Development of a measurement system able to determine the flow velocity field on models of hydraulic turbines

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Motivations & Objectives

The project was driven by the need to improve the measurement of velocity fields and pressures in a hydraulic turbine. The development of a new probing system and new associated software was required in order to reduce acquisition times and measurement errors.

The measurement technique involves an intrusive method allowing the determination of the velocity vector (characterized by the standard V) and angles (a and τ) and the total pressure P, by pressure data acquired from a probe placed at a given position in the flow.

Such a probe typically has a spherical head with 5 holes.

Calibration of a five-hole pressure probe

In order to determine the four unknowns (V, a, τ and P), a link between the pressures measured by the probe and the reference variables representing the physics of the flow has to be established. To do this, it is essential to have a perfectly axisymmetric flow in the calibration rig and a Pitot tube used as a reference.

Calibration process:
- For each in the range [-20 °; 20 °], the pressure differences (P1, P2, P3, P4 and P5) and (P5 - Pitot) are computed.
- Then, these new values are combined into three factors (Kτ, K et KT) specific to each of the unknowns (τ, |V| and PT).
- Finally, a regression curve is computed for each factor. These three curves (Kτ = Kτ(τ), K = K(τ) and KT = KT(τ)) describe a direct relationship between (τ, |V|) and the pressure measurements (P1, P2, P3, P4 and P5).

Definitions of coefficients

From the pressure measurements from each of the 5 holes, one can deduce the following three factors, computed for each angle τ:

- Kτ = \frac{(P1 - P2) + (P3 - P4)}{2(P5 - PT)}

This coefficient is directly related to the angle τ. During the probing, only the pressure measurements between holes #1, #2, #3 and #5 determine the orientation of the velocity.

- K = \frac{P5 - PT}{P1 - P2}

This coefficient represents the relationship between the total pressure, measured by the Pitot tube, and the pressure at hole #5.

- KT = \frac{P5 - PT}{P5 - Pitot}

This relationship associates the standard velocity measured by the Pitot tube with the pressure given by holes #5 and #1 of the pressure probe.

Old vs. New measurement system

Old device:
- A single differential pressure sensor.
- 7 solenoid valves allowing sequential measurement of pressure differences.

New device:
- 6 differential pressure sensors connected in parallel to the same reference pressure.
- Space reduction with the technology of Scanivalve.
- Removal of solenoid valves and their power supply.
- Improved accuracy because each sensor can have a specific range.
- Ease of transport and connection.
- Ability to compensate for temperature errors.
- Acquisition time of 10 seconds.
- Sequential acquisition of pressure differences –→ Resulting in an increase in the dispersion of results and the measurement error.

Studies of parameters influencing the calibration of a five-hole pressure probe

During the probing, the flow velocity is allowed to be different from the reference velocity used for calibration. To ensure the quality of measurements, the study of the influence of velocities on the three different computed coefficients is required.

The flow is highly influenced by the spherical geometry of the five-hole probe, so are the pressures at the 5 holes locations. Therefore, the velocity must fall within the range 4 to 8 [m/s] to guaranty the independence of the coefficients from the velocity and to prevent the structure of the probe from being damaged by the flow. Finally, the calibration must be performed for values of τ in the range [-20 °; 20 °] to obtain good quality regressions and to avoid the development of recirculation zone.

Evolution of pressure differences during a calibration at 6 [m/s]. It is now possible to study independently the pressure at each hole.

Evolution of coefficients Kτ, K et KT, in terms of velocity and angle τ.

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