ASPECTS REGARDING THE TENSIONS APPEARANCE IN ELECTRIC MACHINES SHAFT

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Abstract*: The paper deals with the factors that give birth to tensions into the electrical machinery shaft. It will also highlight how each of these factors influences the induced voltage. For conducting the study we used an electromagnetic field calculation program based on the finite element method (FEM).*

1. INTRODUCTION

With an experience of over 40 years, the finite element method is one of the most used methods in the study of electromagnetic fields, but also in other branches of engineering, is the mathematical underpinning of many programs dedicated to numerical calculations of vector fields [1]. The method is easily applicable to complex domains in form, both homogeneous and inhomogeneous, with a relatively simple mathematical apparatus, advantages which have made a world in comparison with the other numerical methods (finite difference method, boundary element method) [1].

1.1 The electromagnetic field equations

The equation that must be resolved by finite element results from laws of electromagnetic field method and it is:

$$\nabla\times\left(\frac{1}{\mu(B)}\nabla\times\overline{A}\right)=\overline{J} \qquad (1)$$

By condition $\nabla\overline{A}=0$ equation (1) becomes

$$\Delta\overline{A} = -\mu(B)\overline{J} \tag{2}$$

The magnetic vector potential $\overline{A}$ satisfies in conductor an equation Poisson type and outside these, (when $\overline{J} = 0$), an equation Laplace type. Electric field intensity can be expressed in terms of potential magnetic vector $\overline{A}$ and by the electric scalar V, thus

$$\overline{E} = -\nabla V - \frac{\partial \overline{A}}{\partial t} \tag{3}$$

$$\nabla \times (\frac{1}{\mu(B)} \nabla \times \overline{A}) = -\sigma\nabla V - \sigma \frac{\partial \overline{A}}{\partial t} \tag{4}$$

In the relation (4), the total electric current density is the sum of two components: the first component ($-\sigma\nabla V$) it represents the density due to external sources, that in problems of electromagnetic current discharge in the massive conductive is in itself a unknown, and second ($-\sigma \frac{\partial \overline{A}}{\partial t}$) is the density of the induced currents.

If in the domain of calculation there are conducting bodies moving with speed, $\overline{v}$, the general expression of the conduction current density is,

$$\overline{J} = -\sigma\nabla V - \sigma \frac{\partial \overline{A}}{\partial t} + \sigma\overline{v} \times (\nabla \times \overline{A}) \tag{5}$$

1.2 The boundary conditions

Depending on the border type, boundary conditions can be divided into:

- boundary conditions of calculation domain, which in turn can be of Dirichlet, the Neumann and Robin type;
- Terms of passage, the surfaces of discontinuity for parameters of the analyzed material.

Considering two different environments 1 and 2, separated from the surface S_{12} of the unit vector, the conditions are:

$$\overline{n} \times \left(\overline{H_1} - \overline{H_2}\right)\Big|_{S_{12}} = \overline{J}_S, \tag{6}$$

in the case of a current blade J_s, on the surface $S_{12,}$ If there is no current, then

$$\overline{n} \times \left(\overline{H_1} - \overline{H_2}\right)\Big|_{S_{12}} = 0 \tag{7}$$

$$\overline{n} \cdot \left(\overline{B_1} - \overline{B_2}\right)\Big| S_{12} = 0. \tag{8}$$

In what follows will be specified some of the most important aspects that influence of the results of an analysis by finite element method.

Boundary conditions must be imposed because any analysis assumes a finite domain when in fact, it is infinite. Moving from the real (infinite) to the limited (computational domain boundaries required) a truncation must be made, that the results obtained are close to the real ones. This requires a good knowledge of the subjects which allows a priori estimation of field lines to form borders imposed [1-6].

Another important aspect is geometrically finite element mesh domain and imposing degree polynomial interpolation, because they can describe as accurately analyzed in the field.

As techniques currently used we can mention automatically refining the mesh and increasing polynomial interpolation. Considering the magnetic nonlinearity implies that the value is dependent permeability field values.

The simplest method is to consider the nonlinearity assumed baseline permeability and solve the corresponding linear equations, and then based on the values obtained permeability values are recalculated from the magnetization curves. The cycles are repeated until a difference between two successive values smaller than a prescribed value.

Reducing the computation time required nonlinear harmonic analysis - while important in comparison with a linear harmonic analysis, when all field sizes vary harmonically in time and can therefore be represented in complex derivative discretization is not necessary magnetic vector potential (induced currents corresponding period) - equivalence can be achieved by nonlinear harmonic regime with one linear harmonic. Defining the equivalent magnetization curve $B_e(H_e)$ based on known nonlinear static magnetization curve $B(H)$ is requiring magnetic energy conservation.

2. FEM SIMULATIONS

2.1 The numerical model of the studied machine

Induced electromotive tension can be continuous or alternative depending on the type electric machine. If c.c.machines is specifically induce a continuous voltage in the shaft.As it stands and where synchronous machine. Alternative voltages can occur in all types of electrical machines. The main cause of this is unbalance magnetic circuit which closes magnetic flow useful. The most important values of the voltages are encountered in the case of alternating current machines.

To determine the electromotive tension induced in the shaft of electric machines using finite element method implies the creation of a numerical model corresponding real machine model [2], [3], [4]. Since the voltage induced in the shaft of a rotating machinery is mainly due to the magnetic field in the core of the machine, making a two-dimensional numerical analysis is conservative. Therefore the numerical model necessary will be bidimensional. Numerical analysis type must match the case when electric and magnetic sizes are variable in time, relative to the shaft, which is the situation that leads to induced electromotive tension in it. For this study we considered a three-phase asynchronous motor with six slots per pole and phase two pole pairs and rotor, the corresponding model is shown in *Figure 1.*

The engine power is considerate 500 kW, the inside diameter of the stator is 470 mm, the outside is 740 mm, length 353 mm, and the gap of 1.5 mm. Stator winding up has shortened to 5/6 out of diametrically step, coils corresponding to a phase of the machine can be seen in Figure 2.

As recommended in specialized literature [1] in the case of rotating machines boundary conditions used are those of "tangential flow" of calculation border area is delimited by external armature magnetic of the circuit (stator in the case of normal construction or rotor for cars build in reverse) (*Fig. 3*).

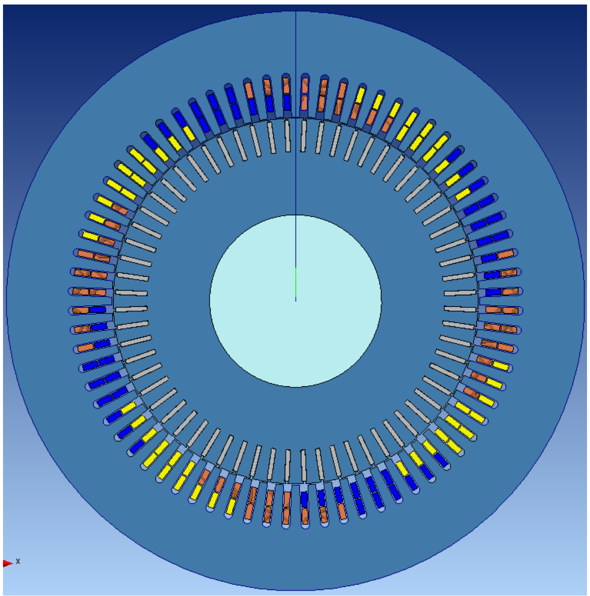


Fig.1. Numeric model

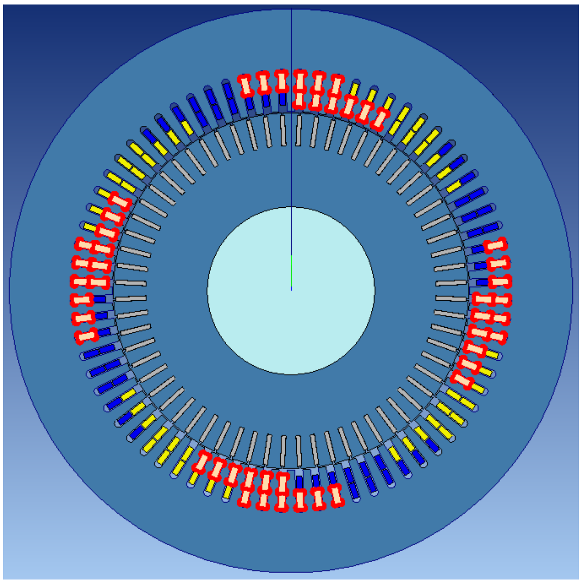


Fig.2. Coils of phase

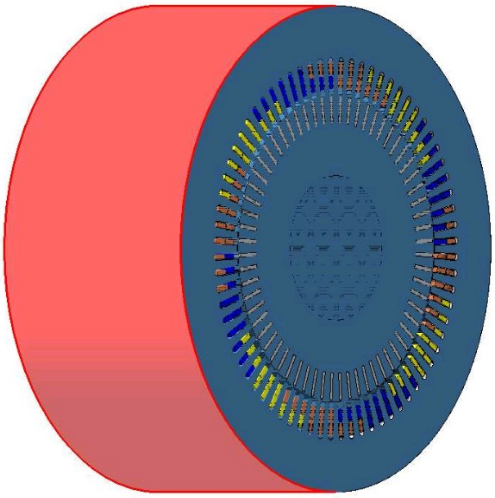


Fig.3. The boundary conditions

` Regarding the conditions under which the analyzes were performed, stated the following: the degree of interpolation polynomial: 2, stator and rotor material non-linear, the maximum number of iterations Newton: 20, Newton tolerance of 1% and maximum tolerance is considerate potential values obtained by the conjugate gradient method, 0.01%. To refine the mesh refining technique to use adaptive setting a 15% share of refining.

As for the shaft material and its position in relation to the air gap, these variables were determined according to the induced electromotive. Changing the position of the shaft in relation is specific to machines that the air gap plain bearings and the bearings when they appear in the game.

2.2 Influence of unbalance magnetic circuit for the induced voltage

Because the main cause of tensions alternative from the shaft is from the unbalance magnetic circuit, they were shaped by interruption of rotor bars cage circuit. The number of interrupted bars changed and the position of the broken bars in the rotor circuit. Simulating a machine rotor winding at which a rotational phase is interrupted can also be performed using the numerical model of the motor in short, but the number of interrupted bars is 1/3 of the total number of bars, the position is properly selected according to the number of poles of the machine. Interruption of the two phases was also simulated by stopping the 2/3 of the rotor bars.

The following will present the results of numerical simulations for different values of the considered variables.

Figure 4 it shows the comparison, the change in electromotive tension induced in the machine shaft according to the number of bars broken, in case if the current in the stator windings is $0.2 \cdot I_n$ respectively $2 \cdot I_n$. It can be seen that the effect of unbalance (interrupted bars) is particularly important as the stator current is higher. A total of six broken rotor bars for a quarter machine, so 24 for the entire machine in the case of rotor in short, equivalent to a phase interruption for a winding rotor. Stator current values are considered small for startup mode, can only be achieved in practice when using a tool that allows controlling the current start.

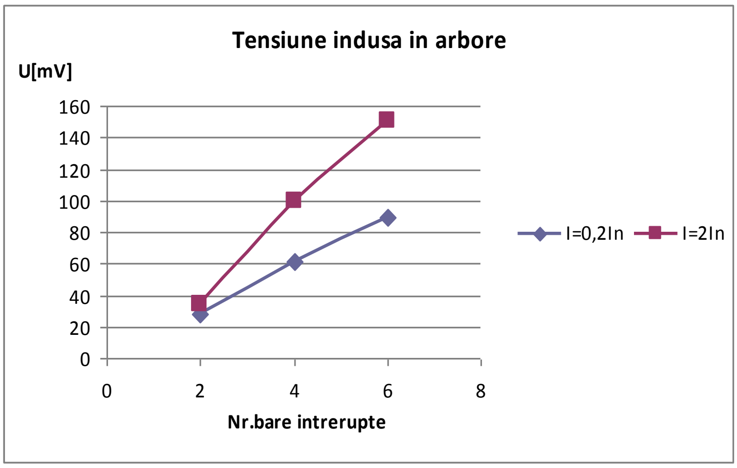


Fig. 4. The induced voltage according to the number of interrupted bars

Figure 5 represents the variation induced voltage based on the number of bars interrupted when the stator current has the value, $6I_n$, value that is common to start of asynchronous motors with the rotor in short-circuit.

The relative step of stator winding has no significant effect on induced voltage in the shaft, *Fig.6*. Voltage variation with relative step is insignificant.

The way in which the induced voltage changes according to magnetic permeability of the material it is made of the shaft shown in *Figure 7*. The case study corresponds to the initial current in value of $6I_n$, the position of the shaft is offset from the center of symmetry of the machine, with 1 mm on each of the two axes, two phases of the rotor is interrupted, *Figure 7a.*

In the above conditions, but with a single- rotor phase voltage variation interrupted relative magnetic permeability is shown in *Fig. 7b*.

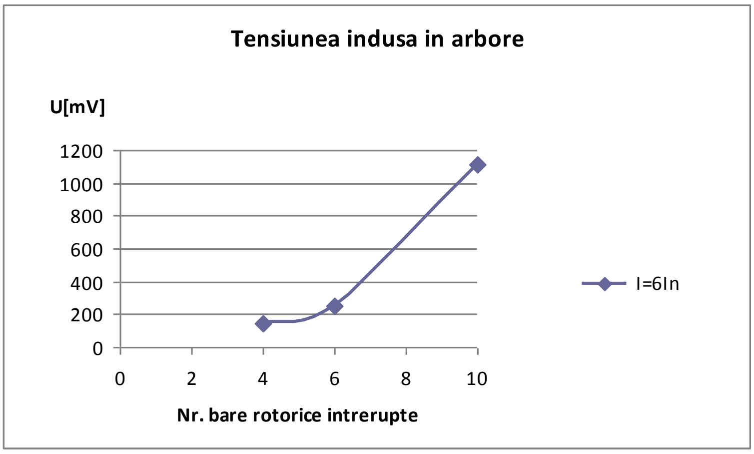


Fig. 5. Voltage induced on $6I_n$

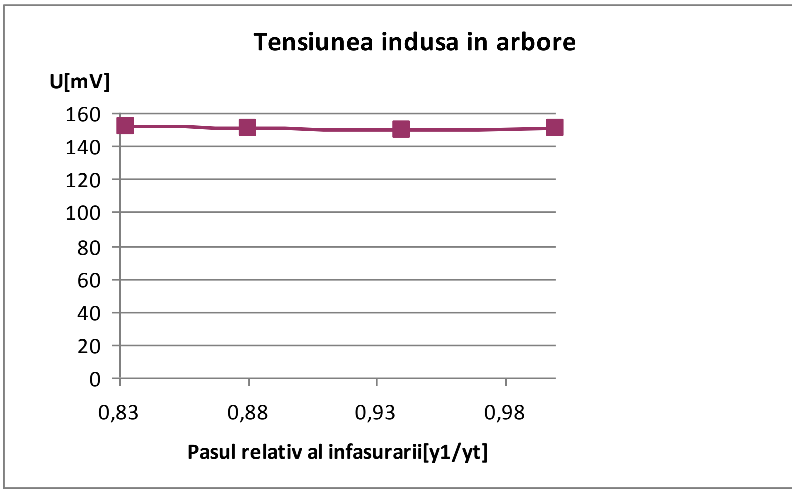
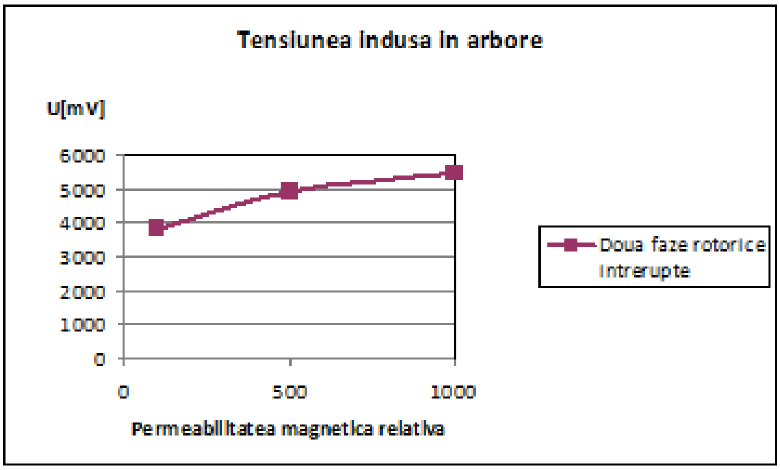
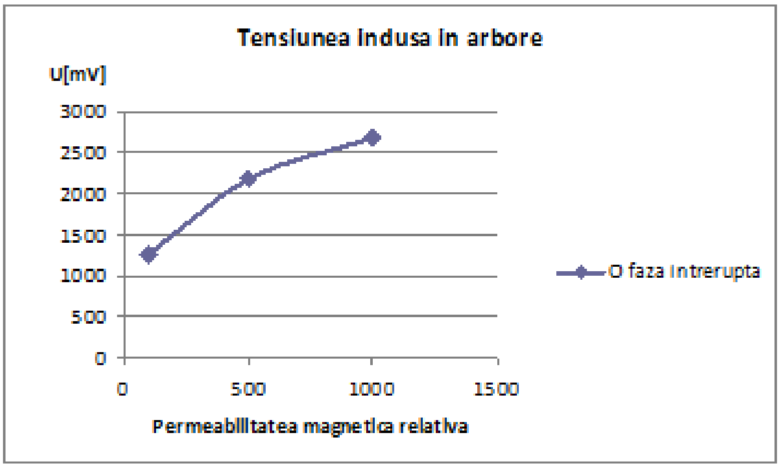


Fig. 6. Voltage depending on the relatively Step

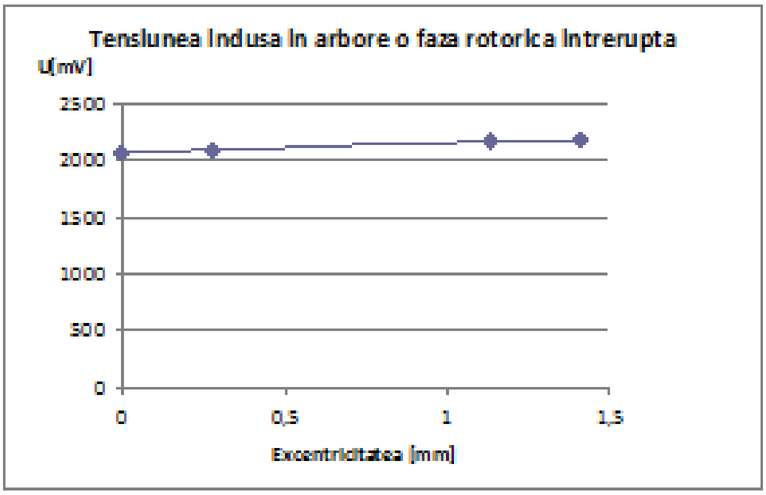


a) two interrupted phases

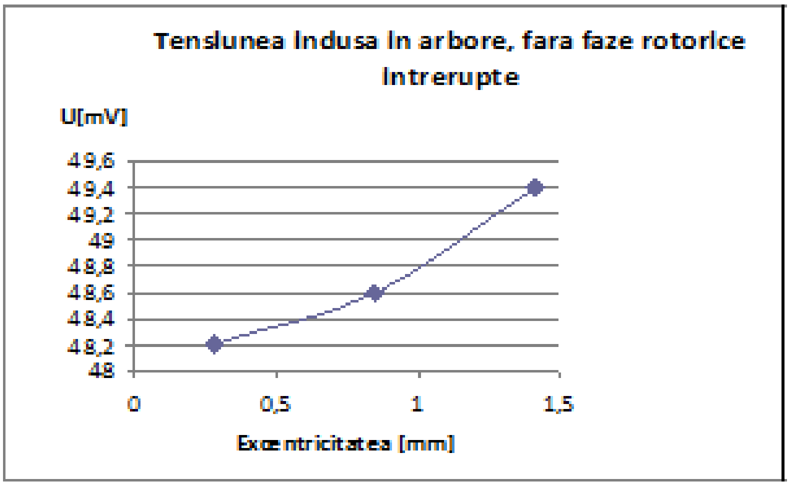


b) single interrupted phase

Fig. 7 The voltage depending on the permeability



a) single interrupted phase



b) without interrupted phase

Fig. 8. The voltage depending on the eccentricity

Another parameter that can influence the value of the induced electromotive shaft is its displacement from the center of symmetry of the machine, i.e. eccentricity.

In *Fig. 8* was presented the dependency, if the current startup is $6I_n$, relative magnetic permeability of the material shaft is 500, and one rotor phase is suspended (a) and all phases are continuous (b).

As could be observed from the examples shown, the voltage induced in the shaft is influenced by the starting current. How it changes depending on the current stator in case we have 4 broken rotor bars and the machine shaft is offset from the center of symmetry with one millimeter on each axis is shown in *Fig. 9*

Form the induced voltage when starting the machine shaft, spindle being supported on bushings (eccentricity of 0.15 mm) obtained by simulations based on FEM is presented in *Figure 10*, and the resulting current through the camps equated with a capacitor is shown in

Fig.11. It can be observed the presence of harmonics of order 3 in the induced voltage. This was expected since the simulation was performed at a voltage of 220 V winding stator, the magnetic circuit of the machine being so saturated.

As will be seen in the case of measurements with increasing saturation, harmonic order 3 becomes increasingly important. The effect is that for voltages higher harmonics data bearing capacitive reactance decreases with increasing harmonic order, which will cause currents higher values than would be present for fundamental harmonic only.

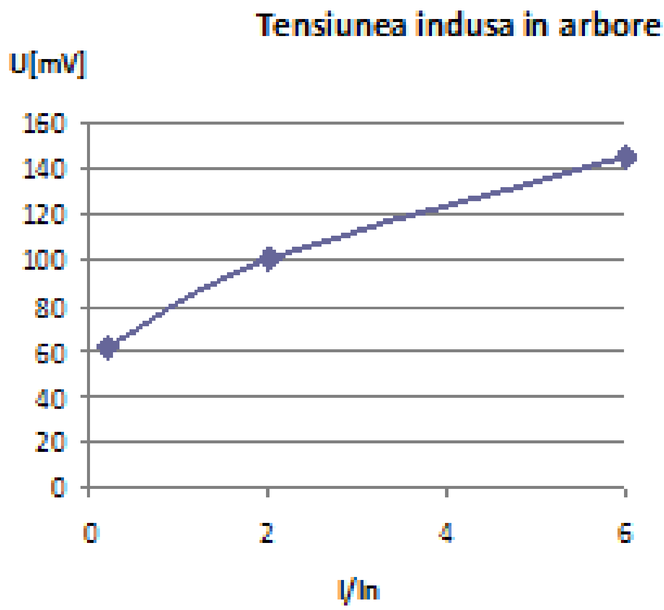


Fig. 9. The voltage induced by the starting current

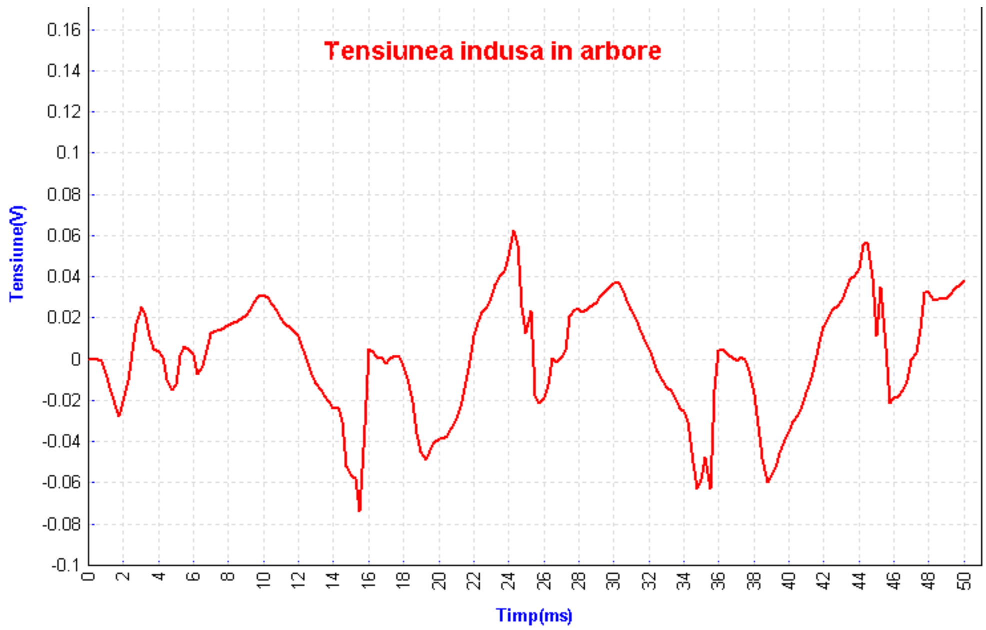


Fig. 10. The induced voltage form in the shaft

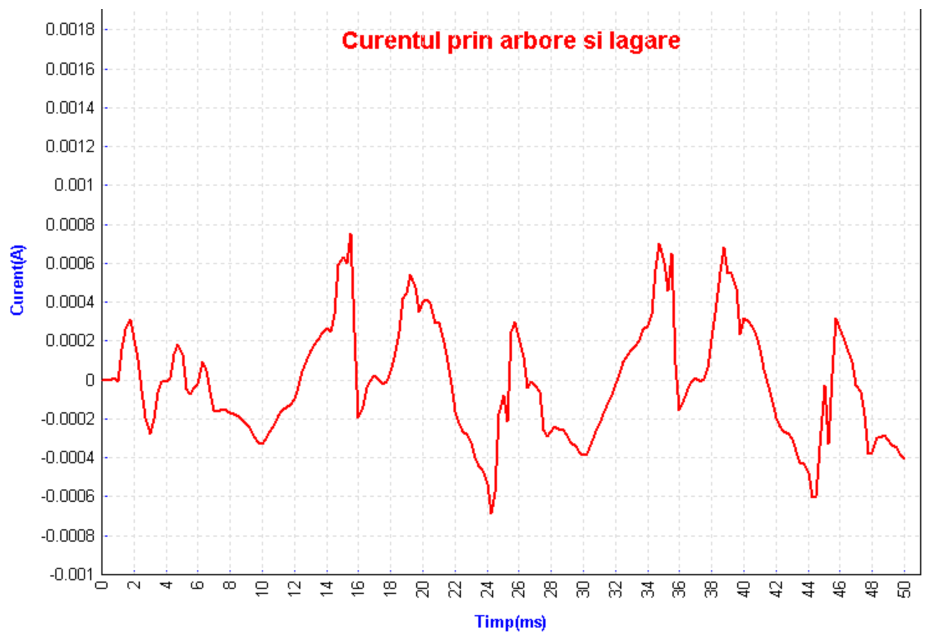


Fig. 11. Shape of current through the camp

3. CONCLUSIONS

From the presented above we can draw the following conclusions:

- machine shaft voltage induced depends insignificantly by the stator step up winding ;
- just moving along with the rotor shaft, from the center of symmetry of the machine, does not cause dangerous ternsions to the shaft. (they are in order of mV-olts) :

This is due to the reaction field current of the rotor, which shields the shaft, the coil field is no longer enter it, so it does not cause the occurrence of a significant electric voltage shaft;

- While starting current influences the induced voltage in the tree, only its value even with displacement from the center of symmetry, it can cause a significant tensions;
- only relative magnetic permeability of the shaft, in the absence of rotor winding defects, does not raise significant tensions therein.

As a general conclusion it can be stated that the main cause of tensions on significant. values in the electric machines shaft is unbalance of magnetic fields rotor. This unbalance may be caused either by different material properties of the magnetic portions of the rotor magnetic circuit, and in particular to some defect occurs in the circuit of rotor windings such as the discontinuation of the cage bars of one of the phases and the rotor winding . In such situations, it can be observed (*Fig. 5, 7 and 8*) that the dangerous tensions appear in the shaft, this time tensions are more influenced by other parameters considered in the present study.

Thus, for the case considered, where one phase of the armature winding stopped, the relative magnetic permeability of the rotor shaft 100, the induced voltage is 1.2 V, reaching a relative permeability of 1000, at value of 2, 65V.

Interruption of the two phases (or of a corresponding number of bars) may cause the relative permeability of the shaft based on the voltage up at 5.5V.

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