Project 1

Yusuf Basri Yılmaz

8 March 2020

1 Introduction

In this report, torque in a variable reluctance machine is examined. Machine diameters given in Figure 1 are used in this study. Inductance and output torque of this machine is examined analytically and numerically. Effect of saturation of core material is observed by making analysis with iron as a linear material and M15-25G as a nonlinear material.

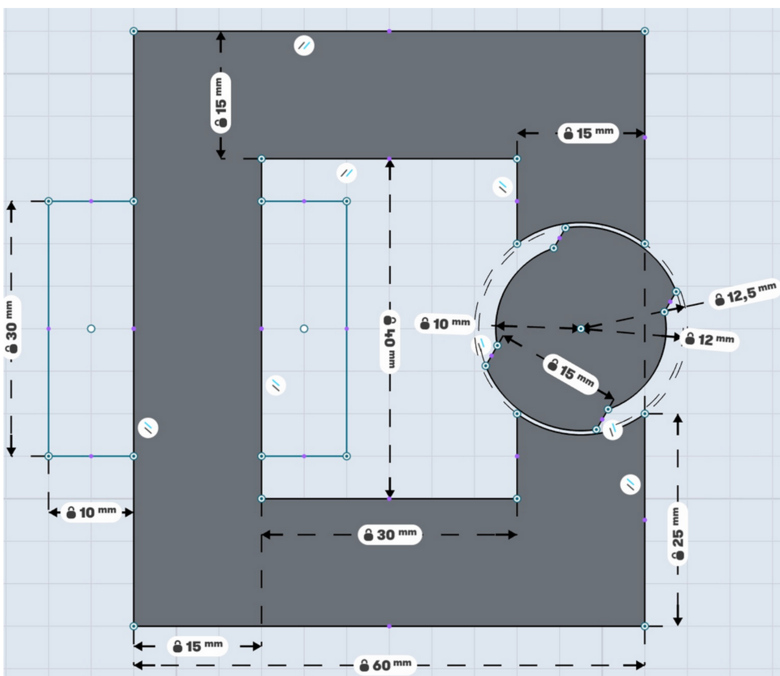

Figure 1: Variable Reluctance Machine

2 Analytical Results

In this part, reluctance and inductance are calculated analytically. By using these results, generated torque is calculated as well.

2.1 Reluctance And Inductance Calculation

In order to calculate reluctance according to position, effective air gap should be obtained for each position. For this purpose, geometry is examined carefully and three intervals are taken consider in effective air gap calculation. First interval is between 0 and 74 degrees. At 0 degree effective air gap is minimum and at 74 degree it is maximum. Between these two angles, reluctance change is assumed linearly. So, the effect of pointed corner is ignored. On the other hand, effective air gap is constant and maximum between 74 and 106 degrees.

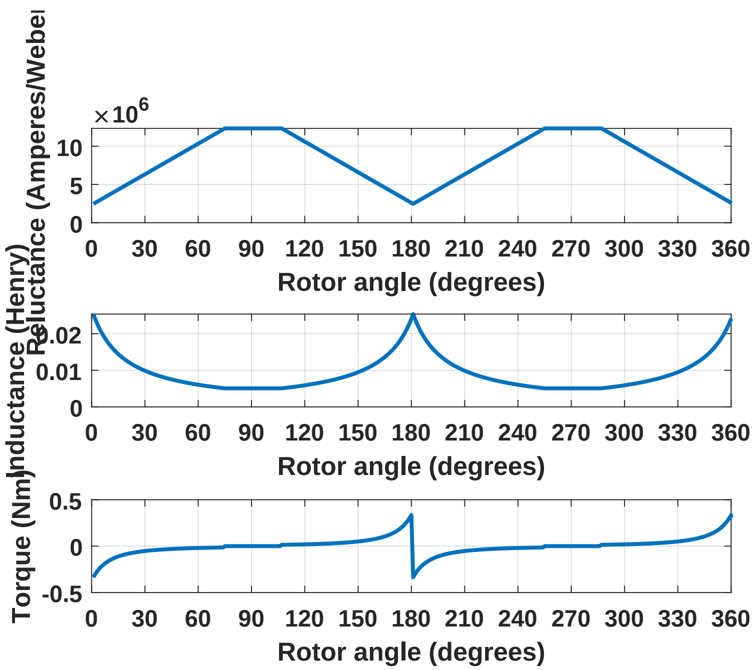

Figure 2: Analitical Results

Furthermore, effective air gap decreases linearly between 106 and 180 degrees. Moreover, its frequency is double due to symmetry of rotor (1 pole pair).Effective air gap between 180 and 360 degrees is same with the one between 0 and 180 degrees. After effective air gap is obtained according to position, reluctance can be obtained by using (1),

$$R = \frac{g}{\mu_0 A_{core}} \tag{1}$$

where g is effective air gap length, mu_0 is permeability of vacuum and A_{core} is cross sectional area of core. Resulting reluctance is given in Figure 2. Then, inductance can be found by using (2) and is given in Figure 2. All these calculations are performed in MATLAB.

$$L = \frac{N^2}{R} \tag{2}$$

2.2 Torque Calculation

Torque calculation is performed by using (3). This process is performed analytically in MATLAB and is given in Figure 2.

$$T = 0.5 i^2 \Delta L \tag{3}$$

ΔL is derived incrementally. In this study, for each one degree, inductance is calculated and corresponding torque is obtained. However, results are not as expected. This is why pointed corner of rotor is ignored in calculations and it causes unexpected harmonics. 2nd harmonic of this resulting torque is approximately the one which is expected.

2.3 A method to Improve Analytic Results

Determining a coefficient is a rapid method to improve results. According to this coefficient, effective core area is calculated and results are obtained by using this effective core area.

3 FEA Results for Linear Material

3.1 Flux Density Vector

At 0, 45 and 90 degree, flux vectors are given in Figures 3, 4 and 7 respectively. Each figure are observed with same maximum value which is 1.3 Tesla in order to see differences between each condition. At zero degree, its magnitude is higher since reluctance is lower. Samely, at 90 degree its magnitude is lower since reluctance is higher at this position. At 0 degree, it can be seen that flux vectors follow shorter way and it can be seen that it follows inner part of C-core. At 45 degree, flux follows the way with minimum reluctance as can be seen in Figure.

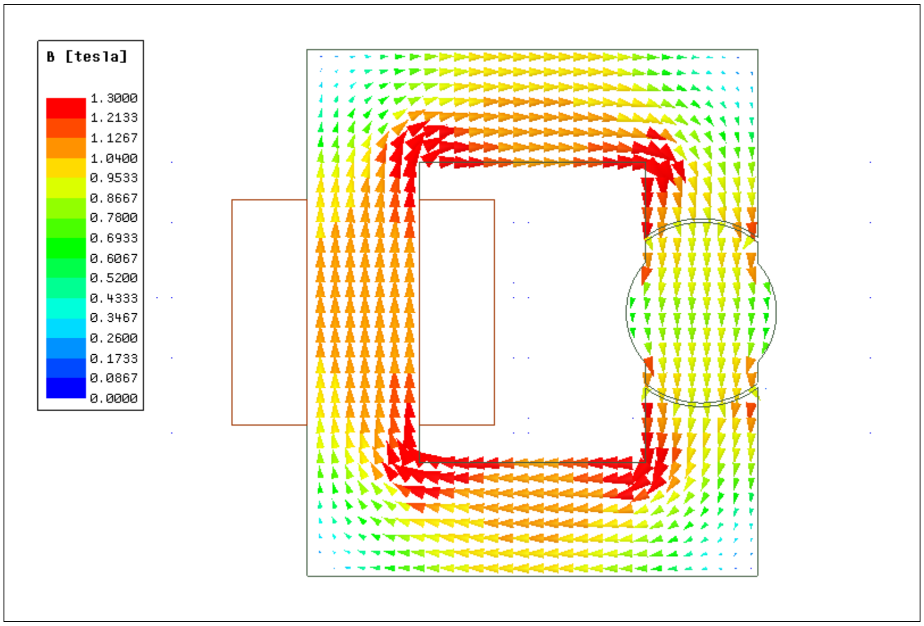

Figure 3: Flux vector in 0 degree (linear)

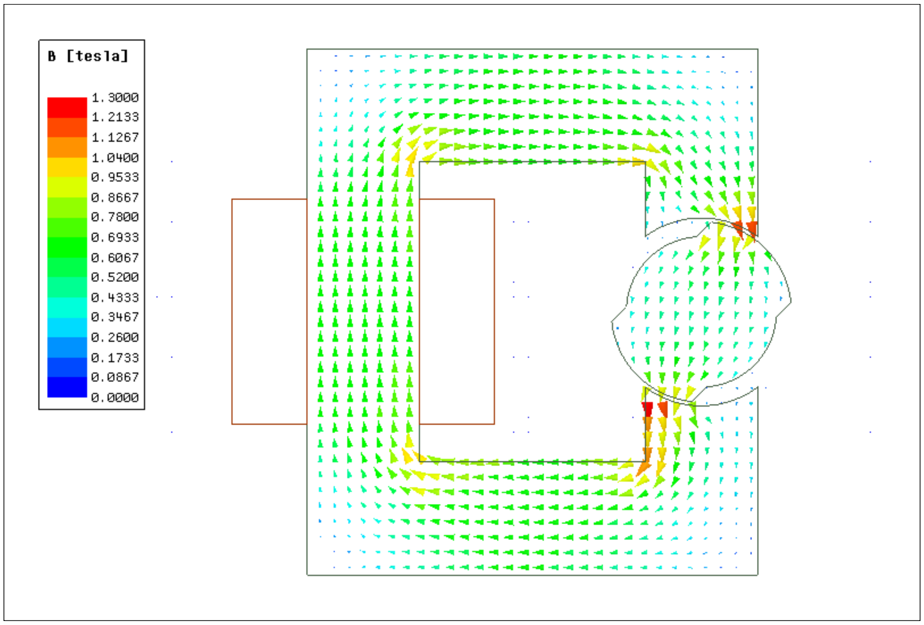

Figure 4: Flux vector in 45 degree (linear)

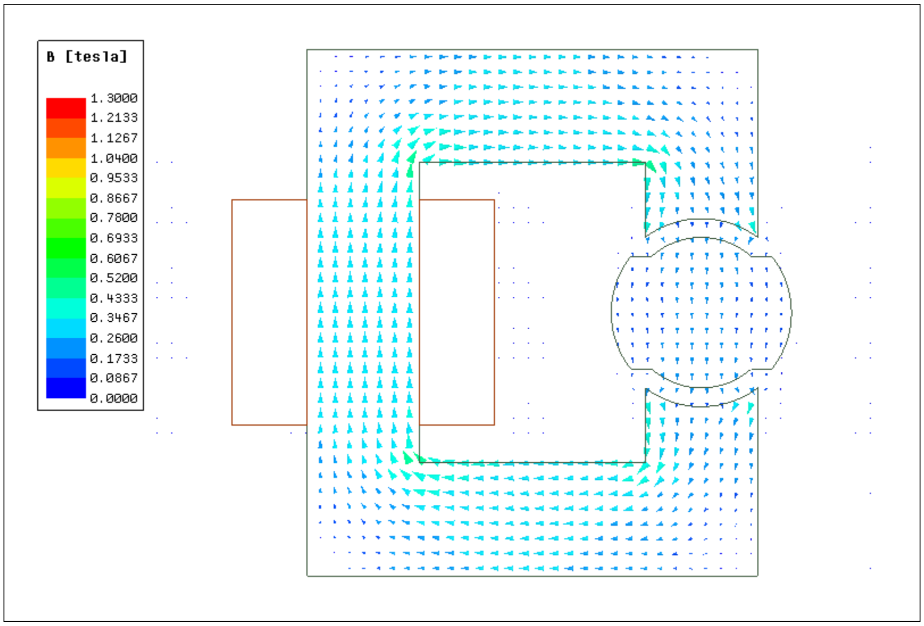

Figure 5: Flux vector in 90 degree (linear)

3.2 Energy and Inductance Calculation

FEA inductance results are approximately equal to analytical results for each position. In FEA, energy is calculated by using calculator tab of software. These results are approximately equal to results obtained by using the formula $E = 0.5i^2L$.

3.3 Torque Calculation

Generated torque for linear core material is given in figure 8. Analytical results and FEA result are different. This is why pointed corner of rotor is ignored. Thus, unexpected harmonics are included to torque. Second harmonic of analytical result is approximately equal to FEA result.

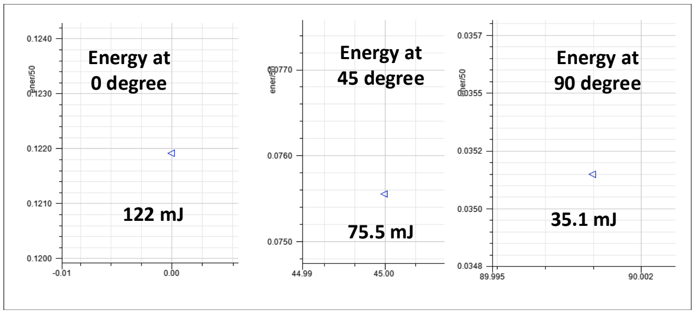

Figure 6: Energy for three positions (linear)

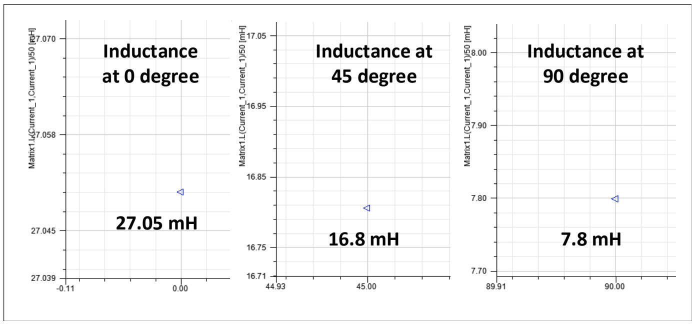

Figure 7: Inductance for three positions (linear)

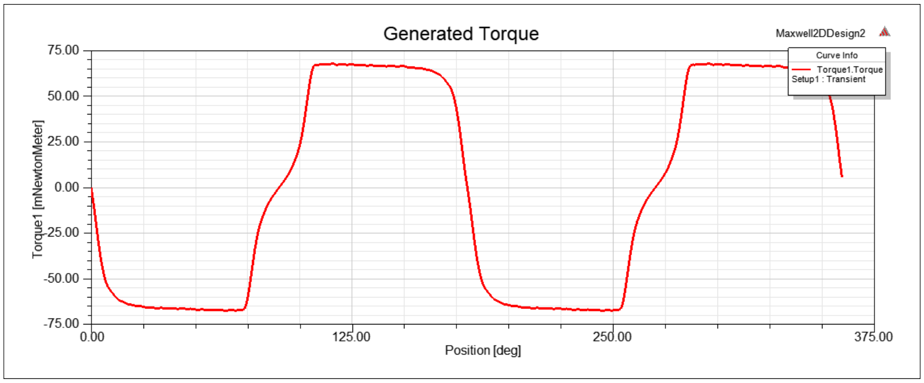

Figure 8: Torque according to position

4 FEA results for nonlinear material

In order to see the effect of nonlinear material, in this section M15-25G is used as a nonlinear core material. Then, inductance, energy and torque results are compared.

4.1 Flux Density Vectors

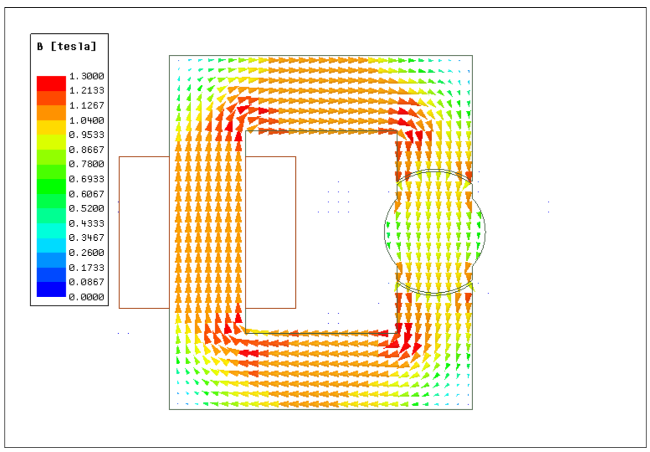

Figure 9: Flux vector in 0 degree (nonlinear)

4.2 Energy and Inductance Results

In Figure 13, results for 45 degree and 90 degree are given reversely. At 45 degree, inductance should be 17.03 mH and at 90 degree it should be 7.84 mH.

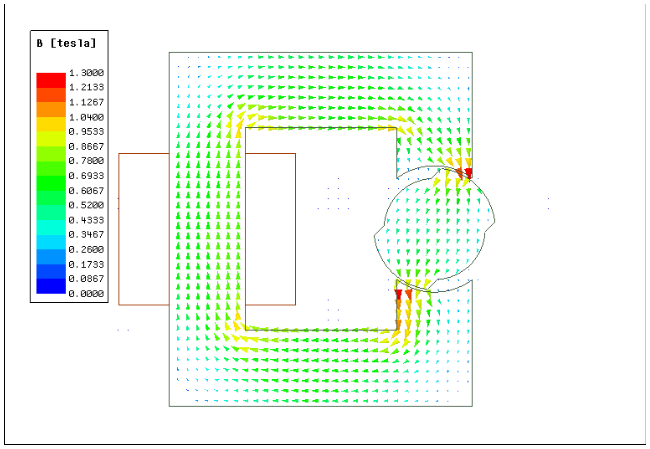

Figure 10: Flux vector in 45 degree (nonlinear)

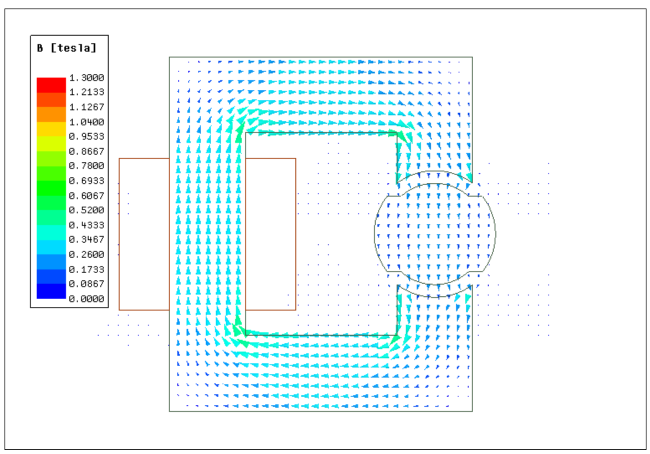

Figure 11: Flux vector in 90 degree (nonlinear)

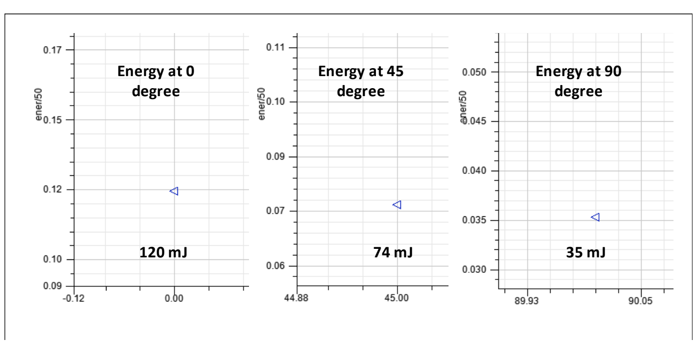

Figure 12: Energy for three positions (nonlinear)

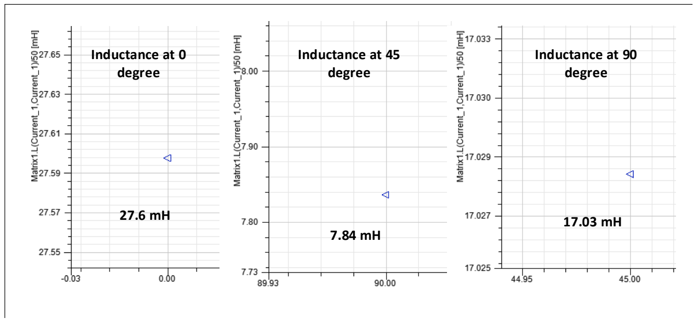

Figure 13: Inductance for three positions (nonlinear)

4.3 Torque Results

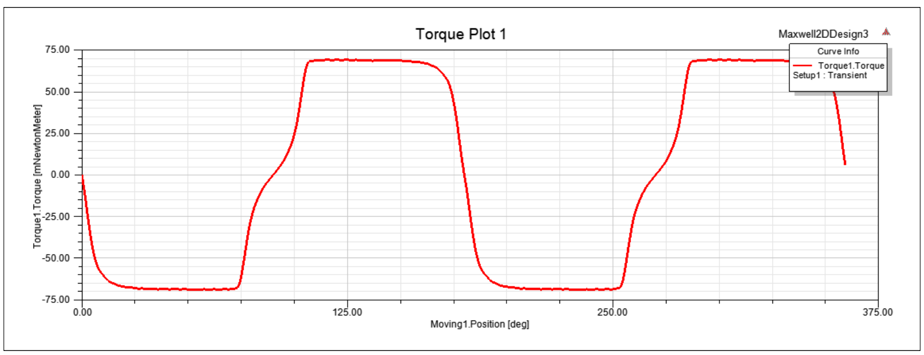

Figure 14: Torque according to position (nonlinear)

4.4 Comparison

It is expected a decrease in the inductance and energy. However, in this case results are approximately equal to each other for linear and nonlinear core. The main result is that machine is not saturated when 3A is applied to winding. Due to change of material, another change is expected in inductance and energy as well. However, properties of materials are approximate so results are close to each other. Samely, torque outputs are same as well. On the other hand, torque may decrease in any saturation condition. Saturation occurs in d-axis of the machine. Thus, d-axis inductance decreases more than q-axis inductance. Then, the difference between d and q axis inductance and torque decreases.

5 Control method

In order to control this machine, input current can be applied as a PWM. Firstly, position censor is a need for control process. Its initially used in order to allign initial position of the machine such as 45 or -45 degree. Then machine is electrified and starts to rotate. When position reaches to 0, 90 or -90 degree, current should be zero in order not to create negative torque. Thus, machine keeps its movement. For this purpose, the frequency and duty cycle of the current should be calculated easily. Since it can not be calculated by the designer, FEA results can not be given in this report.

6 Animation

Animation link (please Click)