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Intake Flow Problems at Low-Head Hydropower

Petr Lichtneger

The questions of intake flow conditions mostly associated with low-head run-off-river plants are discussed in the paper. As an example an intake flow non-uniformity and the arising problem with shaft vibration is presented to document the flow influence. Finally the IFLOW project is introduced which is going to deal with intake flow phenomena and possibilities of their simulation and optimisation.

Im Beitrag wird die Problematik der Einlaufströmung diskutiert, die am meisten mit Wasserkraftanlagen der niedrigeren Fallhöhen verbunden ist. Am Beispiel werden eine Anströmungsungleichmäßigkeit und die entstehenden Probleme mit Wellenvibrationen präsentiert, um die Wirkung der Strömung zu dokumentieren. Schließlich wird das Projekt IFLOW vorgestellt, das sich mit der Einströmungsproblematik und den Möglichkeiten der Strömungssimulation und Optimierung beschäftigen wird.

1 Introduction

An effective exploitation of renewable resources has been increasingly accentuated in the recent years. Operators of the existing water power plants therefore carry out overhauls in order to increase the efficiency and output of a machine. First of all, it is the modernization of the turbine hydraulic profile, i.e. modernization of the runner. However, the desired efficiency and turbine output may be reduced by hydraulic losses in an incorrectly profiled intake part. Apart from these, there are other characteristics of inappropriate hydraulic conditions:

- Formation of free surface vortex accompanied by air entering the turbine water passage;
- Increase in vibration caused by additional radial forces, as a result of non-uniform influx on the runner.

High-head water power plants usually have their intakes designed in accordance with well-proven methods. However, with low-head run-off power plants (usually equipped with a Kaplan turbine) water intake structure geometry can vary significantly from case to case.
Under optimal working conditions of a water machine the streamlines and the guide vanes surfaces should be parallel; otherwise an additional local loss occurs on the guide vanes. Non-uniform influx causes irregular load on the turbine runner producing additional radial forces acting on the rotor. Influx swirling structures also indicate an improper solution of the intake configuration design. Strong surface vortices may also suck air into the turbine water passage, thus adversely affecting the turbine efficiency and vibration.

2 A case of irregular intake flow at run-off-river power plant

A particular case of irregularity of intake flow at a run-off water power plant will be presented here. The ill-designed intake structure induces a non-uniform loading of the turbine and its increased level in shaft vibration. The objective hydro power plant Vrane (1936) with two vertical units with Kaplan turbines and the generating capacity of 2x9 MW is situated on a right bank of Vltava River in Czech. The next figure shows the HPP location on a satellite picture. The connection to the main river bed is illustrated there as well as the wake zone at the weir pile which seems to be the essential problem of the flow irregularity as will be demonstrated below.

Figure 1 The HPP Vrane Situation

After the Unit Nr. 2 (the left one at the weir pile) was refurbished in 2007 the commissioning and field acceptance tests were done to verify the hydraulic machine condition. Surprisingly a higher level of shaft vibration occurred at turbine radial bearing. A causal study brought an explanation in the uneven flow at entrance section of the pressurized part of the turbine water passage.
2.1 Flow measurement

During the turbine efficiency measurement the discharge was gauged with OTT current meters. A horizontal frame with 12 current meters was slowly dragged down and up across the cross-section in grooves of inspection gate behind the fine rack. The flow measurement was done in accordance with the direct integration method (refer to ISO 3354). Thus the perpendicular mean velocities in 12 perpendiculars were measured for the down and up direction separately, which were then integrated across the width to determine the total flow rate. Because the intake structure was split into two channels to achieve smaller inspection gate area, all measurements were done twice, in the left and in the right intake channel. The result charts showing the distribution of perpendicular mean velocity across the intake width presents the Fig. 2. The red shaded regions and arrows document the influence of the running unit no. 1 on the unit no. 2 when the flow distribution goes to the right slice yet more. When running unit no. 2 only the right to left slice flow ratio equals to 1.25 for all discharges (from 25 to 94 m³/s), when running both the unit no. 2 and no.1 the ratio increases to 1.35 (2x40 m³/s).

![Diagram showing perpendicular mean velocity distribution in the intake section at flow rates from 25 to 94 cubic meters per second.](image-url)
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Figure 3  Hydrometry frame with 12 current meters above the right inspection gate slice opening

To analyse the flow quality more precisely the multi-point measurement by velocity-area method was carried out for discharge 67 m$^3$/s. The resulting velocity fields (see Figure 4) in the left and right slice validate the intake flow non-uniformity; the right slice shows a flat flow distribution whereas the left slice shows significant regions with smaller velocity values which are supposed to be caused by a wake region in front of fine rack in the intake bay and / or a partially blinding of the fine rack. The wake zone flow disturbances were clearly observed (see the wake zone in Fig. 1).

Figure 4  Velocity fields in the pressurized intake section – the left and the right slice separated with a pillar (the regions with maximal velocities are red coloured, the regions with minimal velocities are blue coloured; all values are positive)
2.2 Shaft displacement measurement

The shaft displacement was measured in turbine radial bearing plane and in lower and upper generator bearing planes. The measuring plane at turbine bearing was set ca 1.3 m above the upper bearing brass edge actually. The measured maximal kinetic shaft displacement $S_{\text{max}}$ (refer to ISO 7919) in dependence on the discharge is shown in Fig. 5. It’s evident that the shaft vibration above the turbine bearing rises up with the discharge compared to the vibrations nearby the generator bearings.

![Graph showing shaft displacement measurement](image)

**Figure 5** Maximal kinetic shaft displacement $S_{\text{max}}$ measured by contact less B&K displacement transducers

2.3 Shaft flexure

The signal phase analysis was done to find out what exactly happens. It seems the turbine-generator shaft flexes the more the discharge rises. The hypothesis of uneven loaded runner by the non-uniform influx onto the runner was checked up upon the static elastic shaft line. The turbo-generator cored shaft was loaded with a moment of force couple of trial value 20 kNm at point of turbine runner junction. The calculated flexure line matches the measured shaft displacement for given trial shaft load qualitative very well; see the Fig. 6 and 7.
3 The IFLOW project

Regarding the general support of power renewable resources, the resolved problems are very current nowadays. It is important to deal with a question, to what extent the ill-shaped intake structures influence the turbine behaviour. That’s why a project titled: “Intake Flow Simulation and Optimisation for Hydropower” was proposed with main goals as follows:

- To identify the negative influence of ill-designed intake structures at run-off river power plants on the water turbine efficiency and the rotor vibrations;
To find and prove the methodology of intake structure geometry optimization by means of the numerical flow simulation and the physical modelling, and to reach the best conditions for maximal turbine efficiency and its output.

The project combines civil hydraulic engineering with mechanical hydraulic engineering. Turbine producers focus on the design of a runner and adjacent water passage, whereas civil engineers concentrate on a broader area of free surface. The project is going to solve the complex intake flow interdisciplinary concerning the entire intake section configuration.

Within this project the entire intake configuration of a low-head run-off river power plant is understood: the nearest weir basin portion, the intake bay connection to the weir basin, the intake structure itself with emergency and inspection gate sections, and the (semi-) spiral case including the distributor and turbine chamber.

To solve such problems the optimization methods are to be implemented leading to geometrical adjustments of the intake part that for a design head and flow rate shall ensure:

- Uniform flow distribution in the area in front of the runner;
- Streamlines parallel with the guide vanes;
- Flow without swirling phenomena and wake zones.

Three dimensional CFD simulations have proved effective for the design of water turbine hydraulic profile. For the design of intake profile and its location, simplified 2D depth-averaged models are used, which however are not quite suitable for computation of flow closest to the intake structure. Both approaches meet at an imaginary boundary formed by an intake entrance or another given section in water passage.

Variant flow computations enable to determine the influence of the intake geometry on the hydraulic conditions in front of the runner, or on the runner itself. The optimal adjustment of the intake geometry will be sought and the final option will be verified on a miniaturized model of the objective water power plant in the hydraulic laboratory. The modern advanced methods of laser anemometry will be used for measurements at the physical model.

The project aims to examine the area of water intakes, to simulate flow in a wider range (including the intake bay connection to the weir basin), to analyze the causes of undesired phenomena and to suggest optimization procedures leading to its removal.
The obtained results should give the answer to how significant it is to assess the construction part of reconstructed water power stations and what negative effects may ill-designed intakes have on the turbine behaviour.

4 Conclusion

The paper primarily gives information about intake flow problems like the non-uniformity influx to the turbine. No optimal working conditions of low-head hydro power plants with inaccurate designed intake structure regarding the water influx (non-)uniformity to the turbine runner as mentioned above were the motivation for the IFLOW project proposal which is assumed to be started in 2009. The project with both the computational and the physical modelling part will be implemented at the Dresden University of Technology, Institute of Hydraulic Engineering and Applied Hydromechanics, and with support of European Commission.

References

Standard IEC 60041: Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines.
Standard IEC 62006: Hydraulic machines - Acceptance tests of small hydroelectric installations.

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