An experimental study of dependence of hydro turbine vibration parameters on pressure pulsations in the flow path

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Abstract. The operation modes of the hydraulic power plant water turbine with the formation of a precessing vortex core were studied on the hydrodynamic set-up with the model of hydraulic unit. The dependence of low-frequency vibrations on flow pressure pulsations in the hydraulic unit was established. The results of the air injection effect on the vibrational parameters of the hydrodynamic set-up were presented.

1. Introduction

The operation of hydro turbine equipment, especially in high head hydroelectric power plants, can be accompanied by various problems. One of them is the operation of equipment under adverse transient modes (partial or high load). In such regimes a stable vortex structure with a pronounced precession frequency formed downstream the water turbine runner. The precessing vortex core (PVC) leads to generation of high amplitude low-frequency pressure pulsations [1 - 4], which are the most dangerous in the case of resonance with the elements of the hydraulic turbine. In this case arising vibrations leads to a faster wear of the equipment and destruction of some unit elements. This work was carried out to determine the effect of pressure pulsations in the water turbine flow path on the vibration of its construction.

2. Experimental results

This work was performed on a hydrodynamic set-up with 1/14.7 scale Francis turbine model. The pumps supply water from storage tank to the pressure tank (in this work a constant water level of 3.5 m was fixed). From the pressure tank water through the flow path enters the spiral case, then passes through the stator columns, guide vanes and then rotates the runner D = 0.3 m (thus the so-called "free runner" mode is realized). Then the flow leaves the water turbine model through draft tube to the drain tank.

The set-up is equipped with piezoelectric pulsation sensors, which mounted in the wall of the conical diffuser of the draft tube. The vibration/acceleration sensor was vertically mounted on the flange of the conical diffuser. Measured signals were recorded to a PC via an ADC. The frequency of the runner rotation is measured using an optical tachometer. For optical observation, the draft tube conical diffuser is made of a transparent material. In Figure 1, one can see a conical diffuser, flow with a precessing vortex and the mounted sensors (1 - vibration acceleration sensor, 2 - piezoelectric pressure sensor).

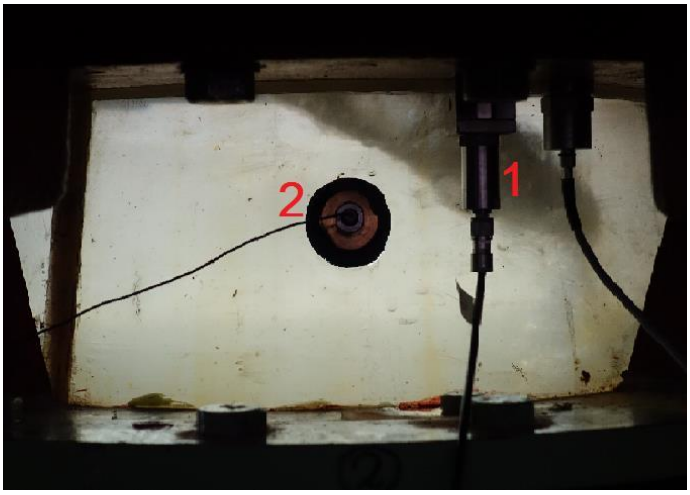

Figure 1 – Flow with a precessing vortex in the conical diffuser

Changing operation modes was performed through variation of vane's opening. The entire range of opening is divided into 15 steps. According to the integral characteristics the optimal opening is 9/15. The minimum level of flow pressure pulsations downstream the runner is also observed in this mode. Modes in range from 3/15 to 7/15 are characterized by the presence of a visible precessing vortex core in the draft tube.

2.1. One-phase flow

In this paper, the results for the guide vanes opening of 3/15 are presented. For this mode, the maximum level of vibration and most noticeable positive effect of the air injection were observed. Figure 2 shows the signal recorded by the vibration sensor.

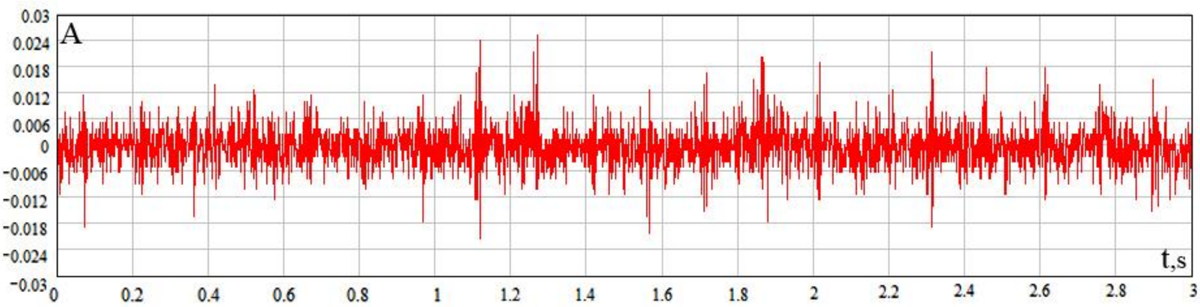

Figure 2 – Vibration sensor signal in arbitrary units

A fast Fourier transform of this signal was carried out. For a more vivid comparison of the vibration acceleration and pulsation spectrum they are presented on the same plot (Fig. 3). On the ordinate axis signal amplitude in a dimensionless form is presented. Only the low-frequency range is considered.

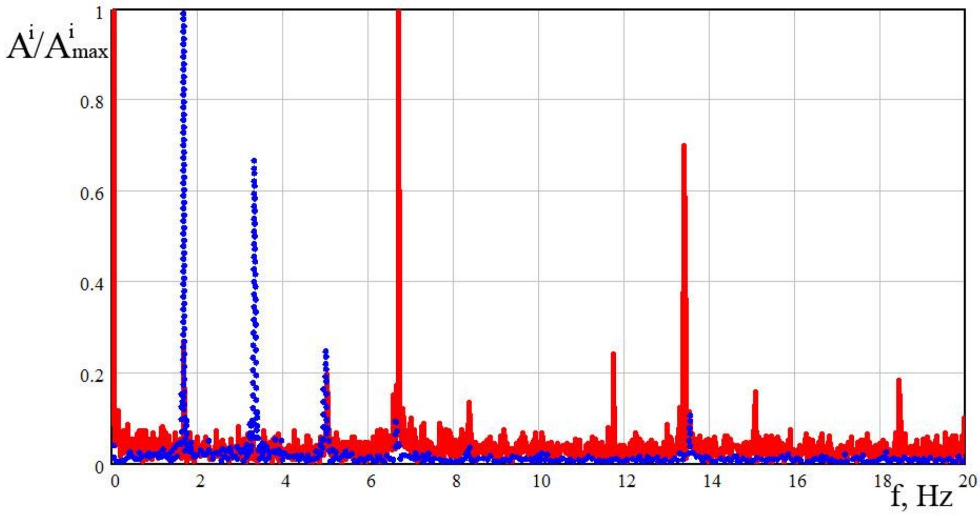

Figure 3 – Frequency spectrum
(Blue dots – pressure pulsations, red line – vibration)

Two main frequencies and their harmonics can be observed on the spectrum:
1.66 Hz – Frequency of precessing vortex core (f_{pvc})
6.68 Hz – Frequency of runner rotation (f_{rot})
It is also possible to notice combinations of these values, for example:

$$2f_{rot} - f_{pvc} = 11.7 \text{ Hz} \qquad \text{and} \qquad 2f_{rot} + f_{pvc} = 15.02 \text{ Hz}$$

In this case $f_{pvc}/f_{rot}=0.25$, this dependence is observed for openings 1/15 – 3/15. For other openings this parameter changes from 0.25 to 0.35.

2.2. Air injection

As is known from [3, 4], the air injection significantly affects the characteristics of a precessing vortex core. Hence, changing of the flow pressure pulsation parameters should lead to a change in the level of vibration.

Because of the technical impossibility of air injection through the shaft of the runner it was made into the spiral case close to the runner. The air flow rate was 6.3 m^3/h (2.4% of the water flow rate). The effect of air injection on the signal of vibration sensor can be seen in Figure 4.):

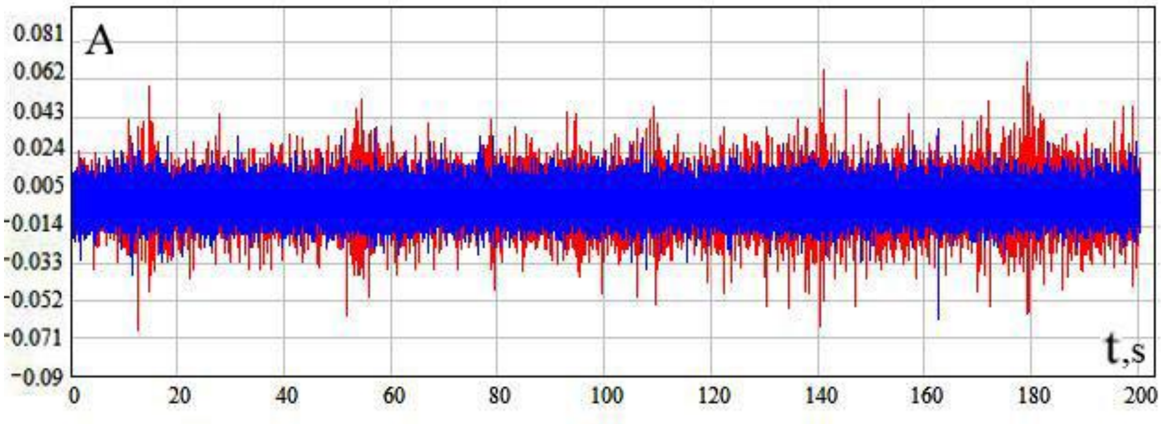

Figure 4 – Vibration sensor signal in arbitrary units
(Red line – without air, blue line – with air)

Based on a fast Fourier transformation, it can be seen that the air injection leads to the disappearance of the frequencies associated with f_{pvc}. In addition, the amplitude f_{rot} decreases.

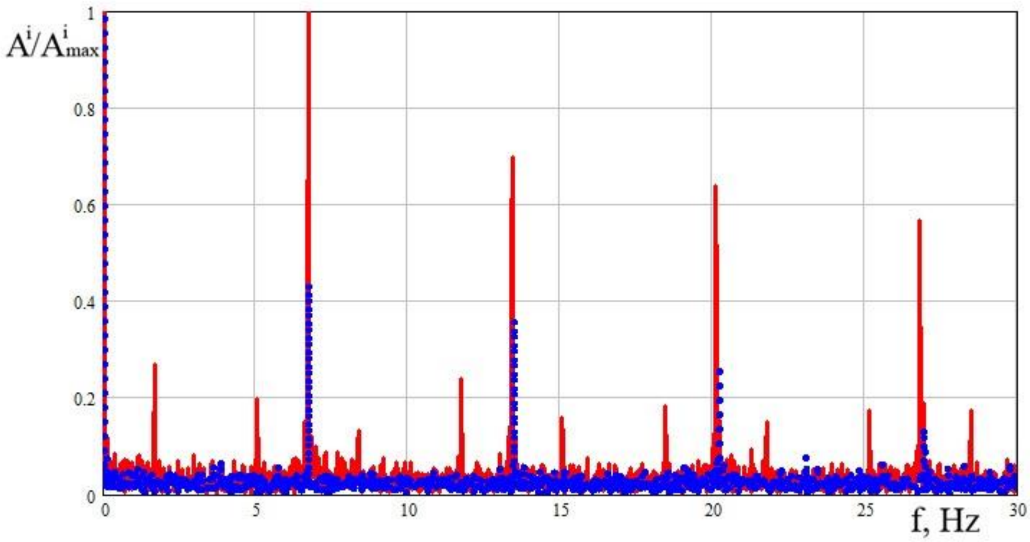

Figure 5 – Vibration frequency spectrum
(Red line – without air, blue line – with air)

It should be noted that in 6/15 and wider openings, the vibration level of the single-phase flow decreases so much that the injection of air leads to the opposite effect - an increase in the overall level of vibration. Therefore, we can talk about the advisability of air injecting only in the cases of suboptimal operating modes of the hydraulic unit.

3. Conclusions

In this paper it is shown that the air supply to the flow path leads to a decrease in the level of low-frequency vibrations arising from the pressure pulsations caused by the precession of the vortex core. However, high-frequency vibrations can increase. Thus, the air supply is expedient only in the so-called transient modes of operation of the hydraulic unit (partial or high load), when contribution of hydrodynamic processes in vibration parameters is the most significant.

Acknowledgments

The work was performed at partial support of the projects funded by the Russian Foundation for Basic Research and Krasnoyarsk Regional Fund for Support of Scientific and Scientific-Technical Activities (16-48-243076).

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