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Different motor models based on parameter variation using method of genetic algorithms

***Abstract**. In this paper is presented optimisation procedure of Single Phase Shaded Pole Motor based on method of Genetic Algorithms coupled with analysis of electromagnetic phenomena inside the optimised motor models by using Finite Element Method. Three new motor models were developed and in each newly developed model number of varied parameters was gradually increased which resulted in gradual increase of electromagnetic torque.*

***Streszczenie.** Artykuł przedstawia procedurę optymalizacyjną, bazującą na algorytmie genetycznym, dla silników jednofazowych z fazą pomocniczą. Procedura zawiera też analizę zjawisk elektromagnetycznych wewnątrz maszyny za pomocą metody elementów skończonych. Trzy nowe modele silnika zostały opracowane i każdy z nich o różnych parametrach był stopniowo powiększany co w wyniku dało stopniowy wzrost momentu elektromagnetycznego. (**Różne modele silnika oparte na zmienności parametrów przy zastosowaniu algorytmów genetycznych**)*

Keywords: Single Phase Shaded Pole Motor, Optimisation Models, Magnetic Field Distribution
Słowa kluczowe: jednofazowy silnik z fazą pomocniczą, modele optymalizacyjne, rozkład pola magnetycznego

Introduction

In this paper object of study and investigation is single phase shaded pole motor (SPSPM) type AKO-16 product of "MikronTech". 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 of 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. 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 one are analyzed with Finite Element Method (FEM) in order distribution of magnetic flux density in motor's cross section to be obtained.

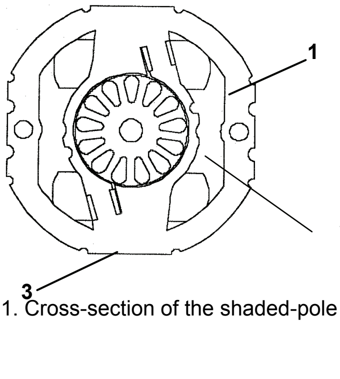


Fig.1. Cross-section of the shaded-pole motor

Application of GA optimisation method

Method of Genetic Algorithms has proved to be very powerful optimisation tool for designing [1]. 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 taking into consideration only certain number of points which do not necessarily represent the global optimum. Optimisation procedure is consisted of several steps:

- Defining the target function in this case electromagnetic torque.
- Prescribing ranges of variations of motor parameters.
- Programing the mathematical model in the program of genetic algorithms.
- Generation of set of output values on the base of varied parameters.
- Implementation of set of output values from program of genetic algorithms in program for calculation of motor performance characteristics developed in FORTRAN.
- 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.
- Obtaining 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 model-M1 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 which contribute to the largest target function (Table 1).

Table 1.Ranges of variation of motor parameters and output results

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

Parameters for basic motor model as well as for optimised motor models are calculated on the base of obtained outputs from GA program presented in Table 1. On the base of these parameters motor performance characteristics are calculated for rated slip and adequately presented in Table 2. For the whole range of motor operation i.e. slip (s=0$\div$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) and input power P_1=f(s) are presented in Figures 2 to 6 respectively.

Table 2. 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 □ [/]	0.229	0.36	0.32	0.34
Torque M_{em} [mNm]	18.075	24.03	30.03	31.5

In Table 3 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 compared with the basic motor model which is important from operational point of view.

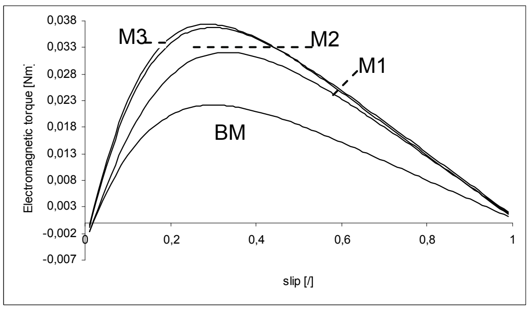


Fig.2. Comparative characteristics M_{em}=f(s)

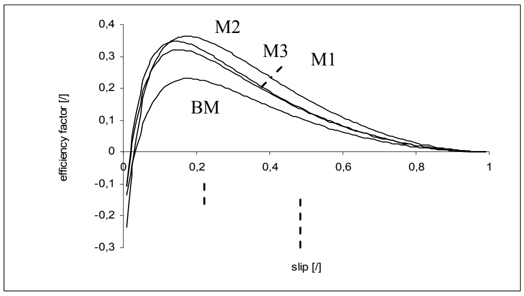


Fig. 3. Comparative characteristics η=f(s)

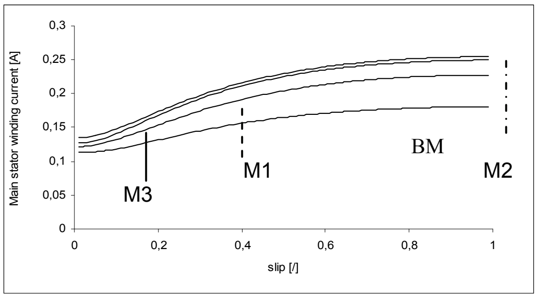


Fig. 4. Comparative characteristics I_1=f(s)

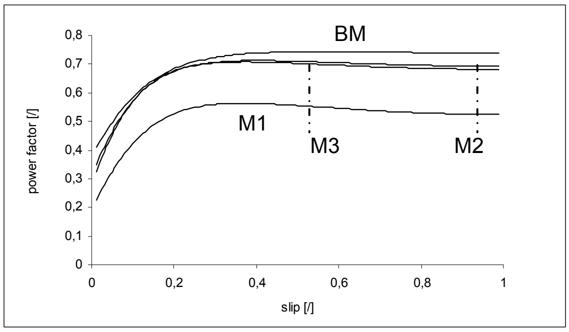


Fig. 5. Comparative characteristics cosφ=f(s)

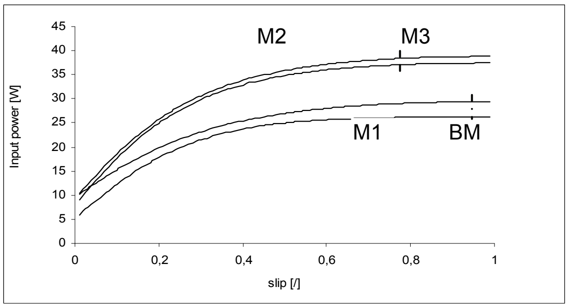


Fig. 6. Comparative characteristics P_1=f(s)

Table 3. Electromagnetic torque at different motor models

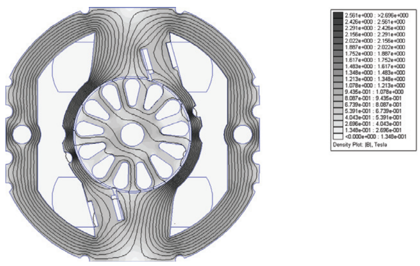
	BM	M1	M 2	M3
Electromagnetic torque M_{em} [Nm]	0.018	0.024	0.030	0.032
Improvement of M_{em} [%]		33.3	66.6	77.7
Efficiency factor η [/]	0.229	0.36	0.32	0.34
Improvement of η		57.2	39.7	48.4

FEM Analysis

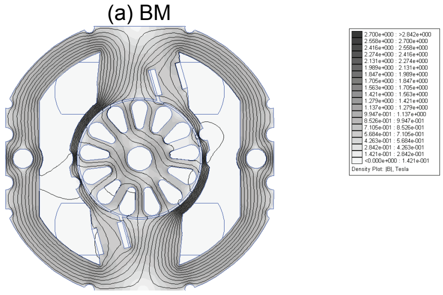
The Finite Element Method is widely used for electromagnetic field calculations in electrical machines. It is usually used as a non-linear magnetostatic problem which is solved in the terms of magnetic vector potential **A**. However, when analysing induction machines, considering their AC excitation, 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 [2]. 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. In that case following partial equation is going to be solved numerically:

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

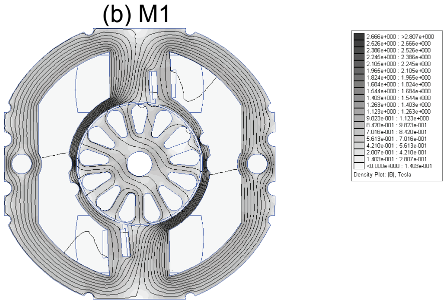
where J_{src} represents the applied current sources. The additional voltage gradient ∇V in 2-D field problems is constant over conducting bodies. In Fig. 7 is presented the magnetic flux distribution in the cross section of basic motor model as well as in optimised motor models, at rated load i.e. slip s=0.16. From Fig. 7 it can be concluded that flux density is higher in optimized motor models. This is comprehensive considering that critical part where the magnetic saturation is mostly emphasized in this type of motor is the bridge between stator poles. In optimized motor models width of bridge between stator poles is decreased which results in higher values of magnetic flux density.



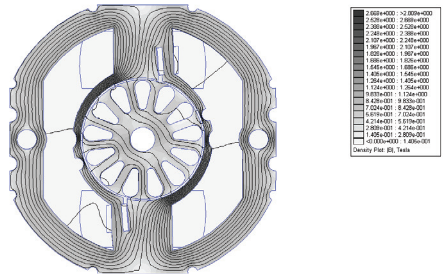
(a) BM



(b) M1



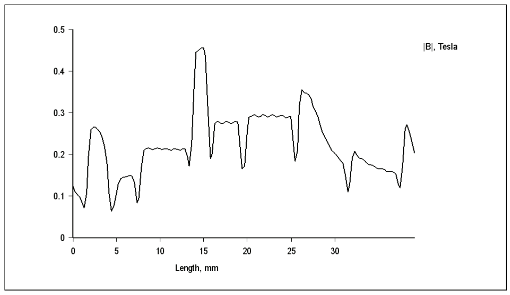
(c) M2



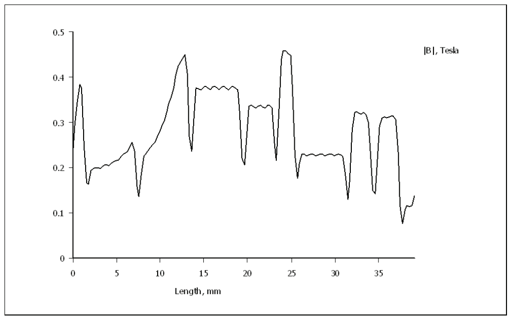
(d)M3

Fig.7. Magnetic flux distribution at rated load s_n=0.016

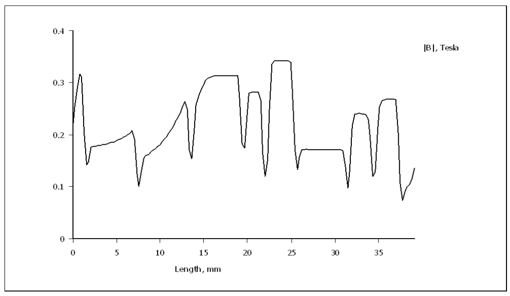
In Fig. 8 is presented distribution of magnetic induction in motor air gap per stator pole for all motor models.



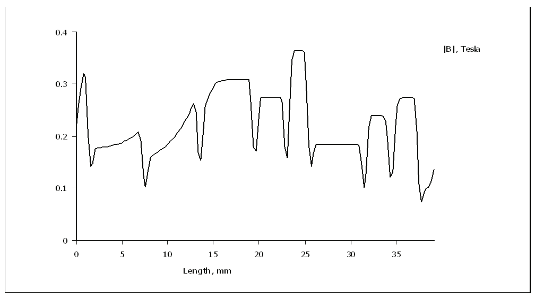
(a) BM



(b) M1



(c) M2



(d) M3

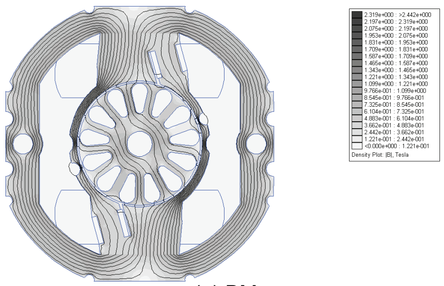
Fig.8 Magnetic induction in motors air gap at rated load

In Table 4 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. Characteristic magnetic values like average magnetic induction in air gap-B_δ and adequate value of flux Φ_p are also presented.

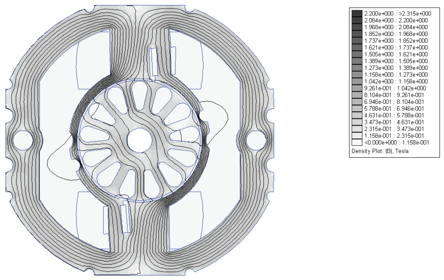
Table 4. Parameters from FEM

	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

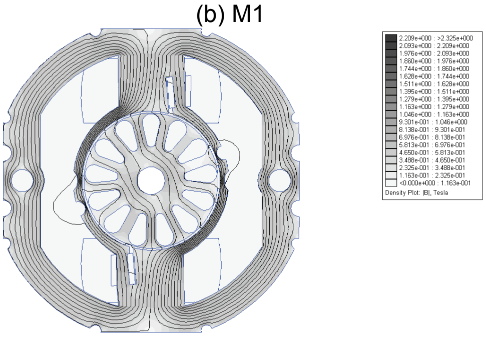
In order value of magnetic induction at optimised motor models to be reduced, soft magnetic material Somaly™500, for stator poles and bridge is used. In Fig.9 is presented consequently magnetic flux distribution for optimised motor models M1, M2 and M3 with application of soft magnetic materials in selected region. From Fig. 9 it can be concluded that maximal value of flux density in some critical points of stator bridge is considerably decreased i.e. for M1 from 2.7 T to 2.31 T, for M2 and M3 from 2.66 T to 2.2 T. Taking into consideration that width of the stator poles, pitch of short circuit coil and bridge between stator poles are constantly changed in optimised motor models, soft magnetic materials are ideal solution which enables electrical machines to be easily shaped into desired form while the maximal values of flux density in regions with high saturations are reduced.



(a) BM



(b) M1



(c) M3

Fig. 9 Magnetic flux distribution in optimized motor models with application of soft magnetic materials 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 flux density, 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 by the 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 flux density i.e. for models M2 and M3 of 2.66 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 flux density contributes to considerable decrease of its value in model M1 from 2.7 T to 2.31 T and in models M2 and M3 from 2.66 T to 2.2 T. On that way the third optimised motor model M3 represents the best 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 compared with basic motor model.

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