Magnetic Analysis and Comparison of Switched Reluctance Motors with Different Stator Pole Shapes Using a 3D Finite Element Method

M. Sundaram, P. Navaneethan and M. Vasanthakumar

Abstract— Optimum design of Switched Reluctance Motor (SRM) and it control circuits require a knowledge of its parameters, Such as inductance, flux linkage and Torque. In this paper, a model of SRM has been developed and analysed with ANSYS Workbench. The variation of Inductance, flux density and directional force with respect to rotor position for two different stator pole shapes has been analysed. It is observed that the parallel slot type stator pole (model 2) gives the improved flux density and directional force/ Torque.

Index Terms— Switched Reluctance Motor, ANSYS, Flux linkage, Directional Force/Torque.

1 INTRODUCTION

The theory of motor with variable reluctance has been started to be used since 1980's for the variable or adjusted speed application and the use of these motors started to be very popular in engineering applications. The advantages brought by the cheap and powerful switching elements enabled the re-discovery of this motor. [2]

Many advanced manufacturing processes require smooth, high precision and/or high speed robotic manipulation in 3D space. Electrical Motors, as energy conversion devices, are widely used in industrial applications.

The simulation and experimental investigations of the electromagnetic field distribution are one of critical topics for developing electromagnetic products [8]

Due to exclusive features of the SRM such as lack of any coil or permanent magnetic on the rotor, simple structure and high reliability, which makes it a suitable candidate for operation in hard or sensitive conditions.

Although the FEM was a time-consuming and difficult method in the past, with contemporary high speed computers with large memory, the method can be used properly in analysis of electric machines. In addition, various commercial finite-element packages ANSYS Workbench have been so far developed for this purpose. [6]

2 THE PARAMETRIC SIMULATION MODEL

In order to analyze the SRM by ANSYS Workbench, the geometrical model of the motor should be plotted at first and appropriate materials are assigned to different regions. The SRM has a complicated configuration and it is cumbersome and time-consuming to draw the geometrical model every time before simulation. This is not practical when the simulation model is supposed to be used in optimal design of the SRM where the design process should be repeated frequently. Therefore, a parametric geometric model is desirable [6].

With a reasonable approximate, the whole geometric structure of SRM can be generated by geometric parameters, including radius of different parts of the motor, stator and rotor pole arc lengths. The values of physical changes of SRM with 6/4 pole are shown in the Table 1. The 2D cross section, size variables and values of 6/4 SRM are given is shown in Fig. 1 [1]. The two different stator pole configuration were taken into analyse, the cross section, size variables and values for a different pole configuration for first model is given in the Fig. 2. with dimensional values in Table 2. and for the second model is given in Fig 3. with dimensional values in Table 3 [4, 5].

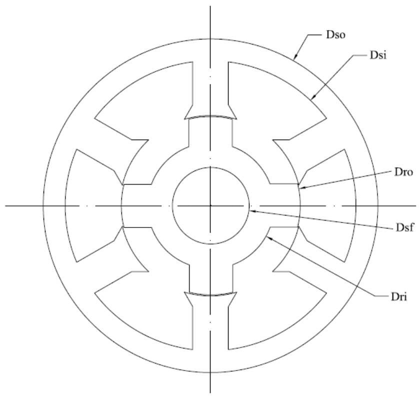

Fig. 1. 6/4 Switched Reluctance Motor Geometry

TABLE 1

THE MAIN DIMENSIONS OF SR MOTOR

Symbol	Meaning and Unit	Value
Dso	Stator outer diameter (mm)	122.0
Dsi	Stator inner diameter (mm)	106.0
Dro	Rotor outer diameter (mm)	65.4
Dri	Rotor inner diameter (mm)	46.0
Dsf	Shaft diameter (mm)	28.0
lg	Air gap (mm)	0.3
Lstk	Stack length (mm)	15.0
ns	Stator pole number	6
nr	Rotor pole number	4
q	Number of phase	3

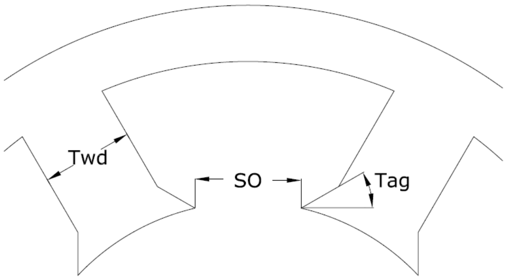

Fig. 2. Stator Pole Configuration of Model 1

TABLE 2

DETAILS OF STATOR POLE SHAPES OF MODEL 1

Symbol	Meaning and Unit	Value
Twd	Tooth Width (mm)	13
SO	Slot Open Length (mm)	15
Tag	Tooth Tang Angle (degree)	30

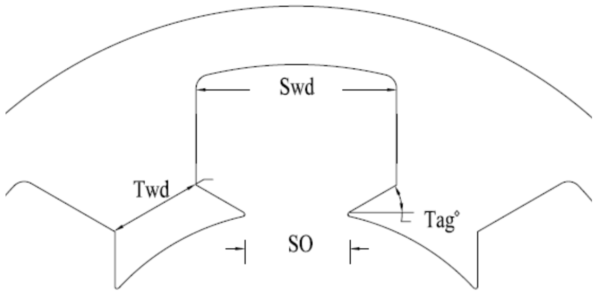

Fig. 3. Stator Pole Configuration of Model 2

TABLE 3

DETAILS OF STATOR POLE SHAPES OF MODEL 2

Symbol	Meaning and Unit	Value
Twd	Tooth Width (mm)	13
SO	Slot Open Length (mm)	15
Tag	Tooth Tang Angle (degree)	30
Swd	Slot Width (mm)	28

3 FINITE ELEMENT MODEL

The magnetic field inside the motor is determined by computing the magnetic vector potential A. This satisfies the non-linear Poisson's equation.

$$\frac{\partial}{\partial x}\left(\gamma\frac{\partial A}{\partial x}\right)+\frac{\partial}{\partial y}\left(\gamma\frac{\partial A}{\partial y}\right)+\frac{\partial}{\partial z}\left(\gamma\frac{\partial A}{\partial z}\right)=-J \qquad (1)$$

in a three-dimensional Cartesian system where γ is the magnetic reluctivity and J is the current density vector. The energy functional is a generalized from of a linear technique

$$F=\int_V\int_0^B \overline{H}.d\overline{B}dv-\int_V\int_0^A \overline{J}.d\overline{A}dv \qquad (2)$$

where B magnetic flux density in Tesla (T), H magnetic field intensity in Amps per meter (V/m), J Current density in Amps per square meter (A/m^2)[3].

The 3D Finite Element Method (FEM) Analysis of SR motor is carried out with help of Ansys workbench with the following assumptions

- The current density within any conductor is uniform.
- Hysteresis effects are neglected.
- The induced conduction current in iron is neglected because of the relatively high resistance offered by steel laminations for eddy currents in the axial direction.

The simulation and experimental investigations of the electromagnetic field distribution of SR motor are analyzed with help of what-if analysis for different rotor positions under different excitation Current.

Torque characteristic is one of the most important electromagnetic characteristics of SRM, which can be used in calculation of average torque and torque ripple. In fact, this static characteristic shows torque exerting on the rotor for different rotor positions. Direct calculation of torque in SRM with analytical method is impossible. Usually, torque is derived from the flux-linkage characteristic of phase. However, analytical methods cannot model precisely the region in where the stator and rotor poles begin to overlap, so prediction of the static torque is faced with a problem in this region [9].

Using ANSYS Workbench, it is possible to predict the torque directly. It is just enough to exert Maxwell work torque boundary conditions on the rotor. [6]

4 RESULTS AND DISCUSSION

- The electromagnetic field quantities are independent of the z coordinate measured along the air gap.
- The iron regions are isotropic and the magnetization characteristics are single valued.
- The magnetic field is confined within the motor and the external contour of the stator periphery is treated as a line of zero vector potential.
- The tangential component of H and the normal component of B in the iron air boundary inside the machine are continuous.
- The variation of inductance for various rotor positions is shown in fig.4. For model 2 it is found that in aligned position the variation of self inductance is minimum.
- The flux density variation for the both model is shown in fig.5. In the model 2 variation of flux density is found less, will give more torque.
- Comparison of fig. 7 and fig. 8 gives the result of improvement of total force on rotor in model 2.
- The variation of directional force/torque along the X axis is shown in fig. 9 and fig. 10 it indicates that model 2 will give more torque than model1.
- The Directional force/torque along y-axis from fig. 11 and fig. 12 can be found more in model-2.
- The flux density variation along motor body for both models is shown in fig. 13 and fig. 14. In model 2 it is clear that 'B' is increased.

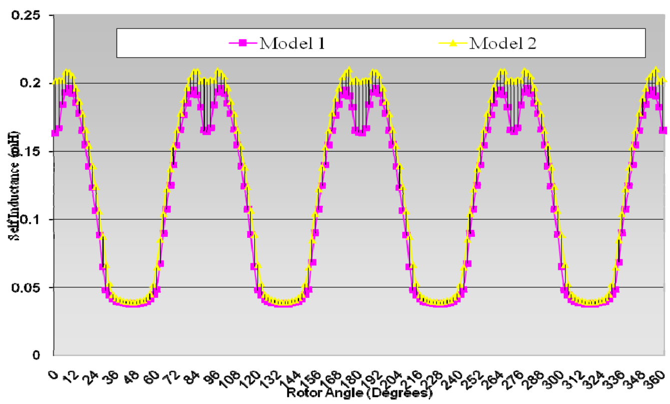

Fig. 4. Self Inductance of winding at various Rotor positions

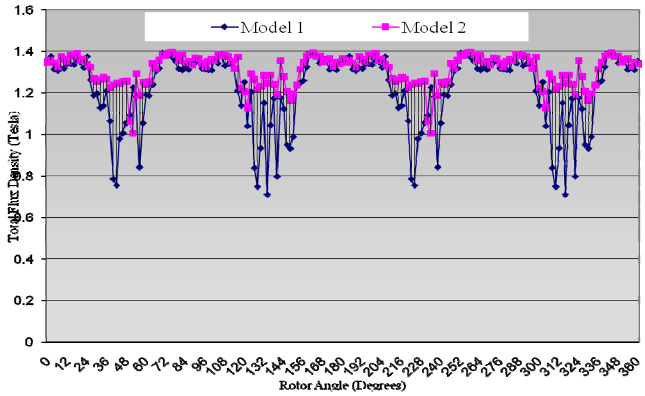

Fig. 5. Flux Density Comparison at various Rotor positions

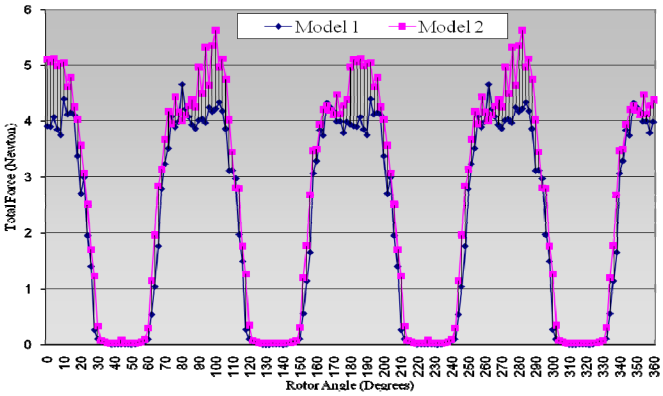

Fig. 6. Total force Comparison at various rotor positions

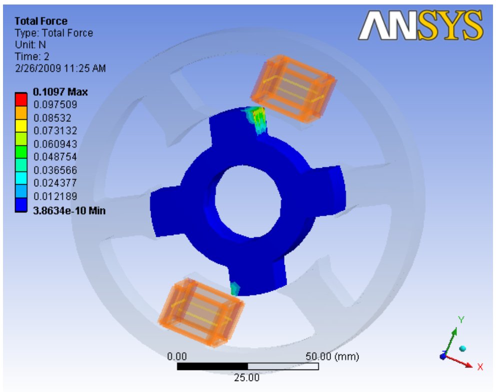

Fig. 7. Total Force in Rotor for Model 1

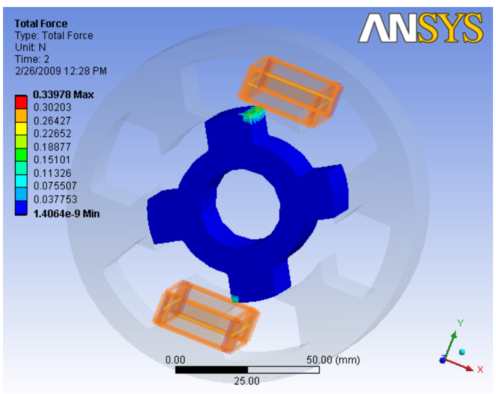

Fig. 8. Total Force in Rotor for Model 2

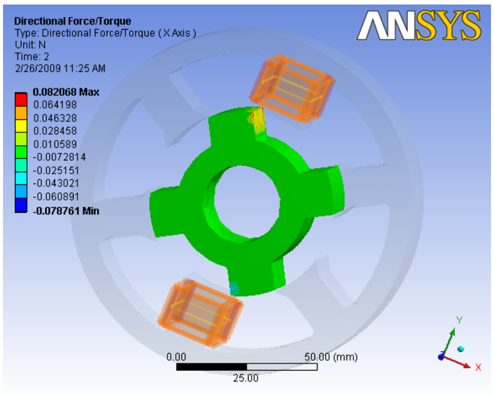

Fig. 9. Directional Force/Torque along X-axis in Rotor for Model 1

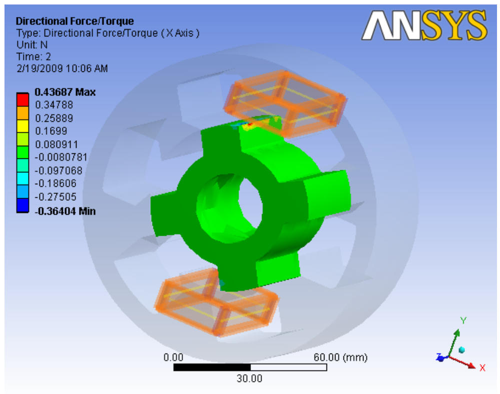

Fig. 10. Directional Force/Torque along X-axis in Rotor for model 2

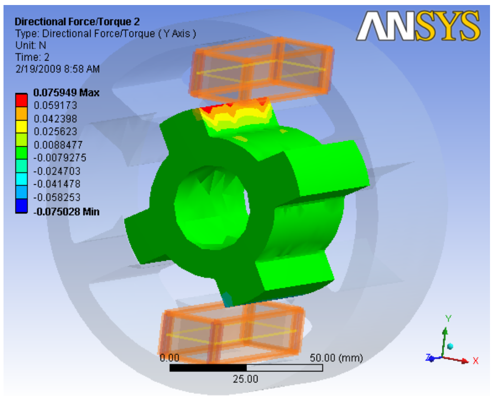

Fig. 11. Directional Force/Torque along Y-axis in Rotor for model 1

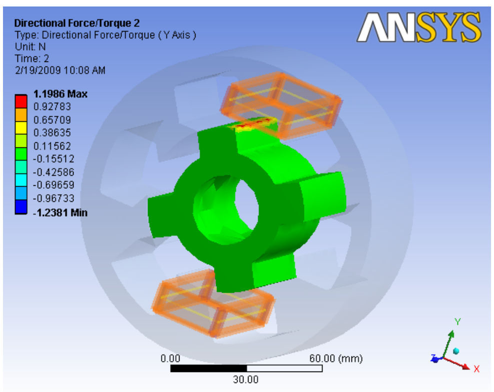

Fig. 12. Directional Force/Torque along Y-axis in Rotor for Model 2

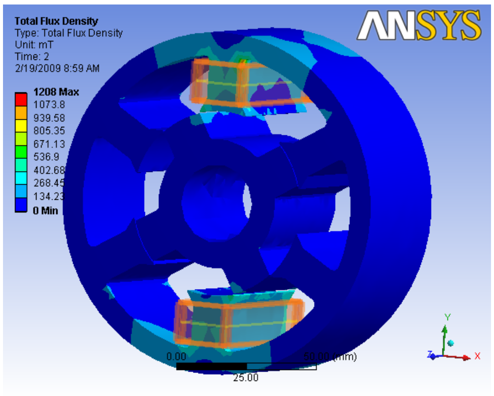

Fig. 13. Variation of Flux Density for Model 1

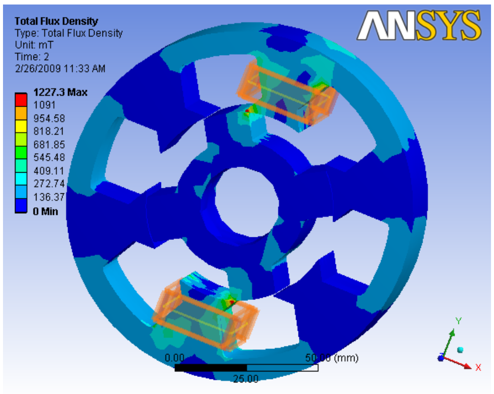

Fig. 14. Variation of Flux Density for Model 2

5 Conclusion

In this paper three-dimensional magnetic analysis of a switched reluctance motor has been given. From the results of analysis the variation of inductance, flux density & directional force along X, Y axis of both the model have been predicted. This study can be used for further modification of physical size of the motor to get more improved performance and to manufacture the SRM.

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