Design and Analysis of 24/18 Switched Reluctance Motor using ANSYS Maxwell

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Abstract: In this study, a design for a 24/18 switched reluctance motor (SRM) characterized by high efficiency and effective performance is proposed using ANSYS Maxwell. First, the dimensions, basic characteristics and operating conditions have been determined based on various mathematical calculations, after evaluating and analyzing the results to ensure that the desired design model was achieved. A two-dimensional model was created to analyze the performance curves and electromagnetic analysis based on the Finite Element Method (FEM) for its speed and accuracy. The results include the magnetic flux density and flux lines, in addition to the torque curve, speed, currents, flux linkages, and induced voltages.

Keywords: switched reluctance motor, efficiency, performance, ANSYS Maxwell, electromagnetic, FEM.

1. INTRODUCTION

Switched reluctance motors (SRM) are characterized by high efficiency, ease of design, durability, simple structure and low manufacturing costs, which make them suitable for many different industrial applications.

The influence of stator and rotor materials selection on the performance of a 6/4 switched reluctance motor was studied in [1]. Several research papers have presented different designs of switched reluctance motors to improve performance and reduce torque ripple in [2-3-4-5]. Thermal analysis of the SRM motor has already been presented in several research works [6-7]. The acoustic noise and vibration analysis were studied in [8-9-10-11].

In industrial applications, switched reluctance motors with a minimum number of poles in the stator and rotor are used to increase speed, but this comes at the expense of torque, which remains low. Conversely, increasing the number of poles leads to higher torque values, but with a decrease in speed. In this design, we are aiming to achieve a balance between speed and torque. In this design, we are aiming to achieve a balance between speed and torque. This study aims to propose a 2D SRM 24/18 motor design with high efficiency This design focuses on achieving high speed and high torque at the same time to optimize the performance of the motor at various operating conditions, allowing the motor to be used efficiently in applications that require high performance in both aspects. A finite element method (FEM) was adopted to simplify the various geometric models in a short time. The presented motor was designed by ANSYS Maxwell. The simulation results include electromagnetic analysis and analysis of the torque, speed, induced voltages, currents and flux linkages.

2. MATERIALS AND METHODS

The basic dimensions of the various switched reluctance motor parts and the appropriate operating conditions are determined based on the mathematical calculations. Steel 1008 was used in the stator and rotor to obtain higher efficiency and reduce the total losses. The prototype was analyzed using the ANSYS RMxprt tool. based on the analysis and evaluation of the motor design a two-dimensional model was created using the Maxwell 2D tool for electromagnetic analysis and various performance curves. The finite element method (FEM) was adopted because it is a versatile tool that is fast and accurate in simplifying complex geometry.

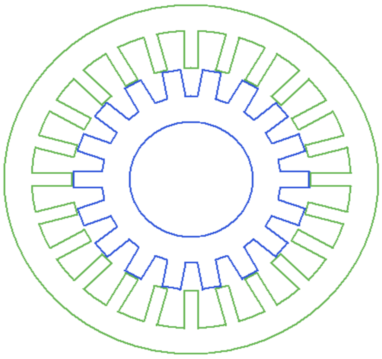

Fig. 1 Geometry of the 24/18 SRM.

Table 1 Parameters of the 24/18 SRM

Parameters	Values
Inner diameter of the rotor (mm)	50
Outer diameter of the rotor (mm)	95
Pole number of the rotor	18
Length of rotor core (mm)	70
Inner diameter of the stator (mm)	96
Outer diameter of the stator (mm)	150
Pole number of the stator	24
Stator core length (mm)	70
Yoke thickness (mm)	11
Core material	Steel_1008
Inner diameter of the rotor (mm)	50

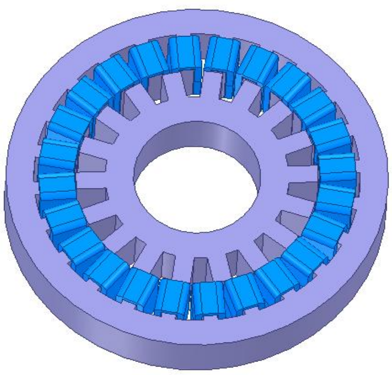

Fig. 2 3D model of the 24/18 SRM.

The attached equations from (1) to (11) represent the basic mathematical model of the switched reluctance motor according to [12].

The voltage per phase equation of SRM is:

$$V = Ri + \frac{d\lambda(\theta,i)}{dt} \quad (1)$$

Where R is the phase resistance; i the current per phase; λ is the flux linkage per phase; θ the rotor position.

The given flux linkage per phase in the SRM is:

$$\lambda = L(\theta,i)i \quad (2)$$

Where L is the dynamic winding inductance.

$$V = Ri + \frac{d\{L(\theta,i)i\}}{dt} \quad (3)$$

$$V = Ri + L(\theta,i)\frac{di}{dt} + i\frac{d\theta}{dt}\cdot\frac{dL(\theta,i)}{d\theta} \quad (4)$$

$$V = Ri + \frac{L(\theta,i)di}{dt} + \frac{dL(\theta,i)}{d\theta}\omega_m i \quad (5)$$

$$L_T(i_{ph}\theta_{ph}) = \frac{d\lambda_{ph}(i_{ph},\theta_{ph})}{di_{ph}} \quad (6)$$

$$T_{ph}(i_{ph},\theta_{ph}) = \int_0^{i_{ph}} \frac{\lambda_{ph}(i_{ph},\theta_{ph})di_{ph}}{\partial\theta_{ph}} \quad (7)$$

The equation for motion is given as:

$$J\frac{d\omega}{dt} = Te - T_L - B_m\omega \quad (8)$$

Where J is the rotor inertia; Te is the electromagnetic torque; T_L is the load torque; Bm is the rotor damping; ω is the mechanical rotational speed.

The instantaneous torque is:

$$T = \sum_{j=1}^{3} T_{ph}(j) \quad (9)$$

The torque ripple of the SRM is given as:

$$T_{\text{ripple}}\,\% = \frac{T_{\text{peak}} - T_{\text{min}}}{T_{\text{peak}}} \times 100 \quad (10)$$

Where T_{peak} is maximum torque; T_{min} is torque of intersection of two curves.

$$\eta = \frac{P_o}{P_{\text{in}}} = \frac{P_{\text{in}} - P_{\text{cu}} - P_{\text{core}}}{P_{\text{in}}} \quad (11)$$

Where P_o is the output power; P_{in} is the input power; P_{cu} is the copper loss; P_{core} is the core loss.

3. RESULTS AND DISCUSSION

The following results represent the electromagnetic analysis and various performance curves of the 24/18 switched reluctance motor. Figures 3 and 4 represent the magnetic flux density and the flux vectorial distribution. Figure 5 represents the flux lines in the SRM. Figures 6 to 10 include the curves of torque, speed, current, flux linkages and the induced voltages. The finite element method was used to analyze and evaluate the performance of the proposed motor.

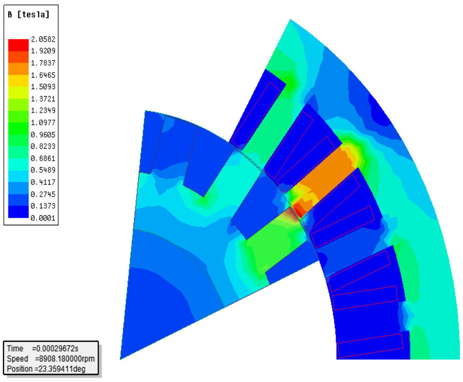

Fig. 3 Variation of magnetic flux density.

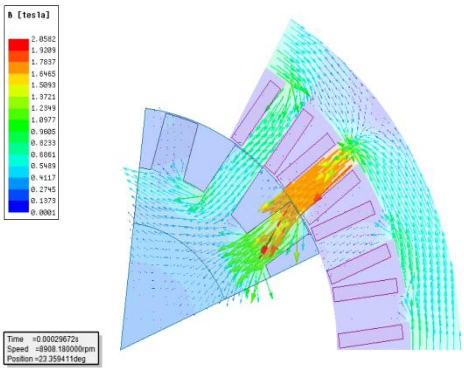

Fig. 4 Vectorial distribution of the SRM magnetic flux density.

In Figure 3, the flux density in the designed SRM is high between the stator and rotor teeth, where the vectorial distribution of magnetic flux is more concentrated in this region, as shown in the figure 4. The flux density in the SRM is relatively high, which explains the motor's ability to produce high torque.

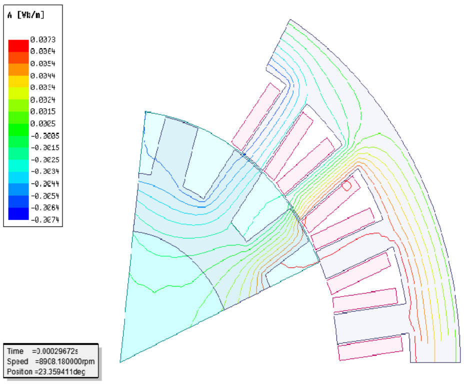

Fig. 5 Distribution of Flux Lines in the SRM.

The flux lines in Figure 5 indicate the direction of the magnetic field in the various parts of the SRM, as they are concentrated between the teeth of the rotor and the stator and are relatively uniform in this region. The flux lines are concentrated where the teeth of the stator and rotor are aligned.

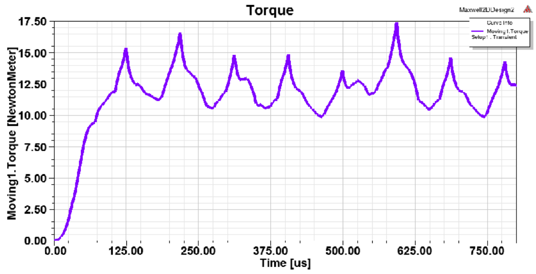

Fig. 6 Variation of the SRM torque with time.

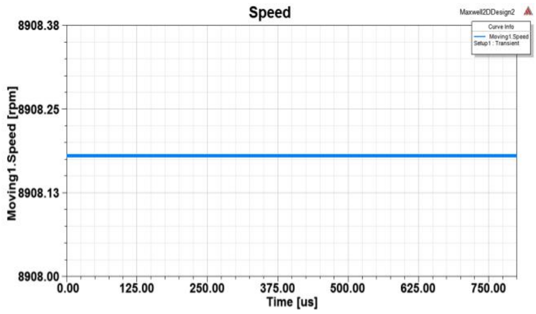

Fig. 7 Variation of the SRM speed with time.

Figure 6 shows the torque curve variations. The presented design has a high torque that changes consistently and smoothly, peaking at the maximum torque value of 17.5 Nm. The torque ripple is very low, indicating low vibrations and noise in the presented SRM. The rated torque is estimated at 12 Nm. The cogging torque and ripple can be significantly reduced by focusing on factors such as rotor and stator pole embrace of rotor and stator, focusing on winding optimization, and adjusting the pole arc ratio between the stator and rotor so that it is appropriate to minimize interference between the magnetic fields, use advanced current control strategies so that the current is smooth when changing the angles between the poles, designing a balanced air gap that minimizes the magnetic flux concentration, which contributes to reducing the ripple torque. Figure 7 shows the speed curve, where the presented SRM has a high speed of up to 8908 rpm.

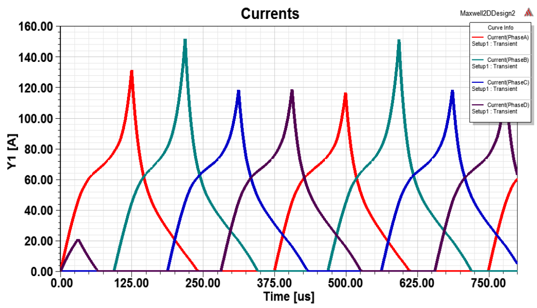

Fig. 8 Variation of the 24/18 SRM currents.

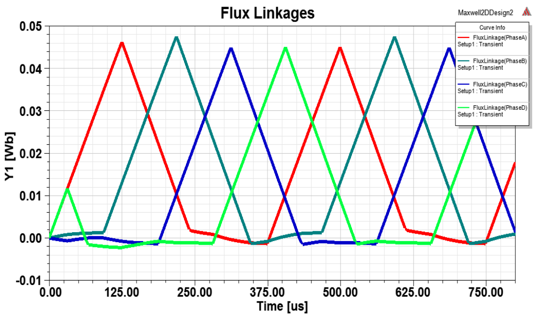

Fig. 9 Flux Linkages of the 24/18 SRM.

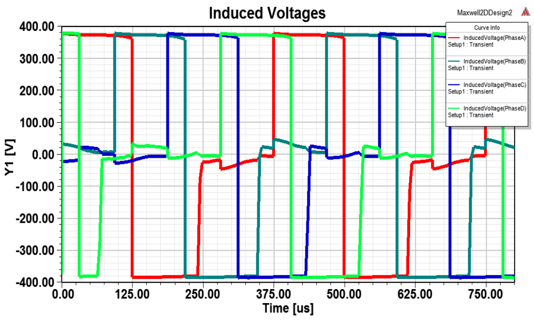

Fig. 10 Induced voltages of the 24/18 SRM.

4. CONCLUSION

In this paper, the design and analysis of the 24/18 switched reluctance motor have been presented using ANSYS Maxwell software. The study shows that the proposed design is distinguished by a high efficiency of 92.8 %, which means low losses, and the motor combines high speed and high torque. The analysis of results shows that the presented motor is suitable for applications that require high performance in both torque and speed, which is what distinguishes it from other switched reluctance motors. The finite element method helps in understanding and analyzing the performance of the machines accurately in a short time. Improving designs through simulation using ANSYS is a powerful tool for simulating electric motors and evaluating performance, providing reliable and accurate results.

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