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# NEWSLETTER OCTOBER 2022

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# 1 | GREETINGS

FROM AFC4HYDRO WP4 LEADER  
MICHEL CERVANTES

*The AFC4Hydro project addresses the development of a novel Active Flow Control (AFC) system for improving off-design operation of hydraulic turbines by mitigating deleterious flow phenomena during steady and transient operation including ramping of produced load.*

**AFC4HYDRO**  
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AFC is composed of 4 subsystems to address these issues: a mitigation system based on rods, a mitigation system based on water injection, a health monitoring system and a controller.

WP4 aims to integrate these different subsystems to create AFC. This integration is performed at different scales: on a Kaplan model at the Vattenfall laboratory, on a 10 MW Kaplan turbine at Porjus, Sweden and on a 200 MW high head Francis turbine at Oksla, Norway.

The experiments on the model scale at Vattenfall were successfully performed during autumn 2021 during two measuring campaigns.

A large number of experimental results were obtained at various operating conditions.

The preliminary results are very encouraging. They highlight the ability of the system to detect and mitigate detrimental operational conditions from speed no-load to high part load. The implementation of the AFC system at the prototype scale was initiated in parallel. The designs of subsystems are frozen and the implementation started. The experiment will be performed from spring 2023.



WP4 Leader Professor  
Michel Cervantes,  
Division of Fluid and  
Experimental Mechanics  
at the Department of  
Engineering Sciences  
and Mathematics.  
Luleå University of  
Technology

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# RESEARCHER

**ALESSIA FABBRI, LTU**

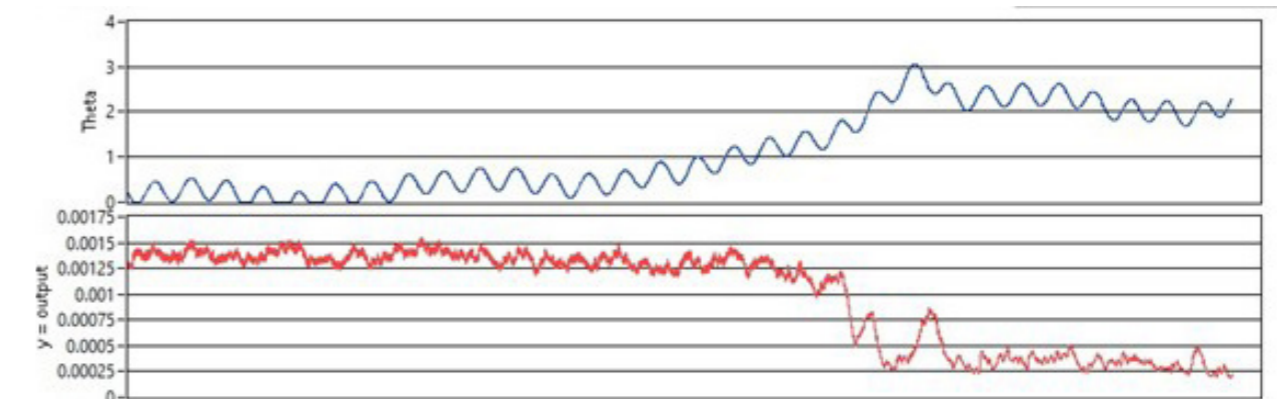
*AFC4Hydro has been studying ways to reduce the pressure fluctuations inside hydraulic turbines by the injection of pulsating or continuous momentum. The purpose of WP4 is then to develop a control system that can automatically select the correct amount of momentum needed to minimize such fluctuations and work combined either with WP1, that studies the pulsating momentum given by rod insertion in the draft cone, or WP2, that investigates the continuous momentum by water injection.*

Together with Professor Khalid Atta, we have been investigating different ways to achieve such task.

The first idea was to implement a controller using the Extremum Seeking Control technique. This approach does not require to know the dynamics of the system because it will adjust the input at every time step based on the feedback of the output.

Another possibility that has been considered was the use of a Bayesian optimization-based algorithm. This method would first map the system to guess its dynamics and then suggest a possible input value of momentum to obtain minimum pressure pulsations.

ESC has been applied to the rod insertion and has been tested both at LTU and Älvkarleby, giving positive results. The controller would start by slowly inserting the rods in the draft tube and checking if the pressure pulsations would increase or decrease. It would keep on incrementing the length of insertion of the rods until the pressure pulsations would stop decreasing and start increasing. Once found the optimal position, the rods would keep oscillating around that optimal length but the controller would still monitor the pressure pulsations in case a change of conditions, for instance in the operating point of the turbine, would require a consequent adjustment of the length of insertion of the rods.

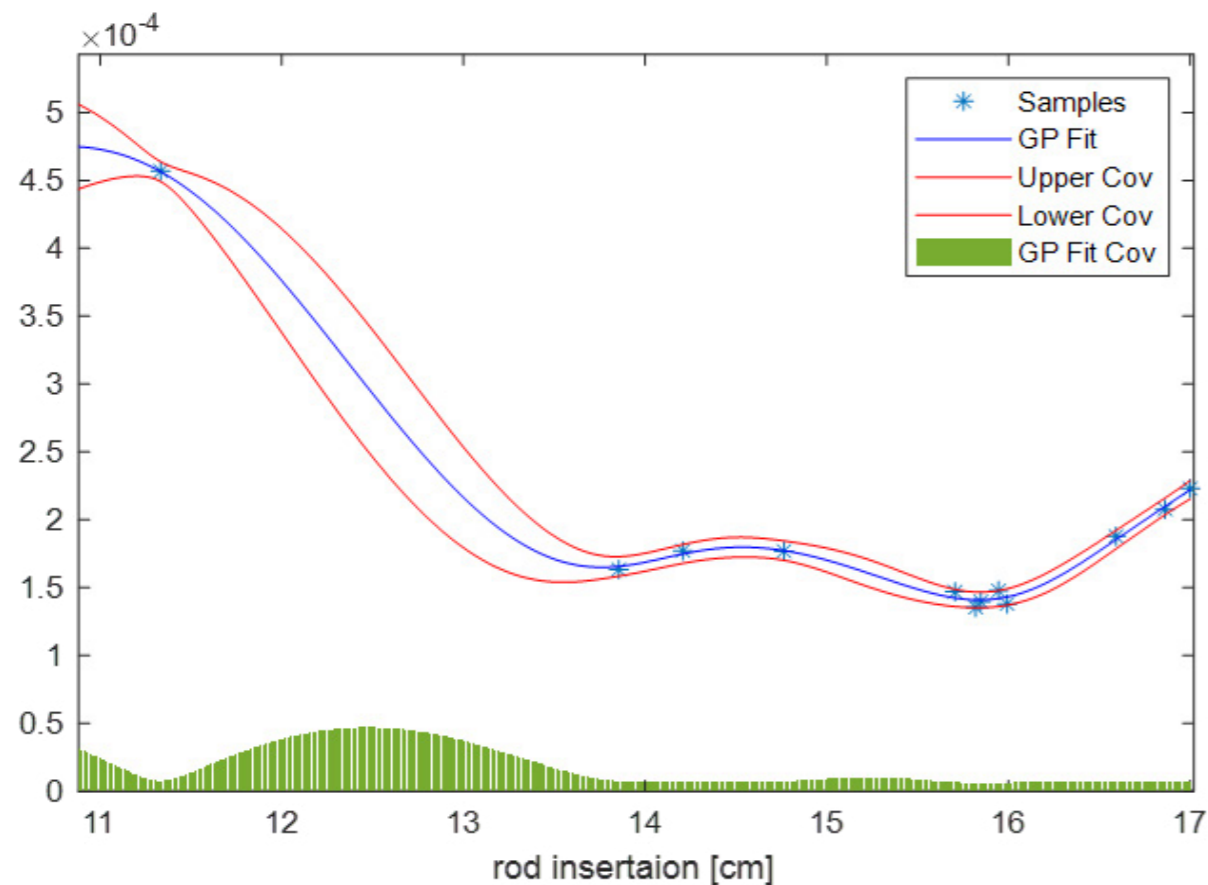


**Figure 1.** an example of ESC applied to rod insertion at LTU. Theta represents the length of insertion in cm while y is the measurement of the pressure pulsations.

The Bayesian optimization-based algorithm has also been applied to WP1 during Älvkarleby's campaign. The algorithm would select some random lengths of insertion for the rods, that can be considered the input variable  $x$ , and record the corresponding pressure, that is the output variable  $y$ . After having tested enough points the program would try and guess the function  $(x,y)$  and therefore find, if existing, the length  $x$  related to the minimum  $y$ . Since this method has also given good results, we are now planning to further develop it and test it more in detail at LTU.

Future plans also comprise the possibility of testing both methods on the prototype turbine units in Porjus and in Oksla.

**Figure 2. An example of the Bayesian Optimization method applied to rod insertion in Älvkarleby.**



### 3 | VIENNAHYDRO

## CONFERENCE PREPARATION

*"Experimental and numerical study on the detection of fatigue failures in hydraulic turbines"*

The IFLUIDS and the REMM research groups from UPC have prepared a new conference article named **Experimental and numerical study on the detection of fatigue failures in hydraulic turbines**.

The work will be presented by Xavier Sánchez Botello under the topic of Operation and Maintenance at the 21st

international seminar on hydropower plants **ViennaHydro 2022** that will be held in Vienna, Austria.

This conference emphasises in long-range impacts of hydropower activities, stating that all measures taken today will always have a major impact for future generations.

## Experimental and numerical study on the detection of fatigue failures in hydraulic turbines

X Sánchez-Botello	A de la Torre	R Roig	E Jau	O de la Torre	J Ayneto	X Escaler
IFLUIDS, UPC	IFLUIDS, UPC	IFLUIDS, UPC	IFLUIDS, UPC	IFLUIDS, UPC	REMM, UPC	IFLUIDS, UPC

9<sup>th</sup> - 11<sup>th</sup> November 2022  
Vienna, Austria

IFLUIDS: Barcelona Fluids & Energy Lab  
REMM: Recerca en Estructures i Mecànica de Materials

**AFC4Hydro**

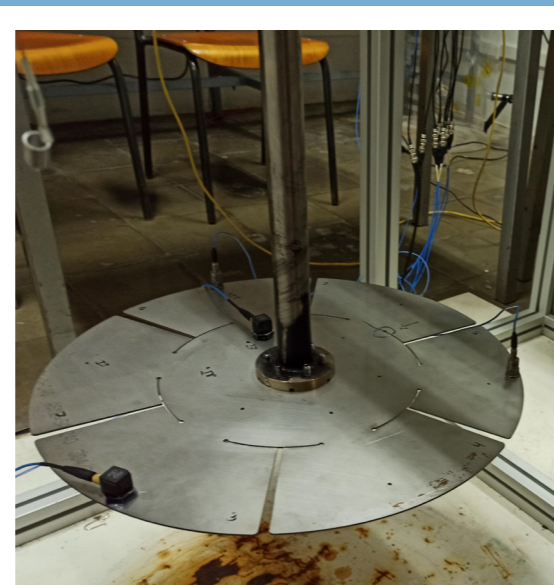
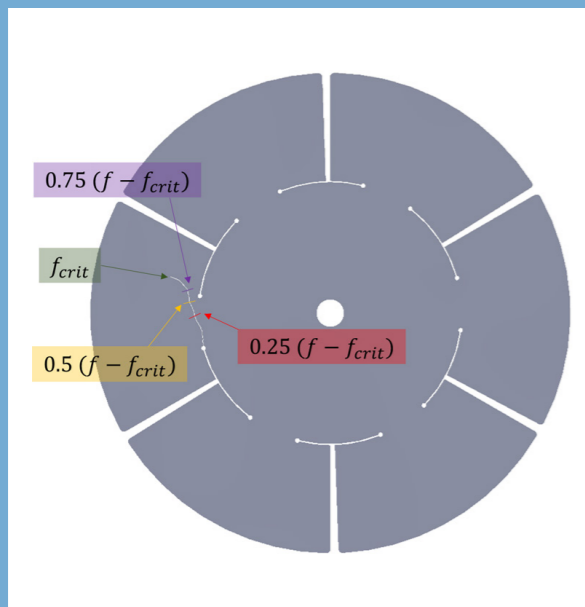
As a part of the H2020 EU-funded AFC4Hydro project, the UPC team is developing a Structural Health Monitoring (SHM) system for hydraulic turbines working at off-design operating conditions and during transients. Under those conditions, high and variable flows are induced by the deleterious hydrodynamic phenomena that take place, such as the rotating vortex rope or rotor stator interactions, which can severely damage the structure by fatigue.

Concretely, the blades of the Kaplan turbine runner are one of the most susceptible parts to be damaged by fatigue, as they might suffer high stresses.

Detecting fatigue cracks in hydraulic turbine runners is costly, as it requires to stop the unit for inspection. This is the reason why an alternative methodology to detect cracks based on the monitoring of the changes of the modal response of the structure induced by the formation and growth of a crack has been investigated.

**Figure 1.** Disk-like structure used for the study and the different stages of the propagated crack that have been sequentially machined.

**Figure 2.** Instrumented disk with several accelerometers and the first machined crack on it for performing the modal analysis.

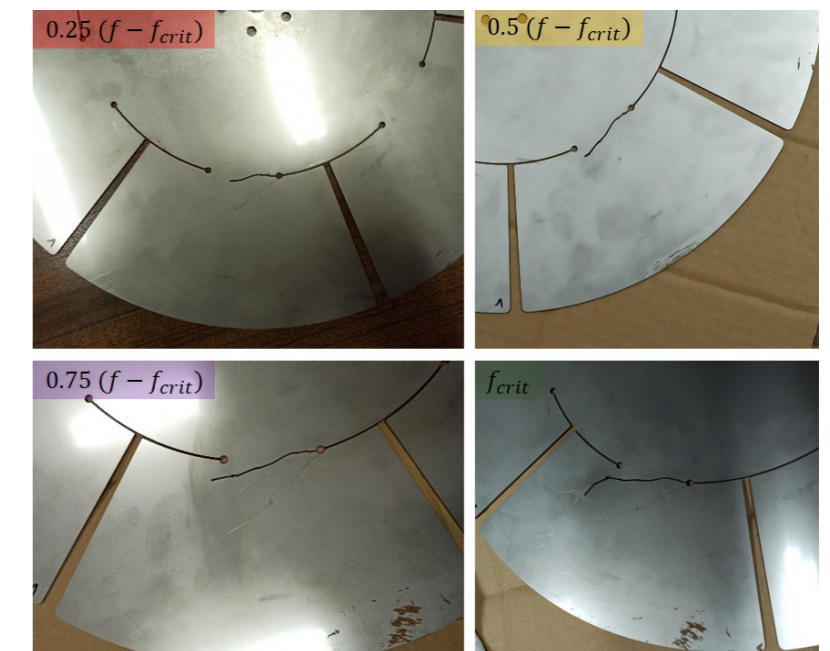


For that, a simplified disk-like structure resembling a Kaplan turbine runner has been manufactured and numerically simulated to predict the path of the crack induced by a given vibrational mode. As the length of this crack has been increased progressively, the frequency of the first vibrational mode has been reduced.

The process has been stopped when the frequency has reached its critical frequency, corresponding to the moment in which the initial rigidity of the vibration mode decreases to its half due to the full developed crack.

In order to experimentally verify the influence of the crack growth on the modal response of the structure, 4 different stages of its growth have been selected to perform experimental modal tests. These stages of the crack have been recreated on the disk-like structure by sequentially machining the computed path. Finally, after comparing the results obtained from numerical and experimental modal tests, it has been demonstrated that the fatigue crack can be monitored based on the change of the natural frequencies and mode shapes of several specific modes.

**Figure 3.** Four machined cracks into the disk to simulate different stages of the fatigue crack.



WP3 leader  
Professor Xavier Escaler,  
Universitat Politècnica  
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BarcelonaTech

# 4 | MANAGING RISK IN AFC4HYDRO

*Risk, defined as the combination of probability of an event and its consequence, requires attention for most activities. Below selected risks are presented and we address how they are managed by AFC4Hydro.*

For AFC4Hydro the risk-assessment relates primarily to the activities taking place in facilities in which we validate technologies.

The AFC4Hydro project aims at TRL5-6 that includes validation in an industrial environment. For this two prototype hydroturbine units have been selected. In hydropower we work with high flow quantities and at times high pressures. For instance, the upstream pressure level reaches 40bar at one of the plants.

The consequence of not controlling the flow and pressure includes drowning but also direct impact from high velocity jets due to leakages.

The way to reduce risk, when knowing the consequence, is to mitigate the probability of any event or accident. AFC4Hydro's solution to risk mitigation includes design features in and surveillance of components and systems, soft measures such as good planning for installation, operation and dismantling, and rules for behavior when present during testing and if an accident occur.

The risk associated the use of AFC4Hydro technologies is well managed, but the project must also deal with non-technical risks. One such risk related to availability of the power plants used for technology validation.

The bigger is a one turbine-unit power plant and the final stage of a two-stage hydropower scheme. Generally, the use of this unit during the winter season is associated restrictions, but the current political situation and associated strain on energy production makes the unit even less available.

A likely consequence for AFC4Hydro is delays and added costs if the unit is unavailable or not accessible for planned installation and testing. Added costs relates typically to non-refundable travel and instrument costs.

When submitting the project proposal, a table of identified risks was included. AFC4Hydro delivered the first stage proposal in 2018, and with a start-up in 2019. And yes, AFC4Hydro did not foresee pandemics nor political unrest.

As with most other projects, and the society, we had to deal with travel restrictions, supply chain hick- ups and a volatile energy business to name a few. If anything this shows that focus on risks for the unforeseen and unthinkable needs to be included; not necessarily by knowing the root cause but by addressing typical consequences.

**Figure 1. AFC4Hydro working environmetn in Oksla (a) and Porjus (b) powerplants.**



**Figure 1. (a)**



**Figure 1. (b)**

## 5 | AFC4HYDRO ACTIVITIES PROGRESS IN OKSLA POWERPLANT

*Major updates at the draft tube cone in Oksla Powerplant were made before starting the testing phase, scheduled for the next few months.*

**Figure 1.** Welding new holes on the draft tube cone to host the IPm and ICM systems.



**Figure 2.** Inserting the draft tube cone into place.



On June 13, the draft tube cone at the Oksla power station (Odda, Norway) has been disconnected and surgically extracted from the turbine room as part of an extraordinary operation.

The cone (5 tons in weight) was then transported to a local mechanical workshop in Husnes where a specialized team of mechanics and welders worked three shifts per day for five days to adapt the draft tube cone for hosting the ICM and IPM systems (designed by FDB and Luleå university respectively. See previous article "2. Researcher Alessia Fabbri, AFC4Hydro", page 4).

The intervention consisted of installing large steel ring, so called pipe stubs, functioning as connection interface for the ICM and IPM systems.

Fire torches were used to hot-cut holes and millimetric precision deployed to install the pipe stubs. Eventually, four layers of paint were applied to protect the cone from corrosion in the humid environment of the power station.

The entire operation lasted eight days and it concluded with the successful reinstallation of the cone back in position at Oksla turbine room.

**Figure 3-4.** Draft Tube Cone in Oksla powerplant, before (top) and after (bottom) the changes.



Elia Antoniali, mechanical engineer, FDB

## 6 | WORK ON STANDARDS FOR AFC4HYDRO

*Technical standards provide norms and requirements for technical systems. For AFC4Hydro an important aspect for the use of standards is the ability to facilitate business transactions. This article outlines both the use and the need for standards from the perspective of our project.*

Several standardization bodies exist worldwide. IEC is one of those with a stronghold in the Hydropower business. A specific standard, the IEC60041, outlines prototype performance evaluation, including hydraulic efficiency, of hydroturbine units. The technology used in AFC4Hydro aims at improving dynamic performance, with minimum impact or even improved efficiency at certain operating points.

For the latter the use of the mentioned standard provides a norm for which the plant owner and the supplier can agree on overall performance when testing AFC4Hydro or similar type technologies. In the current project a method, the thermodynamic efficiency, and as described in IEC6004 will be used for evaluating the AFC4Hydro technologies in an industrial environment. A brief introduction to this method is given as the blog entry "Determine Hydroturbine Performance" on the AFC4Hydro website.

The primary objective of AFC4Hydro is to reduce wear-and-tear of the unit while extending the operating range. To achieve such objectives the Flow Control technologies, need to address cavitation and pressure pulsations that affects the rotating shaft system. Most Flow Control technologies are characterized by parasitic(!) loss or drag. For the ICM system this include the direct power loss-by letting a fraction of the upstream flow bypass the turbine unit before being injected into the draft-tube. A hypothetical Flow Control (FC) standard therefore needs to address how to 1) quantify the reduction of wear-and-tear with and without the

FC technology applied and 2) the cost of using the same. Another important aspect for the business transaction is potential consequences of the FC installation on the hydroturbine unit lifetime expectancy. This is especially important since FC technologies often are retro-fit on existing turbine units.

AFC4Hydro participated in the IEC plenary meeting in Stockholm in June 2022. The project and some of the ideas of having a "Flow Control" standard for hydropower were presented. In the subsequent discussion a decision was made to try including some of this into the appendix of an existing standard.



# International Electrotechnical Commission

Morten Kjeldsen,  
WP2 leader  
FDB

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# THANK YOU

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VATTENFALL

