DIFFERENT MOTOR MODELS BASED ON PARAMETER VARIATION USING METHOD OF GENETIC ALGORITHMS

Vasilija Sarac[1], Goga Cvetkovski[2]

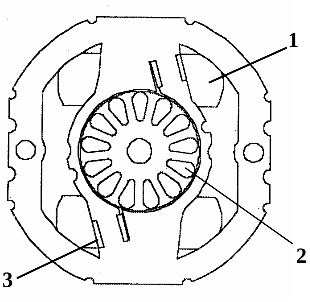
[1]University Goce Delcev Stip, Faculty of Electrical Engineering,
P.O. Box 201, MK-2000 Stip, Macedonia, e-mail: vasilija.sarac@ugd.edu.mk
[2]Ss. Cyril and Methodius University, Faculty of Electrical Engineering and IT
P.O. Box 574, MK-1000 Skopje, Macedonia, e-mail: gogacvet@feit.ukim.edu.mk

Abstract: *Three new motor models of Single Phase Shade Pole Motor were developed using the method of genetic agoithms for optimisation purposes of motor design. In each of newly developed motor models number of varied parameters was gradually increased which results in gradual increase of electroamgnetic torque as target function for optimisation. Increase of electromagnetic torque was followed by the increase of efficiency factor. Finite Element Method Analysis was performed in order to be obtained magnetic flux distribution in motor cross section. Since newly developed motor moders were experiencing high values of magnetic induction in stator bridge soft magnetic materials were used in that region which finally resulted with lower values of magnetic induction compared to the basic motor model.*

Keywords: Single Phase Shaded Pole Motor, Method of Genetic Algorithms, Finite Element Method

Introduction

In this paper as an object of study and investigation, a shaded pole motor type AKO-16 "MikronTech" product, is considered. Although motor construction is relatively simple, electromagnetic processes which occur inside the motor are quite complex considering the fact that inside the motor exist three electromagnetically mutually coupled windings which contribute to occurrence of elliptical electromagnetic field (Fig.1). This was a challenging task since up to now there is no standardized method or procedure for determination parameters and performance characteristics for this type of motor. Therefore, as a first step analytical method based on symmetrical components method for calculation of motor data and performance characteristics was developed [1]. Motor rated data given by the producer are: $2p = 2$; $U_n = 220$ V; $f_n = 50$ Hz; $I_{1n} = 0.125$ A; $P_{1n} = 18$ W; $n_n = 2520$ rpm. This motor is adopted as a prototype, i.e. basic model – BM. Using advanced optimisation method of genetic algorithms (GA) three optimised motor models are derived with variation of different motor parameters and their number is gradually increased starting from four up to six varied motor parameters. Limitation in choice and type of varied parameters is motor's outer dimensions to remain unchanged. As a result three motor models are derived which gradually give a significant increase of electromagnetic torque with unchanged motor's outer dimensions including motor's axial dimension. In all optimised motor models electromagnetic torque is chosen to be target function for optimisation. All motor models including the basic model are analyzed with Finite Element Method (FEM) in order distribution of magnetic flux density in motor's cross section to be obtained.



1 - main stator winding
2 - rotor cage winding
3 - short circuit coil

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

Application of GA optimisation method

Method of Genetic Algorithms has proved to be very powerful optimisation tool for designing [2]. It aims toward the maximisation of chosen target function while variation of input parameters is put within certain range. It belongs to stochastic methods for optimisation. It a reliable method for optimisation due to the fact that optimum of certain target function is reached by searching for a global optimum on a family of possible solutions. On that way, it is avoided optimum to be obtained by evaluating possible solutions taking into consideration only certain number of points which do not necessarily represent the global optimum. Optimisation procedure is consisted of several steps:

1. Defining the target function in this case electromagnetic torque.
2. Defining the limits of variations of motor variables.
3. Programing the mathematical model in the program of genetic algorithms.
4. Generation of set of output values on the base of varied parameters.
5. Implementation of set of output values from program of genetic algorithms in program for calculation of motor performance characteristics developed in FORTRAN.
6. Iterative proceduree for aproximation, with satisfactory and in advance defined accuracy of output and input data set, in a program for calculation of motor performance characteristics.
7. Obtainign the final results and list of output data.

Different motor parameters are varied in each of the optimised motor models and their number is gradually increased. Analysis starts from basic motor model –BM which is defined with motor rated data and parameters and characteristics obtained from calculation. In first motor (M1) model four input parameters are varied: current density-Δ[A/mm^2], magnetic induction in motor air gap- B_δ[T], angle of the rotor skew- α_{sk} [°] and width of bridge between stator and rotor core- d [mm]. Non of these parameters have any influence of motor outer dimensions and they can be changed during the process of motor manufacturing by changing the number of turns of main stator winding, or by changing the dimensions of stator and rotor core. Second and third motor model (M2 and M3) are developed by introducing the fifth and sixth varied parameter: width of stator pole- b_p [m] and shading portion of stator pole – a [/]. The program is adjusted to create 6000 generations of each varied parameter and as an output GA-ODEM gives a set of most favourable values of varied parameters with which is achieved the largest target function. They are presented in Table I.

Table I. Ranges of variation of different motor parameters and their output results

	BM	M1		M2		M3	
Motor parameter		Variation range	Output	Variation range	Output	Variation range	Output
Current density Δ [A/mm^2]	8	5 ÷ 10	5.005	5 ÷ 10	5	5 ÷ 10	5
Magnetic induction B_δ[T]	0,404	0.4 ÷ 0.45	0.44995	0.4 ÷ 0.45	0.4499	0.4 ÷ 0.45	0.449
Angle of rotor skew α_{sk} [°]	17	15 ÷ 20	15.015	15 ÷ 20	15.065	15 ÷ 20	15.0115
Width of bridge between stator poles d [mm]	2,4	1.5 ÷ 3.5	1.5	1.5 ÷ 3.5	1.51	1.5 ÷ 3.5	1.5
Width of stator pole b_p [m]	0,016	b_p=0.016=const	0.016	b_p=0.012 ÷ 0.02	0.012	b_p=0.012 ÷ 0.02	0.012
Shading portion of stator pole a [/]	0,25	a=0.25=const.	0.025	a=0.25=const.	0.25	a=0.2 ÷ 0.4	0.2

Optimisation results are obtained at rated slip s=0,16. In Table II are presented parameters for basic motor model and optimised motor models calculated on the base of input parameters presented in Table I. On the base of parameters from Table II motor performance characteristics are calculated for rated slip and adequately presented in Table III. For the whole range of motor operation (s=0÷1) motor performance characteristics: electromagnetic torque M_{em}=f(s), efficiency factor η=f(s), input current I_1=f(s), power factor cosφ=f(s), input power P_1=f(s) and output power P_2=f(s) are presented in Figures 2 to 7 respectively.

Table II. Comparison of motor parameters

BM	M1	M2	M3
Δ=8 [A/mm^2]	Δ=5.005 [A/mm^2]	Δ=5 [A/mm^2]	Δ=5 [A/mm^2]
$B_{\delta=}$0.404[T]	$B_{\delta=}$0.44995	$B_{\delta=}$0.4499	$B_{\delta=}$0.449
α_{sk}=17 [^{0}]	α_{sk}=15.015 [^{0}]	α_{sk}=15.065 [^{0}]	α_{sk}=15.0115 [^{0}]
d=2,4[mm]	d=1,5[mm]	d=1,5[mm]	d=1,5[mm]
b_p=0,016 [m]	b_p=0,016 [m]	b_p=0,012 [m]	b_p=0,012 [m]
a=0.25	a=0.25	a=0.25	a=0.2
d_{Cu}=0.14 [mm]	d_{Cu}=0.56 [mm]	d_{Cu}=0.18 [mm]	d_{Cu}=0.18 [mm]
W=3488 turns	W=3487 turns	W=3132 turns	W=3132 turns
R_1=492.98 Ω	R_1=107.717 Ω	R_1=272.91 Ω	R_1=273.04 Ω
X_1=498.17 Ω	X_1=505.1742 Ω	X_1=357.27 Ω	X_1=351.6 Ω
R_2=497.04 Ω	R_2=449.7459 Ω	R_2=362.763 Ω	R_2=362.687 Ω
X_2=76.71 Ω	X_2=76.72 Ω	X_2=72.78 Ω	X_2=78.5926 Ω
R_3=18474 Ω	R_3=18474 Ω	R_3=14218,54 Ω	R_3=21586,96 Ω
X_3=127.53 Ω	X_3=127.53 Ω	X_3=100.43 Ω	X_3=98.983 Ω
X_{12}=2163.3 Ω	X_{12}=2163.5 Ω	X_{12}=2052.48 Ω	X_{12}=2216.22 Ω
X_{13}=175.91 Ω	X_{13}=176.3 Ω	X_{13}=150.61 Ω	X_{13}=173.79 Ω

Table III. Comparison of motor performance characteristics

Quantity	BM	M1	M2	M3
Stator current I_1 [A]	0.126	0.144	0.163	0.157
Shaded coil current I_3 [A]	0.0063	0.0073	0.0091	0.0061
Rotor current I_2 [A]	0.0878	0.11	0.118	0.118
Power factor cosφ [/]	0.654	0.497	0.646	0.648
Input power P_1 [W]	18.11	15.81	23.17	22.36
Output power P_2 [W]	4.149	5.72	7.15	7.7
Efficiency factor η [/]	0.229	0.36	0.32	0.34
Torque M_{em} [mNm]	18.075	24.03	30.03	31.5

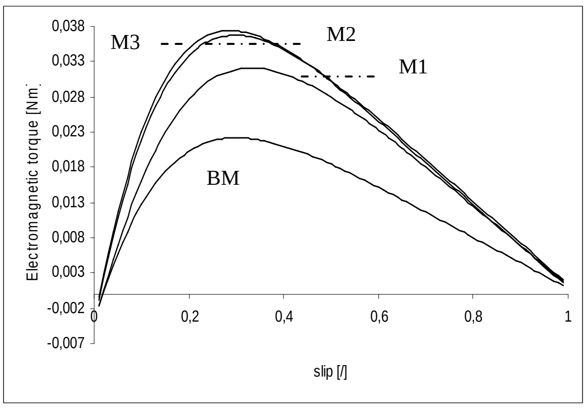


Fig. 2. Comparative characteristics M_{em}=f(s)

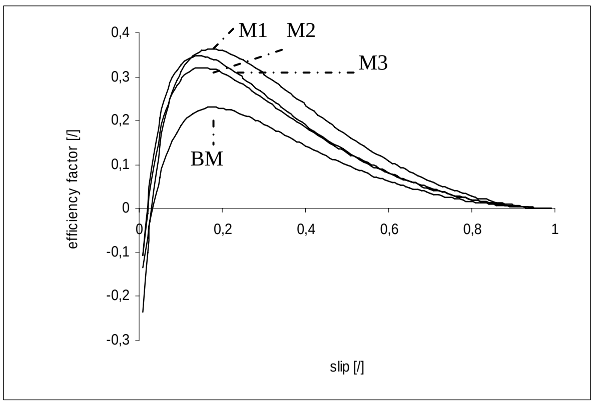


Fig. 3. Comparative characteristics η=f(s)

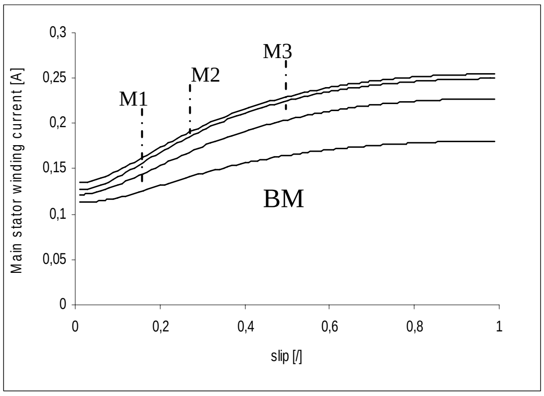


Fig. 4. Comparative characteristics $I_1=f(s)$

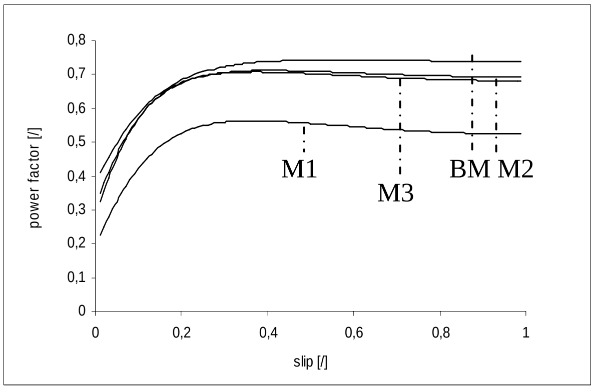


Fig. 5. Comparative characteristics $\cos\varphi=f(s)$

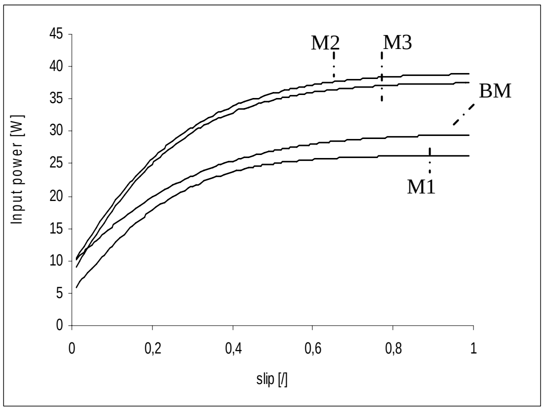


Fig. 6. Comparative characteristics $P_1=f(s)$

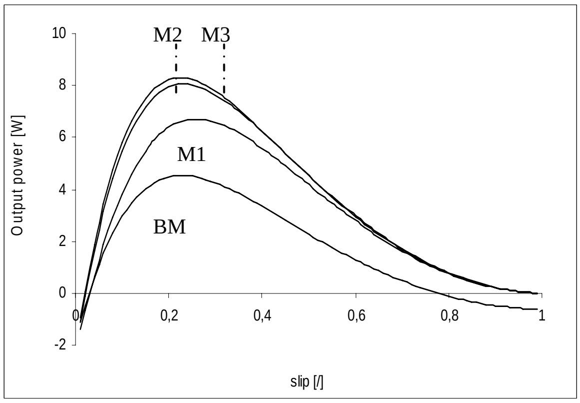


Fig. 7. Comparative characteristics $P_2=f(s)$

In Table IV is presented comparison of improvement of electromagnetic torque and efficiency factor compared to the basic motor model. From the presented results it can be concluded that due to the variation of different constructive motor parameters significant increase of electromagnetic torque as well as efficiency factor is achieved. With model M3 which is the most complex one, due to simultaneous variation of six motor parameters the largest increase of electromagnetic torque of 77 % is achieved followed with satisfactory increasment of efficiency factor of 48.4 %. In the same time, at model M3 power factor is maintained on the same level with the basic motor model which is important from operational point of view.

Table IV. Electromagnetic torque at different motor models

	BM	M1	M 2	M3
Electromagnetic torque M_{em} [Nm]	0.018	0.024	0.030	0.032
Improvement of electromagnetic torque compared to the basic motor model [%]		33.3	66.6	77.7
Efficiency factor [/]	0.229	0.36	0.32	0.34
Improvement of efficiency factor compared to the basic motor model		57.2	39.7	48.4

In order analysis of motor models to be complete one, it is necessary magnetic field distribution and magnetic flux density in motor cross-section to be obtained. On that way, it is possible areas with high magnetic saturation to be detected as week points in motor construction. Therefore Finite Element Analysis (FEM) in time –harmonic domain, i.e. f=50 Hz is performed and magnetic field distribution in motor cross section and air gap is obtained.

FEM Analysis

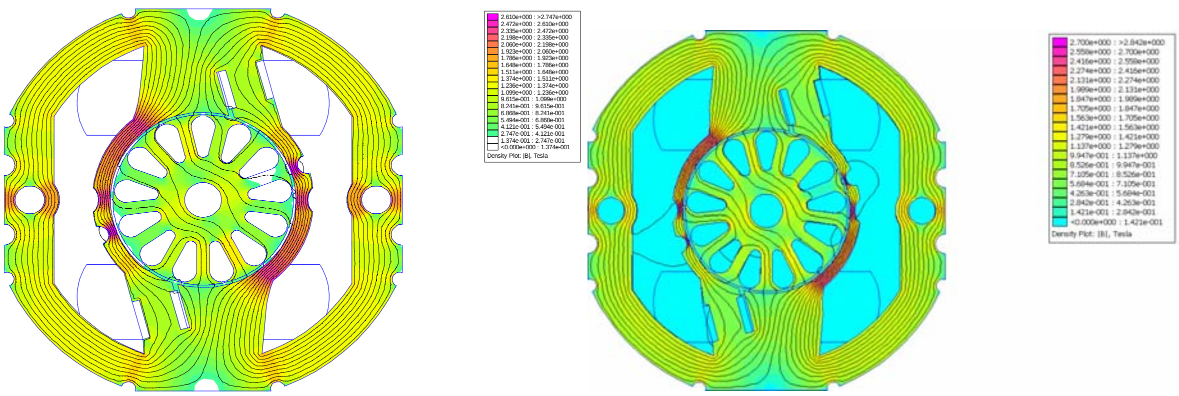
The Finite Element Method is widely used for electromagnetic field calculations in electrical machines, in general. It is usually used as a non-linear magnetostatic problem which is solved in the terms of magnetic vector potential **A**. However, when analysing induction machines, considering their AC excitation, the air-gap magnetic field is always a time-varying quantity. In materials with non-zero conductivity eddy currents are induced; consequently, the field problem turns to magnetodynamic, i.e. non-linear time harmonic problem. Even more, when rotor is moving, the rotor quantities oscillate at slip frequency, quite different from the stator frequency, and the direct implementation of the non-linear time harmonic analysis is improper. The problem is solved by adjusting the rotor bars conductivity σ, corresponding to the slip. Hence, the non-linear time harmonic analysis, by using FEM, is performed at fixed stator winding supply frequency f=50Hz, while the rotor slip is changing with load. When field is time varying, in materials with non-zero conductivity eddy currents are always induced. In that case following partial equation is going to be solved numerically:

$$\nabla \times \left(\frac{1}{\mu(B)} \nabla \times A \right) = -\sigma \dot{A} + J_{src} - \sigma \nabla V \tag{1}$$

where J_{src} represents the applied current sources. The additional voltage gradient ∇V in 2-D field problems is constant over conducting bodies. FEM considers the equation (1) for the problems in which the field is oscillating at the single (fixed) frequency; its developed form in the 2-D domain of the motor, yields the diffusion equation for time harmonic problems which FEM is actually solving:

$$\frac{1}{\mu} \frac{\partial^2 A}{\partial x^2} + \frac{1}{\mu} \frac{\partial^2 A}{\partial y^2} = -J_{src} + j\omega\sigma A \tag{2}$$

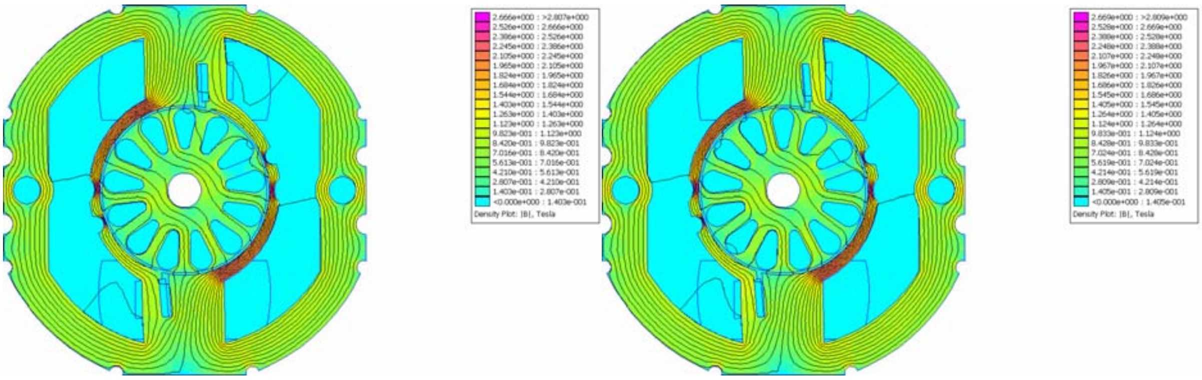
In Figures 8 and 9 the magnetic flux distribution in the middle cross section of basic motor model as well as for optimised motor models, at rated load slip s=0.16, is presented.



(a) BM (b) M1

Fig. 8. Magnetic flux distribution in motor cross section at rated load s_n=0.016 at BM and M1 model

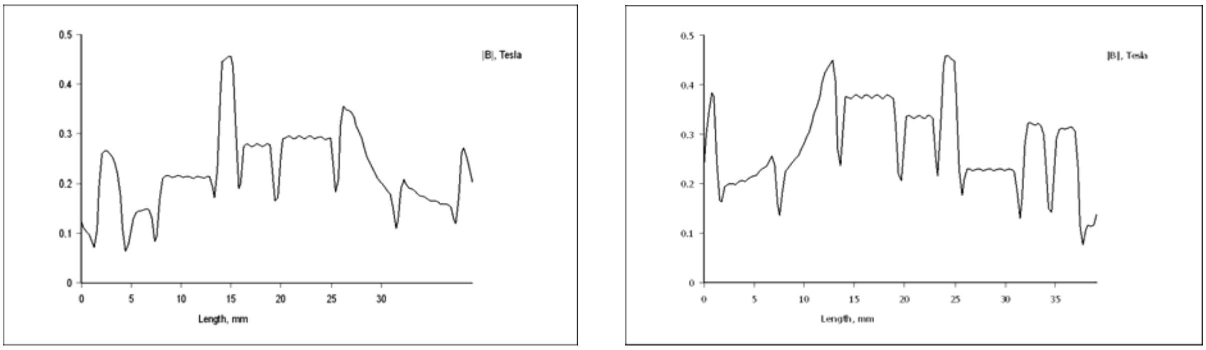
From Figures 8 and 9 it can be concluded that flux density is higher in optimized motor models. This is comprehensive considering the fact that critical part where the magnetic saturation is mostly emphasized in this type of motor is the bridge between stator poles. Optimized motor models are experiencing variation of width of bridge between stator poles i.e. it is decreased which results in higher values of magnetic flux density.



(a) M2 (b) M3

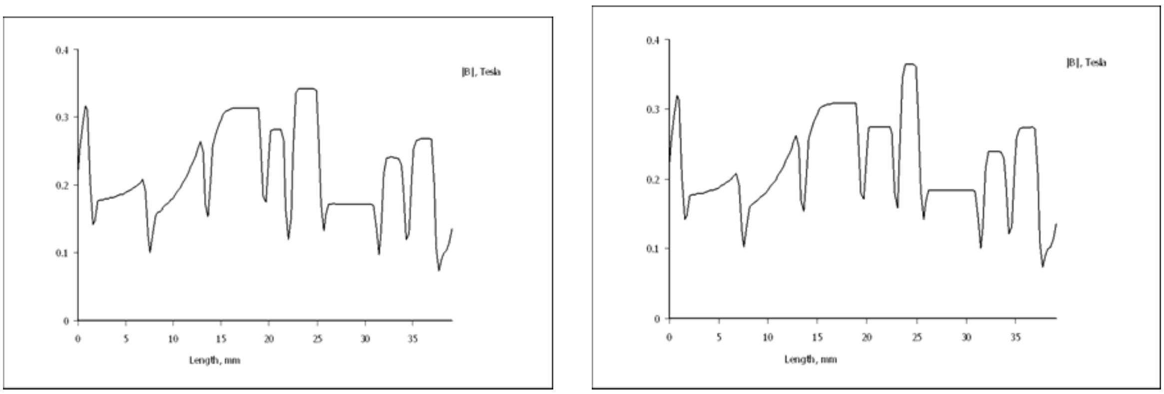
Fig. 9. Magnetic flux distribution in motor cross section at rated load s_n=0.016 at M2 and M3 model

In Figures 10 and 11 is presented distribution of magnetic induction in motor air gap per stator pole while in Figures 12 and 13 is presented distribution of electromagnetic field in motor air gap per stator pole.



(a) BM (b) M1

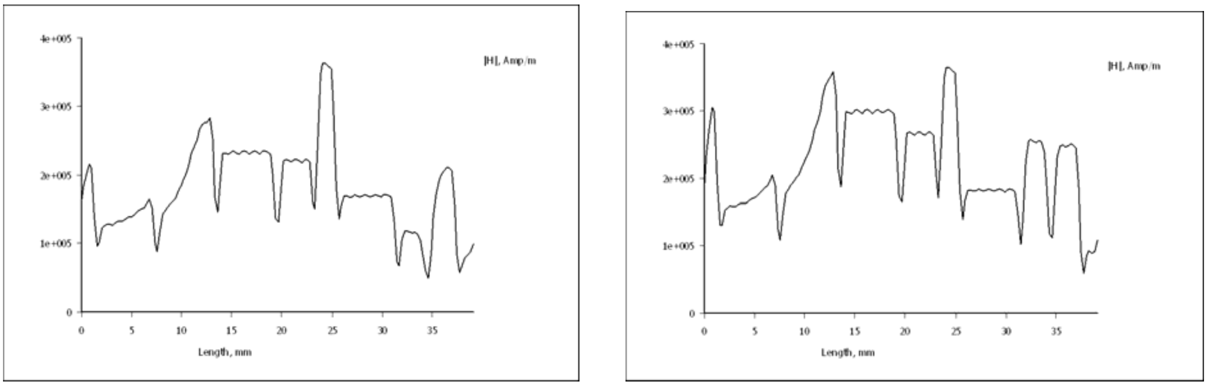
Fig.10. Magnetic induction in motor air gap s_n=0.016 for BM and M1



(a) M2 (b) M3

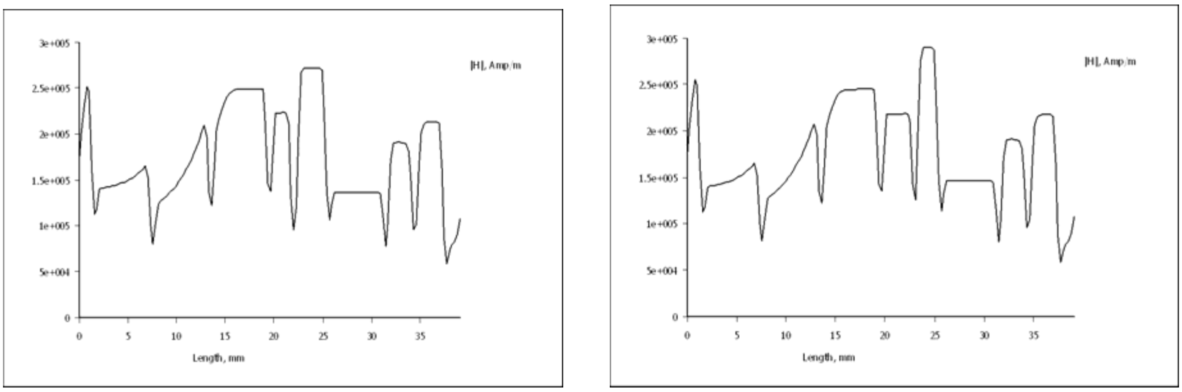
Fig.11. Magnetic induction in motor air gap s_n=0.016 for M2 and M3

In Table V are presented some of the most interesting results from calculations of basic motor model and optimised motor models such as: maximal magnetic vector potential A_{max} and number of lines of magnetic field-n. Distance between two lines designates the same change of value of magnetic vector potential ΔA. Characteristic magnetic values like average magnetic induction in air gap-B_δ and adequate value of flux Φ_p are also presented.



(a) BM (b) M1

Fig.12. Magnetic field distribution in motor air gap s_n=0.016 for BM and M1



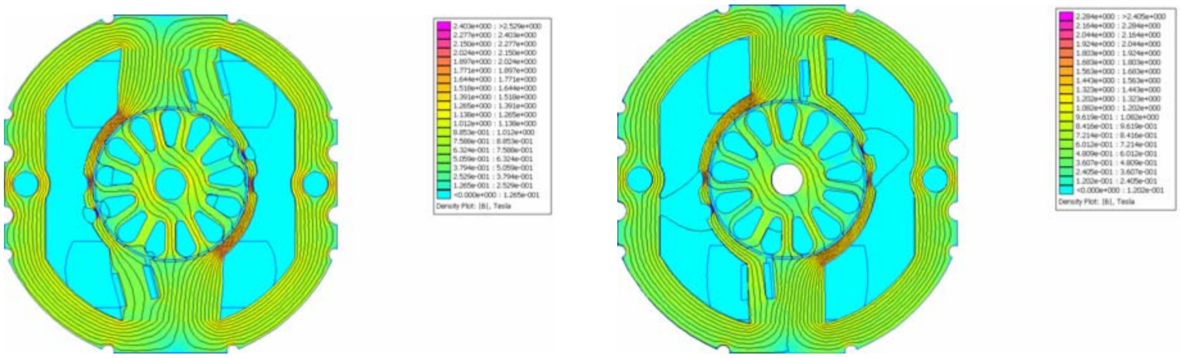
(a) M2 (b) M3

Fig.13. Magnetic field distribution in motor air gap s_n=0.016 for M2 and M3

Table V. Parameters from FEM

	OM	M1	M2	M3
I_1 [A]	0.126	0.144	0.16	0.157
A_{max}[Vs/m]	0.00505	0.004363	0.003587	0.0037
n	19	19	19	19
$\Phi_p x10^{-3}$[Vs]	0.147	0,18	0,14	0,14
B_δ[T]	0.235	0.289	0.226	0.227

In order value of magnetic induction at optimised motor models to be reduced, soft magnetic material Somaly™500, for stator poles and bridge is used. In Figs. 14 and 15 is presented consequently magnetic flux distribution for optimised motor models M1, M2 and M3 with soft magnetic materials used for stator poles and bridge. From Figs 14 and 15 it can be concluded that maximal value of magnetic induction in some critical points of stator bridge is considerably decreased i.e. for model M1 from 2.8 T to 2.5 T, for models M2 and M3 from 2.8 T to 2.404 T. Taking into consideration that width of the stator poles, pitch of short circuit cooil and bridge between stator poles are constantly changed in optimised motor models soft magnetic materials are ideal solution which enebales electrical machines to be easily shaped into desired form and reduces the maximal values of magnetic induction 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.



(a) M1 (b) M2

Fig.14. Magnetic flux distribution in M1 and M2 with application of soft magnetic material for stator bridge.

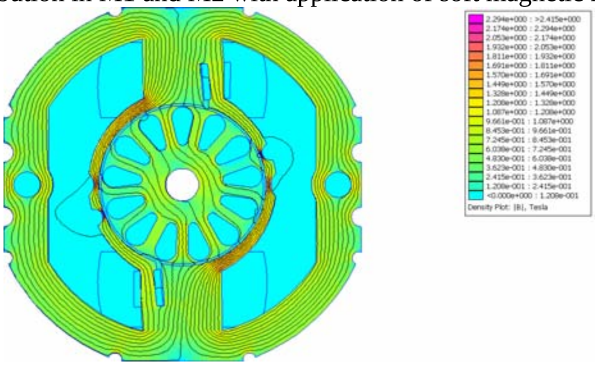


Fig.15. Magnetic flux distribution in M3 with application of soft magnetic material for stator bridge.

Conclusion

Method of genetic algorithms is used for developing three new optimized motor models by gradual increase of number of varied parameters from four in first model M1 up to six in third model M3. Optimisation was done for rated operational point i.e. for slip s_n=0.16 with electromagnetic torque as target function and by taking into consideration motor outer dimensions to remain unchanged. The last fact, lead to variation of current density, air gap magnetic induction, width of stator bridge and angle of a rotor skew in first motor model M1, followed by the variation of width of stator pole in second motor model M2 and shading portion of a stator pole in third motor model M3. As a result of optimisation process in model M1 increase of electromagnetic torque of 33 % is achieved, in models M2 and M3 of 66.6 % and 77.7 % respectively. This significant increase of electromagnetic torque is followed with increase of efficiency factor of 57.2 % in model M1, 39.7% and 48.4% in models M2 and M3 respectively. Since width of stator bridge was decreased as a result of optimisation process FEM analysis of electromagnetic field inside the motor proved that stator bridge in some points is experiencing very high values of magnetic induction i.e. for models M2 and M3 of 2.8 T. Therefore as a next step in the research of new optimised motor models was introduction of soft magnetic materials in the region of stator pole and bridge. Application of soft magnetic materials in critical regions with high values of magnetic induction contributes to considerable decrease of its value in model M1 from 2.8 T to 2.5 T and for models M2 and M3 from 2.8 T to 2.4 T. On that way the third motor model M3 represents the most optimised solution of single phase shade pole motor with increase of electromagnetic torque of 77.7 % efficiency factor of 48.4 % while in the same time power factor is maintained on the same level with basic motor model. By introducing soft magnetic materials in model M3 magnetic induction in some critical points of stator bridge was lowered to 2.4 T.

References
[1] V. Sarac, L.Petkovska, and M.Cundev, "An Improved Performance Analysis of a Shaded Pole Motor",Proceedings of PCIM'01 conference, Vol. 2/3, Nuremberg, Germany, pp. 399-404, 2001.
[2] V. Sarac, L.Petkovska, " Application of Soft Magnetic Materials in Development of New Experimental Model of Single Phase Shaded Pole Motor ", Journal Prezglad Electrotechniczny, ISSN 0033-2097, R.83,7-8/2007, 127-130