



# **Simulation and Magnetic Analysis of Switched Reluctance Motor with Various Rotor Pole Shapes Using Finite Element Method**

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**ABSTRACT:** Optimum design of Switched Reluctance Motor (SRM) and its control circuits require a knowledge of its parameters, such as inductance, flux linkage and torque. A model of SRM has been developed and analysed with COMSOL Workbench. The variation of flux density and directional force with respect to stator position for different rotor pole shapes has been analysed. From the results of analysis the variation of flux density and directional force of the models can be 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.

**KEYWORDS:** Switched Reluctance Motor, COMSOL, Finite element analysis, Flux density, Torque.

## **I. INTRODUCTION**

Recently, many industrial application fields are adopting the switched reluctance motor (SRM) for its number of advantages such as easy control, simple structure and low cost. In particular, the SRM is mainly applied to wind turbines and high-speed equipment because it can be operated in a wide speed range. To complement the existing permanent magnet machine with the issue of reliability and price, the SRM has been applied especially in the field of wind power. 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 simulation and experimental investigations of the electromagnetic field distribution are one of critical topics for developing electromagnetic products. 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 COMSOL Workbench have been so far developed for this purpose.

There were many previous works about the simulation of SRM. A brief description about the literature that have been carried is explained. M Sundaram et.al [1] presents the analysis of two geometries of SRM of different stator parameters keeping rotor parameters constant. Three dimensional magnetic analysis of SRM is done in this paper. From the results of analysis, the variation of inductance, flux density and 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 motor to get more improved performance and to manufacture SRM. F Soares et.al [2] presents the comparison of three phase induction motors with two different stator slot shapes of same ratings. The new design has resulted in a lower magnetising current, higher efficiency, good operating powerfactor and less drop in speed. The design modification was found to require less cost and need no complex manufacturing process. With the fixed operating conditions, the machine has been simulated in

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RMxpert. The efficiency of the motor with the proposed slot is significantly improved. Da-Woon Choi et.al [3] describes the simulation of a 6/4 SRM. All simulations are completely documented by their block diagram and corresponding special matlab functions and parameters quickly develop its model to the reader. Based on the developed model, simulation studies are performed and compared with measured phase currents either for hysteresis and voltage control strategies to validate the model. Dr. M. Balaji et.al [4] deals with the design of wind generator with the aim of reducing the torque ripple. Initially generator is mathematically designed and then simulation is performed in order to obtain the optimum design. Saphir Faid et.al [5] deals with the design of switched reluctance motor based on the aim of reducing the torque ripple. This paper presents a comparative study on torque ripple minimization in SRM with modified pole shapes such as stator pole taper, stator pole face with non-uniform air gap and pole shoe attached to rotor pole. Further this paper presents a detailed sensitivity analysis of the effect of different geometrical parameters that alter the pole face shapes on the performance of SRM. The analysis is performed using finite-element method considering average torque and torque ripple as performance parameters

## II.PARAMETRIC SIMULATION MODEL

In order to analyze the SRM by COMSOL Workbench, the geometrical model of the motor should be plotted at first and appropriate materials are assigned to different regions. 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. More geometrical models are plotted varying the rotor parameters keeping the stator shape constant as shown in fig. 2.

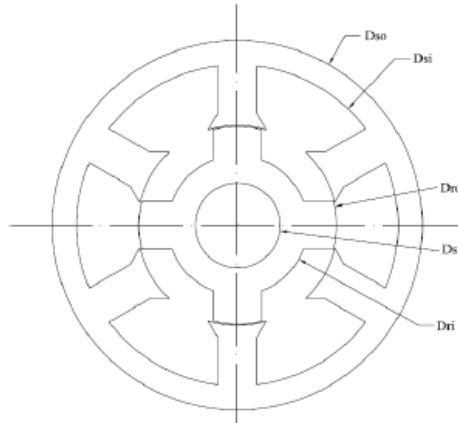


Fig. 1 6/4 SRM Geometry

TABLE I

Main Dimensions of SRM		
Symbol	Meaning and Unit	Value
Dso	Stator Outer Diameter (mm)	125.4
Dsi	Stator Inner Diameter(mm)	120
Dro	Rotor Outer Diameter(mm)	82.08
Dri	Rotor Inner Diameter(mm)	67.94
Dst	Shaft Diameter (mm)	28
Lg	Air gap (mm)	0.5
Rstk	Stack Length (mm)	125
Ns	No: of Stator poles	6
Nr	No: of rotor poles	4
<i>q</i>	No: of phases	3

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So as to perform a comparative analysis of Switched Reluctance Motor, four different SRM structures are drawn keeping the above mentioned dimensions constant and varying the rotor shapes as shown in figs. 2.

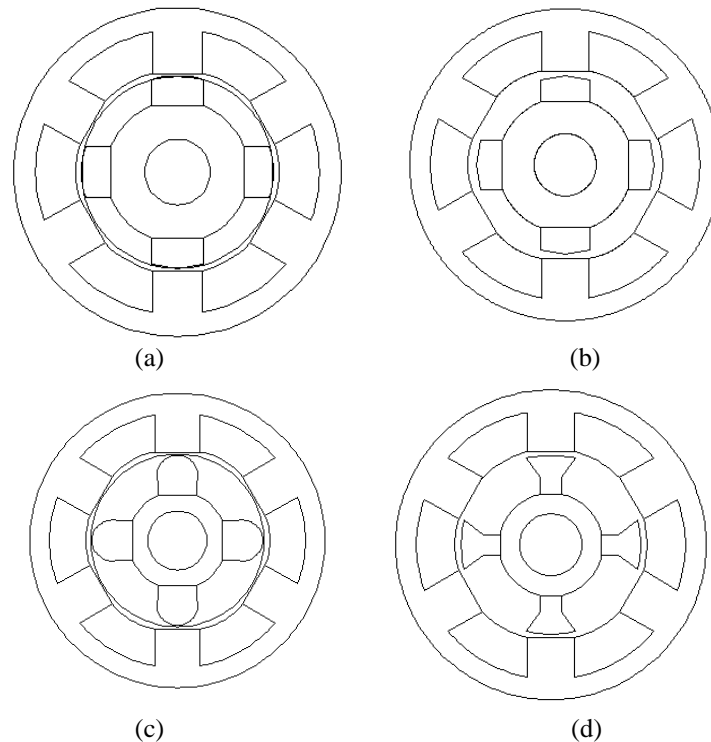


Fig 2. Configurations of SRM

### III. FINITE ELEMENT ANALYSIS

The 3D Finite Element Method (FEM) Analysis of SR motor is carried out with help of COMSOL workbench. The simulation and experimental investigations of the electromagnetic field distribution of SR motor are analyzed with help of what-if analysis for different rotor shapes under constant stator shapes and excitation. Torque characteristic is one of the most important electromagnetic characteristics of SRM, which can be used in calculation of average torque and torque ripple. 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. Using COMSOL Workbench, it is possible to predict the torque directly. The torque is computed in COMSOL using the Maxwell's stress tensor method given by

$$T = \int_B (r - r_0) \times (n_1 T_2) dS$$

where  $r_0$  is the point on the axis of rotation and  $n$  is the unit vector to the surface of  $S$ .

### IV. SIMULATION OUTPUTS

The cadd drawings are imported to the software COMSOL and simulation procedures are performed so as to obtain the static and transient characteristics.

#### 1. Static characteristics

The cadd drawings are imported to the software COMSOL and excitation is given to stator poles and rotor aligns with the excited stator poles. A static characteristic shows the aligned position of rotor poles with the excited stator poles

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along with the flux linkage. The variation in magnitude of flux density can be observed. The scale of flux density is given in the characteristics and based on this; comparison of flux density of four SRM structures can be obtained. Referring to figure 3(a) V1, V6 and V4, V3 winding slots are excited therefore teeth A and D get magnetized. So rotor will align in minimum reluctance position.

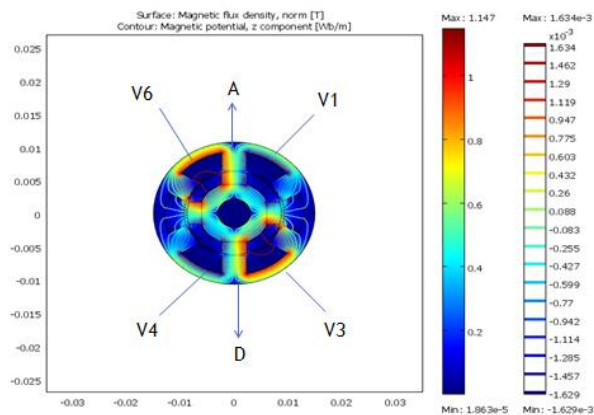


Fig 3. Static characteristics of fig. 2(a)

## 2. Transient characteristics

Transient characteristics clearly explain the working of SRM. Periodic variation of excitation is done and rotor tries to align in the max flux density region (minimum reluctance region). The variation of flux density as per the change in excitation and the movement of rotor towards the maximum flux density position can be observed.

## V. RESULT AND DISCUSSION

The torque characteristics of SRM depends on the stator rotor pole overlap angle, pole geometry, material properties, number of poles, and number of phases. The torque output and torque ripple of SRM are sensitive to stator and rotor pole arcs. Average torque and torque ripple are considered as performance measures while determining optimum pole arc. From the results of simulation, the SRM structure giving the maximum torque output and minimum torque ripple is find out giving consideration to copper loss. This chapter focuses on computational intelligence based optimization techniques combined with static finite element simulation for determination of optimal pole shapes of SRM.

### 1. Analysis of Torque characteristics

TABLE I

Tabulation of maximum torque values	
SRM configuration	Max. Torque (Nm)
1(a)	2.6
1(b)	0.075
1(c)	0.32
1(d)	0.145

Table I gives the tabulation of max values of torque output. Torque characteristics of each SRM are shown below.

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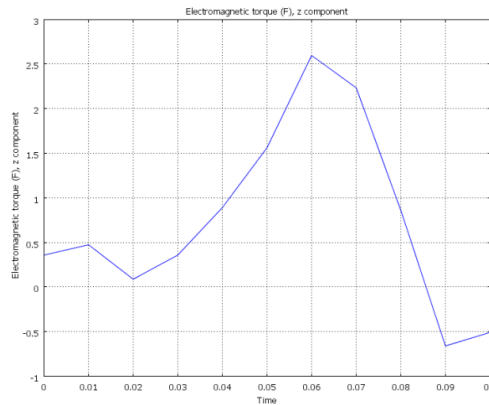


Fig. 4(a) Torque characteristics of fig. 1(a)

Fig 4(a) shows the torque output of fig 1(a). The maximum torque is obtained as 2.6 Nm.

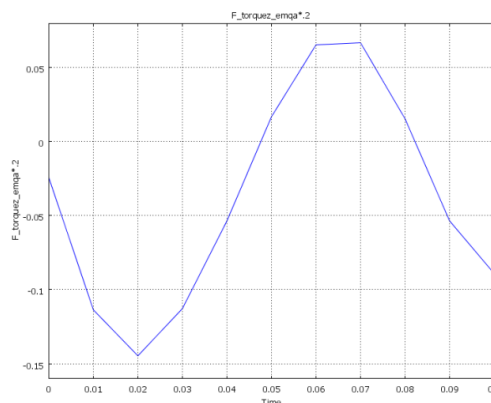


Fig. 4(b) Torque characteristics of fig. 1(b)

Fig 4(b) shows the torque output of fig 1(b). The maximum torque is obtained as 0.075 Nm. The maximum torque value is found to be reduced and this is due to the fringing effect caused due to the change in the rotor shape.

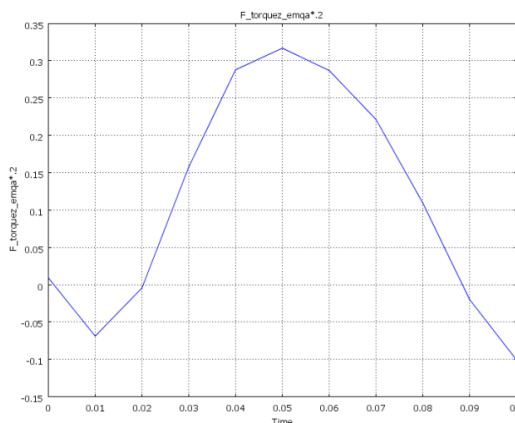


Fig. 4(c) Torque characteristics of fig. 1(c)

Fig 4(c) shows the torque output of fig 1(c). The maximum torque is obtained as 0.32 Nm

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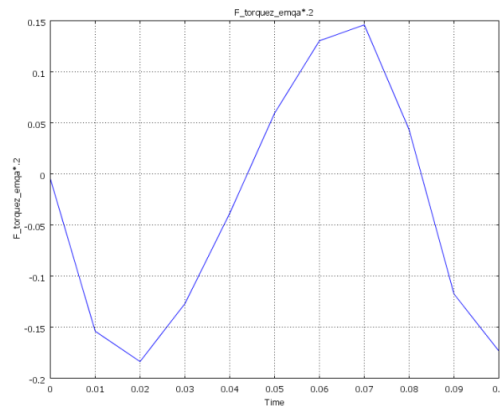


Fig. 4(d) Torque characteristics of fig. 1(d)

Fig 4(d) shows the torque output of fig 1(d). The maximum torque is obtained as 0.145 Nm. Max torque has been observed for the first structure Fig. 1(a) and is found to be 2.56 Nm. Maximum torque values been inferred from the torque curves comparison of which gives the best rotor structure which is expected to have max flux linkage and minimum fringing effect. This study can be used for further modification of physical size of the motor to get more improved performance and to manufacture the SRM.

## VI.CONCLUSION

In this paper three-dimensional magnetic analysis of a switched reluctance motor has been given. From the results of analysis the variation of flux density and torque of four different srm models 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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