Final publishable summary

IFLOW – Intake Flow Simulation and Optimization for Hydropower

The aim of the project was focused on the increasing demand of intake efficiency in hydropower. In this project, the whole hydro-mechanical system of the power plant and the site specific interaction of the approaching flow, intake structure and the runner respectively were taken into consideration. The hydraulic losses due to flow separation and swirling as well as the vibration stimulation were investigated. A low head run-off-river power plant must generally be adapted to the local topography and environmental condition, and the Intake structure should be designed to bring the flow field uniformly distributed and free from disturbances to the turbine. Due to the low head, even very low hydraulic losses are responsible for relative high financial losses in the total annual energy production. Since the losses depend up on the local conditions, the general solutions are not available for all cases. Moreover, the solution obtained from one project cannot be directly replicated to other project unless the local conditions are matched. Hence, there is a need to develop the methods of investigation and optimization of intake structures for low head hydropower so the IFLOW project was executed. There were two methods of investigation concerned in foreground of the project:

- CFD (computational fluid dynamics) represented by the commercial code ANSYS CFX,
- Physical modeling methods and PIV (Particle Image Velocimetry) as an enhanced measurement technique used within the hydraulic laboratory experiments.

The PIV, often used in experimental hydromechanics, thermodynamics etc. provides the velocity data at sufficient resolution which are comparable with them from numerical modeling (CFD). The measured flow is being illuminated by a laser light sheet and one or two side viewed cameras capture images of small reflecting particles which are seeded in the water. The local particle displacements and the corresponding vector field on the illumination plane can be analyzed from a pair of time shifted images. The PIV represents disturbance free measuring technique due to its optical principal, which is still rarely implemented in hydraulic engineering research. Over the numerical modeling with CFX, the proper utilization of a stereo-PIV-system for the intake flow measurement were a big challenge within the IFLOW project.

In the initial phase of the IFLOW, a numerical study of flow condition of a semi-spiral Kaplan turbine was carried out using CFX and U-RANS (Unsteady- Reynolds Averaged Navier-Stokes) modeling. The aim was to examine the influence of artificial flow distribution disturbances at intake section on the flow field in front of the runner. The numerical results have shown that the continuous flow acceleration governed by the narrowing semi-spiral casing eliminates the flow disturbances very quickly and the flow becomes rather independent on the intake condition. Since only the flow distribution non-uniformity was modeled, the next investigation concerned the swirl phenomenon which was found to play an important role by the turbine operation problems. Although the flow acceleration may help to adjust the flow distribution, the swirl becomes stronger due to acceleration and is drawn deep inside the turbine passage. Pressure fluctuations, turbine cavitation, reduction of discharge and hydraulic losses may certainly be the main consequences of it.

The intake structure of a simplified bay-type run-of-river power plant with a half-cylindrical dividing pier was designed as a test case and as physical model built into a big test canal in the Hubert Engels hydraulic Laboratory (HEL) at the host institute. The intake flow was characterized by the side approach and strong 3D flow patterns. The free surface swirl of several strengths entering the intake was observed at the model. Stereo PIV measurements were conducted in several positions to capture the flow fields across the vortex core in front of the intake and inside of the pressurized intake canal. Because of the optical measurement, the model was built up from transparent material (acrylic glass). The fellow training in the PIV operation and data processing was integral part of this experimental research. The numerical modeling was carried out in many variants differing in type of discretization and turbulence model. A good qualitatively but also quantitatively match between numerical and experimental results could be finally achieved. There are some illustrative images about this experiment enclosed.

Thereafter, a project partner was involved to bring in a real case power plant to be investigated using the proved concept i.e. combining the numerical and experimental methods on a model consisting of a complete set of a low head hydropower including basin, the intake and the turbine area. The implementation of research methods under the real case conditions was then focused as foremost reason. The challenges include as:

- To design a reduced scale (1:20) hydraulic model of the particular power plant including one fully modeled turbine,
- To implement the optical stereo PIV system into the model,
- To model the swirl phenomena both in physical and numerical manner.

To do this, the field measurements were necessary to get better knowledge about the flow characteristics in situ. At the weir, the ADCP (Acoustic Doppler Current Profiler) was employed to measure the river bed geometry and the velocity profiles under several flow conditions. The pressure as well as vibration parameters of the turbine were also measured. The obtained data were used for the designing of the model. The model turbine, equipped with the guide and stay vanes and the runner, was prefabricated from acrylic glass partially to acquire the optical access to the measurement region located inside the intake passage. A surprisingly good match between the nature and the physical model was achieved in the swirling flow formation at intakes. Unfortunately, optical error free measurements with PIV were not possible because of a series of practical problems with a proper seeding or refractive index discontinuities. Nevertheless, sufficient good results of flow velocity profile measurements inside the intake were obtained which provided us valuable information about the negative influence of the intake swirl onto the flow profile. On the model, the flow condition (combination of adjacent turbines or total discharge) could be simulated on the hydraulic model. Furthermore, the turbine parameters and hydraulic losses were measured and their dependency on the intake flow condition was investigated. The numerical model was also created in ANSYS CFX, however due to the time consuming computations, the right numerical model couldn't be found and verified with experimental data in time. Similarly, the methods of optimization weren't addressed as deep as planned within the project because of the time demand of the experimental laboratory based works which logically had to be preferred.

Within the IFLOW project a huge amount of experiences with stereo PIV measurements and their applications in hydraulic engineering research were collected and intensive disseminated not only at the host institution. Papers concerning the intake flow problems and the current research as described above were published and presented at several scientific venues. A special workshop on optical measurements in hydraulic engineering was also organized at the host institution to establish new contacts and cooperation in that research field. The current tools for numerical flow simulation still need experimental data for the validation or verification. It was shown that the optical methods as PIV can be effectively applied in hydraulic engineering research for this purpose. But not only for that – because of their disturbance free features they are able to qualitatively visualize the flow patterns at a range of scales as no other standard measuring probe. Therefore the standardization in their daily use should be required and supported.

The hydraulic engineering researchers may profit from the presented research using the published results and experiences. Particularly, concerning the problematic intake flow at low head hydropower, the methods implemented in the applied hydraulic research will help to analyze and to solve the flow problems effectively which will contribute to the increasing of power production efficiency.

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