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Torque Enhancement of Switched Reluctance Motor with Teethed Stator Pole

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Abstract*: Switched Reluctance motors are very demanding among all type of motor due to its simple construction. Feedback circuit (control circuit) and design of Switched Reluctance Motor (SRM) require information of its parameters, like inductance, flux linkage and torque. High torque, high reliability and cheap manufacturing cost are the attractive features of the SR motors. In this paper we have simulated SR motor with initial design, teethed stator pole and multi-teethed stator pole using COMSOL multi-physics CAD software. We have plotted inductance profile and static torque characteristics which shows that the static torque characteristics has peak value with sharp reduction in torque in intermediate position with teethed stator pole, that can be overcome by using multi-teeth stator pole with compromising in maximum torque.

Keywords: COMSOL, Switched Reluctance Motor, teethed stator pole, torque.

I. INTRODUCTION

Recently, the SR motor are adopted in many industrial application fields for its number of benefits like informal control, simple construction and low cost. It is operated in a very wide speed range that the SRM is especially applied to wind turbines and high-speed equipment. To enrich the prevailing static magnet machine with the problem of reliability and price, the SRM has been applied particularly within the field of wind power generation. the speculation of motor with variable reluctance has been began to be used since 1980's for the variable or adjusted speed application and also the use of those motors began to be very popular in engineering applications. One among critical topics for developing electromagnetic products is the simulation and experimental soundings of the electromagnetic field delivery. While the FEM was a time-intense and difficult method within the past, with modern high speed computers with large memory, the tactic will be used properly in analysis of electrical machines. Additionally, various commercial finite-element packages COMSOL Workbench are up to now developed for this purpose. From last few years there were many researchers are worked about the simulation of SRM. A brief description about the literature that have been carried is explained.

The analysis of SRM of two different stator geometries keeping rotor parameters constant is presented [1] from the result analysis, the variation of inductance, flux density and directional force along X, Y axis of both the model have been predicted. This study can be used to get more improved performance and to manufacture SR with further modification of physical size of motor [2]. Discussed about the comparison of three phase induction motors with two different stator slot shapes of same ratings. In this new design we got lower magnetizing current, higher efficiency, good operating power factor and less drop in speed. The design modification was found to require less cost and need no complex manufacturing process. The machine has been simulated in RMxprt with the fixed operating conditions. The efficiency of the motor is significantly improved with the proposed slot [3] describe simulation of a 6/4 SRM. All simulations are completely documented by their block diagram and corresponding special MATLAB functions and parameters quickly develop its model to the reader [4].

This paper mainly focused on designing and simulation using COMSOL software to verify the influence of magnetic flux density which is varied according to stator pole designing with teethed and multi-teeth stator pole and rotor position and their torque profile inductance profile.

II. SIMULATION OF SWITCHED RELUCTANCE MOTOR

For the analysis of performance of the SRM by CAD software, the geometrical structure of the motor is designed and proper materials are assigned to different sections. During this, CAD software design of SRM is designed using as shown in Table 1. The 2D cross section, size variables and values of 8/6 SRM are given is shown in fig.1 varying the stator pole design and keeping the rotor shape constant as shown in Fig.1.

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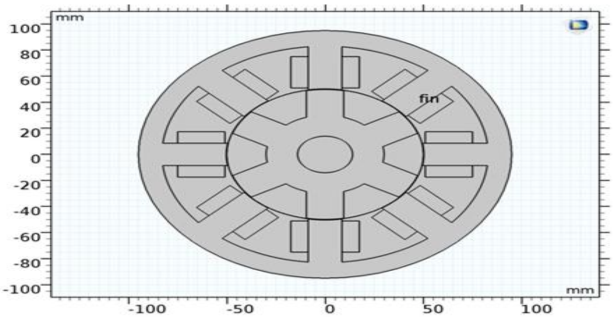

Fig.1. (a) Initial design

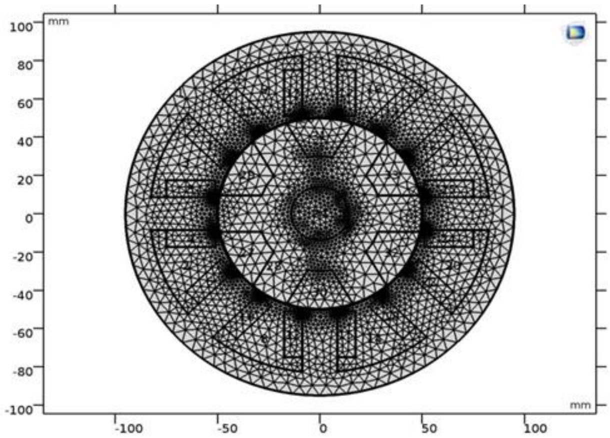
Fig.1. (b) Meshing of Initial design

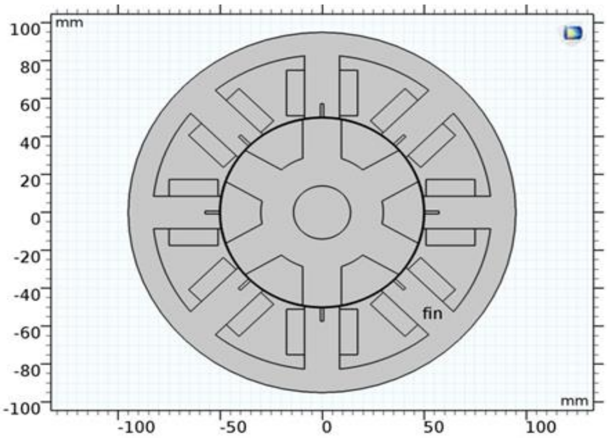

Fig.1. (c) Teethed stator pole geometry

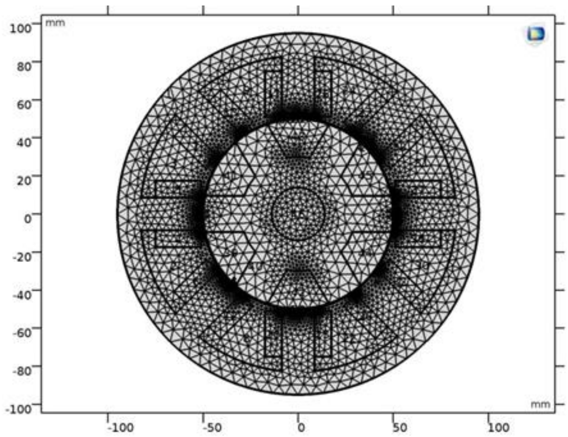
Fig.1. (d) Meshing of teethed stator pole SR motor

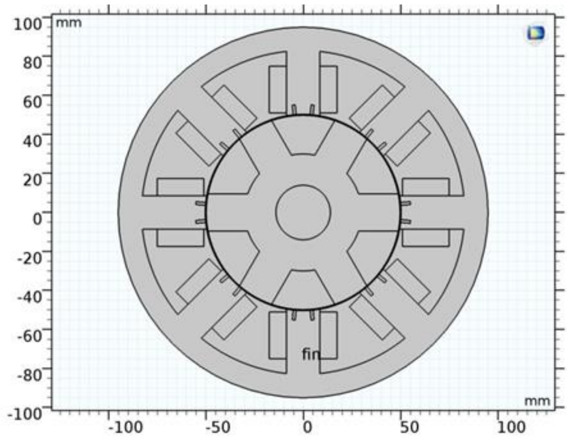

Fig.1. (e) Multi-teethed stator pole geometry

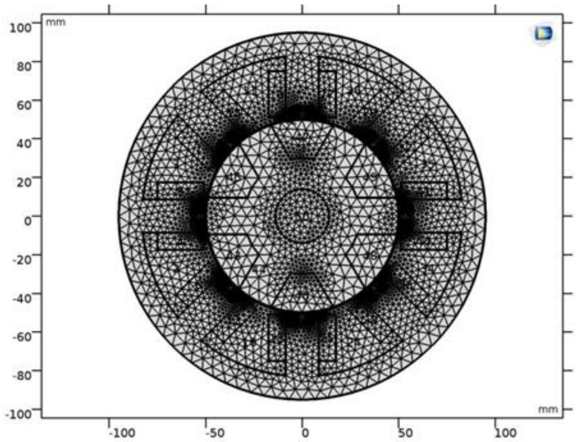
Fig.1. (f) Meshing of Multi-teethed stator pole geometry

We easily modify the design of the machine by changing the value of parameters given in table and improve your design as per your requirement.

Torque characteristics are very important for EM behavior, in calculation of average torque and torque ripple. The torque is computed in COMSOL using the Maxwell's stress tensor method given by

$$T = \int B(r - r_0) \times (n_1 T_2) D_s$$

Where $r_0$the point on the axis of rotation and n is the unit vector to the surface of S. In COMSOL Multi-physics software a module is called "Rotating Machinery, Magnetic" module which is specially designed to conduct simulations on electric rotating machines. So far this module is only available in 2D mode (version 4.3a). The work started with the 2D modeling of the machine. Table-I indicates the basic parameters of this machine. A Steps in Modeling COMSOL software is a finite element analysis, solver and simulation software for many engineering applications.

i. The geometrical modeling in this steps 8/6 SR Motor produces its model comprise three part geometries first stator, rotor and coil domain.
ii. The magnetic modeling is difference between the magnetic domain and magnetic isolation.
iii. The mesh constraints have component with triangle shape.

Table- I: Technical Data of SRM

Main Dimensions of SRM		
Symbol	**Meaning and Unit**	**Value**
x_0	Stator Outer Diameter (mm)	190
x_2	Stator Inner Diameter(mm)	178
r	Rotor Outer Diameter(mm)	100
r_1	Rotor Inner Diameter(mm)	60
D_{sh}	Shaft Diameter (mm)	28
g	Air gap (mm)	0.5
L_{stk}	Stack Length (mm)	200
Ns	No: of Stator poles	8
Nr	No: of rotor poles	6
q	No: of phases	4
β_s	Stator pole arc(degree)	18
β_r	Rotor pole arc(degree)	22
n	No. of turns per phase	154
w	Width of air gap between teeth(mm)	1.5
d	Depth of air gap between teeth(mm)	5

III. RESULT AND DISCUSSION

The excitation is set to stator poles and rotor aligns with the excited stator poles. A stationary characteristic shows the aligned position of rotor poles with the excited stator poles in aggregation with the flux linkage. The variation in magnitude of concentration is often observed. The size of concentration is given within the characteristics and supported this; comparison of concentration of SRM structures are often obtained. Concerning Fig.2. (a) Stator winding slots are excited in sequential manner. So rotor will align in minimum reluctance position.

The COMSOL software is capable to form a parametric sweep with reconstructing the geometry and therefore the mesh at each run. With this function it is possible to calculate the field of force distribution of the machine while one phase is energized and therefore the rotor is changing its position. Position 0 degrees implies that one among the rotor poles completely Un-aligned with the energized stator pole see in Fig.2 (a) and position 30 degree means completely aligned position of rotor pole with excited stator pole see in Fig.2. (d) and Fig.2. (b) and (c) shows intermediate position. After checking model with magnetic induction simulation, it is possible proceed with the calculation of parameters necessary for drive simulation, like phase-inductance and torque.

Here we discussed about the performance of three different geometries of SR motor –

(1) **Initial design SR motor**: Here we discussed the performance of initial structure of SR motor shown in fig.1. (a)

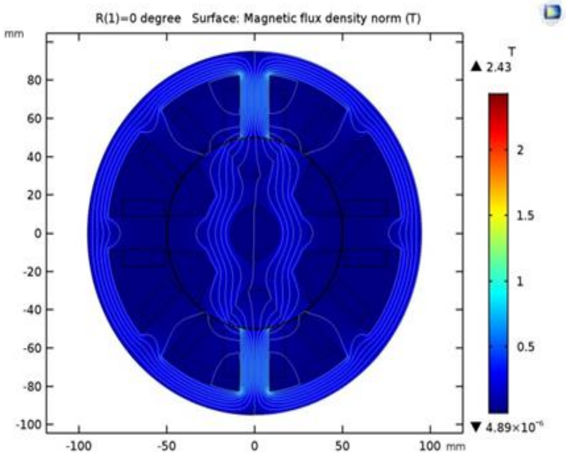

Fig.2. (a) Magnetic flux density at 0 degree

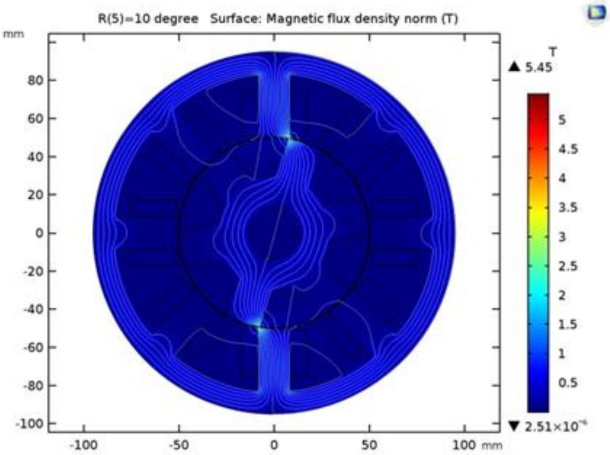

Fig.2. (b) Magnetic flux density at 10 degree

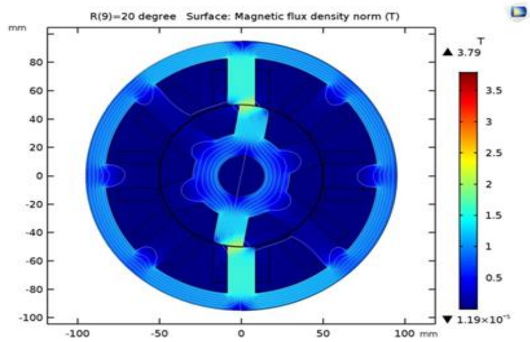

Fig.2. (c) Magnetic flux density at 20 degree

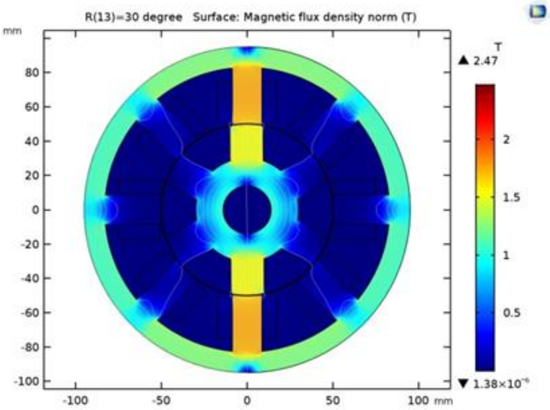

Fig.2. (d) Magnetic flux density at 30 degree

From the Fig.2 we easily understand that the magnetic flux density norm different at different rotor position. Magnetic flux density increases from un-aligned position to intermediate position and again started to decrease from un-aligned position to completely aligned position. Its value is maximum at 10 degree 5.45 T and minimum at completely un-aligned position 2.43 T. Here color scale shows the magnetic flux density norm in tesla.

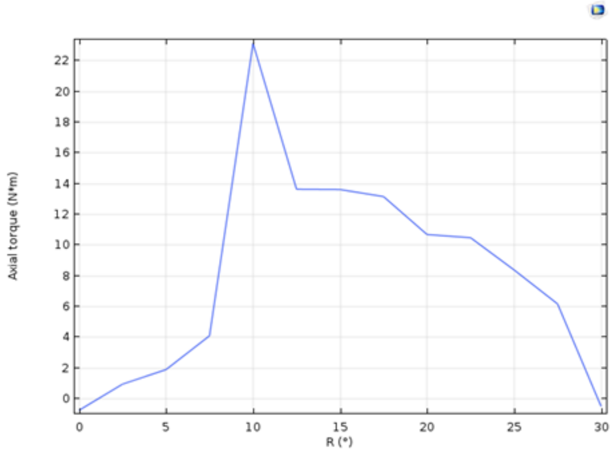

Fig.3. (a) Torque characteristics with rotor position (Initial design)

Fig.3. (a) shows the torque characteristic of the motor, torque has maximum value at 10 degree rotor position which is 23.33 N-m. The inductance has maximum value at aligned position 0.189 H shown in Fig.3 (b). The torque and inductance values are tabulated in Table-II.

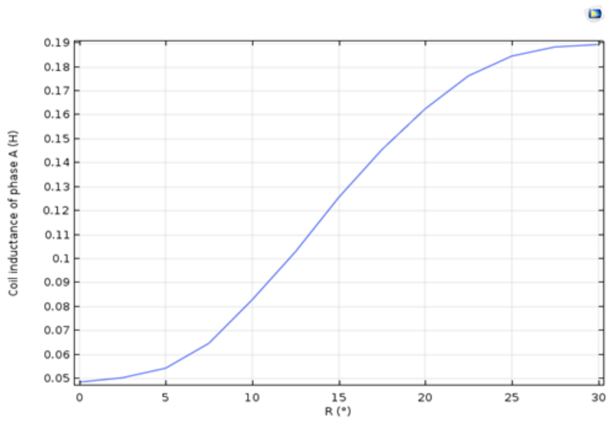

Fig.3. (b) Inductance profile with rotor position (Initial design)

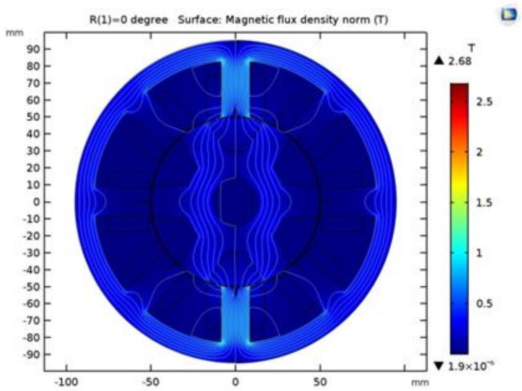

Fig.4. (a) Magnetic flux density at 0 degree

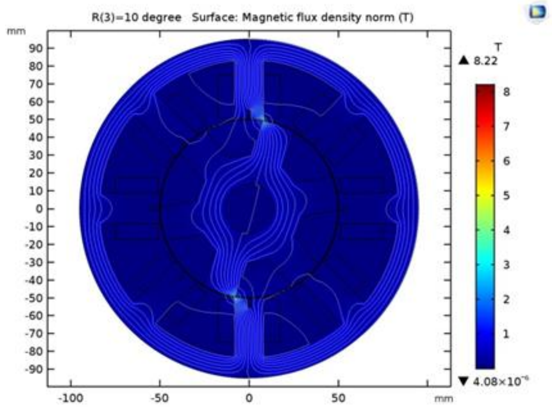

Fig.4. (b) Magnetic flux density at 10 degree

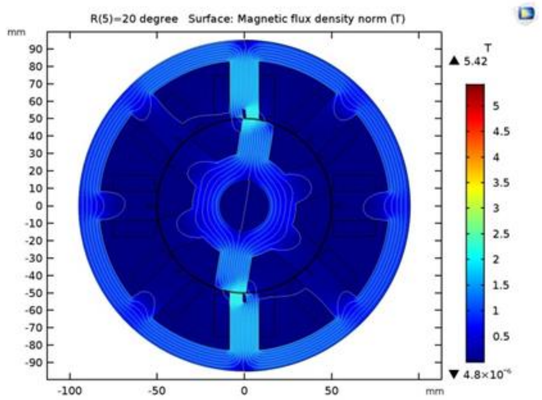

Fig.4. (c) Magnetic flux density at 20 degree

Table-II Torque and Inductance of SR motor (Initial design)

S. No.	Rotor position (degree)	Torque (N-m)	Inductance of coil (H)
1	0	-0.130	0.048
2	5	1.923	0.053
3	10	23.33	0.081
4	15	14.08	0.124
5	20	10.28	0.124
6	25	0.19	0.184
7	30	-0.744	0.189

(2) Teethed stator pole SR motor: In this geometry we create teeth in the pole of SR motor stator with introducing air gap in it. The air gap dimension between teeth are 1.5 mm width and 5 mm depth.

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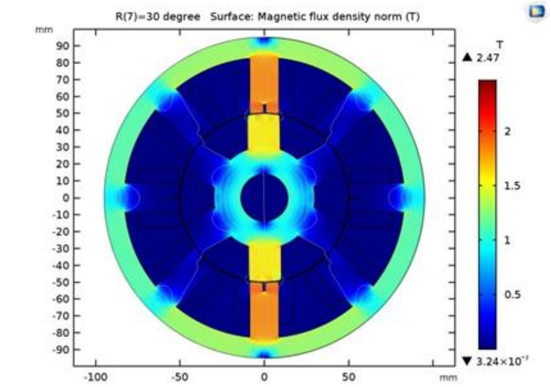

Fig.4. (d) Magnetic flux density at 30 degree

In teethed stator pole SR motor magnetic flux density increases from un-aligned position to 10 degree intermediate position (8.22 T) and again decrease up to 15 degrees. At 20 degrees again it reached second maximum value (5.42 T) and decreased (2.47 T) at completely aligned position. Fig. 4 (a), (b), (c) and (d) shows the magnetic flux density norms at different rotor position of teethed stator pole SR motor.

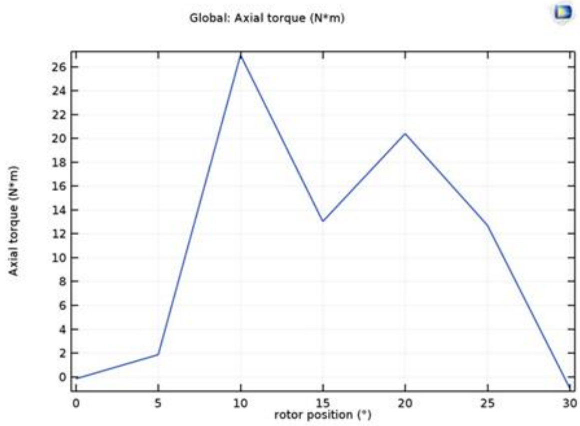

Fig.5. (a) Torque characteristics with rotor position (teethed stator pole)

Fig.5 (a) and (b) show torque characteristic and inductance profile in function of the rotor position of SR motor with teethed stator pole respectively. When we use the teethed stator pole, the effect of teething is evident near the intermediate position (means moving 10 degree from its initial position) got maximum torque which is higher than the initial design and one more peak (secondary high peak) of torque introduced at 20 degree position.

We have higher values of torque at the edges created by teeth formation where the magnetic flux density is high. All over analysis is done only for 30 degree rotation of rotor from un-aligned (0 degree position) to aligned (30 degree position). From table-III maximum torque is 26.026 N-m and another high value of torque 21.12 N-m at 20 degree of SR motor with teethed stator pole. We overcome the negative part of this portion that is vilely seen in middle section of torque characteristic from 10 degree to 20 degree, in next topic.

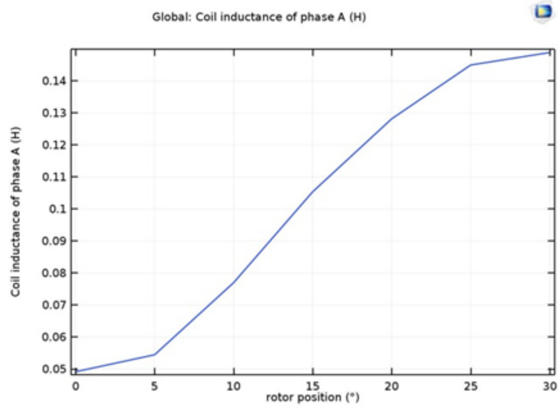

Fig.5. (b) Inductance profile with rotor position (teethed stator pole)

Table-III Torque and Inductance of teethed stator pole SRM

S. No.	Rotor position (degree)	Torque (N-m)	Inductance of coil (H)
1	0	-0.094	0.049
2	5	4.524	0.054
3	10	26.026	0.077
4	15	11.982	0.105
5	20	21.12	0.128
6	25	13.483	10.145
7	30	-1.00	0.149

(3) **Multi-teethed stator pole SR motor:** From the torque characteristic of SR motor with teethed stator pole in fig.5 (1) vilely portion is seen that is removed by using multi-teeth in stator of SR motor. Tow Air gaps between multi-teeth are at 5 degrees and -5 degree from the y-axis. Width is 1.5mm and depth is 5mm for both air gaps.

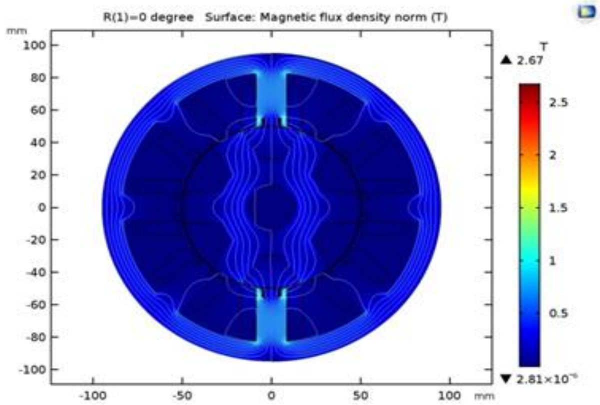

Fig.6. (a) Magnetic flux density at 0 degree

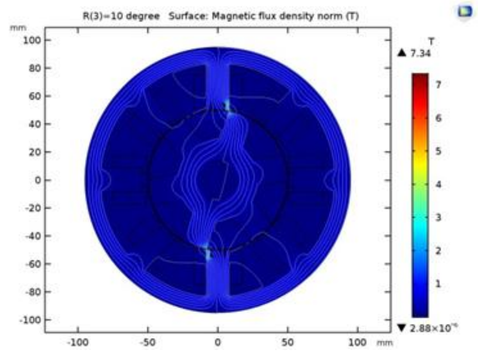

Fig.6. (b) Magnetic flux density at 10 degree

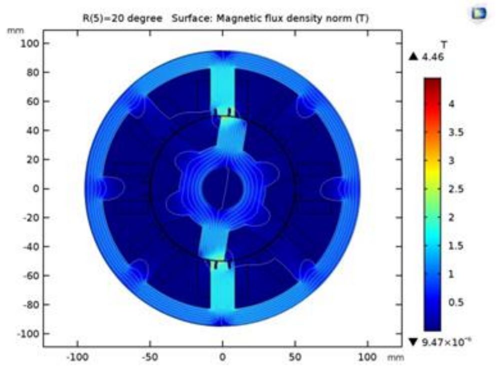

Fig.6. (c) Magnetic flux density at 20 degree

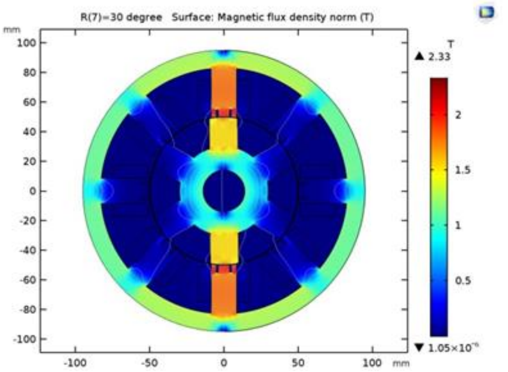

Fig.6. (d) Magnetic flux density at 30 degree

Multi-teethed stator pole SR motor magnetic flux density norms are shown in Fig. 6 (a), (b), (c) and (d) at different rotor position. The maximum magnetic flux density is 7.34 T at 10 degree rotor position.

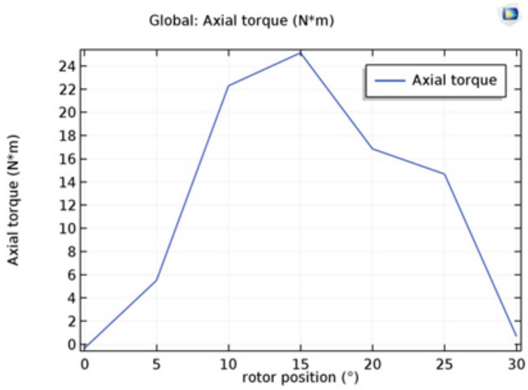

Fig.7. (a) Torque characteristics with rotor position (multi teeth stator pole)

From Fig.7. (b) which shows the inductance profile of multi-teeth stator pole approximately same as shown in Fig.5. (b) for teethed stator pole SR motor, but effect of multi-teething is evident in torque characteristic of motor which is shown in Fig.7. (a).

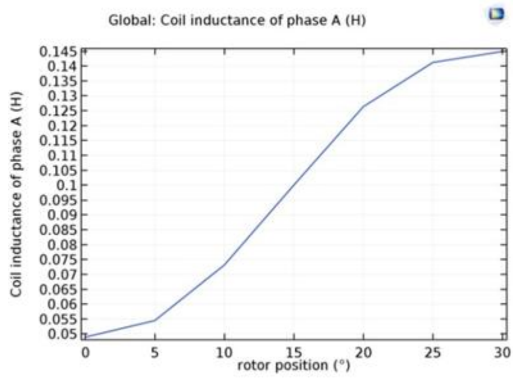

Fig.7. (b) Inductance profile with rotor position (multi teeth stator pole)

Table-IV Torque and Inductance of Multi teethed stator pole

S. No.	Rotor Position (degree)	Torque (N-M)	Inductance of coil (H)
1	0	-0.32	0.049
2	5	5.521	0.054
3	10	22.30	0.073
4	15	25.14	0.1
5	20	16.86	0.126
6	25	14.69	0.141
7	30	0.69	0.145

The maximum value of torque is reduced from 26 Nm to 25.14 Nm when we use multi-teethed pole in stator of SR motor. In this case an advantage is that the valley portion is removed from the torque characteristic by using multi-teethed stator pole in SR motor that overcome the sudden reduction in torque after 10 degree rotation of rotor.

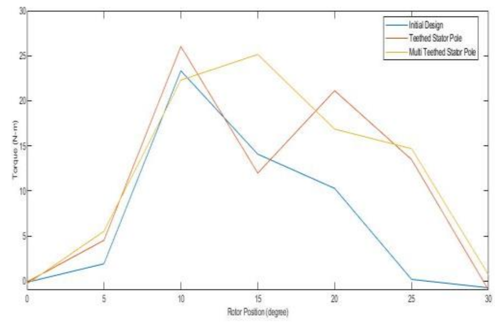

Fig.8 Torque characteristic of three proposed designs

From the Fig.8 it is clear that the multi teethed stator pole SR motor has improvement in the average torque and reduction in torque ripple as compare to initial design and teethed stator pole SR motor with respect to rotor position.

IV. CONCLUSION

The torque of the SR motor is improved intentionally with teethed stator pole in this work. In this paper COMSOL software has used, that provide user friendly environment to change the machine design as per our requirement and apply multiple physic, which is enable to optimal design of machines which may fulfill complex requirements.

The axil torque of SM motor with teethed stator pole is 26.026 T above the initial design 23.03 T, and has two peaks when rotated from un-aligned position to aligned position. We have much better torque characteristic when we use multi-teeth in stator pole of SR motor with maximum torque 25.14 T. We can improve the performance of motor by varying the dimension of the air gap between teeth that you can see in my further work. “Float over text” should *not* be selected.

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