10 Measures to Improve Fish Passage Through a Turbine

Franz Geiger, Peter Rutschmann, and Ulli Stoltz

10.1 Introduction

Besides the economic performance, the ecologic footprint of a turbine is becoming more and more relevant. One impact of hydropower usage on river ecology is related to fish damage during turbine passage (c.f. Chap. 9). Therefore, several mitigation measures have been developed to avoid fish passage through turbines, e.g. by screening and bypass systems (c.f. Chaps. 7 and 8). Moreover, special turbine types and designs can provide improved passage conditions for fish (e.g. Chap. 9). These approaches are often related to high construction costs and maintenance efforts as well as drawbacks in energy production. For numerous sites, the technical feasibility is questionable, especially regarding various existing hydropower plants and within suitable time scales.

Therefore, alternative approaches are desirable, which enable cost and energy efficient ecological improvement, and which can be implemented in short time scale. Instead of avoiding fish passage through the turbine or replacing the existing turbine, potentially combined with a powerhouse upgrade, the strategy of such approaches should target to improve the interaction of turbine and fish. Modelling fish damage probabilities during

F. Geiger (✉)
Ecohydraulic Consulting Geiger, Wallgau, Germany
e-mail: franz.geiger@hycor.de

P. Rutschmann
Hydraulic and Water Resources Engineering, Technical University of Munich, Munich, Germany
e-mail: peter.rutschmann@tum.de

U. Stoltz
Voith Hydro Holding GmbH & Co. KG, Hydraulic Development, Heidenheim, Germany
e-mail: ulli.stoltz@voith.com

P. Rutschmann et al. (eds.), *Novel Developments for Sustainable Hydropower*,
https://doi.org/10.1007/978-3-030-99138-8_10

turbine passage (see Chap. 9) provides a detailed understanding of damage risk relations and offers opportunities to reduce these risks and the associated ecological impacts.

On the one hand, this goal can be addressed by adapting the turbine operating conditions. The physical impact on fish can be reduced by changing the hydraulic conditions during the turbine passage and with adapted blade and guide vane openings also mechanical risk can be reduced. On the other hand, the behaviour of the fish influences the damage rates during turbine passage, as they depend on the passage location, body orientation and potential swimming speed of the fish. Therefore, influencing the fish behaviour prior or during the passage process can also reduce damage risks.

Depending on the hydropower site, such techniques potentially provide a feasible alternative for the above-mentioned measures or they can be combined with the classical approaches to further improve fish passage conditions at sensitive sites, e.g. regarding small fish which cannot be addressed by screening systems.

10.2 Changing Operation Modes for Reduced Risk—Best Practice Guidelines for Turbine Operation

Fish passage through the turbine is not only dependent on factors like machine size, number of blades and rotational speed but also on the influence of different operating conditions. Therefore, it is beneficial to assess the impact of changing operating conditions on the different physical stressors acting on the fish during turbine passage. The generation of so-called fish passage hill-charts provides the potential to adapt operation based on migration periods of different fish species.

In order to identify the individual damage mechanisms, the CFD based fish passage modelling as presented in Chap. 9 was applied. Besides the localization of critical passage regions, the evaluation of a complete set of operating points helps to better identify which parameters affect the fish passage at a certain operating scheme. As part of the research within the FIThydro project, a representative set of operating points were analysed for the Testcases Bannwil and Guma. This range was extended from the original operating range in order to obtain a significant influence of each stressor and to identify trends. The focus was to determine the influence of the stressors such as nadir pressure, strike, shear and turbulence on fish. For a better representation of the results, the BioPA performance score was converted into a scoring system from 0 to 10, where 10 is the best score and corresponds to the BioPA score of 100. The scoring of 0 corresponds to 70 in BioPA.

The performed study used a representative fish length of 10 cm and the biological response data for salmon. For both Testcases, we used the boundary conditions based on operational data of recent years. Special care was necessary to use the correct water levels and acclimation depth of the fish for each operating condition to represent a realistic pressure level, when analysing barotrauma. For example, for the Bannwil HPP, the pressure score was calculated based on an acclimation depth of 5 m, the tail water level was calculated based on a constant head water level and the head of the respective operating point.

The calculated survival rates for turbulence based on the biological response of salmon were close to 100%. As no influence of operating conditions was apparent, the results were not analysed further. However, secondary effects like disorientation are not in the scope of this study.

Figure 10.1 presents exemplarily the results of the Bannwil turbine, showing the hill-charts of the different stressors, as well as a combined score with equally weighted factors. It is obvious that the influence of the different stressors on fish survival is varying with the operating condition. Large blade openings with high discharge show a reduced risk related to strike. The effect of nadir pressure is oppositional as for large flows low-pressure zones especially close to the runner blade are present and the pressure change during the turbine passage increases. Strain is closely related to flow separation zones and bad flow quality. This is not only dependent on the hydraulic shape of a turbine, but also on the operating condition as seen in Fig. 10.1. The results of the Guma Testcase show in principle the same tendency as the analysis of the Bannwil machine (Geiger and Stoltz 2019). Depending on different boundary conditions like size, rotational speed and machine type, as well as fish length and acclimation depth the hill charts differ in value and peak.

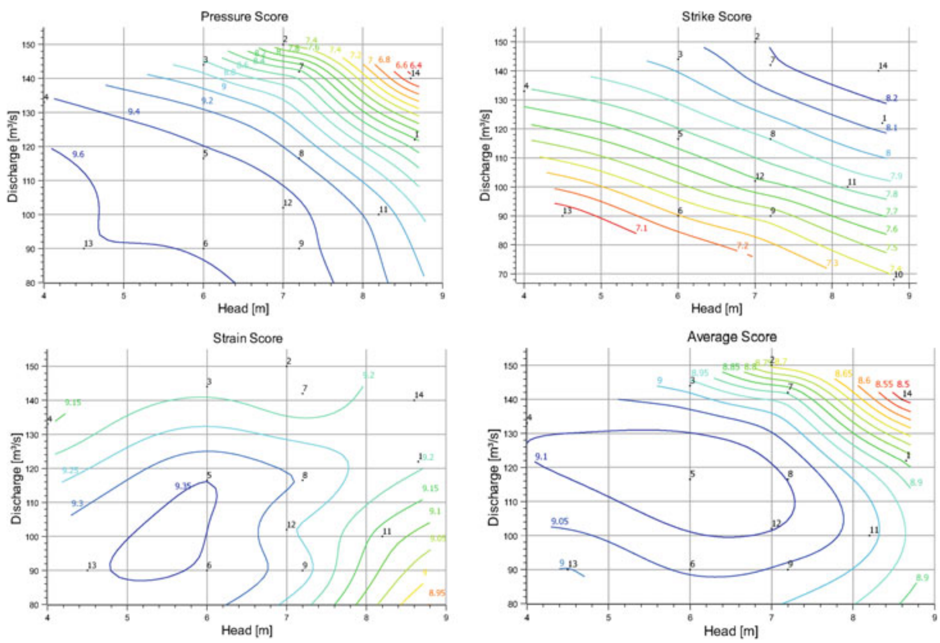

Fig. 10.1 Bannwil HPP—Individual fish passage hill-charts and combined chart using equally weighted stressors

In summary, one can say that the fish passage hill-charts can be helpful to adapt the power plant operation while a migration period of a certain fish species to improve the fish passage through the turbine. Additionally, the stressor variables are judged individually to adapt the operational scheme of the power plant as function of the individual susceptibility of the relevant species. Finally focusing on the most significant operating conditions improves the hydraulic design. All relevant impacts while operation can be taken into account for the design of an optimized turbine blade for an enhanced fish passage through the turbine.

10.3 Influencing the Impact on Fish During Turbine Passage—IDA

The work presented in Chap. 9 showed that the survival ratio of fish during turbine passage depends on the passage position, fish orientation and swimming speed. The actual impact of the different aspects depends on the site-specific conditions. For example, Fig. 10.2 shows on the left the damage probability dependent on passage radius and discharge for a 2 MW Kaplan turbine. Experimental fish passage investigations e.g. by Geiger et al. (2020a), indicate that fish naturally do not pass the turbine in a favourable way. Based on such findings and further considerations, an innovative method was developed and patented at TUM (EU Patent EP3029203): The fish protection system IDA (Induced Drift Application) increases the survival probability of fish during a turbine passage by influencing the fish behaviour.

The behaviour of fish can in principle be influenced by stimuli like light, sound or electric fields as suggested e.g. by Kruitwagen 2014, Jacobson et al. 2017, Murchy et al. 2017, Sonny et al. 2006 or Parasiewicz et al. 2016. Electric fields are especially favourable for IDA implementation. In general, low electric field strengths exert a repulsive effect on

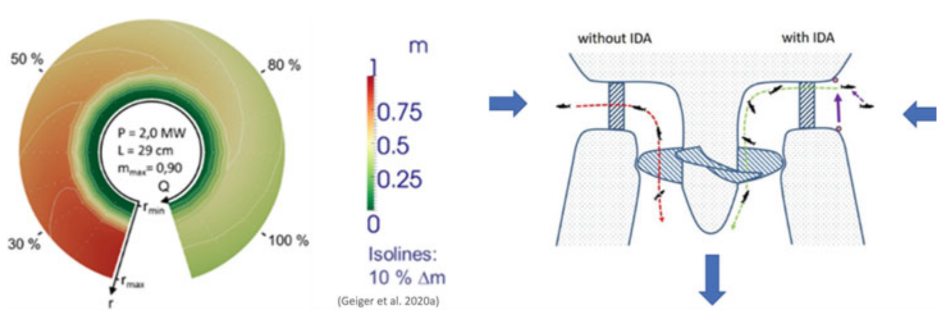

Fig. 10.2 Modelled damage rates m for an exemplary 2 MW Kaplan turbine, in dependency of passage radius r, discharge Q (normalized by design discharge) and fish length L (total length); m_{max} provides the maximum value observed (left) and schematic presentation of fish passage through a vertical axis Kaplan turbine without and with IDA implementation (right) (see Geiger et al. 2020a)

fish. In contrast, fish move towards the anode at high field strengths, so-called galvano-taxis. Depending on the strength of the electric field and period of time the fish are exposed to it, an electric field can cause a shorter or longer anesthesia of a few seconds to a few minutes. The reaction of fish is already technically used for behavioural barriers, electro-fishing and electro-narcosis. When applied correctly, these effects do not harm the fish.

Therefore, an adequate electric field can achieve exactly a desirable effect in terms of an increased fish survival probability: Fish are directed against the turbine hub where the survival probability is higher if the anode is placed there. In addition, fish are briefly impaired in their ability to swim by electro-narcosis, which means that they are exposed to the strike probability risk for less time and that their body is randomly angled to the streamlines, which results in higher survival probabilities. Moreover, the field strengths should be minimized as much as possible to avoid an unintentional exposure of the fish to damage by predators after turbine passage.

Figure 10.2 shows on the right the schematically depicted difference without and with the principle of galvano-taxis exerted to fish. In the course of the FIThydro project, the IDA invention was tested for the first time with live fish experiments on a small Lab prototype using a Bulb turbine at the Lab of TUM. The fish behaviour was influenced with an electric field for these investigations and yielded promising results. The exemplary considerations were based on strike damage considerations for Kaplan turbines, which is the most relevant aspect for run-of-river power plants with rather small heads like the FIThydro Testcases. The IDA principle can be adapted to other turbine types and the positioning and field strengths can be optimized on a case-by-case basis. Also, it can be combined with other stimuli, like light and sound.

The first results with IDA were obtained by carrying out tests on a 35 kW Kaplan Bulb turbine in the hydraulic engineering laboratory of TUM in Obernach. The experiments were conducted in the scope of an animal experiment permit (ROB-55.2-2532.Vet_02-19-66). 1201 Brown trout (*Salmo trutta fario*) with a total length from 5 to 30 cm were deployed. Two series of experiments were conducted with and without IDA. After passing through the turbine, all fish were collected, and injuries and mortalities were recorded. To also record non-visible damage due to internal injuries, all fish were observed for 96 h. The mortality or injury rates include those fish with relevant injuries, which put in question the long-term well-being of the fish. This corresponds to all categories except 1A and 2A in the classification according to the working aid of the German “Forum Fischschutz und Fischabstieg” (Schmalz et al. 2015).

The generation of an electric field required two electrodes and a power/voltage supply unit, with which the existing Kaplan turbine was retrofitted. Figure 10.3 shows the two ring-shaped copper electrodes at the inlet to the turbine. Their arrangement was tailored for the respective turbine type. In the case of the Bulb turbine in the TUM Lab, the ring-shaped anode was mounted around the Kaplan turbine hub to direct the fish to the passing location where their probability of survival is highest.

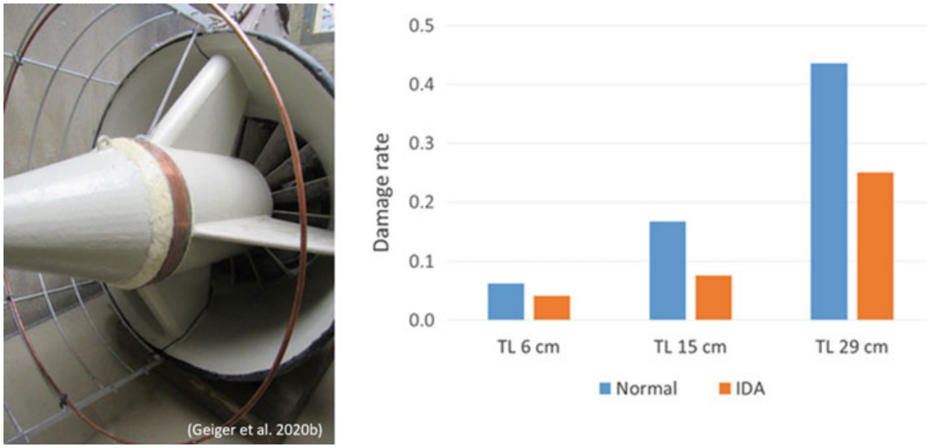

Fig. 10.3 The electrode setup at the bulb turbine intake (left) and exemplary results for damage rates (right) without IDA (normal) and with IDA (IDA) in dependency of the fish total length (TL) (see Geiger et al. 2020b)

The first results of IDA studies are provided in Fig. 10.3 (right). They show a reduction of the fish damage rate to about 55% and for all fish size classes compared to turbine operation without IDA. While the IDA efficiency was found to be limited by spatial aspects in very small-scale turbines, even higher ecological improvements can be expected for turbines of larger size. Further improvement can be achieved by optimizing the electric field strength and the combined use of other behavioural stimuli.

The IDA technology provides an alternative approach to reduce fish damage rates during turbine passage in order to improve ecological conditions of fish populations. In this context, it has to be acknowledged, that solutions for fish downstream passage at HPPs in general cannot and do not intend to fully protect downstream passing fish as this is not feasible. While damage to individual fish is justifiable given the benefits of hydropower production, damage rates have to be restricted to enable sustainable fish populations. Accordingly, the IDA technique reduces damage quota. It should be noted, that even mechanical barriers can only address fish of respective size, while smaller fish are subjected to turbine passage and corresponding damage.

The IDA's potential of damage rate reduction is turbine specific as the damage rates themselves. For given HPP sites, the allowable damage rates, the common fish damage rates for the particular turbines and operating conditions and the IDA damage reduction need to be assessed individually. For suitable cases, the IDA technology can provide a reduction of turbine related damage rates from non-allowable to acceptable values for sustainable fish populations.

At the same time, the IDA technology is associated with low construction, maintenance and servicing costs, especially compared to conventional screen and bypass systems. It has the further advantage that it does not affect power generation and can be easily and cost-effectively retrofitted in existing hydropower plants of medium and large capacity. The use of the IDA technology requires consideration of national animal welfare laws and appropriate authorization for its use, as well as consideration of intellectual property rights.

Moreover, the IDA technology can also be combined with conventional mitigation strategies e.g. be employed to reduce damage rates of small fish, which can pass through mechanical barriers and enable larger bar clearance for mechanical barriers. Further research and development are recommended. The achieved results provide promising perspective and show further potential for improvements. The installation and investigations of a prototype facility of larger size is advisable.

Acknowledgements Special thanks to Carl Robert Kriewitz and Manuel Henzi of BKW (Bannwil) and Juan Carlos Romeral de la Puente (Guma) of SAVASA for the support with the sensor fish tests as well as making the geometry and operational data available for the numerical modelling. Also, we would like to thank Geppert GmbH for providing the hydraulic geometry of the Obernach turbine for the numerical modelling.

References

Geiger F, Stoltz U (2019) D3.1—Guidelines for mortality modelling. FIThydro project report. https://www.fithydro.eu/deliverables-tech/

Geiger F, Cuchet M, Rutschmann P (2020a) Zur Berechnung der Schädigungsraten von Fischen bei der Turbinenpassage. Wasserwirtschaft Dec 2020a

Geiger F, Cuchet M, Rutschmann P (2020b) Zur Verringerung von Fischschäden in Turbinen mittels Verhaltensbeeinflussung. Wasserwirtschaft Dec 2020b

Jacobson P et al. (2017) Recent research on the effect of light on outmigrating eels and recent advancements in lighting technology. Tech. rep. Electric Power Research Institute (EPRI)

Kruitwagen G (2014) Research at IJmuiden lock complex provides unique insight in fish guidance. WIT Transactions on State-of-the-art in Science and Engineering 71

Murchy KA, Cupp AR, Amberg JJ, Vetter BJ, Fredricks KT, Gaikowski MP, Mensinger AF (2017) Potential implications of acoustic stimuli as a non-physical barrier to silver carp and bighead carp. Fish Manage Ecol 24:208–216

Parasiewicz P, Wiśniewolski W, Mokwa M, Zioła S, Prus P, Godlewska M (2016) A low-voltage electric fish guidance system—NEPTUN. Fish Res 181:25–33

Schmalz W, Wagner F, Sonny D (2015) Arbeitshilfe zur standörtlichen Evaluierung des Fischschutzes und Fischabstieges. Forum, Fisch Und Fisch

Sonny D, Knudsen FR, Enger PS, Kvernstuen T, Sand O (2006) Reactions of cyprinids to infrasound in a lake and at the cooling water inlet of a nuclear power plant. J Fish Biol 69:735–748. https://doi.org/10.1111/j.1095-8649.2006.01146.x