THE CALCULATION OF EDDY CURRENT LOSSES IN THE PERMANENT MAGNETS OF SERVO MOTOR

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Abstract: The eddy current losses generated inside the magnets of (PM motors) permanent magnet motors, due to both of the high conductivity of the rare-earth magnet, neodymium-iron-boron (NdFeB), and to the harmonics of slot/tooth. These losses can increase the temperature inside the magnets that may deteriorate the magnets. The paper presents a calculation of the eddy current losses in the permanent magnets using the mathematical equations. The losses calculation depended on a 3D model of servo motor is created using Autodesk Inventor program, and on the magnetic analysis of this servo motor. This magnetic analysis using program FEMM is applied to 2D model of servo motor is created using AutoCAD program.

Keywords: PM motors, servo motor, eddy current losses, Autodesk Inventor, AutoCAD, FEMM

1. INTRODUCTION

The use of PM motors in different applications has significantly increased due to their excellent properties such as high power density, better dynamic performance and high efficiency. Three sorts of Permanent magnet materials are used in structure of electrical machine (Alnico, Ceramics (ferrites) and Rare-earth magnet materials). Applying the permanent magnet materials to the electrical machines bring many advantages such as increasing of the efficiency because no electrical energy is absorbed by the field excitation system, therefore no excitation losses which means higher torque and higher output power per volume than when using electromagnetic excitation, better dynamic performance and higher magnetic flux density in the air gap.

Permanent Magnets (PMs) can keep their magnetic field stable under a proper application after they are magnetized, because they have a high coercive force. They can produce a magnetic field in an air gap with no winding and no dissipation of electric power; however, they easily exposed to irreversible demagnetization under severe thermal conditions.

2. MODELING AND ANLYSIS

Parameters of Servo motor (M 718)

- Voltage: 280 V
- Current: 11.56 A
- Nominal load: 16.5 Nm
- Number of pole pairs: 6
- Speed 3000 rpm

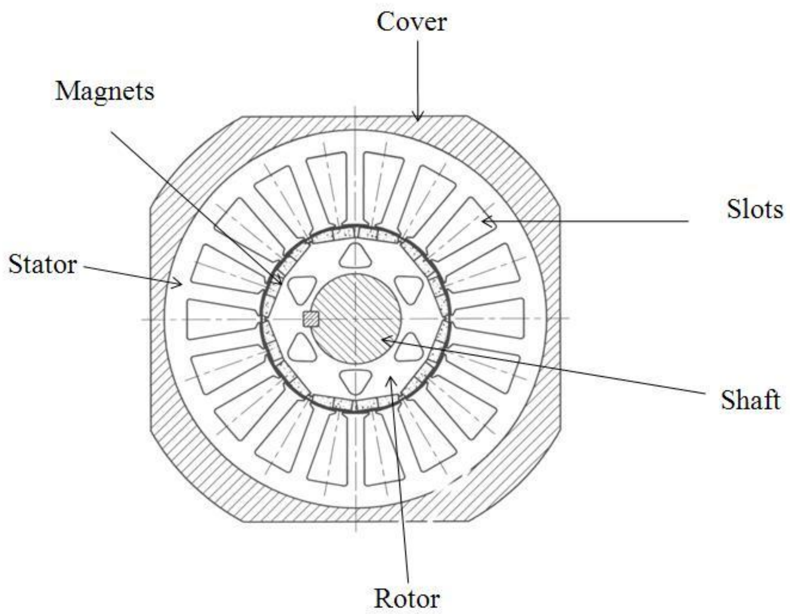

Figure 1: Outline of servomotor (M 718).

Figure 1 presents the structure of a servo motor (M 718) consisting of:

- Stator with 18 slots
- Coils
- Solid rotor
- Permanent magnets mounted on the surface of the rotor.

The permanent magnets (*MagnetFabrik),* applied to the servo motor belong to the type rare- earth magnet material *(NdFeB*). The main properties of this material are high remanent magnetic flux density, high Coercive force, high energy product and linear demagnetization curve.

2.1. CALCULATION OF EDDY CURRENT LOSSES IN THE PERMANENT MAGNETS

The eddy current losses generated in the permanent magnets due to the time-harmonics by non-sinusoidal input waveform and to the space-harmonics by non-constant reluctance because of stator slotting. These losses may cause significant heating of the permanent magnets, due to the relatively poor heat dissipation from the rotor, and result in partial irreversible demagnetization, particularly of NdFeB magnets, which have relatively high temperature coefficients of remanence.

Eddy-current losses per unit of magnet volume:

The current density in the magnets is calculated according to the second of Maxwell's equations:

$$\oint E \cdot ds = -\frac{d}{dt}\iint_{s} B \cdot d\alpha. \qquad (1)$$

The magnet segments are small, therefore the magnetic flux density can be considered constant over the magnet width. Consequentially, the current density is an odd function of x: $J_z(-x) = -J_z(x)$

The electric field strength can be replaced by the product of the current density and the resistivity of the magnet: $E = \boldsymbol{\rho}_m.J$. Thereby, the current density can be written as:

$$J_z(x) = \frac{x}{\rho_m}\frac{dB}{dt}. \qquad (2)$$

The eddy-current losses per unit of magnet volume are calculated as:

$$k_m = \frac{1}{b_m} \int_{-b_m/2}^{b_m/2} \rho_m J_z^{\,2}(x)\, dx = \frac{b_m^{\,2}}{12\rho_m} \left(\frac{dB}{dt} \right)^2 . \qquad (3)$$

The magnets are numbered from 1 to N_m, since the magnetic flux density, which causes the losses in the k^{th} magnet can be written as:

$$B_k = B(\alpha_k) = \hat{B} \cos(p(\alpha_k - \beta)). \qquad (4)$$

By replacing the flux density in equation (3), the eddy current losses per unit of magnet volume in the k^{th} magnet can be calculated as follows:

$$k_{m,k} = \frac{b_m^{\,2}}{12\rho_m} \left(\frac{d}{dt} \left\{ \hat{B} \cos(p(\alpha_k - \beta)) \right\} \right)^2 . \qquad (5)$$

The total magnet losses equals to summation of the magnet losses in total N_m magnets:

$$P_m = l_s l_m b_m \sum_{k=1}^{N_m} \frac{b_m^{\,2}}{12\rho_m} \left(\frac{d}{dt} \left\{ \hat{B} \cos(p(\alpha_k - \beta)) \right\} \right), \qquad (6)$$

where, l_m, l_s, b_m, α_k, ρ_m, β, p, B, are the magnet thickness, the stack length of motor, the magnet width, the axis of k^{th} magnet lays at rotor coordinate, the magnet resistivity, a function of time, the number of pole pairs in motor, the magnetic flux density, respectively. The eddy-current losses in the magnets can be estimated as:

$$P_m \approx \frac{V_m b_m^{\,2} \hat{B}_m^{\,2} \omega^2}{12\rho_m}, \qquad (7)$$

where, ω, ρ_m, V_m, B_m. are the frequency, the magnet resistivity, the magnet volume, the magnetic flux density in the air gap, respectively. The magnet dimensions are defined from a 3D model of servomotor which is created using program Autodesk Inventor as follows:

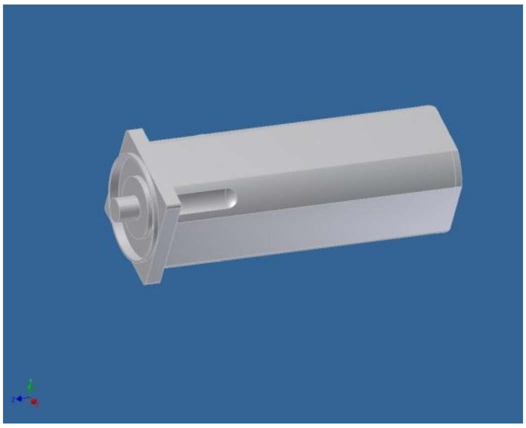

Figure 2: 3D model of servo motor (M 718).

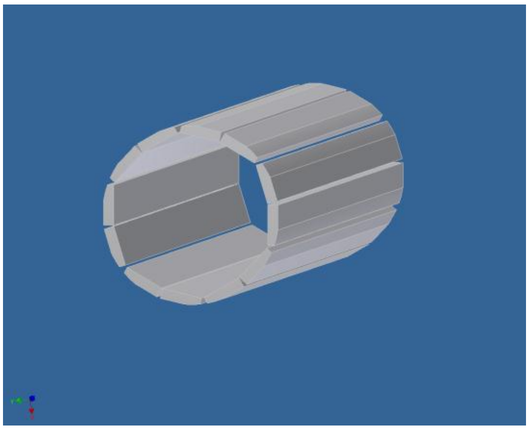

Figure 3: 3D model of permanent magnets.

The value of magnetic flux density can be defined from the magnetic analysis of this servo motor. The magnetic analysis is performed using FEMM program.

2.2. THE MAGNETIC ANALYSIS OF SERVO MOTOR (M 718)

Two magnetic fields in the PM motor are existed, the magnetic field produced by the winding in the stator and the magnetic field produced by the permanent magnet on the rotor. The magnetic analysis of the servomotor is performed using FEMM program. For this purpose a 2D model of servo motor is created using AutoCAD program. The results are displayed as follows:

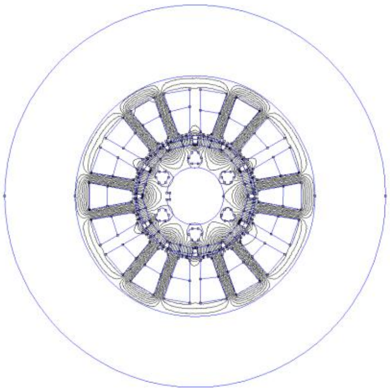

Figure 4: The magnetic field intensity inside the servo motor.

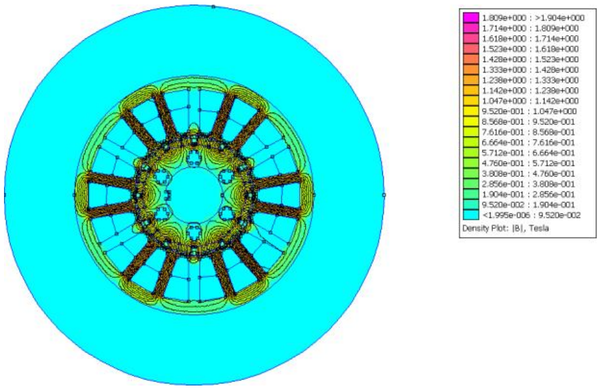

Figure 5: The magnetic flux density inside the servo motor.

The following graph presents the magnitude of magnetic flux density in the air gap according to the air gap length, which is considered as an arc=180° in the air area around of the rotor.

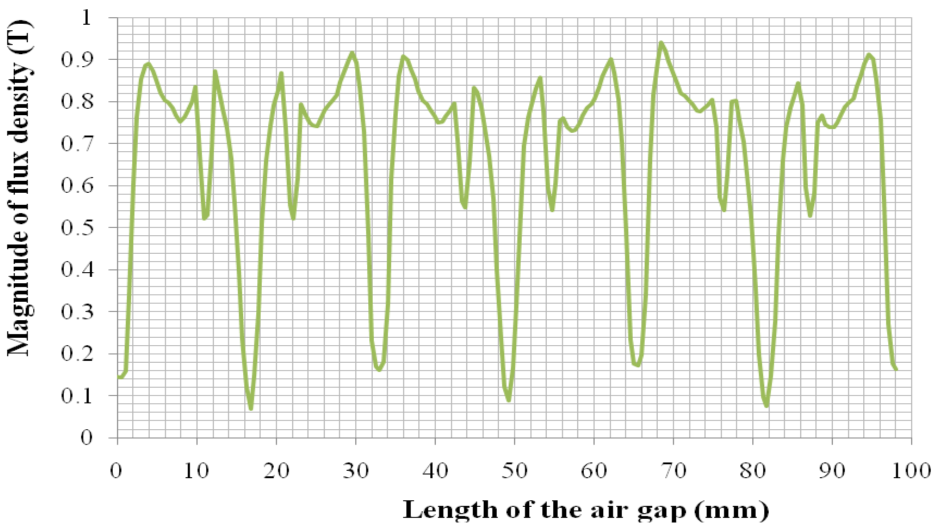

Figure 6: The magnetic flux density in the air gap.

From the 3D model and the magnetic analysis, the following values can be obtained and applied to the equation (7) to calculate the eddy current losses in the permanent magnets:

V_m (m^3)	ρ_m (Ω.m)	b_m (m)	$\hat{B}_m$ (T)
1.0282×10^{-5}	1.6×10^{-6}	14×10^{-3}	0.62

Table 1: Properties of PMs.

The following table presents the results of calculation and a comparison between the given and the calculated values:

P_m (given)	P_m (calculated)	default
52 W	47.8 W	8 %

Table 2: The given and the calculated eddy current losses in the magnets.

3. CONCLUSION

The difference between the real value of the losses in PMs and the calculated one is due to different reasons such the approximation made in the value of the magnetic flux density in the air gap and the different distribution of the windings in the stator slots, in addition to the error existed during creating the 2D and 3D models of the servo motor.

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