Field-circuit modeling of the 12-pole magnetic bearing characteristics

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***Abstract*— Has been presented a computer method for simulation of active the magnetic bearing (AMB) characteristics. We have used field-circuit model which contains the magnetic field analysis, and is founded on the Lagrange'a technique including the equations for electrical and mechanical quantities. The field integral parameters for unconventional 12-poles bearing have been computed with using 3D FEM. Some characteristics of the radial AMB have been calculated and compared with the measured ones, and good agreement has been obtained.**

***Index Terms*—active magnetic bearing, field-circuit method, 3D FEM, measurements of stiffness performances**

I. Introduction

The bearing technology is a crucial problem in the hi-speed devices and drives, like compressors, centrifuges, precise machine tools, etc. Thus, the typical bearings are more and more replaced by magnetic ones, to provide the contactless suspension of the rotor.

II. Description of the 12 poles AMB

The 12-poles active magnetic bearing (AMB) is a new construction which enables to create 4 stator kinds because of different coil configurations, and has many advantages. AMB with nonsymmetrical stator excitation was presented in the previous paper of the authors, [1]. In this work the symmetrical coil configuration is considered (Fig 1a).

a) b)

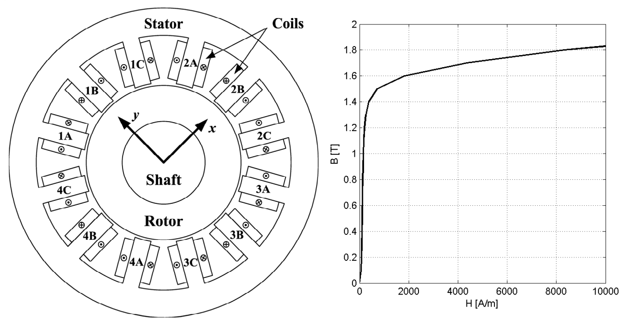

Fig. 1a. Coil configuration in 12-pole active magnetic bearing
Fig 1b. Magnetization curve for the stator and rotor lamination

Typical AMB stator poles are created from the horseshoe shape electromagnets, mainly [2, 3]. The presented new construction of the stator is built from the E-type electromagnets with 3 coils (denoted A, B, C). Therefore, this construction permits to create 4 systems in pole arrangements, which generates the magnetic force acting on the shaft.

Fig 1a shows configuration of the coils for symmetrical 12-poles AMB. The main windings (numbered from 1 to 4) of the stator are easy to assembly. Each one has N_1=38 turns. In each one excitation current I is flowing. The total current in the winding consist of the bias component I_b and control current i_c

$$i_1 = I_b + i_{cy}, \quad i_3 = I_b - i_{cy} \tag{1a}$$

$$i_2 = I_b + i_{cx}, \quad i_4 = I_b - i_{cx} \tag{1b}$$

Both, the bias and control windings are located separately, and generate the fluxes crossing three stator poles. The bias flux distribution in the AMB12 is presented in Fig. 2.

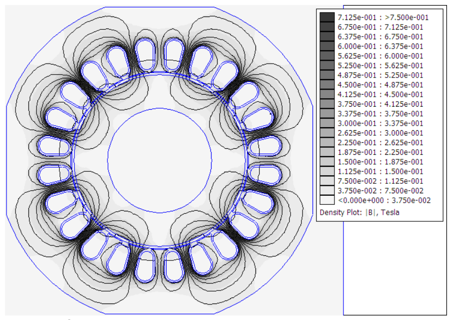

Fig. 2. Magnetic flux distribution under bias excitation I_b=5A in AMB12

III. Mathematic model of AMB

The model for AMB dynamics characteristics is founded on the Lagrange'a technique, and is given as the set of the ordinary differential equations:

$$u_1 = R_1 i_1 + L_{d1}\frac{di_1}{dt} - k_{iy}\frac{dy}{dt} \tag{2a}$$

$$u_2 = R_2 i_2 + L_{d2}\frac{di_2}{dt} - k_{ix}\frac{dx}{dt} \tag{2b}$$

$$u_3 = R_3 i_3 + L_{d3}\frac{di_3}{dt} + k_{iy}\frac{dy}{dt} \tag{2c}$$

$$u_4 = R_4 i_4 + L_{d4}\frac{di_4}{dt} + k_{ix}\frac{dx}{dt} \tag{2d}$$

$$m\frac{d^2 y}{dt^2} = k_{iy} i_{cy} + k_{sy} y + m\varepsilon\omega^2 \sin(\varphi) - \frac{\sqrt{2}}{2} mg \tag{3a}$$

$$m\frac{d^2 x}{dt^2} = k_{ix} i_{cx} + k_{sx} x + m\varepsilon\omega^2 \cos(\varphi) - \frac{\sqrt{2}}{2} mg \tag{3b}$$

The current stiffness coefficients k_{iy}, k_{ix} and position stiffness coefficients k_{sy}, k_{sx} are defined as the partial derivatives of the appropriate radial force and move, [4]. The voltage and current-balance equations (2), with voltages u_1, u_2 ,u_3, u_4 and currents i_1, i_2, i_3, i_4 as well as their current stiffness coefficient k_{iy}, k_{ix} govern electrical characteristics of the AMB system. Their coefficients have been obtained from the magnetic field analyses with FEM, for nonlinear boundary problem (Fig. 1b).

Mechanical equations (3) describe the relation between the generated forces and shaft movement into *x* and *y* directions. They have been solved including mass *m* of the rotor as well as its eccentricity ε and the gravitation force. The current and displacement stiffness k_{iy}, k_{sy} and dynamic inductances L_{d1}, L_{d2}, L_{d3}, L_{d4} have been calculated within the numerical analysis of AMB magnetic field [5]. Using the field model of the bearing, the magnetic flux density distribution has been obtained for different current excitations.

The flux distribution in our prototype of the bearing, under the bias current excitation, is shown in Fig. 2. In this case, the shaft was centrally positioned. The field distribution is symmetrical according the bearing geometrical axis. The magnetic flux lines are concentrated in four regions. The field determination is used to calculate the magnetic force (Fig. 3a) which acts on the rotating bearing shaft, and to determine the dynamic L_d (Fig. 3b) inductances of the stator windings.

a) b)

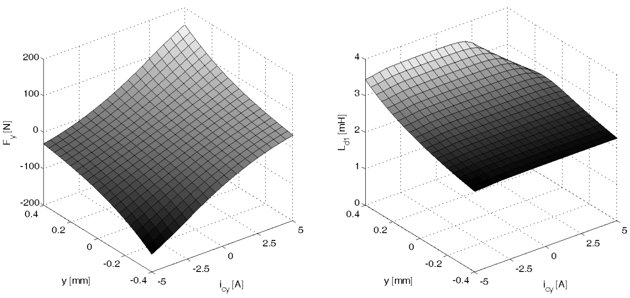

Fig. 3a. Magnetic force vs. control current i_{cy} and shaft position *y*
Fig. 3b. Dynamic inductances vs. control current i_{cy} and shaft position *y*

IV. AMB DYNAMICS SIMULATION AND ITS TESTING

In our calculations, we assumed that the force in each direction is generated by the electromagnets which act along one Cartesian axis. For the assumed rotation speed n=6000 rpm, the eddy currents and hysteresis phenomena can be neglected, in our computer simulations. Moreover, we have supposed that the force acting on the shaft along the *x* control axis does not influence the force acting along *y* direction. Because of the assumptions the characteristics of the AMB prototype are differ a little bit from the calculated ones.

a) b)

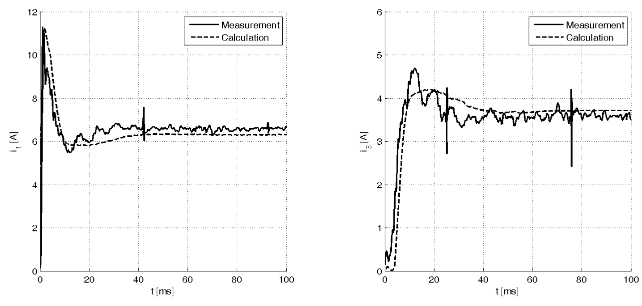

Fig. 4. Time response of the currents in windings a) i_1, b) i_3

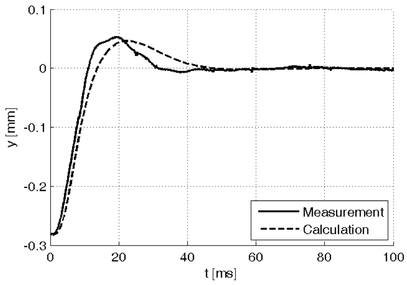

Fig. 5. Time response of the AMB shaft displacement in *y* direction

The time response of the AMB currents has been presented in Fig. 4. The measured and calculated transients of the currents i_1 and i_3, which generate magnetic force along *y* axis, represent current characteristics of the AMB. Figure 5 presents AMB lifting transients of the shaft in *y* direction. It is visible, that for numerical simulation the shaft stabilization time is longer than the measured ones for the physical prototype.

V. CONCLUSIONS

In this work we have created the mathematical model to simulate transients for AMB with symmetrical arrangements of the stator poles created from the E-shape electromagnets. The simulated characteristics with the field-circuit model have been compared with the measured results. Due to brevity we presented the time response of the current and shaft displacement. The measurement results are in good agreement with the simulated ones.

The calculated integral parameters of the magnetic field have also been compared with the measured ones. The calculated errors occur due to neglecting of eddy currents and anisotropy of the magnetic circuit material. Estimation with their including is very difficult, and should be considered for extremely high rotation speed, only. Despite the simplifications in the mathematical modeling, the measured results confirm computer simulations.

In this work, the magnetic bearing has been analyzed in terms of coupled mathematical models for both the magnetic field analysis and time-stepping numerical calculations. This approach constitutes effective solution of the differential equations and very economical analysis of AMB transients.

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