U.P.B. Sci. Bull., Series D, Vol. 76, Iss. 3, 2014 ISSN 1454-2358

AXIALT A SUCCESS STORY IN HYDRAULIC TURBINES RESEARCH

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This paper presents an overview of the AxialT project initiated in 2007 by the Laval University Consortium on Hydraulic Machines. The aim of this project was to improve the knowledge of hydraulic phenomena in a propeller turbine. Experimental, numerical and theoretical approach was employed. Modern experimental techniques as 2D-LDV, 3D-PIV, unsteady pressure probe and unsteady embedded pressure measurements using a telemetric data transmission system were used to qualify the flow in an axial turbine model. Specific methods were developed for the analysis of the experimental data and numerical simulation results. A database, shared between Consortium partners is available for future analysis.

Keywords: Axial turbine, propeller flow, vortex detection, 3D PIV

1. Introduction

The Laval University Consortium on Hydraulic Machines was launched in 2007, aiming at achieving a better understanding of the hydraulic behaviours of low-head turbines. The Consortium is collaboration among turbine manufacturers, utilities and Canadian governmental agencies. The Consortium projects are designed by its committees and lead by the University. All partners share the full experimental and numerical data, organized in a database produced by the Laboratory of Hydraulic Machines (LAMH).

The Consortium's first project, AxialT, has been operating since 2007, supported by the Natural Sciences and Engineering Research Council (NSERC) of Canada through a Collaborative Research and Development (CRD) Grant [4]. The main objective of the AxialT project is to improve the comprehension and the numerical simulation of the flow through a low-head axial (propeller) hydraulic turbine. It consists of measuring and numerically simulating the flow in a scaled propeller turbine.

The project is a close collaboration between Consortium researchers, engineers and graduate students in scientific meetings and workshops (more than 30 partners representatives), which triggered the development of an invaluable expertise in confronting experimental data and numerical simulations.

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The AxialT project was focused on a helix axial turbine flow investigation. Theoretical, experimental and numerical methods were employed for the investigation.

This project was an opportunity for new developments in the hydraulic machines field in terms of scientific instrumentation (unsteady pressure probes, 3D PIV inside the runner, etc.), flow analysis (experimental data base for the flow behaviour in the complete hydraulic machine for a large range of operating regimes) and numerical calculations (influence of geometrical differences of the geometry, influence of the different ways to consider rotor/stator gap, etc.).

The project is completed, but the consortium partners are continuing the analysis and investigations, based on the existing database.

2. Experimental setup

The model used in the framework of this project is a 1950's-era propeller turbine with a counter clockwise rotation. The standard 1:17 scale model used for this project has a semi-spiral casing with 24 stay vanes and 24 wicket gates. It is shown in Fig. 2, also featuring the coordinate system (*z* vertical, *x* horizontal toward the draft tube, *y* horizontal toward the left of the turbine when looking downstream from the top.

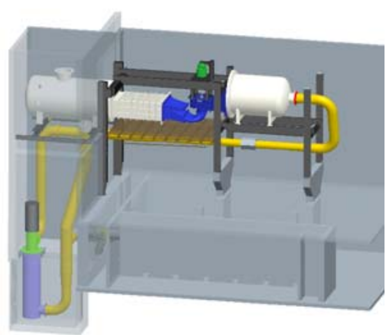


Fig. 1 LAMH Test stand

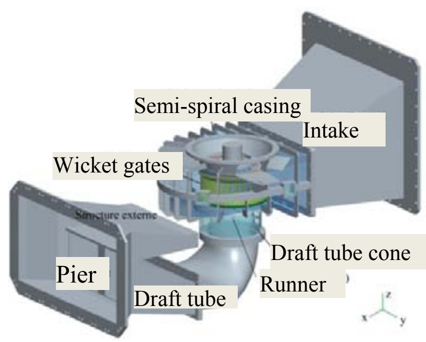


Fig. 2 AxialT propeller model

Flows were investigated for ten different operating conditions spread both from partial to overload and from low head to high head. The location of those points on the efficiency hill chart is presented in Fig. 3.

The axial turbine model is implemented in the test stand suitable for performance measurements of turbine according to the IEC 60193 standard. This test rig shown in Fig. 1, consists of a classical closed-loop hydraulic facility with flow rate up to 1 m^3/s, head up to 50 m, rotational speed up to 2000 rpm and a net power at the test section up to 170 kW.

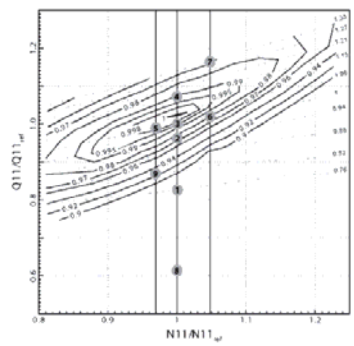


Fig. 3 Investigated operating points on hill chart

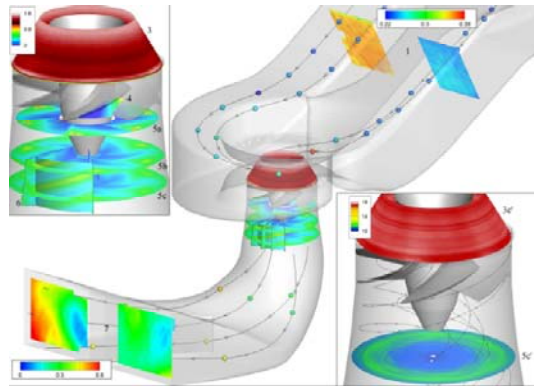


Fig. 4 Locations of velocities measurements in different locations : intake, propeller inlet, inside propeller, draft tube cone, draft tube outlet

3. Investigations methods and analyses developed in the project

Many investigation methods and analyses were developed for detailed flow investigations. In this paper only the developments and the relevant bibliography will be indicated.

A first topic, at the beginning of the project, was the accuracy and the influence of the accuracy of the model/prototype geometry for the performances, and especially of the runner. The complete geometrical recovery of the runner was performed and the influence of the geometrical differences of the blades and the gap blades/hub was analysed by numerical calculations [10].

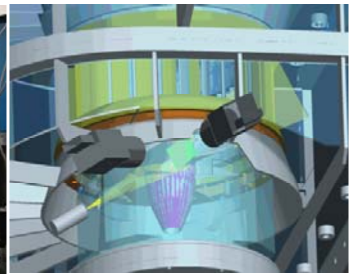
Another topic was the influence of the unbalanced of the flow at the runner inlet. LDV measurements were performed on the two intake channels [8]. This unbalance was followed from intake to runner entrance and runner outlet. Between the guide vanes and the runner were performed unsteady total pressure investigations. At the runner outlet was performed 3D LDV (re-composition of the 3 D velocity field by 2 measurements with 2 velocity components) – see

Fig. **5** and 3 D PIV measurements [7]. Numerical calculations were performed too [8], [12].

The main research subjects where related to interaction rotor-stator [6], energetic balance of the runner [1], draft tube stability [7] and operation at partial load [9]. The draft tube cone flow was particularly investigated. Phenomena like blades wake propagation [11], vortex rope and unsteady pressure evolution was addressed by both experimental and numerical investigation methods.

Modern measurement tools was developed / employed to investigate the unsteady flow behavior. Unsteady pressure probe - see

Fig. **7**, [2], PIV in two phase flow [5], unsteady embedded sensors and telemetric system for the runner blades instrumentation [3] was developed and implemented.



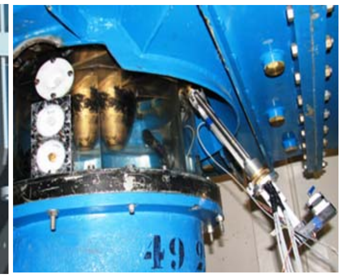


Fig. 5 3D LDV at runner outlet

Fig. 6 3D PIV inside the runner

Fig. 7 Total pressure at runner inlet

In this paper will be presented results of the velocity runner investigations, one of the most important and original results of the project.

4. Runner velocity investigations

The measurements performed inside the runner represent an important breakthrough in experimental measurements investigations. The experimental results of unsteady flow within a blade channel of a hydraulic turbine runner are presented with a 3D PIV system – see
Fig. **6**.

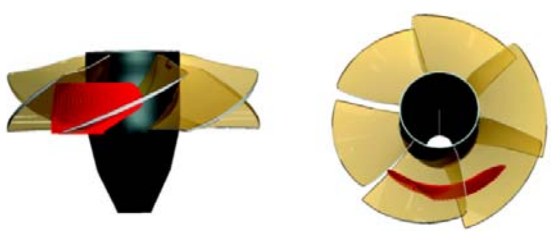


Fig. 8 Superposition of the measurement plane in the runner reference frame for the 20 measured phase angles

Those measurements allow us to analyze the flow fluctuations synchronous with the runner rotation and to identify coherent flow patterns. The vertical measurement plane was located at mid-span of the runner blade in the channel formed by blades 2 and 3. The in-plane spatial resolution was 3.0 x 3.3 mm. Circumferential measurements were done for 20 angular positions of the runner over a complete blade passage, representing a resolution of 3° for this 6-blade runner. Fig. **8** presents the superposition of the measurement plane in the runner reference frame for the 20 measured phase angles, showing the reconstructed measured volume.

The relative velocity field is represented for 3 operation points OP3 (best efficiency point) and part load operating points OP1 & OP8 in Fig. 9 and Fig. 10.

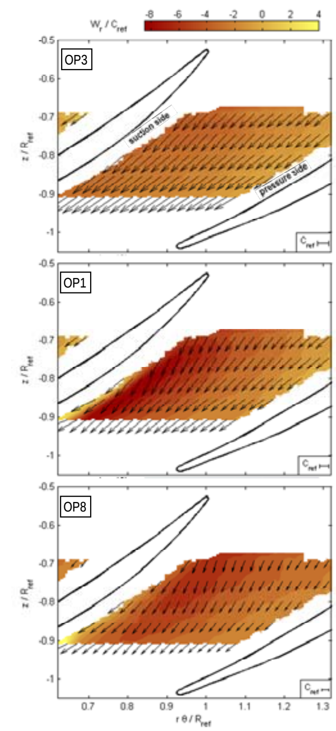


Fig. 9 Relative average velocity field; vectors: (Wθ, Wz) and contours: Wr /Cref ; r/Rref = 0.68

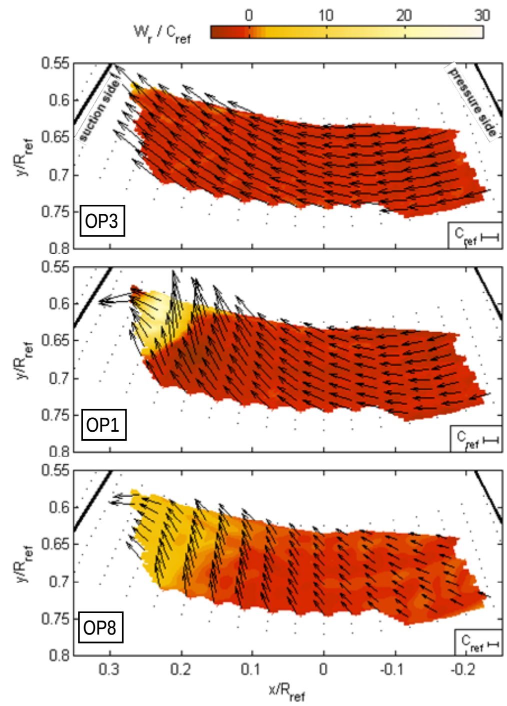


Fig. 10 Relative velocity field; z/Rref = -0.8; velocity vectors: (Wr , Wθ); vorticity contours: ωz/ΩR

The relative flow within the inter-blade channel presents a pattern similar to the hydrofoil theory. In Fig. 9, using OP3, OP1 and OP8 as examples, the velocity field is extracted for a vertical slice at constant radius. The velocity norm $\sqrt{W_\theta^2 + W_z^2}$ (relative velocity components (m/s)) is higher at the suction side of the blade than at the pressure side. This non-uniform velocity distribution in the blade-to-blade channel was observed at the runner outlet and its convection/dissipation in the draft tube cone was followed in [11]. At part load conditions, the axial and tangential velocities are lower than at optimal conditions OP3. From optimal to full load conditions, OP3 to OP7, the main flow direction remains parallel to the blade showing a good flow behavior and no flow separation has been detected based on observation of W_θ and W_z, (Fig. 9 top). However, at part load, OP1, OP2, OP8 and OP9, a local deviation of the vector direction is noticed next to the suction side of the blade associated with a higher magnitude of the radial velocity W_r (Fig. 9, center and bottom). Concerning the radial component of the velocity, a gradient is noticed in the azimuthal direction ($\partial W_r/\partial\theta$) indicating lateral movement of the fluid in the inter-blade channel. Analyzing W_θ and W_r velocity fields, the operating conditions became clearly distinguishable. Fig. 10 presents the three tendencies observed in horizontal planes using OP3, OP1 and OP8 as examples. OP3 to OP7 are alike showing no local phenomena (optimal to full load conditions). For part load operating points, OP1, OP2 and OP9, a local counter-clockwise vortex is present next to the blade suction side. Finally, OP8 stands alone with also a counter-clockwise structure on the blade suction side but covering about a third of the measurement area.

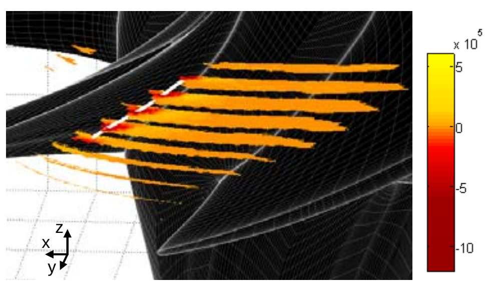


Fig. 11 Vortex center line identification using λ_2 contours at OP1

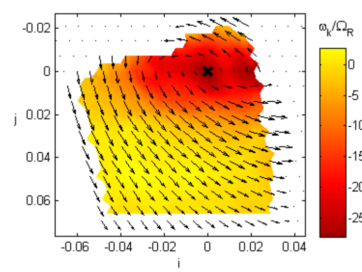


Fig. 12 Velocity field and vorticity ω_k at OP1

Inside the relative reference frame rotating at the runner rotation speed Ω_R (runner rotation speed (Rad/s)) the Coriolis acceleration induces a relative flow of rotation opposite to the runner (i.e. clockwise). The vorticity of the relative flow was found systematically equal to about $-1.3\times\Omega_R$ (note that Ω_R depends on the OP). A horizontal vorticity field at OP3 is presented in Fig.11, similar uniform vorticity field have been observed from OP3 to OP7. The relative flow induced by Coriolis acceleration covers the entire inter-blade channel and local phenomena interact with it. For example, at part load operating conditions, the leading edge vortex induced a local counter-clockwise rotation near the blade suction side with a vorticity of $\omega_z \approx 25\times\Omega_R$(OP2 and OP9 similar to OP1 presented in Fig. 10, center). At OP8, the local flow structure induce a counter-clockwise rotation with a vorticity of $\omega_z \approx 3\times\Omega_R$. For the part load operating points, the leading edge vortex was identified starting of the PIV measurements using a λ_2 (second eigenvalues of $S^2+\Omega^2$) method – see Fig. 11.

The vorticity contours - see Fig. 12, give estimation, even approximate, of the vortex extent. The vortex is counter-clockwise, parallel to the blade and close to the suction size at around mid-span.

The vortex indicates an elliptical shape that can be seen in cross sectional view see

Fig. 14. This vortex behavior was observed in cavitating conditions – see Fig. 13.

Fig. **15** show comparison of the numerical calculation of the flow compared with the experimental results (vorticity contours in maroon and PIV results in red).

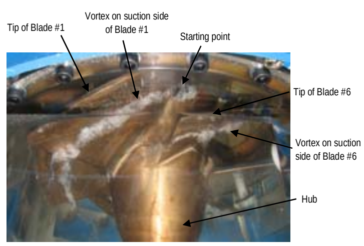


Fig. 13Flow visualization in cavitating conditions for OP1

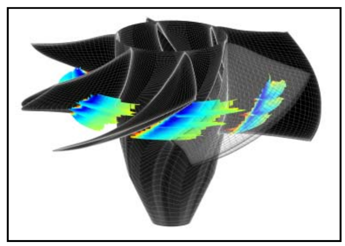


Fig. 14 PIV isocontours of relative velocity OP1

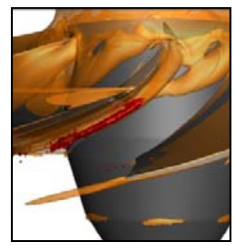


Fig. 15 Numerical calculation for OP1

6. Conclusions

AxialT is the first project of the Consortium on Hydraulic Machines of Laval University. The consortium insures a strong partnership among university, turbines manufacturers, utilities and governmental agencies. The scientific committee meetings and the workshops are occasions to exchange valuable information between university and industry, thus ensuring research relevancy.

Flows through a propeller turbine have been thoroughly investigated in the framework of the AxialT project, providing a detailed mapping of velocity and pressure fields from inlet of the intake to the outlet of the draft tube. Experimental data have been obtained over the whole operating range; from minimal to maximal head and from part load to full load. The relevant bibliography related to this research is presented.

Velocity measurements within a runner channel represent progress for the turbo machinery field. A suction side- corner vortex was detected and measured. Detail of the flow behavior is presented for many operating points.

This project permits the development of new knowledge for the university and its industrial partners related to the measurements methods, numerical calculation, and flow analysis. A database is available for future analysis and developments. Finally, the experience developed within this project shows that training support from the expert researchers participating in the Consortium is important.

Acknowledgments

The authors would like to thank the participants of the Consortium on Hydraulic Machines for their support and contribution to this research project: Alstom Power & Transport, Andritz Hydro LTD, Edelca, Hydro-Quebec, Laval University, NRCan, Voith Hydro Inc. Our gratitude goes as well to the Canadian Natural Sciences and Engineering Research Council who provided funding for this research.

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