Optimizing The Magnetic Core Structure Of Multi-stack Switched Reluctance (SR) Motor Using Finite-Element Modeling

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Abstract—This proposal described the application of Finite Element Magnetic Method (FEMM) on analysis of optimizing the magnetic core structure of a multi-stack switched reluctance motor (SRM). The motor stack is modeled in Finite Element Magnetic Method (FEMM) package and the performance parameter computed such as inductance, resistance, flux linkage, voltage drop and etc. The pole widths of the stator is varied in steps to search for the optimum rotor pole width for a given stator pole width. After that flux linkage over current and rotor position versus torque index are plotted. The process is repeated for other stator pole widths until both optimum stator and rotor pole widths are obtained.

Keywords-Finite Element Magnetic Method, Switched Reluctance Motor

I. INTRODUCTION

Most of SR motor structures are reported as single stack type, where multi-phase pole-pairs which normally diametrically opposite are spaced evenly around the stator inner circumference. In other words, the spaces available are share evenly amongst the phases. Multi-stack design is common in stepper motor but not common in SR motor. In multi-stack each stack represents a phase. Multi-stack can has an odd number of poles as compared to single-stack motor must have even number of poles. For the pole windings, it can be connected in series or parallel and the implementation can be simplified for both low and high speed motor. In terms of size, multi-stack can be compared to single-stack design at the condition of same speed and power rating .The total pole cross-section area for each phase of both designs have to be the same for the same rating.

Switched reluctance motor drive present several advantage such as high efficiency, maximum operating speed, better performance of motor in terms of torque and inertia.[] For better performance it needs a small air gap. Switched reluctance motor is a type of motor which produce torque.

Torque is produced from the movement of stator and rotor and the combination of ideal stator and rotor will produced an optimum torque. On its stator windings, there are wound with field coil whereas there are no coils or magnet on its rotor. Usually switched reluctance motor have 3,4 or more phases. For same application needing a single direction of rotation, the two phase SR motor may be used due to cost reason. Lately, this motor type have meet the interest of customer because of its low cost and driver circuit which is cheaper and better in configuration compared to the other multi-phase configuration. This motor differs from the conventional motor in a few terms: [1]

- The stator is composed of two-stack or two parts which is magnetically independent.
- Stator has simple ring type winding
- The magnetic flux path per pole has a radial/axial loop.

SRM can be classified into two category; rotary SRMs and linear SRMs .Rotary SRMs can be divided into two parts which named radial field and axial field. Axial field have two subcategory that are single-stack and multi-stack .In this project axial field multistack are used. If the magnetic field path is perpendicular to the shaft, which may also be seen as along the radius of the cylindrical stator and rotor, the SRM is classified as radial field. When the flux path is along the axial direction, the machine is called an axial field SRM.[2]

Simulation software used to design the motor structure is Finite Element Magnetic Method (FEMM).FEMM is a finite element package for solving 2D planar and axisymmetric problem in low frequency magnetics and electrostatics. It is composed of a graphical pre-process; a graphical post-processor, a mesh generator and a solver. A scripting language, Lua 4.0 is integrated with the program. Lua helps to create batch runs, describe geometries

parametrically and perform optimization. This is one of the alternative way to find the torque index.[3]

Other than using FEMM, software used is Scilab/Simulink Xcos. Two methods to solve the current difficult problem which SCILAB accessing database in the SCILAB technology are presented. The first method uses Excel as the intermediary to achieve. The second method uses the features of the interface of SCILAB with C computer language which can access database. Using the second method, SCILAB can access database conveniently in the near future.[4]

II. DESCRIPTION OF MOTOR STRUCTURE

This paper present on how the magnitude of stator and rotor would affect the torque produces. The design produce has proven that torque produced is closely related to changes in the position of the stator and rotor. For this motor, both stator and rotor have a structure of salient pole which contribute to produce a high output torque. Torque is produced by the alignment tendency of poles. SRM has a doubly salient structure but there are no permanent magnets on the rotor. This paper uses a 6/6-pole rotor configuration. The rotor pole surface asymmetrically shaped so that ununiformed air gap between stator and rotor pole can be generated continuous positive torque at every rotor position.[5] Figure 1 show the structure of the motor and the initial position of stator and rotor. To rotate the stator and rotor, point on stator and rotor are selected and move according to the calculated angle. To rotate clockwise the angle must be in negative sign while to rotate counterclockwise angle must be in positive sign.
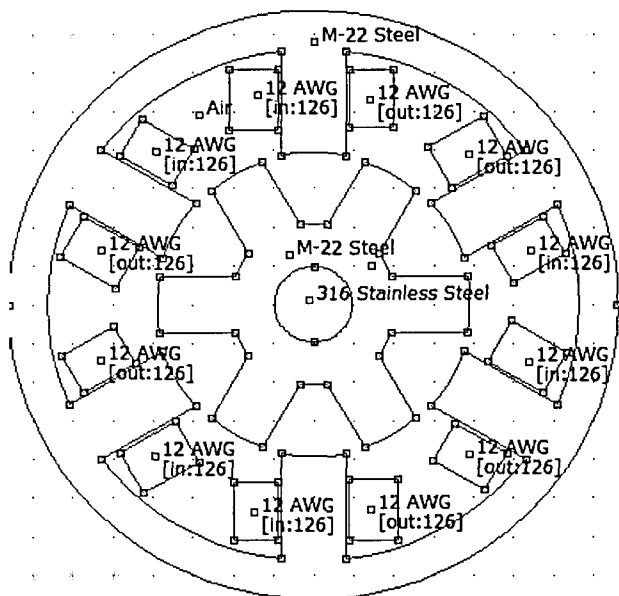

Figure 1

Stack length:	40mm
Stator pole arc:	24degree
Rotor pole arc:	22degree
Number of windings:	126turns
Resistance:	0.292Ω

The components used in this design are 316 stainless steel , M-22 steel, 12 AWG copper wire.

1. 316 Stainless steel

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low oxygen, high salinity, or poor circulation environments. It is also called corrosion-resistant steel or CRES when the alloy type and grade are not detailed, particularly in the aviation industry. Stainless steel differs from carbon steel by the amount of chromium present. Unprotected carbon steel rusts readily when exposed to air and moisture.[6]

2. M-22 steel

Usually M-22 is used in large motor and generator that is more than 100 HP, M-15 to M-47, have exceptionally low carbon content and have been processed at the mill to develop their magnetic properties. Most cable, the typical core loss is appreciably lower than the maximum core loss.[7]

3. 12 AWG copper wire

In this project, 12 AWG (American Wire Gauge) copper wires are used because small size of copper wire will be costly. The maximum current rating is 25 Amps in free air, maximum of 20 Amps as part of a 3 conductor cable.[8]

Table 1: Characteristics of 12 AWG wire

AWG	Diameter [mm]	Area [mm²]	Resistance [Ohms / 1000 ft]	Max Current [Amperes]	Max Frequency for 100% skin depth
12	2.05232	3.31	1.588	9.3	4150 Hz

A.   *Operation of the motor*

Initial position of stator and rotor are 24 degree and 22 degree. Initial current is set to 1ampere for current in and out. Angle used for overall simulation is 30 degree. For the starting performance stator and rotor are set to unaligned position. When rotor poles are aligned with the stator pole, this condition is called aligned position and when rotor pole is in the middle between the stator poles it is called unaligned position.

Once everything is set accordingly mesh analysis will operate. It is to generate a triangular mesh for the motor. After that, select the crank button to analyze the motor. All information will be displayed. To extract different sort of information it can be found from postprocessor. To see the flux linkage, torque and current at different point, just point anywhere on the motor model .To get the overall current, torque, rotor position and flux linkage, Lua script is import into the FEMM model .It will keep run to generate all the data. After half an hour all the data come out .The data are used to calculate torque for every different stator and rotor position .Then, graph of rotor position versus torque index are plotted. The range for rotor position is from 16-30 degree and stator from 18-30 degree. After all data plotted it show that the torque is increase proportionally with rotor position.

III. METHODOLOGY

The motor model   function is to generate the data. Lua script is run to obtain the parameter such as torque, flux linkage, current and inductance. After all the parameter are obtain ,it will be converted into Scilab script and will be execute in order to plot the curve of flux linkage over current and position over torque. In order to design the model, all the process must put in detailed flow of work in this project. It consists of the simulation part to get the desired result.

IV. RESULT AND DISCUSSION

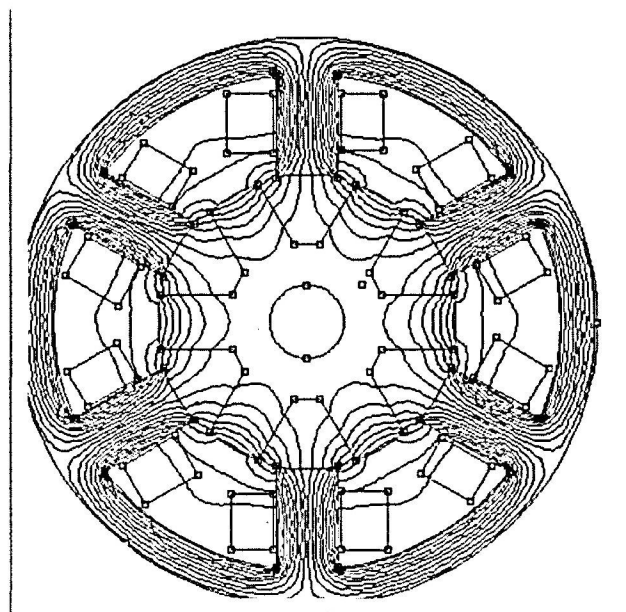The following model has been design and tested practically. It is used to find the initial parameter.

Figure 2: FEMM model

The model show in Figure 3 is set to 300W, 2000 rpm, 230V.This model is used to generate initial parameter such as inertia, flux and torque for every point. To get the final result Scilab function is used. SRM requires small air gap which is 0.373mm.The FE model are run manually to find the inductance and flux distribution. During computing the data, angle of rotor used are up to 30 degree only because in this project, only positive path are considered. Other than that, all the calculation are calculated in radian and then converted to degree.
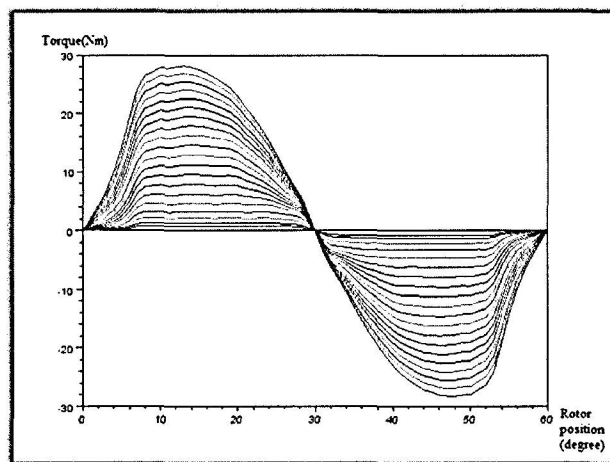

Figure 3: Torque versus Rotor position

Figure 3 above show the curve for torque versus position of rotor produce. When rotor pole is in aligned position with the stator poles, no torque is produced as rotor

is at higher inductance. In this case only positive torques are considered. The angle is set from 0 to 60 degree. Torque characteristics depend on the flux linkage as well as the rotor position. As the flux linkage is increase with the rotor position, positive torques are produce.
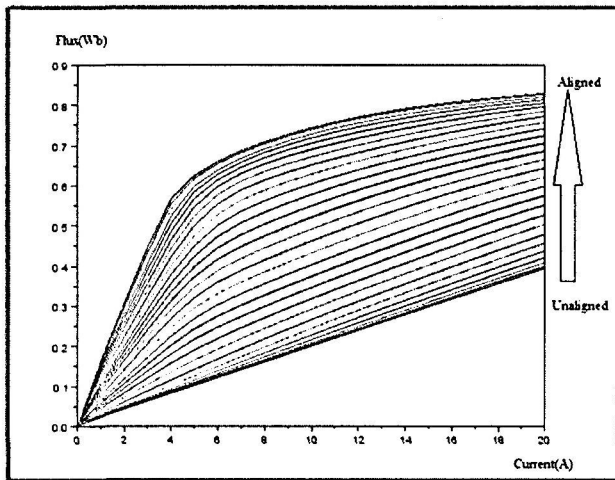
Figure 5 shows a few lines of flux linkage versus current. It consists of lines for 10, 20 and 30 degree of rotor position. As the position angle increase the value of the flux linkage also increase. At 10 degree it is in unaligned position due to large air gap.

Figure 4: Flux linkage versus current

Figure 4 show flux linkage versus current. The flux waveform is nearly flat-topped. The curves are plotted from unaligned position to aligned position .In SRM when one phase is aligned the other phase is unaligned. The relationship between flux linkage and current is nonlinear because of magnetic saturation. When rotor is at aligned position, the flux and inductance are generally higher, the stator and rotor poles can be highly saturated. When the rotor is at unaligned position, the magnetic flux is lower and the inductance is minimum . From this curve maximum flux linkage can be obtained. The flux linkage is increase when the current increase.
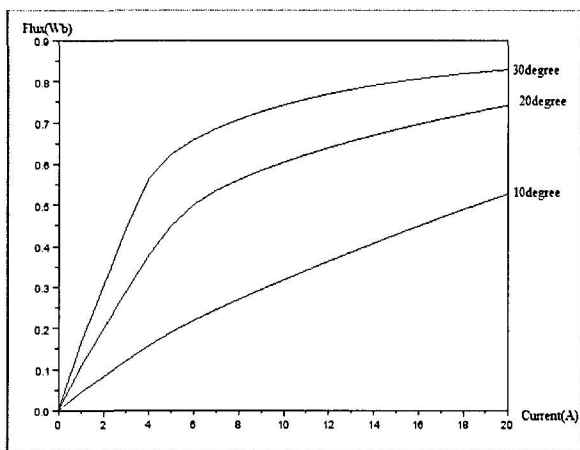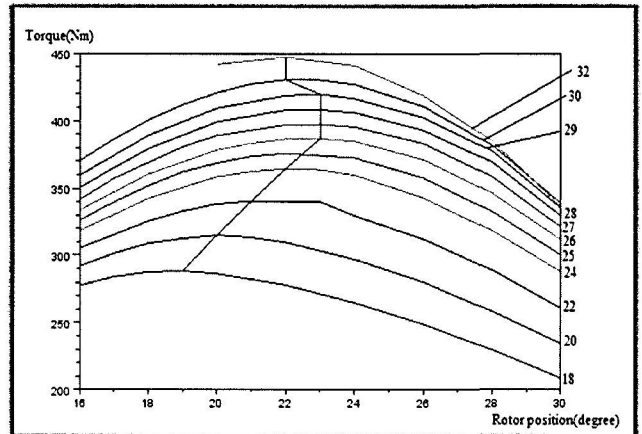

Figure 6: Torque versus Rotor position

Figure 6 depicts the graph of torque versus position of rotor. Position of stator are varied from 18-32 degree while rotor position are also varies from 16-30 degree for every stator angle. As the stator position is increase, the torque is also increase. To obtain an optimum torque, the script model need to be run in FEMM to extract the data needed. From this, the value of torque, current and flux linkage are obtained. At first stator position are varied from 18-32 in order to get the initial structure for the next step. After that the rotor position are varied from 16-30 for every angle of stator which have been change before. Then the script will produce the value of current, flux linkage and torque. This value will be convert into Scilab script and once again need to be execute to obtain the final torque index for that position of stator and rotor. This step will continue to get the torque value to plot the next curve.

Figure 7: The three highest stator position against torque.
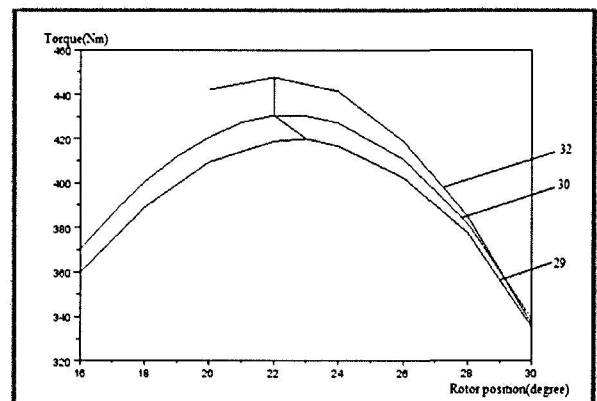

Figure 5: Flux linkage versus current

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Figure above show the best three combinations of stator and rotor with optimum torque produce. The stator position for this case are 29,30 and 32 degree. Though rotor position are varied from 16 – 30 but at position 22 degree it gives the optimum value of torque. The highest torque produce from the combination of stator and rotor is 447.61 Nm. From this simulation, the result shows that torque will vary and increase proportional to stator and rotor position.

V. CONCLUSION

This paper has presented a way of optimizing the magnetic core structure of 1- stack of a multi-stack Switched Reluctance (SR) Motor using Finite-Element Modeling Method (FEMM).The project indicated that the optimized structure of 6/6 pole stack have stator and rotor pole width of 32 and 22 respectively.

For the last stator position which is 30 degree, the lamination shapes are adjusted to optimize the torque. Although the shapes are different with the initial figure, it did not give any effect to the final result.

FUTURE OF WORK

In the future of work, it can be suggested that 3-D finite element approach should provide a more accurate trend data as the end-leakage flux may be modeled explicitly. Other than that ,physical prototypes need to be constructed to verify the conclusion .

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