TORQUE OPTIMIZATION FOR SRM BY CHANGING STATOR AND YOKE GEOMETRY

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ABSTRACT

The paper shows the effects of dimensional variation for the base yoke thickness and stator pole width on the torque developed for switched reluctance motors (SRM). By using finite element method to achieve the task for the torque optimisation, simulation for different dimensional yoke thickness and stator pole width of SR motors have been performed and analysed. While various SRM shapes are setting the same value for the Ampere-Turns for. This paper shows the torque optimisation depends on changing the dimension of the yoke thickness and stator pole width. Useful conclusions are drawn from the study and future work is recommended.

Key Words: Finite Element Method, Simulation, SRM

1. INTRODUCTION

A switched reluctance (SR) motor is a rotating electric machine where both stator and rotor have salient poles. The rotor, which consists of a laminated with poles, is a passive device with no coil winding or permanent magnets. The stator typically consists of slots containing a series of coil windings, the energization of which is electronically switched to generate a moving field, only a single coil set is activated at any one time. When one stator coil set is on, a magnetic flux path is generated around the coil and rotor. The rotor experiences a torque and moves the rotor in line with the energized coils, minimizing the flux path. In the SRM no permanent magnets are used therefore the stator coil produces the magnetic flux[1-10].

To simplified torque equation, the general equation, equation (1), is usually simplified for values of constant current.

$$T = \frac{id\phi - (\phi di + id\phi - d\mathrm{Wc}\{\theta, i\})}{d\theta} \quad (1)$$

The differential co-energy can be written in terms of its partial derivatives as, ϕ = flux linked by the windings.

$$d\mathrm{Wc}\,(\theta, i) = \frac{\partial \mathrm{Wc}}{\partial \theta} d\theta + \frac{\partial \mathrm{Wc}}{\partial i} di \quad (2)$$

From equation (1) and (2), it is fairly easy to show that under constant current, where θ = rotor position.

$$T = \frac{\partial \mathrm{Wc}}{\partial \theta}, i = \text{Constant} \quad (3)$$

SRM analysis proceeds under the assumption that, magnetically, the motor remains unsaturated during operation. This assumption can be useful for performance predictions. When magnetic saturation is neglected, the relationship from flux to current is given by,

$$\phi = L(\theta).i \quad (4)$$

For fixed angle, θ, let the magnetization curve define flux as a function of current, instead of current defines as a function of flux. W_c is defined as the magnetic field co-energy.

$$\mathrm{Wc} = \int_0^i \phi(\theta, i) di \quad (5)$$

Substituting Equation (4) into Equation (5) and evaluating the integral yields, $L(\theta, i)$ = the instantaneous inductance

$$\mathrm{Wc} = \frac{i^2}{2} L(\theta) \quad (6)$$

Then substituting Equation (6) into Equation (3) gives the familiar simplified relationship for SRM torque,

$$\mathrm{T} = \frac{i^2}{2} \frac{dL}{d\theta} \quad (7)$$

The motor inductance varies as a function of rotor angle. The work, which have been done targeting better performance and optimal design of Switched Reluctance motors [5-10]

2. TORQUE OPTIMISATION FOR SRM BY YOKE DIMENSIONAL VARIATION

The direction of torque generated is a function of the rotor position with respect to the energized phase, and is independent of the direction of current flow through the phase winding. To achieve the task "torque optimization" particular reference SRM has been picked to perform the simulation tests. Fig. 1 shows the reference SR motor, which has a three phases, six stator poles, and four rotor poles. The setting mmf value is 150 AT for each tested motor. Leaving the stator and rotor poles width geometries with the same dimensions for the particular reference motor, then by increasing or decreasing the yoke thickness dimension and watch the influence of these changes on the motor torque.

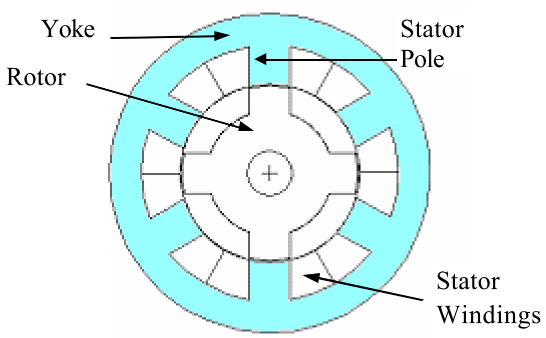

Fig. 1: Reference SRM.

The first motor SRM #1 is the particular reference SR motor, which has yoke thickness = 7.5 mm, the yoke thickness for SRM #2 is 7 mm, the yoke thickness for SRM #3 is 6.5 mm, the yoke thickness for SRM #4 is 6 mm, and the last lowest possible value for yoke thickness of SRM #5 is 3 mm (decreasing values tests). The yoke thickness for SRM #6 is 8 mm, the yoke thickness for SRM #7 is 8.5 mm, the yoke thickness for SRM #8 is 9 mm, and the last highest possible value for yoke thickness of SRM #9 is 10 mm (increasing values tests). In this paper the air-gap between stator and rotor poles is 0.4 mm. Fig. 2 shows the torque developed in the particular reference SR motor versus displacement angles. Changing the mmf from 30 -> 210 in step of 30 mmf, found the torque is increasing as soon as the ampere - turn increases.

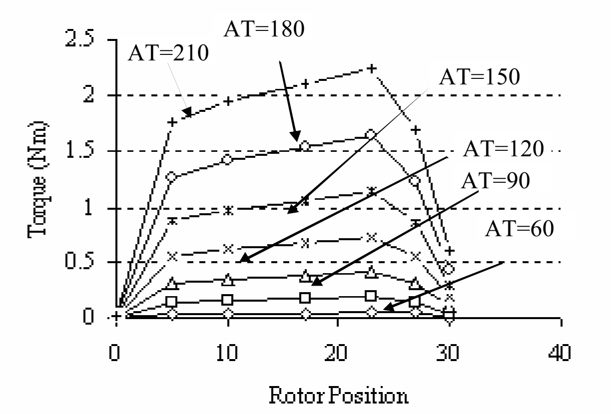

Fig. 2: Torque versus Rotor Position at different mmf for SRM#1

3. SRM WITH WIDER YOKE THICKNESS.

The simulation tests started with decreasing the yoke thickness of the SR motor from (7 → 3) mm in a random step. Watching the influence of these decreasing steps on the developed torque, found the torque decreases as soon the yoke thickness decreases. The mmf used for wider and narrower yoke thickness is 150 AT. Fig. 3 shows the shape of the wider yoke thickness. The yoke thicknesses for these motors are wider than the yoke thickness for the particular reference motor. The range for increasing the yoke thickness varies between (8→10) mm.

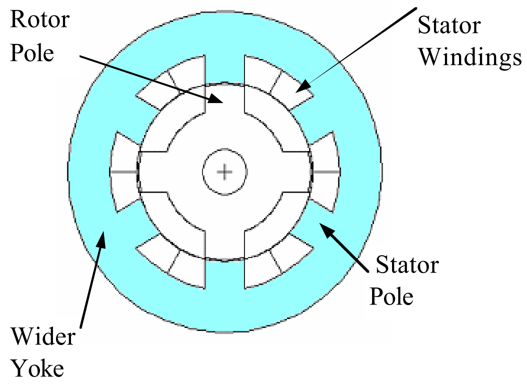

Fig. 3: Wider yoke SRM

Fig. 4 shows the torque developed in the switched reluctance motor versus displacement angles. Changing the mmf from (30 → 210) in step of 30 mmf, where the yoke thickness is wider than the particular reference yoke thickness. Found the torque is increasing as soon as the ampere - turn increases. The yoke thickness for this switched reluctance motor is 10 mm.

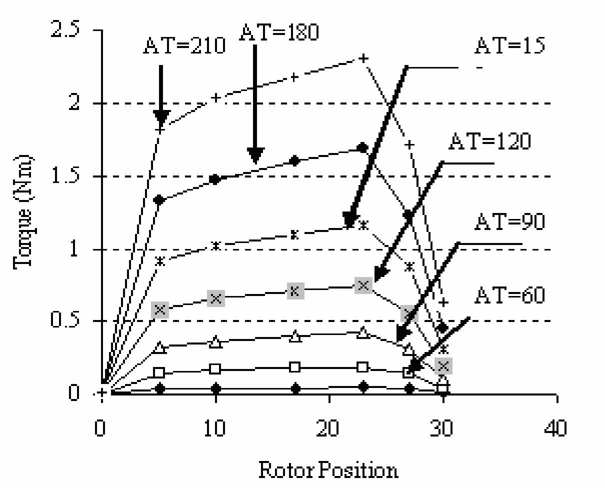

Fig. 4: Torque versus Rotor position at different mmf for wider yoke SRM 10 mm

4. SRM WITH NARROWER YOKE THICKNESS

Fig. 5 shows the shape of the narrower yoke thickness, where the yoke thickness is narrower than the particular reference yoke thickness. The yoke thicknesses for these motors are narrower than the yoke thickness for the particular reference motor. The range for decreasing the yoke thickness varies between (7→3) mm.

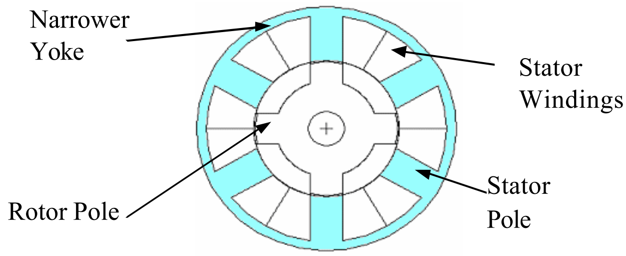

Fig. 5: Narrower yoke SRM.

Fig. 6 shows the torque developed in the switched reluctance motor versus displacement angles. Changing the mmf from (30 → 210) in step of 30 mmf, found the torque is increasing as soon as the ampere - turn increases. The yoke thickness for this switched reluctance motor is 3 mm. In this motor the developed torque is reached the lowest value, which is less than the developed torque of the reference particular motor.

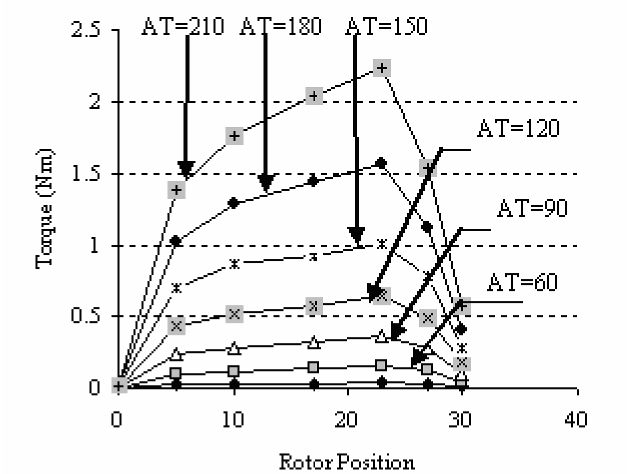

Fig. 6: Torque versus Rotor Position at different mmf for narrower yoke SRM 3 mm

5. SIMULATION RESULTS FOR YOKE DIMENSIONAL VARIATION

Fig. 7 shows the developed torque versus yoke thickness; each yoke thickness represents a switched reluctance motor. Increasing and decreasing the yoke thickness have an influence on the torque developed as this paper illustrates. Increasing the yoke thickness between (8→10) mm is increasing the developed torque of switched reluctance motor, while decreasing the yoke thickness is decreasing the developed torque in the range between (7→3) mm. Fig. 8 shows a comparison of the torque developed by a switched reluctance motor with different yoke thickness. The figure shows that the motor with narrower yoke thickness is developing a lower torque in comparison with the reference yoke thickness. That figure also shows that the motor with wider yoke thickness is developing a higher developed torque.

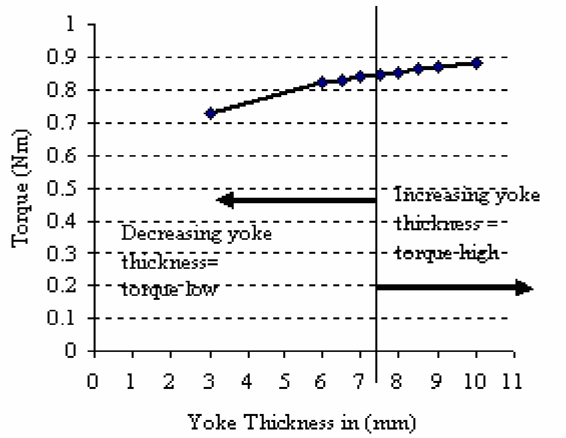

Fig. 7: Torque versus yoke thickness variation

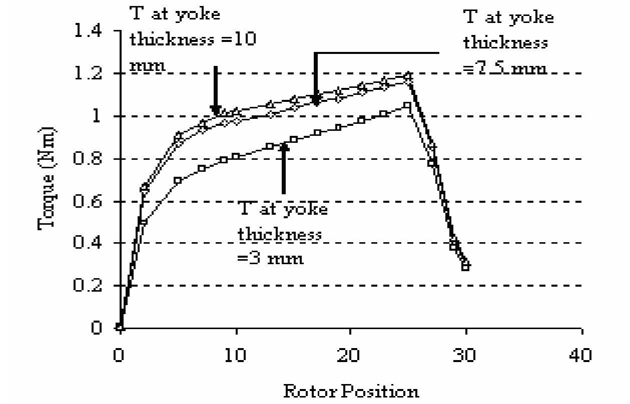

Fig. 8: Torque versus rotor position for three SR motors

6. TORQUE OPTIMISATION FOR SRM BY STATOR POLE DIMENSIONAL VARIATION.

Finite element method is used to perform the simulation. The configuration of the 6/4, 3 phase SR motor considered for investigation is shown in Fig. 9a with equal stator/rotor poles, Fig. 9 (b) shows the SR motor with wider stator poles while Fig. 9 (c) shows the motor with narrower stator poles.

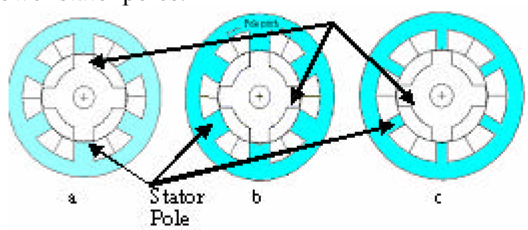

Fig. 9: a) Reference SRM, b) wider SRM, and c) narrower SRM.

7. SMULATION RESULTS FOR STATOR POLE DIMENSIONAL VARIATION

The stator pole arc/pole pitch ratio is varied from 0.246 to 0.74 in eleven random steps as shown in Fig. 10 the stator pole arc/pole pitch ratio for the reference SR motor is ? = 0.443 and reduced into four steps and monitor the effect of this change on the developed torque of SR motor.

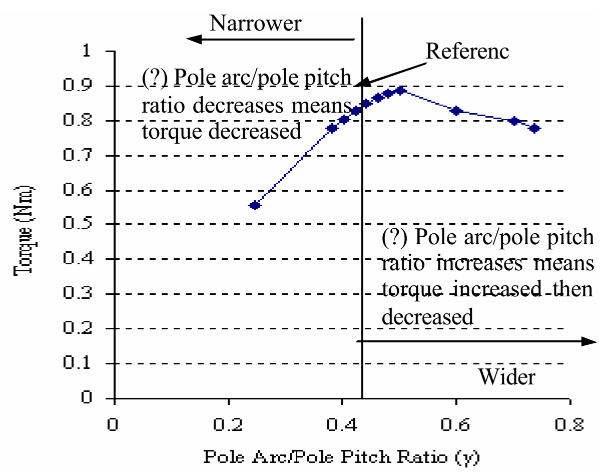

Fig. 10: Torque versus pole arc/pole pitch ratio (?)

The rotor is rotated from unaligned to aligned positions and the developed torque is compared it with the average developed torque of the reference SR motor. The developed torque in Table 1 is shown as a function of ?.

Table 1: Variation of torque as a function of ? (stator pole arc/pole pitch)

Torque (Nm)	? (p.u.)
0.83	0.42
0.8	0.4
0.78	0.38
0.55	0.25
0.847 Base SRM	0.443
0.86	0.46
0.88	0.48
0.89	0.5
0.83	0.6
0.8	0.7
0.78	0.74

When ? changes between 0.46→0.5, the developed torque starts to increase from 0.86Nm till it reaches the highest value at 0.89 Nm. Further increasing ? between 0.6→0.74, the average developed torque varies between (0.83→0.78) Nm. The highest developed torque occurred at stator pole arc/pole pitch ratio = 0.5. The ampere-turn for each model of SR motor is 150 AT. The results are shown in graphical form as Fig. 10.

Fig. 11 shows the graphical results for three SRM models, first one is the reference or base SRM with pole arc/pole pitch ratios (?) equal to 0.443, second model is the wider (best) pole arc/pole pitch ratios (?) equal 0.5, the third model is the narrower (worst) with pole arc/pole pitch ratios (?) equal 0.25.

Starting to analyze the developed torque when rotating the rotor from 0º to 30º with base and wider models. Both models have nearly the same torque developed when rotor rotates from 0º to 14º, the torque developed for wider model is starting to decrease slightly when the rotor rotates from 14º to 26º, finally the developed torque for the wider model is higher than the developed torque for the reference model when the rotor rotates from 26º to 30º.

Now comparing the reference and narrower models, the developed torque for the narrower model is less than the developed torque for the reference model when the rotor rotates from 0º to 8º. The developed torque for narrower model is higher than the developed torque of the reference model when the rotor rotates from 8º to 22º. Finally the developed torque for the narrower model is lower than the developed torque for the reference model when the rotor rotates from 22º to 30º.

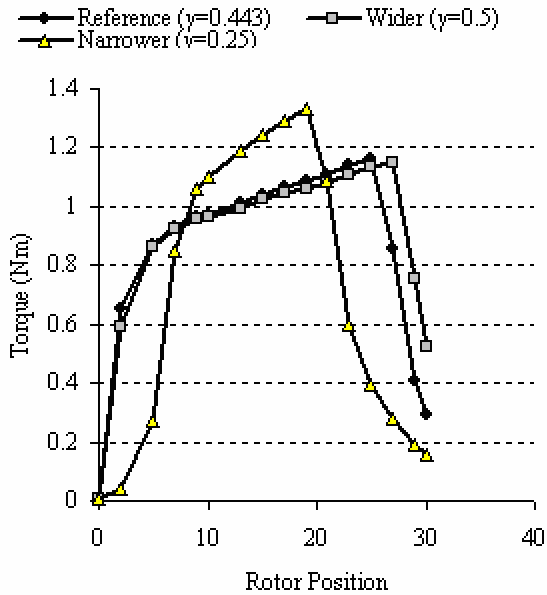

Fig. 11: Torque versus rotor position for three SR motors.

8. CONCLUSIONS

This paper outlined the torque optimisation design for particular reference of SRM. The reference particular motor has a 7.5 mm yoke thickness. Two areas of developed torque have been occurred in the simulation test by yoke dimensional variation:

- Torque decreases between (7→3) mm
- Torque increases between (8→10) mm

3.64% is the incremental developed torque percentage in comparison with the particular reference motor, which is found when the yoke thickness is equal to 10 mm. Further study on optimisation SRM is the priority task and different approach to achieve this goal.

This paper is also outlined the torque production in SR motors as a function of stator pole arc/pole pitch variation. The following conclusions can be drawn also from stator pole dimensional variation.

- Developed torque decreases between ? = (0.443→0.25).
- Developed torque increases between ? = (0.443→0.5)
- Developed torque decreases between ? = (0.5→0.74).

REFERENCES

[1] J.Rizk; M.Nagrial and A. Hellany, Design optimisation of switched reluctance motors, *Australian Journal of Electrical & Electronic Engineering, Australia,* vol. 1, no. 1, 2004, pp. 33-39.

[2] J.Rizk, M.Nagrial and A.Hellany, Design and performance of switched reluctance motors, *4th International Power Electronics and Motion Control Conference (IPEMC 2004)*, Xian, China 14 - 16 August, 2004.

[3] M. S. Islam, I. Husain, R.J. Veillette and C. Batur, Design and Performance Analysis of Sliding-Mode Observers for Sensor less Operation of Switched Reluctance Motors, *IEEE Trans. On Control Systems Tech.,* vol. 11, no. 3, May, 2003, pp. 383-389.
[4] I. Husain, Torque Ripple Minimization in Switched Reluctance Motor Drives, *IEEE Trans. On Industrial Electronics*, vol. 49, no. 1, Feb. 2002.
[5] M. Llic-Spong, T.J.E. Miller, S. R. MacMinn and J. S. Thorp, Instantaneous Torque Control of Electric Motor Drives, *IEEE Trans. Power Electronics*, vol. 2, Jan. 1987 pp. 55-61.
[6] T.J.E. Miller, *switched reluctance motors and their contro,* (Oxford Science Publication), England, 1993.
[7] S. Vukosavic, V. R. Stefanovic, Inst. Nikola Tesla, Beograd; SRM Inverter Topology: Comparative Evaluation, *IEEE Transaction on Industry Applications*, vol. 27, no. 6, 1991.
[8] O. Ichinohura, W Kimura and G Yanada, Analysis of Dynamic Characteristics of SRM based on SPICE, *IEEE Transaction on Magnets*, vol.34, no. 4, 1998, pp. 2147-2149.
[9] R. Becerra, M. Ehsani and T.J.E., Miller Commutation of SR Motors, *IEEE Transactions on Power Electronics*, vol.8, 1993, pp. 257-263.
[10] Y. Murai, J. Cheng, M. Yoshida, New soft-switched/switched-reluctance motors drive circuit *32nd IAS Annual Meeting IEEE*, 1997, pp-1811-1816.