INVESTIGATION ON E-CORE SWITCHED RELUCTANCE MOTOR: OPTIMIZATION, ELECTROMAGNETIC ANALYSIS AND EXPERIMENT

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Abstract: *The switched reluctance motor (SRM) is superior in the field of automobile applications due to their abundant features such as reliability, single excitation, high starting torque, etc. Even though SRM has salient advantages there is a major demerit as torque ripple. This article describes the optimization technique involved in the reduction of torque ripple with 8/10, 500W, 1.8Nm and 120V E-Core SRM. Asymmetric rotor, Gashed rotor, Stack Length and Claw pole are the optimization technique involved in the minimization of torque ripple. The optimized machine is analyzed with static and time varying methods. The evaluation of simulation results is predicted with a prototype model.*

Key words: *E-Core SRM, Electromagnetic, FEA, Torque Ripple, Optimization*

1. Introduction.

Now-a-days switched reluctance motor is spreading wider in the field of automobile applications, due to their major concern in the advantages such as high starting torque; single excitation etc. The effect of torque ripple will lead to degrade in the performance of the electrical machine. [1] Describes the E-core SRM with 9stator poles including three inter shared poles and 12 rotor poles. The torque ripple is reduced by increasing the number of rotor poles, varying the height of poles of the stator and by cutting edges of the rotor poles. [2] Influences the effect of claw pole in the rotor, which minimizes the torque ripple. More over to this aspect, rotor pole arc variation is investigated to obtain the better pole arc angle and the excitation angle is optimized to get the better turn ON angle and turn OFF angle. The E-core SRM is segmented into L and I shape body.[3] since the two phase motor is not self-starting motor, the rotor poles are laminated with asymmetric poles ensuring non uniform air gap in the machine. The iron loss in the machine is condensed by reducing the active region in the stator. [4] The electromagnetic analysis is estimated with symmetric and non-asymmetric rotor in SRM and compared with the conventional SRM. The experimental model is also examined and verified with simulation results. [5] Combines the E-core stator and conventional rotor to obtain the hybrid flux in the SRM to upgrade the performance of the machine. [6] Detects the fault in the machine with transverse flux stator and conventional rotor in SRM. The SRM is laminated with high silicon steel in order to minimize the iron loss. [7] The simulation and experimental results are evaluated to obtain the unidirectional self-starting asymmetric SRM leads to variation with magnetic flux in the air gap.

The switched reluctance motor can be classified as rotator and linear. [9], [10], in rotary machine the basic configuration is 6/4, 6/8, 8/6, 8/10 and so on. Depend on the flux path the SRM gets further classified as long and short flux SRM. The long flux is with classical winding and short flux is with mutually coupled winding. The long and short flux has higher and lesser active region with respect to their flux density. The long flux machine has high maximum torque whereas the average torque remains approximately equal.

2. Conventional E-Core SRM

[11], [12] states that the inter pole in the E-Core SRM is having passage of flux on the excitation of either Phases. The design data is indicated in table.1. The torque profile is plotted with the torque ripple as 2.08Nm, having average, maximum and minimum torque as 1.76Nm, 3.8Nm and 0.123Nm respectively as shown in Fig.4. The utilization of the iron parts is predicted as active region of motor as 2.17T indicated in Fig.1, Fig.2 and Fig.3. The torque ripple for conventional E-Core SRM is shown in the table.2. Torque ripple is evaluated by equation1.

$$T_{ripple} = \frac{T_{max} - T_{min}}{T_{avg}} \quad (1)$$

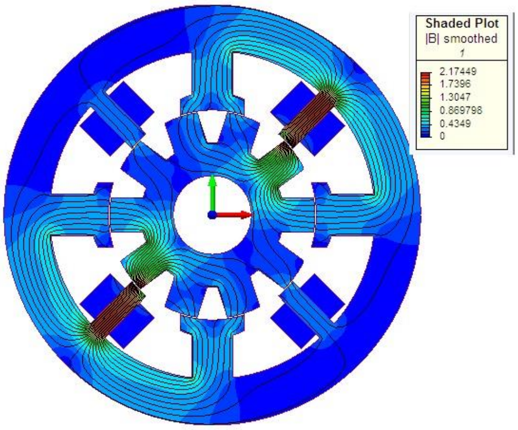

Fig.1. Phase A Excitation and its Flux Path

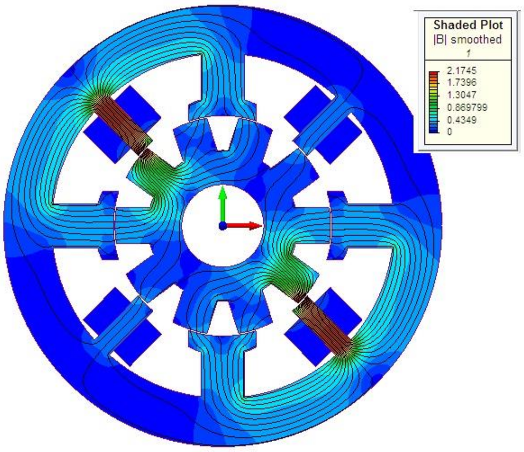

Fig.2. Phase B Excitation and its Flux Path

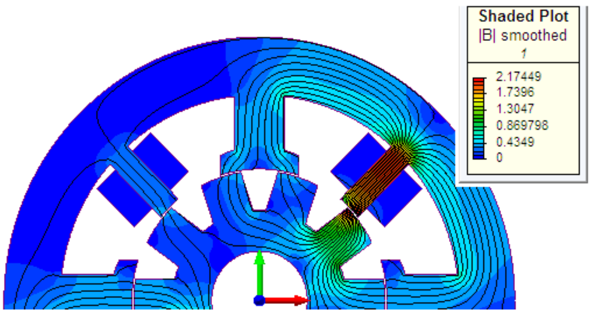

Fig.3. Phase A Excitation in Semi E-Core SRM

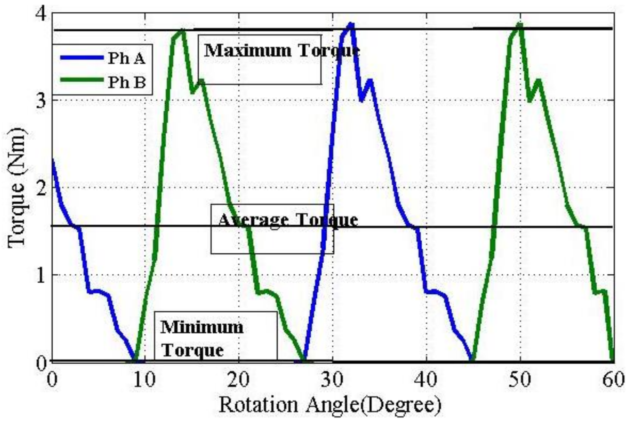

Fig.4. Torque Vs Rotation Angle

Table.1. Specifications of E-Core SRM

Specifications	E-Core SRM
Number of phases	2
Number of stator poles	4 Main Pole 4Shared Pole
Stator Pole Arc(deg)	36, 10
Rotor Pole Arc(deg)	18
Number of rotor poles	10
Shaft diameter(mm)	20
Stack length(mm)	60
Rotor back iron(mm)	36.4
Rotor outer diameter(mm)	52.6
Air gap length(mm)	0.3
Stator pole height(mm)	83.2
Stator outer diameter(mm)	106.5
Number of turns	280/phase
Rated torque(Nm)	1.8Nm
Rated power(W)	550

Table.2. Torque Ripple for conventional E-Core SRM

S.No	Maximum Torque (Nm)	Minimum Torque (Nm)	Average Torque (Nm)	Torque Ripple (Nm)
1	3.8	0.123	1.76	2.08

3. Optimization

The switched reluctance motor is investigated in the following aspects such as,

a. Asymmetric
b. Claw Pole
c. Stack Length
d. Symmetric

3.1 Asymmetric

[13], [14] In this technique, minimum torque is slightly increased by creating uneven air gap by asymmetric rotor leads to reduction in the torque ripple. The asymmetric rotor with Fig.5 obtained for 1, 2 and 3mm as tabulated in table.3. The effective torque profile is displayed in the fig.7. The flux density and flux path utilized for this cut edge rotor is 1.570T shown in Fig.6.

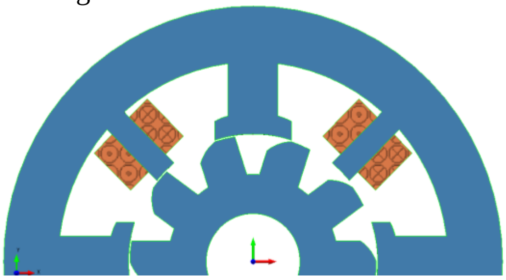

Fig.5. Asymmetric rotor E-Core SRM

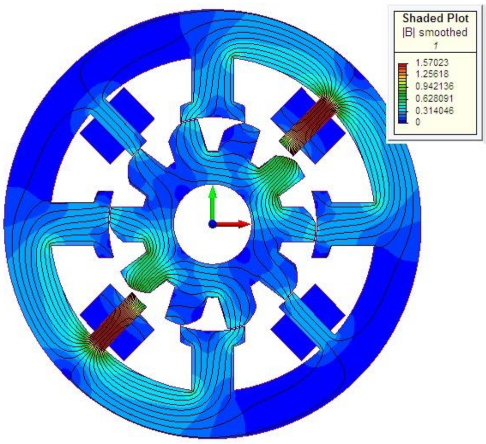

Fig.6. Flux Path for Asymmetric rotor E-Core SRM

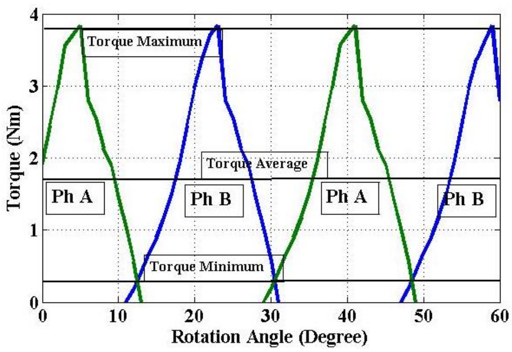

Fig.7. Torque Ripple with 1mm Asymmetric rotor

Table.3. Torque ripple with optimized asymmetric rotor

Dimensions in mm	Average Torque (Nm)	Torque Ripple (Nm)
1	1.6061	1.745
2	1.7001	2.0586
3	1.8803	2.039

3.2 Claw pole

The claw pole in the rotor indicated in Fig.8 reduces the leakage flux in the air gap. So the average torque gets higher. The torque profile is shown in Fig.10 and the parameters are displayed in the table.4. The flux path and its density distribution is 1.573T as shown in Fig.9.

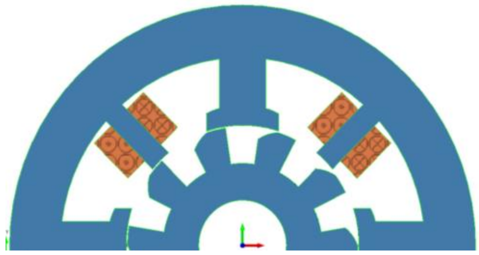

Fig.8. Claw pole E-Core SRM

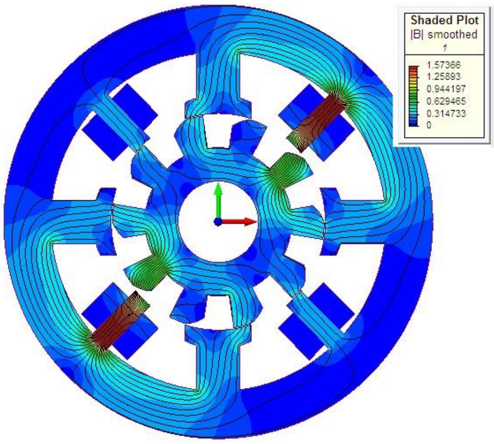

Fig.9. Flux Path for Claw pole E-Core SRM

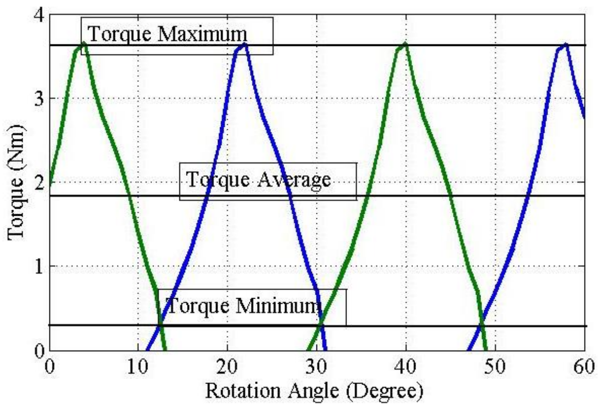

Fig.10. Torque Ripple with 9.5degree Asymmetric claw pole rotor

Table.4. Torque ripple with optimized claw rotor poles

Rotor pole arc in degree	Average Torque (Nm)	Torque Ripple (Nm)
9.5	1.848	1.972
10.5	1.726	2.084
11.5	1.625	1.731
12.5	1.618	1.985

3.3 Stack Length

The main dimension of the machine design is said to as bore diameter and stack length of the machine. The stack length and material is assumed to be same for both stator and rotor displayed in Fig.11. The torque profile for best optimization is shown in Fig.13 and tabulated in table.5. Fig.12. distributes the flux density as 1.570T.

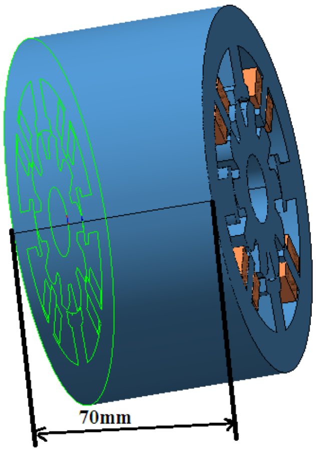

Fig.11. Stack Length with 70mm E-Core SRM

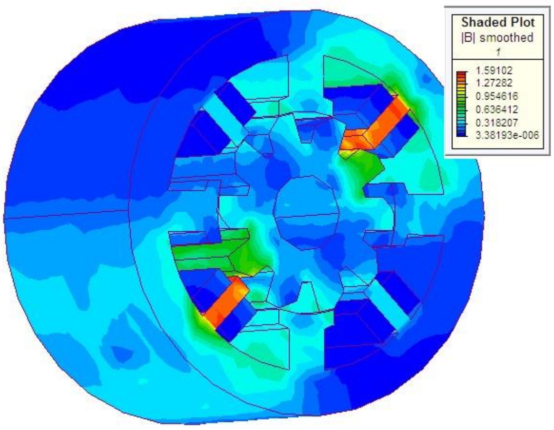

Fig.12. Flux Density in 70mm E-Core SRM

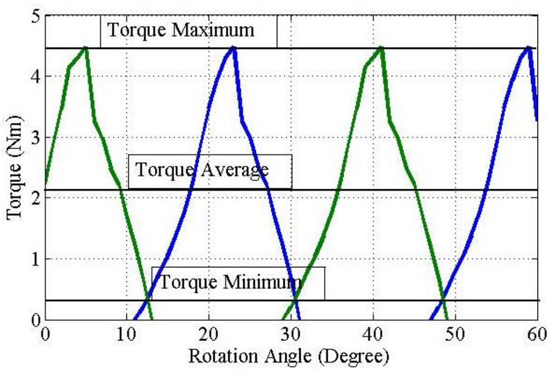

Fig.13. Torque Ripple with Stack Length as 70mm E-Core SRM

Table.5. Torque ripple with optimized stack length E-Core SRM

Stack Length in mm	Average Torque (Nm)	Torque Ripple (Nm)
45	1.381	1.788
50	1.535	1.810
55	1.688	1.818
60	1.8803	1.904
65	2.0203	2.056
70	2.1809	1.868
75	2.336	2.052

3.4 Symmetric

The symmetric rotor pole provides asymmetric torque profile (continuous conduction) by gashed poles. The torque profile is displayed in Fig.16. The symmetric pole and the torque parameters is shown in Fig.14, Fig.16 and indicated in table .6. The distribution of tesla within the machine is estimated as 2.321T

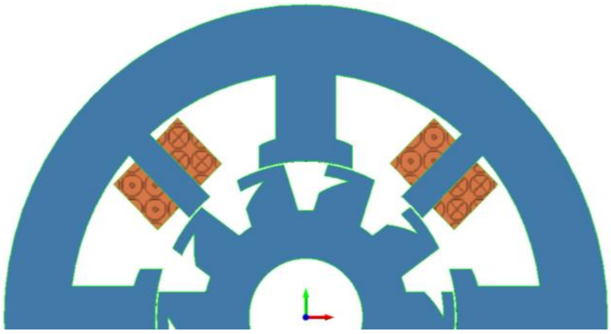

Fig.14. Gashed pole with 3mm E-Core SRM

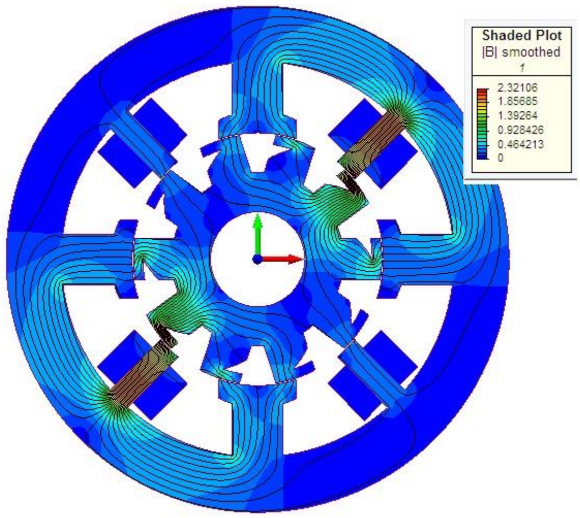

Fig.15. Flux Path for Gashed pole with 3mm E-Core SRM

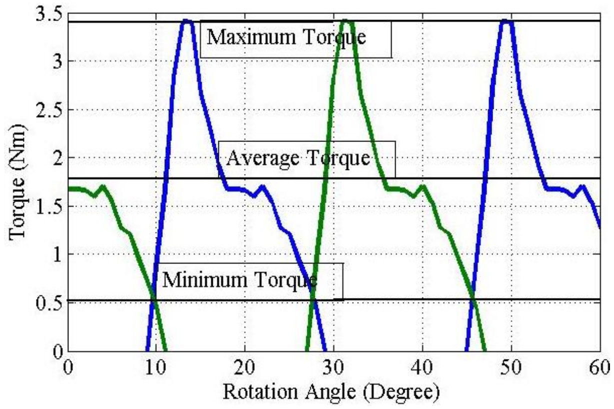

Fig.16. Torque Ripple with gashed pole as 3mm E-Core SRM

Table.6. Torque ripple with optimized gashed pole E-Core SRM

Gashed pole in mm	Maximum Torque (Nm)	Minimum Torque (Nm)	Average Torque (Nm)	Torque Ripple (Nm)
1	3.692	0.45	1.782	1.819
2	3.552	0.5	1.7633	1.730
3	3.410	0.55	1.765	1.620

4.Time Varying Analysis

This research article continues with time varying analysis, [15] and [16] so the Turn-On and Turn-Off angle is displayed in table.7 and calculated by,

$$\theta = \frac{360}{Q * N_r} \text{ -- (2)\textbackslash}$$

Table.7. Commutation Angle for two Phase E-Core SRM

S.No	Phase A		Phase B	
	Turn-On	Turn OFF	Turn-On	Turn-OFF
1	0	13	13	31
2	31	49	49	67
3	67	85	85	103
4	103	121	121	139
5	139	157	157	175
6	175	193	193	211
7	211	229	229	247
8	247	265	265	283
9	283	301	301	319
10	319	337	337	355
11	355	13	13	31
12	31	49	49	67

The Fig.17 indicates the excitation circuit for SRM with its commutation angle is predicted and tabulated in table.6. At Zero Position, the starting current is maximum so the flux, corresponding torque and ohmic losses also are maximum as indicated by Fig.18, Fig.19, Fig.21 and Fig.23 respectively. The supply voltage to SRM is of 120V as indicated in Fig.20. The Speed of the machine is seems to be increasing in linear manner which is indicated by the rotation angle in Fig.22.

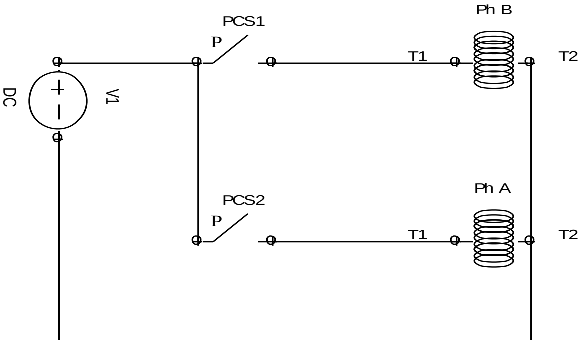

Fig.17. Equivalent Converter Circuit for Two Phase E-Core SRM

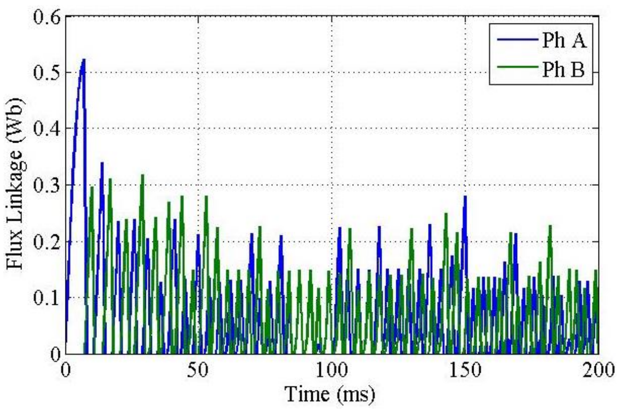

Fig.18. Flux linkage for E-Core SRM.

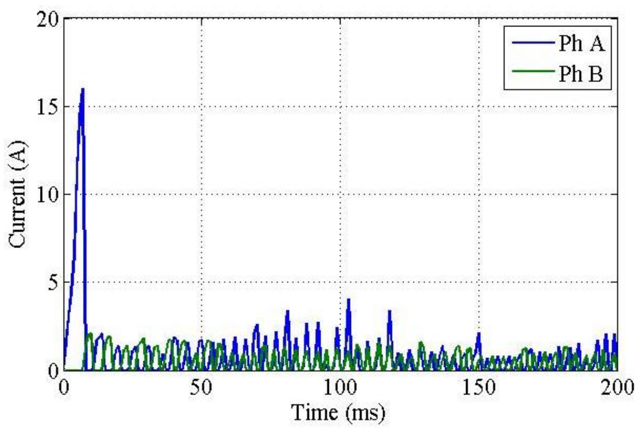

Fig.19. Current for E-Core SRM

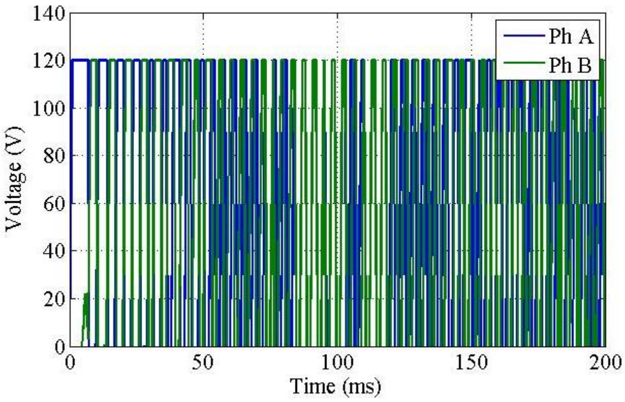

Fig.20. Voltage for E-Core SRM

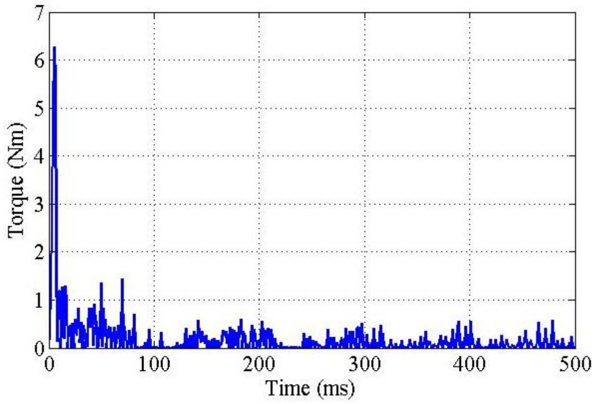

Fig.21. Torque for E-Core SRM

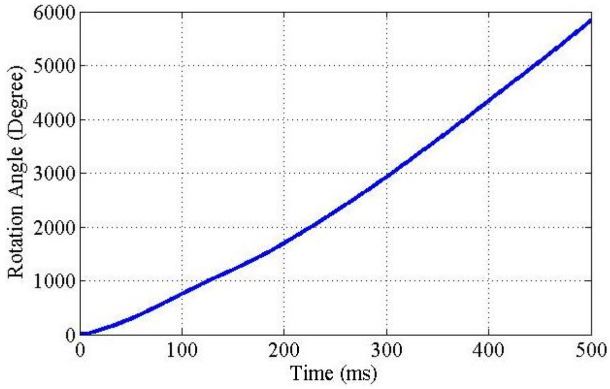

Fig.22. Rotation Angle with Rotor for E-Core SRM

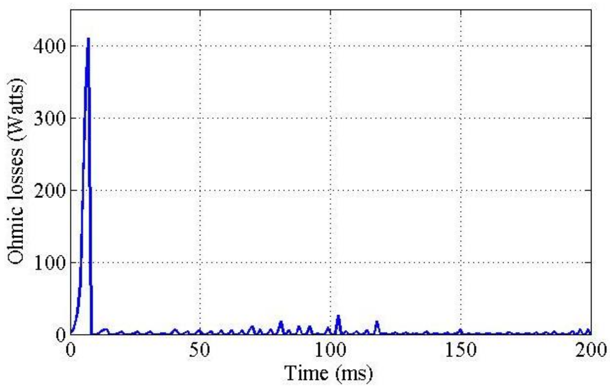

Fig.23. Ohmic Losses for E-Core SRM

5. Hardware Implementation

The Experimental setup is build up for the Electromagnetic analysis of E-Core SRM. FPGA is used to feed the triggering pulses to the two phase Converter of SRM. The proximity sensor is used to sense the rotor position; there by the phases can be excited approximately. Fig.24 indicates the Prototype model of the experimental arrangement. The current, voltage and speed waveform is indicated in Fig.25, Fig.26 and Fig.27respectively.

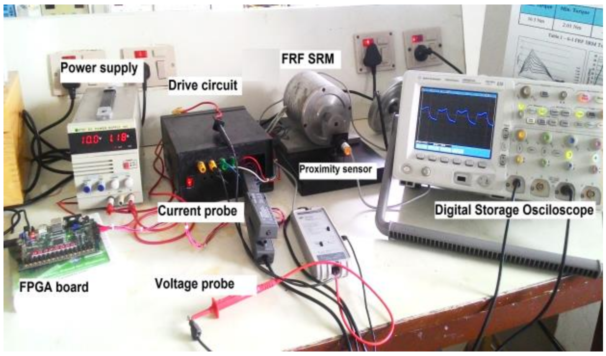

Fig.24. Prototype Model

Fig.25. Current waveform

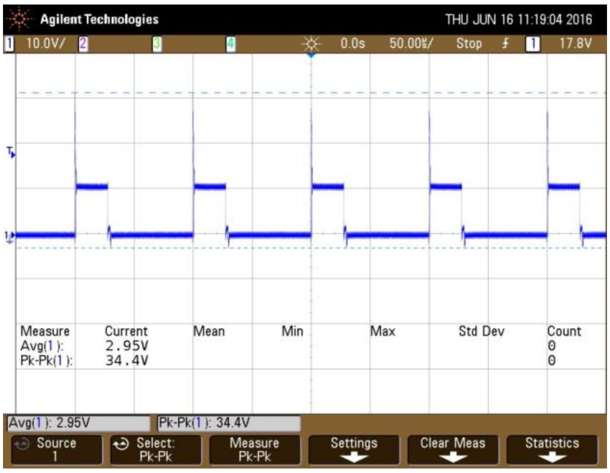

Fig.26. Voltage waveform

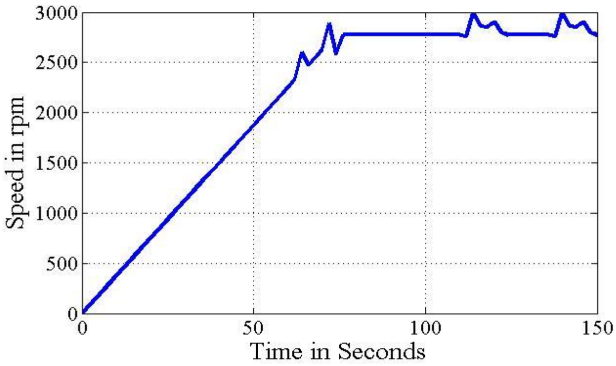

Fig.27. Speed Vs Time

6. Conclusion

The E-Core SRM is investigated by various optimization techniques such as, asymmetric, Claw pole, Stack Length and Symmetric (Gashed Pole). The best optimization technique for this E-Core Design is seems to be Variation in the Stack Length. The E-Core SRM is evaluated with the experimental arrangement. The future scope of this research work is on reducing the vibration and total losses.

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