# Electromagnetic fields calculation at single phase shaded pole motor

**Vasilija J. Šarac, Dobri M. Čundev**

*Finite Element Method (FEM) is used for calculation of electromagnetic field inside the single phase shaded pole motor, product of company Micron-Tech from Prilep under trade name AKO-16. Four different motor models for FEM application are developed. In first motor model magnetostatic approach for electromagnetic field calculation is implemented, meaning all electromagnetic quantities are evaluated at zero Herz frequency. Second model is developed using time-harmonic approach at fifty Herz frequency. Third and fourth motor model are developed by implementing soft magnetic material in stator notch and pole respectively and analyses is carried out in time harmonic domain. Obtained results are compared and conclusions are derived.*

**Introduction**

In spite of its simple construction single phase shaded pole motor (SPSPM) is very complex due to the existence of three magnetically coupled windings which produce an elliptic rotating magnetic field in motor's air gap. Motor's prototype rated data are: $U_n$=220 V, $f_n$=50 Hz, $I_{1n}$=0.125 A, $P_{1n}$=18 W, $n_n$=2520 rpm and 2p=2 (Fig.1).

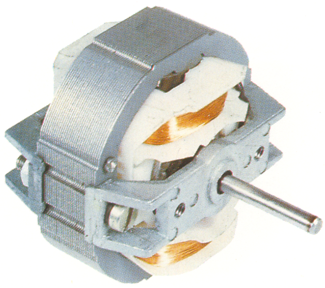


*Fig.1 Prototype of motor AKO-16.*

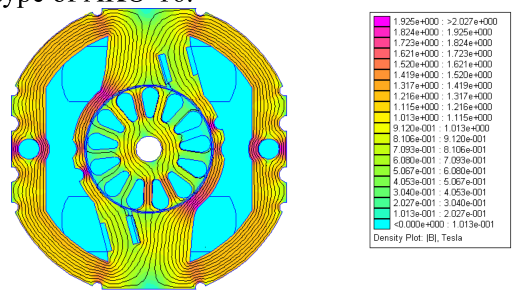
Extensive analysis of motor performance characteristic is implemented and they are calculated on the base of symmetrical components theory [1], [2]. Obtained characteristics are verified by experiment [3]. Next step in motor research is to calculate electro-magnetic characteristics such as magnetic flux density inside the motor cross section. Therefore Finite Element Method was employed as valuable tool in calculation of motor electro-magnetic characteristics [4].

**FEM motor models**

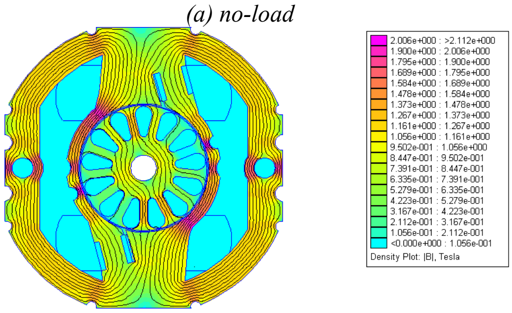
Over the past years Finite Element Method has proved itself as valuable tool in motor design and analysis. In order to enable FEM calculation to be applicable, exact motor geometry with material characteristics is input in FEM pre processing part. Very important issue is to define boundary conditions on outer motor geometry and in this case Dirichlet boundary conditions are used. 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 (triangles) the true solution of magnetic vector potential is approximated by a very simple function. Two different approaches are used in magnetic field calculation: magneto-static and time-harmonic [5]. In magneto-static approach all electromagnetic phenomena inside the motor are analyzed in certain moment of time i.e. f=0 Hz. First, motor model is built by inputting current density in main stator winding, than from the value of magnetic flux in short circuit coil, current in the coil is calculated and input in the model. Finally having the both stator currents and from the value of magnetic flux in motor air gap, current in rotor squirrel cage winding is calculated. Having all three currents in the model the program is run at stator frequency f=0 Hz. In time-harmonic motor model only stator current is input and consequently currents in short circuit coil and rotor windings are freely induced. On that way analysis 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. Both analyses are performed in 2D domain. Further improvement in motor design is achieved with implementation of soft magnetic powders in motor construction. On that way, rather high value of motor magnetic flux density in time-harmonic analysis is decreased which contributes towards decreased core saturation and iron losses.

**Results from magneto-static analysis**

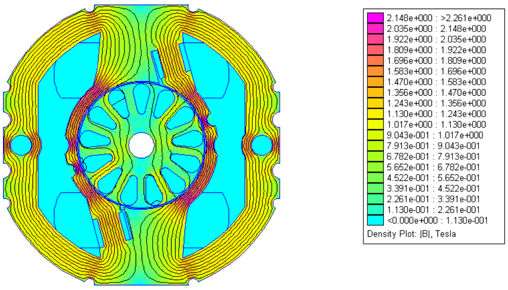
After preparing all motor models program is executed and post-processing results such as magnetic field distribution in motor's cross section as well as spatial distribution of magnetic flux density in the middle of air gap line are obtained. All results are presented for magnetostatic and time-harmonic case. In Fig. 2 is presented magnetic flux density distribution in motor cross-section for all three operating regimes: no-load, rated load and locked rotor while in Fig.3 is presented spatial distribution of magnetic flux density in motor air gap for above mentioned operating regimes. Further on, in Fig.4 is presented characteristic of air gap flux versus current in main stator winding $\Phi_\delta=f(I_1)$, when only stator windings are energized and there is no current in rotor winding, $I_2=0$, for rotor starting position 0°. This is adequate to ideal no-load operation and obtained characteristic represents the magnetization curve of proto-type of AKO-16.




*(a) no-load*

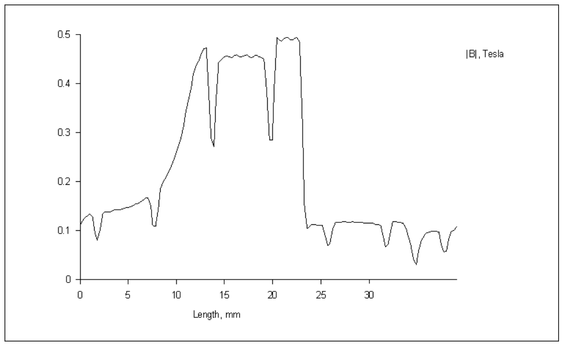



*(b) rated load*

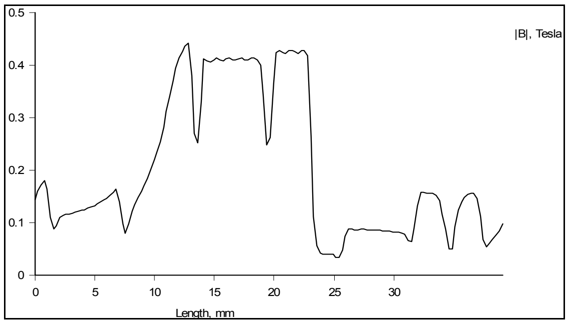



*(c) locked rotor*

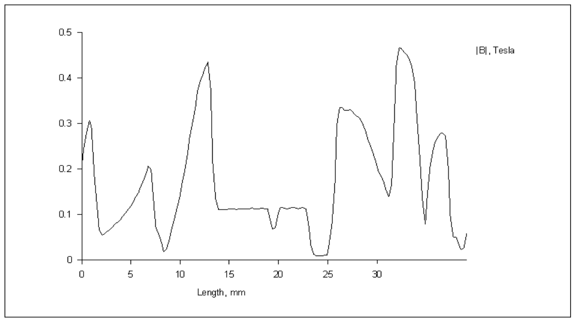
*Fig.2. Magnetostatic flux density distribution.*




*(a) no-load*




*(b) rated load*




*(c) locked rotor*

*Fig.3. Flux density distribution in motor air gap.*

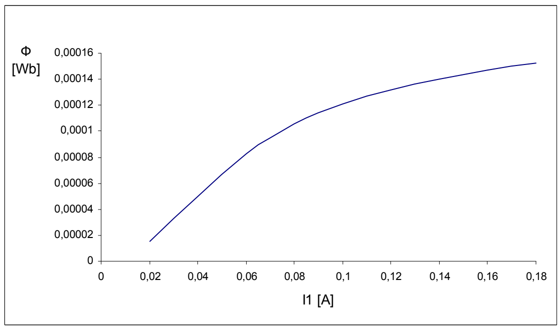



*Fig.4. Air gap flux for $I_1$ and $I_3\neq0$, $I_2=0$.*

Values of flux in motor air gap as well as electromagnetic torque-$M_{em}$ when all three windings are energized for different rotor positions are presented in Figs. 5 and 6 respectively.

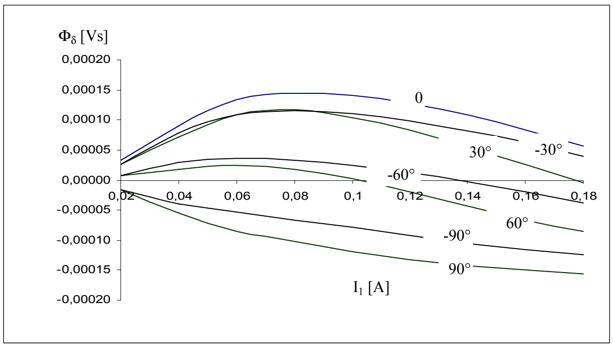



*Fig.5. Air gap flux for $I_1$, $I_2$ and $I_3 \neq 0$, different rotor positions.*

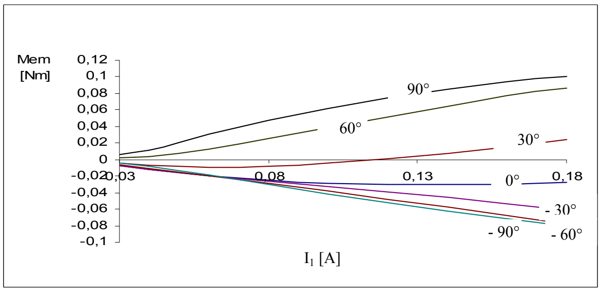



*Fig.6. Electromagnetic torque for different rotor positions.*

Skewing of rotor's channels in electrical motors has proved to be a valuable tool in lowering the harmonics content, noice and machine vibrations. In order skewing of rotor channels to be considered in calculation of motor electromagnetic parameters such as electromagnetic torque, a 3D calculation of electromagnetic field inside the machine is required. Some authors [6] propose application of quasi 3D motor model based on discretisation of third motor dimension. Motor axial dimension is devided into n parts with equal length as it is presentd in Fig. 7. Each neighbor parts are rotated by a simetrical angle of α/n, where α is the angle of skewing of rotor chanels. In analysed model of motor AKO-16, angle of skewing of rotor chanels is 17˚ and axial length is 16 mm. Modeling of motor in quasi 3D domain results in larger calculation time which deepends lineary with respect to the number of parts.

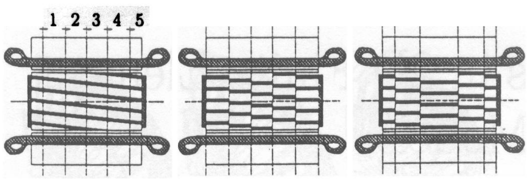



*Fig.7. Modeling of rotor skewing.*

In Fig. 8 is presented value of electromagnetic torque for rated load operating conditions and for different rotor positions.

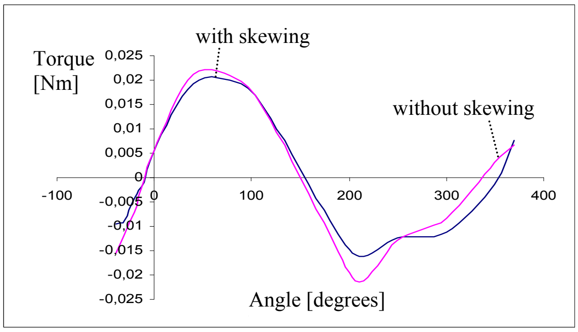



*Fig.8. Electromagnetic torque with and without skewing.*

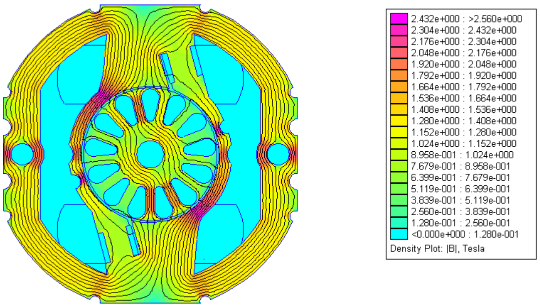
**Results form time-harmonic analysis**

Time-harmonic analysis at f=50 Hz and for different operating regimes is carried out. When analyzing 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 into magneto-dynamic i.e. non-linear time harmonic problem. When rotor is moving, the rotor quantities oscillate at slip frequency. In this case the rotor bars conductivity δ is adjusted corresponding to the slip. Consequently following partial equation is going to be solved numerically:

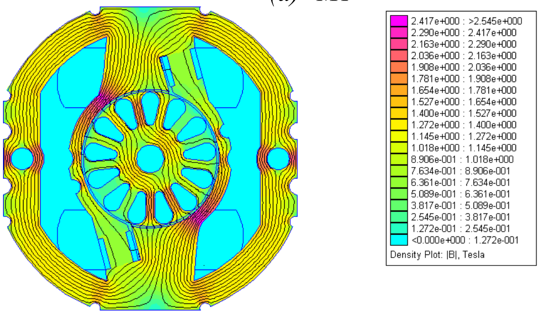
$$\nabla x\left(\frac{1}{\mu(B)}\nabla xA\right)=-\sigma\dot{A}+J_{src}-\sigma\nabla V \tag{1}$$

where $J_{src}$ represents the applied current sources. The additional voltage gradient in 2-D field problems is constant over the conduction body. In motor model is input only current in main stator winding while currents in short circuit coil and rotor winding are freely induced.

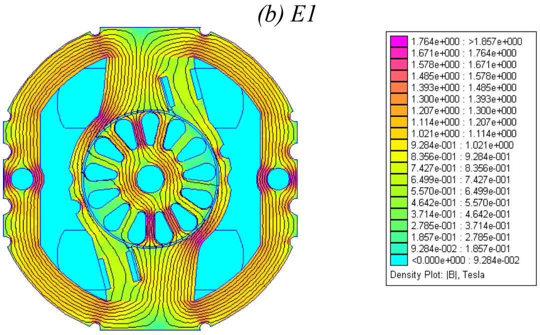
In Fig. 9a is presented flux density distribution for no-load operating regime at model of motor prototype-M1. From presented results it can be concluded that in some critical points of model-M1 stator bridge has increased value of flux density up to 2.43 T. Therefore soft magnetic material Somaly™500 is implemented in construction of stator notch (Fig. 9b) thus obtaining the experimental model E1 and further on, in construction of complete stator pole (Fig. 9c)-model E2. Usage of soft magnetic materials contributes towards decreased machine losses due to the eddy currents. Application of powders with increased percentage of iron contributes in machine construction towards enlarged values of magnetic induction 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.



*(a) M1*



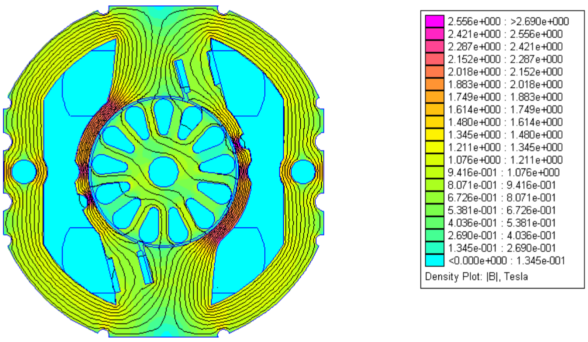
*(b) E1*



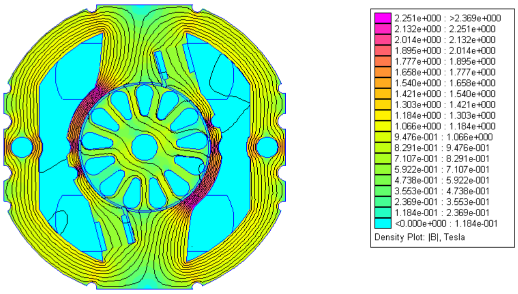
*(c)E2*

*Fig.9. Time-harmonic flux density distribution at no-load.*

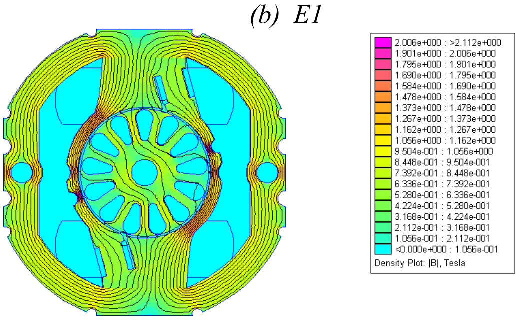
In Fig. 10 and 11 are presented magnetic flux density distribution for rated load and locked rotor operating conditions for all motor models respectively.



*(a) M1*

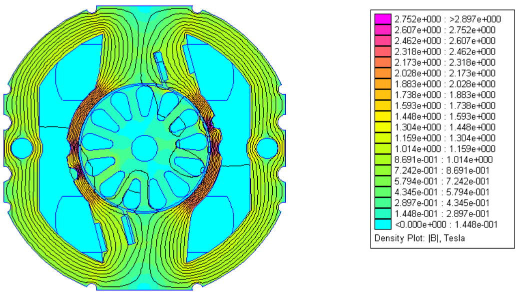


*(b) E1*

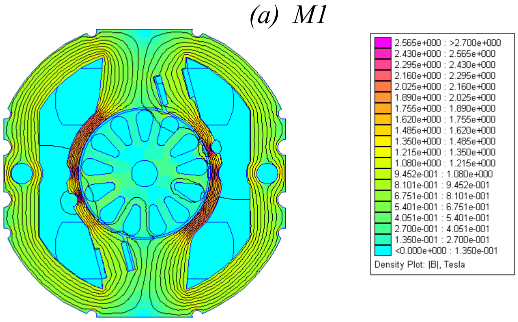


*(c) E2*

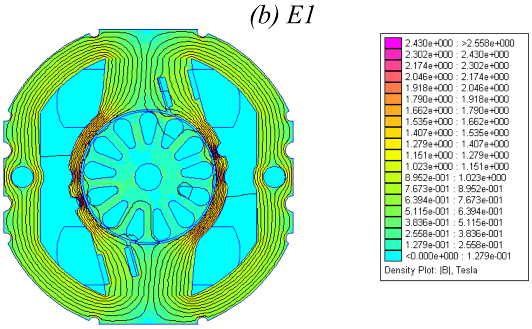
*Fig.10. Time–harmonic flux density distribution at rated load.*



*(a) M1*



*(b) E1*



*(c) E2*

*Fig.10. Time- harmonic flux density distribution at locked rotor.*

Electromagnetic torque is calculated from time-harmonic analysis of model –M1 for different motor's slips-s and obtained results are compared with results obtained from analytical and simulation methods and they are consequently presented in Table 1.

**Table 1**

*Results of electromagnetic torque*

| slip [/] | FEM | Analytic method | Simulation |
|---|---|---|---|
| 0.01 | 0.0017808 | 0.001625 | 0.00167 |
| 0.10 | 0.0156608 | 0.012647 | 0.01141 |
| 0.16 | 0.0199774 | 0.018075 | 0.01890 |
| 0.30 | 0.0196288 | 0.022175 | 0.02023 |
| 0.50 | 0.0147680 | 0.018423 | 0.01639 |
| 0.80 | 0.0088368 | 0.008042 | 0.00800 |
| 0.99 | 0.0028912 | 0.001809 | 0.00200 |

## Conclusion

FEM is used for calculation of electromagnetic field in-side SPSPM. Analysis is performed for magneto-static case at frequency f=0 Hz and time-harmonic case at frequency f=50 Hz. Different electro-magnetic quantities are calculated such as magnetic flux density inside the machine cross section for three different operating regimes: no-load , rated load and locked rotor as well as spatial distribution of air gap flux, enabling "week" parts in motor construction to be discovered, i.e. areas with high saturation. Angle of rotor skewing is also implemented in motor model and electro-magnetic torque is calculated for different rotor positions. Numerical analysis is extended with time-harmonic motor analysis at 50 Hz. Obtained result of magnetic flux density in motor cross section for all three operating regimes has proved that there is a considerable saturation of magnetic core due to high values of flux density in stator bridge. Therefore soft magnetic material is applied in stator notch and bridge which considerably lowered the vale of magnetic flux density from 2.4 to 1.7 T at no-load , from 2.5 to 2 T at rated load and from 2.7 to 2.43 T at locked rotor. Electromagnetic torque is calculated for different motor slips and obtained results are compared with results from analytical calculation and simulation showing acceptable agreement especially at rated operating point meaning slip of 0.16.

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***Assist. Prof. Dr. Vasilija Sarac** – presently employed at University Goce Delcev, Electrotechnical Faculty. In 1999 she received M.Sc. degree in electrical engineering-electrical drives at Electrotechnical faculty at Ss. Cyril and Methodius University in Skopje and in 2005 PhD degree in electrical machines at the same institution. Her scientific interest includes electrical machines, drives and power electronics.*

*tel.:++38932550660 e-mail: vasilija.sarac@ugd.edu.mk*

***Assist. Prof. Dr. Dobri Cundev** –presently employed A.D. TE-TO combined gas power plant. He received in 2000 M.Sc. degree in electrical engineering-electrical machines at Electrotechnical faculty at Ss. Cyril and Methodius University in Skopje and in 2010 PhD degree at Czech Technical University in Prague. Her scientific interest includes electrical machines, drives and hybrid electrical vehicles.*

*tel.:++38970672602 e-mail: dobri.cundev@ugd.edu.mk*



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