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NEW HYDRAULIC TEST RIG FOR SMALL-POWER TURBOMACHINES

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ABSTRACT

A new universal test rig has been installed at the HES-SO VS Sion - Switzerland to assess the hydraulic performances of different types of small-power turbomachines (up to 10 kW) and other hydraulic components with complex geometry, following the IEC 60193 standard recommendations. The closed-loop circuit allows simulating different implantation levels of the model and therefore recovering the cavitation performances as well.

The present work introduces a state-of-the-art approach of an automatic regulation for hydraulic test rigs. An autonomous regulation system based on real-time measurements is developed using the capabilities of a National Instruments compact Reconfigurable Input Output device. Indeed, during operation, the system can keep constant the value of the desired parameters (e.g. testing head, discharge, pumps speed, Thoma number, etc.). Then, the implemented wireless communication architecture between the hydraulic test rig and further measurements/monitoring systems offers flexibility. Moreover, the control system of the test rig manages a dedicated cloud of variables and shares it with the client systems. Finally, this approach ensures safe data centralization and storage on hydraulic turbomachinery model testing.

Keywords: *small-power turbomachines, hydraulic performance, test rig, smart control*

1. MOTIVATION

Numerical simulation represents a relatively fast and cost effective tool to evaluate performances of hydraulic turbomachines during the design and optimization process. However, experimental model testing remains essential to validate the simulation process and to complete the final development, especially beyond the best operating point of the machine. Actually, the latest allows for high precision measurements necessary to predict the hydraulic performances in the hole operating range. To underline the importance of model testing, all the large-hydro manufacturers in the world hold hydraulic test rigs and actively maintain them. In the same time, the presence of academic laboratories (Bovet and Henry, 1970, Kirschner et al., 2012), usually dedicated to neutral certified model testing, comes to reinforce the idea. When addressing the small-hydro production technologies, the shape of hydraulic turbines goes often beyond the classical type of Kaplan, Francis or Pelton. Of course, one may cite here several test rigs adapted to small-hydro technologies such as: Deriaz diagonal turbine (Denis, 2010), swirl turbine, very low head turbine (Fraser et al., 2007), micro-turbine (Deschênes, 1997), Archimedean screw, etc.

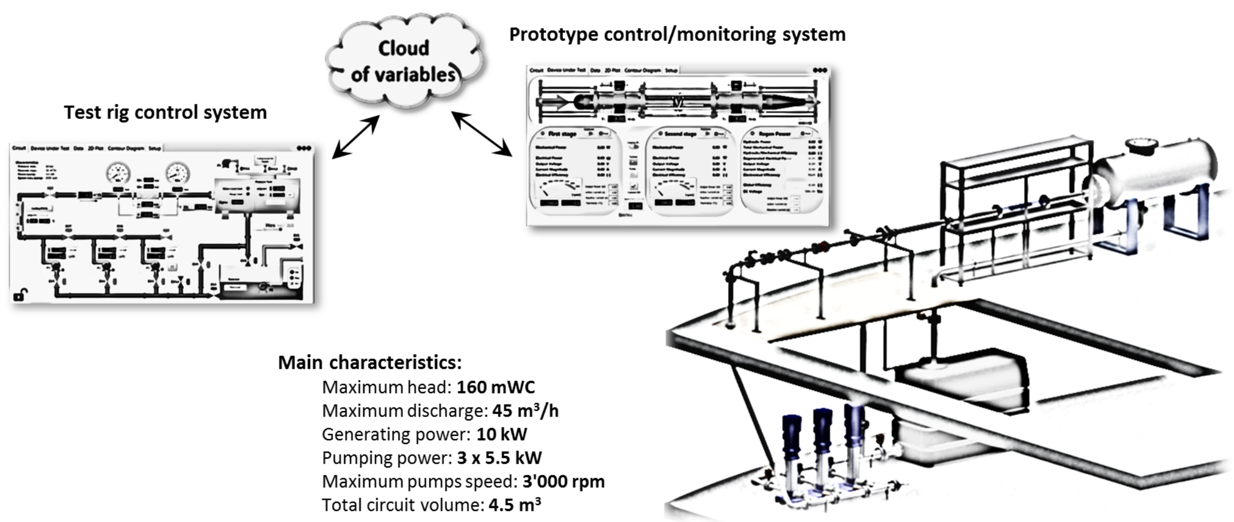

Figure 1. New hydraulic test-rig of the HES-SO Valais//Wallis – Sion, Switzerland, Hasmatuchi et al. 2014.

2. METHODOLOGY

The hydraulic performance of a turbomachine depends on the specific energy, the discharge, the rotational speed of the runner/impeller, the main torque at the runner shaft and the pressure at the low side of the machine. The hydraulic efficiency and the cavitation behavior are calculated on the whole specific energy-discharge operating range using these measured parameters. Then, measurements of the runaway characteristic, different loading forces (either on the runner or on the guide vanes), pressure fluctuations and observations on the draft tube vortex rope development come to complete a typical set of tests (Jacob, 1993). Moreover, the dimensionless characteristics (e.g. using the discharge-energy coefficients, or the speed-discharge factors, etc. – see IEC 60193, 1999) established on the reduced-scale model may be transposed to the target prototype, with the condition of respecting both the geometric and hydraulic similitude laws. Finally, when addressing micro-power turbomachines, the testing may be often performed directly at prototype scale.

2.1 Hydraulic circuit of the test rig

The closed-loop hydraulic circuit (see Figure 1) is supplied with fresh water from a main reservoir, fed at its turn from the drinking water system. Its drain is ensured by an immerged centrifugal pump. Three recirculating multistage centrifugal pumps connected in parallel, supply the circuit with hydraulic power. The variable speed pumps, with a power of 5.5 kW each, can deliver a maximum discharge of 3x15 m^3/h and a maximum pressure of 160 mWC. The testing variable-speed model, with a power of maximum 10 kW, is installed in the upper part of the circuit in an optimal position, in terms of instrumentation, operation and observations. Then, the free-surface pressurized reservoir placed downstream the test section allows simulating different implantation levels of the model and therefore determining the cavitation performances as well. Several valves, either solenoid or manual, are employed to control the hydraulic circuit configuration, as well as its filling, cooling, spillway, control, security and operation. Finally, two honeycomb sections ensure a uniform axial flow at the inlet of the flowmeter and of the testing model.

2.2 Instrumentation

The full testing conditions and particularly the hydraulic power of the testing model are recovered with the help of several measurement instruments that equip the test rig. The discharge is measured with the help of an electromagnetic flowmeter. Differential pressure transducers are employed to measure the head and the implantation level, whilst the static pressure at the wall is measured with capacitive absolute pressure transducers. The water temperature is retrieved with the help of a PT100 transducer. Optical tachometers give the rotational speed of the recirculating pumps. The water level measurements are done with vibrating tuning fork detectors. In addition, manometers and manovacuumeters offer visual indications to the test rig operator. Finally, the measurement precision of the sensors stands between 0.01% and 1%.

3. AUTOMATIC REGULATION SYSTEM

The autonomous regulation system, based on real-time measurements, has been developed using the full capabilities of a National Instruments cRIO-9074 (see Figure 2), equipped with five modules (of different types) to fit the deployed sensors and relays. The communication between the hydraulic test rig and the further measurement/monitoring systems (e.g. testing model control system) is ensured through a wireless architecture. The specific network architecture, implemented within the LabVIEW 2013 environment, provides robustness and modularity to the automatic regulation system. Moreover, values from different acquisition systems are collected by the Shared Variable Engine (SVE), running into the controller, and shared to every local or remote client. Such approach allows actually for safe data centralization, storage and sharing.

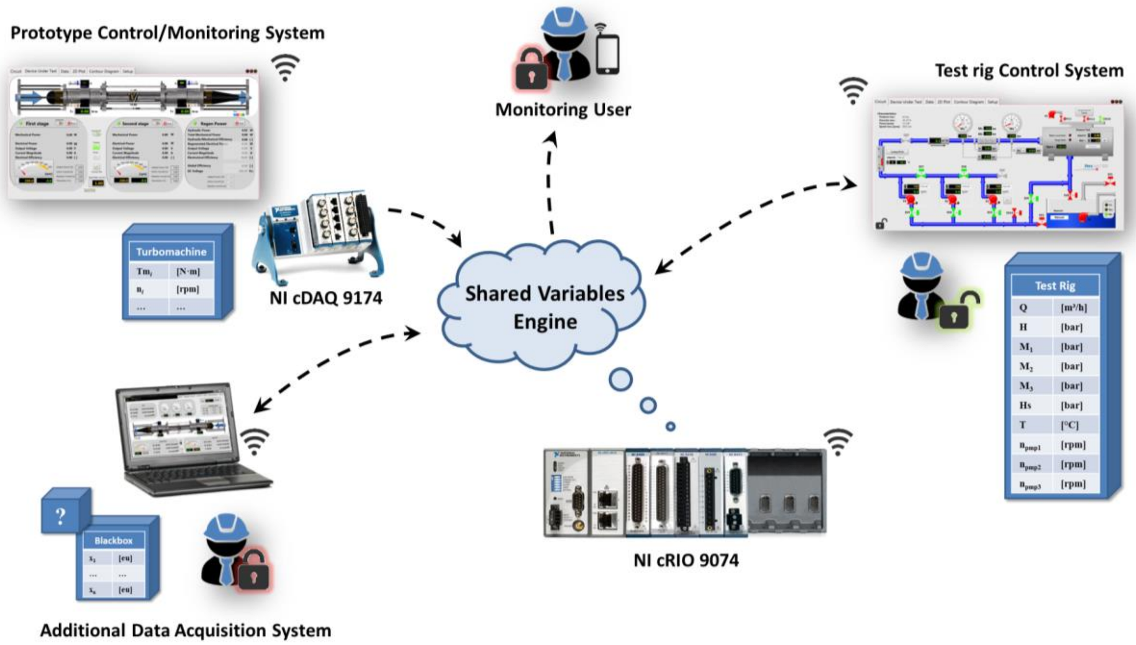

Figure 2. Multi-user control system architecture of the test rig.

Then, a multi-loop Proportional-Integrate-Derivative (PID) has been implemented to control the regulation of the recirculating pumps rotating speed. Their set point can be fixed by three different parameters: the rotating speed, the head and the discharge. The initial calibration of the PID coefficients has been performed for each pump using the step response method (Ziegler and Nichols, 1942). Furthermore, the PID gains are further adjustable, depending on the desired system response speed and stability.

The control of the test rig and of the testing model is performed through six specially designed Human-Machine Interfaces (see Figure 3). The first ensures the control and monitor specific parameters of the test rig. The second is dedicated to the testing model, controlled and monitored through a NI cDAQ-9174 system, physically connected to one of the remote clients. Then, a third interface allows the user to setup different parameters for the acquisition and control. Finally, the last three interfaces give access to the full measurement data, along with 2D and 3D plots of the desired parameters. Such tools provide real-time location of the operating point over the performance hill-chart of the model under test.

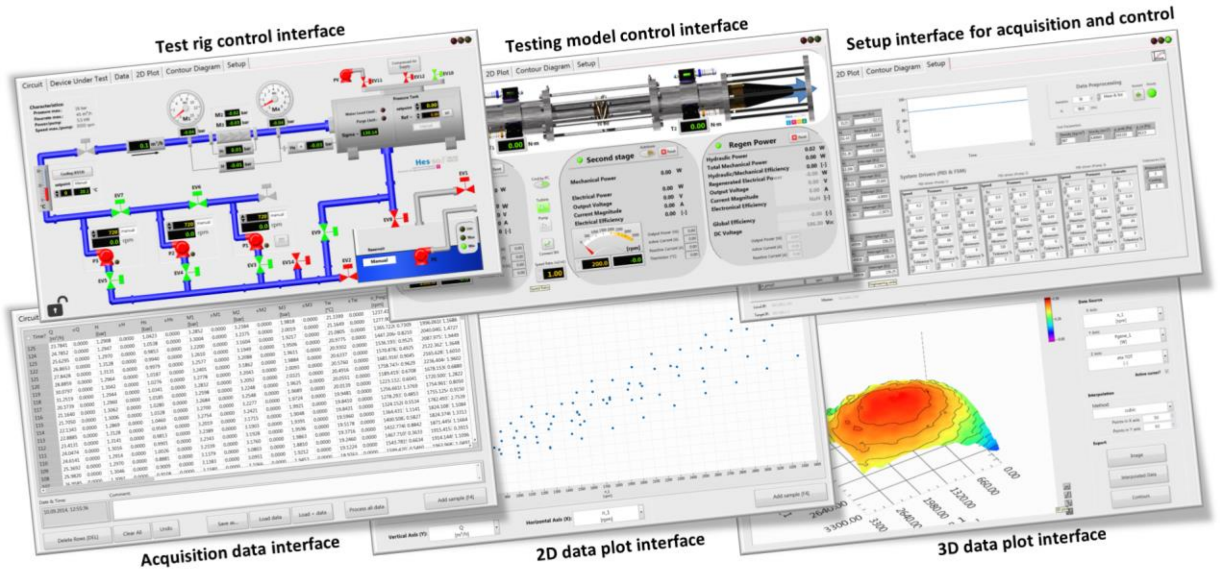

Figure 3. Human-Machine Interfaces designed for the control of the test rig and of the testing model.

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REFERENCES

Bovet T., and Henry P. (1970). Le nouveau stand d'essai universel pour machines hydrauliques à réaction. *EPFL-IMH,* Publication No. 6, Lausanne, Switzerland.

Denis V. (2010). Petite hydroélectricité: de la théorie à la pratique. *Bulletin ElectroSuisse*, 5, 61-65.

Deschênes M. (1997). Essais préliminaires et étalonnage d'un banc d'essai de micro-turbines. *Université Laval*, Quebec, Canada, ISBN 0-612-26189-1.

Fraser R., Deschênes C., O'Neil C., and Leclerc M. (2007). VLH: Development of a new turbine for Very Low Head sites. *Waterpower XV*, Chattanooga, TN, USA.

Hasmatuchi V., Botero F., Gabathuler S., and Münch C. (2014). Design and control of a new hydraulic test rig for small-power turbomachines. *Hydro 2014*, Cernobbio, Italy, Paper no. 14.5.

International Electrotechnical Committee. (1999). Hydraulic turbines, storage pumps and pump-turbines – Model acceptance tests". *International Standard IEC 60193*, 2nd Edition.

Jacob T. (1993). Evaluation sur modèle réduit et prédiction de la stabilité de fonctionnement des turbines Francis. *EPFL Thesis No. 1146*, Lausanne, Switzerland.

Kirschner O., Ruprecht A., Göde E., and Riedelbauch S. (2012). Experimental investigation of pressure fluctuations caused by a vortex rope in a draft tube. *IOP Conf. Series: Earth and Environmental Science,* 15(6).

National Instruments. (2010). CompactRIO cRIO-9072/3/4 Operating instructions and specifications.

Ziegler J.G., and Nichols N.B. (1942). Optimum settings for automatic controllers. *Trans. ASME*, 64(11).