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POLISH ACADEMY OF SCIENCES

# TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

114

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GDAŃSK 2003

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- 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.

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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 100$^{\text{th}}$ 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

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

No. 114, 2003, 37-47

MARCIN ŁUCZAK*

# Experimental modal analysis of support structure incorporating a three-support rotor by means of impact test

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## Abstract

In the paper presented are distributions and results of a first stage of investigations of dynamic properties of support structure incorporating a three-support rotor. The stage encompassed investigations of the object by means of experimental modal analysis using the impact test. In the paper presented have been preliminary activities for the test, its course, the results of conducted investigations and expected further scope of research.

**Keywords:** Modal analysis; Impact testing; Support construction; Rotor dynamics

# 1 Introduction

Numerical models find a wide application in diagnostics of turbines of large power. Such models are tuned based on the results of experimental investigations and measurements conducted both on real objects and laboratory apparatus. The objective of tuning a numerical model is a more precise mapping of the real object. In the research conducted at the Division for Rotor Dynamics and Slide Bearings utilized are codes simulating the dynamic states of the turboset. Tuning of such codes is based, amongst the others, on the results of experimental investigations performed on the large-scale laboratory stand for investigations of a three-support rotor fixed in slide bearings. One of the methods of acquisition of data regarding dynamic properties of laboratory rotor and the support structure is experimental method of modal analysis. The present work presents the results of the first

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stage of investigations of the support structure and the rotor obtained by means of impact test. The impact test is relatively fast and easy to perform, but the obtained results are approximate. These, however enable planning of a more accurate test using the electro-dynamic inducer, which will be a subsequent part of conducted research. The objective of the first part of presented investigations are preliminary determination of the modal model of supporting structure with the rotor founded at a standstill in the supports together with determination of the further progress of investigations.

## 2 Measurement setup

The object of investigations is a steel frame (item 6 in Fig. 2), which is a part of a support structure. In the bearings fitted in the bearings stands there is a rotor, which during the tests remained at standstill. In the course of investigated configuration the rotor was founded in three supports. Investigated setup has been presented in Fig. 1.

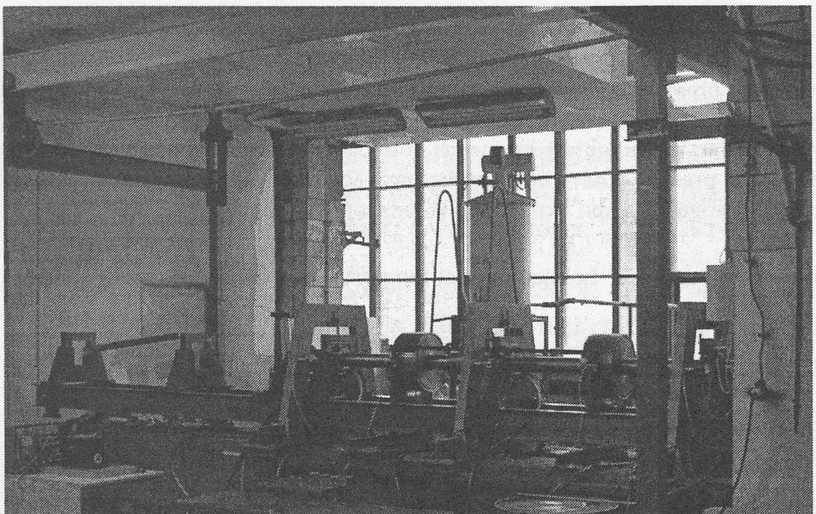



Figure 1. A rig together with a support structure.

A schematic of the laboratory stand has been presented in Fig. 2. A multi-channel analyzer Scadas III together with accompanying equipment has been

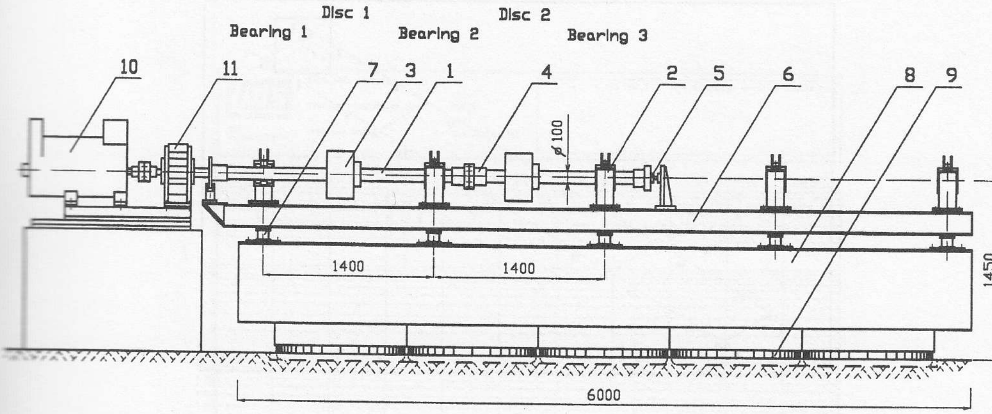



Figure 2. Rig for investigations of rotor and bearings dynamics. 1 – shaft, 2 – bearings stand, 3 – bearings loading disc, 4 – coupling, 5 – resistance bearing, 6 – frame, 7 – frame supports, 8 – foundation block, 9 – pneumatic absorbers, 10 – propelling engine, 11 – gear box.

used in the course of investigations as well as the Cada-X software.

Vibrations of the structure have been excited by means of the modal hammer manufactured by the PCB company with a socket ensuring excitation of vibrations in the range 0-2.5 kHz. Measurement of vibrations were realized by means of axial piezoelectric probe of vibration accelerations manufactured by Endevco. The frame has been modeled by means of a Cada-X software package using 30 measurement nodes. The geometric model of a frame together with location and notation of measurement points as well as the excitation point in the assumed coordinate system have been presented in Fig. 3.

## 3 Measurement

The test has been realised in two excitation and measurement planes – horizontal and vertical in 30 measurement points. Values of spectral transition function, ordinary coherence and spectral function of power density have been measured. The measurements have been taken in the frequency range from 0 to 1100 Hz with the resolution of 1 Hz. During the first measurement series excitation and measurement have been realized in the horizontal plane, whereas in the second measurement series these were taken in the vertical plane.

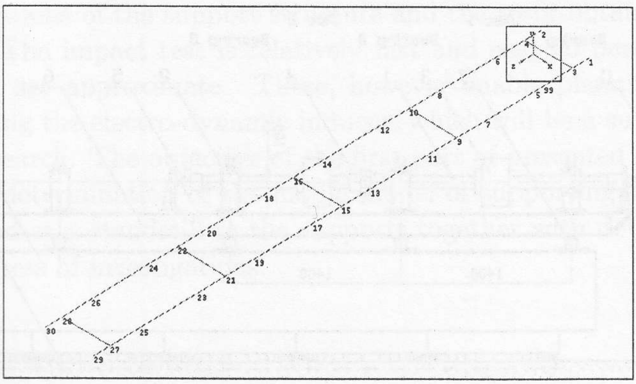


Figure 3. Geometrical model of a frame together with assumed mesh of measurement points, excitation point (99)and the coordinate system of investigated frame in the environment of Cada-X.

# 4 Estimation of modal model parameters

Estimation of modal model parameters has been performed by means of the Time Domain MDOF module for both series separately.

After performing measurements in the search for values of natural frequencies developed have been the distributions of SUM and MIF indicators for both planes. In Fig. 4 and 5 presented have been distributions of the above indicators for the case of horizontal plane.

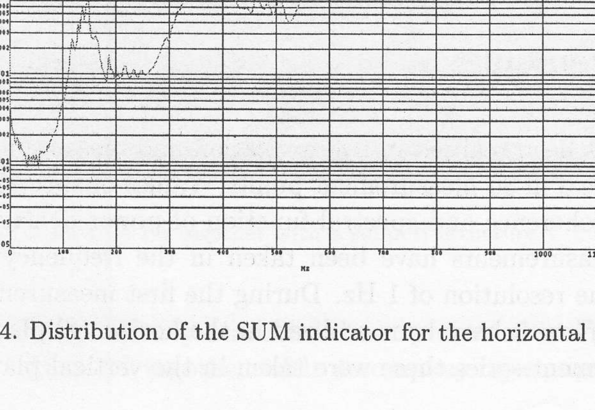



Figure 4. Distribution of the SUM indicator for the horizontal plane.

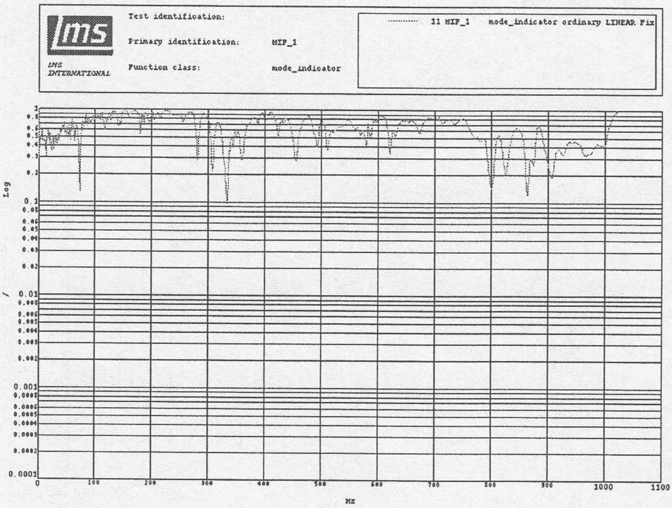



Figure 5. Distribution of the MIF indicator for the horizontal plane.

On the basis of distributions of indicators SUM and MIF conducted have been division of the entire range of frequencies where measurements were made onto partial ranges in order to achieve better accuracy of estimation.

Estimation has been conducted in the following sub-ranges:
0-100 Hz, 87-284 Hz, 282-548 Hz, 545-873 Hz, 871-1013 Hz in the case of horizontal plane and 0-100 Hz, 101-261 Hz, 261-538 Hz, 536-756 Hz, 756-1011 Hz for the vertical plane. For each sub-range determined have been the following:

- estimated were the poles of spectral transition function,
- constructed has been the stabilisation diagram,
- selected have been the poles,
- determined have been the forms of the frame free vibrations,
- compared have been measured and determined during analysis distributions of spectral transition functions,
- conducted has been the assessment of identified modal model by means of the MAC criterion, enabling orthogonality testing of identified forms of free vibrations,
- constructed have been distributions of determined forms.

Below is presented an example of estimation for range $282 \div 548$ Hz.

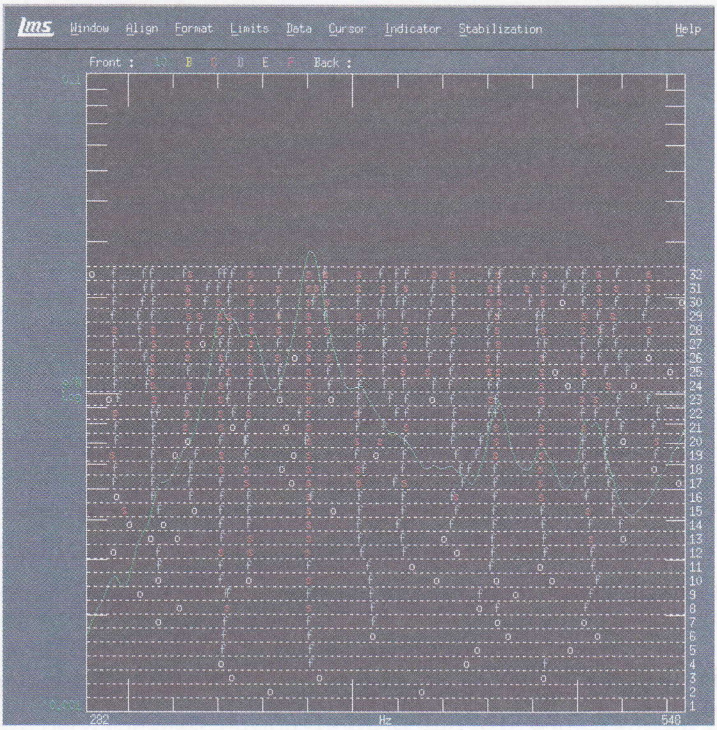
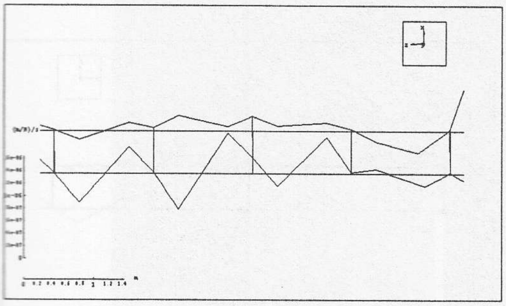
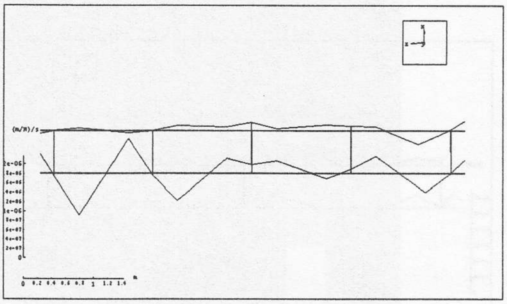



Figure 6. Stabilisation diagram with estimated poles of spectral transition function for the range 282-548 Hz.

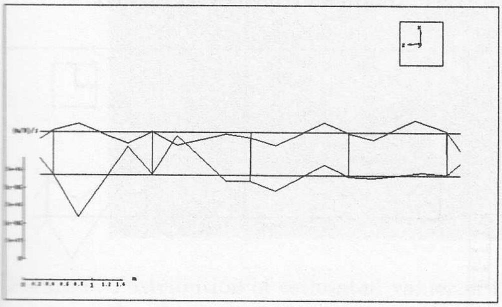

Figure 7. Comparison of measured and determined during analysis distributions of spectral transition functions in the range 282-548 Hz.



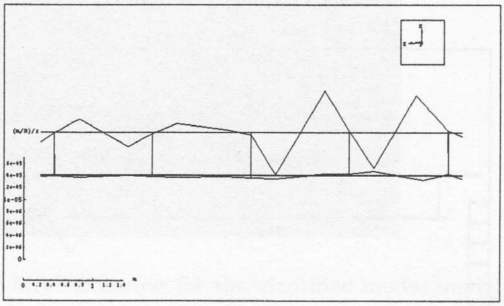
Form 1 Frequency 293.71 Hz



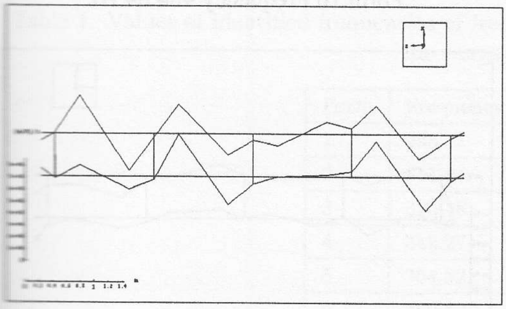
Form 2 Frequency 311.94 Hz



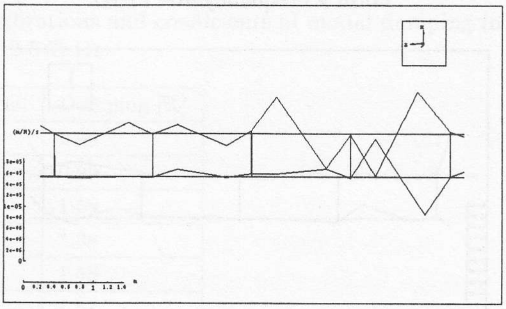
Form 3 Frequency 326.48 Hz



Form 4 Frequency 342.27 Hz

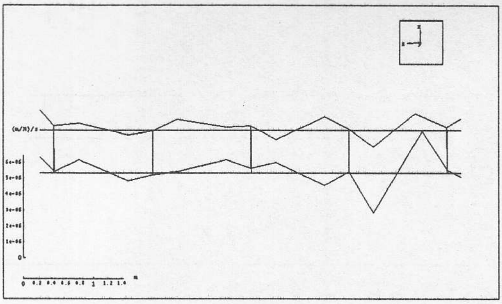


Form 5 Frequency 354.82 Hz

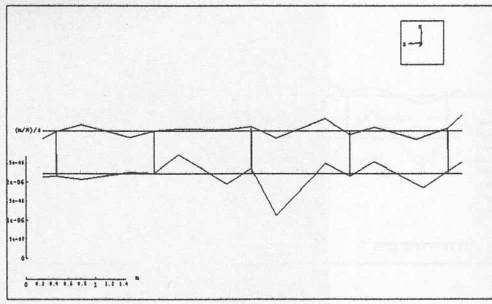


Form 6 Frequency 380.82 Hz

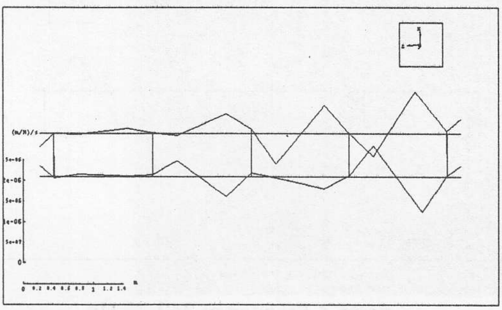
Figure 8. Identified forms of free vibrations in the range 282-548 Hz.



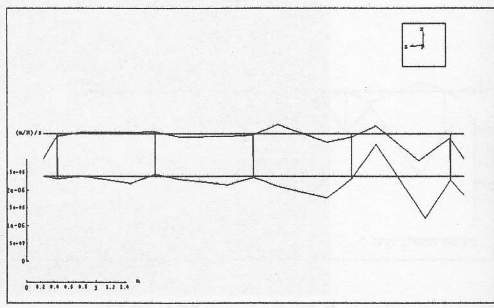
Form 7 Frequency 403.38 Hz



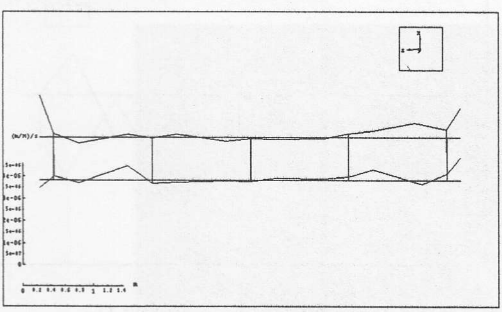
Form 8 Frequency 423.64 Hz



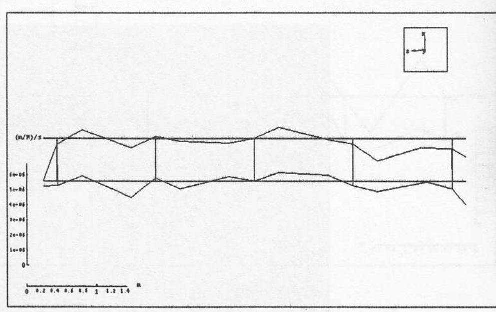
Form 9 Frequency 464.21 Hz



Form 10 Frequency 484.64 Hz



Form 11 Frequency 502.79 Hz



Form 12 Frequency 508.95 Hz

Figure 8. Identified forms of free vibrations in the range 282-548 Hz.

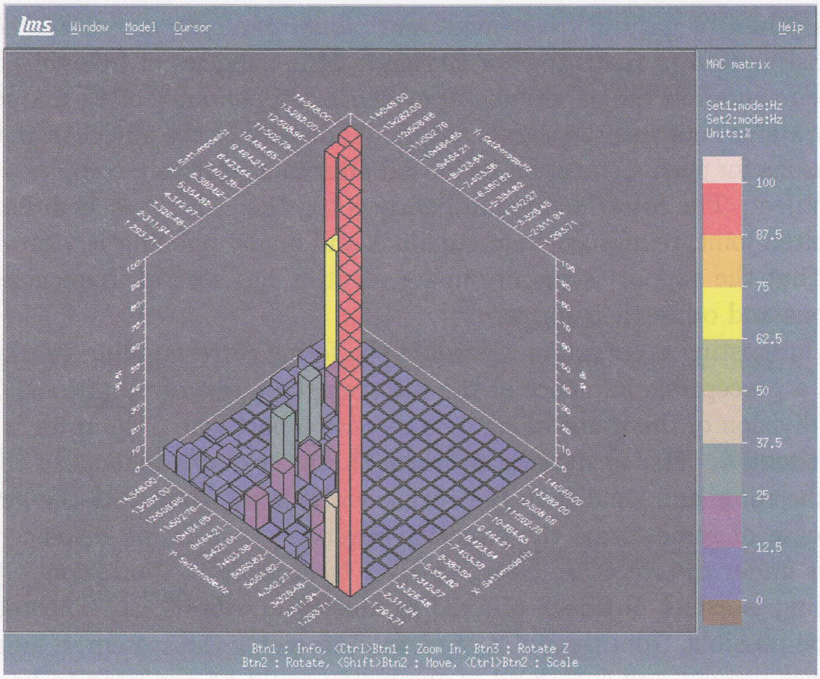



Figure 9. Distribution of estimated values of the MAC criterion for the identified modal model for the range 282-548 Hz.

Table 1. Values of identified frequencies of free vibrations and coefficients of modal damping in the range 282-548 Hz.

| Form | Frequency [Hz] | Damping [%] |
|---|---|---|
| 1 | 293.71 | 2.09 |
| 2 | 311.94 | 0.99 |
| 3 | 326.48 | 1.59 |
| 4 | 342.27 | 1.38 |
| 5 | 354.82 | 1.58 |
| 6 | 380.82 | 1.57 |
| 7 | 403.38 | 1.68 |
| 8 | 423.64 | 1.16 |
| 9 | 464.21 | 0.81 |
| 10 | 484.64 | 1.09 |
| 11 | 502.79 | 0.89 |
| 12 | 508.95 | 2.01 |

The values of natural frequencies and modal damping are presented in Table 1. Estimation in that range of 12 ranges of frequencies of free vibrations are well documented in the experimental evidence. Appearance of 12 frequencies of free vibrations confirms the significant modal density of the object in that range. The reasons for such a state can be looked after in a relatively complex structure of the object. The rotor founded in bearings together with attached discs, cushions, bolted joint, reinforced-concrete block and finally pneumatic vibro-isolators render that the support structure under scrutiny has several frequencies of free vibrations and other their forms.

An interesting observation regarding the forms corresponding to such vibrations is a perceptible influence of the rotor on the forms of vibrations. There is a clear division of the frame along its axis onto a part where the rotor is and the part without it. This is showing up through bigger displacements in the region under the rotor and smaller in the region without the rotor. At the same time in the case of some forms the situation reverses – the frame displacements in the part under the rotor are clearly weaker than those in the region without it. Interesting is a fact of a lack of axial symmetry of vibrations. Theoretically it would be possible, from the point of view of geometry the system, if axialy symmetry was present and such kind of symmetry could be expected to be revealed in the pattern of vibrations. However, due to real conditions, such situation is not present – different tension of bolts fixing the frame to a reinforced-concrete, various values of cushions stiffness, which are placed under the frame.

Vibrations in a vertical plane do not render observed displacements of the frame cross-bar underneath the bearings stands, both in the supports where there is a rotor and those without it. That can indicate either insufficient number of measurement points (however the measurement point are placed in the locations of the cross-bar fittings) or adequate structural properties of the frame which does not render displacements of supports and at the same time does not introduces unnecessary excitations to the rotor.

Identical procedure has been applied to each of the assumed ranges for both planes. In effect obtained has been a preliminary modal model of the investigated structure.

## 5 Conclusions and future research

In the frame of conducted investigations determined has been preliminarily a modal model of a supporting structure with a rotor founded on it using the impact test. The results of investigations will serve for planning of subsequent course of investigations by means of the electro-dynamical inducer. Modal analysis of a rig using such inducer will enable more accurate determination of frequencies of free vibrations of corresponding forms and damping. The results of these investigations will find applications in a more precise tuning of the numerical models developed in the group.

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