Installation of sensors inside penstock for Pressure – Time method

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Introduction

Site acceptance tests of turbines and pumps require exact flow rate measurement. But the power plants are not often designed with respect to the installation of device for the future flow measurement although the standard [1] recommends performing such measures in plant design stage. Additional installation of standard equipment for flow measurement requires machine shutdown for couple of days before measurement and also some days out of operation for equipment removal.

Good alternative for mid-head hydro power plants (HPP) to the most often used current meters method is Pressure – Time method (also called Gibson method). This method, based on Newton's second law, consists in measuring a static pressure difference which occurs between two cross-sections of a penstock as a result of a flow change (water hammer). It was used by the author and the colleagues from his team for approx. 140 units and information about its reliability is available in references [2] and [3]. The OSC team is permanently looking for minimizing the preparatory works impact on plant operation. The co-authors and their companies provided substantial support by improvement of Pressure – Time method as described below.

1. Principle of sensors installation

The Pressure – Time method needs a clearly defined section in closed penstock in order to function correctly. The discharge calculation is based on pressure difference between planes normal to the axis of the conduit at the beginning and end of this section. Typical mid-head HPP has pressure taps at the beginning of spiral case or in front of main inlet valve (MIV) but there are missing pressure taps at the beginning of the penstock. Example of such HPP (EDF Carbonne on Garone River) is presented in Fig. 1.

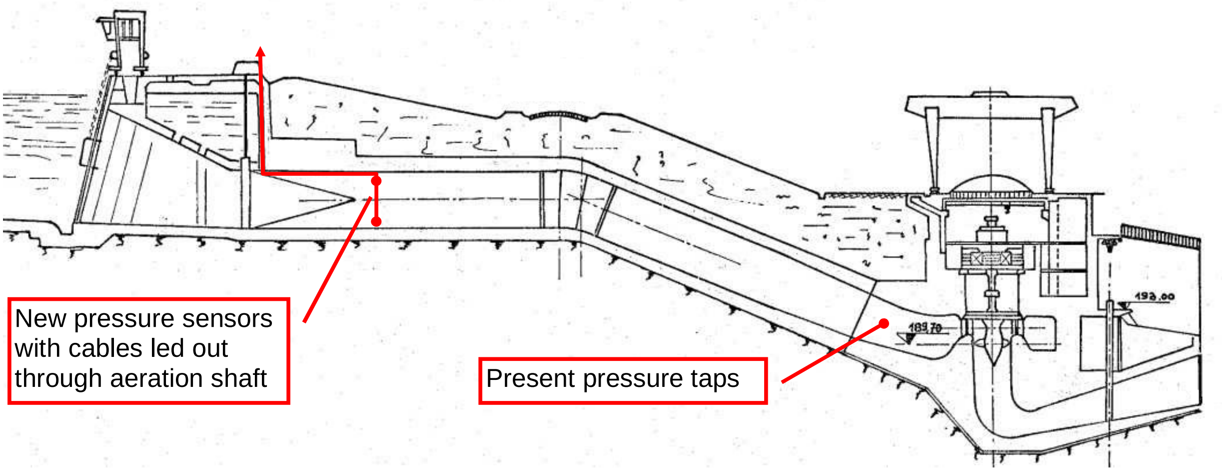

Fig. 1. Example of typical additional installation of pressure sensors.

The upper part of penstock is often inaccessible from outside. The following principles of sensor installation must be complied with in order to achieve the correct measurement conditions:

- Separate pressure sensors (2 or 4 pcs) with protection IP68 or IP69 should be installed on the inside penstock wall.
- Standard [1] requires that the distance between the upstream and downstream cross-section must be superior to 10 m

- The sensors have to be installed as near as possible to the inlet of the penstock. The reason is to achieve the maximum pressure difference when the measuring section is almost the whole penstock length.
- The sensors have to be installed approx. 2D behind the significant irregularity of the conduit.
- Separate pressure sensors should be installed also on the present pressure taps in front of MIV or at spiral case intake.

1.1 Sensors description

OSC Company implements standard submersible pressure sensors supplied worldwide by many producers. The range is determined during the preparing of measurement project individual for each HPP. The sensors are installed in special holders – see Fig. 2. Streaming around the holders was simulated in Victor Kaplan Dept. of Fluid Engineering of Brno University of Technology. These results are mentioned in chap. 1.3.

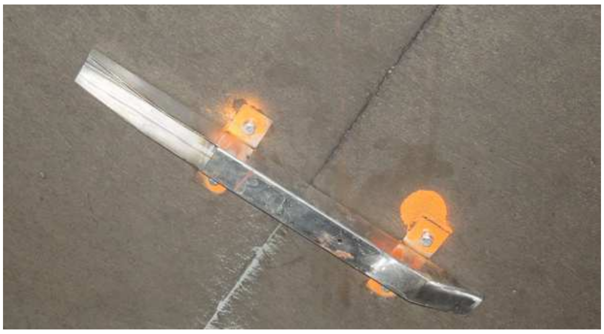

Fig. 2. Pressure probe holder on concrete wall prepared for probe installation

Fig. 3. Installation of cables protection pipe in a sloping rectangular penstock (EDF Salignac HPP)

The holders can be fixed on the inside wall by various techniques:

- Welding to the metallic surface (possible during penstock painting renovation).
- Fixing by dowels in the wall (see Fig. 2).
- By direct fastening technology with especially hardened studs driven into steel by a piston-type tool (HILTI X-BT). This technique doesn't impact the inside conduit surface.

1.2 Sensors installation

Installation of sensors in closed conduits is not easy and it requires climbing technique. The third co-author has long term experience with work at heights. His company is a regular cooperator of OSC for the installation of pressure sensors under difficult conditions.

The subject of this activity is not only probes installing but also conducting cables out of the penstock. Cables are usually routed in protection pipes which have to be also fixed to the penstock walls as carefully as the sensors. There is seldom a simple way how to route the cables outside from penstock. So far installed cable routes were as follows:

- Through the aeration pipe / shaft. This is the most common option.
- Through the surge tank.
- Through the manhole using cable glands. The standard cable glands are available for a maximum pressure of 10 bar.

There is no problem with the long length of cable routing. The signal 4 ÷ 20 mA is possible to be transferred on long distances or it is also possible to use distributed data acquisition system with units connected via LAN or Wi-Fi.

1.3 Impact of probe holders on pressure measurement

The probe holders protrude over the wall surface. They have been designed in order to optimize the flow around them. The simulation performed by the Brno University of Technology demonstrated a negligible difference between the pressure tap in the pipe wall and on the probe holder with a 30 x 30 mm cross section placed on the wall. Pressure distribution along the probe holder for penstock ϕ 4 000 mm and mean velocity c = 5 m/s is presented in Fig. 4. Waveform of pressure difference on measuring section in HPP Carbonne (see Fig. 1) together with other measured and calculated quantities for emergency shut down from Q = 87 m^3/s (c = approx. 4.5 m/s is presented in Fig. 5.

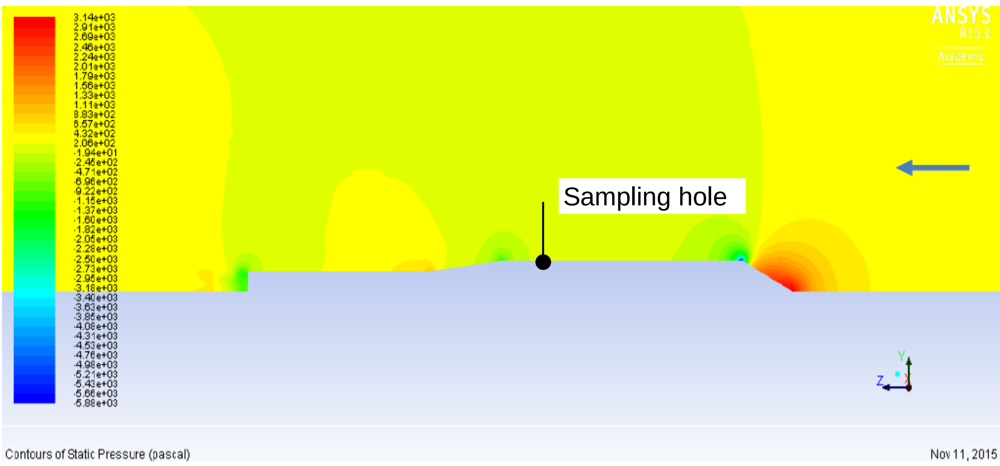

Fig. 4. Pressure distribution along the probe holder

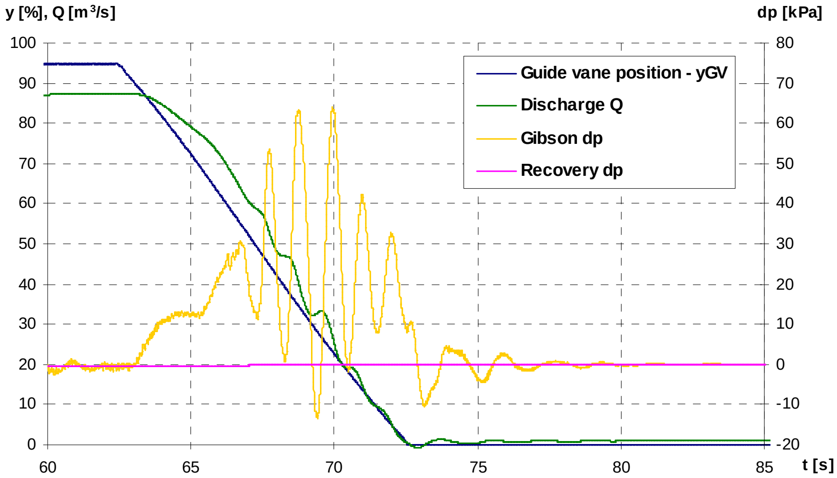

Fig. 5. Main quantities waveforms from HPP Carbone for Q = 87 m³/s, c = 4.5 m/s

A rough comparison of the probe holder impact from wall pressure in upstream cross section and mean differential pressure on measuring P-T section is presented in Tab. 1. Above mentioned deviation is caused by the flow, it is dependent on the velocity quadrate and is actually included in the recovery curve calculated for each measured point. The impact of probe holder shape on measured pressure difference can be considered as negligible.

Experiment	***D [mm]***	***c [m/s]***	***Deviation*** p_{1G}	***Mean*** dp_G	***Dev.*** p_{1G} ***/*** dp_G
Simulation	4 000	5.0	120 Pa		0.3 %
Real test	5 000	4.5		30 kPa	

Tab. 1. Rough evaluation of probe holder impact on differential pressure signal

2. Comparison of Pressure – Time and current meters methods

The easily applicable and the most commonly used methods of flow measurement are current meters and Pressure – Time methods. Both methods have some advantages and disadvantages. Comparison of device installation for both methods is briefly given in Tab. 2. Advantages are marked by green background, disadvantages by pink background.

Pressure – Time	***Current meters***
4 pressure probes, price 4 x 300 – 1000 € including calibration	Approx. 40 current meters: 40 x 2000 € Calibration expenses approx. 40 x 500 €
Simple probe holders + protection pipes	Massive special support structure for current meters.
Installation inside penstock without necessity of welding.	The current meters supporting structure has to be screwed to base plates welded on the inside wall.
Sensors installation is possible couple of weeks / months prior site tests. Unit operation has not impact on sensor features / calibration.	Current meters have to be installed immediately before site tests. It is impossible to operate the unit for long time with installed current meters
Sensors can remain in penstock after site tests. It is not necessary to stop the unit operation for device dismantling.	Current meters as well as the supporting structure has to be removed from penstock after site tests.
Usual accuracy of flow measurement ≈ 1 – 1.3 %	Usual accuracy of flow measurement ≈ 1 – 1.8 %
Shut down has to be performed for each measuring point	Measurement during stable unit operation

Tab. 2. Comparison of installation demands for Pressure – Time and current meters

3. Conclusion

Turbines in power plants equipped with penstock can be tested using Pressure – Time method. But the penstocks are often imbedded in concrete and there is no access to the pipe from outside to arrange pressure taps needed for this method. OSC Company is used to installing pressure sensors from inside the penstock for more than 10 years. Usually four pressure sensors with protection IP68 or IP69 are installed in special holders on the pipe wall in upstream cross section. This practice corresponds to the recent trend to use independent sensors instead of the connection of pressure taps to common manifold. The cable path from sensors is often routed out through aeration pipe or through other possible way. Such installation in difficult conditions requires specialists for work at heights. To reduce the cost of the operation, it is sometimes possible to install the pressure sensors during planed outage e.g. couple of weeks/months before site tests. And because of sensors acceptable price it is possible to let the sensors inside penstock without unit shutdown for their dismantling. This method brings significant limitation of unit outages and also financial savings.

References

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The Authors

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Mr. Grégory ROLANDEZ, Eng, graduated in Fluid Mechanics from the École Nationale Supérieure de Techniques Avancées in Paris, in 2001. He began his professional career working in an engineering company dealing with dams, civil engineering structures, water environment, flood and hydropower. After a few years managing hydroelectric plants in the Vercors mountains, he is now a test engineer with EDF DTG. He has a 15 year experience in hydraulics. He performs discharge and efficiency measurements at EDF power plants, with various flow metering techniques based on IEC 64001.

Mr. Frantisek Necas founded his company for work at heights in 1990 utilizing his rich experience with mountaineering as well as knowledge in civil engineering. Besides the works with extreme technical demands he is well known as experienced instructor for work at heights. His company is based on family tradition with well skilled staff following new technological trends.