

Optimisation Of Central Disc Position On Elastic Rotor Supported With Active Magnetic Bearings

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Abstract — This paper presents process and results of optimization of central disk position on elastic rotor supported with active magnetic bearings. Goal of the optimization was to find which position of the central disk will give the largest value of elastic rotor first and second natural frequency. For natural frequency calculation and position optimization numerical methods are used.

Keywords—Active magnetic bearings (AMB); elastic rotor; natural frequency; optimization.

I. INTRODUCTION

In order to provide more accurate and better active control (development of active control methods) for elastic rotor with masses, supported with active magnetic bearings (AMB), it is necessary to be familiar with elastic rotor natural frequencies and corresponding modes of vibration (and therefore the critical speeds) and the possibility of their increase [1], [2], [3]. Numerical analysis was used to optimize the location of a central disc (label 3 in Figure 1) in order to obtain the maximum first and second natural frequency of the elastic rotor with masses supported with AMB shown in Figure 1. It was necessary to analyze in which direction is better to move disk 3, to AMB A or B, to find maximum natural frequencies. Also, goal of the optimization was to avoid resonance at first natural frequency ($60 \text{ Hz} - 3600 \text{ min}^{-1}$) while monitoring second natural frequency. Experimental test rig of elastic rotor with AMB is shown in Figure 2. In real machines it is preferred that value of natural frequency be as large as possible, so that rotor would

not come to critical area during rotation. If rotor come to critical area, resonance can occur, which can causes large deformation of the rotor. For the analysis and optimization numerical methods are used because the mathematical description of the dynamics of elastic rotor is rather complex, which will be explained in greater detail in part 2 of this paper. Elements of elastic rotor and AMB on the Figures 1 and 2 are: 1 – elastic rotor, 2 – rotation part of AMB B (mass), 3 – central disk (mass), 4 – rotation part of AMB A (mass), 5 – disc on the overhang (mass), 6 – AMB A, 7 – AMB B, 8 – elastic coupling, 9 – electric motor.

II. MATHEMATICAL MODEL OF ELASTIC ROTOR

Dynamic behavior of elastic rotor can be described analytically by a set of partial differential equations. However, they can be solved only in the simplest cases, because of that, modeling and analysis of dynamic behavior of the elastic rotor must be done using some of numerical methods such as finite element method.

The basic principles of the finite element method is structure discretization of solid body into smaller components with known geometry. In this way, complex differential equations are replaced by ordinary differential equations. Basic equation for description of elastic rotor dynamic behavior is given by [4]:

$$M\ddot{q} + (D + \Omega G)\dot{q} + Kq = f \quad (1)$$

Where: q – displacement vector, M – mass matrix, D – damping matrix, G – gyroscope influence matrix, K – stiffness matrix, f – external force matrix.

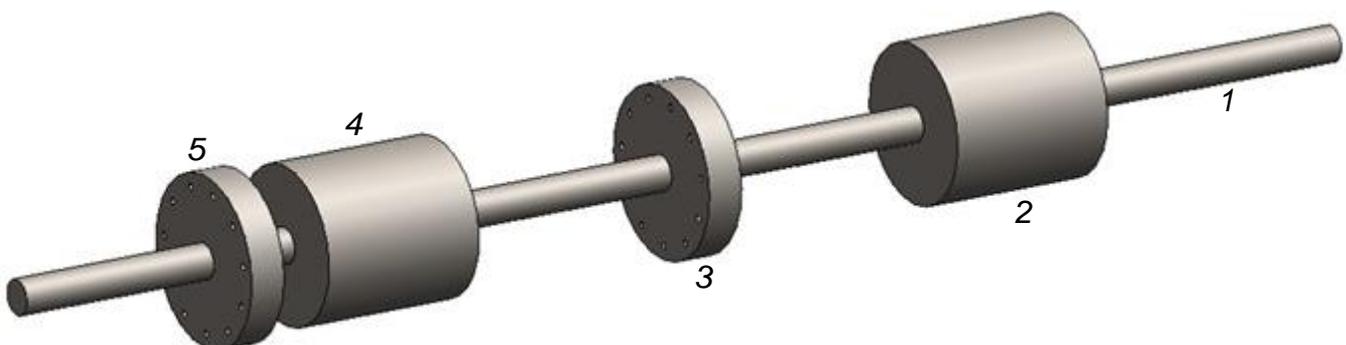


Fig. 1. 3D geometrical model of elastic rotor with masses

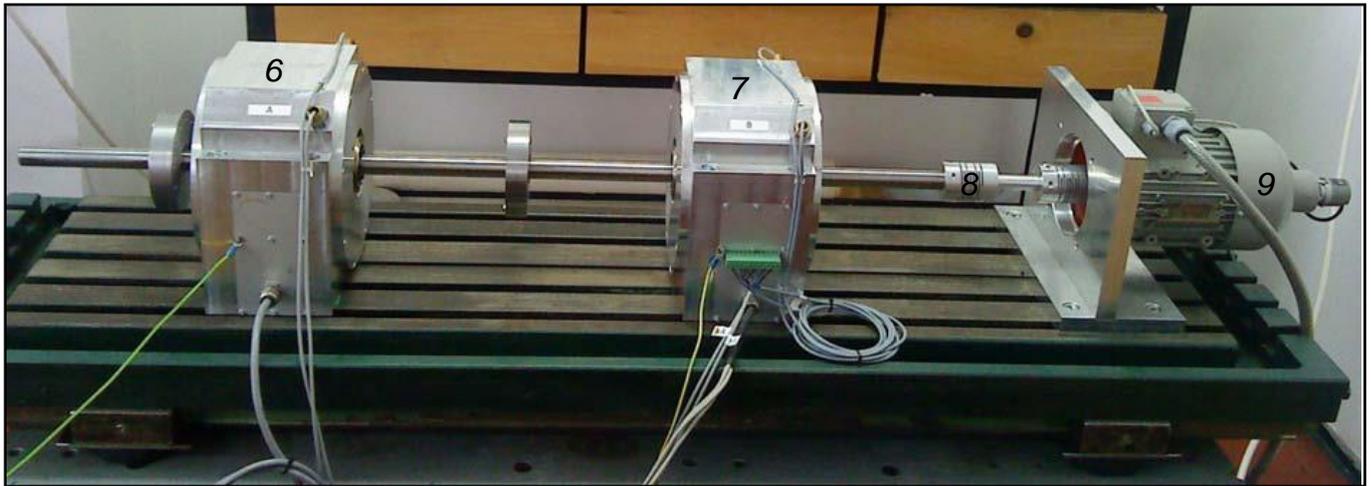


Fig. 2. Experimental test rig of elastic rotor with AMB

External forces are: magnetic force of AMB, force of gravity and forces of imbalance. Mathematical models of other components like AMB, inverters, sensors, control methods and delay are not analyzed in this paper because they are not relevant to the analysis implemented in this paper.

III. ANALYSIS OF ELASTIC ROTOR NATURAL FREQUENCY FOR INITIAL POSITION OF CENTRAL DISC

In the initial position central disk is in the middle between AMB A and AMB B. In order to perform position optimization and to find ideal position of central disc between AMB A and AMB B, first it is necessary to perform analysis of natural frequencies of rotor for initial position. Optimization was done using SolidWorks Simulation module.

A. Creating of 3D model

Before the analysis it is necessary to create a 3D geometrical model of elastic rotor with masses. Creation of model is done using SolidWorks software based on the geometry shown in Figure 3. 3D model is shown in Figure 1.

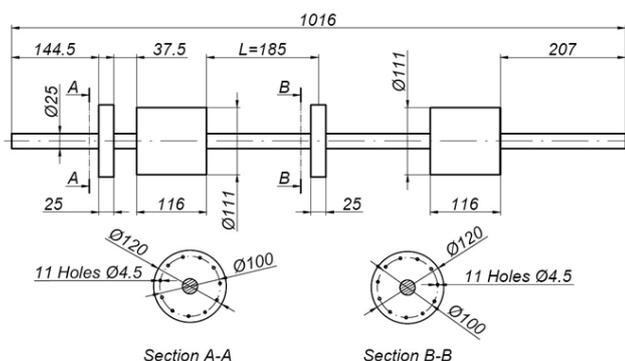


Fig. 3. Geometry of elastic rotor with masses

B. Analysis settings

First step to perform analysis and optimization on the created 3D model is to form finite element mesh. Created mesh is shown in Figure 4. SolidWorks

generate mesh automatically, also it can be seen that mesh is smaller around small holes. Type of finite element used is 4 node tetrahedron. After creation of finite element mesh it is necessary to add supports and connections. To simulate the situation from Figure 2 it is necessary to model stationary parts of AMB around rotation parts (in the form of tube with small thickness) and small cylinder at right end of the rotor which represents a shaft of electric motor. From Figure 2 it can be seen that elastic rotor is connected with electric motor with flexible coupling, flexible coupling can be simulated using spring connection with defined stiffness.

Electric motor shaft is fixed at the right side. Influence of AMB force on elastic rotor can be simulated using elastic bearing connection with defined stiffness, in this case 680000 N/m [4], it is necessary to apply elastic bearing connections between rotation and stationary parts of AMB. Also it is necessary to fix stationary parts of AMB. Elastic rotor with connections, supports and mesh is shown in Figure 4.

C. Results of analysis

Results of natural frequencies are shown in the form of displacements. SolidWorks automatically calculate rigid and flexible frequencies modes, it is necessary to recognize first natural frequency mode by the shape of the rotor.

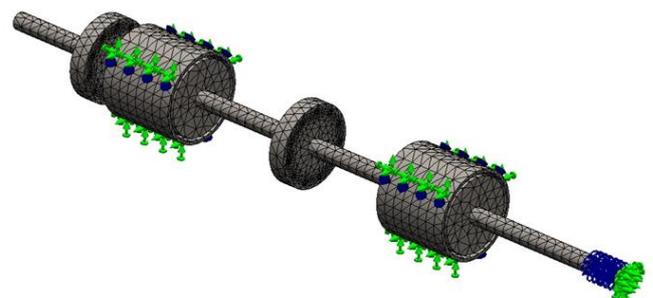


Fig. 4. Elastic rotor with connections, supports and finite element mesh

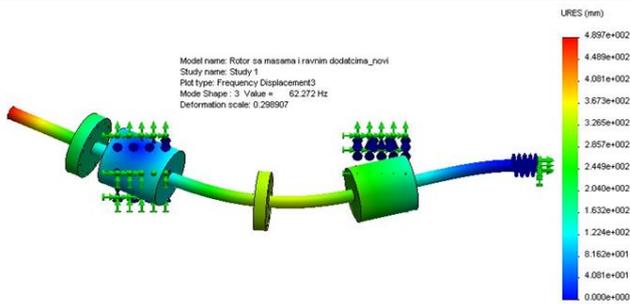


Fig. 5. First natural frequency

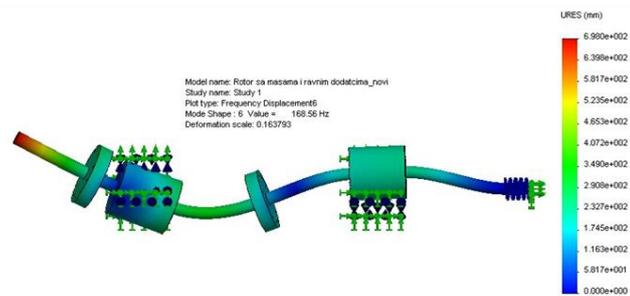


Fig. 6. Second natural frequency

From Figure 5 it can be seen that the first natural frequency occurs at 62,272 Hz, experimental result in [4] is 66 Hz. In Figure 6, the second natural frequency occurs at 168.56 Hz, the experimental value in [4] is 165 Hz.

IV. OPTIMISATION OF CENTRAL DISC POSITION

Using process of optimization it is necessary to find the ideal position of central disc so that the first and second natural frequencies have the highest possible value. Optimization parameter is dimension (distance L [mm]) which represent distance of central disk from AMB A (Figure 3.). Type of parameter is *Range with step*, range is from 10 to 310 mm and step is 20 mm which gives 16 possible scenarios. Goals of optimizations are set using sensors, it is necessary to set sensor at mode shape 3 (first natural frequency) and mode shape 6 (second natural frequency). Data for all scenarios are shown on diagram in Figure 7.

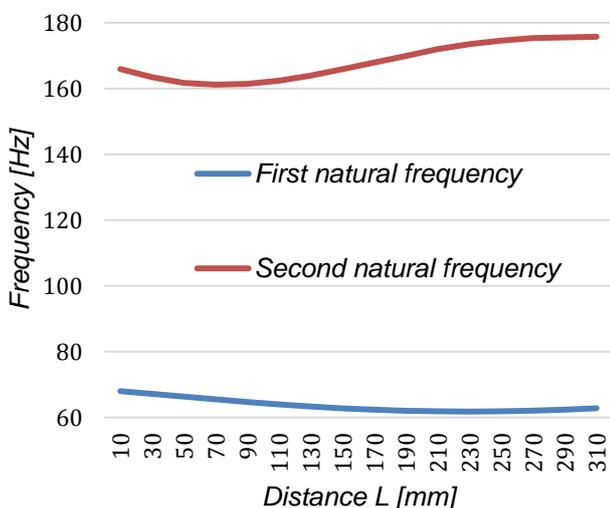


Fig. 7. Results of optimization

From Figure 7 it can be seen that value for first natural frequency is biggest at scenario 1 (68,013 Hz) and for second natural frequency at scenario 16 (175,76 Hz).

First natural frequency have lowest value when disk is 240 mm away from AMB A and second natural frequency have lowest value when disk is 70 mm away from AMB A. This data can be used when is necessary to achieve first critical speed as soon as possible.

V. CONCLUSION

Numerical analysis have become irreplaceable tool for engineering problems solving, especially when it comes to problems which, due to their complexity, can't be solved using analytical methods. However, as it can be seen from the example above, it is necessary to be very careful when we use them.

It is necessary to have a thorough understanding of physics of the problem in order to know the proper way to establish all relations in the numerical model, to perform analysis and optimization and ultimately interpret obtained results. Without a numerical optimization methods this problem can be solved only using experimental approach, the implementation of the experimental testing is quite complex and it would require a lot of time.

Comparing numerical solutions from this paper and experimental solutions from [4] the validity of the established numerical model can be confirmed. Therefore formed numerical model can be used for further research.

Optimization process presented in this paper can be used in the design process of machines or machine elements, in the case when maximum or minimum natural frequency of machine or machine element is needed.

Results acquired in this research will be used to design and optimize controls methods for control of active magnetic bearings.

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