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# Using the Numerical Methods in the Study of Magnetic Field of the Alternative Current Machines

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## Abstract

*This paper analyzed the influence of the constructive elements of the windings of alternative current on the curve of repartition of the rotating magnetic field inside the air gap. At the alternative current machines, the magnetic field in the air gap has an fundamental harmonic which conditioned all the phenomena's and also the superior harmonics. These harmonics affect the quality of the energy supplied when the machine operated as a generator, respectively the characteristics of starting and operating for the regime of motor.*

**Key words:** *alternative current machines, magnetic field.*

## Introduction

In literature the study of the asynchronous machine is made with the assumption that the magnetic field is sinusoidal in air gap. In retaliate, the alternative windings are not sinusoidal on the polar step, the armatures have got slots and the magnetic circuit is non saturated. So, in the air gap there is a non sinusoidal magnetic field, with an important number of harmonics. Like in the literature, for the motor regime for example, these harmonics produced parasite torque, worsening the mechanical characteristics of the machine. If the machine is working like generator, those harmonics establish a no sinusoidal curve of the terminal voltage.

To find the level of the distortions of the magnetic field in the air gap, respectively to overhear the possibilities to decrease the important harmonics, it is imposing the usage of the numerical methods for thoroughgoing study.

Very important, in the establishing of the performances of the machine of alternative current (operating characteristics, overload capacity, mechanical characteristics, etc.), is the shape of the curve of spatial repartition on the polar step for the resulting magnetic field in air gap at the load operation.

In conclusion the magnetic field in the air gap can be known and also the behavior of the electric machine in different operating regimes, if there are establishing the turn ampere curves of the windings.

## Influence of the components of the coils on the magnetic field

Mostly, in a electric machine, at the producing of the magnetic field in air gap, takes part much more coils placed in slots. If in a point of the air gap, at a distance x from an arbitrary reference it is known the total ampere turn on a pair of poles $\theta(x)$, of the coils, corresponding to a closed curve $\Gamma$ overlap on a line of magnetic champ, the induction in this point is:

$$B_{\delta}(x) = \mu_0 \frac{\theta(x)}{2\delta^{//}(x)} \quad (1)$$

Where at the calculus of the equivalent air gap it taken account on the Carter coefficient and on the magnetic saturation factor of the machine.

In literature there are given analytical relations which express the time and space dependence of the phase ampere turn of the poly phased coils. At the poly phased machines with constant air gap, the repetition's curve of the magnetic field on the polar step has the following expression:

$$B(x,t) = \sum_{k=2mj+1}^{\infty} B_{\max k} \cos\left(\omega t - \frac{k\pi}{\tau} x\right) - \sum_{k=2mj-1}^{\infty} B_{\max k} \cos\left(\omega t + \frac{k\pi}{\tau} x\right) \quad (2)$$

Amplitude of the superior harmonics of the magnetic champ could be reducing by the factors of inclination, shortening and assessment which are depending by the constructive dates of the coil, in concordance with the relation:

$$\theta_k = \frac{2\sqrt{2}}{\pi} \frac{1}{k} m_1 N_1 k_{Bk} I_{1\mu} \quad (3)$$

$$k_{Bk} = \left( \frac{\sin \frac{c_1 \pi}{2\tau} k}{\frac{c_1 \pi}{2\tau} k} \right) \left( \frac{\sin \frac{q_1 \alpha_1}{2} k}{q_1 \sin \frac{\alpha_1}{2} k} \right) \cdot \left( \sin \frac{\pi}{2} \frac{y_1}{y_{1\tau}} k \right) \quad (4)$$

where: $m_1$ - phase number of the stator; $N_1$ - number of spire on a phase; $k_{Bk}$ - winding factor of the armature coiling for the k orders harmonic; $I_{1\mu}$ - magnetization current; $c_1$ - armature's slot inclination toward of generatrix; $\tau$ - polar step ; $q_1$ - number of slots on pole and phase at the armature; $\alpha_1$ - electric angle between two neighborhood slots of the armature; $y_1$, $y_{1\tau}$ - step of the armature coil, respective the diametrically step.

*Factors of the harmonically analyses,* are defined like in literature and allowed to establish the deforming level of the magnetic field. Those are: *- factor of top, factor of distortion and deforming factor.*

In conclusion, using an adequate soft we can established the constructive elements specifics for the three phased windings which, feeding with a symmetrical three phased system of voltages, are producing a rotating magnetic field with a repartition almost sinusoidal on the polar step.

## Calculus of the magnetic induction at the machines with notched armatures

There are some assumptions at the base of the previously calculus which usually, aren't carrying out. For example, it was assumed that the armature isn't notched, whereas today are built only machines with notched armature.

For the complete open notched, the magnetic field in air gap could be analytical finding with the corresponding representation, if the walls of the notches are parallels, if could be neglected the curvature of the polar piece surfaces and of the armature, and if the polar piece surfaces and the armature surfaces could be considering level surfaces. Calculus is very complicate, even is limiting only to the determination of the normally of the induction on the surface of the polar piece, which, in fact, gives a sufficient image on the behavior of the notched armature.

It is known that because of the presence of the notches on the armature, the induction create in the air gap by the armature field is modulated in amplitude. Amplitude of the modulated waves is in determinate relation with the induction magnetic of the air gap created by the armature field which, at its turn is invert proportional with the air gap width. Amplitude of the modulate waves, function of air gap width, is:

$$B_{10\max} = \frac{\mu_o}{2} U_{m\delta} \frac{\beta}{k_C \delta} \tag{5}$$

where $U_{m\delta}$-magnetically tension of the air gap on a pair of poles; $\mu_o$- vacuum permeability; $\beta = B_o / B_{\max}$ ; $B_{\max}$ -value of induction in air gap in tooth's ax; $k_C$- coefficient of Carter; $\delta$- real air gap's width. Between the amplitude of the fundamental harmonics and the amplitude of the modulated waves of the induction there is the relation:

$$B_{10\max} = k_B B_0 \tag{6}$$

where: $k_B$ factor dependent on the shape of the modulated waves of the induction in air gap.

Curve of magnetic induction is obtaining by the interpolation with linear and squared function on intervals. So, under the dental equivalent step the induction is constant equal with $B_{\max}$ , and in areas of slot is approximating by a parabola with the arms up. Calculus relation for the induction allowed determining the variable width of the air gap in rapport with the position of slots:

$$\delta(x) = \frac{\mu_0 U_{m\delta}}{2 B_\delta} \tag{7}$$

## Simulations and final results

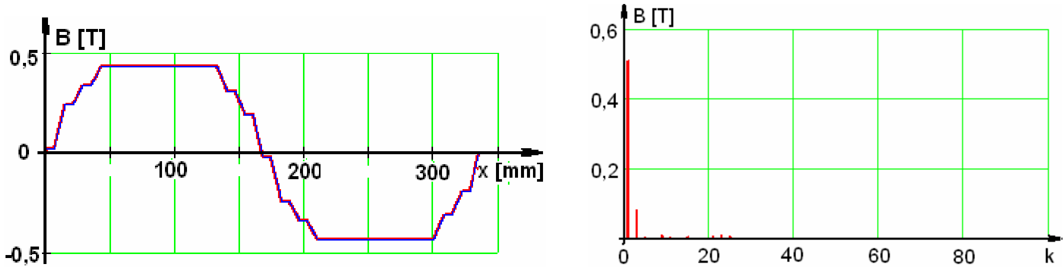
Program establishes the placement of the wires afferent with the phase windings in slots and in layers, reported with the constructive dates of the winding. Ampere turn in q axe – the origin of the reference system is zeros. After the establishing of the ampere turns curve it is plotting OX axe to delimitated equal surfaces. Repartition in steps could be decomposed in harmonics thus besides the magnetic field which is the fundamental harmonics (with sinusoidal repartition on the polar step) it is obtaining also the odds superior harmonics.

Using the methods of numerical calculation, on the shown theoretical aspects and those known in literature it was realized a calculation soft for the plotting of the magnetic field of the alternative current machines using the software of Mathchad.

This software and the realized program allowed a permanently conversation of the engineering with the computer, until the establishing of the final solution.

It was studied the curve of the magnetic field in the air gap of an asynchronous motor, feed by a three phased symmetrical source. Rated values of the motors and the parameters afferent with the armature coil are: $P_N = 60$ kW; $U_N = 380$ V, $n_1 = 1000$ rot/min, $I_N = 115{,}5$ A, $I_{10} = 34{,}7$ A, $N_{c1} =$ 72 slots, $q_1 = 4$, $y_{1s} = 10$ slots, p=3, $c_1 = 0$, $m_1 = 3$, $\delta_e = 2{,}12$ mm; $N_1 = 54$ spire.

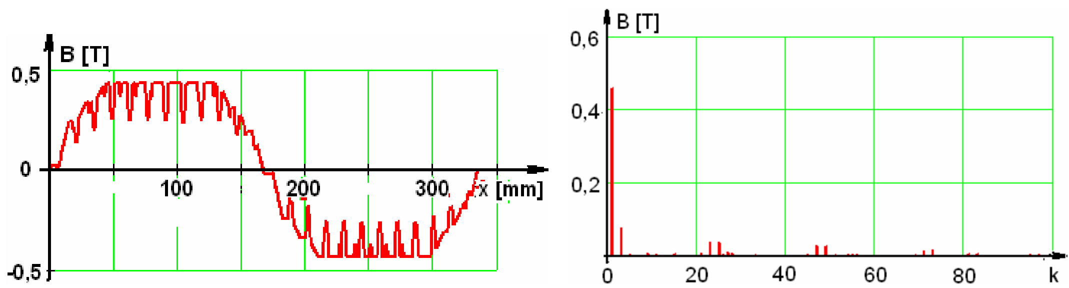
Ampere turn's curve was finding wising the graphical method, where is considering that in the areas of tooth the ampere turn is constant and in the areas of slot has a linear variation. Follow up is showing the optimal variant obtained with this soft for the analyzed motor, solution which is very closed with the initial imposed conditions ($k_v \approx 1{,}41, k_{dis} \le 5\%, k_{def} \le 5\%$).Follow up curves (fig. 1) shows, waves shape for the induction produced at a single phase feed, with its harmonically spectrum in the ideal case when the air gap is constant.




a) b)

**Fig. 1.** a) . Magnetic induction curve in air gap at mono phase supply, in the case of constant air gap; b) spectrum of harmonics.

At the real alternative machines, because of the presence of slots on the armatures, the air gap isn't constant and the curves are modified (fig. 2).




a) b)

**Fig. 2.** Magnetic induction curve in air gap at mono phase supply , in the case of slots in stator and rotor; b) spectrum of harmonics.

Factors of harmonically analyses of the induction (fig. 2), at mono phase supply of coil are:

$$B_1 = 0{,}457\ T \quad k_{vB} = 1{,}30 \qquad k_{f\,B} = 1{,}08 \quad k_{dis\,B} = 23{,}07\% \quad k_{def\,B} = 51{,}88\% \qquad (8)$$

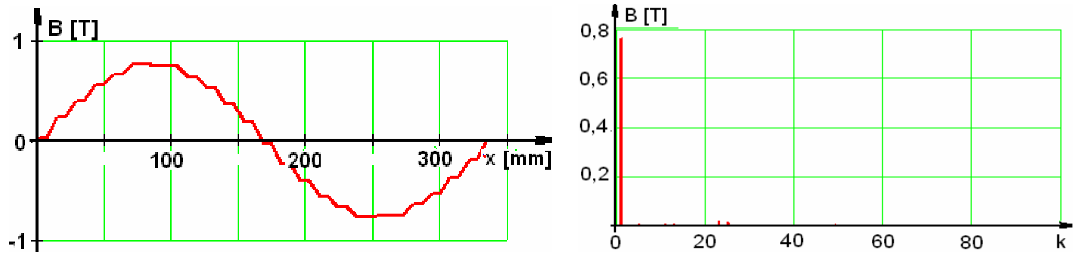
When the three phase stator windings are feeding simultaneous, for the same effective value of the phase current, the curve of the ampere turns is varying, and with these, the magnetic induction in air gap is varying.

A much true curve obtains to consider constant magnetic induction in the dent and the linear variation of the sectors of slot (fig.3). It could be observed that at three phased supply the third harmonics despairs and the weight of the superiors harmonics decrease.

Factors for the analysis of the harmonic of magnetic induction (fig. 3), for this case are:

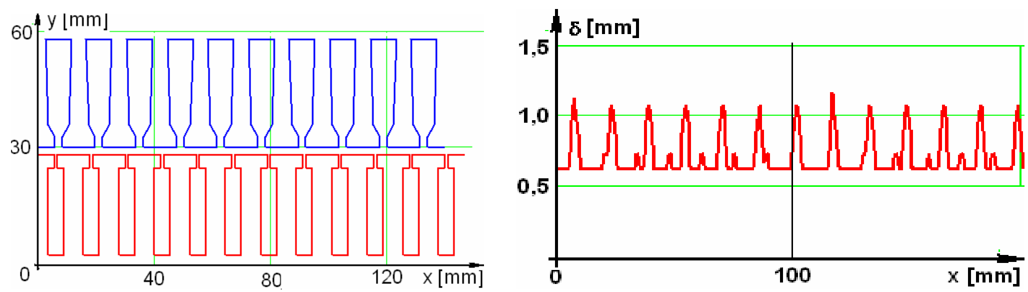
$$B_1 = 0{,}761\,T \quad k_{vB} = 1{,}42 \qquad k_{f\,B} = 1{,}108 \quad k_{dis\,B} = 3{,}81\% \quad k_{def\,B} = 7{,}56\% \qquad (9)$$

The machine analyzed is an asynchronous motor with slots on both armatures ($a_{c1} = 2{,}5$ mm, $a_{c2} = 1$ mm, $a_{c1,c2}$-slots isthmus). Curve of magnetic induction in air gap, when it considers the slots from the rotor and stator armature smooth, is showing in detail in fig.4a, and in 4.b we can see how is varying the length of the field line in air gap because of the relative position of the slots.




a) b)

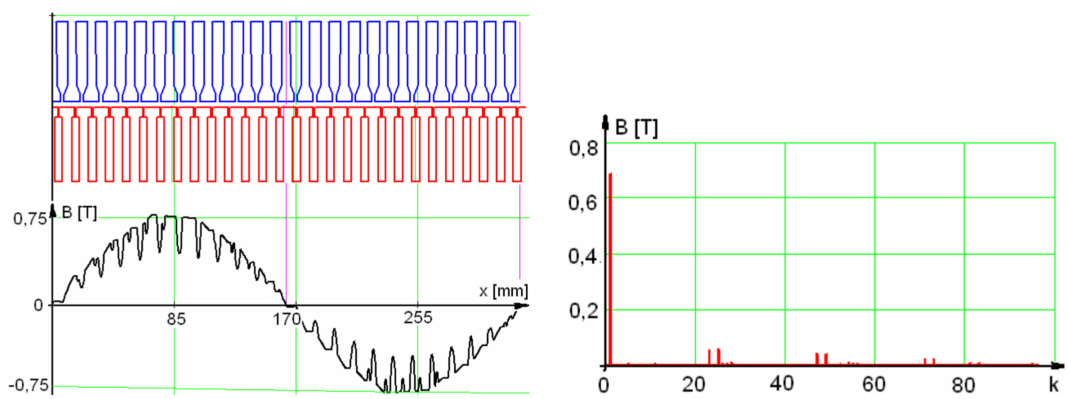
**Fig. 3.** a) Magnetic induction curve at constant air gap; b) spectrum of harmonics.




a) b)

**Fig. 4.** a) Detail on the positions of slots in rotor and armature at a moment of time; b) air gap for a real machine.

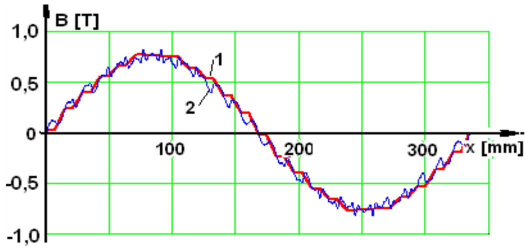
All of this are reverberate in an other curve of repartition of the magnetic induction on the polar step (fig. 5, a), with a bigger content of superior harmonics (fig. 5, b).



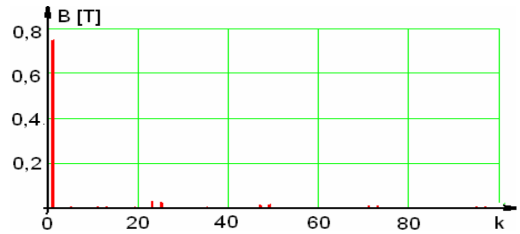

a) b)

**Fig. 5.** a) Section in a machine and the induction curve on a pair of poles in the presence of notches from armature and rotor; b) harmonics spectrum.

In fig. 6 are plotting the curves of induction for the machine with constant air gap, finding by graphical method (curve 1) and analytical method (curve 2). The analytical curve has much more harmonics because the algorithm considers the wire placed in the axe of notch, toward with the graphical curve which considers that the ampere turn rise linear in the areas of notch.




a)




b)

**Fig. 6.** a) Induction curves at the real machine: 1-graphical curve ; 2- analytical curve; b) harmonics spectrum for the analytical curve.

Factors for the analysis of the harmonic of magnetic induction (fig. 6, curve 1), are:

$$B_1 = 0{,}685\,T \quad k_{vB} = 1{,}603 \quad k_{f\,B} = 1{,}12 \quad k_{dis\,B} = 16{,}08\% \quad k_{def\,B} = 40{,}7\% \qquad (10)$$

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# Utilizarea metodelor numerice în studiul câmpurilor magnetice la maşinile de curent alternativ

## Rezumat

*In lucrare se analizează influenţa elementelor constructive specifice înfăşurărilor de curent alternativ, asupra curbei de repartiţie a câmpului magnetic învârtitor din întrefier. La maşinile de curent alternativ, câmpul magnetic din întrefier are o armonică fundamentală care condiţionează toate fenomenele şi armonici superioare. Aceste armonici afectează calitatea energiei electrice furnizate atunci când maşina funcţionează ca generator, respectiv caracteristicile de pornire şi funcţionare pentru regimul de motor.*