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DESIGN, MODELING AND FEM ANALYSIS OF DISC ROTOR TYPE STEPPER MOTOR

Kathiriya Krishna[1], Golakiya Nilam[2], Gujarati Pruthvi[3], Kheni Vaidehi[4]
Student of Electrical Engineering Department, Shree Swami Atmanand Saraswati Institute of Technology, Surat, Gujarat, India

ABSTRACT

Generally four types of stepper motors are used Variable Reluctance stepper motor, permanent magnet stepper motor, hybrid Stepper Motor, and disc rotor type permanent magnet stepper motor. The Disc Rotor Type Stepper Motor is new technology which is recently introduced. It suggests many advantages over conventional stepper motor like higher torque at high speed, high torque to weight ratio, very low moment of inertia, high torque to inertia ratio, low power consumption, no iron structure is there in the rotor and also with SiFe laminations in the stator, eddy current losses are minimized, Disc magnet stepper motor are suitable for high performance high volume applications such as computer peripherals, robotics, CNC machine. They are extremely reliable and compact having better dynamic performance than other stepper motors.

KEYWORDS- *Permanent Magnet, SiFe laminations, FEM software.*

I. INTRODUCTION

The brushless DC motor whose rotor rotates in discrete angular increments when its stator windings are energized in a programmed manner. Rotation occurs due to magnetic interaction between rotor poles and poles of the sequentially energized stator windings. The rotor has no electrical windings but has salient or magnetized poles.

In this paper two processes is described, mathematical modeling and FEM analysis of Disc rotor type stepper motor. These both process used for design and analysis of machines. Disc Rotor type stepper motor is designed and analyzed by mathematical modeling and FEM analysis. The mathematical and FEM analysis is carried out by using FEM software.

Mathematical modelling is analytical method to design a motor in which related equations are used for calculation of motor parameters. In this process some fix parameters of motor like rated speed, outer stator and rotor diameter and axial length of motor and some variable parameter air gap and magnet length are taken and by using modelling equations other parameter like torque, air gap flux density are calculated. FEM (Finite Element) Analysis is done by FEM software for same rating of motor. In FEM analysis, 2D and 3D geometries of motor are designed. This geometry is divided in subdivision is called mesh. Doing analysis for that particular mesh and integrating all results final result is carried out.

II. CONSTRUCTION

The basic construction of disc rotor type stepper motor is as shown in figure 1

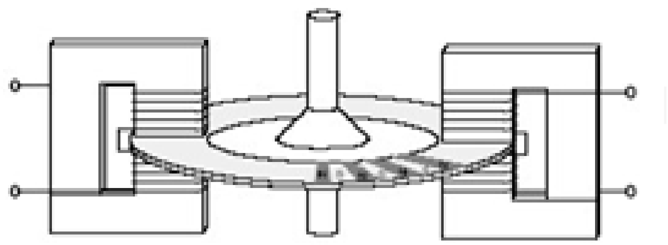

Figure 1: Disc magnet stepper motor

In which rotor is 1mm thin disc made of rare earth permanent magnet which is axially magnetized. Disc is magnetized by method of higher no. of magnetized poles so that getting much smaller steps. And low moment of inertia .the stator segment is made of SiFe laminations with short iron circuit thus iron loss is less. Stator segment are of C shaped. Each group consists of no. of elementary circuit and two electric coils coupled to said elementary circuit. Selection of stator segment is based on step angle. The 20 elementary circuits are grouped to form one phase. The other phase is made from another 20 elementary circuit. These 20 stator segments is equally angularly spaced by $2\pi k/N$ degrees apart (k is an integer). The 2 groups of stator segments are further angularly shifted by $2\pi r/N \pm \pi/2N$ (r =3, 4). This shifting of the group is done so that when one pole is completely inside the air gap in one of the groups, the air gap in the other group does not envelops one complete pole ,there remains some offset in the pole pitch which provides a higher resolution. Width of each elementary circuit = $(\pi / N)*R_i$; R_i=inner radius of the rotor disc.

III. MODELING OF DISC ROTOR TYPE STEPPER MOTOR

The flux due to PM disc Magnetic flux density caused by excitation of one segment. Considering an elementary magnetic circuit and applying ampere's law

$$H_{\delta} * \delta + H_{fe} * I_{fe} + H_{pm} * D_{Pm} = W * I$$

H_{pm}= Magnetic field strength of permanentmagnet
H_{fe}= Magnetic Field strength of stator segment
H_{δ} =Magnetic field strength of air gap
δ = air gap length
I_{fe} = iron length
D_{pm} = thickness of rotor
W = no of. Turns
I = winding current

Thus the magnetic flux density in the air gap due to an elementary magnetic circuit consisting of a single stator element is (neglecting the magnetic strength of iron as $\mu_o << \mu_{fe}$)[5]

$$B_{\delta} = \frac{W\mu_0 I}{\delta} - \frac{\mu_0 D_{pm} H_{pm}}{\delta}$$

The distribution of flux density due to the permanent magnet disc will be alternating in direction due to the alternating North & South poles. It will vary like a cosine function with maximum at an interval of π/p degrees. (p=no of pole pairs). Hence the flux density due to the PM disc can be found to be

$$B_R = \frac{\mu_0 D_{PM} H_{PM} COS(p\gamma_2)}{\delta}$$

This flux density we find based on rotor coordinates γ_1 is fixed to the stator and γ_2 is fixed to the rotor γ is the difference between these two coordinates.

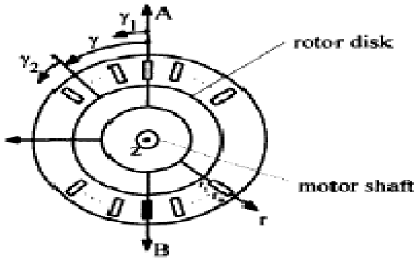

Figure 2: Rotor and stator Co-ordinate System

the torque developed is

$$Tm = \frac{w\mu_0 D_{PM} H_{PM} ({R_0}^2 - R_i^2)(I_b \cos(P\gamma) - I_A \sin(P\gamma))}{\delta}$$

IV. TABLE CONTENT

Table 1: Specification of motor

Holding Torque(Kg.cm)	10.8
Speed(steps/sec)	3600
Voltage(volt)	24-48
Step angle(deg)	1.8
Current(amp)	5-6

V. MODEL OF DISC STEPPER MOTOR

Using FEM software we made 2D and 3D model of disc rotor type stepper motor and analyze it below Figure 3 and Figure 4 shows the FEM analysis of 2Dand 3D model respectively which shows the value of flux density for disc rotor type stepper motor in which rotor is made of NdFeB material and stator is made of SiFe laminations.

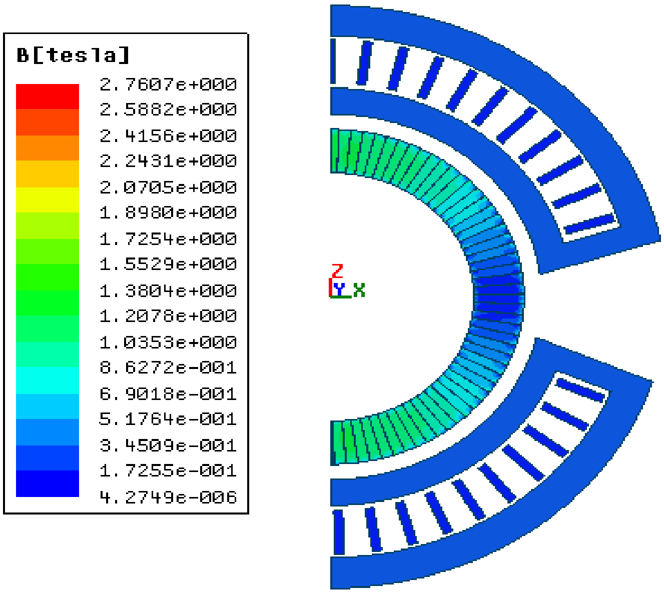

Figure 3: 2D model of disc rotor type stepper motor

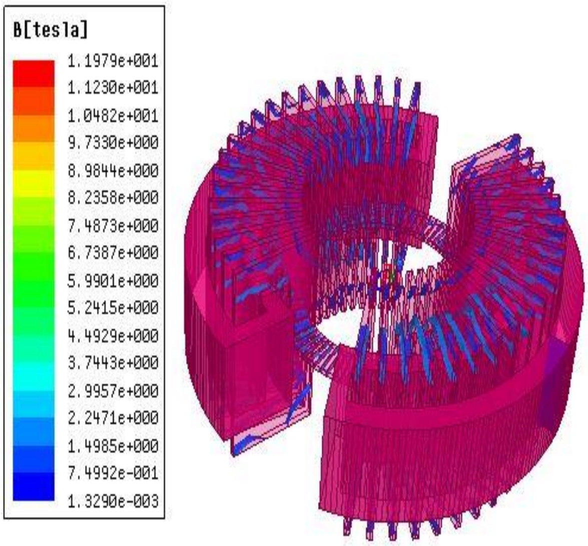

Figure 4: 3D model of disc rotor type stepper motor

In FEM software the analysis of object is done by dividing a whole object in very small parts in terms of mesh analysis. In mesh analysis of disc rotor stepper motor the software divides the motor in small nodes and apply the mesh operation and then the FEM analysis is done below Figure 5 and Figure 6 shows the mesh analysis of one phase and two phase of disc rotor type stepper motor.

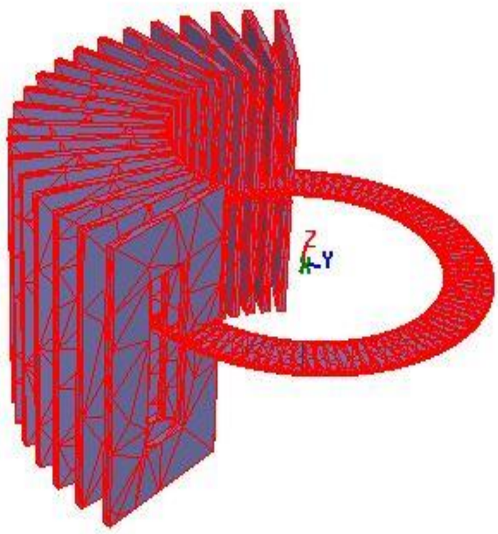

Figure 5: mesh analysis of one phase of disc rotor stepper motor

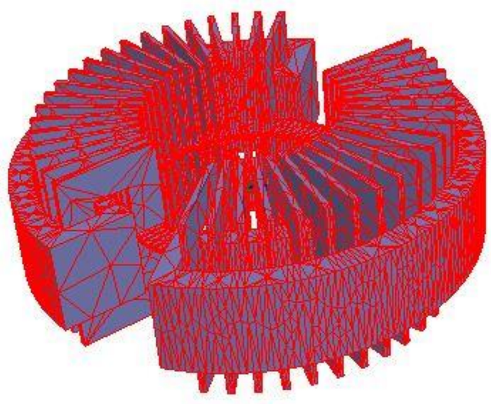

Figure 6 mesh analysis of disc rotor type stepper motor

With the help of FEM software the flux density analysis by combination of different materials for stator and rotor which is shown in below table.

Table 2: combination of different material

Lamination	Permanent Magnet	Torque(Kg.cm)
Steel1008	SmCo24	9.0275
Steel1008	SmCo28	9.6425
Steel1008	NdFeB	8.9674
SiFe	SmCo24	7.5371
SiFe	SmCo28	8.0474
SiFe	NdFeB	10.829

Figure 7 shows the torque angle profile foe different rotor and stator material combinations. and from that it is observed that from combination of NdFeB and SiFe lamination batter torque is achieved.

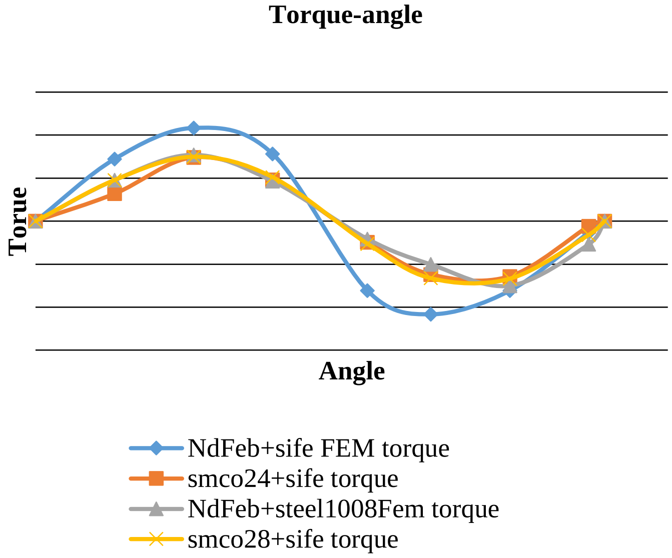

Figure 7: Torque angle Profile for Different material

Therefore the motor is designed for this combination of material NdFeB and SiFe. The torque angle profile for this combination is achieved for rated current and at different current which is shown in Figure 8 and Figure 9.And the Figure 10 shows the comparison of Torque current curve by FEM analysis and Mathematically.

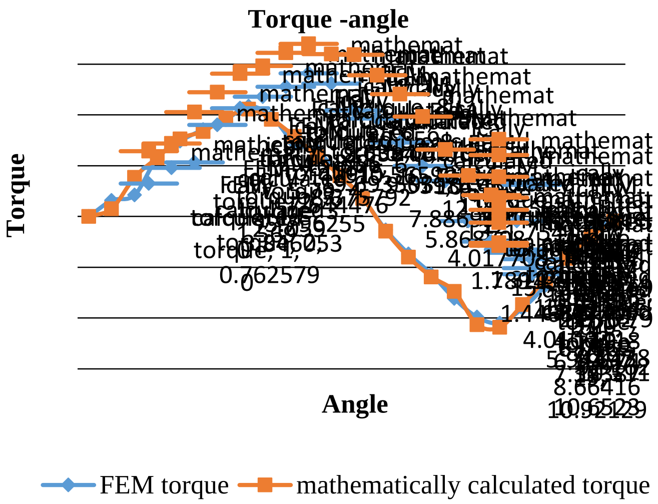

Figure 8 Torque Angle Profile at Rated Current

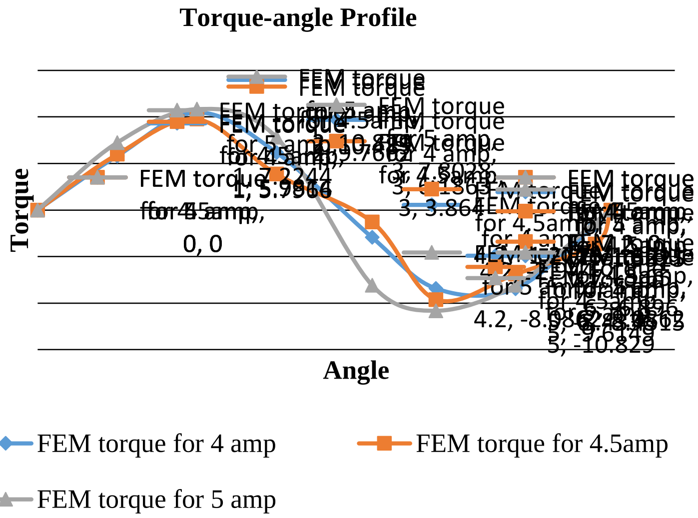

Figure 9: Torque Angle Profile at different current.

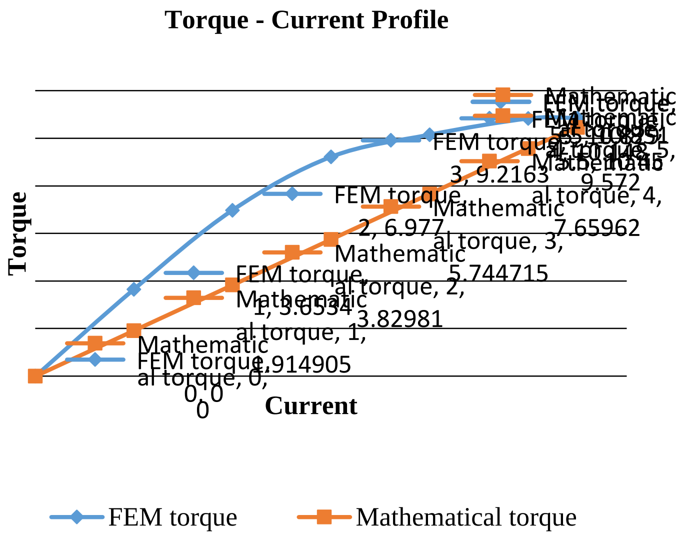

Figure10: Comparison of Torque Current curve By FEM and Mathematically

VI. CONCLUSION

Disc magnet stepper motor is special design for micro stepping. Here stator segments are independent. There is no interconnecting between two phases. Hence Designing and modelling all dimension of motor is to be calculated. Optimization of these types of motor is required to improve the dynamic performance of motor to suit there application. Based of FEM selecting the material grade for rotor disc for getting excellent and dynamic performance of motor. Air gap length is optimized at time reluctance is decreased based on the flux is increased and at time the
resultant magnetic field is strong so finally getting excellent torque.

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