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Numerical and Experimental Research of Natural Frequencies and Mode Shapes for Runner of Francis Turbine

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Abstract

The construction of the physico-mathematical model for the runner of a Francis turbine for calculation of natural frequencies and vibration modes taking into account the influence of liquid is given. Calculation studies on the analysis of natural frequencies and modes of oscillations of the runner were performed on the basis of the application of a coupled finite and boundary elements method.

The developed methods also used for comparison of numerical and experimental parameters of natural vibrations for different types of hydraulic machines. The results of calculations for runner Francis turbine and the blade of the runner Kaplan turbine showed good agreement with the experimental data

Keywords: natural frequencies and mode shapes; finite element method; boundary element method; vibration; resonance frequency; structural strength; Francis turbine

1. Introduction

Recently, modernizing the HPP leads to higher requirements of the energy characteristics for components of hydro turbines . This situation gives to such design solutions, which require additional research in the field for resonant vibration of the turbine parts.

For designing turbines the methods of estimation of natural frequencies of all elements turbines such as the stator vanes, guide vanes and runner of Francis or Kaplan turbines are very importance. The finite elements method the most widely used to solve such problems. In Fjeld (2015); Zhongyu and Zhengwei (2016) are examples of analysis

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of natural frequencies of the runner turbines using commercial software ANSYS. In Doujak and Eichhorn (2016) the study of the natural frequencies and shapes of the runner Kaplan turbines are also based on ANSYS software. In this case eigenvalues were identified based on the solve of a problem of hydroelasticity. In [5] illustrates the use of open source software packages OPENFOAM and CODE ASTER to calculate natural frequencies and forced vibrations. This approach presents a number of difficulties: the complexity of the creating of grid , the modelling boundary conditions in the gaps.

This paper presents an approach to solving the problem of calculation of natural frequencies and mode shapes of the turbines using coupled of finite and boundary elements method. The basics of the method are given in Yugov et al. (2000).

2. Numerical approach

To calculate the natural frequencies and forms of oscillations in water, it is necessary to solve the following problem for the search of eigenvalues:

$$\left(\mathbf{K} - \omega^2 \left(\mathbf{M} + \mathbf{M}_a(\omega)\right)\right) \mathbf{U} = 0, \tag{1}$$

where $\mathbf{K}$ and $\mathbf{M}$ are the stiffness and mass matrices of the structure, $\mathbf{M}_a$ the matrix of added mass, which is formed on the basis of the use of BEM. In the process of calculations, the matrix of added mass is calculated for a given frequency ω_a , $\mathbf{U}$ is the displacement vector.

The desired vector can be sought in the form of a superposition of vibration forms of a ”dry” construction:

$$\mathbf{U} = \mathbf{\Psi}\xi, \tag{2}$$

where $\mathbf{\Psi}$ is the matrix of eigenmodes of oscillations obtained on the basis of the application of the FEM, the ξ vector of the contributions of the proper forms of the ”dry” structure to the shape of the oscillations of the structure in ”water”. Substituting (2) into (1) and multiplying the left from the transposed matrix of ”dry” oscillation modes, we obtain:

$$\left(\mathbf{\Psi}^T\mathbf{K}\mathbf{\Psi} - \omega^2 \left(\mathbf{\Psi}^T\mathbf{M}\mathbf{\Psi} + \mathbf{\Psi}^T\mathbf{M}_a(\omega_a)\mathbf{\Psi}\right)\right) \xi = 0. \tag{3}$$

If we assume that the ”dry” eigenforms are normalized to a mass matrix, i.e. the following relations hold:

$$\mathbf{\Psi}^T\mathbf{K}\mathbf{\Psi} = \mathbf{I}, \qquad \mathbf{\Psi}^T\mathbf{K}\mathbf{\Psi} = \mathbf{\Omega}^2 \tag{4}$$

where $\mathbf{I}$ is the identity matrix, $\mathbf{\Omega}$ is the diagonal matrix of eigenfrequencies, then equation (3) is simplified and can be written in the form:

$$\left(\mathbf{\Omega}^2 - \omega^2 \left(\mathbf{I} + \mathbf{\Psi}^T\mathbf{M}_a(\omega_a)\mathbf{\Psi}\right)\right) \xi = 0. \tag{5}$$

Thus, in calculating the natural frequencies and modes of oscillation of the structure, the vector ξ of contributions of the ”dry” forms of oscillations to the shape of the vibrations of the wetted surface is determined. This allows us to establish a connection between the ”dry” forms of oscillations and the forms of vibrations of the immersed structure. We can assume that the ”dry” form of the oscillations, which gives the maximum contribution to the shape of the vibrations of the immersed structure, will be decisive for this form, and the natural frequency of the submerged structure for this form will correspond to the corresponding natural frequency of the ”dry” design.

3. Compare with experimental results

To calculate the natural frequencies of the blades of the runner Kaplan turbines in the air was used a grid of elements of type HEX20. Mesh the runner blades shown in Fig. 1. Nodes for wetted surface coincide with the corresponding nodes of a volume grid of the blade..

As a basis for the calculation of natural frequencies of the blade in the water you used the first 50 mode shapes of the dry structure. In Fig. 2 and 3 shows the first four modes of vibration of the blade.

The results of the calculations for the first four natural frequencies are given in table 1. In parentheses are the experimental values. Data of calculation and experiment are relative to the given frequency of rotation of the turbine