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Step by Step Design of Flux Switching Machine using Electromagnetic Principle

Ramesh P[1,a], Gokulakrishnan R[2,b], Sathyanarayanan N[3,c], Hemantha kumar R[4,d], Lenin NC[5,e] *

[1,2]M.Tech PED, VIT University, Chennai, India

[3,4]Research Scholar, VIT University, Chennai, India

[5]Associate professor, School of Electrical, VIT University, Chennai, India

[e]lenin.nc@vit.ac.in

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Abstract. Flux switching motor (FSM) is one of the classification of brushless DC motor. The major drawback of the conventional DC machine is presence of brushes and commutator. This makes conventional DC machines not suitable to operate in hazardous conditions. FSM is a type of brushless DC motor without commutator and rotor windings, which has the advantages of both conventional DC and switched reluctance machines. Here a step by step electromagnetic design of FSM using the basic reluctance principle. The designed parameters are verified using two dimensional finite element analysis (FEA). Finally, the analytical results are compared with the simulated results.

Introduction

The DC machines were invented during the second half of the 19th century. During the starting days, only brushed DC machines are used. Later, because the development of the power electronics sector, brushless DC machines are introduced [1]. FSM is the type of brushless DC machine, which doesn't have windings in the rotor. This makes the construction of the motor much simpler when compared to other type of motors and more robust [2]. Because of no windings in the rotor, the cooling is also easier and faster [3]. The switching circuit for this motor needs only two switches for any pole configuration, which makes more cost effective than other DC and AC drives [4]. Because of these advantages, the usage of FSM in the industries is increasing for the applications where robustness, high torque and high speed are main concern.

This paper is organised in the following manner: Section 2 gives the constructional details of FSM. Section 3 explains the principle of operation. Section 4 gives step by step analytical design. Section 5 shows the Finite Element Analysis. Section 6 comparison of the results and Section 7 provide the conclusion.

Construction of FSM

The construction of the flux switching motor is similar to the switched reluctance motor, in which both the stator and rotor are having salient type poles. FSM contains two type of windings, field winding and armature winding. Both the windings are present in the stator, so there is no winding in the rotor. The field winding is the normal concentrated winding and the armature winding is the bifilar winding [6]. The switching circuit is used to alter the direction of the current in the armature winding.

Principle of operation

In the field winding, dc current is supplied throughout the operation. So, the flux is produced in the field winding of the stator. The orientation of the field flux is then switched from one pole set to the other pole set of stator by reversing the polarity of the current in the armature winding, to which the rotor gets attracted as shown in the Fig.1

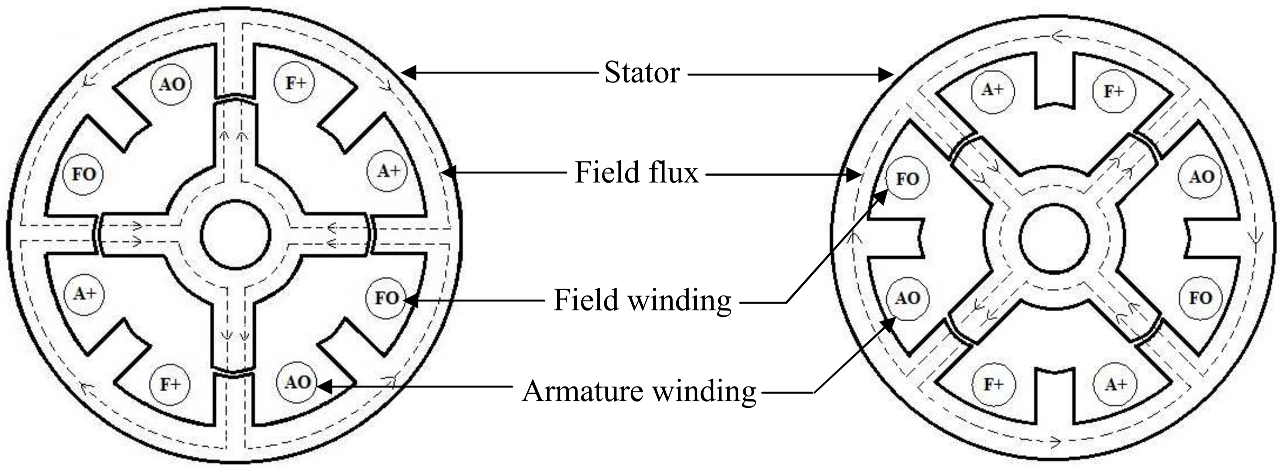

Fig.1 Flux path in Flux Switching Machine

Step by step design

FSM is designed for the power rating of 70W and the speed of 2000 rpm.

The required torque is calculated as,

Output power (P_o) = $\omega * T$ (Watts) (1)

Where, ω - Speed (rad / sec)

T - Required torque (N-m)

Assuming, the stator pole arc (β_s) and the rotor pole arc (β_r) has,

$\beta_s = 22^o$

$\beta_r = 23^o$

Stator design

Pole area, $A_s = \frac{D}{2} L \beta_s$ (mm$^{2)}$) (2)

Where, D = Stator bore diameter (mm)

L = Stack length (mm)

Back iron thickness, $C_s = \frac{A_s}{L}$ (mm) (3)

Pole height, $H_s = \frac{D_o}{2} - C_s - \frac{D}{2}$ (mm) (4)

Where, D_o = Stator outer diameter (mm)

Rotor design

Pole area, $A_r = \left(\frac{D}{2} - g\right) * L * \beta_r$ (mm^2) (5)

Where, g = Air gap (mm)

Core area, $A_{rc} = \frac{A_s}{1.6}$ (mm^2) (6)

Pole height, $H_r = \frac{D}{2} - g - \frac{D_{sh}}{2} - \frac{A_{rc}}{L}$ (mm) (7)

Where, D_{sh} = Shaft diameter (mm)

The designed stator and rotor parameters are plotted in Figs. 2 and 3 respectively.

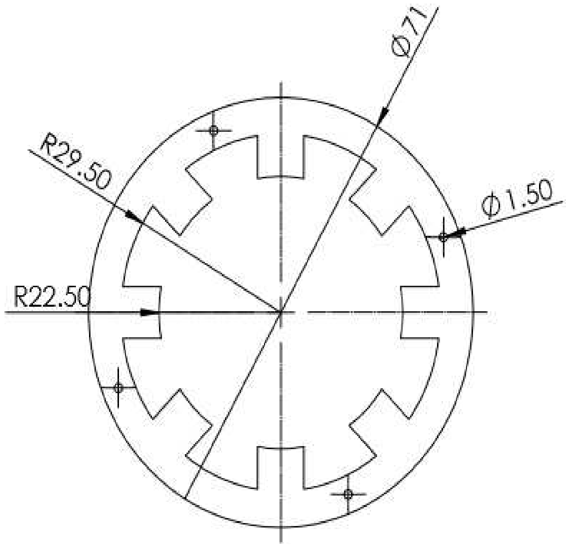

Fig.2 CAD model of the designed stator

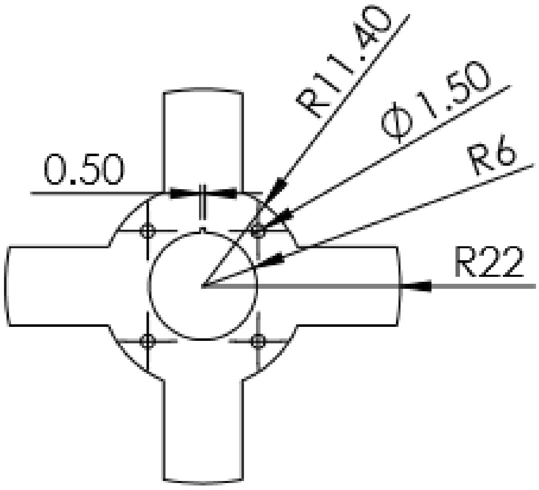

Fig.3 CAD model of the designed rotor with shaft

Winding design.

Assuming, Current density, J = 4.28 (A/mm^2) (approximately)

Area of the conductor, $A_c = \frac{I}{2J}$ (mm^2) (8)

Where, I = Input current (Amps)

Diameter of the wire, $D_w = \sqrt{\frac{4 * A_c}{\pi}} + 0.1$ (mm) (9)

Considering the area and diameter of the winding, Standard Wire Gauge (SWG) 23 is chosen.

Based on the equations (1) to (9), the design parameters are summarized below

Table I: Specifications

Parameters	Ratings
Output Power, P_o	70 Watts
Input voltage, V	36 Volt
Input current, I	2.5 Amps
Speed, N	2000 rpm
Torque required, T	0.33 N-m
Stator outer diameter, D_o	71 mm
Stator bore diameter, D	45 mm
Stack length, L	23 mm
Airgap, g	0.5 mm

Finite Element Analysis

The time stepped finite element analysis is the most accurate method available to obtain the magnetic characteristics in an electromagnetic device. In this paper a two-dimensional finite element analysis has been carried out on the machines depicted in Fig.1 using FEA based CAD package MagNet. Fig. 4 shows the torque developed by the machine at the rated current. The speed developed to this corresponding torque is shown in Fig. 5.

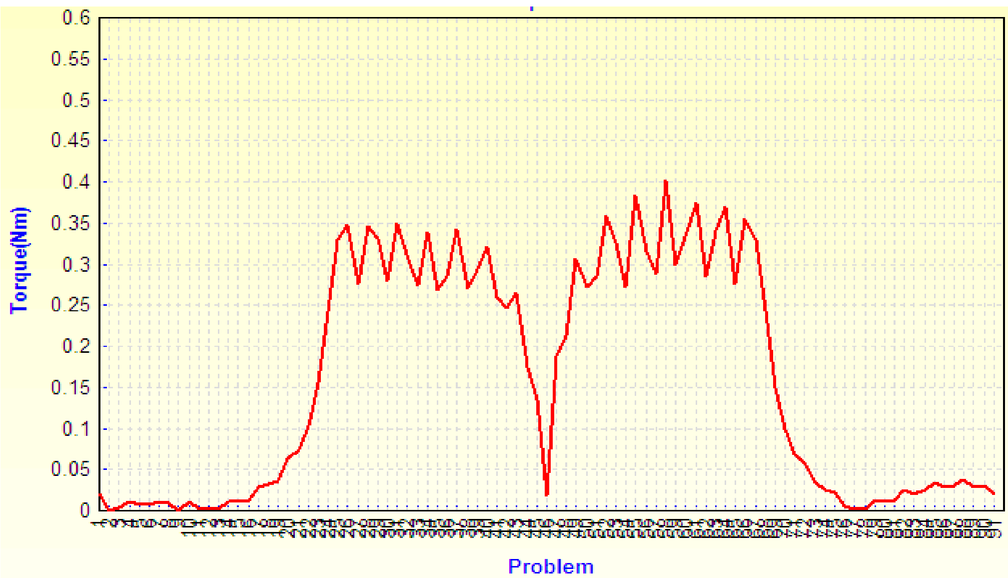

Fig. 4 Torque plot

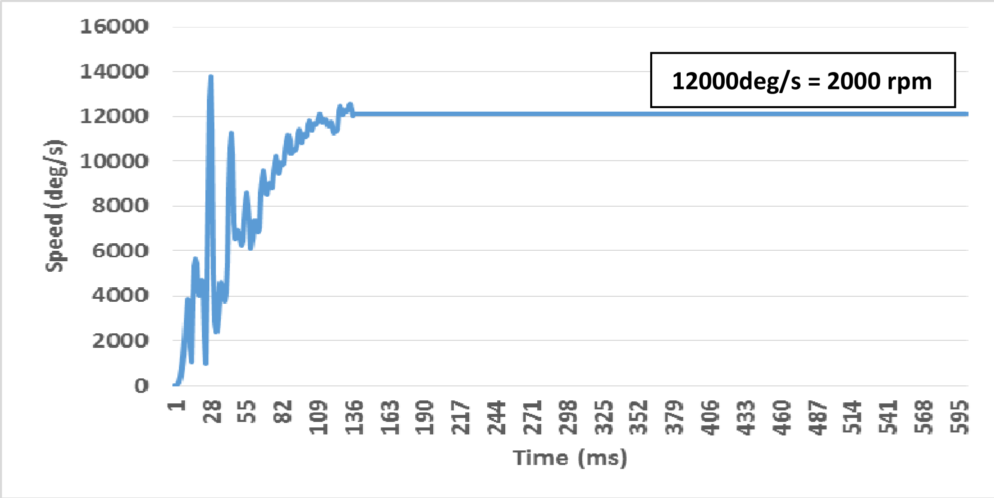

Fig. 5 Speed plot

Conclusion

In this paper, the step by step analytical design of the flux switching machine is developed and their desired parameters are cross checked with the FEA. The developed torque and the required speed are quite satisfactory with the analytical design. The analytical and FEA result shows that both are closely correlated. The future plan is to develop the machine and tested for electromagnetic, vibration and thermal behaviours.

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