Excerpt from the Proceedings of the COMSOL Conference 2010 Paris

MODELLING OF SELECTED ELECTROMECHANICAL PHENOMENA IN THE DC MACHINE

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Abstract - The paper presents the results of the experiment consisting in determination of the influence of the magnetic field on deformations of the stator and the rotor of the DC motor. The numerical model of the motor for the frameless DC machine of the G series has been elaborated. Calculations were realized for the 2D model. Calculations were made for the steady state and for the selected position of the rotor. The machine was supplied from both the DC power source (without the variable component of the current) and the unregulated full-diodes Graetz bridge. The results of numerical calculations of the stator deformations have been compared with the results of measurements.

I. INTRODUCTION

The electrical machines produced today, in addition to requirements concerning their functional properties, must meet very high economic and ecological requirements. This concerns among other things the following:

- Manufacturing expenses (e.g. by the minimization of cost used for the production of materials - absence of the frame),
- Operating costs (e.g. by an appropriately high efficiency and suitably long interoverhaul periods),
- Minimization of the negative environmental impact (electromagnetic and electromechanical compatibility).

The above presented criteria are often contradictory. For example, a frameless machine will be a technologically simpler structure, having however a stronger impact on the environment than a machine with the frame. The modern designer must however meet all expectations.

This tendency concerns both induction machines and direct current machines. Research on behavior of induction machines is advanced. In case of direct current machines, mechanical and especially vibratory-acoustic phenomena are described rather modestly in the literature. In a frameless machine, the magnetic stator circuit constitutes its „casing". It causes also changes of mechanical-vibratory parameters of the machine. The lack of the casing causes that all phenomena occurring in the stator can directly affect the nearest environment of the machine (the working environment). Observations show that so called silent-running machines require specific constructional solutions.

The work presented here is a continuation of actions aiming the determination, what is the influence of electromagnetic forces coming into being in the direct current machine in stationary states, on the machine itself, and more exactly on its body **[1, 4].**

In stationary states, there are electromagnetic forces directed tangentially and radially to the rotor, as well as bending and torque moments working in a DC machine. All above-mentioned influences produce mechanical stresses in both the rotor and stator.

The mechanical stresses of the rotor are most often ignored in studies. The stresses coming into being in the stator are observable by the user. Vibrations and noise emitted to the environment as well as deformations of machine structure give evidence of their occurrence.

II. DESCRIPTION OF THE RESEARCH SUBJECT

Simulatory investigations of the numerical model and measurements were realized for a G series DC machine of a mechanical size 13, with a power of 3 kW at a speed of 2090 rpm, a rated voltage of 160 V, with a separate excitation, intended for continuous operation and supplied from converter systems. This is a modern, bipolar machine with a completely sheeted stator (Fig. 1).

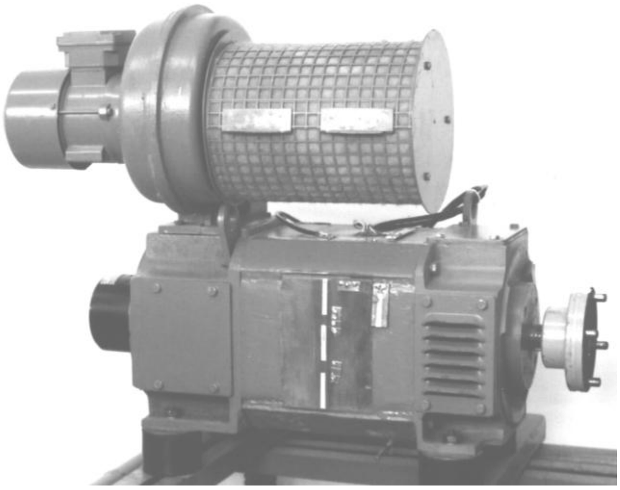


Fig.1. View of tested DC motor

The packet of laminated stator (sheet metals) is connected with remaining structure components by means of screws and dorsally welded on flat bars. The machine stator is represented in Fig. 2.

The considered machine does not possess any frame and therefore all phenomena occurring in its structure affect directly the environment. This effect concerns mechanical stresses, shape deformations, noise emission and vibrations as well. The purpose was to elaborate a numerical model that would make possible to determine with specified accuracy quantitative and qualitative variations of values of stresses arising in the machine and thus the range and size of shape deformations. A coupled model of electromagnetic and mechanical phenomena was considered.

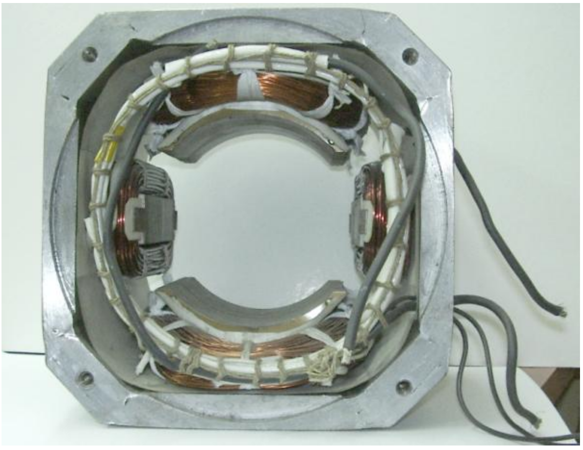


Fig.2. The model stator with non-impregnated windings

III. NUMERICAL MODEL OF THE OBJECT

The numerical model of the machine was elaborated in COMSOL environment. A two-dimensional (2D) model was considered. A nod-net has approx. 50 000 nodes **[2, 7].**

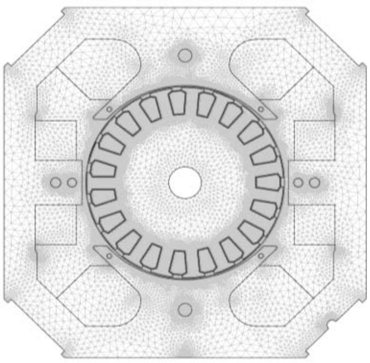


Fig. 3 View of nod-net DC machine model

The electromagnetic field described by the equation [3, 4, 7]**:**

$$\nabla \times (\mu \nabla \times A_z) = J_z^e \qquad (1)$$

where: only A_z is non-zero component of magnetic vector potential (all currents being perpendicular to the modelling plane); μ is the permeability of the medium; J_z^e is the externally applied current.

The normal strain components are related to the deformations as follows **[2, 6, 7]:**

$$\varepsilon_x = \frac{\partial u}{\partial x}; \quad \varepsilon_y = \frac{\partial v}{\partial y} \qquad (2)$$

Where: u-displacement in x direction, v- displacement in y direction, ε_x – engineering strain depending on small deformation in direction x, ε_y – engineering strain depending on small deformation in direction y.

The shapes of sheet metals of both stator and rotor were exactly mapped in the model. Dimensions of windings were determined on the basis of the documentation and direct measurements of realized machine **[5, 8].** Exemplarily presented results concern calculations done for rated values of particular currents. The nonlinearity of magnetization characteristics of the magnetic stator and rotor circuit was taken into account in calculations.

The stress calculations require declaration of minimal modulus of elasticity. Since the stator is packaged, the value of this parameter was determined experimentally. A testing machine was used for it **[4].**

IV. RESULTS OF MEASUREMENTS

The tests by using the tensometric method were mainly conducted with the machine staying in the rest condition (Fig. 4).. The excitation winding was powered with the current values changed from zero to 1,5 I_{fn}. The machine winding was powered from both the direct current network and rectifier systems (unregulated full-diodes Graetz bridge).

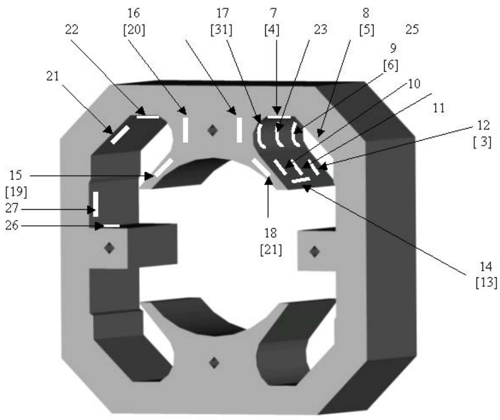


Fig. 4. Distribution of strain gauges on the surface of the stator iron

The realized tests showed that the forces coming from the field of the main poles have the critical significance in the examined structure. In the moment of switching on the excitation winding the whole stator is subjected to the action of forces, which cause considerable mechanical stresses.

Registered stress courses (Fig.5) allow determining the approximative shape, which is taken on by the stator of studied machine under the influence of the deformation arising when the machine is powered with the rated current. The field produced by the main poles, causes particularly large deformations (Fig. 5.) [5].

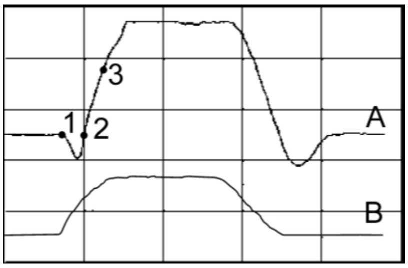


Fig. 5. Signal from the strain gauges located on the outer surface of the stator at the edge of the main pole; point 1 represents the moment of power supply, point 2 – the moment of stress decay, point 3 — the moment when rated current is reached

This allows to "calibrate" the calculation results, i.e. to compare the results of calculations with those of a measuring-experiment. Furthermore, the knowledge of real coefficient values makes possible to determine stresses and deformations appearing in places that are inaccessible for measurement, e.g. the deformations of the rotor or of its tooth.

The experiment was carried out with a machine intended for the work both in the first regulation zone (constant electromagnetic torque) and in the second one (constant mechanical power) as well. This requires a wide regulation range of excitation current regulation.

The experiment confirmed the character of stator shape variations caused by electromagnetic effects (Fig.6).

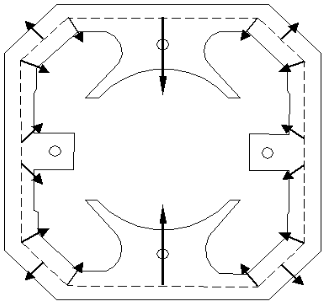


Fig.6. Distribution of forces in the yoke, produced by the electromagnetic forces of the main field, acting on the stator

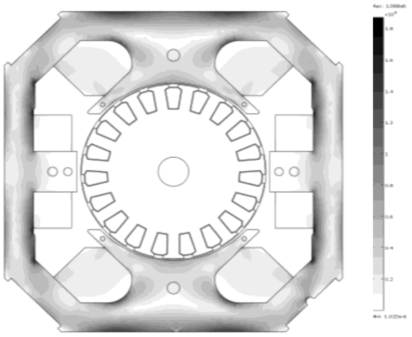
IV. RESULTS OF CALCULATION

Calculations of distribution of the electromagnetic field caused by individual windings are represented in successive figures. The calculations show the local saturation of the magnetic circuit.

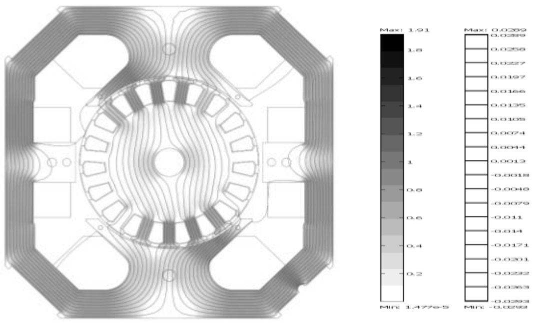
Calculations of mechanical stresses in individual fragments of the stator do not exceed the values recognized as admissible by specialists. Adopted computational algorithm requires that one of structure points be rigidly fixed in the default basis. It was made an assumption that this would be the point at the centre of the stator base. Such assumption results in stress appearing in that point.

On the basis of stress distribution, the stator shape deformations (dislocations of its individual fragments) were also determined.

The Figures 6 & 7 show the calculation results.

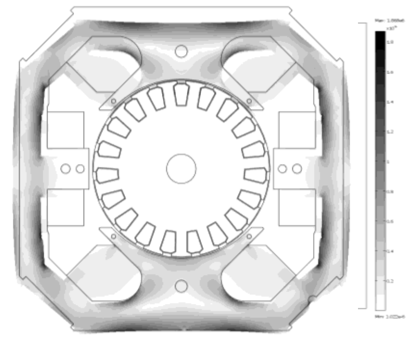


a)



b)

Fig. 6.a) Magnetic flux density distribution (current I_f – nominal value, I_a -zero; I_{com} –zero; Bmax=1,93T)
b) Distribution of stresses in stator (conditions the same as in Fig. 3.a);stream line represents magnetic field



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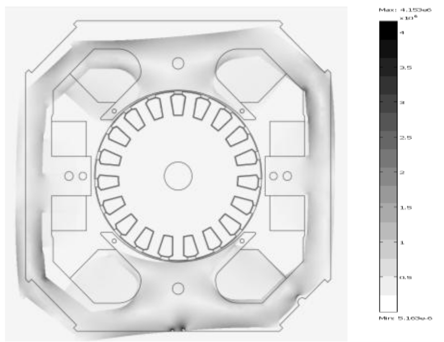

b)

Fig.7.a) Dislocation of stator elements (conditions the same as in Fig 3.); δmax = 1,28e-5 m; b) Distribution of stresses in stator for nominal value of all currents, maximum value of dislocation - δmax = **2,8e-6 m** (the scale of figure 20000:1)

Contour presented shape of the stator before deformation.

Powering the machine from a full diode bridge has not caused any essential changes in the deformation patterns though the variable component of stresses is higher – see Fig.8.

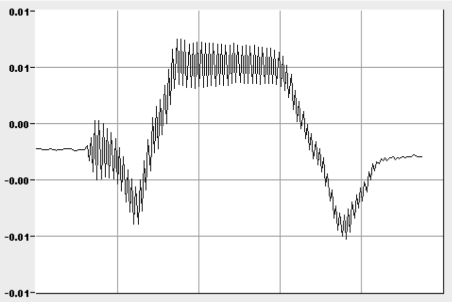

Fig.8. Stresses within the main pole caused by the current of strong variable component

The variable component of excitation current generate the vibrations of surface of stator with frequency 100 Hz.

Fig. 9. present results of calculation of these stator stresses.

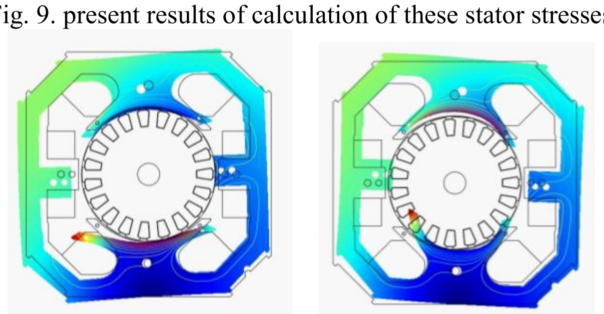

Fig.9. Influence of variable component of excitation current on stator deformation

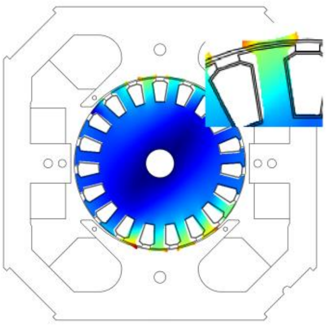

Fig.10. Deformations of rotor

V. FINAL REMARKS

The verification of calculations by means of measurements has confirmed a high accuracy of the numerical model. To assure the high conformity of calculations with measurement results, the knowledge of many material parameters characterizing the structure is necessary. Making material and geometric parametric data assures the possibility of virtual prototype variant modelling. The use of presented model of coupled phenomena could substantially improve the quality of produced machines.

The researches revealed that the excitation current value influences the stator deformations in a decisive way. A strong de-excitation ($I_f < 0,7\ I_{fr}$) of the machine causes a change of the character of the stator deformation first of all, and a minor increase of its displacement only (Fig. 9).

The elaborated numerical model makes possible to conclude about the stresses arising in rotor teeth. This is particularly important for the machines with small tooth heads and for high-speed machines.

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