Comparison of Mechanical Vibration in a Double-Stator Switched Reluctance Machine and a Conventional Switched Reluctance Machine

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***Abstract*— Vibration and acoustic noise are viewed as the most important drawback of switched reluctance machines which prohibit their widespread use in many industries. Double-stator switched reluctance machines (DSSRMs) can be considered as a solution to this problem by presenting a unique topology which reduces the radial forces in the machine. This paper compares vibration behavior of a DSSRM and a conventional SRM using a multi-physic analysis. Finite element (FE) electromagnetic method is used to calculate force density at various parts of the stator surface in both machines. These force densities are then used in a FE structural analysis as an input to find the acceleration, deformation and velocity of vibrating surface in selected points on the outer surface of the machine.**

Index Terms— **electric machine, acceleration, vibration, finite element method**.

I. INTRODUCTION

Unique features of switched reluctance machines (SRMs) such as low cost, simple and rugged construction and fault tolerant nature makes them good candidates for many applications such as traction in electric and hybrid electric vehicles (EV and HEV) [1]. However, vibration and noisy behavior of these machines is a barrier against their widespread usage. Vibration of the stator in SRMs is mainly due to radial forces acting on the stator frame. Although, different design and control methods have been presented to mitigate these forces, they are still a major cause for vibration [2, 3].

Double Stator Switched Reluctance Machine (DSSRM) has been proposed as a high power density machine with a novel flux path resulting in generation of much lower radial forces [4]. However, the vibration characteristics of the DSSRM have not been reported yet. In this paper, using coupled magneto-structural finite element method (FEM), vibration analysis of a DSSRM is performed and the results are compared to a conventional SRM with relevant mechanical and electrical attributes.

II. METHOD OF ANALYSIS

A DSSRM and a conventional SRM are chosen for analysis and comparison. Both machines are depicted in Fig. 1, where the outer diameter and stator yoke thickness are kept the same in both models to have more realistic comparison. However, for an identical value of the magneto-motive force, DSSRM offers more torque density level. The average torque of the DSSRM is 2.1 Nm at 2000 rpm whereas that of the SRM is 1.3 Nm.

A coupled magneto-structural analysis based on FEM is carried out. The algorithm used for the analysis is shown in Fig. 2. In the presented method stator currents are first calculated based on rotor position and circuit parameters and are then applied to the electromagnetic FE model. The same profile with the same rising and falling times are assumed for both motors to attain a fair comparison. Edge force density calculated in electromagnetic FE model by Maxwell stress tensor method is then used as input to the transient structural analysis. The time step in structural analysis is selected ten times smaller than that of electromagnetic analysis to take into account the mechanical damping between applying two consecutive forces. Also frame and coils of both machines are considered in this analysis to reflect their impact on natural frequency and mechanical damping factor of the machines [5]. The frame is fixed in four positions as depicted in Fig. 1c. Four points on the outer surface of both machine selected for extracting vibration profile are also shown in this figure.

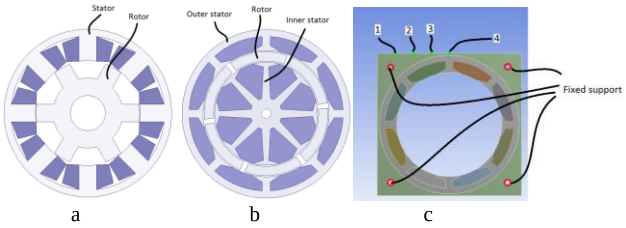

Fig. 1. Cross section of conventional SRM (a) and DSSRM (b) frame, supporting and selected points positions (c)

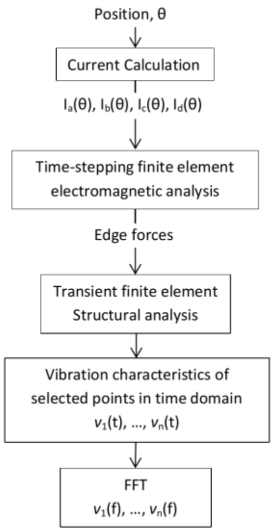

Fig. 2. Analysis algorithm

By performing structural analysis, vibration characteristics i.e. deformation, velocity and acceleration are computed.

III. RESULTS

The vertical accelerations of the SRM at point 1 to 4, as a function time for one mechanical cycle, is shown in Fig. 4. It is seen that the point 4 experiences the most intense vibration which is reasonable as it has the longest distance from fixed support sections of the frame. The harmonic component of acceleration is also illustrated in Fig. 5 where the main components are around 4.2 kHz and 6 kHz. As the positions get closer to the center the 6 kHz components become more intense. To check the validity of the results, modal analysis of the machine has been performed which shows that the first mode of SRM natural frequencies is at 4130 Hz and it has two other modes at 6050 Hz and 6053 Hz which are excited by radial forces. It is notable that, natural frequencies of the machine greatly depend on fixing supports. The results for the DSSRM are presented in Fig. 6 and 7. It is seen that the amplitude of acceleration is much lower than that of the SRM while the power density is almost twice. Obviously with an equal power density DSSRM has even much lower vibration compared to the conventional SRM. Dominant harmonics in this case are 4 kHz and 11.2 kHz. By performing modal analysis it has been observed that the DSSRM has first mode natural frequency at 4014 Hz and another mode at 11400 Hz in which shows a good agreement with vibration characteristics. A maximum amplitude value for acceleration, velocity and deformation for both motors are recorded and compared in Table I. This comparison illustrates a significant reduction in vibration of the DSSRM with respect to the conventional SRM.

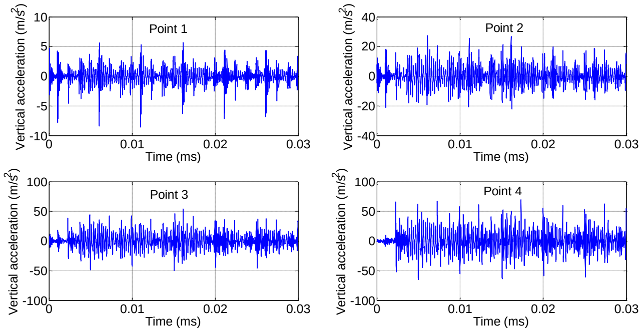

Fig. 4. Vertical acceleration of conventional SRM in time domain

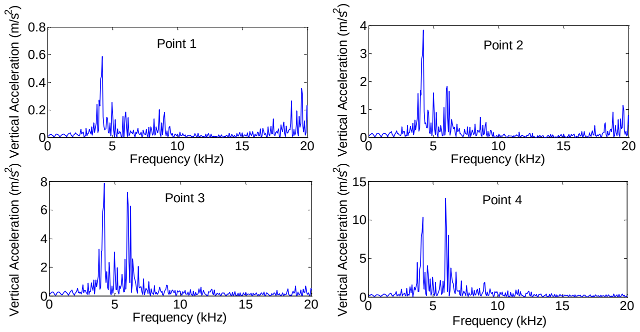

Fig. 5. Vertical acceleration of conventional SRM in frequency domain

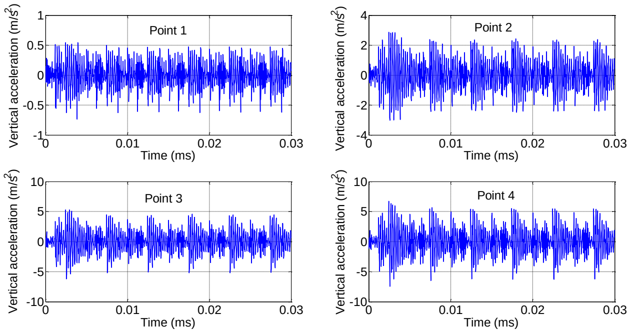

Fig. 6. Vertical acceleration of DSSRM in time domain

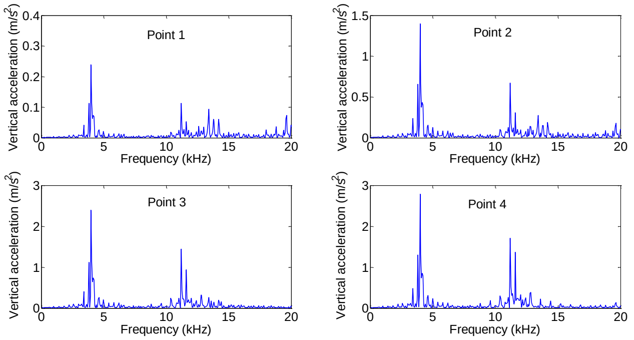

Fig. 7. Vertical acceleration of DSSRM in frequency domain

TABLE I: Vibration characteristics of SRM and DSSRM

Item	SRM	DSSRM
Maximum acceleration (m/s^2)	60	6
Maximum velocity (µm/s)	1800	260
Maximum deformation (nm)	120	11

IV. CONCLUSION

This paper compares vibration characteristics of a DSSRM and a conventional SRM with the same outer diameter and yoke thickness. Transient electromagnetic-structural analysis has been carried out using FEM. Acceleration, velocity and deformation of selected points of the outer surface of machines are calculated and compared. Results show that the DSSRM machine experiences much lower vibration than the conventional SRM. The maximum deformation in the DSSRM is an order of magnitude lower than that of the SRM. Velocity and acceleration are also lower by factors of 7 and 10 respectively.

V. REFERENCES

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