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Review on Numerical Investigation and Optimization of Switched Reluctance Machine with Geometrical Parameters using Ansys

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Abstract— Due to SRM's robust construction, high operation reliability, high efficiency, high torque to inertia ratio, and low manufacturing costs, they have been attracting substantial attention over the last two decades. Their simple brushless structure and the absence of commutators can be considered as the principal advantage that leads to their stable operation. Since SRMs have no winding or permanent magnet on the rotor, the rotor losses are low, and as such they require no rotor cooling. Switched reluctance motors (SRMs) are used in numerous applications due to their simple and robust structure. In addition to being mechanically and thermally robust, features such as high torque density, efficiency, and reliability, coupled with their fault tolerant structure and low manufacturing cost make SRMs quite attractive. Although SRMs have many features and advantages, large torque ripple, vibration, and acoustic noise are the major disadvantages of these machines. The vibration and acoustic noise of SRMs are mainly generated by the radial forces. The radial forces cause deformation on the stator yoke, which results in vibrations and consequently, frame deformation. When these vibrations resonate with the motor body's natural frequencies, the amplitude of the oscillations and the deformations are intensified. Hence, the acoustic noise increases significantly. The vibration and acoustic noise of SRMs have been deeply investigated throughout the years, and various methods are reported based on modifications on the motor structure and motor control for reducing them. In this thesis, a new vibration and acoustic noise mitigation method is proposed. This method combines the radial force reduction and damping improvement on the stator. The radial force is reduced by introducing rectangular windows on the rotor and the stator poles, which result in a reduction on the stator deformation.

Keywords: Acoustic noise, Switched Reluctance Machine (SRMC), Modal analysis, field-programmable gate arrays (FPGA), pulse width modulation (PWM) and vibration, Ansys

I. INTRODUCTION

Since SRMs have no winding or permanent magnet on the rotor, the rotor losses are low, and as such they require no rotor cooling. The SRM simple rotor structure also maximizes the torque to inertia ratio. Another important feature of the SRM is that its stator phases are electrically independent, thereby making SRMs more tolerant to faults than any other drive system. The stator phases are also magnetically independent from each other, which provides an advantage of controller flexibility to the drive system. Moreover, the absence of rotor windings or magnets makes it possible to achieve very high speeds. The torque-speed characteristics of the motor can be customized based on the application requirements more easily during the design stage due to their inherent flux weakening capabilities. These attractive features make SRMs potential candidates for applications in industrial and commercial markets. However, dealing with the large torque ripple, high vibration, and acoustic noise are the biggest problematic issues of SRMs. The main causes of vibration and acoustic noise are the radial force and the torque pulsation due to flux switching between the phases. Abrupt variations in the radial forces deflect the stator back iron, which cause a pressure change in the surrounding air giving rise to acoustic noise. Numerous methods for the reduction of vibration and acoustic noise are proposed in the literature. These methods can be grouped as design and control methods. This thesis mainly focuses on the vibration and acoustic noise reduction of SRMs from the machine design perspective.

The radial force is reduced by introducing rectangular shaped windows on the stator and rotor. This reduces the total deformation on the stator back iron and the motor frame. The total deformation is further reduced by introducing diamond shaped holes on the stator. These distributed air gaps act like little springs on the stator, whose spring coefficients change with the location and size of the holes. Consequently, the natural frequencies of the motor body change, allowing the acoustic noise to be reduced by pushing the vibrations out from the audible spectrum. The sizes and the positions of the distributed air gaps are adjusted such that the motor average torque is not affected while the stator deformation is minimized. The electromagnetic, structural, and harmonic analyses are performed on ANSYS Maxwell and ANSYS Mechanical FEA software packages.

II. LITERATURE REVIEW

Over the past two decades, SRMs have been intensely developed. The origin of SRMs can be tracked back to 1838, but the SRM concept was not fully implemented due to the lack of the necessary power electronic devices and high power switching techniques. Over the past decades, the progress made in motor design and high power switching devices made SRMs more attractive to researchers; therefore, SRMs became popular in both academia and industry.

Robust and straightforward construction is the most attractive feature of SRMs, which contain no rotor windings, permanent magnets, brushes, or commutators. The rotor is basically made of a piece of steel with laminations which are shaped to form salient poles without any windings. Because of the absence of brushes, SRMs provide a long life. Due to the lack of a permanent magnet and windings, SRMs have a low manufacturing cost, high power to weight ratio, high efficiency over a wide speed range, high speed and acceleration capabilities, and high fault tolerance. The advantages that are mentioned above make SRMs attractive and favorable for researchers and various industrial applications.

SRMs can address unique and varied requirements such as speed-torque relationship and high fault tolerance, which make them an ideal candidate for utility vehicles, golf carts, electric cars, buses, and trains. Furthermore, SRMs are well suited to the aerospace field due to their high-speed capability and robustness .For a smooth movement, the SRM`s phases need to be excited at certain rotor angles. Conventionally, the position of the rotor is measured using mechanical sensors mounted on the rotor shaft. Aside from increasing the cost and making the drive system more complex, most of the times the mechanical position sensors cause reliability issues. Although sensorless position estimation methods exist in the literature, these methods make the control even more complex as they require excessive calculations.

Another disadvantage of an SRM is the high level of torque ripple at low speeds, especially when it is operated in single-pulse voltage control mode that contributes to speed ripple and vibration in the stator. Compared with the sinusoidal AC machines, the torque ripple is higher in SRMs. The torque ripple is mainly due to the nonlinear behavior of the inductance based on the position of the rotor and the excitation current. The existence of the torque ripple causes accuracy problems, especially on the servo systems. There are various known torque ripple reduction methods in the literature. Torque ripple reduction is achieved with different approaches such as improving the motor design, improving the control strategy, and selecting a higher number of commutation phases. A better design may include optimizing the rotor and stator pole arcs, inserting pole shoes into the rotor poles, etc. Minimizing the torque ripple through the control may cause average torque reduction. Selecting a higher number of phases increases the number of required power electronic components, which raises the cost of the drive system.

III. OBJECTIVE OF THE STUDY

Our main objective of the study is to investigate the SRM Model by provide holes in the stator and rotor laminations are introduced to reduce the radial force and mechanical vibration in SRMs. The placement of the holes can be optimized to maximize the benefits. Reducing the radial force is one way to reduce the vibration. However, there is a tradeoff between the radial force reduction and the torque production. A decrease in the radial force leads the tangential force and torque to decrease. Therefore, while reducing the radial force, the reduction in the average torque should be observed, and thus an optimization process needs to be introduced. Other than the radial force reduction, the damping effect of the motor body can be improved to reduce the vibration. In this way, the natural frequencies of the motor can be pushed out of the audible spectrum, or at best the amplitudes of these frequency components can be reduced by adding damping elements to the motor body.

IV. PROPOSED METHODOLOGY

The following steps will be taken in research methodology for the current study:

- Electromagnetic Force Generation Mechanism.
- Windows on the Stator and Rotor Poles.
- Distributed Air Gaps on the Stator.
- Modal Frequency Analysis
- Window on the Rotor Pole
- Window on the Stator Pole
- Analysis of the Distributed Air Gaps
- Analysis of the Distributed Air Gaps with Stator and Rotor Windows
- Post-Processing in Ansys

V. PROPOSED RESULTS

- Electromagnetic Forces
- Torque (average) with peak load
- Deformation in different mode in Modal Analysis
- Acceleration
- Graphical representation of magnetic field

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