Performance Comparison and analysis of (HEFSM) and (FEFSM) using Segmental rotor Structure

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Keywords: Hybrid Excitation Flux Switching Motor (HEFSM), Field Excitation Flux Switching Motor (FEFSM), Hybrid Electric Vehicle (HEV), and Segmental.

Abstract. This paper presents a new structure of hybrid excitation flux switching motor (HEFSM) using segmental rotor and the comparison of HEFSM and FEFSM using segmental rotor is performed to find the best candidate for hybrid electric vehicles (HEV). (HEFSM) using segmental rotor contains both the FEC and PM on the stator to produce maximum flux linkages. Initially, the coil arrangement tests are examined to validate the operating principle of the (HEFSM) using segmental rotor. Moreover the profile of flux linkage, cogging torque, and torque characteristics at various armature current densities of both the (HEFSM) and (FEFSM) using segmental rotor are observed based on 2D- finite element analysis (FEA). Initially performances show that HEFSM using segmental rotor produces torque of 18 Nm with low cogging torque and sinusoidal flux waveform. Thus by further design optimization the proposed motor will effectively achieve the target performances.

Introduction

Throughout the latest research a new machine FSM has been developed, having all the flux generating sources on the stator and keep away from the problem of brushes. The machine works on the principle of changing the polarity of flux linking in the stator with respect to the rotation of the rotor. FSM has three types that are permanent magnet (PMFSM), field excitation (FEFSM) and hybrid excitation (HEFSM). PM and FE coils are main sources of flux generation in (PMFSM) and (FEFSM) respectively, while in (HEFSM) both PM and FE coils are combined to produce flux linkage in the stator [1, 2]. (HEFSM) is the alternative option for hybrid electric vehicles HEVs combining the advantages of both (PMFSM) and DC FEC machines. (HEFSM) has the potential to improve the flux weakening performance, power and torque density, variable flux capability and efficiency [3, 5].

In more recent work, the use of segmental rotor structure has been adopted by the authors for SRMs and single phase FSM which provides more considerable gains over other topologies. The basic function of segments in the design is to provide the defined magnetic path for communication of the field flux to the adjacent stator armature coils with the rotation of rotor, to produce bipolar flux linkage in the stator. Using segmental rotor design, arrangement of each coil is around single tooth that provides the clear advantage of short end winding than the toothed rotor structure. By means of this arrangement there are many advantages like less conductor material is required, low cost and hence improve the performance efficiency of the motor [6-7].

This paper initially presents the principle of flux switching machine with segmental rotor structure. The new structure of (HEFSM) with segmental rotor is proposed and working principle of (HEFSM) with segmental rotor is verified, the performance results with no-load and load characteristics are also examined. Finally, the performance of proposed (HEFSM) with segmental rotor is compared with (FEFSM) employing segmental rotor.

Design Methodology

The design specification and parameters of proposed (HEFSM) and (FEFSM) with segmental rotor are listed in table 1. Using FEA simulation, designs of (HEFSM) and (FEFSM) are examined, conducted via JMAG-designer ver. 13.0 released by Japan Research Institute (JRI) and make a discussion on the attributes of each design based on the flux linkages, emf production flux distribution and cogging torque. Firstly the stator of the motor, rotor with segments, armature coil and DC field excitation coil are designed using JMAG Editor. After that material, conditions, circuits and properties of the machines are assigned in JMAG designer. For stator core and rotor segments the electromagnetic steel of 35H210 is used. In addition, coil arrangement tests are examined to confirm the operating principle of (HEFSM) with segmental rotor and to set the position of each armature coil phase.

Performance Analysis Based on 2D FEA

A. Coil Test Analysis

To verify the operating principle of (HEFSM) with segmental rotor, and find the proper position of each armature coil phase, arrangement of coil tests are performed separately. Fig. 1 shows that all the armature coils and FE coils are arranged in alternate direction and DC current of 51.27 A is applied to confirm the operating principle of (HEFSM) with segmental rotor structure. With this arrangement of coils the three phase flux linkage is defined as U, V, and W and maximum flux linkage of 0.054Wb is attained as illustrated in Fig. 2.

TABLE I. Design Specification Of 12S-8P HEFSM andFE-FSM With Segmental Rotor

Items	(HEFSM) and (FEFSM) with segmental rotor
Number of slots	12
Number of rotor segments	8
Stator outer radius (mm)	75
Stator back inner width (mm)	11
Stator tooth width (mm)	12.5
Armature coil slot area (mm^2)	250
FEC slot area (mm^2)	250
Rotor outer radius (mm)	45
Rotor inner radius (mm)	30
Air gap length (mm)	0.3
Span of the Segment	40^0
Number of turns per field tooth coil (FEC)	44
Number of turns per armature coil slot (AC)	44

B. Cogging torque test

The cogging torque analysis of three phase (HEFSM) and (FEFSM) with segmental rotor is shown in Fig. 3. From figure it is very obvious that (HEFSM) with segmental rotor has moderate peak to peak value of cogging torque that is approximately 4.021Nm. While (FEFSM) has lowest value of 2.88Nm. From the analysis of cogging torque, (HEFSM) with segmental rotor has not the better result even though it will be further improved in optimization.

C. Magnetic Flux Charectristics

Magnetic flux characteristics of (HEFSM) and (FEFSM) with segmental rotor are shown in Fig. 4. From Fig. it obvious that the magnetic flux strength of (HEFSM) and (FE-FSM) with segmental rotor has nearly the same value of approximately 0.052Wb. As the value of (HEFSM) is same as that of (FE-FSM) with segmental due to the reason that magnetic fluxes are not combined properly. however in by doing further optimization fluxes of FE coil and PMs will be easily combined and transferred from stator to rotor segments and able to generate more magnetic flux strength.

Torque Vs Armature Current Densities Ja, at Various Field Current Densities Je

Torque vs. armature current densities Ja, at various field current densities Je, of (HEFSM) and (FEFSM) with segmental rotor are shown in Fig.5 Fig. 6 respectively. In case of (FEFSM) it is noticeable from figure that the torque at Je 30A/mm^2 is increasing almost linearly as the armature current density Ja is increased and reached at the maximum value of approximately 32.8Nm. When the value of field current density Je decreased below 25A/mm^2 the value of torque initially increased up to certain value of Ja and then begins to decrease slightly due to the reason of magnetic saturation, which shows armature current density cannot be increased further. On the other hand to analyzing the torque characteristics of (HEFSM) with segmental rotor, Fig. 4 shows that the value of torque is also increasing linearly in each case of field current density Je, and reaches to the maximum value of approximately 18Nm at armature current density of 30Arms/mm^2. Although the value of torque at this stage is less compared to the (FEFSM) with segmental rotor, but by analyzing the torque characteristics, it is possible to improve the value of torque up to required target.

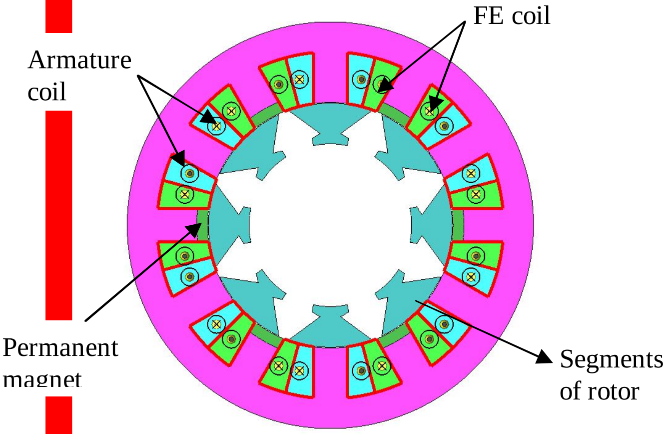

Fig.1 (HEFSM) with segmental rotor coil arrangements

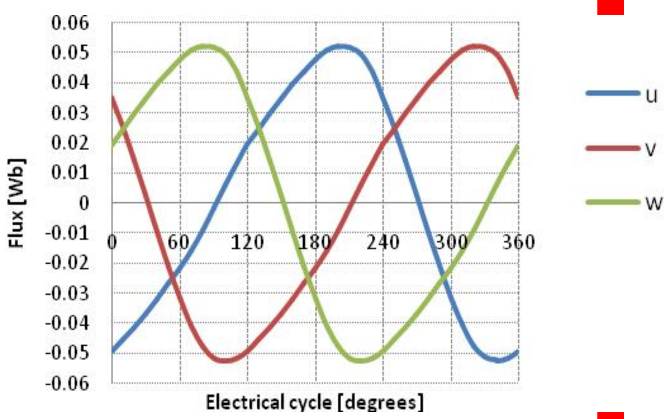

Fig. 2 Flux linkage of (HE-FSM) with segmental rotor in terms of U, V, W

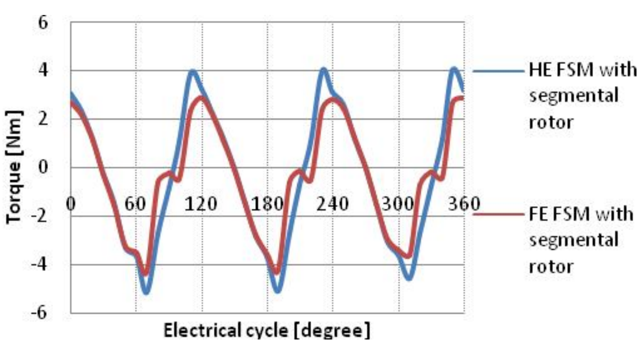

Fig. 3 Cogging torque of (HEFSM) and (FE FSM) with segmental rotor

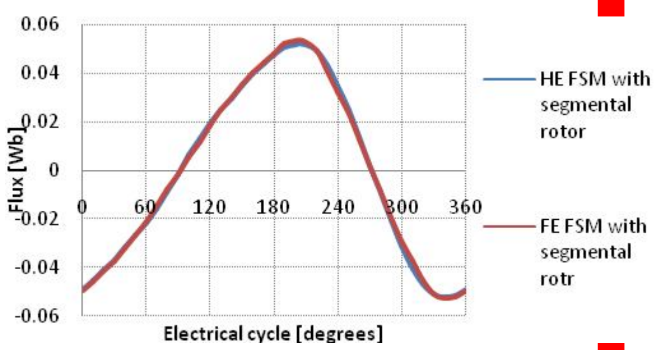

Fig. 4 Magnetic flux characteristics of (HEFSM) and (FEFSM) with segmental rotor

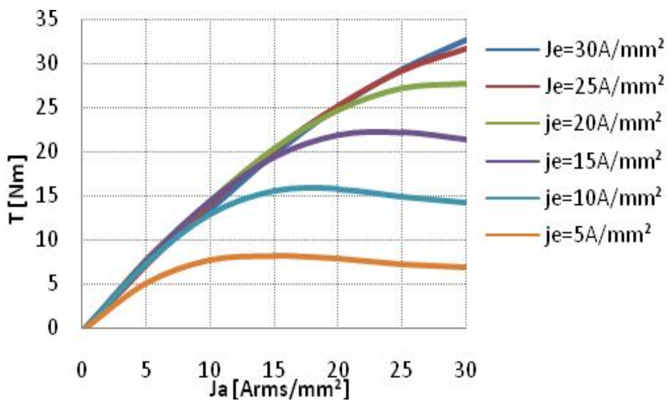

Fig. 5 Torque vs. Ja at various Je for (FE-FSM) with segmental rotor

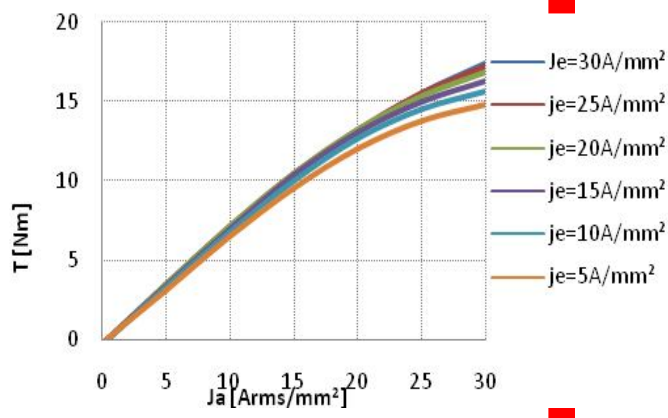

Fig. 6 Torque vs. Ja at various Je for (HE-FSM) with segmental rotor

Conclusion

In this paper the design study and analysis of (HEFSM) with segmental rotor has been introduced to investigate and confirm the working principle with segmental rotor based on 2-D FEA. Besides this a comparative performance is analyzed between (HEFSM) and (FEFSM) with segmental rotor. Based on 2-D FEA coil arrangement test, cogging torque, magnetic flux characteristics and torque vs. Ja at various field current densities Je, have been investigated. Although the performance (HEFSM) with segmental rotor is not adequate as compared to (FEFSM) with segmental rotor. However by further design improvement and optimization, the target performances will be attained.

Acknowledgement

This research was supported by GIPS (Vot U083) under Research, Innovation, Commercialization and Consultancy Management (ORICC) UTHM, Batu Pahat and Ministry of Higher Education Malaysia (MOHE).

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