DEVELOPMENT OF IMPROVED OPTIMISED MOTOR MODELS USING OPTIMISATION AND NUMERICAL TOOLS IN MOTOR DESIGN

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Abstract: *In this paper is presented development of two new optimized models of single phase shaded pole motor using the method of Genetic Algorithms. Constrains in development of optimized motor models were to preserve the motor's other dimensions unchanged as well as to keep the motor input power on the same level with respect to the basic motor model. Optimization is performed with electromagnetic torque as target unction, resulting in larger electromagnetic torque as well as efficiency factor compared to the basic motor model. Magnetic field distribution inside the basic and optimized motor models is calculated using Finite Element Method (FEM). Obtained results are analyzed and further improved by using soft magnetic materials in motor construction.*

Keywords: SINGLE PHASE SHADED POLE MOTOR, OPTIMISATION, METHODS, SOFT MAGNETIC MATERIAL

1. Introduction

In the paper is analyzed a model of a single phase shaded pole motor (SPSPM), with rated data: U_n=220 V; f_n=50 Hz; I_{1n}=0.125 A; P_{1n}=18 W; n_n=2520 rpm; 2p=2 product of company Micron-Tech. The arrangement of the motor magnetic core and windings is presented in Fig. 1.

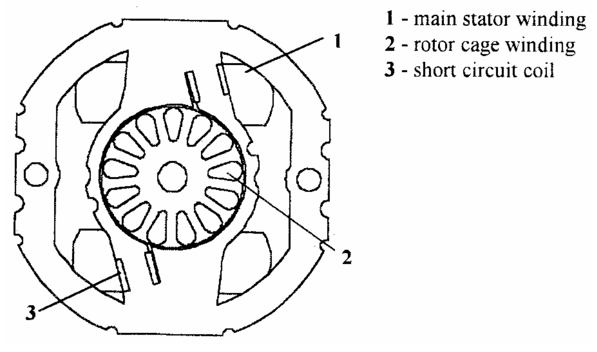


Fig. 1 *Cross-section of shaded pole motor*

In spite of its simple construction complex electromagnetic processes occur inside the motor as a result of existence of three mutually coupled winding which produce elliptic electromagnetic field inside the motor air – gap. Since there is no standardized procedure for designing of this type of the motor, a mathematical model for calculation of motor parameters and characteristics was developed by an application of revolving field theory [1]. Accuracy of developed mathematical model was verified by experiments. As a next step in motor analysis optimization procedure based on Genetic Algorithms Method (GA) is performed. As a result of the optimization process two motor models were developed, first one with three varied parameters and second one with four. Both motor models have an increase of electromagnetic torque followed by an increase of efficiency factor while power factor is maintained on the same level compared to the basic motor model. In both optimized motor models, outer motor dimensions remain unchanged as well as motor input power. Analysis of optimized motor models was deepened by obtaining the magnetic filed distribution with the aid of numerical calculation, using Finite Elements method-FEM. As a result of applied FEM analyses on the basic and optimized motor models it was concluded that there is a rather high flux density in stator bridge. Therefore soft magnetic material Somaly™500 was used for construction of stator pole and bridge. Usage of soft magnetic material contributes to considerably improvement of value magnetic flux density and lowering of iron losses.

2. Optimised motor models

At the design stage of an electric motor, all efforts are focused to the achievement of desired motor features in faster, more economical and more reliable way. The optimization procedure is always searching for an extreme of the function: maximum or minimum of its value. In order to be provided the derived solution to be practically acceptable, certain requirements should be satisfied; that means some important electrical or magnetic quantities, such as windings current density Δ [A/mm^2], or the air-gap magnetic flux density B_δ [T], must have values inside the prescribed limits. During optimization procedure the main task is to define and to select the most suitable target (objective) function of optimization. Since the object of investigation is motor, electromagnetic torque is one of the most important characteristics and it is adopted to be the target function for optimization [2]. Optimization is performed for one motor operating point in this case rated load meaning slip s_n=0.16. Another important thing is to make the right choice of variable parameters and to put them in prescribed limits of variation. Since two main constrains were put in development of optimized motor models: motor outer dimension to remain unchanged as well as to keep the same input power for motor's rated operating point, choice of varied parameters for the first motor model (M1) was: width of stator bridge d=[1.5÷3.5]mm, angle of rotor skewing α_{sk}=[15÷20] mm, and shading portion of stator pole a [/] while for the second model (M2) was added as a fourth variable width of stator pole b_p=[12÷16] mm. Ranges of variation of input parameters are defined in separate input file which is an integral part of the originally developed software program GA-ODEM which operates under C++ programming language. In second file which is by software means linked to input file motor mathematical model is input which enables calculation of target function. After the optimization procedure is completed, the results are presented in tables and on diagrams. In Tab. 1 the comparison of most important motor parameters, at rated load conditions for basic motor model-BM, models-M1 and M2 is presented. In Tab.2 comparison of motor performance characteristics at rated load conditions is presented.

Table 1: *Comparison of motor parameters*

BM	M1	M2
Δ=8 [A/mm^2]	Δ=8[A/mm^2]	Δ=8 [A/mm^2]
B_δ=0.404 [T]	B_δ=0.404 [T]	B_δ=0.404 [T]
α_{sk}=17 [^{0}]	α_{sk}=15 [^{0}]	α_{sk}=15 [^{0}]
a=0.25	a=0.2	a=0.2
b_p=16 [mm]	b_p=16 [mm]	b_p=12 [mm]
d=2.4 [mm]	d=1.5 [mm]	d=1.5 [mm]
d_{Cu}=0.14 [mm]	d_{Cu}=0.14 [mm]	d_{Cu}=0.14 [mm]
W=3488 turns	W=3488 turns	W=3488 turns
R_1=492.98 Ω	R_1=494.6 Ω	R_1=494.6 Ω
X_1=498.17 Ω	X_1=449.9 Ω	X_1=435.9 Ω
R_2=497.04 Ω	R_2=449,57 Ω	R_2=449.58 Ω
X_2=76.71 Ω	X_2=87.68 Ω	X_2=97.5 Ω
R_3=18474 Ω	R_3=27807,9 Ω	R_3=26758 Ω
X_3=127.53 Ω	X_3=125.14 Ω	X_3=122.73 Ω
X_{12}=2163.3 Ω	X_{12}=2472.48 Ω	X_{12}=2750 Ω
X_{13}=175.91 Ω	X_{13}=180.5 Ω	X_{13}=215.82 Ω

Table 2: *Comparison of motor performance characteristics*

Quantity	BM	M1	M2
Stator current I_1 [A]	0.125	0.123	0.119
Shaded coil current I_3[A]	0.0063	0.0044	0.0046
Rotor current I_2 [A]	0.0878	0.0904	0.0897
Power factor cosφ [/]	0.654	0.682	0.693
Input power P_1 [W]	18.11	18.5	18.14
Output power P_2 [W]	4.149	5.03	5.4
Efficiency factor η [/]	0.229	0.272	0.297
Torque M_{em} [mNm]	18.075	21.4	22.8

From presented results in Tab.2 it can be concluded that optimized motor models have increased electromagnetic torque and efficiency factor while power factor is slightly increased and in the same time input power is kept on the same level compared to BM model. In Table 3 is presented percentage improvement of electromagnetic torque- Mem and efficiency factor-η in optimized motor models compared to basic motor model.

Table 3: *Improvements in optimized motor models*

BM		M1		M2	
M_{em} [mNm]	η [%]	M_{em} [mNm]	η [%]	M_{em} [mNm]	η [%]
18.075	22.91	21.4	27.52	22.8	29.7
Improvement compared to basic model [%]		18	20	26	29.6

From Tab.3 it is evident that in optimized motor models in the same time two improvements are achieved: increased torque and efficiency factor. Obtained improvements are only result of variation of inner motor dimensions while motor outer dimension remain unchanged which is important from application point of view i.e. motor mounting position while input power and power factor are kept constant which is important from power consumption point of view. For better understanding of the behavior of all shaded pole motor models, comparative performance characteristics of electromagnetic torque M_{em}=f(s), efficiency factor η=f(s), power factor cosφ=f(s), main stator winding current I_1=f(s) and input power P_1=f(s), with respect to the motor slip-s, are presented in Figures 2, 3, 4, 5 and 6, respectively.

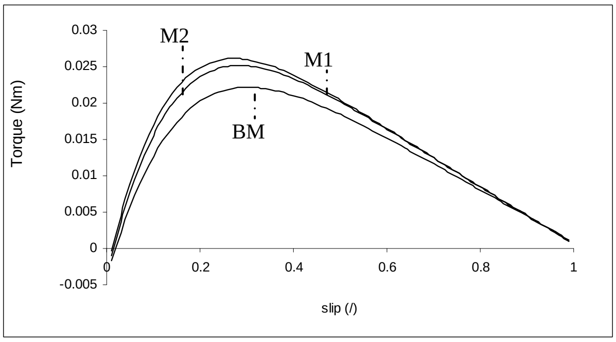


Fig. 2 *Comparative characteristics of electromagnetic torque*

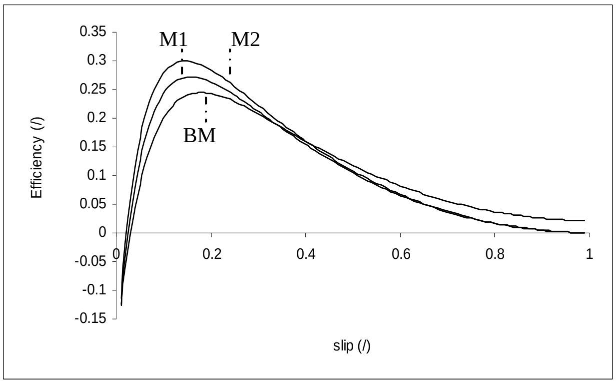


Fig. 3 *Comparative characteristics of efficiency factor*

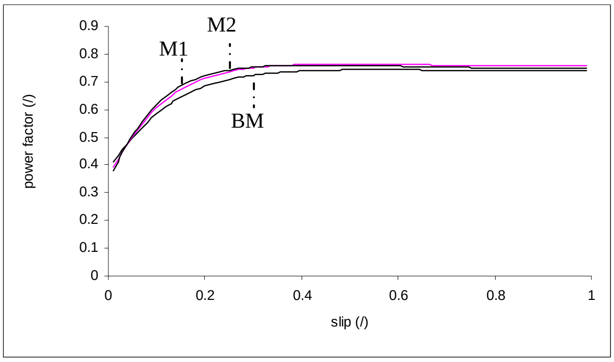


Fig. 4 *Comparative characteristics of power factor*

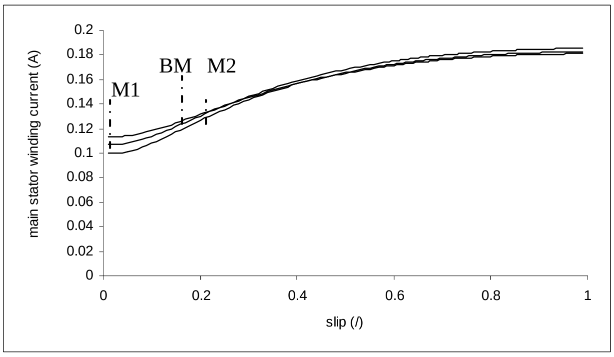


Fig. 5 *Comparative characteristics of power factor*

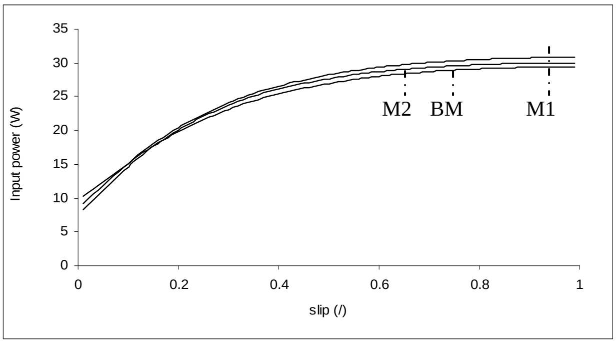
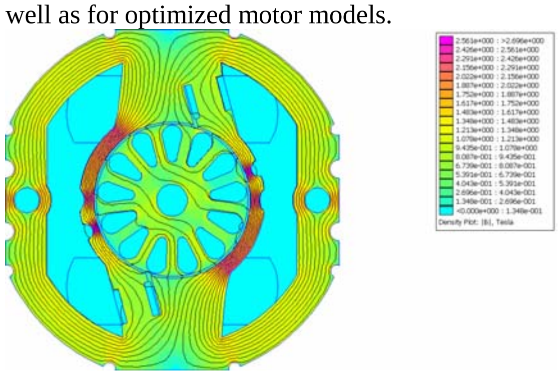


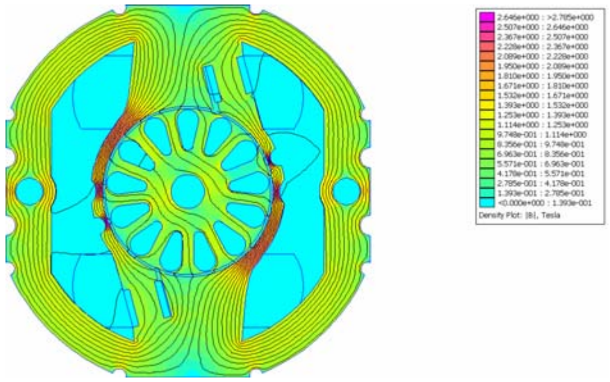
Fig. 6 *Comparative characteristics of input power*

3. FEM Analysis of motor models

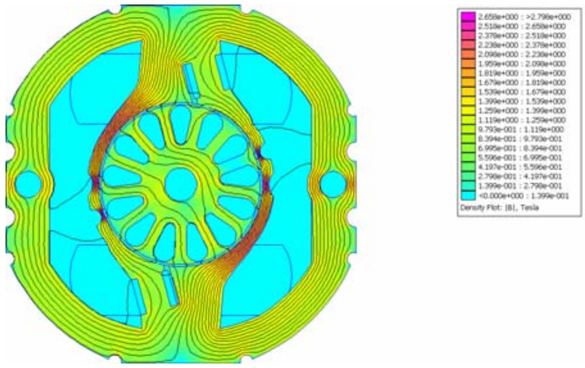
In order to be analyzed electromagnetic phenomena inside the motor FEM method is used which enables two different approaches: magneto-static and time-harmonic [3]. Before starting the FEM analysis motor model is defined by inputting the exact motor geometry in software program. Afterwards properties of all materials inside the motor are defined. Very important issue is to define the boundary conditions on outer motor geometry and in this case are used Dirichlet-boundary conditions. Another important subject in motor modeling is defining the mesh of finite elements. By dividing the motor's cross section into large number of regions i.e. elements with simple geometry, the true solution of magnetic vector potential is approximated by a very simple function. In magneto-static approach all electromagnetic quantities are time constant and they are analyzed in certain moment of time, i.e. at frequency f=0 Hz, while in time harmonic magnetic approach all electromagnetic quantities are analysed at frequency f=50 Hz. In time-harmonic motor model only stator current is input in motor model and consequently currents in short circuit coil and rotor winding are freely induced. On that way analyse of electromagnetic phenomena inside the motor is closer to the real electromagnetic process inside the machine when it is supplied with voltage 220 V, 50 Hz. Time harmonic analysis in 2D domain will be performed on SPSPM for characteristic operating regimes no-load and rated load. When analysing induction machines, considering their AC excitation the air gap magnetic field is always a time-varying quantity [2]. In materials with non-zero conductivity eddy currents are induced, consequently the field problem turns into magneto- dynamic i.e. non-linear time harmonic problem. After preparing the motor model program is run and post-processing results such as magnetic field distribution in motor's cross section is obtained. In Fig. 7 is presented magnetic flux distribution in cross section of SPSPM at rated load i.e. slip s_n=0,16 for basic motor model as well as for optimized motor models.



(a) BM



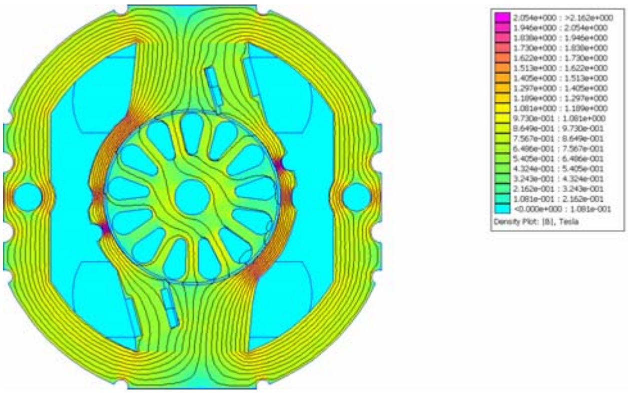
(b) M1



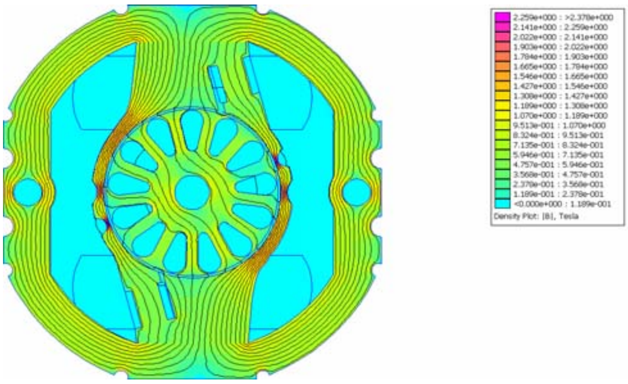
(c) M2

Fig. 7 *Magnetic field distribution at rated load*

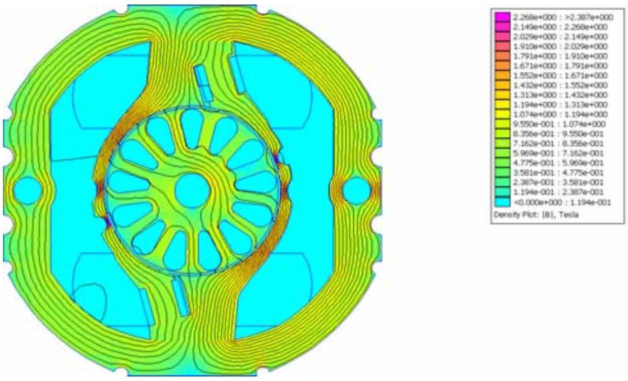
As it can be concluded from presented results of magnetic flux distribution in Fig.8 all motor models are experiencing high values of magnetic flux density in the region of stator bridge. Values of magnetic flux density in this region are becoming even greater taking into consideration that in optimized motor models width of stator bridge and pole are decreasing resulting in higher values of magnetic induction. Therefore it was considered stator pole and bridge to be built of soft magnetic material Somaly™500. Usage of soft magnetic materials contributes towards decreased machine losses due to the eddy currents. Similar to the procedure of lamination of conventional magnet materials, in soft magnet materials each granule of powder is isolated from adjacent ones resulting in magnetic core lamination. Usage of powders with increased percentage of iron contributes towards enlarged values of magnetic flux density at which saturation occurs. Soft magnetic materials enables larger filling of winding space with copper resulting in smaller winding dimensions and consequently in lower production costs. This is especially important in production of small size motors. But one of the most important features which makes the soft magnetic materials attractive for application in construction of electrical machines is their capability to be easily shaped into desired form enabling modular construction of stator and/or rotor of the electrical machine. In Fig.8 are presented experimental motor models developed from basic motor model and optimized motor models by inputting soft magnetic material Somaly™500 in stator pole and bridge and consequently experimental models –EBM from basic motor model and EM1 and EM2 from optimized motor models M1 and M2 are developed.



(a) EBM



(b) EM1



(c) EM2

Fig. 8 *Magnetic field distribution in experimental models at rated load*

From Figs. 8 it can be concluded that maximum value of magnetic flux density in some critical points of stator bridge is considerably decreased i.e. for basic model from 2.4 T to 1.98 T, for models M2 and M3 from 2.5 T to 1.97 T at no load operation. For rated load operation magnetic flux density for basic model is reduced from 2.56 T to 2 T while for models M1 and M2 from 2.66 to 2.26 T consequently. Taking into consideration that width of the stator poles, shading portion of stator pole and bridge between stator poles are constantly changed in optimized motor models, soft magnetic materials are ideal solution enabling electrical machines to be easily shaped into desired form and reducing the maximal values of magnetic flux density in regions with high saturations. Calculations of magnetic flux distribution as well as magnetic flux density are preformed taking into consideration the magnetic material non-linearity.

4. Conclusion

Purpose of the investigation in this paper was to develop optimized motor model of single phase shaded pole motor by taking into consideration two constrains: motor outer dimensions to remain unchanged and motor input power to be kept same as in the basic motor model. Two optimized motor models M1 and M2 were developed. First one with three varied parameters and second one with four. Model M1 has an increase of electromagnetic torque of 18 % and efficiency factor of 20 % compared to basic motor model. Model M2 has further increase of electromagnetic torque of 26 % and efficiency factor of 29,6 %. In both optimized motor models input power is 18 W, same as in the basic motor model, and power factor is slightly increased. FEM numerical analysis is performed on all motor models in time-harmonic domain and obtained results of magnetic field distribution in motor cross section have proved that there is a rather high value of magnetic flux density in stator bridge. Therefore experimental motor models were developed by using soft magnetic material Somaly™500, which was input in stator pole and bridge in all motor models. Results of the distribution of magnetic flux in motor cross section were satisfactory since magnetic flux density in some critical points of stator bridge is considerably decreased i.e. for basic model from 2.4 T to 1.98 T, for models M2 and M3 from 2.5 T to 1.97 T at no load operation. For rated load operation magnetic induction for basic model is reduced from 2.56 T to 2 T while for models M1 and M2 from 2.66 to 2.26 T consequently. General conclusion is that model M2 with four varied parameters: width of stator pole and bridge, shading portion of stator pole and angle of skew of rotor channels is giving satisfactory results regarding the increase of electromagnetic torque, efficiency factor and distribution of magnetic field in motor cross section while input power, power factor and motor outer dimension are kept on the same level compared to the basic motor model.

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