DEGASSING OF AIR BUBBLES IN A CHAMBER SURGE TANK

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Abstract

Due to the increased requirements of hydro power plants concerning shifting times and increasing discharges an optimized surge tank design is still in development. The surge tank facility has three main benefits: the protection of the pressure tunnel from water hammer propagation, improved controllability and an enhanced mass oscillation behavior due to the needs of the electrical facilities. In the past decades surge tanks especially in Austria have become more and more sophisticated to fulfill technical as well as economical aspects. Therefore the design of chamber surge tanks has been adapted with throttles and overflows to use differential effects such as symmetrical or asymmetric hydraulic losses or column separation.

In case of the downsurge process after filling the upper chamber the water column separates at a certain time at the overflow edge of the upper chamber. The water surface in the main shaft is dropping while water remains in the upper chamber. The remaining water plunges as a waterfall down the main shaft and entrains air bubbles by a jet into the water body at the level of the lower chamber. It is important to avoid an entering of air bubbles into to pressure tunnel. To check the functionality of a specific large surge tank facility a physical model test was carried out. In order of hybrid modeling additional investigations in terms of 3D-numerical calculations were tested and applied to the results of the physical model test. Here are introduced the investigations regarding the degassing process of a waterfall that entrains air bubbles into the lower chamber.

Keywords: hydraulic model test, two-phase numerical simulation, CFD simulation, surge tank, degassing air bubbles

Introduction

A physical model test for checking the behavior of the transient hydraulics acting on the surge tank of the planned pump storage plant *Atdorf* in the Black Forest was tested in the laboratory of the Institute of Hydraulic Engineering and Water Resources Management, TU Graz. The schematic overview of the hydropower plant is given in Figure 1. In terms of improving hybrid modeling and the enhancement of the output of physical model tests additional investigations with 3D-numerical simulations are carried out. For the presented analysis the CFD program Ansys CFX® was used.

Model test

A complete model of the surge tank was constructed in acrylic glass to visualize flow situations and prove a secure behavior regarding flow distribution, filling and emptying of the chambers. Basically the pressure tunnel has the main influence on the design of the surge tank because of the mass of water in the conduit that has to be accelerated. Due to reasons of space it is not possible to build a model including the pressure tunnel. Instead of this the surge tank is connected on the side of the machine caverns and the pressure conduit to a controlled valve that ensures the transient flow regarding to a previously calculated input with 1D-numerical methods.

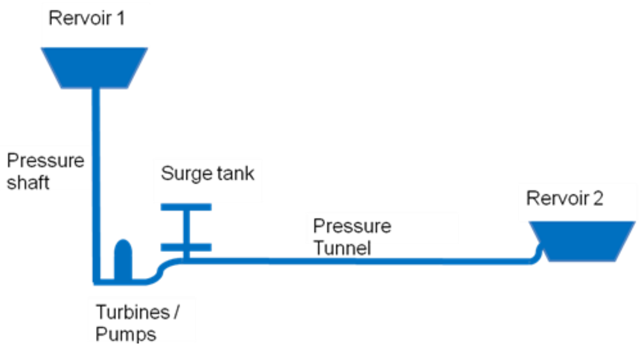

Figure 1 Hydraulic system

The model test of the surge tank has a scale factor of 1:40 and is scaled by Froude's similarity law. Hence the surface wave propagation and behavior is represented in the model test. Other hydraulic phenomena that occur in the facility like air bubbles that are entrained by a waterfall due to

column separation of the upper chamber don't follow the scaling laws for discharge and time. Therefore adaptations had to be found to model a realistic degassing for the prototype scale.
Due to structural advantages as well as better behavior for flow situations and filling of the chambers an eight loop shape was chosen by planers (see Figure 2). Some views of the model are shown in Figure 3 and Figure 4.

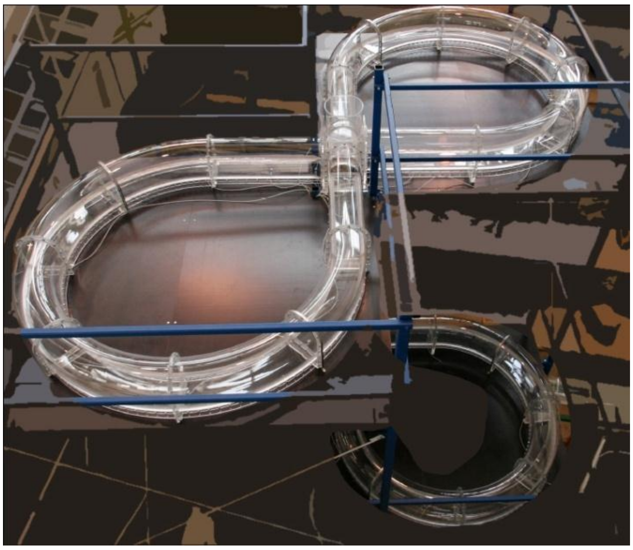

Figure 2: Model test of the surge tank, acrylic glass

The transient input parameters from 1D-numerical calculations to operate the model test represent already the results from the hydraulic design process. Therefore the complete tail water scheme including the turbines and the boundary conditions of the basin where computed to design the conduit system as well as the dimension of the surge tank (Brost et. al. 2010).

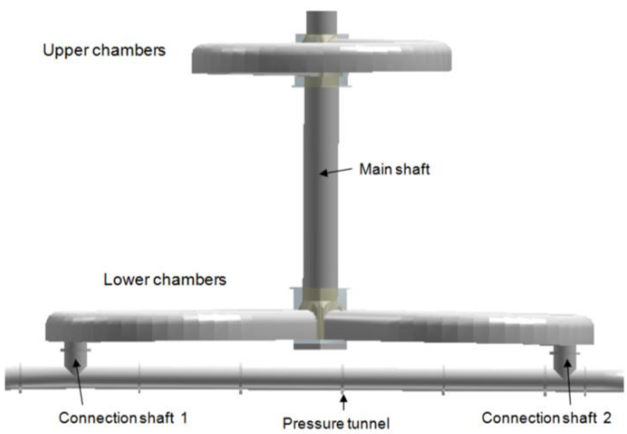

Figure 3: Front view of investigated surge tank

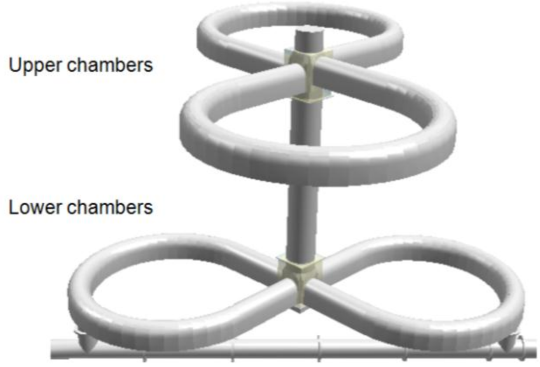

Figure 4: Perspective view of surge tank

Characteristics of surge tank

Providing a suitable controllability and stability of the hydraulic system that needs to fulfill the requirements of the shifting specifications the surge tank has to be designed. It is balancing the oscillations of mass in the pressure tunnel as well as damping the water hammer propagation from the turbines and pumps. Due to the free water surface in the surge tank water hammer waves from operating actions can be reflected and prevent the behind pressure tunnel from additional pressure heads. Regarding load cases at capacity level the upper chamber and at drawdown level the lower chamber is dimensioned. The design shifting is set at time points of maximum velocity in the pressure tunnel. A high upsurge or downsurge rate in the shaft is affecting the volume demand of the chambers in respect of a more economical solution (Jaeger 1949). Due to the stability of the hydro power facility in operation the shaft diameter is limited (Giesecke 2009).
In order to provide a good controllability of the power units good damping of the conduit system is important. Regarding economical chamber sizes and ideal damping differential effects are used to improve the oscillating system. This can be achieved by either additional devices like damping orifices, symmetrical or asymmetrical throttles or by optimizing secondary hydraulic effects.

Secondary effects in surge tank calculations

In case of upsurge action first the lower chamber is filled starting from an optional level. Then the main shaft is filled and water rises to the overflow level at the upper chamber. Due to sharp edge intersection from shaft into upper chamber an inflow resistance is acting as an additional head on the conduit system. Also an important hydraulic effect is given in certain load cases of downsurge after a partially filled upper chamber. At a certain discharge in pressure tunnel the upper chamber cannot follow the demand and the water column in the shaft separates at the overflow. The water level drops from upper chamber in the shaft reaching the lower chamber. The remaining water from the upper chamber follows as a water fall into the water cushion of the lower chamber (see Figure 5). While separation the water level in the shaft is acting as pressure head onto the transient flow in the conduit system. Due to the separation an earlier drop of pressure allows a lower acceleration of the water in the pressure tunnel. The lower maximum velocity in the tunnel is followed by lower suction capacity out of the surge tank. This leads to lower volume demand of the surge tank. A separation can also be forced by a wall or beam at the overflow.

Waterfall at initial surge tank design

The initial surge tank design was considering a direct connection from the pressure tunnel to the main shaft. The visualization of the transient flow conditions in the model test has shown an inacceptable waterfall that entrains massive amounts of air into the conduit system. Solutions needed to be found to avoid problems with air by keeping main parts of the initial surge tank design. Figure 3 and 4 show the final scheme of the surge tank where the lower chamber is connected by two shafts to the pressure tunnel.

Waterfall from upper chamber to lower chamber

The upper chamber is filled from water from the main shaft in case of upsurge process. At a certain point of time the upper chamber reaches a maximum filling and the flow accelerates in opposite direction and starts emptying the upper chamber. Since the chambers are just very slightly inclined a separation of the water column is forced at a certain discharge rate from the upper chamber. A waterfall starts dropping into the main shaft by a transient flow rate. At the separation only the head by the water surface height in the main shaft acts on the hydraulic system and responses to the head at the reservoir.
The aim is to use the positive damping effects of the water fall by providing enough degassing length in lower chamber.

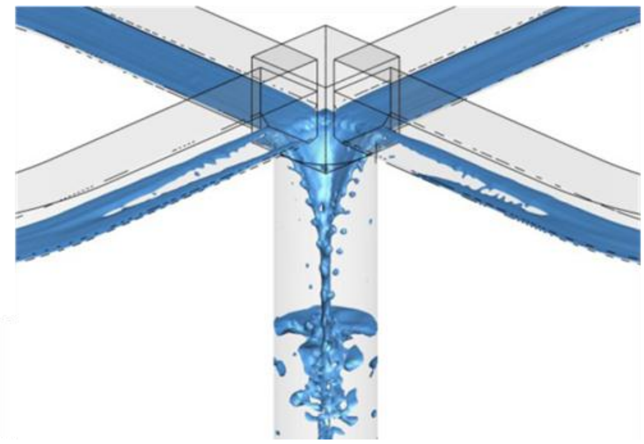

Figure 5: Column separation at overflow from shaft to upper chamber

Investigated load case

Tests and resulting figures that are shown in this paper reference to a four shift resonance load case for maximum discharge at draw down level in the reservoir. It includes opening of the turbines which leads to a starting upsurge and an acceleration in the pressure tunnel. At maximum velocity in the pressure tunnel the turbines close – the water level in the surge tank drops in the lower chamber until the counter oscillation accelerates the water in the pressure tunnel.

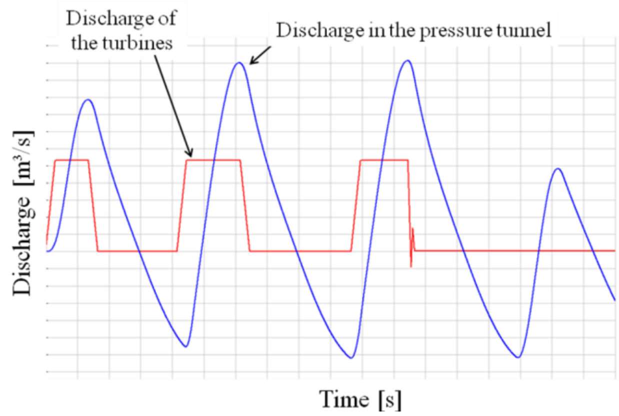

Figure 6: Shifting time regarding to peaks of discharge in pressure tunnel

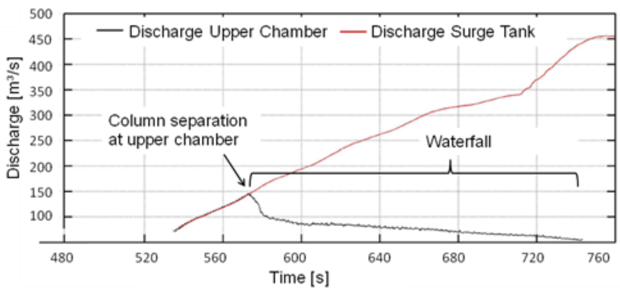

Figure 7: Discharge of waterfall after separation

In Figure 8 a clear difference in the shape of the surge tank oscillation between upsurge and downsurge is visibly. The straight upsurge direction leads to a filling of the upper chamber and no secondary effect is breaking the hydraulic process. This is advantageous to quickly build-up a counter pressure on the conduit system. For downsurge characteristics a curved line indicates the breaking from the discharge of the waterfall due to its transient flow. But a consideration of the separation allows an earlier downsurge process. This leads to a lower acceleration of the flow in the pressure tunnel because an earlier drop causes an earlier decrease of maximum head on the conduit. In succession this results in a lower volume demand of the surge tank chambers.

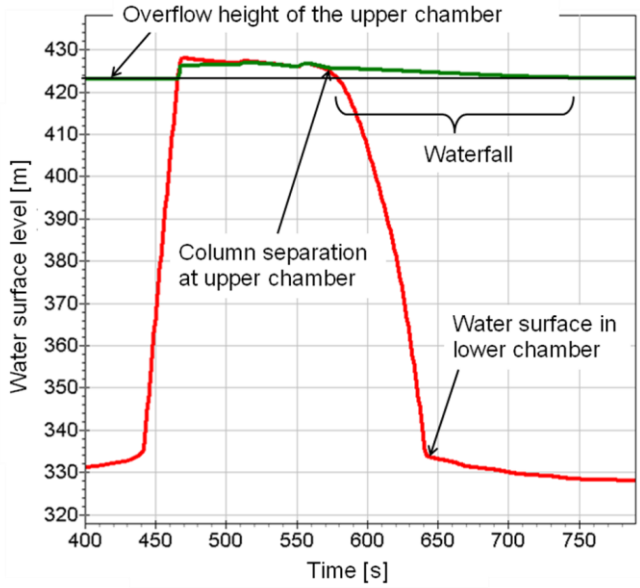

Figure 8: Shape of oscillation at water fall situation

Air entrainment in shaft due to the waterfall

In the model test it is visible that right after the separation at the upper chamber high amounts of air are entrained into the shaft as air bubbles. The water fall entrains air over the whole downsurge process. This leads to air bubbles reaching the lower chamber.

In particular the rising velocity of single bubbles is faster.

Water fall in prototype

Due to the reason that the water fall drops about 100 m to bottom the effects of dissolving and showering of the water fall for the prototype scale imply uncertainties.

But facts are the high discharge drop at the time of separation that entrains large amounts of air and the continuous process of air entrainment over the whole period of downsurge.

For the extrapolation to prototype scale it is assumed that an air concentration of 10 % reach the bottom of the shaft. Numerical calculations have shown that higher concentrations lead to an even improved degassing process.

Numerical approach for two-phase flow

Since there are no numerical models developed yet for simulating bubble entrainment (Danciu 2011), existing models have to be adapted to simulate the degassing process of air induced by impinging water jets. In case of the water fall in the surge tank, following assumptions where found to be applicable:

- 6 mm bubble size (rising velocity of 20 cm/s) for single bubble (see Figure 10)
- 10 % air fraction reaching the lower chamber
- Continuous concentration of air bubbles

Degassing implemented in software

The Software used for analysis is Ansys CFX® V.12.1 with a two-phase flow realized as dispersed fluid and regarding the drag due to turbulence by the implemented drag coefficient.

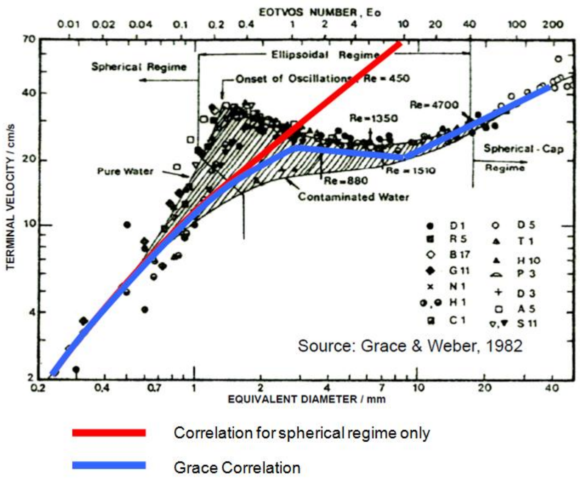

Figure 10: Terminal bubble rise velocity, implementation in Ansys CFX® (Frank 2011)

Verification of degassing model

The verification was set for recalculation of a degassing gradient to be compared with measurements from a prototype scale facility as well as for the degassing of the present model test.

Measurements from tail water of pelton turbines

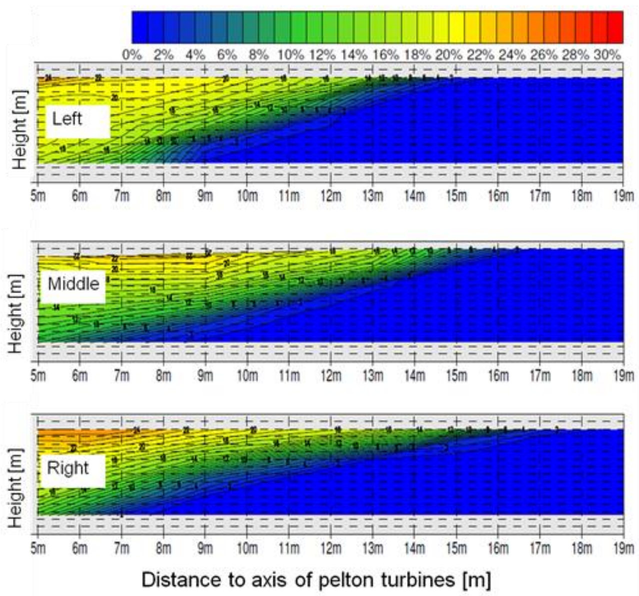

Figure 10: Degassing in tail water channel of HPP Koralpe, Arch (2008), (modified)

Figure 10 indicates degassing measurements taking in tail water channels of pelton turbines of air concentration.

Starting from 5 m behind the axis of the turbines the air is degassed after a length of 17 m to 18 m after the axis. The analysis of the measurements combined with the fluid speed leads to rising velocity of the air bubbles in the range of 20 cm/s (Arch 2008).

A numerical investigation in a simple rectangle flume with 6 mm bubbles as dispersed comes to the rising velocity as indicated for 6 mm single bubbles and suits for the measurements and results of Arch (2008).

The degassing in the model test is visible while downsurge in the shaft and very significant at in the lower chambers. The water fall plunges with a speed of 6.6 m/s in the water cushion and drags the entrained air bubbles to the bottom of the chamber. In the numerical model the air is entrained from the shaft and transported by the drag force with the liquid flow. Because the entrainment by plunging jet was not realizable by the numerical tool an inlet at top of the lower chamber (Figure 11) entrains the water-air mixture at the bottom to comply with the model test.

Boundary conditions of numerical model

The boundary conditions of the transient model test (Figure 11) where scaled by Froude's similarity law. The discharge out of the model is a parameter from the 1D – numerical calculations.

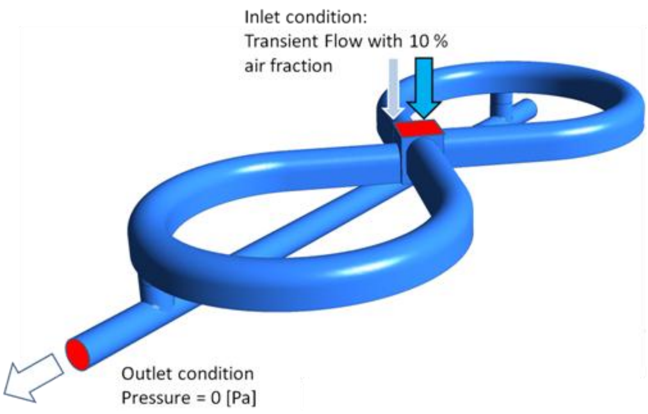

Figure 11: Boundary conditions for the numerical model

Comparison with model test

The comparison with the degassing process present in the model test could be made visible in the same amount and quality. Figure 12 shows a photograph of the degassing process in the lower chamber in the model. In Figure 13 and Figure 14 the numerical results of the degassing process are demonstrated at two different time steps.

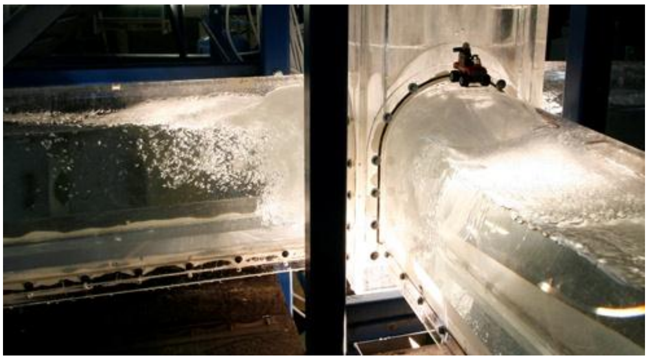

Figure 12: Degassing in lower chamber, model test 1:40

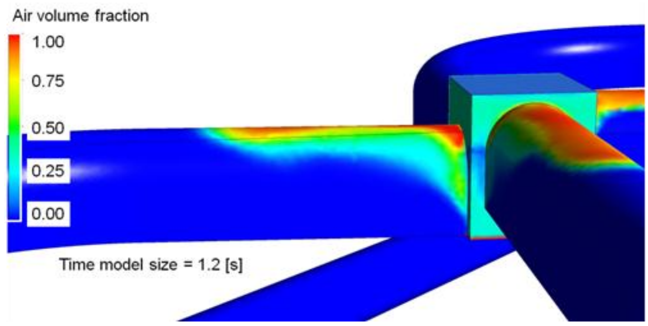

Figure 13: Degassing in lower chamber, model test 1:40 in numerical two-phase model at model time 1.2 [s]

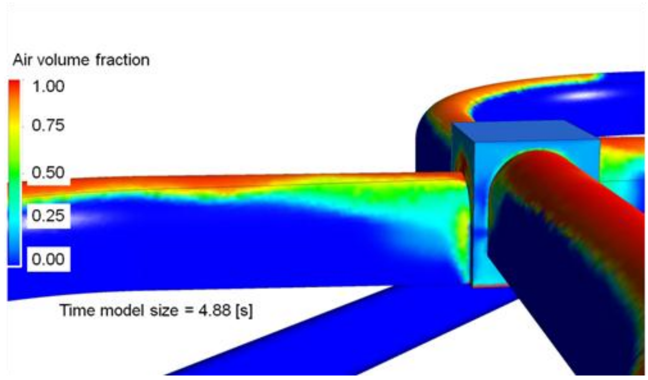

Figure 14: Degassing in lower chamber, model test 1:40 in numerical two-phase model at model time 4.88 [s]

The degassing process as well as for the model test and the numerical simulation it is a continuous procedure that of course fluctuates due to turbulence but with a stable gradient over time. Accordance between the physical and the numerical modeling could be demonstrated.

Extrapolation for Prototype scale

Important for extending the range of a hydraulic model is the possibility of visualizing not only the scaled effect by the taken law, but also other hydraulic phenomena. In this case the Froude model is extended to visualize a possible situation about how air bubbles raise.

For simulating the degassing process for the prototype scale the boundary conditions were set as for the CFD simulation of the model scale simulations with prototype discharges, but also 10 % air fraction (Figure 15). The impact of the water fall is not applied in the way that it reaches the bottom of the chamber. Furthermore it is assumed that air bubbles reach the crown of the lower chamber tunnel ahead of the water surface level, because of entraining depth of the water fall in the main shaft.

As long as the water surface has not reached the lower chamber the flow is not symmetrical through the four chamber branches. Figure 16 and Figure 17 show the degassing for the prototype scale.

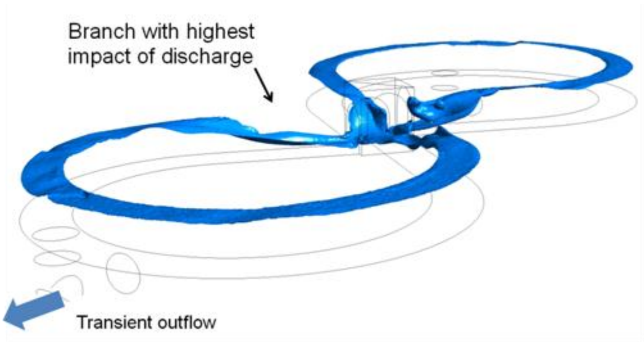

Figure 15: Isosurface of the 10 % air fraction at time 57 [s]

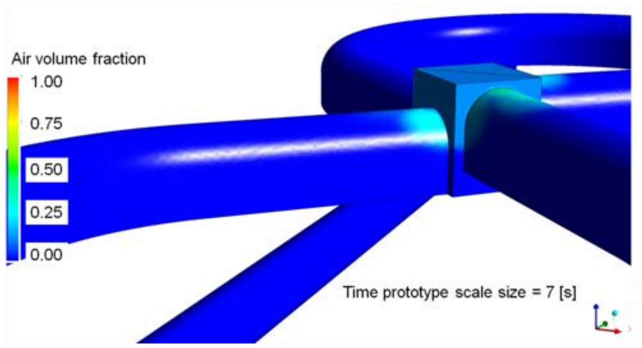

Figure 16: Degassing in lower chamber, prototype scale in numerical two-phase model at model time 7 [s]

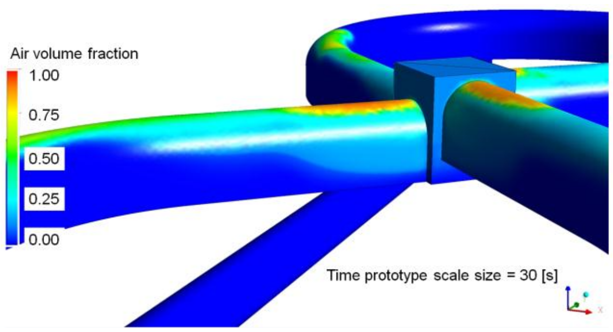

Figure 17: Degassing in lower chamber, prototype scale in numerical two-phase model at model time 30 [s]

Conclusions

Due to consideration of secondary effects in surge tank oscillation a reduction of volume demand is computable by analysis with 1D-numerical methods. An important secondary effect is column separation at the crest of the upper chamber in case of a starting downsurge process. This leads to a water fall entraining air into the shaft and lower chamber.

To ensure an adequate degassing behavior of the chamber a minimum length needs to be given. In case of the investigated surge tank a double connection from the pressure tunnel and the shaft could fulfill the hydraulic requirements. Hybrid modeling in sense of extending the results of the physical model test by numerical simulations could give a reasonable valuation of the

Numerical simulation could show a good accordance between degassing process for the model test as well as for a comparing degassing gradient from measurements in prototype scale. A bubble size with the rising velocity of 22 cm/s was found to fulfill the comparing load cases in an adequate way.

Although the bubble entrainment by plunging jets is not yet presentable by aims of numerical simulations it is seen to be possible to set up a model with precautions to describe the degassing of a waterfall in a surge tank.

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