ACQUISITION OF SOME RELATIONS CONCERNING BEARING MISALIGNMENT DEFECTS APPLICABLE IN TECHNICAL DIAGNOSTICS

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Summary

The investigations aimed at determining the tolerable misalignment areas of two neuralgic bearings in the turbine set, taking into account criteria of permissible load of the bearings. The areas have been evaluated by numerical analysis of the discrete model of the machine with the aid of a package of MESWIR computer codes. The ranges of tolerable misalignments of the bearings to any direction are presented in the graphs as the envelopes of maximum permissible bearing load. Basing on the method it is possible to correct the location of particular bearings to optimize tolerable bearing misalignment areas. The research will make possible to formulate a system of diagnostic relations connected with the bearing misalignment defects.

Keywords: technical diagnostics, rotating machine, slider bearing.

POZYSKIWANIE PEWNYCH RELACJI ZWIĄZANYCH Z DEFEKTEM ROZOSIOWANIA ŁOŻYSK MAJĄCYCH ZASTOSOWANIE W DIAGNOSTYCE TECHNICZNEJ

Streszczenie

Badania miały na celu wyznaczenie obszarów bezpiecznych rozosiowań dwóch newralgicznych łożysk turbozespołu z punktu widzenia kryterium dopuszczalnego obciążenia łożysk. Obszary te zostały wyznaczone w drodze numerycznej analizy dyskretnego modelu maszyny przy użyciu pakietu oprogramowania MESWIR. Zakresy bezpiecznych rozosiowań łożysk w dowolnym kierunku są prezentowane na wykresach jako miejsce geometryczne maksymalnych dopuszczalnych obciążeń łożysk. Bazując na zastosowanej metodzie możliwa jest korekta położenia poszczególnych łożysk maszyny w celu optymalizacji obszarów dopuszczalnych rozosiowań łożysk. Praca umożliwi sformułowanie systemu relacji diagnostycznych związanych z defektem rozosiowania łożysk.

Słowa kluczowe: diagnostyka techniczna, maszyna wirnikowa, łożysko ślizgowe.

1. INTRODUCTION

Large-power turbine sets consist of a number of rotors linked together by couplings and supported in a number of slider bearings. For such a machine, the bearings have to be set in a precisely defined manner with respect to each other, namely shafts should create a catenary line [1, 2, 3]. Deviations of bearing locations with respect to their design location change operating conditions in this one bearing and also in other bearings. The static load of the shafts and bearings as well as the shaft line shape is changed [2, 4, 5]. Exceeding the tolerable bearing misalignments makes further operation of a machine at least dangerous [2, 5].

Relations between bearing misalignments and the machine bearing loads, make in fact a set of relations linking the defects and their symptoms. Therefore matching like bearing displacement – bearing load characteristics can be considered as diagnostic relations and included to the diagnostic knowledge basis for the examined machine. Such a knowledge basis is necessary for automatic diagnostic systems.

The motivations for examining the effect of bearing misalignment defect on bearing load characteristics originated from the earlier research activities in the subject, which resulted in determining tolerable displacements of bearings in the 13K215 turbine set in two directions only: horizontally to the left and to the right and vertically upward and downward [6, 7].

2. APPLICATION OF THE DIAGNOSTIC RELATIONS IN DIAGNOSTIC SYSTEMS

For their operation, automatic diagnostic and advisory systems need the information, based on which they can formulate diagnoses, suggest, or even make decisions in certain situations of object's behaviour. This information should be delivered to the diagnostic system in such a form that the inherence algorithms, implemented in the system in the form of rules bearing the names of diagnostic relations, could make use of it. Preferably, this information should have a form of sets of already formulated rules, but advanced diagnostic systems can formulate these rules themselves. The diagnostic relations are the cause-effect relations linking the type of defect with its symptoms [3, 9]. If the set of diagnostic relations is based on discrete values assumed for defect simulations, these relations can be given a form of simple logical sentences of the following type: „if (cause) then (effect)", (P → S). Sets of relations of P → S type are usually obtained using of the simulation method. The method consists in assuming a defect in the machine model and finding a response to the defect simulated in this way. A direction in which diagnostic and expert systems are developed is „artificial intelligence". This name is given to systems capable of simulating the way of inference characteristic of human beings. A similar method of formulating conclusions in computer science is referred to as heuristics. The heuristic inherence allows finding an approximate solution to the examined problem, without guarantee of its correctness. However, this solution is frequently the optimal and only possible one in a certain situation, for instance when an exact solution algorithm or sufficient database are missing.

The investigations presented in this article aimed at creating sets of diagnostic relations describing bearing misalignment defect in a multi-support rotating machine, a large-power turboset. In the examined the causes were the locations and scales of rotor misalignment defect, described by numerical values of displacements of particular bearings. Each individual cause P_i can be defined by a set of three numerical values:

$$P_i = [bearing\_number,\ \Delta_x\ ,\ \ \Delta_y],$$

where: Δ_x – horizontal bearing displacement,
Δ_y – vertical bearing displacement.

A displacement of the bearing to any direction may be presented as a vector sum of the Δ_x and Δ_y.The effect of the defect, describing the resultant static and dynamic state of the machine, is expressed by a set of values of quantities selected taking into account certain requirements of the diagnostic system. Generally, the set of values describing the effect is larger, and its size depends on the number of parameters considered significant for diagnostic purposes. If the state of bearing loads is of some interest from the diagnostic point of view, this set may include average pressures on bush surfaces in bearings in horizontal and vertical projections. If of certain interest is the dynamic state of the machine, this set can be composed of values characterising the intensity of absolute and relative vibrations, horizontal and vertical, of all bearings.

From the point of view of practical applications in automatic diagnostic systems of high importance are the relations, which allow indicating a defect from the set of its symptoms, i.e.: S → P. These are inverse relations to those directly obtained using simulation methods. A way to find the relations of S → P type is inverting the P → S type relations obtained using simulation methods. An expected result of this operation is a set of mutually unique relations. This task can be done in an exact and unambiguous way only when certain assumptions concerning the sets of causes and effects are made. In practice it is not unambiguous due to the physical nature of the object of examination and the resultant nature of phenomena treated as symptoms, as well as the nature of the simulation procedure applied for obtaining these relations. The set of simulation results is limited in size and does not include all possible effects of the assumed defects. Moreover the results of simulations are burdened with errors, therefore obtaining sets of inverse diagnostic relations is only possible using the mentioned above heuristic methods.

These methods were successfully applied by a research team of the Silesian University of Technology for examining bearing misalignment defect in a turboset [8, 9]. They inversed the diagnostic relations, which had been obtained from simulation calculations in IF-FM, and then used these relations in the developed experimental diagnostic system making use of heuristic procedures [8]. This system is capable of indicating, with certain probability, the type of defect from given symptoms. The experimental diagnostic system was trained on sets of simulation-based diagnostic relations describing the bearing misalignment defect in the 13K215 turboset in horizontal and vertical direction [6, 7]. These data included relations between maximum permissible displacement of bearings 5 and 6 in four directions: right, left, up and down, and the vibration state of the turboset resulting from those displacements. The same material was used for verifying the operation of the system.

In this article presented are the results of investigations being the continuation and extension of the above investigations. Determined were ranges of permissible displacements of the two turboset bearings in arbitrary direction from the point of view of the permissible bearing load criterion and the permissible vibration criterion. Discrete maximum states of permissible bearing displacements were linked with the parameters characterising the machine state, such as loads and vibrations of all bearings. This way sets of diagnostic relations were created in the form:

$$P_i\ [bearing\ number,\ \Delta_x\ ,\ \ \Delta_y]\ \ \rightarrow$$
$$\rightarrow\ S_i\ [bearing\ number,\ Q_x\ ,\ \ Q_y],$$
$$P_i\ [bearing\ number,\ \Delta_x\ ,\ \ \Delta_y]\ \ \rightarrow$$
$$\rightarrow\ S_i\ [bearing\ number,\ A_x\ ,\ \ A_y\ ,\ V_x\ ,\ V_y].$$

All these sets of diagnostic relations can be used in the experimental diagnostic system developed at the Silesian University of Technology. The article presents part of this work, which is the results of investigations of permissible displacements of bearings 5 and 6 in the 13K215 turboset, and related diagnostic relations from the point of view of bearing load criterion. The diagnostic relations

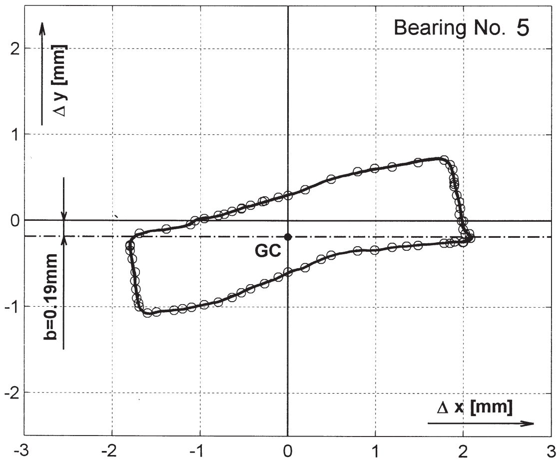

Fig. 1. The map of tolerable misalignment of the bearing No. 5 with regard to load criterion

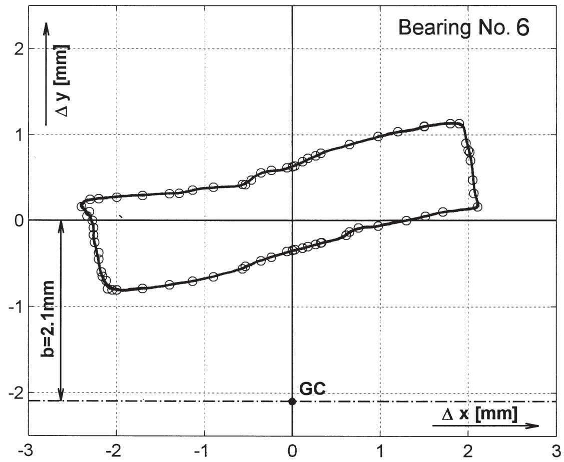

Fig. 2. The map of tolerable misalignment of the bearing No. 6 with regard to load criterion

making use of this criterion are better determined than those making use of the vibration criterion, and can be more useful as the starting data for training and developing the experimental diagnostic system.

3. METHODOLOGY OF INVESTIGATIONS

The investigations were carried out for a large power turbine set consisting of a 200 MW turbine and a generator [6, 7]. The object is a four-cylinder set, which rotors are supported on seven slider bearings. Four shaft sections are linked together by three semi-stiff couplings. Of special interest is the distribution of the pair of bearings between the LP turbine cylinder and the generator. The two bearings are located close to each other and share a common support, which is a reason of great mutual interdependence of the two bearings. The investigations were limited to misalignment of bearings No. 5 and 6 to any direction. These bearings are heavily loaded and are the source of relatively big maintenance troubles [6, 7].

The calculations were carried out using a series of the MESWIR system computer codes for non-linear analysis of rotors supported in slider bearings. The system was developed and is used in IFFM, Gdansk [6, 10]. In the MESWIR system bearings are regarded as hydrodynamic slider bearings of finite length. Oil film diathermic model is applied in the model. Bearing characteristics are calculated by solving the two-dimensional Reynolds equation applying Reynolds boundary conditions. Rotors are modeled by means of finite element method [10]. Scripts written in the MATLAB package were used to supervise the calculations. The calculations were carried on until a required convergence of iterative process was obtained i.e. until bearing misalignments attained the limiting values determined by the assumed criterion of permissible bearing load with sufficient accuracy.

An analysis concept of misalignment defect o bearings have been illustrated and explained in particulars in previous papers [6, 7], therefore here is shortly mentioned. The task was carried out by introducing a bearing misalignment defect into a basic model of the machine and observing effects. Dislocations of the bearings, representing the defects of the machine, were added to the basic bearing dislocation values resulting from rotor catenary in the basic case. The basic case was represented by a defect-free numerical model of the turbine set, in which all bearing centres were located along the design catenary line.

It was assumed that qualification criterion that allows considering the status of the turbine set acceptable is simultaneous fulfilment for all seven turbine set bearings of the bearing load condition. The average pressure on the bushing surface must be lower than 2 MPa. The limiting pressure on a bush surface was assumed after turbine industry for designing large slider bearings.

4. RESULTS

The Tab. 1 contains calculated values of maximum tolerable misalignments of analyzed bearings No. 5 and No. 6 purely in horizontal and vertical direction: to the right, to the left, upward and downward. The number of bearing in which the load was exceeded as well as direction of load being exceeded is pointed out in the last column. The table allows comparison of areas of purely vertical and purely horizontal tolerable misalignments of bearings No. 5 and No. 6. It is seen in the last column of the table that permissible values of bearing load can be surpassed in any bearing, not only this one on which a defect was imposed.

Ranges of tolerable displacements of the bearings No. 5 and No. 6 to any direction are graphically presented as maps of tolerable displacements in Fig. 1 and 2. The origin of the coordinate system represents the initial location of the centre of bearing bush, with respect to which the bearing was dislocated. A dotted-broken line represents an axis crossing the geodesic line (horizontal stright reference line) at the point marked GC. It results from Fig. 1 and 2 that tolerable misalignment areas calculated with regard to the load criterion are confined by almost regular closed loops. The graphs for the two bearings theoretically should be similar, as the bearings have almost the same construction and the same direction of rotation. But they become similar in mathematical meaning when one of them is turned 180 deg around the coordinate system origin.

Tab. 1. Calculated values of maximum tolerble misalignments of bearings

No. of bearing	Direction of displac.	Displacement delta [mm]	Load exceed in bearing
5	right →	Δx = 1.9811	bear. 5, dir. x
	left ←	Δx = -1.0605	bear. 5, dir. y
	up ↑	Δy = 0.2963	bear. 5, dir. y
	down ↓	Δy = -0.5949	bear. 6, dir. y
6	right →	Δx = 1.2994	bear. 5, dir. y
	left ←	Δx = -2.2720	bear. 5, dir. x
	up ↑	Δy = 0.6290	bear. 6, dir. y
	down ↓	Δy = -0.3435	bear. 5, dir. y

The observed equality of ranges of allowable bearing displacements of the two neighbouring bearings to two opposite sides may lead to the conclusion that these bearings impose load to each other becouse bearing No. 5 is located too high with respect to the bearing No. 6. Moving bearing No. 5 down by about 0.2mm or moving bearing No. 6 to opposite direction by the same value loads one of the bearing and lightens the second bearing at the same time. This would result in higher vertical symmetry of the diagrams. Similarly, moving bearing No. 5 to the right by about 0.5 mm or moving bearing No. 6 to the left by the same value also results in higher horizontal symmetry of the diagrams. Symmetry of the diagrams cause wider tolerance of the machine to random, always possible, emergency displacements of these bearings.

Very important part of the results of the work, impossible for paper presentation is set of parameters expressing the static and dynamic state of the machine corresponding to particular bearing misalignment defects. The sets of parameters containing information about machine defect and its status can be included into the knowledge base of the turbine set diagnostic system, which is built-up.

5. SUMMARY

1. The areas of tolerable misalignments of bearings delimited with regard to load criterion reveal approximate central symmetry.
2. For the pair of bearings located close to each other, one bearing reveals the range of tolerable misalignments in a given direction close to that revealed by other bearing in opposite direction.
3. The mirror reflected shapes of the area of tolerable misalignments of the two neighbouring bearings suggests, that the bearings impose the load reciprocally one to another.
4. The fact, that the bearings load themselves reciprocally suggests that the constructional rotor line is not optimal from viewpoint of machine's resistance to bearing misalignments. It can be corrected basing on results of this work.

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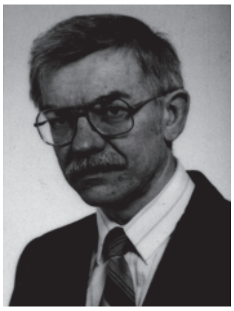

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