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EXPERIMENTATION OF THREE PHASE OUTER ROTATING SWITCHED RELUCTANCE MOTOR WITH SOFT MAGNETIC COMPOSITE MATERIALS

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Abstract

This paper presents the application of Soft Magnetic Composite (SMC) material in Outer Rotating Switched Reluctance Motor (ORSRM). The presented stator core of the Switched Reluctance Motor was made of two types of material, the classical laminated silicon steel sheet and the soft magnetic composite material. First, the stator core made of laminated steel has been analysed. The next step is to analyse the identical geometry SRM with the soft magnetic composite material, SOMALOY for its stator core. The comparisons of both cores include the calculated torque and torque ripple, magnetic conditions, simplicity of fabrication and cost. The finite element method has been used to analyse the magnetic conditions and the calculated torque. Finally, tested results shows that SMC is a better choice for SRM in terms of torque ripple and power density.

Keywords: Finite element analysis, Soft magnetic composite, switched reluctance motor, Torque ripple.

1. Introduction

The proliferation of power electronics technology with advances in material technology has led to the development of special machines for myriad applications in recent times. One of such special machines gaining wide acceptance in recent times is the switched reluctance motor characterized by simple and robust construction, high speed operation and high power density along with compactness. This paper presents some aspects of SMC material application in outer rotating switched reluctance motor.

Dou et al. reviewed the investigation on various types of motor topologies for the best use of SMC and possible further work required for the commercial success of SMC machines [1]. Nord et al. proposed a vertical motor design using Powder Keg^{TM}, which employs a very different physical architecture compared to a standard electrical machine [2]. Guo et al. presented the comparative study of 3-D flux machines such as transverse flux and claw pole motors with soft magnetic composite core [3-5]. Rabinovici suggested that introduction of Soft Magnetic Composites, as an alternative for the SRM stator construction would be beneficial for torque ripple, vibrations, and acoustic noise mitigation [6]. An optimal design of a high-speed SRM with lower torque ripple using the Taguchi method for household appliances has been presented in [7-10].

This paper presents the analysis and experimentation of an 8/6 switched reluctance motor with SMC material. First the stator core has been made of laminated silicon steel sheet and secondly of soft magnetic composite material. The investigation is focused on the influence of the choice of material for the stator core on the magnetic characteristics and on manufacturing costs of switched reluctance motor.

2. Design and Simulation

The SRM is a doubly salient but singly excited machine wherein the stator carries the winding while the stator is simply made of stacked silicon steel laminations. This lends to a simpler geometry for SRM as evidenced from the two dimensional (2D) model of an SRM shown in Fig. 1.

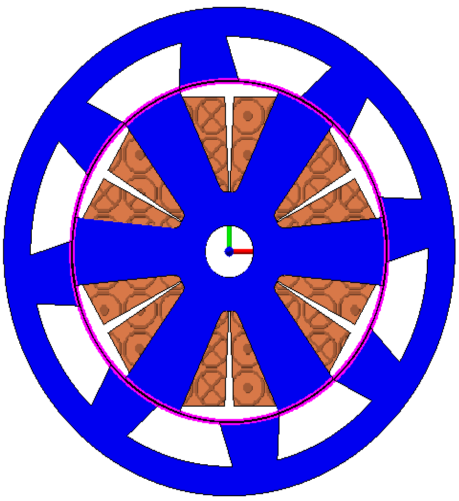


Fig. 1. 2D CAD model of ORSRM.

The study of static electromagnetic characteristics will help to determine and analyse the flux density and self inductance of the machine. These parameters are to decide the dynamic performance of the machine for linear and non-linear mode of operation. In this work, the static and dynamic characteristic was obtained using Finite Element Analysis (FEA) software MagNet. The torque profile for SRM-SMC 1000 motor is shown in Fig. 2.

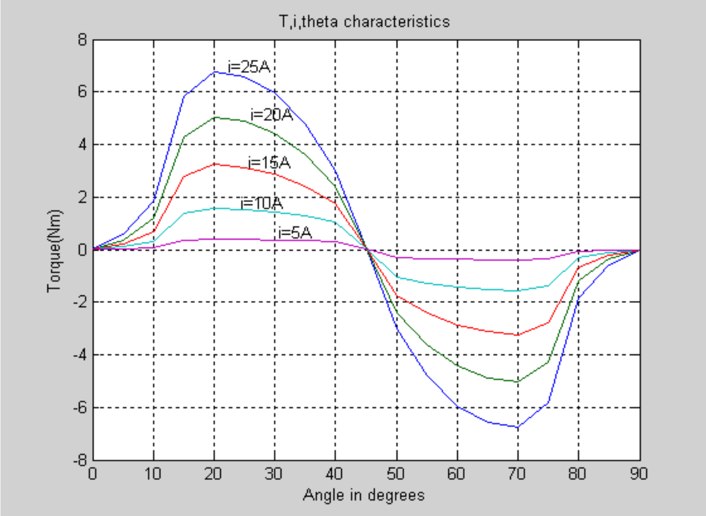


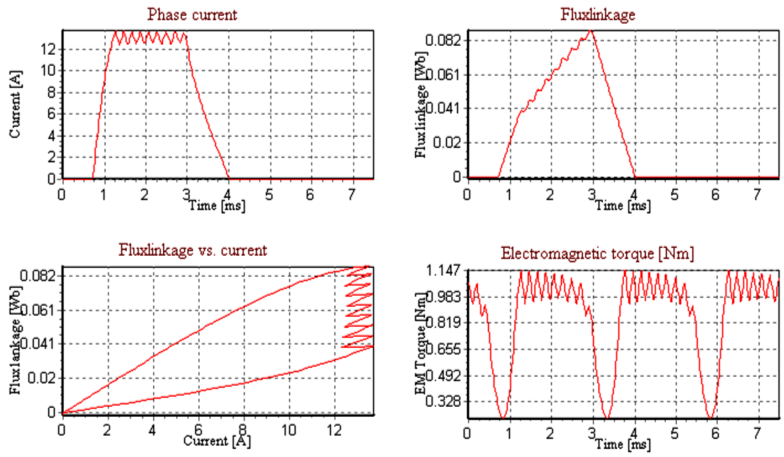
Fig. 2. Torque profile of SRM-SMC1000.

The comparative study results of torque and phase winding inductance for the three motors given in Table 1. SRM-SMC motor suffers from poor effective torque owing to poor relative permeability of SMC material which is also evident from dynamic characteristics of the SRM-SMC1000 motor shown in Fig. 3. The dynamic characteristics of switched reluctance motor at a rated current of 13A and at a speed of 2000 rpm has been estimated for the three configurations using switched reluctance design and simulation software (SRDaS). The obtained dynamic simulation wave forms such as phase current, flux linkage, energy conversion capability and the electromagnetic torque for M-19, SMC500 and SMC1000 are shown in Figs. 3 (a), (b) and (c) respectively.

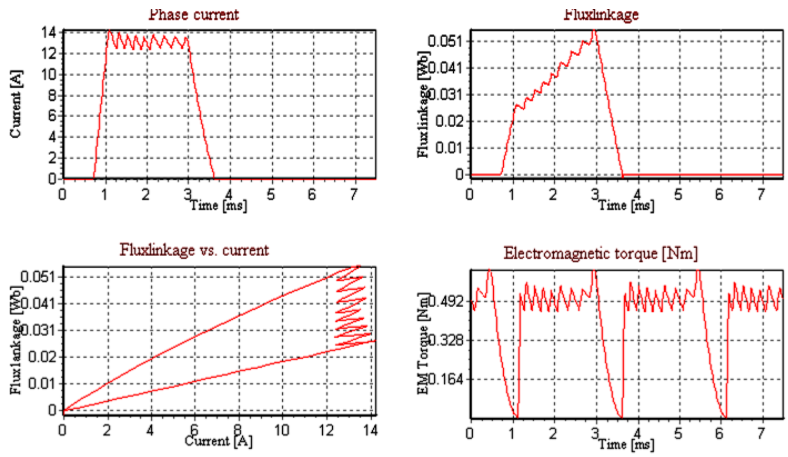
Table 1. Comparison of static torques and inductances for the three configurations.

Configurations	Inductance (H)		Torque (N.m)			Torque Ripple
	Aligned inductance	Unaligned inductance	Effective Torque 5A	10A	15A	
SRM-M19	0.016	0.005	0.4	1.29	2.18	26.3%
SRM-SMC 500	0.012	0.005	0.27	0.91	1.59	22.2%
SRM-SMC 1000	0.014	0.005	0.31	0.95	1.64	19.5%

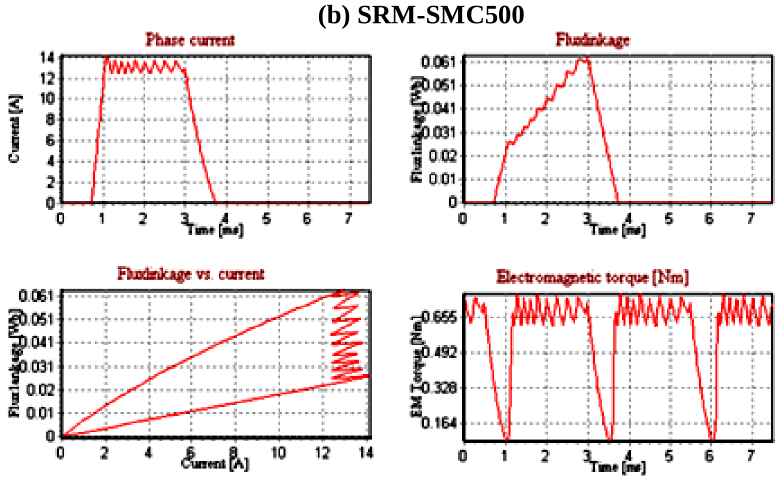
For the first two configurations of SRM the differences are marked as for as dynamic electromagnetic torque curve shapes as well as their maximum torque levels are concerned whereas the SRM-SMC 1000 configuration shows quasi–super imposable results. The superior permeability of M-19 steel renders configuration 1, the most powerful machine as for as level of shaft torque is concerned.



(a) SRM -M19



(b) SRM-SMC500



(c) SRM-SMC1000

Fig. 3. The SRDaS dynamic simulation wave forms at a speed of 2000 r/min.

In the flux linkage (λ) vs. Current (i) characteristics the area enclosed is indicative of the energy conversion capability of the machine which also demonstrates the superior performance of conventional machine with efficiency at 65.37%. The effective torque obtained from SMC configurations is 23% lesser than SRM-M19 configuration. However, the toque ripple of SMC500 and SMC1000 are 15.6% and 25.8% lesser than the conventional machine.

3. Hardware Implementation

To measure the dynamic performance of the prototype model of SMC-SR motor, a test bench was developed with a mechanical type loading arrangement as shown in Fig. 4. The speed-torque, current-torque characteristics curves and measured inductance profile for I=1A is shown in Figs. 5-7 respectively, which clearly delineates the operating range of the fabricated SMC based SR prototype machine. The machine was applied with constant dc voltage of 22V while phase voltage and phase current waveforms with and without load condition at a speed of 1550 rpm had been measured as shown in Fig. 8.

From the comparative point of view, the measured torque-speed curve is extremely poor when compared with SRM-M19 because of poor permeability level of SMC material (somaloy®1000 3P, μ_{max}= 850) and this can be distinguished by the two regions of operation.

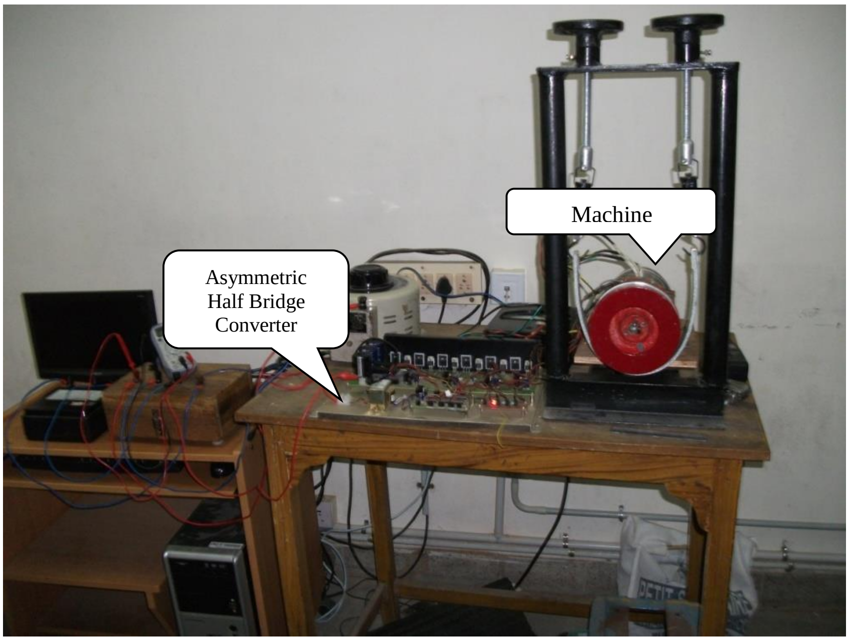


Fig. 4. Test bench set up for measuring dynamic performance of SMC-SR prototype machine.

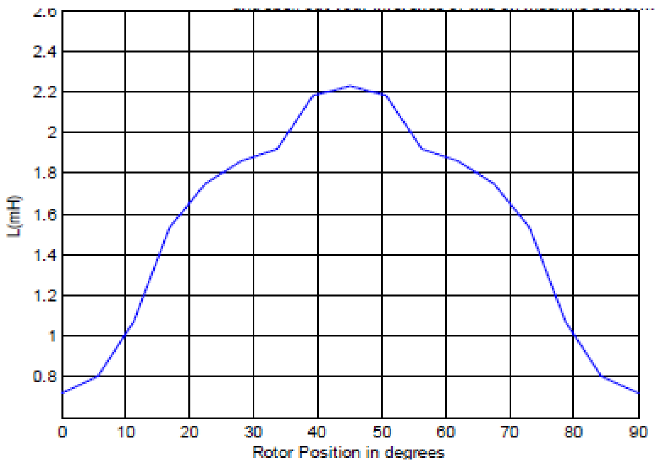


Fig. 5. Measured inductance for current I = 1A.

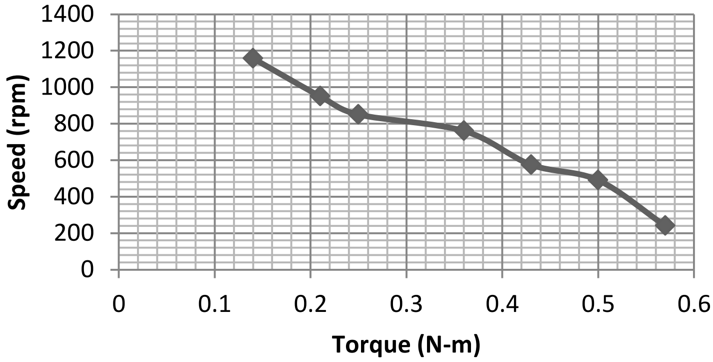


Fig. 6. Speed-Torque characteristics.

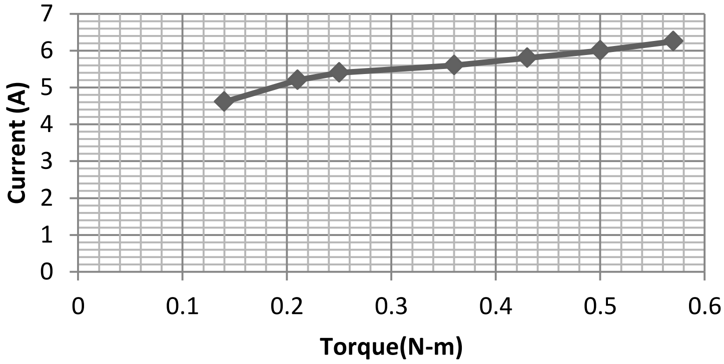
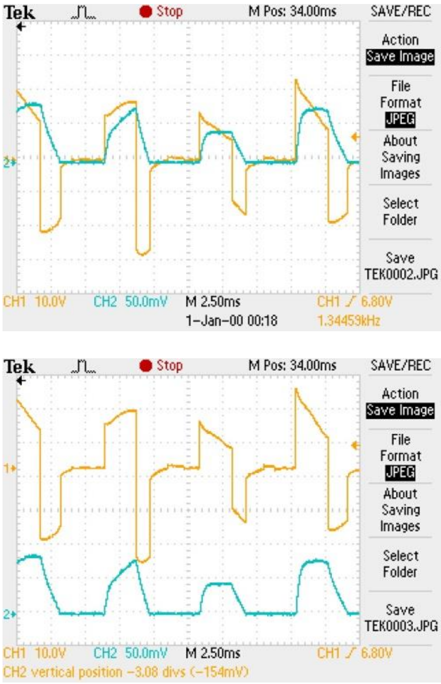
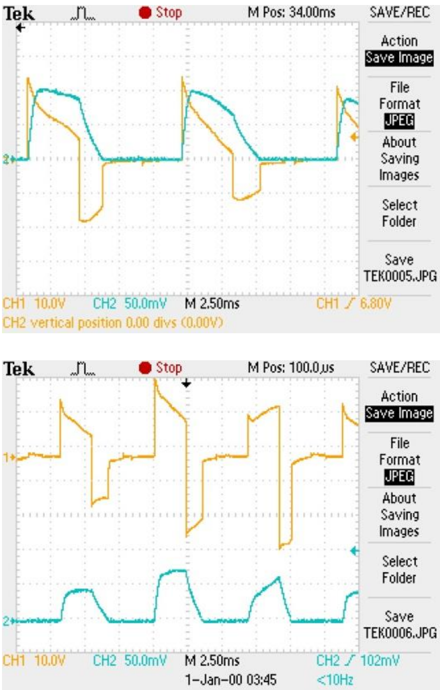


Fig. 7. Current-Torque characteristic.



(a) without load-1550 rpm and V= 20V& I=4.5A



(b) with 50% load-850 rpm and I=6.1A

Fig. 8. Measured voltage and current waveforms for phase A.

4. Conclusion

This paper addressed the influence of soft magnetic composite material in development of an SRM. Time stepped two dimensional FEA has been used to obtain the static and dynamic characteristics. The toque ripple of SMC500 and SMC1000 are 15.6% and 25.8% lesser than the conventional machine. The future course of research may involve study of machine thermal characteristics and vibration behaviour of the SMC in ORSRM.

References

1. Dou, Y.; Guo, Y.; and Zhu, J. (2007). Investigation of motor topologies for SMC application. *Proceedings of International Conference on Electrical Machines and Systems*, 695-698.
2. Nord, G.; Johnson, P.; Petersen, C.C.; and Yamada, T. (2005). Vertical electrical motor using soft magnetic composite materials. *Proceedings of IEEE International Conference on Electric Machines and Drives*, 373-377.
3. Guo, Y.G.; Zhu, J.G.; Watterson, P.A.; and Wu, W. (2005). Development of a claw pole permanent magnet motor with soft magnetic composite stator. *Australian Journal of Electrical & Electronic Engineering*, 2(1), 21-30.
4. Guo, Y.G.; Zhu, J.G.; Lin, Z.W.; and Zhong, J.J. (2005). Measurement and modeling of core losses of soft magnetic composites under 3D magnetic excitations in rotating motors. *IEEE Transactions on Magnetics*, 41(10), 3925-3927.
5. Guo, Y.G.; Zhu, J.G.; Watterson, P.A.; and Wu, W. (2006). Development of a PM transverse flux motor with soft magnetic composite core. *IEEE Transactions on Energy Conversion*, 21(2), 426-434.
6. Rabinovici, R. (2005). Torque ripple, vibrations, and acoustic noise in switched reluctance motors. *HAIT Journal of Science and Engineering B*, 2(5-6), 776-786.
7. Gaing, Z.-L.; Kuo, K.-Y.; Hu, J.-S.; and Tsai, M.H. (2014). Design and optimization of high-speed switched reluctance motor using soft magnetic composite material. *Proceedings of 2014 International Power Electronics Conference* (*IPEC-Hiroshima 2014 – ECCE Asia*), 278-282.
8. Hamler, A.; Goričan, V.; Šuštaršič, B.; and Sirc, A. (2006). The use of soft magnetic composite materials in synchronous electric motor. *Journal of Magnetism and Magnetic Materials*, 304(2), e816-e819.
9. Persson, M.; Jansson, P.; Jack, A.G.; and Mecrow, B.C. (1995) Soft magnetic composite materials-use for electrical machines. *Proceedings of the Seventh International Conference on Electrical Machines and Drives*, Durham, UK. 242-246.
10. Guo, Y.G.; Zhu, J.G.; Watterson, P.A.; and Wu, W. (2003). Comparative study of 3-D flux electrical machines with soft magnetic composite cores. *IEEE Transactions on Industry Applications*, 39(6), 1696-1703.