THE ARCHIVE OF MECHANICAL ENGINEERING

Vol. LV 2008 Number 1

DOI: 10.24435/ame.2008.131610

Key words: rotor system, tilting-pad journal bearings, frequency, resonance, parameters

VLADAS VEKTERIS, AUDRIUS ČEREŠKA***

RESEARCH ON ROTARY SYSTEM WITH TILTING-PAD JOURNAL BEARINGS

This paper presents the results of research on self-vibrations of rotary systems with segmental tilting-pad journal bearings having different frequencies of rotor revolution. The problem of research formulated in this work concerns technical characteristics of primary elements of the investigated system and its principle of operation. The obtained results are illustrated with graphs. The paper also contains comparison of results and discussion. General conclusions are given at the end of the paper.

1. Introduction

Hydrodynamic bearings are one of the primary elements of construction of high-power rotary machines. Bearings hold the rotor together and rotate in high-power steam turbines, in compressors, and in pumps [1]. According to EEI (Edison Electrical Institute) statistical data, breakdowns of hydrodynamic bearings are the reason of 23 % of cases of breakdown of the systems. Similar research of thermal power stations done by EPRI (Electrical Power Research Institute) shows that power stoppages happen mostly because of problems with these bearings [1], [2].

One of the undesirable phenomenon that occurs in rotary systems is the operation in the resonant regime [3]. The resonant regime is attributed to the crash of bearings, because a bearing working in resonant regime could damage all the mechanism in which it is embedded.

* *Vilnius Gediminas Technical University, Mechanical Faculty, Department of Machine Building, Basanavičiaus str. 28, 03224–Vilnius, Lithuania; E-mail: vekteris@me.vgtu.lt*

** *Vilnius Gediminas Technical University, Mechanical Faculty, Department of Machine Building, Basanavičiaus str. 28, 03224–Vilnius, Lithuania; E-mail: audrius@me.vgtu.lt*

Hydrodynamic bearings are stocks of rotors and are subjected to some workloads with increasing frequencies of revolution. They are characterized by unstable work in the regime of natural frequency. If such instabilities occur in the elastic (limp) rotor, which works at critical, resonant rotational frequency, then breakdown of the machine is unavoidable [3]. Such a breakdown is sudden, therefore catastrophic. There are some mechanisms that can evoke the phenomenon of instability.

One can notice a substantial difference between vibrations of rotor that arise because of unstable work of sliding bearings caused by friction, and between other vibrations of rotor that arise, for example, because of unbalance of the rotor, deflections of truths of rotors, wear of turning parts and so on [4], [5], [6].

Vibrations that arise through lubricant of sliding friction appear as spontaneous cross vibrations of rotor. In the case of rotor system – it raises vibrations in the system, when energy of vibrations of vapour, gas, or liquid of the lubricant is transmitted to the rotor. **These vibrations result from sucks and agitation of the lubricant raising impacts in the sliding bearing [3].** Dynamic parameters of the "rotor-lubricant-bearings" system and the parameters of liquid taken together decide of the degree of stability of rotary system that is expressed by rotational rate of rotor [1], [7]. When the increase of rotor rotational frequency is exceeded, it causes spontaneous cross vibrations of sub-synchronic frequency of the rotor, which is started by whirls of lubricant in the oil clearance of the bearing. It forms whirls of lubricant arising in the oil clearance of the bearing that have much smaller frequency than rotational frequency of rotor revolution [7], [8]. The meaningful characteristic feature is instability of whirls of the lubricant, because they increase dynamic powers, and these increase whirls. Rotor becomes unstable when the lubricant cannot remain in its axle or when the frequency of whirls is coincident with the frequency of vibrations of axle. The result of the above-mentioned phenomenon is an increased cross-vibration of rotor at a steady frequency [1], [7]. Fig. 1 depicts a Spp spectogram – a cascade of graphs of spontaneous cross vibrations [6], [7], [8].

In the spectrogram cascade it can be seen that stable revolution of the axle without vibrations ends at 2400 rev/min. It is the degree of stability of the rotary system. Spontaneous vibrations of the rotor originate from whirls of lubricant starting at 2400 rev/min and lasting up to 3300 rev/min. The frequency of these spontaneous vibrations is 0.47X relative to frequency of rotor revolution. When the rotational frequency of rotor increases, the spontaneous vibrations grow up in proportion. When rotor reaches rotational speed of 3300 rev/min, the spontaneous cross vibrations of rotation disappear. Spontaneous

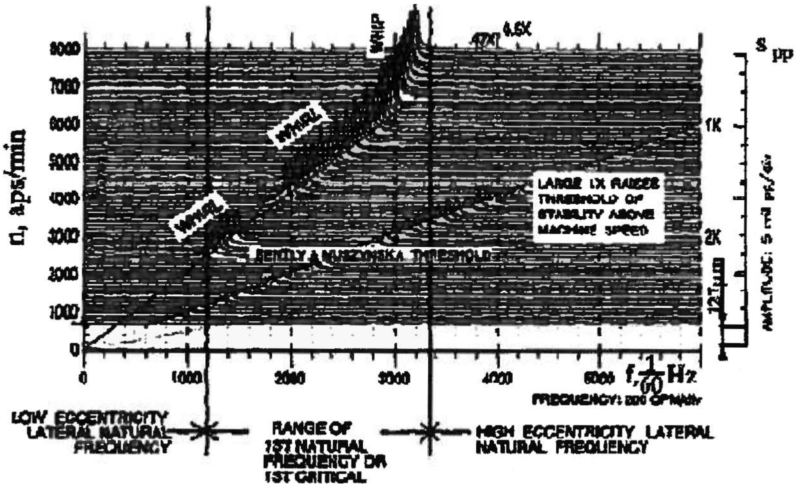

Fig. 1. Spectograms of changes of axle vibrations in rotary systems that rise lubricant of sliding bearing – graph of cascade with "step of Bently and Muszynska" [6], [7], [8]

vibrations of rotor do not occur in the interval from 3300 rev/min to 4000 rev/min.

When the increasing rotational frequency of rotor exceeds 4000 rev/min, the amplitude of vibrations of the synchronic frequency 1X begins to decrease, because of the decrease of dynamic eccentricity.

When the frequency of rotor revolution grows further, from 6200 to 8000 rev/min, the spontaneous cross whirls of rotor appear again evoked by stirring of lubrication; their frequency is steady and the amplitude is significant.

However, spontaneous cross vibrations arise at different frequencies of rotor revolution than those in simple slide bearings [9], [10].

Additional experimental research is needed to determine the characteristics of spontaneous self-excited vibrations in these bearings.

2. Basis of research

All the investigated systems (research stands) consisted of four subsystems: the investigated system (rotary system with tilting-pad journal bearings); the stepless system of regulation of rotor revolution frequency; lubrication system of rotary elements, and the system of measurement and results analysis (Fig. 2).

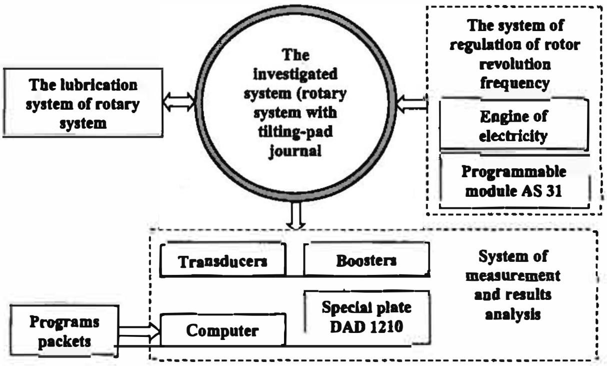

Fig. 2. Principal scheme of testing system

2.1. The investigated system (rotary system with tilting-pad journal bearings)

The investigated system is a rotary system with tilting-pad journal bearings (Fig. 3).

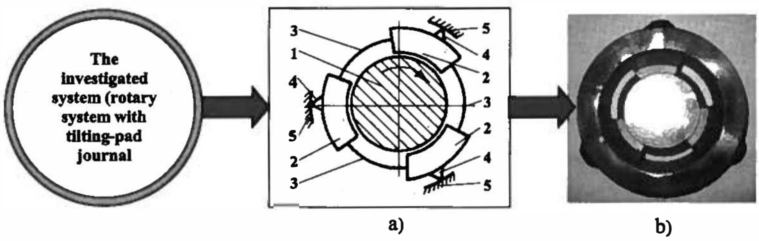

Fig. 3. The investigated system: a - tilting-pad journal bearings, 1 - rotor, 2 - segments, 3 - elastic coupling, 4 - adaptive thrust, 5 - spindle head; b - photo of bearing

2.2. The system of regulation of rotor revolution frequency

The stepless system of regulation of revolution frequency of German firm "INDRAMAT" was used for controlling the frequency of the rotary system with tilting-pad journal bearings. Its technical data are as follows:

– The supply voltage 380 V;
– The electric power of electric motor equals 6.5 kW;
– Frequency of revolution of stepless control is 0-8000 rev/min.

The stepless system of control of rotor rotational frequency consists of asynchronous three-phase electric motor and its control block that allows for starting and stopping the motor, as well as for controlling the settings of fixed or stepless frequencies of revolutions.

The programmable module AS 31 was installed for adapting the block of control to the mechanics of the asynchronous motor. The module performs the function of constructional transducer; it has a programmable supply and the necessary parameters of compatibility stored in its memory. Programming was done with the use of KDA keyboard. Fig. 4 shows the system of regulation of rotor revolution frequency.

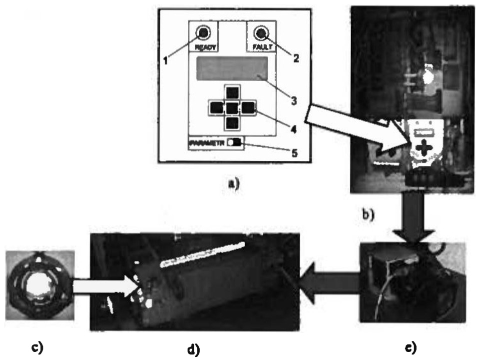

Fig. 4. Keyboard KDA and display of programmable module AS 31
a - keyboard KDA: 1 - signal denotative, that system is making for work, 2 - signal denotative, that caused mistake, 3 - screen, 4-keyboard of gear's control and programming, 5 - adapter of parameters change; b - programmable module; c - tilting-pad journal bearing; d - rotary system; e - electricity engine

2.3. The lubrication system of rotary system

The lubrication system of the rotary system fulfills the functions of lubrication and refrigeration of the rotary system (Fig. 5).

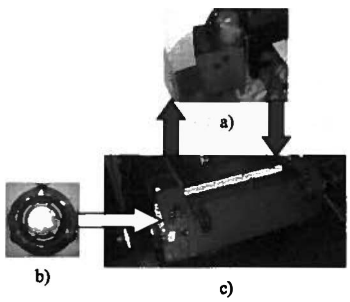

Fig. 5. Lubrication system: a - lubrication block; b - tilting-pad journal bearing; c - rotary system

2.4. The system of measurement and analysis of results

The system of measurement and analysis of results consists of: various measurement transducers, its boosters and supply units, and a computer with the special plate DAD 1210 installed. All the results of measurement are given and cumulated in the computer with the help of the plate. The results of measurement were analyzed with the use of several programming batches (Fig. 6).

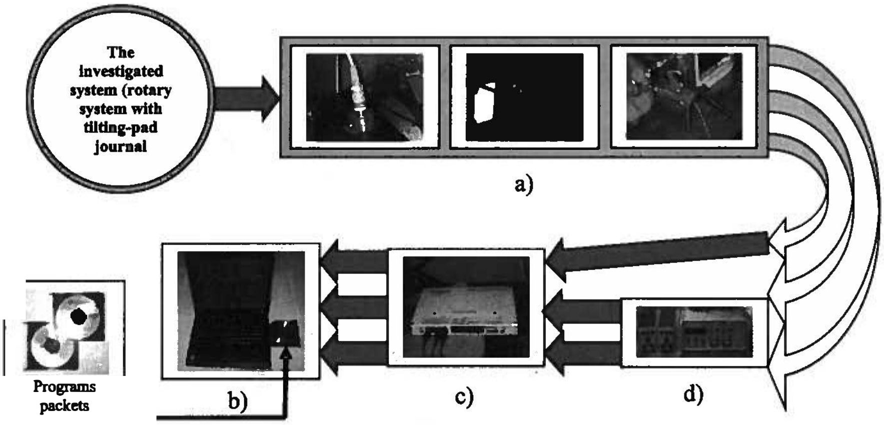

Fig. 6. The system of measurements and analysis of results: a – non-contact induction displacement, accelerometer, transducer of measurement phases; b – computer; c – special plate DAD1210; d – boosters

3. Results of measurement and its discussion

The obtained results of measurements as well as zones of resonant frequencies of the rotary system with tilting-pad journal bearings are shown in Fig. 7 and 8.

The system starts working from 0 to 1934 rev/min (I zone) and is working steadily in that range, when exceeding 1934 rev/min spontaneous vibrations of rotor appear, which continue up to 2921 rev/min. As the rotor reaches a rotational frequency of 2921 rev/min the spontaneous vibrations decrease and that effect continues until the frequency reaches 3918 rev/min (II zone). No spontaneous vibrations are observed when revolves in the range of 3918 rev/min to 5500 rev/min (III zone).

Rotary systems with tilting-pad journal bearings are recommended when the clearance between the rotor and bearing is 50 μm.

Comparing the obtained results with "Step of Bently and Muszynska" graph (Fig. 1), one can seen it that there is a difference between simple and segmental sliding bearings as far as the bands of resonant frequencies are concerned.

Rotary system working in resonant frequency that is rotor rotating 2500 rev/min, its orbits of rotation are broken and have variable forms (Fig. 8a). Thickness of orbit rings is balanced between 2,5 and 3 μm (Fig. 8a).

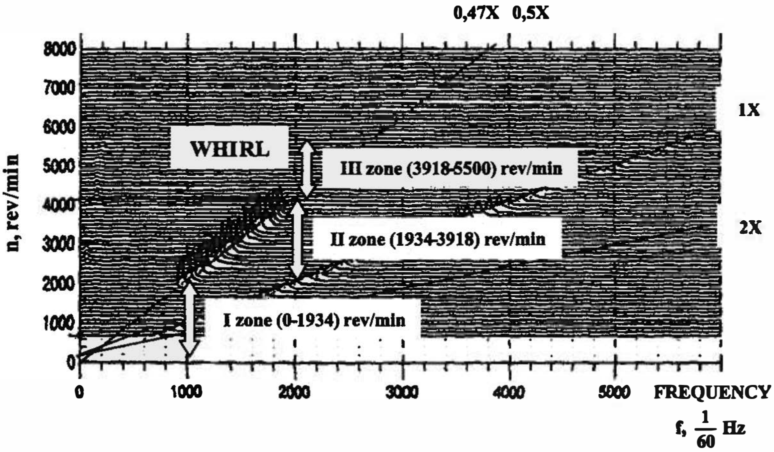

Fig. 7. Resonant frequencies of rotary system with tilting-pad journal bearings, when clearance between rotor and bearing is 50 μm

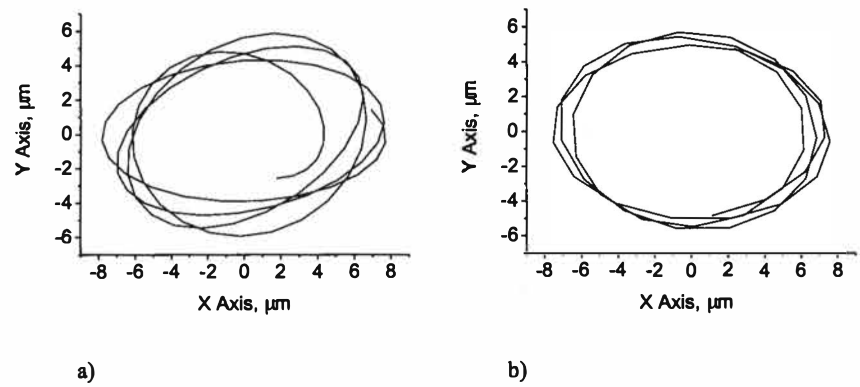

Fig. 8 Orbits of rotor axis revolution, when clearance between rotor and bearings is 50 μm: a – when frequency of rotor revolution is 2500 rev/min (II zone); b – when frequency of rotor revolution is 5000 rev/min (III zone)

When rotary system works in no resonant frequency, which is 5000 rev/min, the orbits are more correct and have forms that are more similar to ideal ring (Fig. 8b). In this instance thickness of orbit rings is about 1,5 μm.

4. Conclusions

1. The change of clearance between the rotor and the tilting-pad journal bearing (decrease or increase) changes the range of spontaneous vibrations of the system, and work parameters of system together.

2. Form of rotor axes orbits of rotation revolution and quality of work system depend on factors that exist during the operation of the system. Resonant frequency is very a negative factor during rotational revolution of the rotation system.

Manuscript reviewed by Editorial Board, March 20, 2007;
final version, March 19, 2008.

REFERENCES

[1] Barzdaitis V., Činikas G.: Monitoring and Diagnostic of Rotor Machines. Kaunas, Technology, 1998.
[2] Lipowsky G., Solyomvari K., Varga G.: Vibration Testing of Machines and their Maintenance. – Amsterdam: Elsevier Science Publishers, 1990.
[3] Jackson Ch.: Back to the Fundamentals Understanding Rotor Resonance. Sound and Vibration. – December, 1993, p.p. 8÷13.
[4] Vekteris V., ČereškaA.: Diagnostic errors of rotating systems with sliding bearing. -Scientific Symposium: Metrology and Metrology Assurance. -Sozopol, Bulgaria, 2004. p. 142÷146.
[5] Bently D.E., Hatch, CH. T.: Fundamentals of Rotating Machinery Diagnostics. -Bently Pressurized Bearing Company, printed in Canada, first printing, 2002.
[6] Muszynska A.: Vibrational Diagnostics of Rotating Machinery Malfunctions. International Journal of Rotating Machinery, USA. 1995. Vol.1, No. 3-4, pp. 237÷266.
[7] Muszynska A., Bently D.E.: Fluid-induced instabilities of rotors: Whirl and whip – summary of results. Orbit: Bently Nevada, March, 1996. Vol.17, No.1, pp. 7÷15 and Bently D.E. The description of fluid induced whirl. Ibi. pp. 3.
[8] Karnopp D.C., Margolis D.L., Rosenberg R.C.: System dynamics: A unifed Approach, 2-nd ed. USA. John Wiley and Sons, Inc. 1990.
[9] Childs D.: Turbomachinery Rotordinamic. Phenomena, Modeling and Analysis. J.Wiley & Sons, Inc. New York, 1993.
[10] Vekteris V.J.: Adaptive Tribological Systems. Theory and application. Scientific publications. Vilnius, Technique, 1996.

Badania częstotliwości rezonansowej systemów wirników z segmentowymi łożyskami ślizgowymi

Streszczenie

W pracy przedstawiono wyniki badań drgań własnych w systemach obrotowych z segmentowymi łożyskami ślizgowymi, pracującymi przy różnych częstotliwościach obrotów wirnika. Sformułowano problem badawczy, który dotyczy charakterystyk technicznych podstawowych elementów badanego systemu i jego zasady działania. Uzyskane wyniki zilustrowano wykresami. W pracy zamieszczono także porównanie wyników i dyskusję. Ogólne wnioski sformułowano w końcowej części artykułu.