USING ULTRASONIC VELOCITY PROFILE MEASUREMENTS IN AN AIR-VESSEL TYPE SURGE-TANK MODEL

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ABSTRACT

The downstream (turbine) portion of a pumped storage station was reproduced in a hydraulic scale model. Water was supplied through three simulated Pelton turbines. The problem to be solved by the model tests was the fact that for structural reasons the turbines are located below the water level of the lower reservoir. As water must be kept away from the turbine rotor, it is necessary to produce overpressure (compressed air). This, however, involves problems which need to be analysed in the physical model by defining the surge movement, because the rotor must by all means be prevented from being submerged. Part of the compressed air escapes together with the turbine outflow. Therefore, it is necessary to optimise the geometries (turbine casing) with a view to minimising this air flow. An ultrasonic measuring instrument (UVP) was used to monitor these processes. Three parameters were considered: the velocity profiles in the surge tank, the movement of the surge, and an attempt was made to identify the distribution of air bubbles.

Keywords: surge tank, air flow, velocity profiles, air bubbles

EXPLANATORY COMMENTS

Hydraulic scale model tests have been carried out at the Hermann Grengg Laboratory of the Department for Hydraulic Engineering and Hydro Resources Management at the Graz University of Technology since 1964. More than 300 tests have so far been performed for projects throughout Austria and abroad as well as for fundamental research purposes.

The studies described in this report were conducted as part of a test on the model of an air-vessel type surge-tank situated in the tailwater system of a pumped-storage scheme. The hydraulic tailwater system (Figure 1) consists of three separate air-vessel type surge chambers uniting in a connection gallery and linked with the lower reservoir by the tailwater gallery.

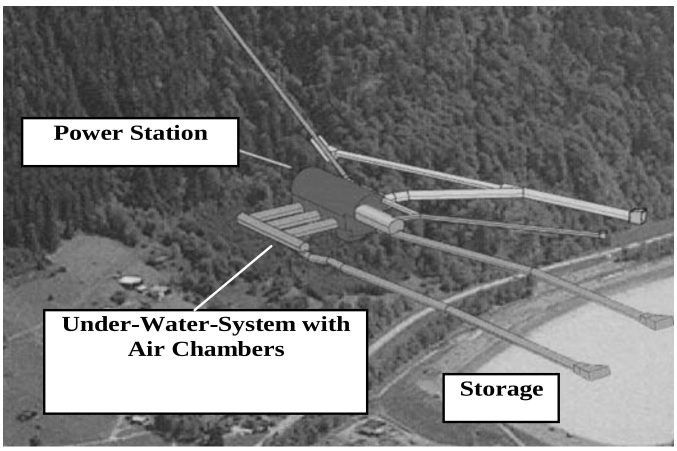

Fig. 1 Tailwater system scheme

As the water surface level of the lower reservoir is always above the axis of the impulse turbines, it is necessary to maintain a pressure of up to 3 bar above atmospheric in order to draw down the water surface within the surge chambers.

The two principal functions of the air-vessel type surge chamber are to dampen the water level fluctuations between the lower reservoir and the surge chambers in the case of mass oscillation and to absorb the air taken in by the turbines and degassing into the surge chamber(Figure 2).

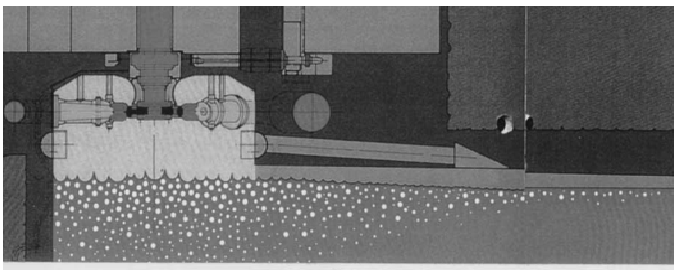

Fig. 2 Degassing into the surge chamber

The problem of such plants is that the air taken in actually does not entirely degas into the surge chamber, but is evacuated from the system through the tailwater gallery and is thus lost to the system. This question is of vital importance, especially where the turbine gallery is joined with the pump inlet line, that is, in the case of a „short-cut“, as this may cause damage to the mechanical equipment (pumps, turbines, etc.).

The plexiglass model shown in Figure 3 was constructed to scale 1:22.5 at the Department and installed in its laboratory.

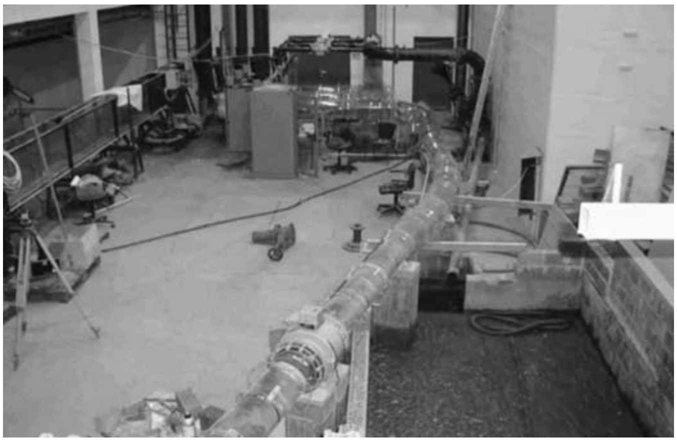

Fig. 3 Plexiglas model in the laboratory

THE MEASURING METHOD

The studies were carried out by use of the XW-3_Psi ultrasonic velocity profile measuring instrument made by Met-Flow. This measuring system consists of a computer (Main Unit) with an integrated keyboard, a display unit and multiplexed ultrasonic transducers. A maximum of four 4MHz transducers, 5mm in diameter, were available.

Fig. 4 Measureequipment XW-3Psi

The measurement window was designed as a function of the instrument parameters within the boundaries of the chamber cross-section. Results from the fringe zones near the contact between water and plexiglass (8mm in thickness) were omitted to avoid including imaginary results and unwanted reflections from the opposite wall.

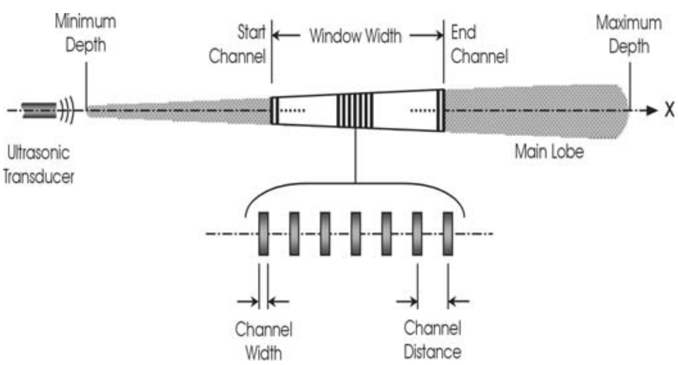

Fig. 5 Measureequipment XW-3Psi

The angle the transducer made with the flow direction (Doppler angle), which is important for defining the measurable velocity range, mainly depended on the structures installed at the entrance to the surge chamber. This angle was 75° for both horizontal and vertical measurements. The feasible measuring range of a 4MHz transducer was between –750 and 750mm/s for a maximum measuring depth of approximately 350mm, .

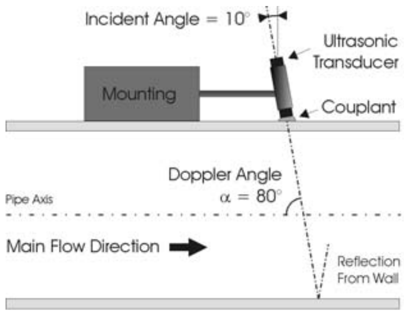

Fig. 6 Measureequipment XW-3Psi

As visual inspection had already suggested that swirl flow and, hence, turbulent flow conditions would occur, the instruments were tested, or "calibrated", by trying them first in positions where steady flow was expected. A further check of the instrument parameters was made by making comparable measurements at two opposite locations in the surge chamber.

The characteristic features of turbulent flow conditions are irregular secondary velocity components diverging from the main flow direction. The reflections of the fluid particles moving in all spatial directions affect the results of UVP measurements. Increased measuring durations proved effective in obtaining better results.

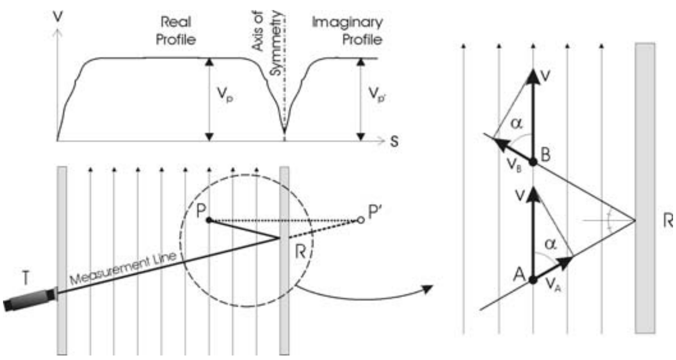

Fig. 7 Measureequipment XW-3Psi

UVP MEASUREMENTS AND RESULTS

During the first phase of the model tests it was important to study different turbine shaft configurations and their influence on the flow conditions. The main criteria of assessment were the length of the degassing zone as well as the velocity curve along the surge chamber. The UVP measurements were intended in the first place to describe the velocity curves in the surge chamber and, secondly, to provide additional information on the boundaries of the zone in the centre of the chamber cross-section where the undissolved air fraction degases. By way of example, the measurements made in a non-symmetric turbine shaft will be described in the following paragraphs.

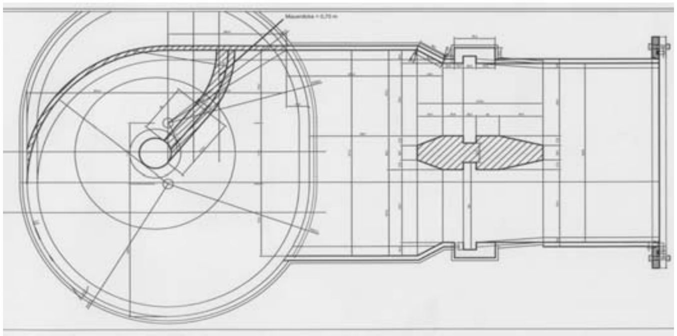

Fig. 8 Non-symmetric turbine shaft

Velocity curve

The velocity curve was described by means of measurements made in 7 cross-sections provided along the surge chamber. The surge chamber is approximately 3.50m long and has a horseshoe cross-section with a maximum internal width of 32.8cm and an internal height of 35.5cm. Allowance had to be made for the geometry of the structures installed within the surge chamber in positioning the measuring cross-sections. The maximum spacing was 50cm.

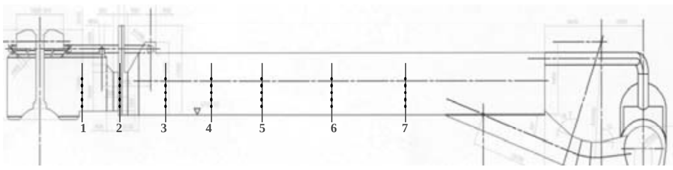

Fig. 9 Chamber-section

The water depth within the surge chambers selected for a certain stationary operating condition was about 24cm. In each cross-section measurements were taken in 5 horizontal planes with a constant spacing of 4.5cm. The measured velocity curves in Profile 1, in the entrance zone of the chamber, are shown plotted in Figure 10. The curves indicate the presence of some reverse flow in the two lower measuring planes as well as unsteadiness in the velocities measured in the foam zone.

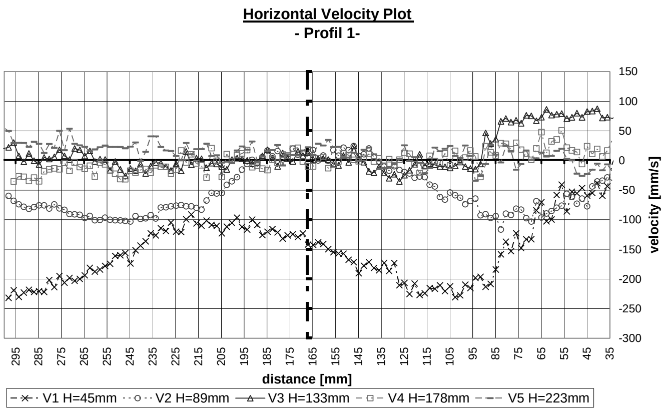

Fig. 10 Velocity plot in Profile 1

Figure 11 is a graph showing horizontal velocities measured in Profile 2. The influence of the asymmetrical inlets to the turbine shafts on outlet flow is clearly seen when comparing the weir openings, which are separated by piers in this area.

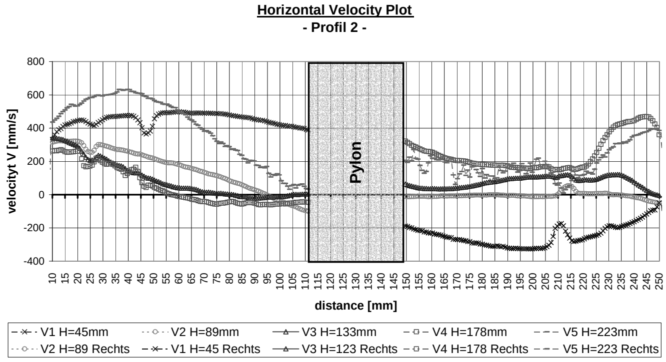

Fig. 11 Velocity plot in Profile 2

This asymmetry in the velocity curve continues, though decreasing, as far as Profile 7 (Figure 12). The results from each measuring cross-section were summarised in tables and diagrams, which served as a basis for the qualitative assessment of the velocity curve.

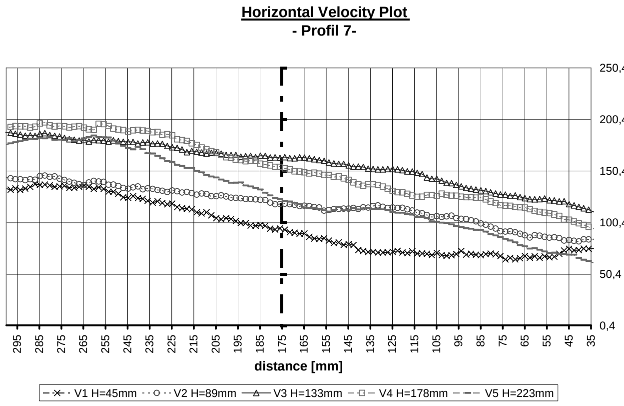

Fig. 12 Velocity plot in Profile 7

Reverse-flow swirls at the chamber floor were seen to extend to the middle of the chamber length. The turbulent swirl flows within the measuring cross-sections have only a minor influence on the velocity curve in general, they do, however, affect the quantitative result of the measurements.

Defining the boundaries of thedegassing zone

Degassing was studied by means of photographic evaluation of the chamber walls supported by the evaluation of the degassing zone in the middle of the cross-section using UVP measurement. The measurements were made at 4 points with a constant spacing of 4.5cm.

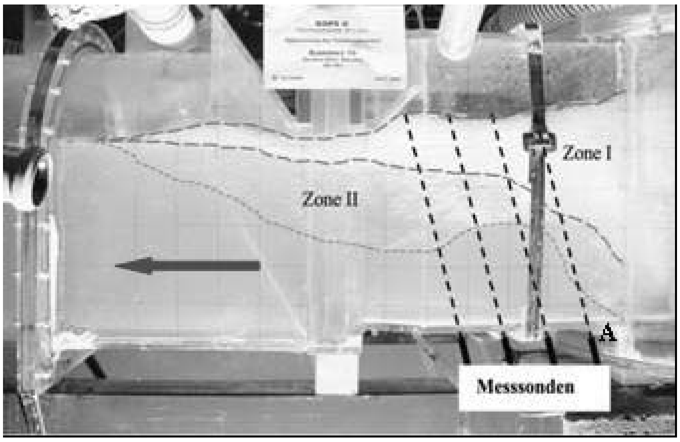

Fig. 13 Picture with degassing zones

The degassing area, shown in Figure 13, falls into two zones: An upper foam zone (Zone I), with a bubble size of up to 15mm and a high proportion of air in the water/air mix, moves at a low velocity.

In the lower area (Zone II), with a smaller proportion of bubbles, the air bubbles are characterised by jerky movement.

Figure 14 is a graph showing the velocities measured during a test as a function of depth, demonstrating, by way of example, a vertical UVP measurement made by Transducer A. The foam area (Zone I) is characterised by extremely fluctuating velocity levels, ranging in this case between 110mm and 270mm.

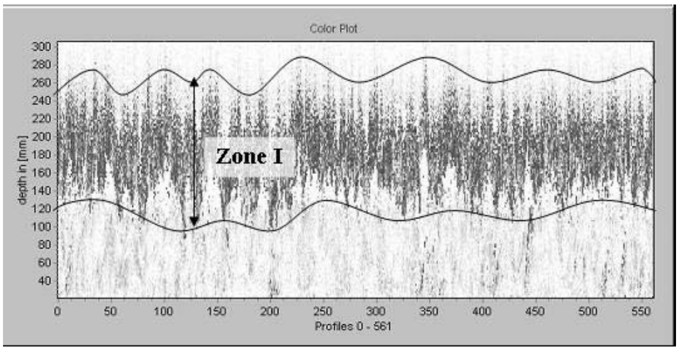

Fig. 14 Example of a vertical UVP measurement

In combination with photographic evaluation of the degassing process, UVP measurement proved a suitable method for a qualitative assessment of the turbine-shaft configuration. As, however, the size of the air bubbles in the model is relatively too large, quantitative transfer of the results to prototype conditions is either very difficult or impossible.

CONCLUDING REMARKS

A complex study programme was required for the scale model test on a compressed-air surge tank. This included identifying the velocity field and the wave movement resulting from the surge phenomena as well as zones characterised by a two-phase water/air mix.

The results of the velocity measurements showed qualititative agreement with the numerical analysis. Greater accuracy in determining the velocity curve would have been obtained if additional transducers had been purchased for the multiplex system. The two-phase zone was largely defined; the boundaries of the foam zone were clearly determined. Irregular two-phase zones were defined by the additional use of photographic analysis.

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