

First experiences with a 420 kW TUM Hydroshaft power plant in the Bavarian Alps

Peter Rutschmann

Hydraulic and Water Res. Engrg.
Technical University of Munich
D-80333 Munich
Germany

Albert Sepp

HYDROSHAFT GmbH
Goethestr. 43
D-80336 Munich
Germany

Christian Hackl

HYDROSHAFT GmbH
Goethestr. 43
D-80336 Munich
Germany

Intro

The TUM hydroshaft powerplant (TUM-HSPP) is an innovative new hydropower concept, which has several advantages with respect to ecology. It differs from conventional hydropower designs as both, the intake and trash rack plain are bottom near and tangential to the riverbed. It is the advantage of this design that in general fish experience low flow velocities at the trash rack and especially low velocity components perpendicular to the bars. Therefore, the chance for fish of being sucked into the intake and into the turbine is very small. Also at the downstream end of the trash rack fish will find a bypass opening in order to migrate from the upstream into the downstream. Altogether there are seven patent families which have been approved or are in the process of being approved in Germany, Europe and the American continents.

Two lines of design families can be distinguished: Namely the simple hydroshaft powerplant and the so called TUM multi-hydroshaft power plant concept (TUM-MHSPP), which consists of several shafts arranged laterally of an eco-migration corridor in the river axis and two smaller migration corridors at the river banks (see figure 1). There is also a third variant of the hydroshaft concept under development. A micro-hydropower plant for decentralized energy production in developing countries, where a conventional ship container is used to transport turbine, trash rack and suction pipe. The transport container will then later be used as the intake shaft.



Figure 1: Simple, single shaft powerplant (left) and multi-shaft power plant with eco-migration corridor (right). (Th. Kaufmann/TUM)

Currently two small pilot plants exist, each about 35kW. One being in Obernach in the Hydraulic Lab of Technical University of Munich (TUM) where design optimizations and tests with living fish had been conducted. Another HSPP was built by a turbine manufacturer as a demonstrator in Heidenheim, Germany. A first and larger powerplant (420kW), situated in a Natura 2000 area near Grossweil at the Loisach River in the Bavarian Alps, will be operational in autumn 2019. The license at this place was challenged in court by NGO's arguing that two populations of red list fish species, the Danube Salmon (hucho hucho) and the bullhead (cottus gobio) could be endangered by hydropower. Thanks to the extensive tests in the Lab of TUM with living fish, this argument did not count in court. The process ended with a settlement that will not be restricting to the operator. The prognosis is that damage to fish will be in the order of 2,5% for fish migrating either through the turbine or the bypass system into the downstream. Not to say that all fish larger than 200mm would be mechanically protected by the 20mm trash rack.

1. The TUM-HSPP at the Loisach River near Grossweil

The site for the first larger TUM-HSPP is in the village of Grossweil at the Loisach River, close to Garmisch-Partenkirchen and about 65 km outside of Munich. The Loisach River is a smaller river with an alpine character. The catchment has a size of some 640 km², a mean annual flow of about 23 m³/s with larger flows during summer time, i.e. a mean winter flow of 17 m³/s and a mean summer flow of 29 m³/s. The maximum flow measured in 1999 was 360 m³/s and during construction, in late May, a flow of 175 m³/s occurred, which corresponded to almost a 5-years flood. The head of the powerplant will be 2,5m and the outputs of the two turbines add to 420 kW and an annual energy output of 2,4 GWh.

The project at this site has a longer history. There were plans to build a hydropower plant going back more than 10 years. At the site there existed an older stone ramp, which was meant to improve the upstream migration of fish. This

ramp was, according to state of the art design guidelines, too steep and not passable for fish species that are weak swimmers. The first planning resulted in a very conventional bay-type power plant. However, the plans were neither

accepted by the citizens of Großweil, nor by the water authorities and the NGOs. The HPP site is actually part of a very sensitive area, with respect to landscape, fish species and also fauna and flora. Therefore, the area is listed in the inventory of Natura2000 reserves including two endangered fish species from the red list, namely the Danube salmon (Hucho hucho) and the bullhead (Cottus gobio).



Figure 2: HPP Site at Grossweil and head difference at the former stone ramp. (Ch. Bäck&A. Sepp/TUM)

The TUM-HSPP was invented in the Hydraulic Lab of TUM in Obernach, only some 10km away from the site in Grossweil. There existed close relations of the inventors with the local population and possible investors for a power plant, who followed the development of the HSPP very closely. After first tests with the HSPP in the Hydraulic Lab of TUM they switched from the conventional bay-type design to the new HSPP design. Although it was quite clear that this new design had several advantages with respect to appearance, to operational noise but also related to fish protection, there still was a strong opposition of NGOs which finally ended in front of the court with a settlement which will not be restricting to the operator. According to investigations in the small prototype in the Lab of TUM the mortality of fish could be predicted quite well, even though the turbine in the Lab and the turbine in the Großweil HPP were quite different with respect to diameter and number of revolutions. The estimate was based on the following assumptions: The survival rates of fish during turbine passage can be predicted according to Montén (1985). The corresponding formula has a strong theoretical, physical background and predicts the probability of fish passing the turbine without blade strikes. Results of the Lab prototype with living fish were compared with the empirical results using the formula of Montén and the comparison showed fair agreement. Upscaling from the Lab prototype to the HSPP at the Loisach river was performed using predictions by Montén for both HSPPs, i.e. in the Lab and at the Loisach river, and such defining a scaling factor. Then the results from the live fish experiments at the Lab HSPP were upscaled using this scaling factor.

The TUM HSPP has a bypass for downstream fish migration which is designed as a permanent opening right at the downstream gate, either as a surface near overfall or/and as bottom near outflow. Fish are guided by the main flow to the turbine intake and find there these continuously working bypass options. Furthermore the horizontal trash rack, tangentially positioned at the river bed, acts as a behavioral barrier for fish. Fish don't like vertically oriented flow into the river bed and therefore avoid it. In addition, the alignment of fish in the flow is in a very flat angle with respect to the trash rack bars and therefore the probability of fish to pass the rack is very small.

The probability of survival for downstream migrating fish can be expressed as a product of probabilities, namely the bypass use probability and the safe turbine passing probability. Smaller fish are more likely to pass the trash rack, but they have a lower risk to be hit by the turbine blades. On the other hand, larger fish have a smaller risk to pass the trash rack but a high risk to be hit by the turbine runner. Resulting damage probabilities for the Loisach HSPP are shown in figure 3.

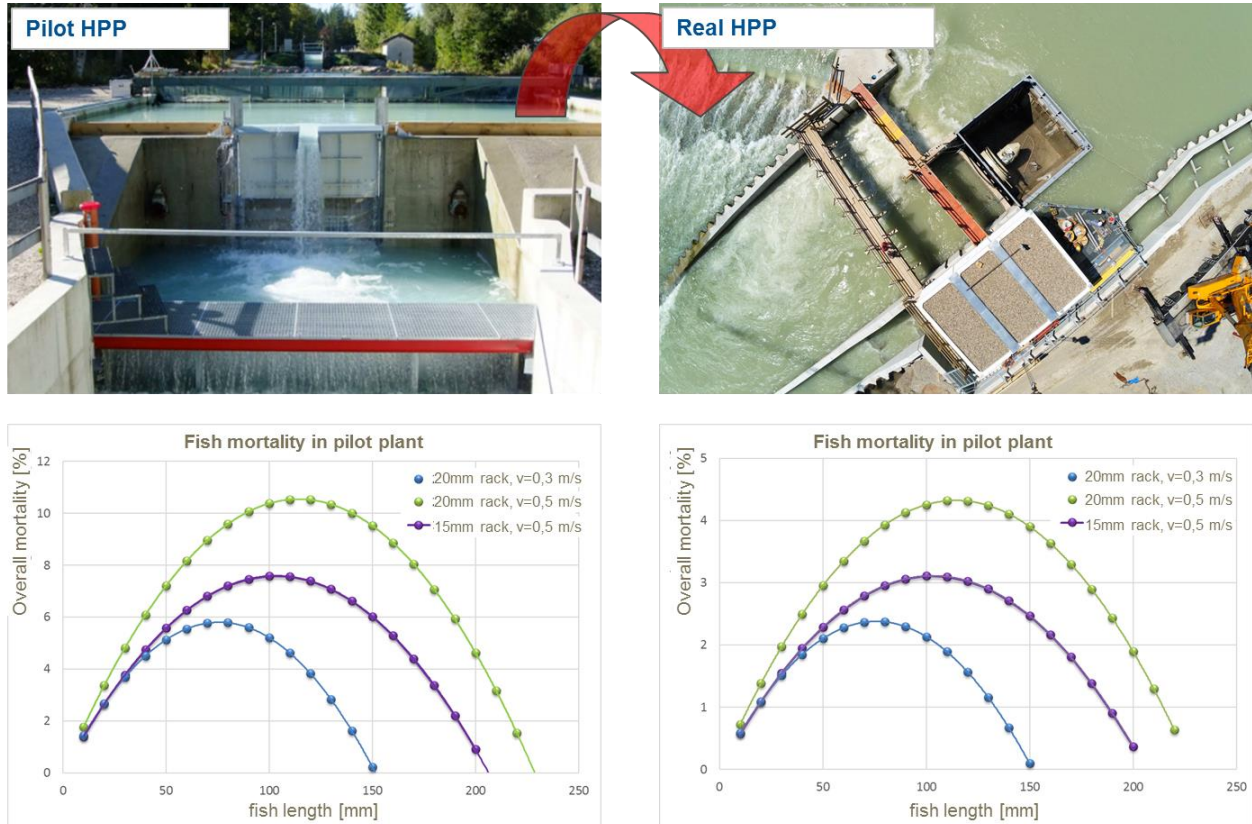


Figure 3: Mortalities of fish for the Loisach HSPP – upscaling of results from Lab HSPP to Loisach HSPP.

Because of the available infrastructure like roads, connection to the grid and others, the HPP was positioned at the orographic left side of the river in an outer curve. The existing block-ramp was meant to be kept and a small increase of 0,5m in head was achieved using hydraulic stands. On the HPP side as well as at the opposite bank fish ladders in form of slotted fish passes were constructed. The size of the pools were adapted to the size of the Danube salmon that can easily reach a length of 1m. The TUM HSPP concept was meant to be designed in a way that it was passable not only for fish but also that the transport of sediments was not disturbed. The 20mm trash rack at the Loisach HSPP will mechanically prevent larger gravel to enter into the shaft. Smaller gravel will enter and will pass the turbine, because of the small head without damage to the turbine. For the larger gravel a trash rack cleaner was developed in joint collaboration with a large and very reputed Bavarian company. Larger gravels will be moved by a scraper to the downstream end of the trash rack and flushed into the downstream by lifting the vertical gate and closing it again. However, during flood there will be an extensive amount of sediment transported. For this situation the hydraulic stands will be lowered and the turbines will stop operation such that most sediments will not reach the intake.

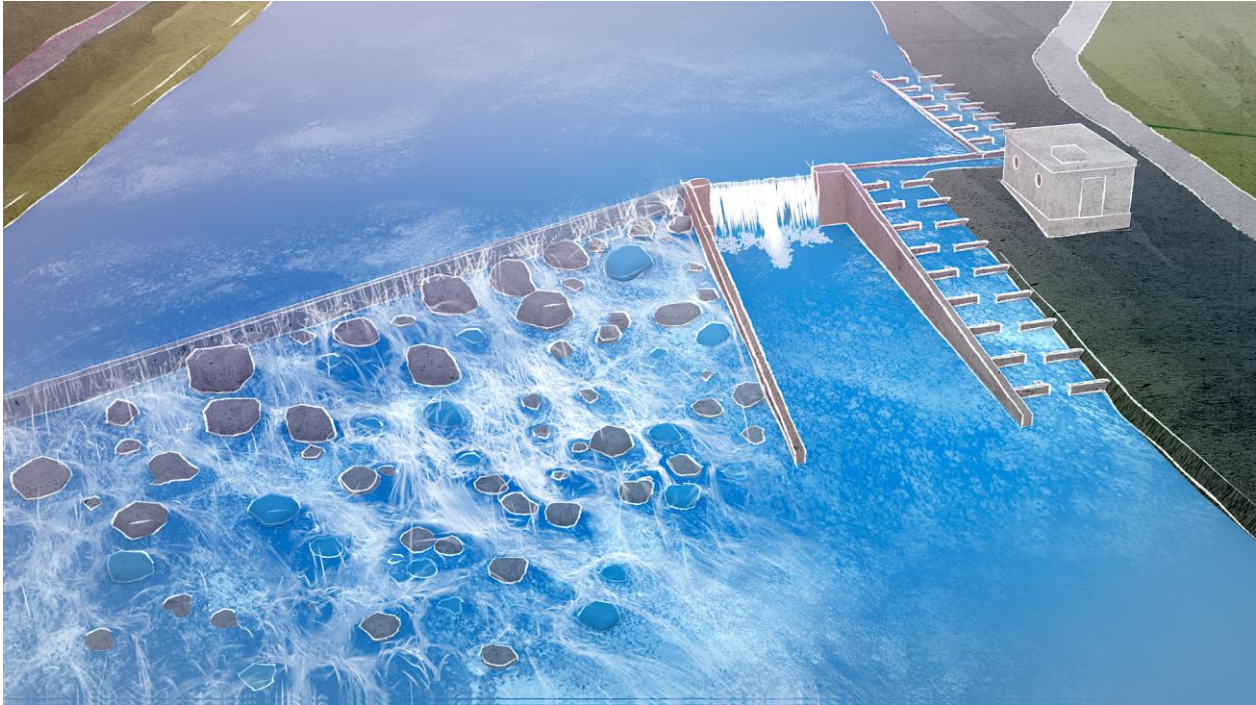


Figure 4: Visualization of the HSPP with block-ramp, shafts, fish-ladder and plant building from left. (Th. Kaufmann/TUM)

2. Construction of the TUM-HSPP

The TUM-HSPP obeys a very simple design philosophy, which can easily be adapted to prefabrication and scaling concepts once larger numbers of HPPs would be constructed. However, the first HPP at the Loisach River was erected in a very classical and therefore more costly way. In a classical construction pit formed by steel piling at the left side of the river, the two shafts and the main fish path as well as a small operation building, containing the oil hydraulics machinery and the power converters, were constructed (see figure 5). Certainly and for the future the construction process has to be optimized in order to lower costs. We think towards constructing the shaft with steel piling as a permanent shuttering or with a bored pile wall not in the dry but in the water. Depending on the site, the use of prefabricated parts or caisson techniques could also be meaningful. A commercial project that will be built using such innovative construction concepts, is under way at the Iller river in Southern Germany.



Figure 5: Construction pit at the orographically left bank. Suction pipes and parts of the vertical slot path are visible. (Ch. Bäck/TUM)



Figure 6: Hydraulic stands on top of the former block ramp, after mounting (left) and with overflow (right). (Ch. Bäck/TUM)

The two turbines of the Loisach HSPP are more or less conventional Kaplan turbines. The only difference is the directly coupled underwater permanent magnetic generator, which sits in a sealed casing. The turbines were lifted in the dry shaft with the help of a mobile crane (see figure 7).



Figure 7: Mounting of the turbine in the dry shaft. (Ch. Bäck/TUM)

Since the intake of the HSPP sits at the level of the river bed, dry access and of course mounting of the turbines in the dry has to be provided. Therefore, a water tight steel shield is placed on top of the concrete shaft. As can be seen in figure 8 there is not much freeboard for higher flows and in fact during the major flood event during construction, a 5-years flood, the shaft was flooded. As long as the turbine is not in the shaft, or if all hydraulic and electric access ways to the turbine are water-tightly closed, the problem is the cleaning of the shaft only. However, a sealing with larger freeboard or even a steel cover should be considered for future HSPP projects.



Figure 8: Mounting of the turbine in the dry. (Ch. Bäck/TUM)

3. Lessons learnt

The TUM-HSPP at the Loisach River near Grossweil is the first larger plant that has been constructed. Its construction was partly funded by the Bavarian States Ministry of Economic Affairs, Regional Development and Energy because of the innovative and exemplary character of the HSPP concept. For this first larger HSPP the mainly the functionality and to a lesser extent its financial viability was in the focus of the investors. However, the costs and the duration of construction of the HSPP will be in the focus of future HSPPs. The following lessons were learnt and the following developments will shift in future focus:

- During construction, two major floods occurred and flooded the shaft. In principle, the HSPP is not sensitive to flooding because it is equipped with a turbine that sits underwater during operation anyway. During the flooding events, the shaft was filled with water and sediments and had to be cleaned afterwards. The mounting phase of the turbine however is a critical time for flooding. At least one has to guarantee that all turbine openings for oil hydraulics or power cables are water tightly closed. Additionally one could think of using a steel cap to close the shaft during this phase.
- It is the advantage of the HSPP that concrete volumes can be reduced to as much as 20% of a conventional HPP. However, this advantage is economically very much reduced, if the HSPP is constructed in a conventional way used for bay-type HPPs. Steel piling and construction in the dry is far too expensive! Therefore, the shaft should not be constructed in the dry but in the water! For smaller rivers like the Loisach River this could be done during the low-flow season using steel piles as a permanent shuttering of the shaft walls or by forming the shaft with bored pile walls. For larger rivers, also the caisson technique could eventually be applied.
- The TUM-HSPP obeys a very minimalistic and rigid design philosophy which can easily be adapted to prefabrication and scaling concepts. Such concepts should be used to further reduce costs and construction time for the HSPP.
- Currently oil hydraulics are used to move the gates, the trash rack cleaners, the guide vanes, and the blades of the turbines. Even though this is standard technique, it increases the complexity compared to the application of electro-motors to do these jobs. The advantage would be having only one cable connected to the shaft, reducing complexity and installation time, and would also reduce the risk of oil spill offering additional benefits to the environment.

References

1. **Sepp, A., Rutschmann, P.**, “Ökologisches Wasserkraftkonzept Schachtkraftwerk“, *Ingenieur-Spiegel*, 2017, pp. 65-67 (in German).
2. **Geiger, F., Sepp, A., Rutschmann, P.**, “Fischabstiegsuntersuchungen am Schachtkraftwerk“, *Korrespondenz. Wasserwirtschaft*, Issue 9, 2017, pp. 627-632 (in German). DOI: 10.3243/kwe2016.10.005.
3. **Geiger, F., Cuchet, M., Rutschmann, P.**, “Experimental investigation of fish downstream passage and turbine related fish mortality at an innovative hydro power setup“ (Étude expérimentale de la dévalaison des poissons et du taux de mortalité au passage d'une centrale hydroélectrique de conception innovante.), *La Houille Blanche*, No. 6, 2016, pp. 44-47, DOI <https://doi.org/10.1051/lhb/2016059>.

4. **Rutschmann P., Schäfer S.**, „Das Schachtkraftwerk - Konzept, Funktion und Betrieb“, *Wasserkraft und Energie*, Issue 21, 2015, pp. 32-39 (in German).
5. **Rutschmann, P., Sepp, A., Geiger, F., Barbier, J.**, „Das Schachtkraftwerk – ein Wasserkraftkonzept in vollständiger Unterwasseranordnung“, *Wasserwirtschaft*, No. 8, Issue 101, 2011, pp. 33-36 (in German).
6. **Rutschmann P., Sepp A., Geiger F., Barbier J.**, „A new take on hydro power design“, *International Water Power & Dam Construction*, Issue 63, 2011, pp. 22-25.
7. **Montén E.**, „Fish and Turbines - Fish Injuries During Passage Through Power Station Turbines“, *Vattenfall Report*, ISBN 91-7186-247-1, 1985, 111 pages.

The Authors

P. Rutschmann did his civil engineering and PhD degree at ETH Zürich. He worked as senior researcher and lecturer at ETH before he shifted in 2002 as full professor to the University of Innsbruck. In 2007 he changed as full professor to the Technical University of Munich (TUM). He is specialized in hydropower, computational fluid dynamics including hydro-morphodynamic and eco-hydraulic modeling. Prof. Rutschmann has investigated, mostly as project manager, some 50 hydropower projects either numerically or in physical model tests. He has extensively published in peer-reviewed papers and proceedings and has been awarded the Bavarian states medal for the environment and the Heinz-Maier-Leibnitz medal of TUM for excellence in research and teaching.

A. Sepp got his diploma from the University of Applied Sciences in Munich. He worked in a consultant company as a hydraulic engineer and later also as a private expert and consultant for small hydro and partly joined TUM. Albert Sepp has designed many small hydropower plants including use of drinking water supply with turbines. He is the father of the shaft hydropower idea and was awarded the Heinz Maier-Leibnitz-Medal of TUM. Albert Sepp is the technical director of the HYDROSHAFT company, the spin-off of TUM for distribution of the HSPP concept.

Ch. Hackl studied and did his PhD at TUM and worked for 5 years as strategy consultant for a renowned management consulting company, which he left to become director of business development for a pan-European start-up. After working as private consultant on the topic of business development and Merger & Acquisitions he joined TUM-Tech GmbH as managing director in 2002, working in numerous projects on technology transfer and innovation management. Christian Hackl has an extensive background in various topics of innovation management including Intellectual Property Rights (IPR). He is an active lecturer for the European Patent Office on the topic of exploitation of IPR and in addition, he is an assistant professor at the chair of Technology and Innovation Management at TUM. Christian Hackl is the administrative and operational director of the HYDROSHAFT company, the spin-off of TUM for distribution of the HSPP concept.