FEM ANALYSIS OF ASYMMETRICAL MAGNETIC FIELD IN ELECTRICAL MACHINES

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Abstract

In this paper is presented an approach to improved and deepened nonlinear magnetic field analysis of the shaded-pole motor, as a particular motor with an asymmetric magnetic field. The authors sugest an approach to the modeling of the magnetic field, excited from the both stator windings only, suitable for the application of the Finite Element Method, as a contemporary and powerful numerical method. By using the iterative nonlinear FEM procedure, the distri bution of the magn etic field, under different excitation currents in the stator windings, will be computed. Afterwards, on the basis of flux densities distribution, as well as on the flux values in the particular domains of the motor, the electromagnetic phenomena at no load will be analyzed. The effect of the rotor bar skewing on the air-gap flux is analysed, too.

Keywords: Shaded-pole motor, Finite Element Method, Magnetic Field, Rotor skewing.

1 Introduction

The development of different appliances, for many years ago, has caused an appearance and an expansion of special different types fractional horsepower motors with enormous possibilities for their application. One of these particular motors is certainly a single-phase shaded-pole induction motor. This motor is well recognized as special in construc tion, but considerably complicated for an analysis. Compared to other types of induction motors, it is more complicated by the fact that there exist three mutually coupled windings and an elliptic rotating magnetic field.

The rated data of the shaded-pole motor which is going to be analyzed are: 2p=2 number of poles, 220 V voltage supply, 24 W input power, 2200 rpm. In Figure 1.1 it is presented the radial cross-section of the motor. The first winding is the main stator winding (1), the second one is the bar squirrel cage rotor winding (2) and the third one is the auxiliary stator winding with one shaded coil per pole (3).

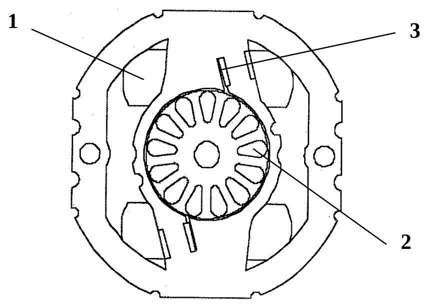


Fig. 1.1 Cross-section of the shaded-pole motor

2 Modeling the Electromagnetic Field

In order to determine electromagnetic quantities and characteristics of the shaded-pole motor, as accurate as possible, the Finite Element Method (FEM) is used. This method is well known as a represent of the contemporary numerical methods, widely used for solution of magnetic field problems in electrical engineering. The nonlinear iterative procedure is applied. The calculations are carried out as magnetostatic case, at given rotor position. At the beginning, FEM is used at separately energized stator windings. The computations continue when both stator windings are energized at rated current, as well as at several other values. The spatial distribution of the magnetic flux density along different air-gap paths is calculated. The air-gap flux linkage and the fluxes in different parts of the stator are calculated, too.

2.1 Preprocessing

In order to carry out the calculations of electromagnetic characteristics by using Finite Element Method, in the pre-processing step the exact geometry of the shaded-pole motor should be input first. Afterwards all materials in each of the motor domains must be defined. This operation is performed with program blocks which contain all requested information regarding electrical and magnetic materials properties, including conductivity and the magnetization curve for nonlinear calculations. The boundary conditions included in the model are from the first type, i.e. they are applied Dirichlet conditions on the outer line of the motor. The mesh of finite elements is generated fully automatically. In this particular case, the mesh of the shaded-pole motor is consisted of 10250 nodes and 20063 elements and it is presented in Figure 2.1.

In the regions where the calculation of the magnetic vector potential is requested to be performed more accurate, especially on an interface between two different materials, the mesh density is increased. In this case the contour of integration should pass at least two elements away from any interface or boundary. The mesh refinement in the shaded-pole motor is applied in the air-gap region as it is shown in Figure 2.2. The greater mesh density increases the computation time. So the good way to find mesh which is “dense enough”, in order the necessary accuracy to be achieved and still computation time to be reasonably small, is the comparison of results from different mesh densities. Then, one can pick the smallest mesh density which gives a good convergence to the desired digit of computational accuracy.

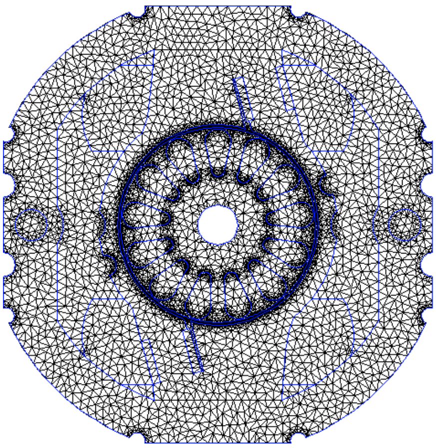


Fig. 2.1 Finite elements mesh

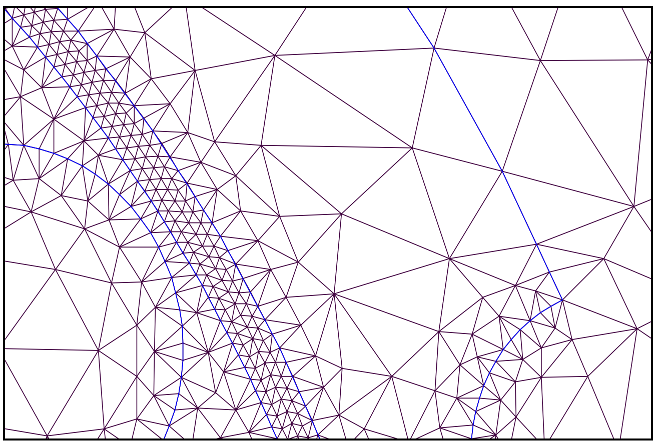
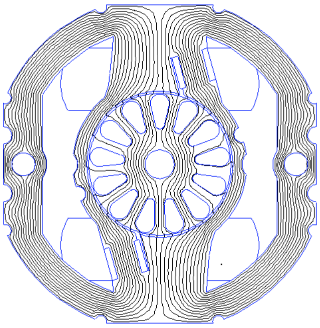


Fig. 2.2 Detailed view of the increased mesh density

2.2 ***Processing***

Quasi-static nonlinear analysis of the shaded-pole motor, when only the stator windings are energized, meaning at no load conditions in the rotor, is carried out in following steps:

Step 1: First only the main stator winding is energized. Currents are applied in the range $(1.1 \div 0.1)I_n$. The flux distribution at rated current I_n is presented in Figure 2.3.

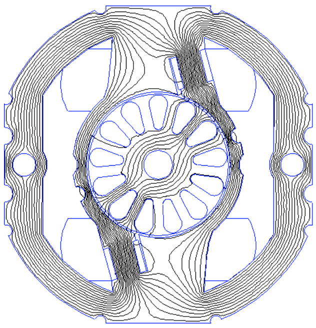


$A_{max} = 8.223 \cdot 10^{-3}$ Vs/m
$A_{max} = -8.223 \cdot 10^{-3}$ Vs/m

$B_{max} = 2.252$ T

Fig. 2.3 Flux distribution when only the main winding is excited

Step 2: From the magnetic field distribution obtained in the step 1, the flux linkage in the shading coil is determined. The emf, as well the induced current in the coil is calculated. Then, the magnetic field calculation is performed again, under the presumption that only the shading coil is energized. The flux distribution is shown in Figure 2.4.

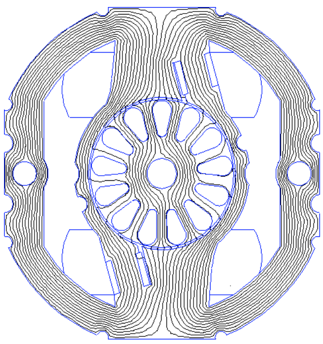


$A_{max} = 3.976 \cdot 10^{-3}$ Vs/m
$A_{max} = -3.978 \cdot 10^{-3}$ Vs/m

$B_{max} = 2.063$ T

Fig. 2.4 Flux distribution when only the shading coil is excited

Step 3: Consequently, at any arbitrary chosen value for the main stator winding excitation current, corresponds an exact value of the shading coil current. Applying these pairs of cur rents in both stator windings, one can calculate the magnetic field in the shaded-pole motor. The flux distribution, at rated current in the main stator winding is presented in Figure 2.5.



$A_{max} = 8.022 \cdot 10^{-3}$ Vs/m
$A_{max} = -8.023 \cdot 10^{-3}$ Vs/m

$B_{max} = 2.224$ T

Fig. 2.5 Flux distribution when both stator windings are excited

2.3 Post processing

The three previous described steps of the nonlinear iterative FEM procedure are repeated for all the range of the main stator winding currents. When only this winding is excited, the characteristic of the air-gap flux in dependence of the current is presented in Figure 2.6.

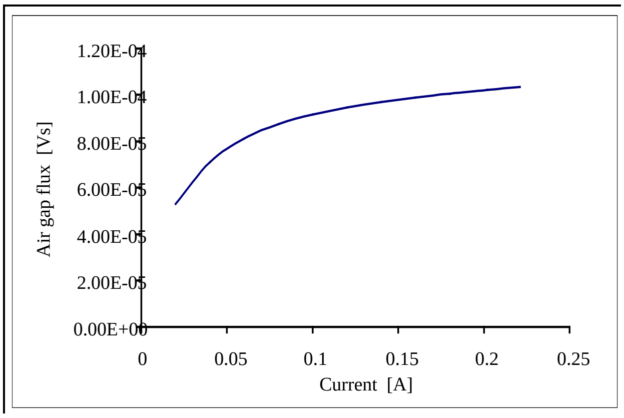


Fig. 2.6 Air gap flux characteristic when only the main stator winding is energized

When both stator windings are excited as described in the previous subheading, the characteristic of the air-gap flux in function of the current in the main stator winding, too, are presented in Figure 2.7.

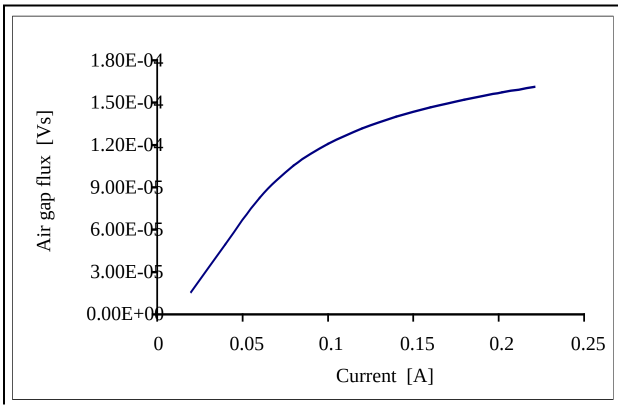


Fig. 2.7 Air gap flux characteristic when both stator windings are energized

3 Analysis

The results of the FEM calculations enable "to get inside the motor" and to perform a deepened analysis of the nonlinear magnetic field distribution, taking into consideration the typical magnetic values, as flux, flux linkage and flux density.

The analysis of magnetic field will be carried out for three different cases, as follows: • the main stator winding is energized with rated current I_n = 0.202 A, while the current in the shading coil is forced to be at zero value; • only the auxiliary stator winding (shading coil) is energized with corres-pondent rated current; • two stator windings are excited with rated currents. In each case, the current in the rotor bar winding is kept at zero. Some of the quantities are presented in tables, and some are presented on diagrams.

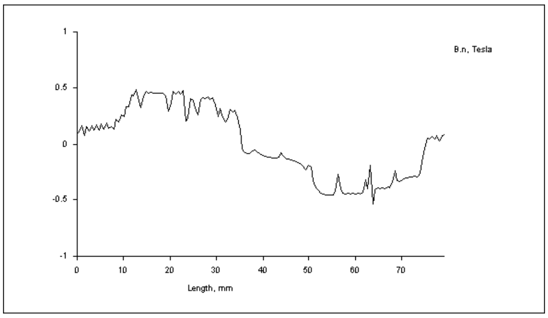
3.1 Main stator winding excited

In this case, the values of the magnetic flux in two typical domains of the motor configuration are presented in Table 3.1.

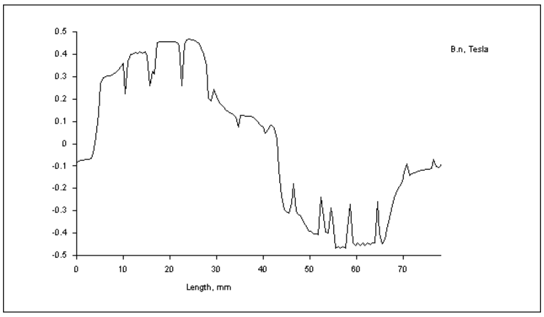
Integration contour	Flux per pole x 10^{-4} [Vs]	Flux density [T]	Flux linkage [Vs]
Along air gap	1.6448	0.2634	0.57897
Stator pole	2.5936	1.0130	0,91295

Table 3.1 Air-gap and stator pole flux

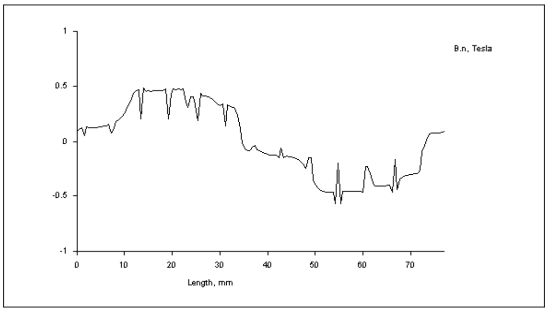
Spatial distribution of flux density is plotted along: • the inner diameter of the stator; • the middle line of the air gap; • the outer diameter of the rotor. In this case, the diagrams are presented in Figure 3.1 (a), (b) and (c), respectively.



(a) inner stator line



(b) middle air gap line



(c) outer rotor line

Fig. 3.1 Spatial distribution of the flux density when only the main stator winding is energized

Additionally, an analysis of magnetic fluxes is performed inside the stator core on different parts of the pole. Results of the calculations are presented in Table 3.2.

Stator pole domain		Flux x 10^{-4} [Vs]	Flux density [T]	Shading portion [p.u.]
Inside main winding		2.6192	1.001	
Inside shading coil	top	1.0227	1.486	
	bottom	1.0323	1.500	0.392
Outside shading coil	top	1.5997	0.980	
	bottom	1.5712	0.773	

Table 3.2 Fluxes in stator pole

The shaded portion of stator pole is an interesting matter of investigation. The considered motor is designed with an angle of 73.2 °; but due to the non-li nearity of the magnetic core, as well as of the leakage fluxes it is a bit different. At no-load condition, it is found that the angle is 70.6°.

3.2 Auxiliary stator winding excited

As the second case fluxes are analyzed when only the shad ing coil is energized, while the excitation current in the main stator winding is kept to zero. The shading coil currents are determined in dependence of the stator current in the main winding, as it is explained in the subsection 2.2. It is necessary to emphasize, that due to the known principle of the shading ring role, the current has an opposite sign, which is evident in the tables below, as well.

In this case, the values of the magnetic quantities in the analyzed sections, presented same as in the previous case, are given in Table 3.3 and Table 3.4.

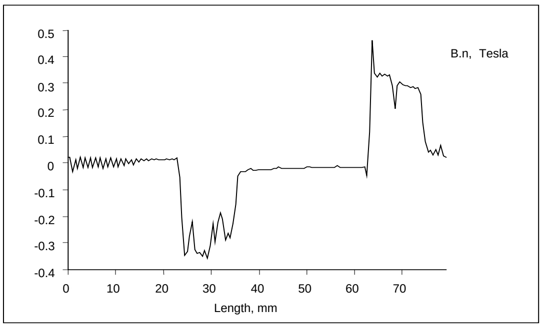
Integration contour	Flux per pole x 10^{-4} [Vs]	Flux density [T]	Flux linkage [Vs]
Along air gap	-0.48720	-0.07802	0.17149
Stator pole	-1.22688	-0.47920	0.43186

Table 3.3 Air-gap and stator pole flux

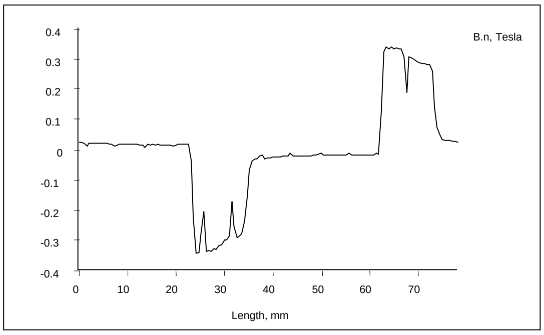
Stator pole domain		Flux x 10^{-4} [Vs]	Flux density [T]	Shading portion [p.u.]
Inside main winding		-1.2288	-0.4696	
Inside shading coil	top	-1.0154	-1.4760	
	bottom	-0.9730	-1.4140	0.809
Outside shading coil	top	-0.2146	-0.1315	
	bottom	-0.2517	-0.2536	

Table 3.4 Fluxes in stator pole

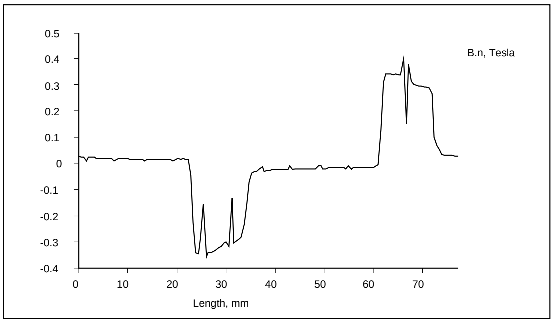
Spatial distribution of the flux density is plotted at the same manner as in the previous case, and the diagrams are presented in Figure 3.2 (a), (b) and (c), respectively. The magnetic field along the airgap line is in opposition with the main field.



(a) inner stator line



(b) middle air gap line



(c) outer rotor line

Fig. 3.2 Spatial distribution of the flux density when only the shading coil is energized

3.3 Both stator windings excited

The analysis of nonlinear magnetic phenomena in the shaded-pole motor is completed with the results obtained when two stator windings are energized. The results of calculation are presented in Table 3.5 and Table 3.6.

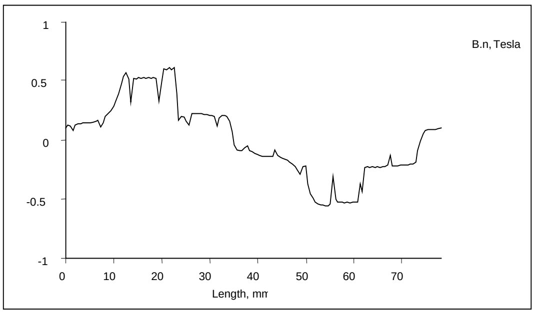
Integration contour	Flux per pole x 10^{-4} [Vs]	Flux density [T]	Flux linkage [Vs]
Along air gap	1.9912	0.2584	0.5601
Stator pole	2.5168	0.9832	0.8859

Table 3.5 Air-gap and stator pole flux

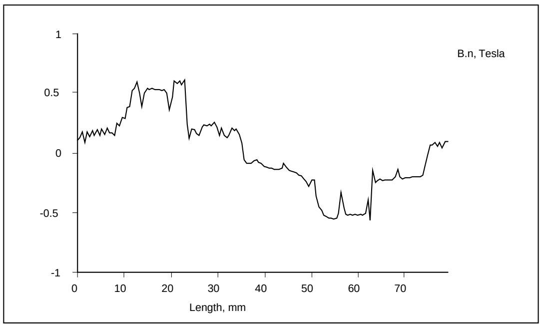
Stator pole domain		Flux x 10^{-4} [Vs]	Flux density [T]	Shading portion [p.u.]
Inside main winding		2.5344	0.9687	
Inside shading coil	top	0.6602	0.9596	
	bottom	0.7101	1.0320	0.270
Outside shading coil	top	1.8752	1.1490	
	bottom	1.8112	0.08824	

Table 3.6 Fluxes in stator pole

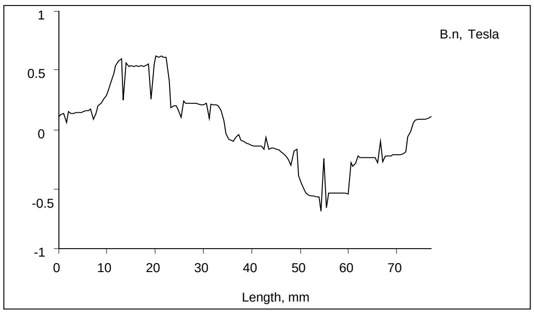
The characteristics of the spatial distribution of the magnetic flux density, along different lines, are presented in Figure 3.3 (a), (b) and (c).



(a) inner stator line



(b) middle air gap line



(c) outer rotor line

Fig. 3.3 Spatial distribution of the flux density when two stator windings are energized

4 Effect of skewing

Almost each electrical machine is performed with skewed slots, either on the stator, or on the rotor. Knowing the particular configuration of the stator core in the shaded-pole motors, the skewing is always applied to the rotor bars. Because of the relatively great part of the stator pole, surrounded with the shading coil, the skewing is always with considerable value. In the shaded-pole motor under consideration it is 17^0.

In order to include in the analysis the effect of the rotor skewing on the characteristics, it is obligate to apply the Finite element Method in the three dimensional domain. But, sometimes it takes a lot of calculations consuming a lot of time. So, it is recommended to apply the 2D modeling of the rotor bars skewing by discretization of the motor along its third dimension. The axial length of the magnetic core l_δ is treated as multi-sliced, cut into n discs by perpendicular planes to the shaft. Two adjacent disks are rotated by an angle α/n where α corresponds to the total angle of the skewing. In this particular case axial length is cut into 4 discs and each is rotated by corresponding angle. Actually, this approach can be considered as quasi three-dimensional modelling of the motor.

The calculations of the air-gap flux per a pole, for a few different excitation currents in the main stator winding and the correspondent currents in the shading coil are presented in Table 4.1. The motor is considered at no-load, i.e. the rotor bar currents are forced to be zero.

Main stator winding current [A]	Air-gap flux x10^{-4} [Vs]	
	without skewing	with skewing
0.08	1.0542	1.0562
0.12	1.3168	1.3186
0.16	1.4664	1.4681
0.202	1.5730	1.5767

Table 4.1 Effect of skewing on the air-gap flux

5 Conclusion

In the paper the non-linear magnetic field analysis, and a computation of electromagnetic characteristics of the single-phase shaded-pole motor is presented. For this purpose, as the most suitable, the Finite Element Method is applied. This contemporary method enables to “enter inside the machine” and to evaluate exactly magnetic quantities, such as air gap flux, flux linkage and flux density in any part of the machine. Application of FEM gives an opportunity to plot and “to view” flux distribution in radial cross-section of the motor, too. On the basis of the analysis of spatial distribution of the flux density in each part of the machine, one can “discover” the weak points in the magnetic core, as well. The electromag netic characteristics are analyzed at different currents in main stator winding and shading coil. At this stage, the rotor bar currents are not still included in the analysis. Because of the asymmetrical magnetic field along the air-gap of the shaded-pole motor, the analysis of its performance could continue only on the basis of the revolving field theory. This paper could be used for getting the initial results.

The next task is foreseen to be an investigation of the motor parameters, especially in dependence of both the shading portion of stator pole and the angle of rotor skewing; these quantities are always linked between. By inclusion of the rotor currents, at load conditions, the magnetic coenergy and static torque will be calculated and analyzed. Further research of the authors will go towards the motor optimization, by using Genetic Algorithms and adopting the torque or efficiency as target function. This work, could serve as a useful guide.

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