Flow field UVP measurements of a Y-shape outlet structure

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Y-shape outlet structures are used to release the turbine water into a reservoir. Classical design often uses a Y-shape over a certain length and with a specific opening angle. Depending on the geometry, especially in turbine mode, significant undesired flow separations may occur at the bifurcation. Investigations were performed with physical model tests using ultrasonic profilers at 1 and 2 MHz emission frequencies in order to assess an approach to control the design of an outlet structure by measuring the flow field and its fluctuations. The distribution and fluctuation of the flow velocities, both at the exit section as well as along the tunnel axes for both outlet openings of the Y-shape geometry allow detecting potential flow detachment at the bifurcation.

Keywords: pump-storage scheme, outlet work, flow field, ultrasonic velocity profiler UVP, physical modelling

1 INTRODUCTION

In hydropower plants, especially for pump-storage, the release of the turbine water into the lower reservoir requires an adequate outlet structure design. For constructive and rock stability reasons, it may be required to split the outlet work gallery into two branches to reduce the portal size and its span. Classical design often uses a Y-shape over a certain length and with a specific opening angle. Depending on the geometry, especially in turbine (outlet) mode, significant flow separations may occur at the bifurcation [1]. This can lead to increased head losses and non-homogeneous flow field at the outlet. An elongated structure with smaller opening angle can often lead to a more homogeneous velocity distribution, but requires more excavation.

This study presents an approach to control the design of an outlet structure by measuring the flow field and its fluctuations.

Investigations were performed on a case study of a project in Switzerland with physical model tests at the Laboratory of Hydraulic Constructions (LCH) of the Ecole Polytechnique Fédérale de Lausanne (EPFL) [2] using Ultrasonic Velocity Profilers (UVP, Met-Flow) [3]. UVP transducers are extensively used for velocity measurements on physical models at the LCH, e.g. [4, 5].

At the exit, for the given flow rates and water level, vertical velocity profiles were measured with UVP at 2 MHz emission frequency. Velocity profiles measurements looking inside the structure branches up to the bifurcation point using long-range UVP at 1 MHz emission frequency were performed as well.

In this paper, first the physical modeling is presented, i.e. the experimental set-up and the measuring technique. Then the experimental results are discussed.

2 PHYSICAL MODELING

2.1 Physical model

A model of a particular Y-shape outlet was built with the geometric scale of 1:32. The hydraulic similitude was considered according to the Froude number respecting Reynolds number for fully turbulent flow. The prototype dimensions (m) are given in Figs. 1 and 2. The opening angle of the Y-shape is 30°.

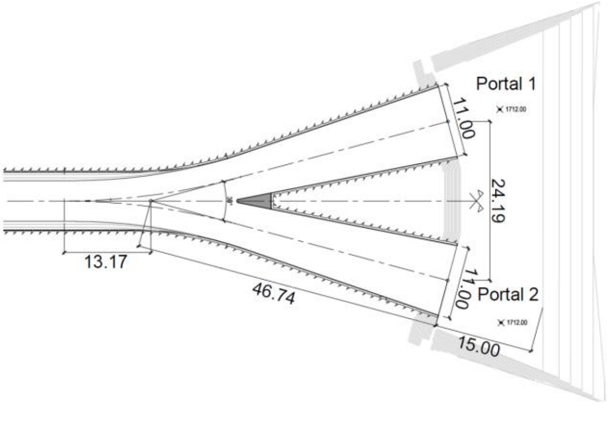

Figure 1: Plan view of the Y-shape outlet structure (m).

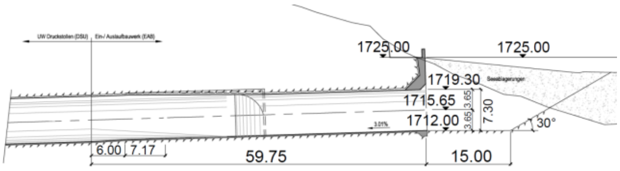

Figure 2: Sectional view of the Y-shape outlet structure (m).

The constructed portals on the physical model are shown in Fig. 3. The Y-shape is embedded in the topography. The prototype maximum nominal discharge is 120 m^3/s. The water level varies from 1767 to 1725 m a.s.l. (minimum operating level).

Figure 3: Physical model, view of the portals.

2.2 Measuring technique

The velocity measurements were carried out with Ultrasonic Velocity Profilers (UVP, Met-Flow) [1]. Details are given in the following.

2.3 Vertical measurements in front of the portals

For the vertical measurements in front of the outlet portals (Fig. 4), 10 UVP transducers with a frequency emission of 2 MHz were used, i.e. 5 per portal (Fig. 5). With this set-up the measured profiles are separated by 1.82 m at prototype scale. The transducers are numbered according to Fig. 5.

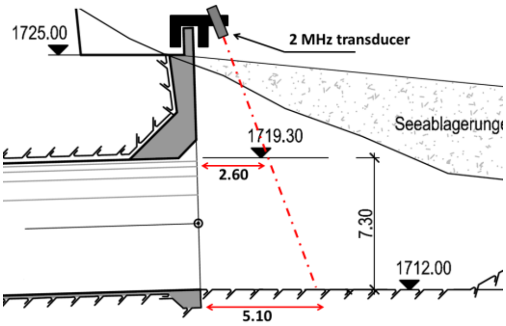

Figure 4: Definition sketch of the location of the 2 MHz transducers (m) – sectional profile.

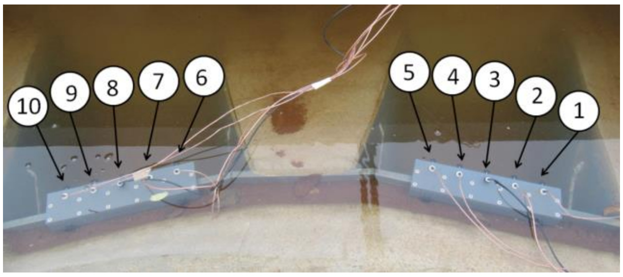

Figure 5: Numbering of the 2 MHz transducers.

The measurements were performed in 1 cycle, recording 4096 (2^{12}) velocity profiles per transducer, with a sampling period of 16 ms. The profiles were divided in 128 channels. A total of 40960 profiles are recorded during the acquisition procedure. Horizontal velocity is obtained by projection.

2.4 Horizontal measurements along the branches axes

For the horizontal measurements along the branches of the Y-shape outlet (Fig. 6), 2 special UVP long range transducers with a frequency emission of 1 MHz were used, i.e. one per portal for each acquisition (Fig. 7). The transducers are numbered according to Fig. 7.

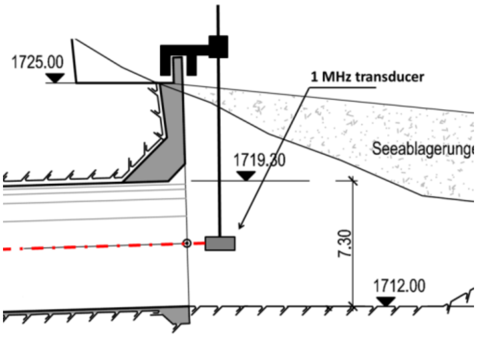

Figure 6: Definition sketch of the location of the 1 MHz transducers (m) – sectional profile.

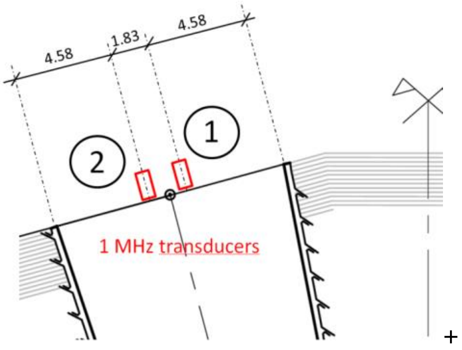

Figure 7: Definition sketch of the location of the 1 MHz transducers (m) – plane view.

Two series of measurements were performed. The first one in 1 cycle, recording 4096 (2^{12}) velocity profiles per transducer, with a sampling period of 18 ms. The profiles are divided in 256 channels. A total of 8192 profiles are recorded during the acquisition procedure. The second one in 256 cycles recording 8 (2^3) velocity profiles per transducer, with a sampling period of 18 ms. The profiles are divided in 256 channels. A total of 4096 profiles are recorded during the acquisition procedure.

3 EXPERIMENTAL RESULTS

Tests were performed for a reservoir water level of 1729 m a.s.l., considering three discharges for the vertical measurements (120, 140 and 160 m^3/s respectively) and two discharges for the horizontal measurements (80 and 120 m^3/s respectively). The most important results are presented in the following, always for the nominal discharge 120 m^3/s, and units are at prototype scale.

3.1 Average vertical velocity profiles

The average velocity profiles are plotted along the height of the portal 2 (Fig. 1), i.e. from 1712 to 1719.3 m a.s.l., in Fig. 8. Together with the corresponding profiles in front of portal 1, these results allow a validation by computing the measured discharge by defining an area of influence for each transducer. Comparing these values with the corresponding theoretical discharges of the tests measured with a flow meter, i.e. 120, 140 and 160 m^3/s, the errors are 3.6%, 0.9% and 0.4% respectively. This observation validates the quality of the measured profiles in terms of averaged values.

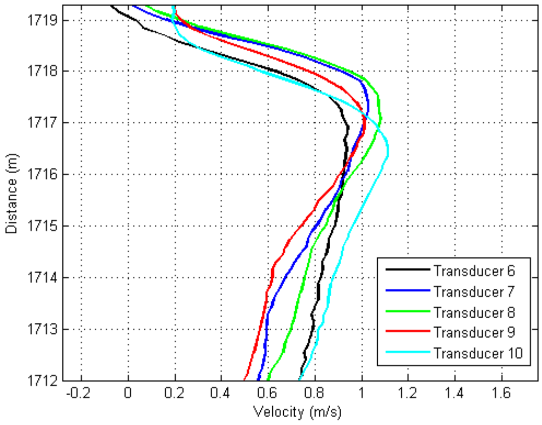

Figure 8: Average vertical velocity profiles (prototype scale) in front of portal 1, averaged on 4096 profiles (sampling period of 16 ms).

3.2 Time series and power spectra

To assess the occurrence of flow detachment, the velocity fluctuation in the Y-shape outlet is studied by plotting time series and corresponding power spectra.

The time series of the horizontal velocity in front of portal 2 at mid-height is represented in Fig. 9, from transducer 2. Smoothened data using 20-, 50- and 80-point moving average are represented as well to visualize low frequency variations without the noise of the signal. Large variations of velocity are observed, on a range of approximately 1 m/s centered on 0.8 m/s, which tends to outline the occurrence of flow detachment at the Y-junction of the outlet. It is possible to estimate expected significant low frequencies in the signal by estimating significant peaks on the smoothened signals. By considering the 20- and 80-point moving average smoothened data, the number of corresponding peaks can be estimated as 20 and 50. Dividing by the total duration of the time series gives a low frequency range between 0.05 and 0.14 Hz. The corresponding power spectral density (PSD) based on the Welch periodogram is shown in Fig 10. It is performed on a signal of 2^{12} samples, divided in 4 segments sampled by a Hamming window with 50% overlapping and a sampling frequency corresponding to the sampling time (Section 2). The unit of the ordinate is $(m/s)^2/Hz$. Peaks of energy density are observable in the same range of frequencies estimated above with the observation of the time series.

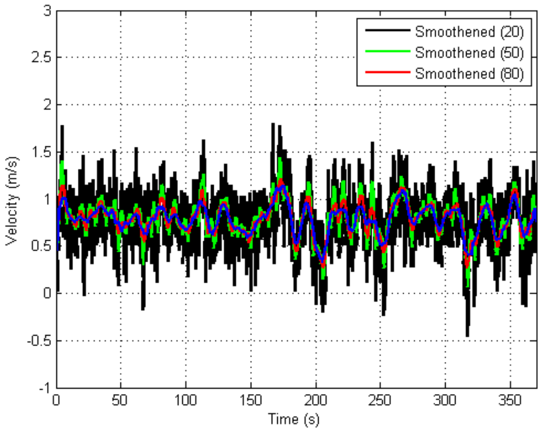

Figure 9: Example of a time series of the velocity (prototype scale) at altitude 1715.6 m a.s.l. in front of portal 2 from transducer 2, with smoothened data using 20-, 50- and 80-point moving average.

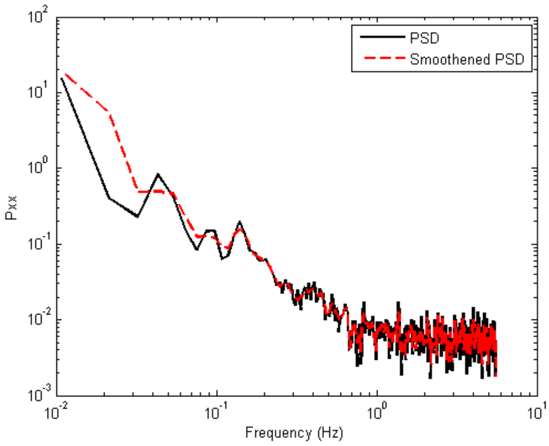

Figure 10: Power spectrum of the flow velocity (prototype scale) in front of the portal 2 at altitude 1715.6 m a.s.l. from transducer 2, with smoothened data using 3-point moving average.

A similar approach was used for the velocity measurements (first series described in subsection 2.4) along the branches of the Y-shape outlet. The time series of the horizontal velocity at 18 m from the portal along the branch of the Y-shape (mid-length) is plotted in Fig. 11. By considering the 20- and 80-point moving average smoothened data, the number of corresponding peaks can be estimated as 25 and 55. Dividing by the total duration of the time series gives a low frequency range between 0.06 and 0.13 Hz. The corresponding PSD is shown in Fig. 12, and was performed with the same parameters than the 2 MHz measurements, but with the corresponding sampling frequency. The energy is concentrated in the same range of frequencies than estimated with the time series.

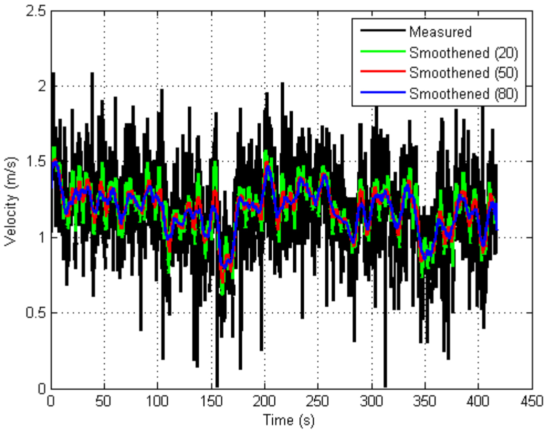

Figure 11: Example of a time series of the velocity (prototype scale) along a branch of the Y-shape outlet at position 1, with smoothened data using 20-, 50- and 80-point moving average.

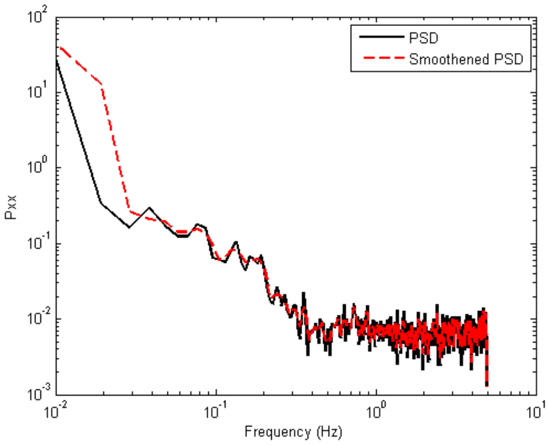

Figure 12: Power spectrum of the flow velocity along a branch of the Y-shape outlet at 18 m from the portal, with smoothened PSD using 3-point moving average.

It may be mentioned that this experimental set-up is not suitable to detect in the PSD frequencies below 0.01 Hz or beyond 1 Hz. Further investigations would be required, with a finer sampling period and a larger number of profiles (and thus a longer measurement period). Moreover, only one time series of the velocity was measured per channel in the scope of this case study. As a consequence, confidence limits cannot be estimated for the PSD and thus the statistical significance of the peaks is not proven herein. Thereby the observations of the PSD herein should be considered as an indication.

3.3 Longitudinal velocity profile

An example of a longitudinal velocity profile (from the second series described in subsection 2.4) along a branch of the Y-shape outlet is plotted in Fig. 13. Considering an approximated low frequency wave length of 10-15 m and an average velocity along the branch of 1.2 m/s, the low frequency component of the signal is around 0.1 Hz. This is consistent with the observations made in subsection 3.2, and thereby indicates a probable flow detachment which may justify such a large variation of velocity.

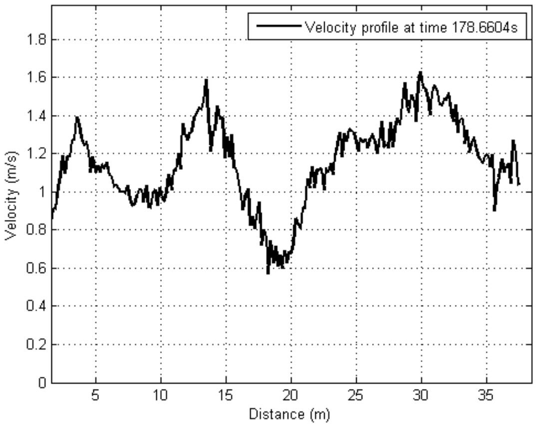

Figure 13: Example of a longitudinal velocity profile (prototype scale) along a branch of the Y-outlet, averaged on 8 profiles (sampling period of 18 ms).

4 CONCLUSIONS

Velocity measurements were performed in front of the portals of a Y-shape outlet and along its branches my means of UVP on a physical model. The variations of the velocity profiles are of large magnitude and, correlated with the analysis of corresponding PSD, tend to outline the occurrence of flow detachment at the Y-junction of this case study. The methodology presented herein thereby provides tools to detect flow separation in outlet structures.

REFERENCES

[1] Mohringer, T: Entwurf von Ein- und Auslaufbauwerken von Pumpspeicherwerken, PhD Thesis, Karlsruher Institut für Technologie (2012).

[2] EPFL-LCH. Pumpspeicherwerk Grimsel III - Hydraulische Modellversuche des Ein- und Auslaufbauwerks im Räterichsbodensee, unpublished report, Ref. LCH 07/2013. Lausanne, Switzerland (2013).

[3] Met-Flow SA. UVP Monitor Model UVP-DUO users guide. Metflow SA, Lausanne, Switzerland (2002).

[4] Martinerie R, Müller M, De Cesare G, Boillat J-L: Vortices at intake works of pump-storage schemes, 6th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering (2008), 119-122.

[5] Pfister M, Duarte R, Müller M, De Cesare G: Cavitation risk estimation at orifice spillway based on UVP and dynamic pressure measurements, 8th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering (2012), 137-140.