Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Numerical and experimental study of the pressure pulsations at the free discharge of water through the turbine

To cite this article: D V Platonov 2017 *J. Phys.: Conf. Ser.* **899** 022012

IOP Conf. Series: Journal of Physics: Conf. Series **899** (2017) 022012 doi:10.1088/1742-6596/899/2/022012

Numerical and experimental study of the pressure pulsations at the free discharge of water through the turbine

D V Platonov[1,2]

[1]Siberian Federal University, 660074, Krasnoyarsk, Russia
[2]Institute of Thermophysics SB RAS, 630090, Novosibirsk, Russia

tov-andrey@yandex.ru

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 situation. The experimental and numerical investigation of flow-induced pressure pulsation in hydraulic turbine draft tube at free discharge was performed.

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.

One of the options for operating the hydraulic unit with the maximum pressure pulsation is a free discharge through the turbines. A free discharge through the hydraulic turbine unit is used in the construction of a power plant or in case of water discharge and is a complex technological process. In any cases of the blank pass, the flow around the main elements of the flow path structure will take place in an unclear mode and, consequently, will be accompanied by a significant increase in non-stationary processes and cavitation, which leads to additional wear and a shortened service life of the unit. There are not many systematic studies of free discharge for high head stations at the current time, so the study and optimization of the process is an urgent task.

2. Experimental technique and numerical algorithm

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 (Leningradsky Metallichesky Zavod). Air supply in the draft tube model was carried out using a high performance air blower with the maximum flow rate Qmax =170 m3/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 of 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 the 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 [3, 4]. Two of these sensors were used to conduct peak-to-peak 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 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 [5]. The experiments were conducted at the runner rotation frequency from f = 0 to 2000 rpm with a step 500 rpm and a flow rate, varing in the range from Q =100 to 150 m3/h with a step of 50 m3/h. At each point, the signal detected by the acoustic sensors was digitized for 5 seconds with a sampling rate of 2 kHz.

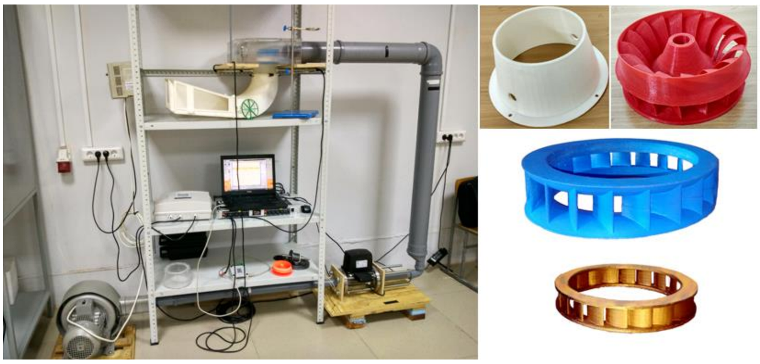

Figure 1. The photo of the experimental stand.

Describing the flows in water turbines numerically, one have to face several problems. The first challenge is related to modelling of turbulence in channels of complex geometric shapes and with strong swirl flow. In this paper, using the numerical technique for calculating of 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 modelling flows with rotating bodies, they include: dynamic grid, sliding mesh, moving mesh and method based on a moving reference frame. In this work the modelling of the runner rotation was performed with rotated reference frame for runner zone. Numerous test calculations show the correctness of this approach, both in the description of integral characteristics of flow and pressure pulsation [6-8].

3. Results and discussion

In this paper, the results of a study of nonstationary processes at free discharge of water through a turbine are presented. The figures 2-4 show the results of experimental studies for three idle modes (without runner, “frozen” runner, free runner). During the experiment, pulsations of pressure in the diffuser of the draft tube were recorded and corresponding spectra of pulsations were constructed. It can be seen that the maximum pulsations are observed for the regime without runner.

IOP Conf. Series: Journal of Physics: Conf. Series **899** (2017) 022012 doi:10.1088/1742-6596/899/2/022012

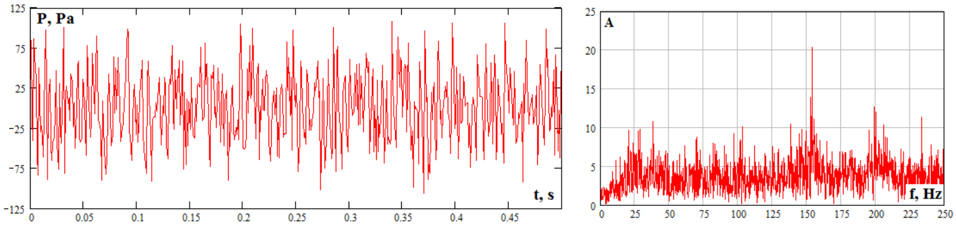

Figure 2. The pressure pulsations and their spectrum in the diffuser of the draft tube *(without runner)*.

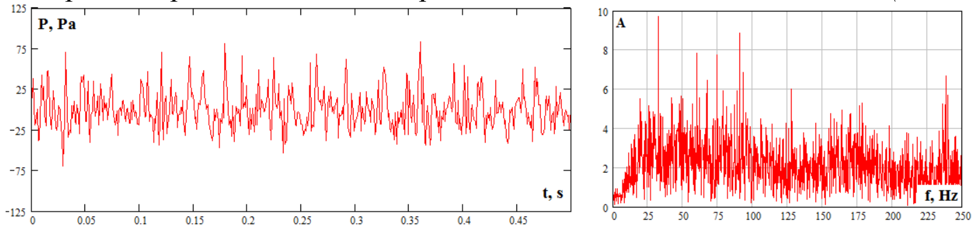

Figure 3. The pressure pulsations and their spectrum in the diffuser of the draft tube *("frozen" runner)*.

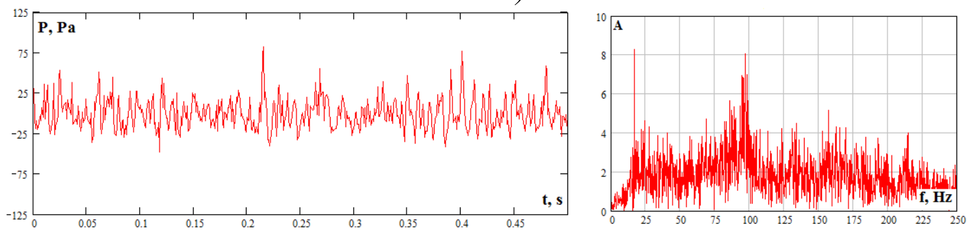

Figure 4. The pressure pulsations and their spectrum in the diffuser of the draft tube *(free runner)*.

Further, for the same regimes, a numerical study was carried out using the proposed numerical technique. Figure 5 shows the results of numerical simulation for the variant with the dismounted runner. The figures show that a structure is formed along the turbine cover, containing several precessing vortex rope. Analyzing the calculations, one can say that the vortex structure is very irregular, the vortices periodically break and form again**.**

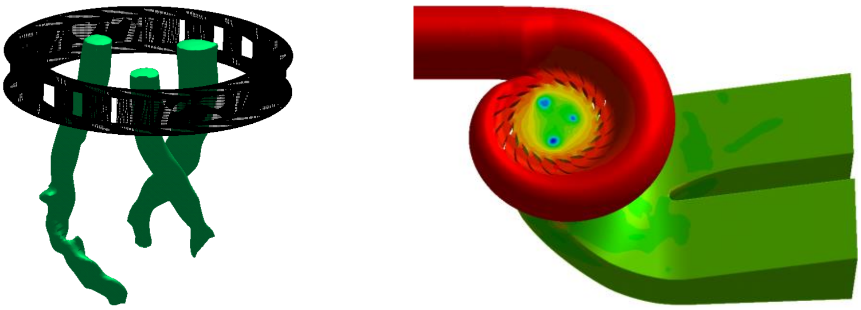

Figure 5. The vortex structure in the turbine chamber and static pressure at the wall of turbine (for regime: opening guide vanes A0=18mm, flowrate Q=130 m3/h).

Figure 6 presents a comparison of the numerical and experimental spectrum of pressure pulsations in the diffuser of the draft tube, for the mode without runner. The graph shows several expressed frequencies, which indicates a structure with several precessing vortex ropes. In general, the calculation and experiment are in good agreement with each other.

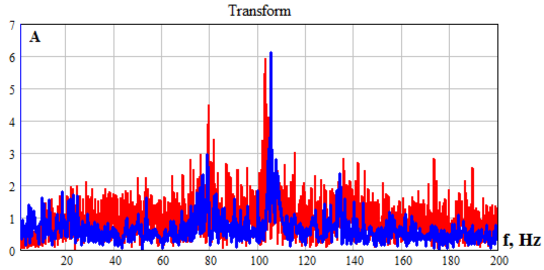

Figure 6. The spectrum pressure pulsations in the diffuser of the draft tube *(red color – experiment data, blue – calculation result)*.

4. Conclusions

In the work, a numerical and experimental study of free discharge through a hydroelectric unit for high head hydro power stations was carried out. On the experimental stand, various options for free discharge were investigated. It is shown that the maximum pulsations are observed for the regime without runner. A numerical technique for simulating of free discharge was also proposed and a numerical study was performed. Comparison of calculated and experimental data is carried out, a fairly good agreement of the results is shown. These results may indicate the adequacy of the numerical technique and its applicability for further research.

Among the options considered for the free discharge as a whole, the lowest level of pressure pulsations was obtained in the cases of the pass with a free runner. The amplitude of pressure pulsations in the diffuser of the draft tube for one of the options is about 8% of the head, which is even slightly lower than the same value at the rated operating mode of the turbine.

Acknowledgments

The current work is 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 (16-48-240707).

References

[1] Rheingans W.J. 1940 Power swings in hydroelectric power plants. Transactions of the ASME. **62** pp 171-184

[2] Deriaz P. 1960 A contribution to the Understanding of Flow in Draft Tubes of Francis Turbines. France, Nice: *Hydraulic Machinery and Equipment Symposium*. p 13

[3] Minakov A.V., Platonov D.V., Litvinov I.V., Shtork S.I., Hanjalić K. 2017 Vortex ropes in draft tube of a laboratory Kaplan hydroturbine at low load: an experimental and LES scrutiny of RANS and DES computational models *Journal of Hydraulic Research*. In press, published online April 26, 2017

[4] Litvinov I.V., Mitryakov A.S., Shtork S.I. A 2016 Study of transient flow modes in a hydraulic turbine draft tube model. *Power Technology and Engineering*. **50** pp 1-5

[5] Litvinov I. V., Shtork S.I., Kuibin P.A., Alekseenko S. V., Hanjalic K., 2013, Experimental study and analytical reconstruction of precessing vortex in a tangential swirler *Int. J. Heat Fluid Flow.* **42** pp 251–264

[6] A.V. Minakov, A.V. Sentyabov, D.V. Platonov, A.A. Dekterev, A.V. Zakharov 2015 The numerical simulation of low frequency pressure pulsations in the high-head Francis turbine *Comp. fluids*. **111** pp 197-205

[7] A.V. Minakov, A.V. Sentyabov, D.V. Platonov, A.A. Dekterev, A.V. Zakharov 2015 The analysis of unsteady flow structure and low frequency pressure pulsations in the high-head Francis turbines International *J. Heat Fluid Flow.* **53** pp 183–194

[8] D. Platonov, A. Minakov, D. Dekterev, A. Sentyabov, A. Dekterev 2016 Numerical and experimental study of low-frequency pressure pulsations in hydraulic units with Francis turbine, *J. Physics: Conference Series* **754**