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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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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

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Numerical analysis of turbine blading vibrations

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Abstract

Turbomachine blading vibrations are one of the most important problems. They are the reason for turbine damages. Numerical methods of vibration analysis are useful in prediction of the frequencies, the distribution and localisation of stress in blades. Accordingly, in this work numerical methods and results of computations are performed for various types of blading.

Keywords: Turbomachines; Blades; Mathematical models; Vibrations; Stresses

Design, operation and modernisation of the contemporary turbomachines are impossible without detailed numerical analysis of vibrations of the blades, as the most important structural element. Such computations involve the vibration analysis of separate blades, blade packets and bladed disc with various interblade connections, as wires and shrouds. In addition to determination of vibration characteristics, often it is necessary to find distribution of vibration stresses and their localisation, to find the influence of temperature fields and stress field following from technological mistuning.

In modern turbomachines the rotor blades have complex geometrical forms, with internal cooling channels [1-7]. In the analysis of such blading structures it is suitable to use a hierarchical system of mathematical models, consisting of beams, shells and three – dimensional solid. Then the estimation of region of their applicability is necessary. For large size problems a method of analysis of complex system by parts (diacoptics) can be applied [1, 4]. This method decrease the size of particular problems at any stages of their analysis.

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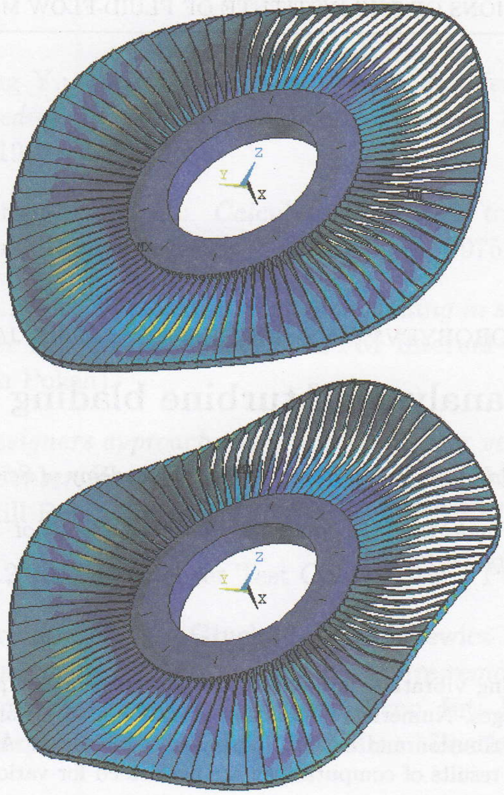

Figure 1. Modes of vibration of the blade closed packet.

In vibration and strength analysis of a blading of complex geometry various three – dimensional finite element models are usually employed. They can take into account not only material nonhomogeneities, structural geometrical complexities, but also temperature fields with significant gradients, as well as results of erosion and corrosion [7].

Development of a finite element code applied together with methods of large systems consisting identical elements, allows obtaining higher efficiency of numerical computations. In this case the whole structure can be divided into several identical sectors. Each sector comprised the blade, segment of wire and shroud, and sector of the disc [1-11]. The repetition of the matrix block, reflecting the peculiarities of the whole structure studied, provided the additional improvement of efficiency of this technique. In the process of building of the finite element global matrix of the system we can separate the matrix of the single blade. The matrix of the single blade can be decomposed into block related to its internal and ex-

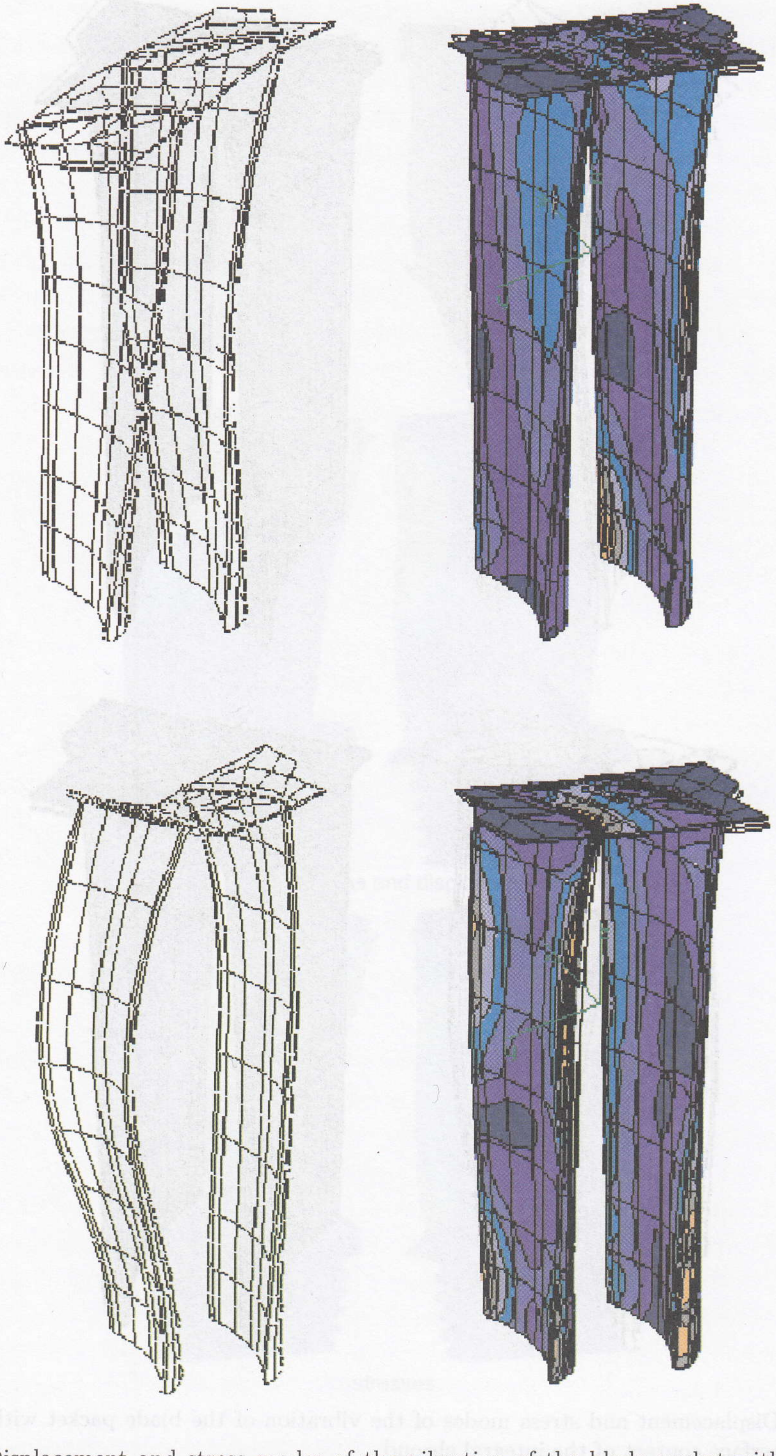

Figure 2. Displacement and stress modes of the vibration of the blade packet with continuos shroud.

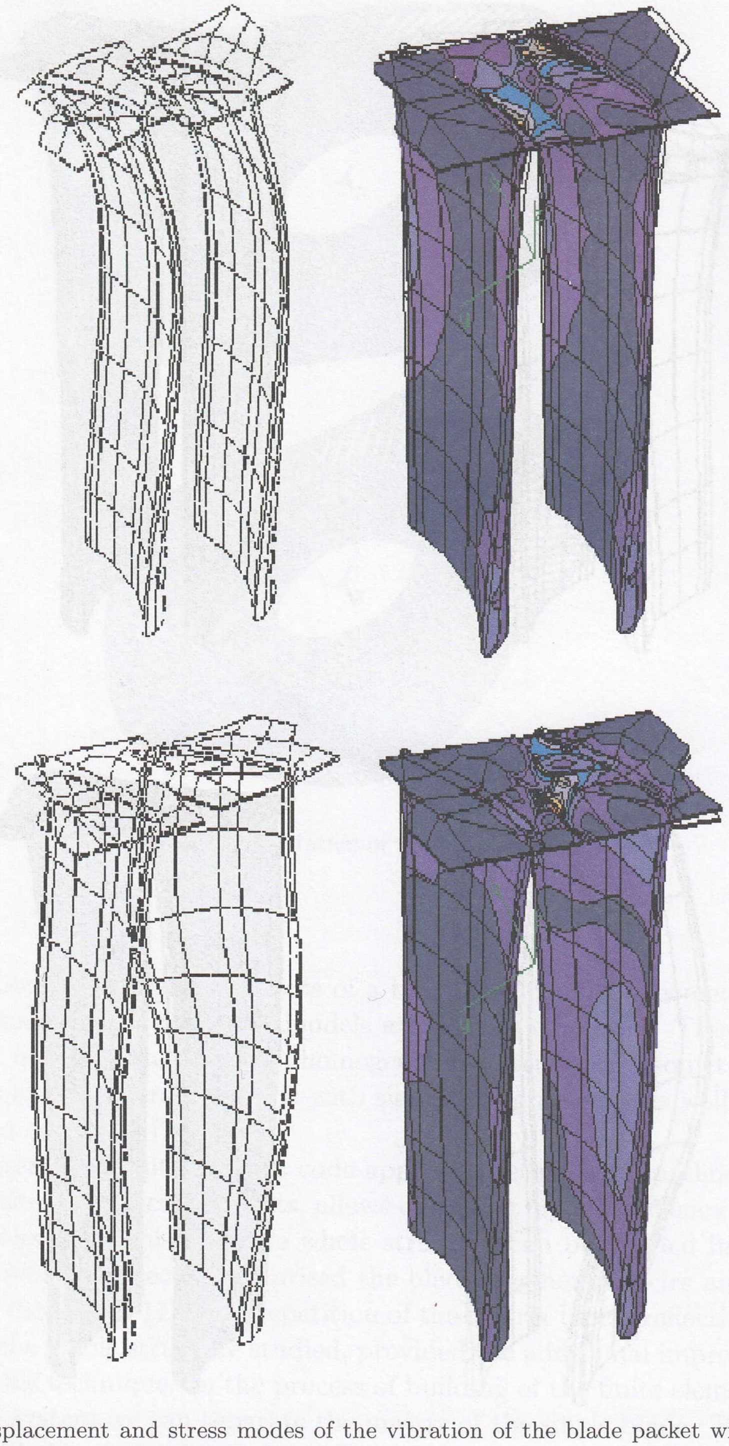

Figure 3. Displacement and stress modes of the vibration of the blade packet with partial interface contact of the integral shroud.

Figure 4. Stress and strain modes of the vibration of the two-blades packet with shroud.

ternal degree of freedom. In most cases dimension of the first matrix block is one order greater than the subsequent block. When the next blade is joined to the structure, we modify only the matrix block associated with the external boundary and additional boundary block is added. In such approach calculations of the blade packets and blades without elastic constraints are not much more complex than for the case of a single blade. In contrast to methods of superelement or various techniques of matrix condensation the presented algorithm describes vibrations of the whole mechanical system. In the finite element model we use three – dimensional, isoparametric, curvilinear elements with 20 dof's [1, 2, 4, 6-9]. The formulation of the blading vibration problem is based on the classical approach of the FEM, and leads to solution of the equation for eigenfrequencies and eigenvectors.

$$(K - \omega^2 M)u = 0$$

where u is the displacement vector, ω is the frequency of vibration, K and M are rigidity and mass matrix of the system, respectively.

The closed blade packet with continuous shroud is the structure of periodic symmetry, which order is equal to the number N of the blades on the disc. This opens the possibility to use the periodic properties for the size reduction of the vibration problem [1, 8, 9]. The general approach to solving such problems consists of its decomposition into the finite Fourier series relative to periphery co-ordinate. Then we may to consider the only one segment of structure which is a symmetry period of the problem. In such case the vibration spectrum of the system with the reciprocal symmetry is arranged into groups of coupled eigenforms. The relation between harmonics with the number k and n exists under the condition

$$k \pm n = mN \quad \text{or} \quad (k \pm n)m = N$$

where N is the order of reciprocal symmetry, m is an integer and k and n are numbers of harmonics.

This gives the possibility to examine only the group of interrelating harmonics [1]. Eigenforms of vibration of the pre-twisted blades are spatial of bending – twisting – longitudinal type. Figure 1 presents the sixth and eight forms of vibration of the turbine packeted blades. The stress fields are pictured on the surfaces of the deformed blade. The stress grows from dark to bright colour zones. We observe there a curved mode diameter, deflections of the shroud and node circles due to the stiffness of the shroud. The deformation of the shroud grows with the growth of frequency of vibration.

In turbomachinery modelling the closed blade rings with discontinuous integral shroud are more and more employed. In these packets the interfaces of shroud segment are usually pre-stressed. Depending on the contact conditions of shroud interfaces (non-sliding, sliding, no contact) it is necessary to solve three different dynamic problems. To verify modelling of the various contact condition of the shroud, the experimental and numerical results were compared [2, 3, 5-10]. These results facilitated the vibration analysis of the real blade packets with discontinuous integral shroud. To find peculiarities of vibrations of blades with shroud, we discuss the real blade packet. Figure 2 presents characteristic eigenmodes of displacements and stresses in the two – blade packet with continuous shroud. For certain vibration modes the maximum stresses appear in the shroud. However, in many cases it is necessary to take into account that the interface contact of the shroud is only partial. We show this in Fig. 3 where we see the relative displacements of segment of the integral shroud, and forms of vibration change as well. To find the correct vibration stresses it is necessary to take into account the real contact conditions (Fig. 2, 3).

Let us examine the wheel of an axial turbocompressor with two – blade packet on the disc. Each packet consists of two pre-twisted blades of non-symmetric cross-sections foundation on one root, and one segment of shroud [11]. Figure 4 presents distribution of eigenfrequencies, as well as, the modal stresses. Although some forms of displacement are similar for both blades, the modal stresses are different. Due to existence of the shroud the maximum stresses move upward from the root zone along the height of blades. Numerical vibration analysis of the blading significantly reduces the amount of necessary experimental investigations, and permits to estimate the influence of various parameters on the distribution and localisation of the stresses.

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