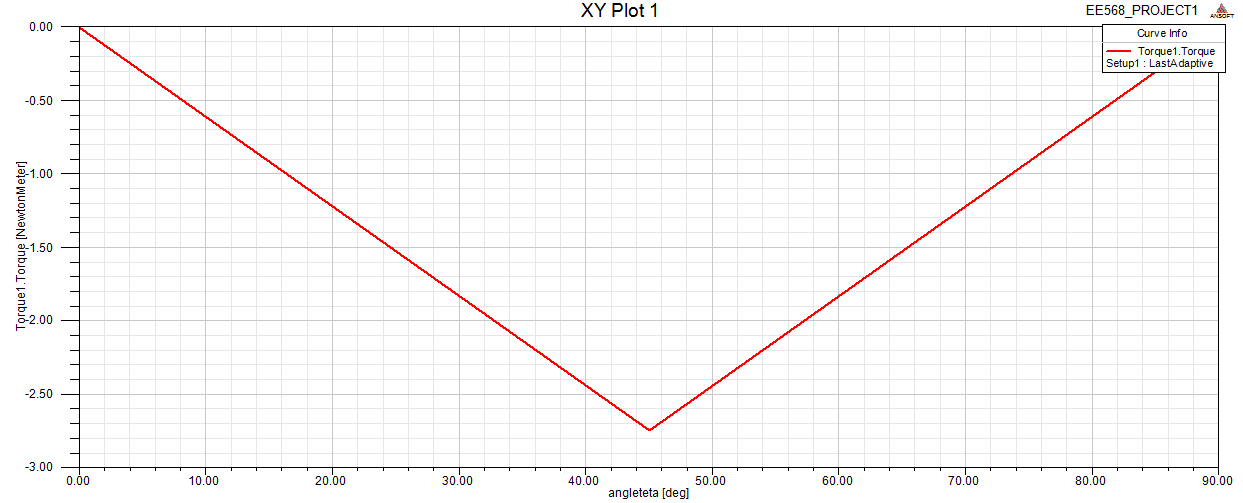


**b) Inductances and Stored Energy in the System**



1/2li^2 matlab

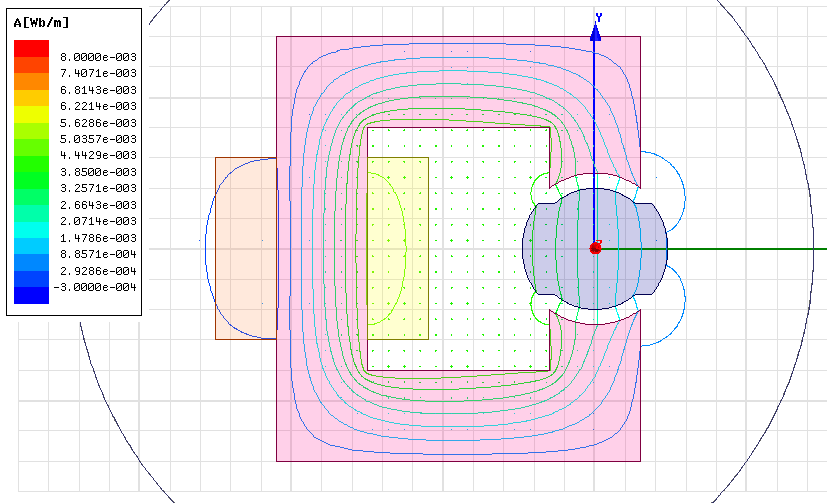
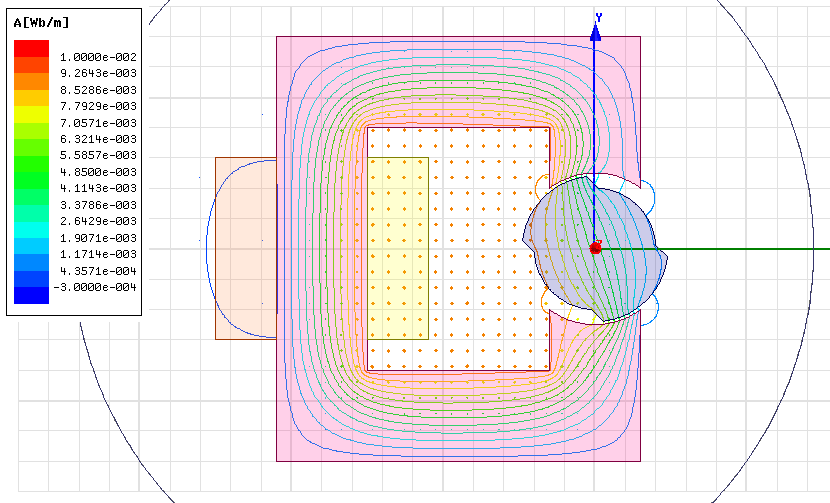
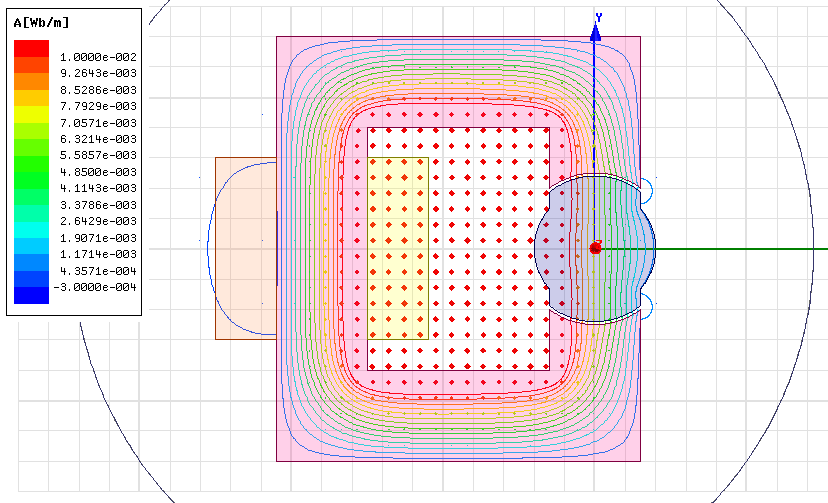
**c) Torque Generation in the System**

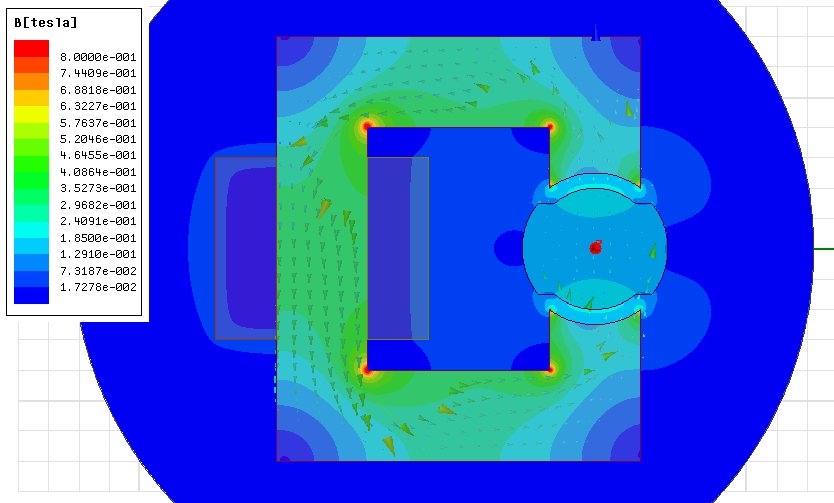
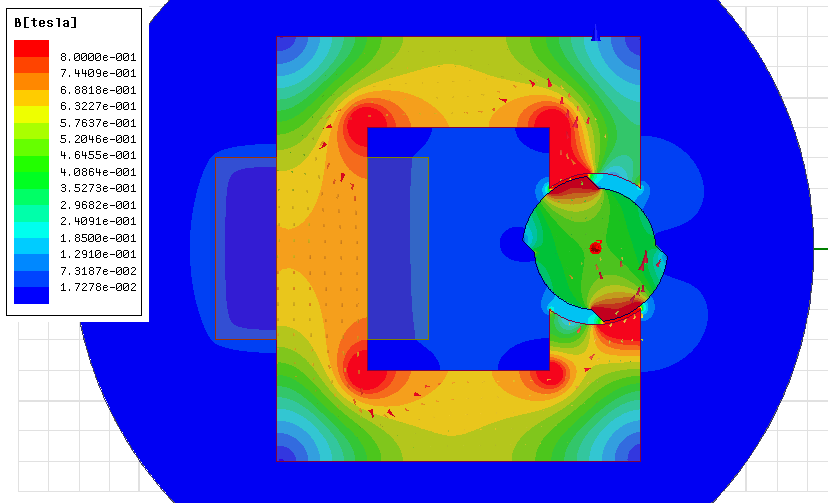
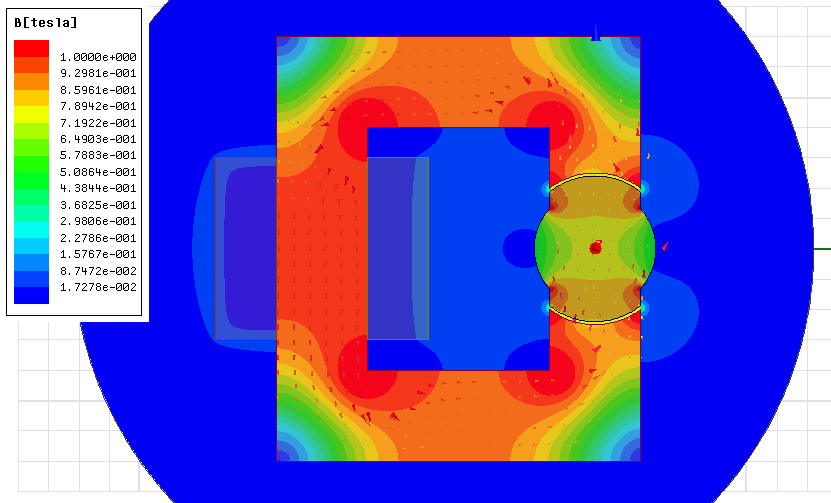


3. FEA Modelling (2d Nonlinear Materials)

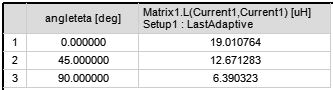
In this section, stator and rotor materials are selected as again steel\_1008 in Ansys/Maxwell library. But, the material property is set as nonlinear characteristic as nonlinear B-H curve that is given in Ansys/Maxwell library.

**a) Flux Density Vectors for NonLinear Materials (0, 45, 90 degree rotor)**



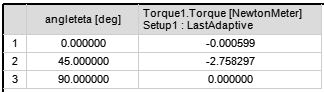
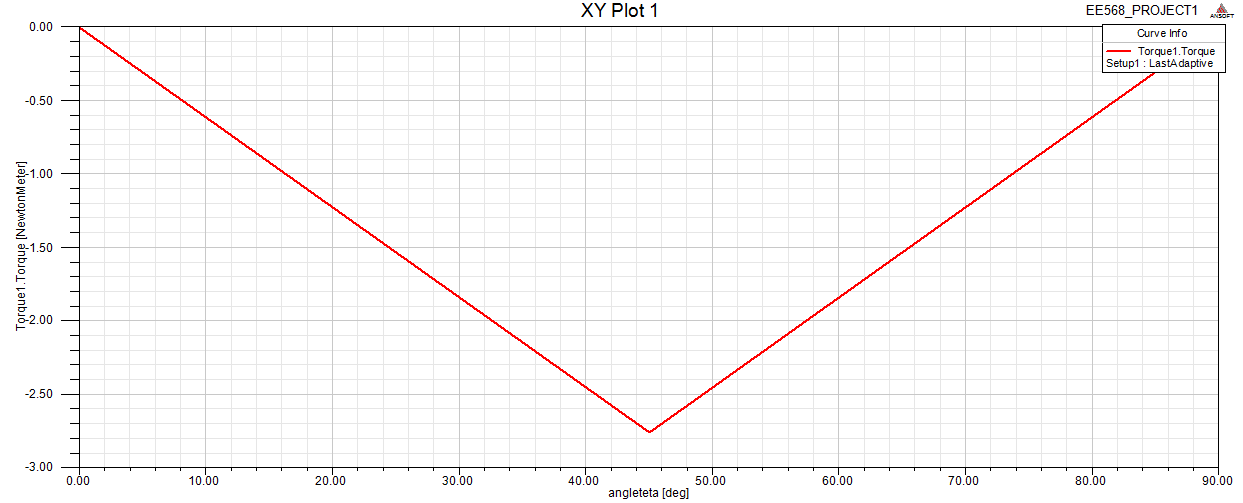


**b) Inductances and Stored Energy in the System**



1/2li^2 matlab

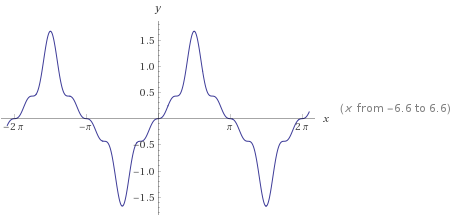
**c) Torque Generation in the System**

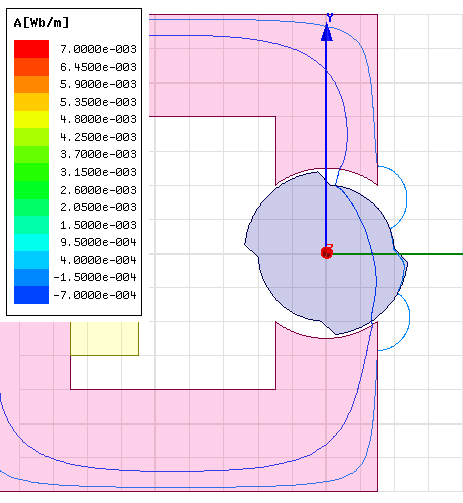
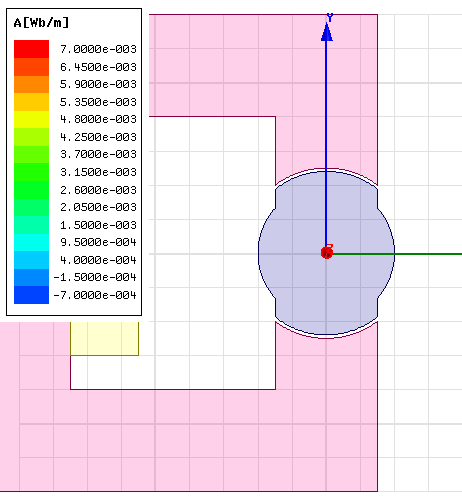
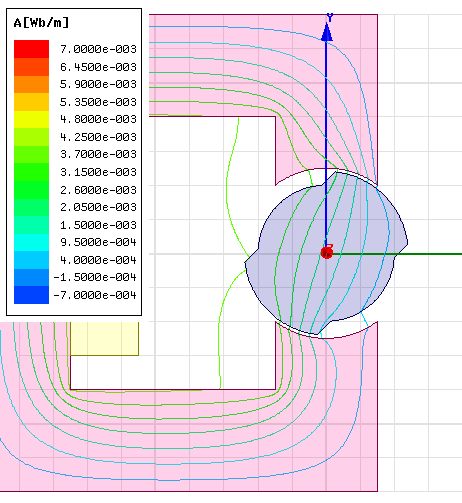
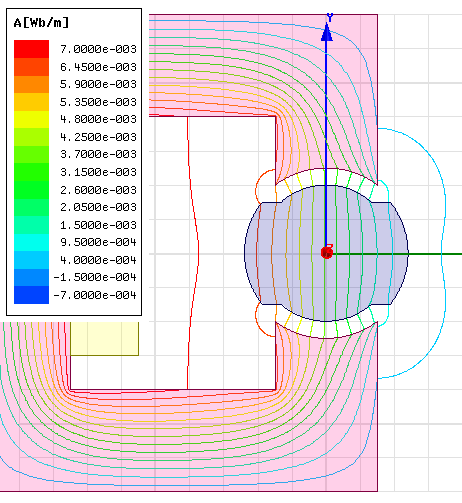


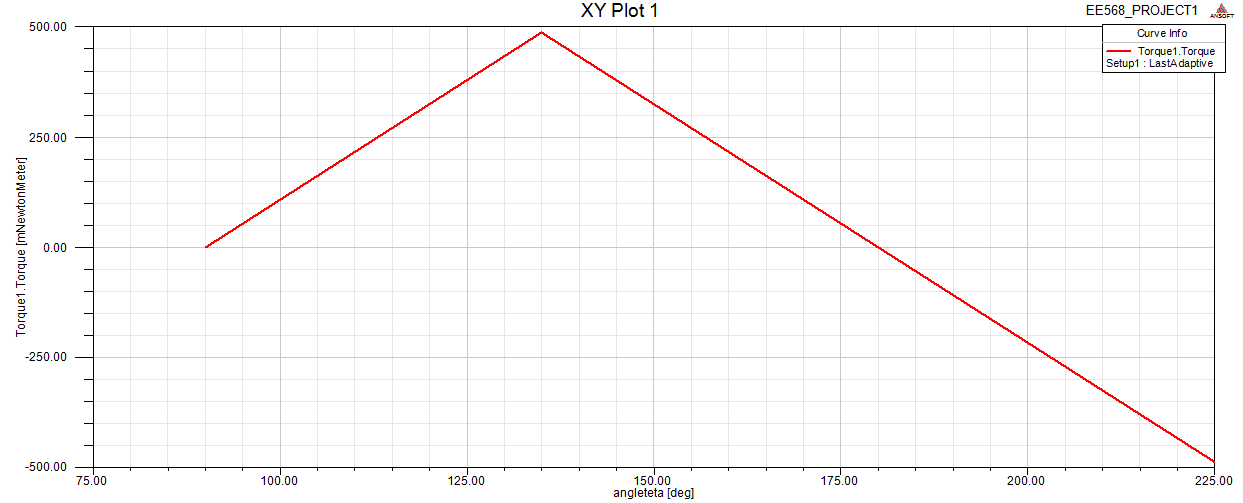
**d) The effects of fringing and saturating effects with the linear and non-linear materials**

4. Control Method

plot | sin(x) - 0.33 sin(3 x) + 0.2 sin(5 x) - 0.14 sin(7 x)







5. Motion Animation