The study of the influence of stabilizing devices on the pressure pulsations at the free discharge of water through the turbine

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Abstract. The free discharge through the turbine is applied in the course of construction of hydro power plant or in case of excessive water inflow during floods or emergency situations. The experimental and numerical investigation of flow-induced pressure pulsations in hydraulic turbine draft tube at free discharge was performed using a special setup for suppression of draft tube surge. Such special equipment in draft tube cone as fins and "spider"-like units was considered for reducing these pressure pulsations. The paper considers influence of these units on vortex structures and pressure pulsations in the draft tube in several regimes.

1 Introduction

Low-frequency flow-induced pulsation occurs in Francis and Kaplan hydraulic turbines at off-design operation. Since early 20th century, oscillations of power of hydraulic turbines have been observed. In 1940, Rheingans [1] showed that the oscillations are associated with draft tube surges. In 1960, Deriaz [2] showed that the draft tube surges are caused by vortex rope precession. Generally, the pulsation is associated with the unsteady swirling flow in the draft tube of the hydraulic turbine. There are several special countermeasures for reducing these pulsations. Air admission is the most widely used method [3]. However, this method is too expensive in case of static pressure at the aeration point exceeding atmospheric pressure. Another way is special equipment for stable operation. The special equipment influences the flow to reduce or destroy the vortex rope. There is such equipment as fins on the draft tube walls, a spider-like unit under the runner, a hollow cylinder under the runner hub, etc. The fins, placed on the draft tube wall along the axis of the runner, are often used to reduce swirl of the flow and, consequently, to suppress the pulsations [4]. The width of the fins is usually of about 0.1 – 0.2 diameter of the draft tube cross-section. Between 2 and 8 fins are usually used [5]. The draft tube fins are almost useless in case of high-load operating points. In addition, disadvantages of the fins are loss in the efficiency of the turbine and necessity to guard the fins from cavitation erosion and structural damage [5].

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2 Experimental and numerical techniques

An experimental study was performed on an open aerodynamic stand. The configuration considered is a 61:1 scaled-down laboratory model of a Francis turbine (RO-230) of an LMZ (Leningrad Metal Industry). Air supply in the draft tube model was carried out using a high performance air blower with the maximum flow rate Q_{max} =170 m^3/h and the excess pressure of Δp=0.4 bar. An ultrasonic flow meter «IRVIS-Ultra» and a frequency converter of the blower with feedback controlled air flow rate were used. Figure 1 provides a photo of the experimental turbine model. The draft tube model, runner, spiral case and guide vanes geometry were provided by the company LMZ and were manufactured using the technology of 3D printing.

Servo drive SPSh10-3410 ensured precise rotation frequency of the runner in the range from 0 to 3000 rpm. A computer ensured the control over the experiment. Using the original software, it was possible to maintain the flow regime with an accuracy of 1.5% and 0.5% of the flow rate and the runner rotation frequency, respectively.

The experiments included measurements of pressure pulsations with special acoustic sensors. The acoustic sensors were based on high precision microphones, attached with tiny tips for capturing pressure pulsations at the local points [6]. Two of these sensors were used to conduct point-to-point measurements. The perturbation mode that corresponds to the precessing vortex core was identified by analysing the signal from the sensors located in diametrically opposite angular positions. Note that the possibility of using well-proven acoustic technology is another advantage of the air model stand.

Pressure fluctuations were recorded using a microphone Bruel & Kjaer Type 2250. The signals from the microphones were digitized by an analog-to-digital converter L-card E-440. The experiments were conducted at the runner rotation frequency from f = 0 to 2000 rpm with a step of 500 rpm and a flow rate, varying in the range from Q =100 to 150 m^3/h with a step of 50 m^3/h. At each point, the signal detected by the acoustic sensors was digitized for 5 seconds with a sampling rate of 2 kHz.

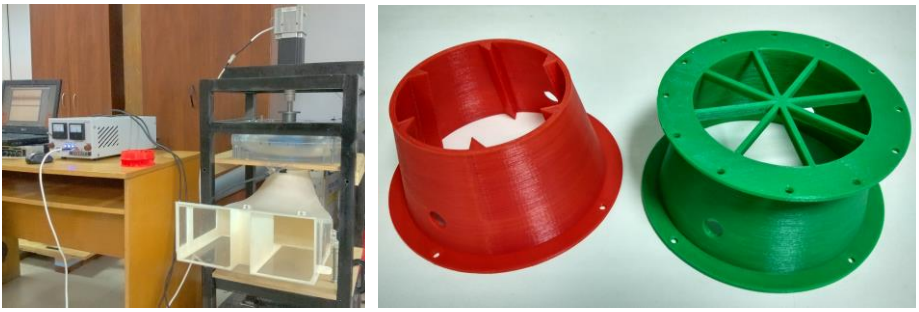

Fig. 1. The photo of the experimental stand and flow stabilization devices.

Numerically describing the flows in the flow path of water turbines one tackles several problems. The first challenge is related to modeling of turbulence in channels with complex geometry and strong swirl flow. In this paper, the used numerical technique for calculating the low-frequency pressure pulsations in a hydraulic turbine is based on the DES turbulence model (based on Menter k−ω SST model). Also in the simulation of hydraulic turbines it is necessary to consider the rotation of the runner. There are many approaches for modeling flows with rotating bodies, they include: dynamic grid, sliding mesh, moving mesh and the method based on a moving reference frame. In this work the modeling of the runner rotation was performed with rotated reference frame for the runner zone. Numerous test calculations show the correctness of this approach, both in the description of integral characteristics of flow and pressure pulsation [7-9].

3 The results

In this paper, the results of a study of nonstationary processes at free discharge of water through a turbine are presented. The free discharge through the turbine is applied in the course of construction of hydro power plant or in case of excessive water inflow during floods or emergency. The variant of free discharge with the dismounted runner of the turbine is considered. In this case, the runner is taken out of the turbine. The hydrodynamic resistance drops, and the flow of water increases substantially. However, in this case, pressure pulsations in the turbine chamber increase significantly. The reason for this are precessing vortices, formed in the spiral chamber. These vortices are clearly visible in Figure 2, which shows the results of numerical simulation. These results are given for the flow regime in which the maximum level of pressure pulsations is observed. The opening guide vanes is A_0=18mm and the flowrate Q=130 m^3/h.

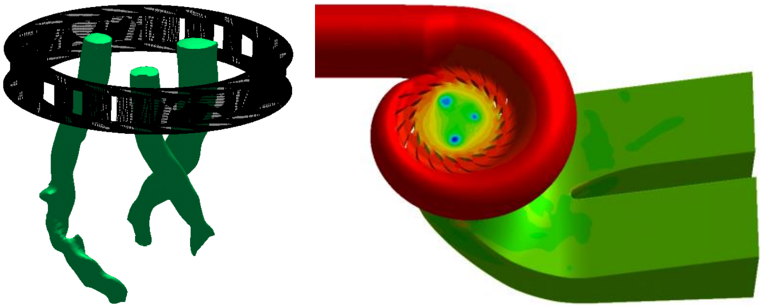

Fig. 2. Vortex structure in the turbine chamber and static pressure at the turbine wall. (For regime: opening guide vanes A_0=18mm and flowrate Q=130 m^3/h).

Pressure pulsations for this mode are shown in Fig. 3. Comparison of calculation and experiment is shown. A good agreement between calculation and experiment on the amplitude and frequencies of pressure pulsations has been obtained.

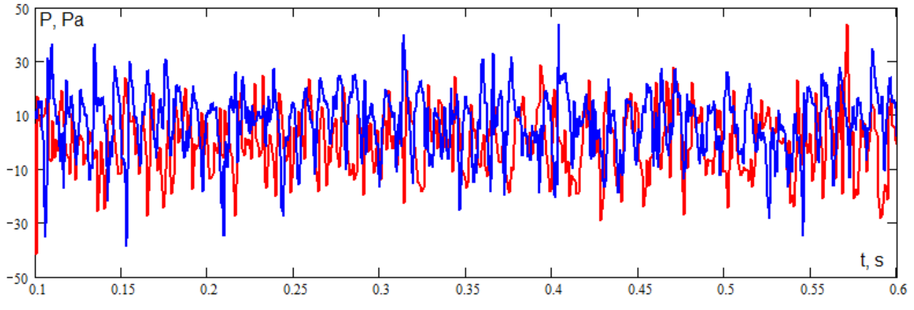

Fig. 3. Pressure pulsations in the diffuser draft tube (red color - experiment data and blue - calculation result).

To reduce pressure pulsations the stabilizing devices are examined (the fins and the cross are shown in Figure 1). These devises were installed in the turbine diffuser, and pressure pulsations were measured. The result of these measurements is shown in Fig. 4. Analysis of the conducted experiments has shown that the use of stabilizing fins may reduce pressure pulsations by 30-40%. The use of a stabilizing cross allows reducing the pressure pulsations by 50-70% for regimes with maximum pulsations.

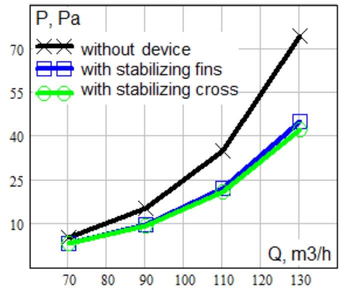

Fig. 4. Maximum amplitude of pressure pulsations in the turbine chamber.

4 Conclusions

The effect of stabilizing structures on pressure pulsations at free water discharge through the turbine is investigated. It is shown, that at free discharge the level of pressure pulsation is significantly higher than in the nominal regime. It has been shown experimentally, that the use of stabilizing devices allows reducing pressure pulsations by almost two times in the regime of maximum pulsations.

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