Influence of local change of stiffness in liquid filled pipe on waterhammer signal propagation

**Context and motivations**
Due to the deregulated energy market, hydroelectric power plants are increasingly subjecting to off-design operations, start-up and shutdown sequences. Consequently, the variation of the operating point leads to transient phenomena that load dynamically all the elements composing a hydroelectric power plant. In this context the development of new design guidelines for pressurized waterway systems is required. The importance of such guidelines has been underlined by the collapse of the shallow pressure shaft at the Cleuson-Dixence hydro plant in Switzerland, in December 2000. Therefore, new models and a non intrusive method for the continuous control of the properties and behaviour of the high pressured shafts are developed in the laboratory for hydraulic construction (LCH). The method consists on using the inherent pressure waves that appears when a change of the operating point of the power plant occurs. Signals acquired at each extremity of the pressurized shafts by geophones, hydrophones and pressure sensors are used to determine and localize, when appears, a local change of stiffness consequent to shafts’ deterioration.

**Objectives**
A test campaign on a physical model in the laboratory for hydraulic machine (LMH) is planned in order to define the parameters and the methodology undertaken for the detection and the localisation of a local change of stiffness consequent to the shafts’ deterioration. The results will also be used for the validation of models taking into account the fluid structure interaction caused by the dynamic loads.

The main objectives are:
- develop some tools to ensure the control of the physical model and to have reliable acquisition of the signals provided by the sensors when a waterhammer occurs.
- define an experimental protocol to ensure safety and repeatability of the tests
- propose a methodology for the analysis of the results in order to see if a local change of stiffness can be detected.

**Physical model**
The physical model conception is defined in order to cause a waterhammer in a test conduit fitted with sensors. It is composed of 4 main elements linked in closed loop as presented in the figure below.
The shut-off valve is controlled via a LabVIEW software and an experimental protocol for the filling of the reservoir and of the air-vessel ensures the same initial conditions for all the tests.

The test conduit conception is defined in order to allow an easy change of local stiffness. It is composed of 8 elements interchangeable: 4 elements 1m long (A) and 4 elements 0.5m long (B) for a total length of 6 m with an inner diameter of 15 cm.

To have a local change of stiffness in the conduit, one or many (B) elements with different materials (steel, PVC, aluminum) can be placed in the conduit.

The sensors used for the waterhammer signal acquisition are listed below:
- Geophones (x5): to measure pipe radial and axial vibrations and displacement
- Hydrophone (x1): for the acquisition of acoustic plane waves in water generated by the pressure fluctuations and pipe wall vibrations.
- Pressure sensors (x8): to measure the inner pressure in the test conduit

The positions available in the conduit for each sensors are presented in the above figure.

**Signals Acquired**
The measurements presented here allowed to detect the presence of a fluid structure interaction after the valve has closed due to the pressure fluctuations.

More than 100 tests over 8 different test conduits combinations have been made. A systematic analysis consisting on the measurement of the wave speed at 2 different time sequences allowed the detection of a significant change of stiffness in the test conduit as presented in the figure below.

- The results presented here allowed to determine a robust parameter for the detection of significant local change of stiffness as the wave speed changes significantly for combination made with one element made with PVC compared to combinations made with 100% steel (SC1 to SC5)
- By comparing the values of the wave speed measured at the different time sequences, an influence of the fluid structure interaction on the results is revealed in this analysis thus justifying to develop models taking account of it.

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