TEMPERATURE OPTIMIZATION OF PM SERVO MOTOR

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Abstract: Paper deals with temperature optimization of a PM servo motor. 3D model of the servo motor M 718 is created using Autodesk Inventor program. Different shapes of cooling channels on the solid rotor of this servo motor are used. The thermal transient analysis of the PM servo motor is computed using ANSYS Workbench program, for the different cooling channel shapes. Simulation results are compared with the servo motor original design.

Keywords: PM servo motor, Temperature optimization, FEM, ANSYS Workbench

1. INTRODUCTION

Motors with permanent magnets (PM motors) are preferred to the induction motors, because of their excellent properties. The applications of these motors have been increased recently. The main properties of these motors are high output power, high efficiency, high magnetic flux density in the air gap, and simple constructions. PM motors are used in industry, control systems, robotics, and in a public life.

The PM a.c. synchronous motors are designed of slotted, slot less stators, or as a cylindrical type built with one of the following rotors:

- surface magnet rotor
- interior magnet rotor
- inset magnet rotor
- rotor with buried magnets symmetrically or asymmetrically distributed.

The a. c. servo motors are of cylindrical or square shape, open or enclosed, and available in a variety of housing sizes and diameters.
This paper focuses on temperature optimization of a PM servo motor M 718. This servo motor contains a surface magnet rotor with six cooling channels. The permanent magnet material applied to this servo motor is of the rare earth NdFeB type. This material is characterized by a high remanence, high coercivity, and high energy product. NdFeB magnets have excellent magnetic properties and low cost, but their demagnetization curves are strongly temperature dependent. They have high temperature coefficients; they may lose all their magnetic properties if they are heated to a certain temperature (maximum operation temperature is T_{max}=190 °C and the Curie temperature is T_{Curie} is 350 °C) [1, 5].
The paper objective is to improve the cooling system of this motor. For this purpose, this article focuses on the cooling channel shape on the solid rotor. Thereby the magnets on the rotor can be avoided the high temperature caused by the eddy current losses in these magnets in addition to the different losses in the other motor parts. This is one of many possibilities that can be used to improve thermal conditions of this servo motor.

The performed transient thermal analysis of the PM servo motor M 718 is computed using ANSYS Workbench program.

2. THEORETICAL BACKGROUND

Improvement of electrical machines design becomes one of the main targets of researches in this area. The main objective of these researches is to get the optimal design which offers the best thermal conditions with the best machine performance. An optimal analysis and design of a three-phase line-start PMSM with simple structure, low cost and good performance is presented. To increase the PM-excited flux-linkage in the windings, the number of turns of stator armaturewinding is increased in the prototype LS-PMSM [2]. The other research focused on the rotor and stator optimal design for a PM spherical stepper motor by experimental design method. This paper has presented the thermal analysis using 3-D FEM. Based on the torque characteristics analysis and full factorial design, three main control factors are selected and their effects on the torque characteristics are discussed in detail. Corresponding single step responses with different parameters were simulated. The thermal analysis in the case of steady state, the relationships between the stator materials, thickness, and cooling modes with the temperature rise are presented and the computation results are given [3]. Article [4] presents a 3D numerical analysis of the thermal behavior of a small permanent magnet DC motor, performed according to Finite Element Method (FEM). A prototype of the motor was tested in the steady-state in order to calibrate the numerical model. The motor was subsequently analyzed using a transient heat transfer numerical model, under various load conditions. The mathematical models of steady state and transient heat transfer are expressed as follows:

The steady state heat transfer equation is given as:

$$\nabla \cdot (-k\nabla T) = Q\,, \tag{1}$$

where

- k: thermal conductivity [W/mK]
- T: temperature [K]
- Q: the heat source [W/m^3]

On the external boundary, cooling via natural convection was considered:

$$-n \cdot (-k\nabla T) = q_0 + h(T_0 - T), \tag{2}$$

where

- n: normal vector to the boundary
- q_0: inward heat flux [W/m^2]
- h: coefficient of heat transfer [W/Km^2]
- T_0: temperature of the cooling agent [K]

Because of the symmetry, half of the model can be considered. The boundary condition of the symmetry surface was given as:

$$-n \cdot (-k\nabla T) = 0\,. \tag{3}$$

It means the surface was thermally insulated.
The governing equation of the transient heat transfer is given as:

$$\rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (-k\nabla T) = Q\,, \tag{4}$$

where

- ρ: material density [kg/m^3]
- C_p: heat capacity at constant pressure [J/kg K]
- t: time [s]
- T: temperature [K]
- k: thermal conductivity [W/K m^2]
- Q: heat source [W/m^3]

3. PM SERVO MOTOR DESCTRIPTION

PM servo motor M 718 is produced by VUES Brno Company. It is a cylindrical enclosed motor with surface magnet solid rotor. The cross section of the servo motor is presented in Fig. 1.

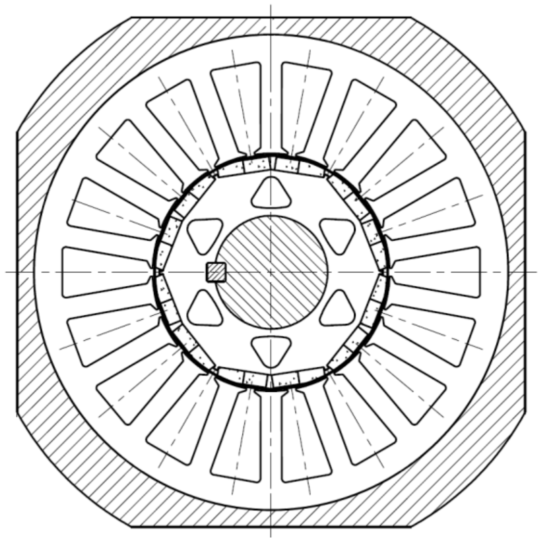


Figure 1: Cross section of servo motor M 718 [5].

Figure 1 presents the structure of a servo motor M 718, which is designed of:

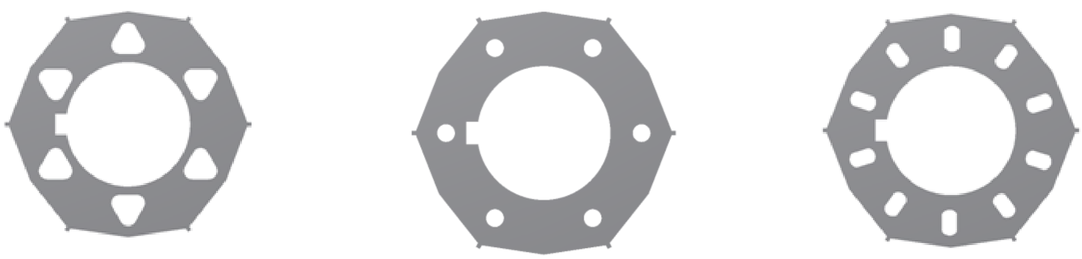
- stator consisting of 18 slots,
- solid rotor with PMs of the rare earth type NdFeB, mounted on its surface.

The nominal properties of this servo motor are as follows:

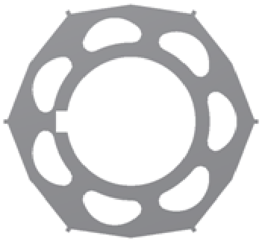
• Voltage	280 V
• Current	11.56 A
• Torque	16.5 Nm
• Rotational speed	3000 rpm
• Output power	5174 W

4. ROTOR DESIGN

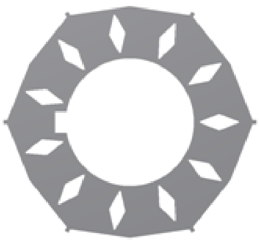
Solid rotor with different shapes of cooling channels is created using program Autodesk Inventor, considering that rotor 1 is the original one.



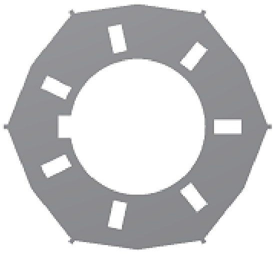
Rotor 1 Rotor 2 Rotor 3



Rotor 4



Rotor 5



Rotor 6

Figure 2: Rotor with different cooling channels shapes.

5. NUMERICAL RESULTS

Transient thermal analysis of the PM servo motor M 718 is performed using ANSYS Workbench program during ten hours of PM servo motor operation. Analysis is computed for the case of nominal load with the initial temperature of 22 °C.
Mesh is generated according to the finite element method (FEM). Results of meshing is shown in Fig. 3, and transient thermal results are shown in Fig.4.

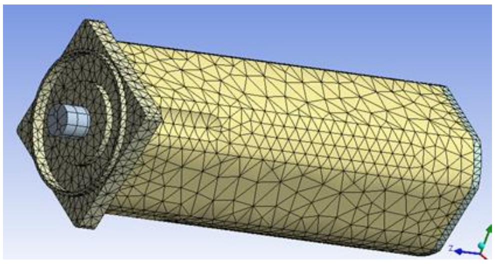


Figure 3: Mesh results.

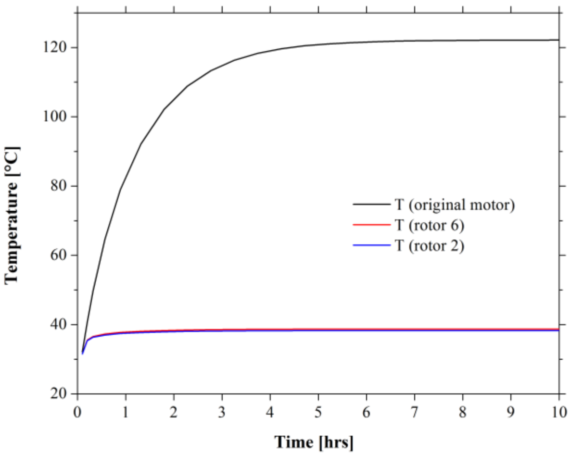


Figure 4: Transient thermal results.

Fig. 4 presents a comparison of the thermal transient results where the maximum temperature is about 122 °C for the original motor, and 38.3-39.6 °C for the motor with open frame (air flows), and different channels shapes.

Results of transient thermal analysis for the different cooling channel shapes shown above in the case of open frame are presented in the following table.

T_1	T_2	T_3	T_4	T_5	T_6
39.5	38.3	39.5	38.5	39.6	38.7

Table 1: Maximum temperature for different rotor shapes.

T_n [°C] is the maximum temperature for the rotor (n).

6. CONCLUSION

The main goal of the presented work is to improve the cooling system of PM machine by adding some modifications to the original motor. This paper focused on the shape of the cooling channels on the solid rotor using open frame motor which should lead to thermal conditions improvement.

Transient thermal analysis of PM servo motor M 718 was computed for six various shapes of the rotor channels. The channel shapes were chosen according to the commonly used ones in electrical machines.

According to the results of the performed analysis, the best simulation results have been found for the motor with the rotor 2, 4, 6 of Fig. 2. The shape 4 of cooling channels is unsuitable for this motor type, due to the fact that the cooling channel shape influences the magnetic field generated by the magnets mounted on the rotor. It is very important to make a compromise between having appropriate thermal conditions and keeping the requested magnetic flux. Consequently, rotors 2 and 6 of Fig. 2 could be a good choice. An automatic optimization can be used to find the optimal number and dimensions of the cooling channels to make the thermal conditions much better.

The motor temperature in the case of the open frame is lower by about one-third (T_2 = 38.3 °C, see Tab. 1) which is very important, especially for motors with NdFeB magnets.

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