Noise and Vibration Analysis of a Flux Switching Motor (FSM) with Segmental Rotor

Hedduri Sanket[1(✉)], M. N. Kishore[2], and Nagesh Suresh[3]

[1] Mechanical Engineering, PES University, Bengaluru, India
sankethedduri@gmail.com
[2] Crucible of Research and Innovation, PES University, Bengaluru, India
[3] Computational Mechanics, PES University, Bengaluru, India

Abstract. Flux Switching Motor (FSM) with segmental rotor is a new class of electric motor, with both AC and DC windings on the stator. The rotor is devoid of any windings. FSM with its high torque density, compactness, less heat production and high ruggedness can prove to be an ideal motor topology to be used for the propulsion systems of electric vehicles. The objective of this study is to investigate the noise and vibration characteristics of an FSM with segmental rotor due to the electromagnetic forces acting on the motor and optimize the design to reduce noise and vibration levels.

Keywords: Flux switching motor · Vibration · Noise · Electromagnetic analysis · Electro-mechanical interaction

1 Introduction

When a rotor spins, unbalance lateral forces and moments are generated due to limitations in machining and assembly accuracy. These forces and moments give rise to vibration at the same frequency as rotational speed. If the excitation frequency matches that of any of the natural frequencies of the rotor, resonance takes place, leading to higher vibration and noise and sometimes costly failures. There are many reasons for induction of rotor dynamic instability, viz., electro-mechanical interactions, misalignments, air gap eccentricity, etc.

2 Methodology

A flux-switching motor of 1 kW power rating, having 8 rotor segments was designed from scratch and 3D CAD model developed. Modal analysis was done to obtain natural frequencies and mode shapes of the rotor. Transient magnetic analysis was then performed to get the electromagnetic forces acting on the rotor and stator. Based on the results of transient magnetic analysis, the rotor and stator design were optimized to, avoid magnetic saturation of the material, provide a low reluctance path for the magnetic flux lines and avoid magnetic flux leakage. Impulse excitation exerted on the rotor by electromagnetic forces was used as the load for vibration transient analysis and the rotor response found out.

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3 Configuration and Design of FSM

Figure 1 shows the construction of an FSM. It consists of stator, windings (coils), rotor segments and rotor core. Based on available research literature, 7-segment and 8-segment rotors are considered to be the optimum options for a 12-pole stator. The rationale behind opting 8 rotor segments was that, more number of rotor segments result in less torque ripples and even number of segments have lesser noise and vibration problems [1]. The configuration of the 8-segment FSM is as listed in Table 1. Table 2 shows the materials assigned for different parts of the motor.

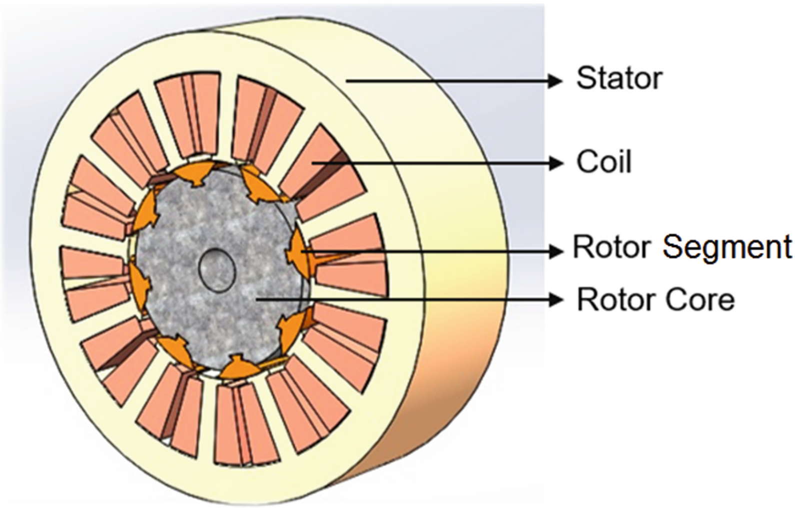

Fig. 1. Flux-switching motor with segmental rotor

4 Electromagnetic Simulation

4.1 FSM Design Optimization

Providing a low reluctance path for magnetic flux, by optimizing the rotor and stator design would not only result in an increased torque output but also reduce vibration and noise levels. Avoiding magnetic saturation of the rotor and stator material would lead to higher efficiency. The magnetic flux density was studied and the dimensions of the stator tooth was iterated to limit the magnetic flux density to around 1.5 T. The same process was employed to finalize rotor segment design. Magnetic flux density of the motor is shown in Fig. 2. It was observed that most of the magnetic flux on the stator and the rotor segments was below 1.44 T, and hence magnetic saturation was avoided. Presence of magnetic flux above 1.6 T (saturation limit) was observed in a very small localized area.

Table 1. Motor configuration

Parameter	Value
Rating of the motor	1 kW
Rated speed	3000 RPM
Number of AC phase	3
Number of AC excited coils	6 (96 turns each)
Number of DC excited coils	6 (96 turns each)
Number of stator poles	12
Number of rotor segments	7 and 8
AC supply current	5 A, 400 Hz
DC supply current	5 A
Air gap	0.5 mm

Table 2. Material configuration

Part	Material
Rotor segments	M36 electrical steel
Rotor core	AISI 304 stainless steel (non-electrical steel)
Stator	M36 electrical steel
Windings	AWG 12 copper

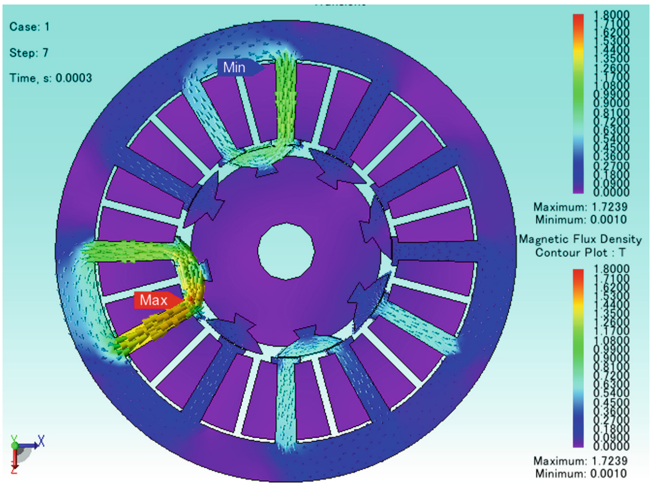

Fig. 2. Magnetic flux density distribution contour plot

4.2 Electromagnetic Force Calculation

The most important vibration excitation is the reluctance force produced in the air gap between the stator and rotor. The reluctance force of electric motor is electromagnetic force which has two components, radial (F_{rad}) and tangential (F_{tan}) components. In electromagnetic FEA calculations, the material boundaries are chosen on edge of the stator tip [2]. Equations (1) and (2) give the formulae for radial and tangential electromagnetic forces respectively. The integral is performed over the length of the stator tip edge length, l.

$$F_{rad} = \frac{L_{stk}}{2\mu_0} \oint \left(B_n^2 - B_t^2\right) dl \tag{1}$$

$$F_{tan} = \frac{L_{stk}}{\mu_0} \oint (B_n.B_t) dl \tag{2}$$

where B_n and B_t are the normal and tangential components of magnetic flux density respectively, $\mu_0 = 4\pi \times 10^{-7}$ H/m, is permeability of vacuum and L_{stk} is stack length of the machine.

Figure 3 shows the maximum nodal force (EMF) acting on the rotor at any point in time. Average absolute total EMF for the 8-segment rotor was found to be 75.86 N.

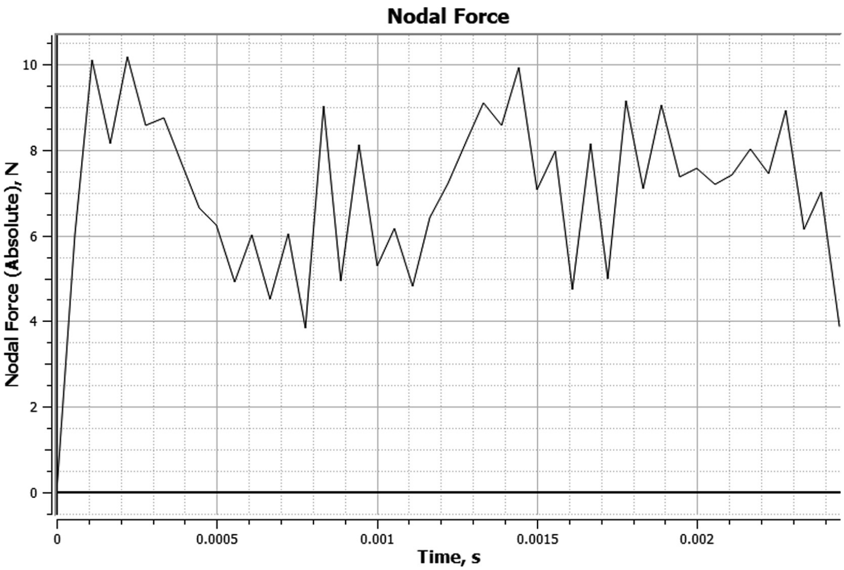

Fig. 3. Maximum nodal force (EMF) versus time

Table 3. Modal analysis results

Mode	Frequency (Hz)
7	13,342
8	13,349
9	14,801
10	14,808

5 Rotor Noise and Vibration Characteristics

5.1 Modal Analysis

A free-free eigen value analysis was then carried out to find out the natural frequencies of the rotor (Table 3). The values of the first six modes were zero or near zero, which verified structural integrity of the FE model.

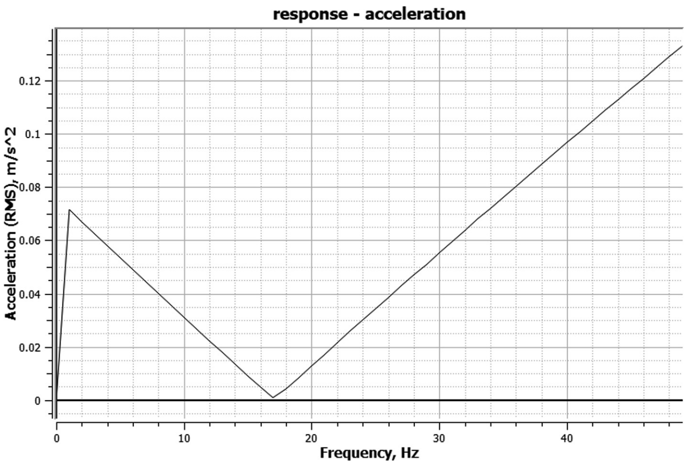

Fig. 4. Rotor response in the operational frequency range

5.2 Rotor Response to EMF

The response of the rotor was found for operational frequency range of 0–50 Hz (0–3000 RPM). From Fig. 4 and the modal analysis results, it can be concluded that the rotor is very much safe in the operation range. Equation (3) gives the equation for Sound Pressure Level (SPL) in decibels.

$$SPL = 20\,log_{10}\frac{P_1}{P_0} \tag{3}$$

where P_1 is actually measured sound pressure level of a given sound, and P_0 is a reference value of 20 μPa, which corresponds to the lowest hearing threshold of the young, healthy ear.

It was observed that in the operational frequency range of 0–50 Hz, the maximum sound pressure level (SPL) was 101.49 dBA at a rotational velocity of 3000 RPM or 50 Hz.

6 Conclusion

In this paper, an effort was made to find out the noise and vibration characteristics of a 1 kW 8-segment FSM rotor due to the EMF acting on the rotor. The rotor and stator design were optimized to reduce noise and vibration by avoiding magnetic saturation of the material, providing a low reluctance path for the magnetic flux lines and preventing magnetic flux leakage.

Modal analysis of the rotor revealed that its natural frequencies lie very far away and hence the rotor is safe in the operation range. The results were analytically verified. Response of the rotor due to the EMF was found out. A maximum Sound Pressure Level of 101.49 dBA was found out at the maximum operation speed (50 Hz) of the rotor. It is to be considered that this analysis was done for the bare rotor, which was not physically connected to the whole motor, through bearings, in which case, the effective mass of the system increases and the SPL comes down. SPL can also be further reduced by using acoustic padding inside the motor.

References

1. Zulu, A.: Flux Switching Machines Using Segmental Rotors, pp. 87–88. Newcastle University, UK (2010)
2. Xin, G.E.: Simulation of Vibrations in Electrical Machines for Hybrid-Electric Vehicles, p. 7. Chalmers University of Technology, Sweden (2014)