BULLETIN OF THE POLISH ACADEMY OF SCIENCES
TECHNICAL SCIENCES, Vol. 71(6), 2023, Article number: e148442
DOI: 10.24425/bpasts.2023.148442

EDITORIAL

SPECIAL SECTION

Selected problems of rotating machinery dynamics

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1. PREFACE

By rotating machines, we understand a very wide range of machines and mechanisms whose main working element, often called a rotor, performs rotational motion. As part of having this special feature, rotating machines differ from each other in terms of geometric dimensions, the shape of components, ranges of rotational speeds, values of transmitted power, drive structure, method of bearing support of the rotors operating under various temperatures and many other features that in a more or less important way influence the nature of their operation. In these respects, typical rotating machines include large energetic turbogenerators and turboexpanders, gas and wind turbines of various sizes, pumps, blowers, compressors, and electric motors, as well as automatic washing machines, tiny dental drills, and many others.

Scientific research on the dynamics of rotating machinery has been conducted for over a hundred years. Depending on the severity of various problems associated with the operation of these machines and real computational possibilities at a given time, research focused on various issues constituting the field of rotating machinery dynamics over these years. From the beginning of the development of these types of machines, their most important problems were lateral and flexural vibrations caused by generally unavoidable unbalances of the rotors and the dynamic effects of various types of bearings supporting the rotor shafts. For this reason, much work was devoted to modelling bearings, mainly journal bearings, where various types of influence of the oil film on the bending and lateral vibrations of the rotor shaft were examined. As new types of bearings supporting shafts of rotating machines were introduced, for example, gas bearings or gas-foil bearings, analogous research conducted for them created additional research areas in this field.

Since most rotating machines are fluid-flow machines, vibrations of rotor blades and the interaction of seals on the dynamic properties of shafts were also tested. As these machines were improved and computational techniques developed, the dynamic research devoted to them gradually became increasingly thorough. Therefore, the stability of motion of entire rotor shaft systems as well as the impact of bearing interaction and cracks in shafts and blades on rotating machine vibrations were examined.

An introduction of active magnetic bearings for non-contact support of rotor shafts, where the classical issues of the dynamics of mechanical systems and fluid mechanics were also joined by the use of the fundamentals of mechatronics, opened new research areas in the field of rotating machinery. This type of support also began to be used for active control of bending and lateral vibrations of rotor shafts, where the active magnetic bearing played the role of an actuator.

In recent decades, the intensive development of sensors and signal processing techniques allows the use of measured mechanical vibration patterns of a rotating machine to assess its wear and tear as well as detect various types of imperfections. In order to be able to better interpret the measured dynamic effects called “vibration signature”, more and more advanced and reliable mechanical models were adopted not only for the rotor shaft systems themselves, but also for the defects that plague them, e.g. cracks, shaft bow or worn raceways of rolling element bearings, and assembly errors in the form of various types of mutual misalignments of successive sections of these shafts and couplings connecting them. In this way, a new research area has been created in the field of dynamics of rotating machinery, which is used to condition monitoring the current state of operation of the machine and to detect and identify any imperfections occurring in it.

Many rotating machines cooperate with electrical machines, i.e. motors and generators, which are also rotating machines themselves. Typical examples are steam- and gas-turbine generators, where testing flexural vibrations of their rotor shaft lines is a routine activity as part of their design process. As is known, electrical machines that are either the source or receiver of the drive can generate severe variable components of the electromagnetic torque, which often cause very dangerous torsional vibrations of the drive system of the rotating machine. Therefore, the study of transient torsional vibrations of the rotor shaft lines of energetic turbogenerators induced by short circuits in the transmission network or in the generator itself is one of the

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Manuscript submitted 2023-11-27, revised 2023-12-04, initially accepted for publication 2023-12-05, published in December 2023.

classic problems of the dynamics of rotating machines. The recent development of new ecological techniques for generating electricity, e.g. by wind turbines or solar panels, results in the generation of variable voltage components in transmission networks, causing variable components of the resistive torque of generators in power plants, which is the reason for inducing very dangerous resonant torsional vibrations of entire lines of turbogenerator rotor shafts. The study of this interdisciplinary phenomenon on the border of mechanics and electrical engineering, called sub-synchronous resonances, is currently a new challenge for scientists and engineers.

In turn, investigating the influence of the electromagnetic variable components of the driving torques of electric motors on torsional vibrations of shafts in the rotating machine drive system requires in-depth analyses of electro-mechanical interactions in a given object. Originally, research of this type was mainly limited to examining transient vibrations during startups of rotating machines driven by asynchronous and synchronous motors, which usually generate very large components of variable electromagnetic torques in unsteady operating conditions. However, the recent intensive development of control electronics, which is increasingly used for these types of electric motors allows, on the one hand, an elimination of these detrimental variable components, and on the other hand, it facilitates a suppression of drive system torsional vibrations excited by variable resistive torques generated by the driven machine and ensuring the required motion parameters of the electro-mechanical system under consideration. Due to the large variety of methods developed to control the operation of electric motors and the great diversity of structures and properties of drive systems of rotating machines, intensive research is currently being carried out in this area, which constitutes another important subfield of the dynamics of rotating machinery.

Apart from this very abbreviated overview of the most important issues in this field, the 10 articles included in this volume can show in which direction outstanding researchers are currently working and what to expect in the future of rotating machinery dynamics.

2. INTRODUCTION TO THE PAPERS

Material damping of a rotating shaft has a significant impact on the amplitudes of its flexural vibrations and on motion stability. As is known, the commonly used Kelvin-Voigt model leads to instability of motion of the rotating shaft. Therefore, it is sometimes replaced with the so-called standard body model that better matches the dynamic behaviour of real rotor shafts made mainly of steel. However, G. Überwimmer, G. Quinz, M. Klanner, and K. Ellermann, i.e. the authors of the paper titled *"Numerical investigation of rotor-bearing systems with fractional derivative material damping models*", went a step further by proposing a model of material damping with partial time derivatives, which particularly better describes vibrations of rotor shafts made mainly of non-metallic materials.

In the paper titled *"Exploiting gyroscopic effects for resonance elimination of an elastic rotor utilizing only one piezo actuator"* written by J. Jungblut, D. Franz, Ch. Fischer, and S. Rinderknecht, a bearing support equipped with a piezoelectric actuator was used to attenuate resonant vibrations of the rotor shaft subjected to gyroscopic effects. Owing to the active control technique proposed in this way, it is possible to reduce resonance amplitudes at critical speeds corresponding to the forward and backward whirls of the rotating shaft.

As one can see, vibrations of steam turbine rotor blade rims are still the subject of research. L. Pešek, P. Šnábl, and Ch. Prasad in their paper titled *"Turbine wheel reduced modal model for self-excited vibration suppression by inter-blade dry-friction damping"* studied dry-friction effects in inter-blade connections on the turbine-bladed disk caused by self-excitation due to aero-elastic instabilities. It turns out that in cases of properly selected parameters of the object under study, the dry friction damping can sufficiently and effectively suppress such self-excitations within a relatively short time of observations.

Out-of-plane vibrations of circular saw blades also belong to the problems of rotating machinery dynamics. The paper titled *"Vibration reduction on circular saw blades with vibroacoustic metamaterials"* written by S. Rieß, W. Kaal, and S. Herold shows how to minimize amplitudes of these vibrations using vibroacoustic metamaterials.

The problem of modelling the impact of the oil film of journal bearings on a vibrating rotor shaft is still vital. In order to possibly accurately and numerically effectively determine the current values of hydrodynamic forces in this type of bearings, in the article titled *"Efficient rotordynamic simulations with semi-analytical computation of hydrodynamic forces"*. S. Pfeil, F. Duvigneau, and E. Woschke solved the Reynolds equations semi-analytically using the scaled boundary finite element method. The computational results determined by means of this approach are compared with analogous findings obtained by the use of the finite element method and the finite volume method.

Modelling gas-foil bearings is a very complex issue due to the complicated description of their structure. Therefore, many authors devote a lot of effort to this field. This is confirmed by the works titled *"Controlling bifurcations in high-speed rotors utilizing active gas foil bearings"* by A. Papadopoulos, J. Gavalas, and A. Chasalevris and *"Thermo-elasto-hydrodynamic analysis of bump-type air foil thrust bearings considering misalignment"* written by M. Eickhoff, J. Triebwasser, and B. Schweizer, in which the first one examines nonlinear phenomena in radial active gas-foil bearings, and the second one conducts a thermo-elastic-hydrodynamic analysis of thrust air-foil bearings. It should be noted that despite the common basis for modelling these types of bearings, in the case of transverse shaft support, active control of an operation of the gas-foil bearing is essential, and in the case of the thrust air-foil bearing, thermal phenomena are emphasized.

As is known, annular seals interact on rotor shafts not only with transverse forces but also with tilt moments. M. Kuhr and P. Pelz in their paper titled *"Experimental identification of the force and moment characteristic of symmetrically and non-symmetrically profiled annular seals"* studied these interactions in detail for various geometric shapes of the annular seal. It turned out that the impact on the shaft is significantly influenced not only by the well-studied characteristics of the transverse force at a given seal profile but also by the not fully researched characteristics of the tilting moment.

Identification of defects and imperfections as well as examination of the influence of manufacturing inaccuracies on the operation of rotating machines is currently an intensively developing field of research. For this purpose, in the paper titled *"Data-driven virtual sensor for powertrains based on transfer learning"* by A. Karhinen, A. Hämäläinen, M. Manngĺrd, J. Miettinen, and R. Viitala, a computational tool called "virtual sensor" based on a data-driven approach and deep machine learning was used for the complex machine drive system. The advantages of this type of method are highlighted against the background of the features of an alternative approach commonly used for the above-mentioned purposes, i.e. the model-based virtual sensor.

Electromagnetic interactions are considered by P. Hańczur, T. Szolc, and R. Konowrocki in their paper titled *"Suppression of rotating machine shaft-line torsional vibrations by a driving asynchronous motor using two advanced control methods"* on the example of torsionally vibrating drive systems of various rotating machines. In this paper, actively controlled asynchronous motors were used as a simultaneous source of drive and actuator. An application of advanced vector- and frequency control methods for the operation of these motors allows for the effective minimization of steady-state resonant vibrations of the electromechanical systems under study.

It should be noted that the issues discussed in this volume do not cover all areas of development in the field of rotating machinery dynamics, but they constitute a fairly representative indication of the direction in which this field of research is currently heading.

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