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POLISH ACADEMY OF SCIENCES

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114

GDAŃSK 2003

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Aims and Scope

Transactions of the Institute of Fluid-Flow Machinery have primarily been established to publish papers from four disciplines represented at the Institute of Fluid-Flow Machinery of Polish Academy of Sciences, such as:

- Liquid flows in hydraulic machinery including exploitation problems,
- Gas and liquid flows with heat transport, particularly two-phase flows,
- Various aspects of development of plasma and laser engineering,
- Solid mechanics, machine mechanics including exploitation problems.

The periodical, where originally were published papers describing the research conducted at the Institute, has now appeared to be the place for publication of works by authors both from Poland and abroad. A traditional scope of topics has been preserved.

Only original and written in English works are published, which represent both theoretical and applied sciences. All papers are reviewed by two independent referees.

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TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 114, 2003, 3-4

Editorial

These Special Issues of the *Transactions of Fluid-Flow Machinery*, Nos. 113 and 114 contain selected papers from the International Conference on *Turbines of Large Output* devoted to commemorate 100th Birthday Anniversary of Prof. Robert Szewalski. The conference was held in Gdańsk, Poland on September 22-24, 2003.

The Conference is a continuation of previous conferences held at the Institute of Fluid-Flow Machinery PAS in former years dedicated to technology of steam turbines. Series of conferences bearing the same name took place in the years 1962, 1965, 1968, 1993. In 1997 organised has been a conference on steam turbines and related topics, but with a slightly amended title – *Problems of Fluid-Flow Machinery*. At present at the Institute of Fluid Flow Machinery there are conduced research of fundamental character encompassing both the issues related to steam turbines and fundamentals of power engineering.

Organisers of the present conference have returned to the traditional name, i.e. Conference on *Turbines of Large Output* to mark the respect to the memory of Professor Robert Szewalski (1903-1993), the founder and a director of the Institute of Fluid-Flow Machinery for several years, and initiator of the conference series devoted to the problems of steam turbines.

The Editors are very grateful to the referees of the papers presented in this issue of the *Transactions of Fluid-Flow Machinery*: J. Badur, W. Batko, E. S. Burka, J.T. Cieśliński, P. Doerffer, A. Gardzilewicz, B. Grochal, J. Kiciński, G. Kosman, T. Król, J. Krzyżanowski, J. Mikielewicz, A. Neyman, W. Ostachowicz, R. Puzyrewski, R Rządkowski, J. Świrydczuk, M. Trela, T. Uhl and Z. Walczyk.

We appreciate cordially the manifested authors interest in our conference. Special thanks are conveyed to Ms 'Maya' Bagińska, for her fruitful editorial help related to directing the papers to reviewers and correspondence with the authors of contributions.

Prof. Jarosław Mikielewicz
Editor-in-Chief

Dr Edward Śliwicki
Managing Editor

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The influence of labyrinth seals on the dynamic state of large power engineering objects

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Abstract

In the research conducted has been an assesement on the influence of the labyrinth seals in the 13K215 turboset on the dynamic properties of the machine working under stable conditions, as well as when there was a reduction in the systems stability margin.
The existing complex and nonlinear model of the 13K215 turboset and the application software for the model's dynamic investigation were used, coupling with two models of the seals. One – a very simplified model, the so-called bearings model, where the barriers in the form of labyrinth plates are neglected allowed the use of a code for the analysis of the static and dynamic properties of the slide bearings. The second one – much more complicated, the so-called fluid-flow model, allowed the incorporation of the disturbance of flow, caused by the labyrinth plates.
Applying computer analysis, utilising a methodology appropriate to model based diagnostics, the process of the system's instability was traced accounting for the forces generated in the seals obtained from the two models, above mentiond as well as in their absence.
A comparison of these processes underlies the conclusions about the influence of labyrinth seals on the dynamic state of the investigated object and the comparison of the proposed models of the labyrinth seals.

Keywords: Rotor dynamics; Slide bearings; Labyrinth seals

1 Introductory remarks

A power engineering object such as a turbine set of great power is an extremely complex object from the point of view of describing the processes that takes place there. Several characteristic systems can be discerned, the most important being:

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1. fluid-flow control system,
2. line of rotors and bearings, labyrinth seals,
3. supporting structure of stands, bodies and foundation,
4. electrical system.

Each of the above systems generates characteristic excitations regarded as forces variable in time and space, which in effect focus on the line of rotors and bearings, and in such a way determine the state of the object.

The presented investigations are connected to the forces generated in seals and the influence of such forces on the operation of the turboset under stable conditions, as well as under conditions where the system stability margin is reduced.

2 The tools of investigations

For obvious reasons a metodology appropriate to the so called model based diagnostics was applied. The basic tasks of the methodology are to obtain the relations between defects and symptoms and the creation of diagnostic relations catalogues.

Accepted research ideas require an appropriate model of the investigated object and application software. In the work a complex and nonlinear model of the 13K215 turboset was used and the application software for the model's dynamics investigation formulated in IFFM.

The purpose of this paper is not a detailed description of the model nor the NLDW application software system. Such a description is included in [1]. The most important information is that after obtaining a satisfactory convergence of theoretical and operating results, the possibility of using the formulated model was confirmed as being able to simulate defects and to build diagnostic relations.

The forces generated in the seals were determined based on two models of labyrinth seals. Both models were constructed applying a full geometry of all 30 stator and all 30 rotor seals. Additionaly assumed were the real fluid-flow parameters of the fluid i.e. pressure and temperature prior to and beyond these stages by means of specialist thermal-hydraulic calculations. Dynamic viscosity, required in calculations of stiffness and damping coefficients was obtained by means of algorithms based on steam tables.

The bearings model of the seals was created based on the code for the analysis of static and dynamic properties of slide bearings. The code used was verified experimentally and during a number of investigations for industry. The way of determining the stiffness and damping coefficients for the bearings model of the seals is described in [2].

The fluid-flow model of the seals was created as a result of a cycle of investigation made by prof. Zbigniew Walczyk and his team. As a consequence of these studies a generalized model was built, which is described in [1]. The results concerning the 13K215 turboset are in [3].

Both the above mentioned models were implemented in the NLDW system [4] which enables analysis of the dynamic state of the turboset taking into account the labyrinth seals.

The reduction of the stability margin, i.e. system damping, was modelled by a reduction of the kinetostatic stiffness of the sixth support (crucial to the considered system) in such a way as to enable the tracing of all the phases of the development of the considered defect. The reduction of the kinetostatic stiffness of the support was realised by a reduction in the value of its vertical location with respect to a geodesic line.

3 The influence of the seals on the turboset working under stable conditions

Incorporation of the forces generated in the seals in the code of the NLDW [4] enabled generation of the transverse, axial and torsional displacements of the arbitrary nodes of the system in function of time, which enabled the development of the non-elliptic trajectories of the transverse vibrations and non-sinusoidal distributions of the axial and torsional vibrations.

The comparison of the results for two models of the seals with results obtained for the basic case – obtained after matching of the model to the operating data, without consideration of the seals – led to the conclusion that the trajectories of the absolute vibrations of the bushes, the trajectories of the relative vibrations of the pin-bush system, as well as the values of the amplitudes of the displacements remain unchanged, hence the investigated interactions are negligible. In Fig. 1, 2 and 3 trajectories of absolute and relative vibrations of bearings and some chosen nodes of the system are presented. Additional nodes were chosen in points where the influence of the forces generated in the seals is extreme i.e. lying in the center of the HP, IP, and LP parts of the turboset.

It ought to be stressed here that in the bearings model of the seals a possibly extreme relative eccentricity of $\varepsilon = 0.9$ was assumed, which subsequently enabled conducting of investigations in such a way, as to induce the greatest expected interaction. For this reason the real interactions may be smaller then shown.

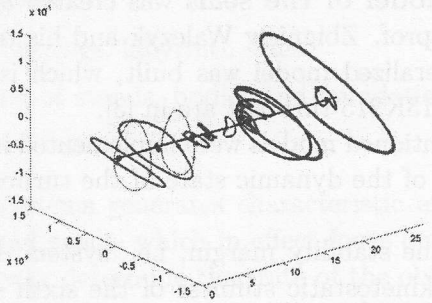

Figure 1. Trajectories of vibrations of some chosen nodes of the system – model without seals.

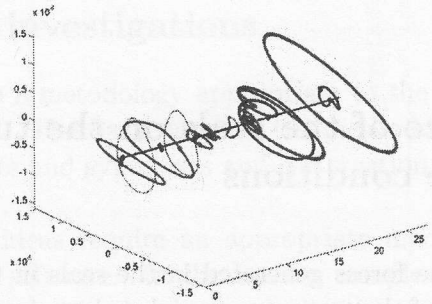

Figure 2. Trajectories of vibrations of some chosen nodes of the system – bearings model of seals.

4 Instability development process

Negligible influence of the forces generated in the seals on the dynamic properties of a powerful engineering machines requires the answer to the question whether the investigation of the processes taking place in such machines, by means of computer simulation methods, and accounting for the seals, is reasonable. In an attempt to answer this question investigations of the process of instability development in the turboset 13K215 taking into account the influence of labyrinth seals as well as without them was conducted.

Destabilisation of the system was modelled by means of a reduction of the kinetostatic stiffness of support no. 6, which in practice is a decrease of its vertical geodesic location with respect to the base location. An approximation was conducted using parametric analysis, in such a way as to enable the smooth ob-

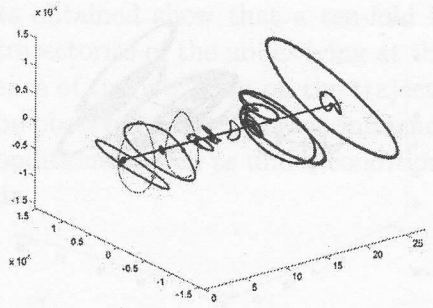

Figure 3. Trajectories of vibrations of some chosen nodes of the system – fluid-flow model of seals.

servation of the destabilization process of the trajectory and the development of the subharmonic components of the vibrations. For our purposes attention could be focused on characteristic cases for a decrease in the bearing support of 0.6 mm and 0.9 mm.

The results of the calculations using the NLDW code for a **model without seals** are represented in Figs. 4 and 5. These results form the basis of the presented figures, which in the case of a reduction of support no. 6 by a height of 0.6 mm (with respect to the base location) changes the picture of the object vibrations (as compared with the base case – Fig. 1). A reduction of the support by 0.9 mm, results in marked changes in the form of a characteristic "split" of the vibration trajectories. The trajectories of the displacements of bearings no. 6 and 7 became clearly unstable.

The same picture of vibrations' trajectories can be seen in the results for

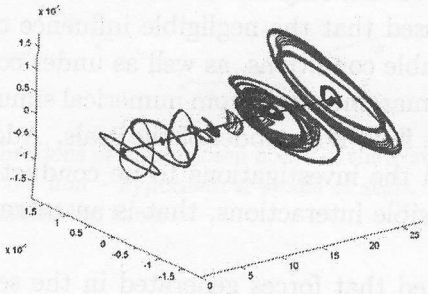

Figure 4. Trajectories of vibrations of some chosen nodes of the system – bearings model of seals, the decrease in support no. 6 of 0.6 mm.

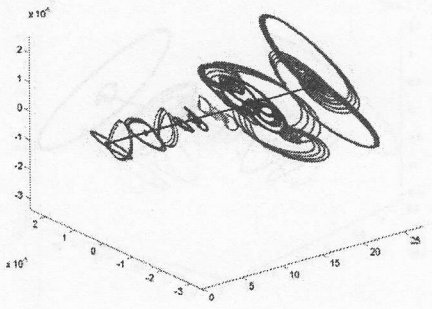

Figure 5. Trajectories of vibrations of some chosen nodes of the system – bearings model of seals, the decrease in the support no. 6 of 0.9 mm.

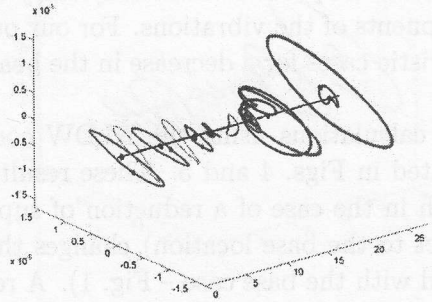

Figure 6. Trajectories of vibrations of some chosen nodes of the system – hypothetical model of seals. The coefficients of stiffness and damping increased ten times.

both cases with seals. For this only one case is illustrated.

It ought to be stressed that the negligible influence of the seals on the turboset working under stable conditions, as well as under conditions of a reduction in the systems stability margin, result from numerical simulations for the bearings model as well as for the fluid-flow model of the seals. Additionally, the eccentric bearings model allowed the investigations to be conducted in such a way as to induce the highest possible interactions, that is an extreme relative eccentricity of $\varepsilon = 0.9$.

It might be expected that forces generated in the seals would influence the destabilized system. For that reason the investigation was continued to estimate how large the forces would have to be to have significant influence upon the dynamic properties of the turboset. The absolute values of the stiffness and damping coefficients increased twice, three times, four times etc when the sign remained

unchanged. The results obtained show that a ten-fold increase influenced the shape of the vibration trajectories of the nodes lying at the centre of the HP and IP parts, with no influence of the vibration on the trajectory of the bearings. In Fig. 6, 7 and 8 it can be observed that the same influence occured on a system working under stable conditions as well as under conditions of a reduction in the system's stability margin.

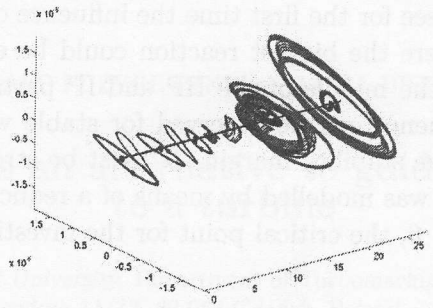

Figure 7. Trajectories of vibrations of some chosen nodes of the system for a decrease in bearing support no. 6 of 0.6 mm – hypothetical model of seals. The coefficients of stiffness and damping increased ten times.

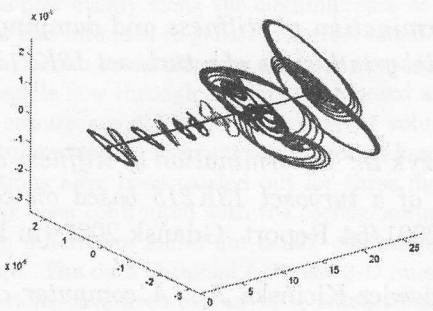

Figure 8. Trajectories of vibrations of some chosen nodes of the system for a decrease in bearing support no. 6 of 0.9 mm – hypothetical model of seals. The coefficients of stiffness and damping increased ten times.

5 Conclusions

In the light of the investigations conducted it turned out that under the given conditions and with the above mentioned tools of investigation the influence of

the labyrinth seals on the dynamic properties of powerful engineering machines are negligible even when the system works within the parameters of a small stability margin.

The results gained from the numerical simulations were taken from two different models of seals. One concentric, which takes into account the existance of the labyrinth plates. The second one, eccentric, takes into account the asymetric location of seals with respect to the external surface of the channels.

When there is a ten-fold increase of the absolute value of stiffness and damping coefficients we can see for the first time the influence on the vibration trajectories of the nodes where the biggest reaction could be expected, which means on the nodes lying in the middle of the HP and IP parts of the turboset. The same character of influence can be observed for stable work conditions as well as for a reduction in the stability margin. It must be stressed that the decrease in the stability margin was modelled by means of a reduction of the kinetostatic stiffness of support no. 6, the critical point for the investigated system.

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