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Hydrolink

SURGE MITIGATION FOR PUMPED STORAGE HYDRO-POWER

BY ELENA PUMMER & WOLFGANG RICHTER

Spectacular surge waves can occur in hydraulic underground structures such as surge tanks and tunnel systems in pumped storage plants. The flexible way of operating these types of plants may cause pressure surges to be transferred to free surface waves and vice versa. The mitigation of these surges is the topic of the research discussed in this article. We aim to optimize the safe and reliable operation of pumped storage plants under the most unfavorable load cases that may appear over their life. This article describes some innovative developments in this field. The first part focuses on hydraulic research on surge tanks and the second part highlights free-surface waves in storage tunnel systems.

Pumped storage hydropower plants, as an important energy storage system, use head differences between open surface reservoirs or underground tunnel systems to efficiently store vast amounts of electric energy. Massive amounts of sustainable energy storage are needed to ensure an economic transition to an expanded renewable energy-based system. This requires the flexible operation of the hydro storage plants with high water discharges in pipes and high heads and that demand damping facilities such as surge tanks to balance the water inertia and to enable the best possible control of the hydraulic turbomachines. Complex surge tanks may consist of a combination of shafts and chambers. Storage tunnels and cavern storage systems are becoming the subject of research seeking ways to improve the utilization of energy storage in under-ground structures that are not constrained by the topography [1].

Surge Formation

Pressure surges result from rapid changes in the operation of hydraulic turbomachines and flow control devices. These operation changes may be due to load variations causing rapidly forced disconnections from the grid or by providing flexible power production. Full load rejection in generation mode or pumping mode may lead to extreme pressure surges and unpredicted failures. Pressure surges and water inertia demands must be mitigated and captured, which is safest done by surge tanks. Surge tanks provide free water surface and often have side chambers where the surging water is transferred and forms free surface surge waves. These waves can be large, and reflections and superposition can occur. To dissipate high pressure surges a robust

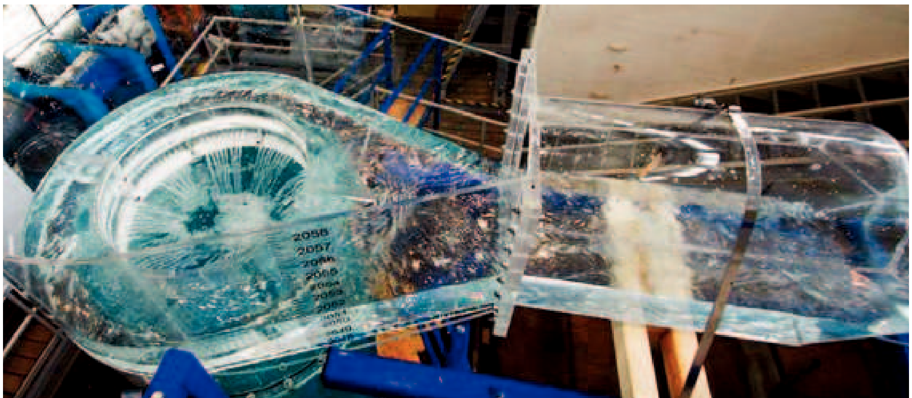


Figure 1. Laboratory scale model at Graz University of Technology of the waterfall dampening device for Obervermuntwerk II pumped storage plant [2], Photograph: Wolfgang Richter.

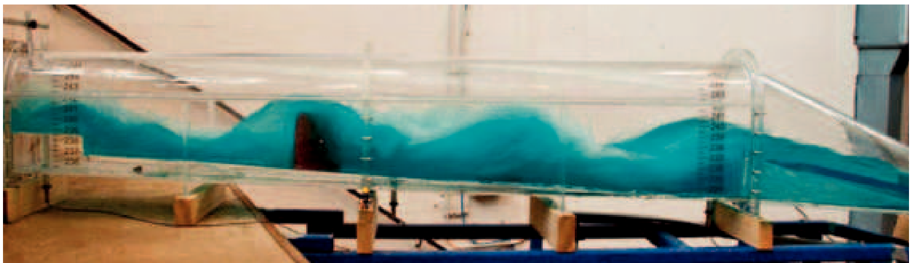
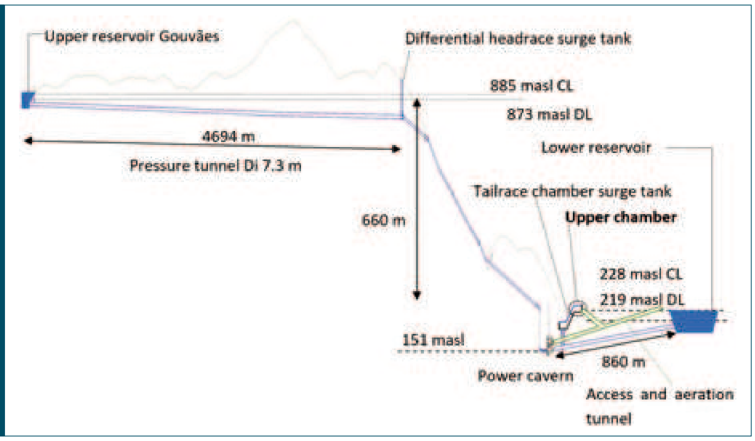
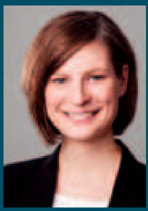


Figure 2. Upper chamber surge wave dissipation for an unfavorable design load case in the tailrace surge tank of the pumped storage plant Gouvães from Iberdrola, Photograph: Franz Georg Pikl [3].

Figure 3. Longitudinal section of Gouvães pumped storage hydropower scheme by Iberdrola, surge tanks hydraulically tested at Graz Universtiy of Technology.





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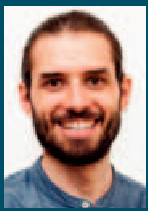

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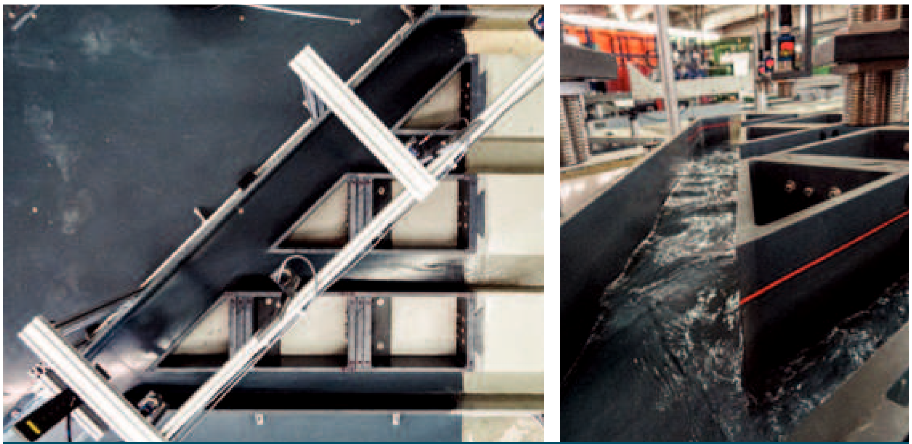

Figure 4. Extract of an open tunnel system model with modular design at RWTH Aachen University. Photograph: Elena Pummer.

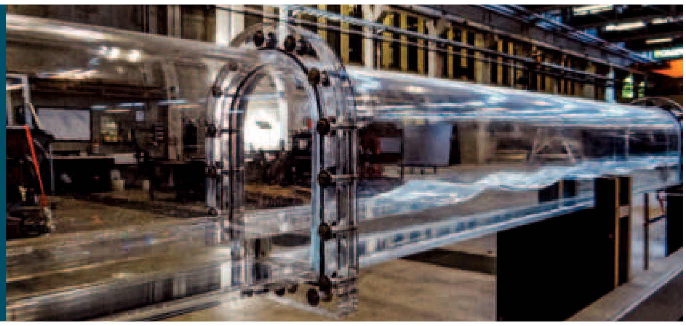

Figure 5. Surge wave formation in a tunnel system model at RWTH Aachen University. Photograph: Elena Pummer.

hydraulic system design is needed. Such a system must allow the flow to transition back to pressurized flow in the pipes, as the oscillating water mass fills and empties the surge tank structure.

Controlling Surges with Innovative Surge Tanks

Structures to mitigate pressure surges are most of the time the subject of unique designs. The flow phase interchange between pressurized flow and free surface flow in the chambers of the surge tank represents a design challenge. Because, hydropower plants are connected to the electrical grid, this hydraulic effect influences the surge tank design by requiring a stability criterion expressed by minimum horizontal cross-section in contrast to surge tanks for water pipelines. Surge tanks that consist of a vertical shaft and an nearly horizontal upper chamber face the additional challenge of air entrainment when the water surface in the main shaft drops while water remains in the upper chamber and plunges in the shaft as a waterfall down the main shaft. In such cases, air bubbles must de-aerate in the surge tank structure or in a controlled way in the power water system to avoid causing any damage.

Surge tanks in pumped storage hydropower plants are designed for several main purposes:

a) To enable machine controllability when pressurized pipes are utilized by mitigating the direct elastic inertia acting on the units
b) To allow quick loading with water supply from the surge tank reservoir
c) To mitigate pressure surges from valves, extreme loads at load rejection in turbine or pumping mode

Due to the vast demand for power control in the electrical grid and the demand for electrical energy time-shifting, i.e. storing power when demand is low and using it during peak demand hours when also prices are highest, pumped storage plants are designed increasingly larger with higher discharges, which increases the demand for flexible operation and surge mitigation. One example of a modern pumped storage plant is the *Obervermuntwerk II* scheme by Illwerke VKW AG in Austria with 360 MW of installed capacity. This plant is equipped with a large surge tank and an upper chamber that can generate massive surge waves creating waterfalls into the main shaft. A waterfall dampening device was developed to force the surge wave into several small openings, which lead to many small jets mitigating the air bubble entrainment by 2/3 compared to a concentrated waterfall jet. Figure 1 shows a snapshot of the transient physical model test of the waterfall dampening device that was investigated in the hydraulic laboratory of Graz University of Technology and has already been successfully constructed at the plant and is in operation. It consists of a balcony structure with defined small vertical and horizontal holes that create multiple small jets instead of one waterfall to spread the jet impact and thus mitigate the air bubble entrainment.

Major hydraulic loading on pipe systems in pumped storage schemes may be generated by pump trips. Due to high heads and large discharges, the flow in the high-pressure section of the system may reverse in a very short time before the guide vanes are fully closed. Such events demand a very quick reaction of the headrace surge tank to prevent sub-atmospheric pressures. On the tailrace side, such a pump trip may cause a significant pressure surge, when filling the surge tank. At this point, the pressure surge is transferred to a free surface surge wave in an inclined upper chamber connected to the surge tank. Figure 2 shows the transient physical model test investigation of the upper chamber from the tailrace surge tank of the *Gouvães* pumped storage scheme in Portugal with 880 MW installed capacity by Iberdrola. To avoid spilling of the aerated chamber into the access tunnel, massive baffles were developed to efficiently dampen even the most severe surge wave. The design developed with the aid of the physical model was adopted by the project, which is still under construction and due to be commissioned in 2021. Figure 3 shows the hydraulic system of the pumped storage scheme and the position of the upper chamber.

Designing Tunnel Systems to Minimize Surges

Tunnel systems and caverns could be used instead of, or in addition to classical free surface reservoirs in pumped storage plants. They might even substitute surge tanks by serving multiple hydraulic purposes. Classical surface reservoirs have a large continuous area, which is not the case for tunnel systems. Their site-specific conditions are always unique, and the tunnels need to be specifically designed for each plant. Since very few plants of this type have been built, the current state of the research is the state of the art.

At the laboratory of RWTH Aachen University, model plants of many different tunnel system designs and operation modes were tested. Figure 4 and Figure 5 show photo extracts of different physical models in the laboratory [4]. Figure 4 shows the modularity of the system and the possibility of design changes in one of the models.

The results show the increased intensity of surges in comparison to classical surface pumped storage reservoirs (Figure 5). Thus, the classical approach of neglecting wave generation by pressure surges is not appropriate for tunnel systems. Also, classical formulas for tunnel dimensions cannot be used, because of complex tunnel filling and emptying processes related to the plant operation. Plant operation and design depend strongly on the local site conditions, including rock quality, operational objectives and cost. Thus, the authors developed new calculation approaches and recommend using numerical and physical modelling to design this type of plants [5].

Conclusion

The mitigation of hydraulic surges has always been a great challenge for the design of pumped storage plants and will be even more crucial with the increased need of flexible operation and higher capacity in these sustainable energy storage systems due to the vast integration of fluctuating renewable energy sources. To overcome topographic limitations for the siting of pumped storage projects, the concept can be economically transferred fully to underground structures. The engineering and research experience gained so far and the ability to build suitable small-scale models and perform numerical simulations makes it possible to address the hydraulic challenges in the design of surge mitigation structures in underground caverns and tunnel systems. ■

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ISHS 2020

The 8th IAHR International Symposium on Hydraulic Structures (ISHS2020) was scheduled to take place on 12-15 May 2020 in Santiago, Chile. Because of exceptional circumstances, i.e. the COVID-19 virus pandemic, the event had to be cancelled in late March 2020.

The ISHS series is the flagship event of the Hydraulic Structures Technical Committee (HSTC) of IAHR. The symposium is organised in different parts of the world every 2 years, aiming to facilitate the sharing of information among water engineers coming from different regions, industries and background, including developed and developing countries, and hydraulic engineering students, young and senior professionals.

ISHS2020 would have been the eighth in a successful series of Hydraulic Structures symposia organised by the HSTC, in cooperation with other Committees, Associations and Institutions. The event aim to facilitate the sharing of information among water engineers coming from different regions, universities, industries and background, including developed and developing countries, and hydraulic engineering students, young and senior professionals. The first was held in Tehran, Iran, in 2004; the second was held in Ciudad Guayana, Venezuela, in 2006; the third took place in Nanjing, China, in 2008; the fourth was held in 2012 in Porto, Portugal; the fifth in Brisbane, Australia, in 2014; the sixth in Portland, Oregon, USA, in 2016; and the seventh was held in Aachen, Germany, in 2018.

The organisation of ISHS2020, in association with the Sociedad Chilena de Ingeniería Hidráulica (SOCHID) was well underway when the unfortunate decision had to be made to cancel the event. Key activities planned for the event included two days of technical presentations, keynote and invited lectures, a site visit to Instituto Nacional de Hidráulica (INH) laboratory and the Rapel hydropower dam, a master class on open channel hydraulics to be held at the Pontificia Universidad Católica de Chile, and short courses on energy dissipators and non-linear weirs, and last but not least the internationally famous water games.

In spite of the cancellation of ISHS2020, the Chairs of the Scientific Committee, Robert Janssen and Hubert Chanson, and Chair of the Local Organising Committee, José M. Adriasola, decided to proceed with the publication of the Proceedings of ISHS2020. The Proceedings focus on many aspects of hydraulic structures and their design, especially in terms of diversity, ecology, energy dissipation, and hydrodynamics relevant to the 21st century.

In response to the Call for Papers which was sent out in 2019, the Scientific Committee received 70 abstracts, followed by 49 full paper submissions. The Panel of Reviewers was drawn from the HSTC community and other international and national experts in fields relevant to the symposium themes. All papers submitted for presentation were peer-reviewed by at least two independent reviewers according to a set of criteria established by the Scientific Committee. Altogether the proceedings contain 36 papers involving 85 authors from 20 countries and 5 continents, including 2 invited keynote papers, 2 invited lecture papers and an editorial paper.

The Proceedings are an University of Queensland publication. Each paper was allocated a direct object identifier (DOI), is accessible open access at the University of Queensland institutional open access repository UQeSpace {http://espace.library.uq.edu.au/} and is indexed by Scopus and Compendex.

The proceedings are available on the Hydraulic Structures Committee webpage which can be found in the Communities section of the **IAHR website**.