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# 2-D Finite Element Optimization of 8/6 Switched Reluctance Motor (SRM)

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**Abstract:** Variable reluctance motors (VRM) are often also called switched reluctance machines to indicate the combination of a VRM and power electronics based circuit which is used to drive it. Variable reluctance motor is very simple in its structure. Although concept and design of VRMs is available for a long time, recently these types of machines are started using in various engineering applications due to its advantages. Usage of these machines is limited by the non-availability of accurate control circuits. This paper deals with design of such an electric machine where the design process is carried using finite element Analysis (FEA). This finite element method is a method for solving partial differential equations. The method requires the discretization of the domain into sub regions or cells. This numerical method is applicable to a wide range of physical and engineering problems. FEA needs computer based model of device and its material properties for analysis. Design process is carried out by the estimation of flux distribution and calculation of inductance value of the exciting or primary winding of the machine. This kind of procedure is done to optimize the design of switched reluctance motor using finite element analysis.

**Key words:** *Reluctance motor, optimization, FEA;*

## INTRODUCTION

A theory is a general statement of principle abstracted from observation. A model is derived based on theory. The derived model will be effective if that model is simple, realistic and it should be easier to be understood. Model will gain scope based on the relevant theory. If the model includes all the aspects of theory then the conclusion derived should be accurate and effective.

The concept of Switched reluctance motor is one of the most important parts of electrical engineering. The aim of present design is to find out the parameters using study of flux distribution through the knowledge of reluctance motor theory [02]. The study is carried out using finite element method (FEM). This method involves lot of mathematical calculations, which needs effective tool to solve. ANSYS is the software package used for high performance numerical computation and visualization. Due to the multiple advantages of ANSYS, it is used for present Design.

## OBJECTIVE

Developing a computer simulation to model of 8/6 pole SRM in order to optimize the system performance and to ensure that it will function within acceptable parameters to various disturbances [01] is the objective of this paper. To accomplish this we will create a mathematical model of the system including its inputs, outputs and disturbances. The model will be tested for its response for its inputs and the value of the reactance of the winding is found using the flux distribution.

Switched reluctance motor (SRM) is a combination of Switching inverter and Variable reluctance motor (VRM). In a VRM, Stator winding inductances are functions of position of rotor and angular position of rotor [05]. Position of rotor is identified based on stator and rotor pole alignment whereas angular position of rotor is measured with respect to the magnetic pole axis. These are the two factors on which total torque produced in SRM depends on.

## PROBLEM DESCRIPTION

A good deal of attention has been paid in designing the SRM. The study of flux distribution by concentrating on the design constraints is well carried out. The major objective is to find out the inductance value using finite element method. Estimation of inductance value is done for both aligned and nonaligned position of rotor poles with stator poles. ANSYS is the right package used for FEA. The standard dimensions of the machine are considered from [01]. The required procedure and formulae are obtained from [03]. This is more advantages than the usual conventional method. This gives effective results for SRM design than the other methods.

### Finite Element Formulations

Finite element method (FEM) is advanced numerical, which can be applied for any field of engineering. It was developed by R.Courant in the year of 1943. It was first applied to get the solution for vibration problem. In olden days due to the non-availability of fast computing devices like digital computers, this method was not reached to all others. In 70’s, this methods was used for mainframes, aeronautics and other industries like automotive and defence. Now a days due to the availability of wide varieties of computing devices, methods like FEM and other advanced numerical methods were being used in almost all the areas in engineering. The first formulations were developed as matrix methods for structural analysis. This lead to the idea to approximate solids and Courant introduced an assembly of triangular elements and the minimum of potential energy to torsion problems. Clough introduced the term "finite element". Thus the initial development was done by engineers and later on its mathematical foundation was laid enabling its extension to other fields.

### Need for Numerical Analysis

Designers of electrical equipment for power applications have to satisfy the customer on a number of points .Criteria include low first cost, low operating cost, high efficiency, high reliability, minimum weight, close tolerance in specified parameters, ability to tolerate occasional sever abnormal conditions, ability to operate satisfactorily from a non-sinusoidal supply. It will be clear that in many cases, it is essential to be able to analyze any proposed design in considerable detail, so that a near optimum may be obtained. This becomes especially important for large or special purpose equipment where cut and try methods are impossible. Many of the critical factors mentioned above are dependent on magnetic and electric field distributions and calculation of these quantities to the accuracy now designed cannot be carried out by analytical procedures. The difficulties of factors such as complicated geometry, saturation effects in iron. The presence of solid material in which eddy currents can be induced, and some cases, three dimensional effects mean that a numerical method is required.

### Working of FE model

FEM model is created based on points which are usually called nodes. These nodes will be represented in the form of point in co-ordinate system. The system may be either 2D or 3D. After formation of nodes a structure is obtained for model which is called mesh. Further analysis for required model will depends on the formation of mesh. The input for mesh are like current density or electric potential in case of preference being electromagnetic and temperature, specific heat, force, displacements in case of structural and thermal conditions. After defining input we can choose different types in analysis. It is possible to perform electric, magnetic, thermal & coupled field analysis using FEM. We can obtain results in the form of pictures, tables and graphs.

### Basic steps of FEM

Any problem solved using finite element method includes four steps named Discretization, Governing equation, solving the equation and obtaining appropriate form of results. Developed model of machine is subdivided into small elements with respect to boundary of the model is known as discretization. After, Equation will be framed individually for each finite element. To get solution the result of each equation will be added. The same method will be implemented for any problem solved using finite element method.

### General procedure for FEM

The basic and general procedure involved in fem is as follows.

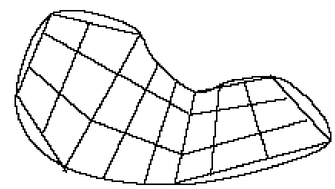
Identify the system (governing) equation. (Usually Differential Equation)

$$L(\varphi) = 0 \qquad (1)$$

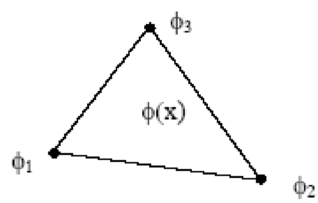
Introduce an integral form equation. According to Method of Weighted Residual Approach

$$\int_{\Omega} \psi L(\phi)\, d\Omega = 0 \qquad (2)$$

Discretize the domain of interest into elements. Fig: 1 a & b represents discretization



(a)




(b)

**Fig.1**. (a) Discretization into elements, (b).Triangular element

Introduce an approximation of the field variable over an element.

$$\phi(X) = N_1(X)\phi_1 + N_2(X)\phi_2 + N_3(X)\phi_3 \quad (3)$$

$\phi_1$: Nodal values of the field variable

$N_1$: Interpolation functions

Evaluate the integral form over each element.

$$[K]^e \{\phi\}^e = \{f\}^e \qquad (4)$$

Assemble the global matrix equation.

$$[K]\{\phi\} = \{F\} \qquad (5)$$

Solve the matrix equation to get the unknowns

$$\{\phi\} = [K]^{-1}\{F\} \qquad (6)$$

Calculate the values of interest from the approximate solution.

$$\text{e.g.} \quad \frac{\partial \phi}{\partial x}, \frac{\partial \phi}{\partial x} \text{ etc.} \qquad (7)$$

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**Switched Reluctance Motor**

The development in power electronics helped to replace the mechanical rectifier of the motor with electronics one. Due to the improvement in material science and various design methods, reluctance motors are entered in variable speed drive market. Due to the absence of rotor winding, efficiency of the motor will be high and can be operated at very high speeds. Due to various advantages of SRM it has been started using in most of industrial applications. Fig 2 represents the model of 2/2,2/4 and 2/6 SRM.

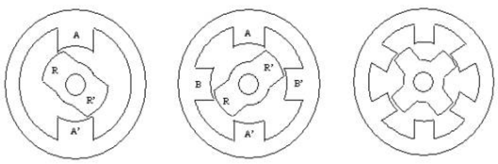


**Fig.2**. Switched Reluctance motor model

**Torque production and optimization**

From energy conversion loop of Switched reluctance motor, we can conclude that efficiency depends on two inductance values names $L_{max}$ and $L_{min}$. $L_{max}$ for phase 1 occurs if the rotor pole is aligned with any of the stator pol.

$$L_{max} = N^2 \mu \alpha RD / 2g \qquad (8)$$

Where αRD is the cross sectional area of the air gap and 2g is the total gap length in the magnetic circuit. Neglecting fringing, the inductance L(θ) will vary linearly with the air gap cross sectional area. Note that this idealization predicts that the inductance is zero when there is no overlap, but in actual practice there exists a value which is very less [06]. The torque equation of the two terms

$$T = ½\, i1^2\, dL(\theta)/d\theta + ½\, i2^2\, dL(\theta-90°)/d\theta \qquad (9)$$

As in any engineering situation, the final design for a specific application will involve a compromise between the varieties of options available to the designer [04]. Because control of SRMs is based on power electronics circuits, due to this we need to consider the additional design constraints to get accuracy in results.

As the total produced in switched reluctance motor is depends on various factors, it needs to be represented in design oriented form, i.e. for the purpose of optimization it can be represented as a function of $L_{max}$ and $L_{min.}$. We can write,

$$dL/d\theta = (L_{max}-L_{min})/\Delta\theta$$

$$= L_{max}/\Delta\theta( 1 – L_{min}/L_{max}) \quad (10)$$

Where Δθ is the angular displacement of the rotor between the positions of maximum and minimum phase inductance and is a function of rotor geometry only. The largest value of $L_{max}/L_{min}$ will produce high torque. To obtain this condition during the operation, we need to maximize the $L_{max}$ value and we need to minimize the $L_{min}$ value. But it is easier to reduce the $L_{min}$ rather than maximizing the $L_{max}$ value by changing the air gap length or by modifying the pole arc or we can do it by changing the length of the poles. In this paper optimization is achieved by changing the pole arc and considerable reduction has been shown in the value of $L_{min}$ value.

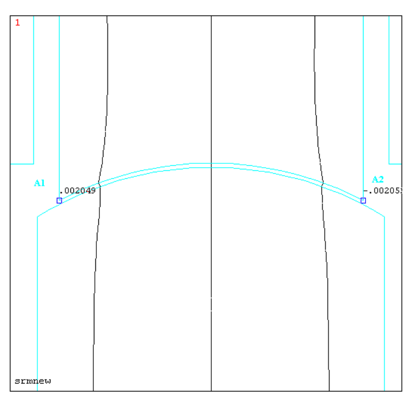
**RESULTS OF 8/6 SRM**

As described in the previous sections, all the basic requirements for designing the SRM are considered and an 8/6 SRM is considered for modeling based on its advantages over other types. The specifications of that model were as follows

**Table: 1.** Specifications of 8/6 SRM

| Design Parameter | Value |
|---|---|
| Stator core diameter | 190mm |
| Stator pole arc | 20 Deg |
| Air gap width | 3mm |
| Rotor pole tip diameter | 21mm |
| Current density values applied for windings | 312500 |

By using above mentioned dimensions in Table: 1, Switcher reluctance motor is modeled in ANSYS. Fig: 3 a, b & c represents the flux patterns obtained for aligned and non - aligned positions of switched reluctance motor using finite element analysis.



(a)

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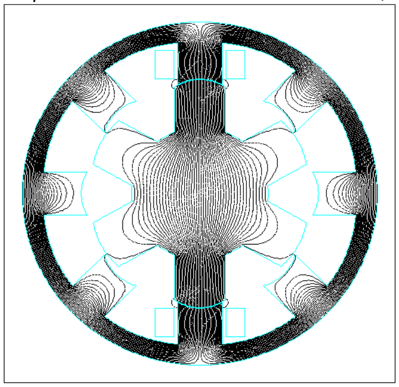

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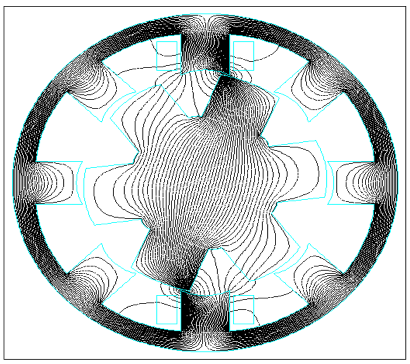

(c)

**Fig.3**. Flux plot for 50A with (a) & (b) stator pole aligned with rotor, (c) Stator pole non - aligned with rotor obtained in ANSYS for 8/6 SRM

By using above flux plots obtained by applying Finite Element Method flowing values are obtained for optimal design of 8/6 SRM.

$$L_{max} = 0.082\text{mH}$$

$$L_{min} = 0.0088\text{mH}$$

From above Values it is clear that considerable reduction is shown in $L_{min}$ value. Due to considerable reduction in $L_{min}$ value, the area of Energy conversion loop increases, which represents increase in the output of motor form the same input value. Losses in machine will be minimized due improvement in Lmin value, which represents the effectiveness of finite element analysis in electric machine design. Due to this design as the losses in machine reduces it can be operated with further higher speeds. Heat produced in machine also very less as the losses reduced due to its design.

## CONCLUSION

The design of the motor can be closely matched to the requirements of any application so that an absolute minimum cost is achieved for the complete drive system. The design results obtained will be more accurate than circuit model design of the machine. Innovative design has led to new solutions which have not been previously investigated. The proposed design is all easy to implement with the minimum of cost.

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