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Performance Analysis of Permanent Magnet Flux Switching Machine Based on Modular Rotor

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ABSTRACT

Nowadays, electric motor with segmented rotor has attained a lot of interest of researcher for electric vehicle applications due to its high output torque and output power. Lately, Salient rotor in permanent magnet flux switching machine (PMFSM)has become attractive for provide high torque and power. unenviably, salient rotor inherited longer flux paths, high iron loss and winding loss, Moreover, PMFSM uses high PM volume and more flux leakage resulting in poor performance. In this paper a new structure of rotor known as modular rotor is introduced which enables reduction in iron losses. The other advantage of modular rotor topology is to reduce the mass of the rotor over a conventional salient rotor. The electromagnetic performance of modular rotor PMFSM machine is analysed by 2-D finite element analyses by using JMAG Designer 14.1 software. The motor performance is examined in terms of coil test, flux distribution, flux lines and average torque. The proposed motor securing the initial torque of 34.44 Nm and power of 12Kw at maximum current density of 30A_{rms}/mm^2.From the result it is concluded that modular rotor based PMFSM motor is suitable for light weight electric vehicles.

Key words: Cogging torque, Electrical vehicles, Flux-Switching, Induced back emf

1 INTRODUCTION

For industrial and domestic appliances electric motors are essential part. Thus, more compact, better efficiency, lightweight and low cost is the main demand of most of the industrial and domestic applications. This leads a challenge for researchers to develop an advanced electric motor. Just a decade ago, Flux Switching machine (FSM) has pulled an interest of researchers because of its all excitation sources situated on the stator, come up with simple cooling systems, while the rotor comprises of robust, simple iron piece, can be used for high speed applications. Flux switching machines are categorized into three kinds as shown in Figure 1, which are (i) field excitation (FE) FSM, (ii) permanent magnet (PM)FSM and (iii) hybrid excitation (HE)FSM. PMFSM and HEFSM both uses permanent magnet as excitation source which generates uniform magnetic flux. While in FEFSM, DC excitation has used which controls the magnet field density [1-3]. The working principle of FSM is conditioned on flux switching. For the better efficiency, easy cooling, robust rotor structure, light weight and low-priced makes FSMs most reliable and effective [4-8].The flux switching machine (FSM) is known as one of the forms of salient rotor reluctance machine with a novel topology, merging the inductor generator principle [9,10] and switched reluctance machine (SRM) [11].

In the flux switching machine all the active sources are placed on the stator such as both field and armature winding. Rotor consists of iron core with a simple shape and high strength. The term “flux switching” is to designate machines in which the stator teeth switches flux polarity resulting the motion of a salient pole rotor, and that’s basic working principle of operation [12,13].In 1955, Rauch and Johnson had innovated a single-phase alternator [14]. From that time diverse designs of PMSFM has been presented. Figure 2 describes a PMFSM conventional design with the disadvantage of high volume of PM.

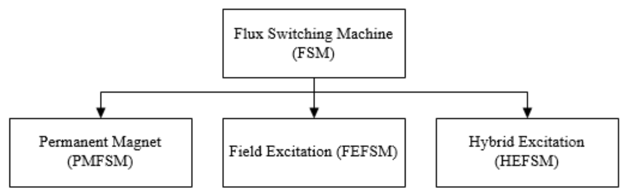

Figure 1: Categorization of FSM

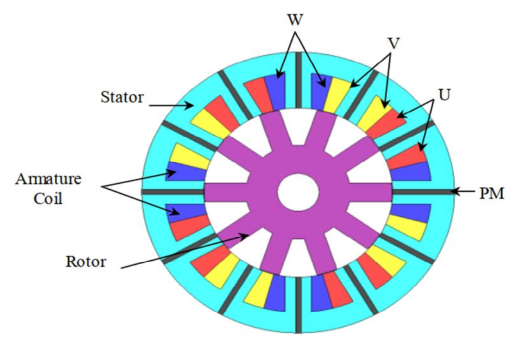

Figure 2: Conventional PMFSM

To use a smaller number of PM, an E-core topology is set up that alternately replaced the stator poles with stator tooth[15, 16]. In E-core configuration PM directions are utilized in Radial and circumferential directions. All radial PM are set up alternately while circumferential magnets are remain identical [17,18]. Furthermore, to increase the armature coil area the middle teeth of E-core has removed which introduces the new C-core topology [19]. Lately another design has introduced in M with segmented rotor [20, 21]. But it carries a drawback of ambiguous operation of high-speed rotor. Moreover, the flux leakage occurs at the tip od the PM due to non-uniform flux distribution, thus causes reduction in efficiency of the motor. This paper describes, a novel topology of PMFSM with 12S-10P modular rotor PMFSM has been investigated. The main advantage of modular rotor is to reduce the iron loss with marginal reduction in output torque as shown in Figure 3. Modular rotor also known as segmented rotor. It helps to reduce the weight of rotor over salient rotor. Modular rotor firstly was introduced in reluctance machines. Due to the shortest paths produces along the iron core through modular rotor decreases iron losses. The flux flows through from rotor pole to another rotor pole [21, 22]. To avoid flux leakage through stator an iron bridge has established. Furthermore, performance of the initial modular PMFSM design has been investigated by 2D FEA (finite element analysis). the performance of the motor is intercept specially at maximum current densities. An optimization technique will be implemented for the better performance of the motor [23].

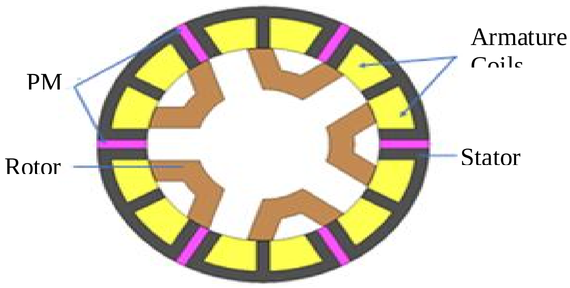

Figure 3: Modular rotor based PMFSM

2 RESEARCH METHOD

The novel modular rotor PMFSM design description and limitations are shown in Table 1. Electrical restrictions associated with inverter are set in the same way. Additionally, the current density for the armature coil are varies from 0 A_{rms}/mm^2 to 30 A_{rms}/mm^2. The complete process to accomplish the objective of this paper is shown in Figure 4.

From the arrangement, armature coil is sandwiched in permanent magnets, which are non-overlapping winding. To design and analysis, 2D Finite Element Analysis (FEA) tool is implemented in JMAG Designer 14.1 introduced by Japan Research Institute (JRI). Firstly, the main parts such as stator, rotor, PM and armature coils of the proposed PMFSM modular rotor are built in geometry editor consequently materials, boundary conditions and machine circuitry of machine are set in JMAG designer. The material employed for stator and rotor are steel 35H210, while NEOMAX-35AH is set for the PM.

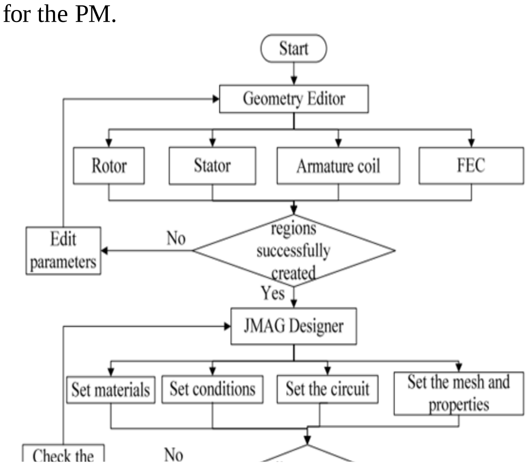

Figure 4: Flow chart for design process

Moreover, to validate the operating principle and the positions of armature coil phase of the proposed design coil arrangement tests are conducted. After the authorisation of the operating principle and coil arrangement test, numerous characteristics of modular rotor PMFSM on no load and at load were examined, respectively. To inspect the numerous executions of the novel proposed motor at no-load armature current density J_a was set to 0 A_{rms}/mm^2. Furthermore, flux distributions lines, back emf, cogging torque and torque characteristics and efficiency were evaluated.

3 RESULTS AND DISCUSSIONS

The outcomes of the proposed 12S-10P modular rotor based PMFSM have been explored in this section. In order to follow through the process results are showed in figures, graphs for better understanding. Table 1 shows the design specifications, parameter requirements and electrical restrictions are provided.

Table 1: Modular PMFSM design parameters

Items	PMFSM with Modular rotor
Number of rotor poles	10
Stator Outer radius (mm)	75
Stator tooth width (mm)	12.5
Rotor tooth width (mm)	10
Stator back iron depth (mm)	11
Motor stack length (mm)	70
Air gap (mm)	0.3
Radius of rotor (mm)	89.7
Armature slot area (mm^2)	300.8
No. of turns per armature coil slot	44
PM volume (Kg)	0.3

3.1 Coil test and operating principle

Coil arrangement test was achieved for each coil individually to validate the armature coil location and operating principle of modular rotor PMFSM. Primarily, Coil arrangement test was achieved for each armature coil 1 to armature coil 12 individually to validate the armature coil location and operating principle of modular rotor PMFSM. The main reason

for this process is to categorize the like pattern flux linkage produced in each coil. Furthermore, likewise flux linkage pattern has grouped one another. Consequently, three different phase linkage patterns established namely U, V and W.

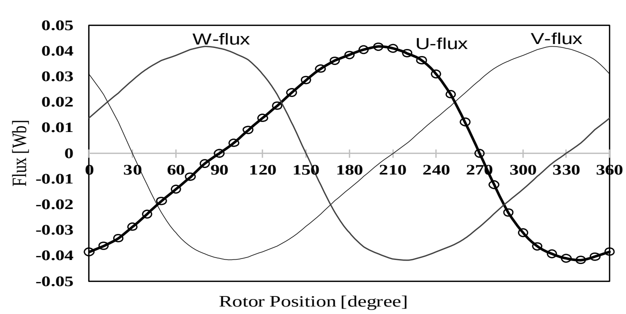

Figure 5:U, V and W phase Flux linkage

3.2 Flux Distribution Analysis

The open circuit test analysis is conducted to monitor the flux distribution of initial PMFSM modular rotor. The purpose of flux distribution is to observe the effects of flux saturation in the machine. Figure 6 shows the flux distribution of modular rotor PMFSM. It is observed that high flux concentration is at near rotor and PM due to maximum flux density. Significantly, low flux distribution is produced in armature coil which helps rotor to rotate smoothly. Some empty spaces are observed shown in red circle in Figure 6. Which can be reduce by optimization of motor.

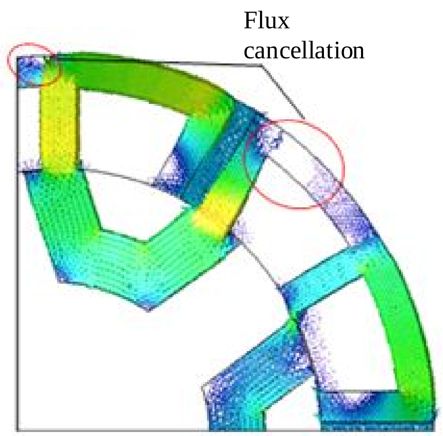

Figure 6: Flux Distribution of modular rotor PMFSM

3.3 Flux line Analysis

The main objective of flux lines is to monitor the flow of flux in motor. Therefore, 2d FEA method is used to examine the flux lines of proposed modular rotor PMFSM. Figure 7 shows the features of 12S-10P modular rotor PMFSM flux lines. Figure 7 shows that, the flux lines pass through the stator teeth to rotor pole between the two PM and rebound to nearest stator pole to complete the cycle. Thus, initial design has flux cancellation, which shows certain empty spaces in Figure 7. Though, design parameter needed to be changed for the improvements to achieve the maximum average torque, in contrast to that optimization technique would be implemented to increase the average torque.

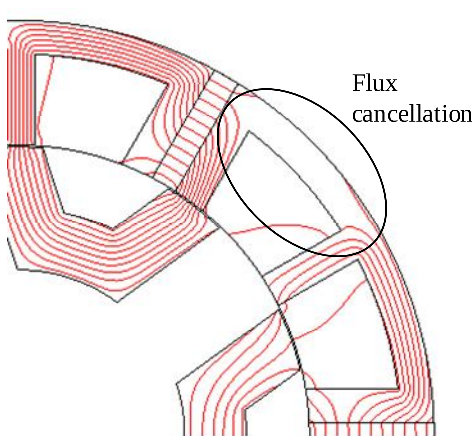

Figure 7: Flux lines of Modular rotor PMFSM

3.2Instantaneous Torque Characteristic

The performance of 12Slot-10Pole E-Core PMFSM at the maximum armature coil current density (Ja) of 30Arms/mm2 is analysed. From the analysis, the average torque obtained at the speed of 500 r/min is 34.44 Nm is depicted in Fig. 8.

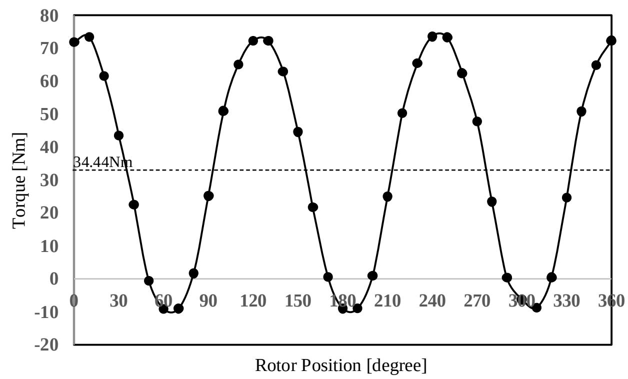

Figure 8: Instantaneous torque of Modular rotor PMFSM

4 CONCLUSIONS

Flux switching motor employing modular rotor has been characterised in this paper. The design considered a three-phase arrangement with permanent magnet flux excitation. The performance of the PMFSM based modular rotor is examined in terms of open circuit test such as flux distribution, flux lines and short circuit test such as average torque. JMAG Designer 14.1 is used to analysis the proposed motor. Thus, the output torque of the proposed design is 34.44 Nm. Moreover, this design can be further altered using optimization technique to obtain an optimal torque. Number of PM are reduced in the proposed design which makes it a good option for light weight electric vehicles.

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