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SIMULATION THE DYNAMICS OF GYROSCOPIC RIGID CENTRIFUGE ROTOR WITH ANISOTROPY OF RESTORING AND DAMPING CHARACTERISTICS OF AN ELASTIC SUPPORT

ABSTRACT

thesis for a degree of Doctor of Philosophy (Ph.D.)
in specialty 6D060300 - "Mechanics"

The study's relevance. In this work, new physical and mathematical models are developed, problems of dynamics of vibrating gyroscopic rotary machines with ideal and non-ideal energy sources are solved analytically and numerically, incl. taking into account the anisotropy and nonlinearity of the elastic characteristic, linear and nonlinear cubic damping of the support. Analytical relationships between the oscillatory and dynamic characteristics and their dependence on the dynamic parameters of the vibration system were obtained. In detail, analytical and graphical dependences of the oscillation amplitude, the amplitude of the transmissibility force moment are established, and the influence on them of nonlinearity of rigidity, linear damping and nonlinear cubic damping and anisotropy of the supporting material in a stationary mode is analyzed, taking into account hopping and other nonlinear effects. The influence of linear and nonlinear cubic damping on the responses of the dynamics of a gyroscopic rotor system is investigated in the case of uneven and nonlinear nature of the support rigidity in an unsteady mode of motion during uprun and downrun of the rotor. The advantage of nonlinear cubic vibration damping with increased amplitude is experimentally confirmed by replacing the material of the shaft support in the resonant region and in non-resonant regions of rotation speed, theoretical and experimental results are compared, which is very important in the development of scientific, technical, design documentation and in the further design of a vibration centrifuge on base of a vertical gyroscopic rotor. The dynamics of regular motion modes before resonances, irregular motion modes during and after resonances, the stability of the vibration system under these motion modes, and methods for controlling resonant oscillations are considered.

The results of theoretical and experimental studies of the dynamics of vibrating gyroscopic rotary machines with nonlinear characteristics with ideal and non-ideal energy sources will be a good basis for the preparation of scientific, technical and design documentation for the design and creation of 3D models, fundamentally new classes of energy-saving, vibration-using and vibration-resistant vibrating rotor machines with optimal parameters and with a control system for the production of high-quality products used in the pharmaceutical, food, oil and gas and mining industries.

Thus, the **relevance of the research** topic is beyond doubt and is of scientific and practical interest.

Purpose of the work: Study of the dynamics of a gyroscopic rotary machine with nonlinear elastic and damping characteristics, ideal and non-ideal energy sources, incl. taking into account the anisotropy of the rigidity of the elastic support, aimed at creating fundamentally new classes of energy-saving, vibration-using and

vibration-resistant machines with optimal parameters and a software control system.

In connection with this goal, the **following research tasks** arise::

– development of physical and mathematical models of new gyroscopic rotary machines, taking into account the influence of linear and nonlinear cubic damping of the support on the response and stability of the rotary machine, incl. with anisotropy of rigidity and taking into account the interactions of the vibration system with the energy source;

– theoretical and experimental studies of the influence of linear and nonlinear cubic damping of an elastic support with a nonlinear stiffness component, incl. unevenness of linear rigidity on the amplitude-frequency characteristic, transferability of the moment of forces of the rotor system during stationary vibrations, on fluctuations in angular displacements during unsteady modes in order to select linear and nonlinear elastic and damping characteristics of the support material, ensuring stable operation of the machine up to critical speeds during their passage and after critical speeds;

– study of regular movement up to critical speeds, irregular movement during and after passing critical speeds, with nonlinear jumps, and other nonlinear effects in vibrating rotor machines in order to determine the causes of irregular movement and ways to mitigate and eliminate them;

– determination of areas of instability and control by vibrations of large amplitudes of vibrating rotary machines in order to select the range of operating speeds of stable movement and to develop methods for controlling irregular movement.

Object of study. Centrifuge based on a vertical rigid gyroscopic rotor.

Subject of study. The influence of nonlinear stiffness, linear and nonlinear damping, anisotropy of the elastic and damping properties of the support on the response of the dynamics of the gyroscopic rotor.

Research methods: For theoretical research, the dissertation uses methods of mathematical modeling of gyroscopic rotary machines, taking into account the influence of linear and nonlinear cubic damping of the support. The development of mathematical models of gyroscopic rotary machines was carried out using the MatLab numerical calculation package. The compilation of a 3D dynamic model of gyroscopic rotary machines was carried out using the Solid Works software package. Experimental studies were carried out using modern strain gauge methods using smart sensors and modules for measuring mechanical parameters.

The scientific novelty of the work is as follows:

– regulation and optimal selection of the rigidity of the support material and suppression of resonant and over-resonant amplitude elevations and elimination of nonlinear jumping effects;

– narrowing the boundaries of areas of movement instability;

– study of the influence of anisotropy of linear stiffness and nonlinear cubic damping of an elastic support on the dynamics of rotary machines, incl. gyroscopic, taking into account the nonlinear cubic component of stiffness.

Scientific provisions submitted for defense:

– modeling of the dynamics of a gyroscopic rigid rotor with linear and nonlinear damping and nonlinear rigidity of the elastic support;

– modeling the dynamics of a gyroscopic rigid rotor with anisotropy of the restoring and damping characteristics of the elastic support;

– resonant oscillations of a non-ideal gyroscopic rotor system with nonlinear restoring and damping characteristics;

–prototype of a centrifuge based on a vertical rigid gyroscopic rotor;

–experimental studies of a prototype centrifuge based on a vertical rigid gyroscopic rotor.

The reliability and validity of scientific provisions, conclusions and results of the dissertation work are confirmed by the use of proven methods of mechanics, the theory of mechanisms and machines, the theory of vibration protection, and the use of proven software systems MATLAB and SolidWorks. The reliability of the results is confirmed by the development and manufacture of a prototype centrifuge based on a vertical gyroscopic rigid rotor, tests of which have shown good agreement with theoretical results under various operating modes.

Theoretical and practical significance of the research.

The theoretical significance of the work lies in the development of physical and mathematical models and methods for studying the nonlinear dynamics of gyroscopic rotary machines, with uneven linear stiffness, linear and nonlinear cubic damping of an elastic support with a nonlinear component of rigidity, ideal and non-ideal energy sources in stationary and non-stationary modes of motion aimed at creating new energy-saving, vibration-using and vibration-resistant machines with optimal parameters, used in the pharmaceutical, food, oil and gas and mining industries, and with high quality products.

The practical significance of the dissertation research consists in experimental studies of the dependence of the vibration amplitude of the rotor shaft on the rotation speed for various values of the linear and nonlinear damping coefficients and the influence of damping parameters on the amplitude-frequency response with nonlinear effects in the areas up to the resonant speed, resonant frequency and high rotation speeds, through replacing the material of the elastic rotor support during acceleration and deceleration of rotation in the experimental resonance curve.

Relationship of this work with other research works. This dissertation work was carried out within the framework of a scientific project for grant funding of scientific research of young scientists under the “Young Scientist” project for 2022-2024 of the Ministry of Science and High Education of the Republic of Kazakhstan “Simulation the dynamics of a gyroscopic rigid centrifuge rotor with anisotropy of the restoring and damping characteristics of the elastic support” (IRN of the project: AP15473701).

Approbation of work. The main provisions and results of the dissertation work were reported and discussed at the following scientific events:

- at the International Conference «Asian IFToMM Mechanisms and Machine Sciences» (AsianMMS 2021, Hanoi, Vietnam);
- at the International Conference «4th International Conference of IFToMM Italy» (IFIT 2022, Naples, Italy);
- at the International Conference «6th International IFToMM Conference» (MeTrApp 2023, Poitier, France);
- at seminars of the RSE “Institute of Mechanics and Engineering named after. U.A. Dzholdasbekova" SC MSHE RK.

Publications. The author has published 6 works on the topic of the

dissertation, 5 publications in foreign scientific journals with a non-zero impact factor (IF) and proceedings of international conferences included in the Scopus and Web of Science databases, 1 Eurasian patent for an invention.

Works published on the topic of the dissertation are given in the list of references.

Author's personal contribution

The main scientific results of experimental research and the conclusions presented in the dissertation were obtained by the author independently. In the works published in co-authorship, the applicant owns a significant part related to software implementation and experimental studies of a centrifuge based on a vertical rigid gyroscopic rotor.

Structure and scope of the dissertation. The dissertation has a title page, contents, a list of symbols and abbreviations, an introduction, six sections, a conclusion, a list of sources and applications used. The total volume of the dissertation is 116 pages, including 99 illustrations and 1 table.

Main content of the dissertation

The introduction provides a description of the problem and a brief overview of the subject area. The relevance of the dissertation work is substantiated, the formulation of the problem and the stages of their solution are formulated.

The first section is devoted to modeling the dynamics of a gyroscopic rigid rotor with linear and nonlinear damping and nonlinear rigidity of the elastic support.

The second section discusses the modeling of the dynamics of a gyroscopic rigid rotor with anisotropy of the restoring and damping characteristics of the elastic support.

The third section examines resonant oscillations of a nonideal gyroscopic rotor system with nonlinear restoring and damping characteristics.

The fourth discusses the development of a prototype centrifuge based on a vertical gyroscopic rigid rotor. A 3D model of a centrifuge based on a vertical gyroscopic rigid rotor has been developed. Based on the 3D model, design documentation (DCD) has been developed for a prototype centrifuge based on a vertical gyroscopic rigid rotor. The manufacture of a prototype centrifuge based on a vertical gyroscopic rigid rotor is shown.

The fifth section presents the results of an experimental study of the influence of nonlinear cubic damping of the support on the amplitude-frequency response of a prototype centrifuge based on a vertical rigid gyroscopic rotor, the results of a study of the influence of stiffness anisotropy and damping on the dynamics of the rotor.

In conclusion, the main results and conclusions of the dissertation research obtained in the work are presented.