Experience with location of cavitation emission measurement

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Abstract. The OSC Hydro Power Group has carried out many performance tests on various types of hydraulic machines. Scan of ultrasonic cavitation emission has been often part of these tests.
In addition to the principle used (in our case, modulation of the ultrasonic emission of flowing water by imploded bubbles), also the ultrasonic sensor placement on the turbine body has an influence on the cavitation sensing success and reliability of measurement results.
This paper presents our experience with cavitation measurements at various locations in the turbine body. Our effort was always to install the contact microphone as close as possible to the point where the cavitation had a typical manifestation (surface greying, material loss). These positions are often located in concreted parts (e.g. runner chamber) usually inaccessible for sensors. Due to the fact, it is necessary to place the sensors at the locations where at least part of the cavitation implosion occurs. We present recommendations, supported by many real tests, where optimal results can be expected.
The results of the determination of cavitation zones are supported by examples from measurements mainly on Kaplan but also Francis turbines, which helped to protect them from cavitation damage by excluding operation in hazardous areas.

1. Variants of cavitation emission measurement

Standard methods of cavitation level determination are based on the testing of secondary effects such as material abrasion, vibrations, power decline etc. However, there is a possibility to indicate the cavitation presence and its intensity with help of ultrasonic noise evaluation.

It's known that the mutual movement of laminas in flowing liquid produces wide spectral ultrasonic noise. The noise intensity grows proportional with discharge. Implosions of the cavitation micro-bubbles modulate to the basic noise. Separation of this signal part allows evaluating of cavitation proportions for various turbine operation states.

On the other hand, the modulated ultrasonic signal can produce also other phenomena like disturbed streaming, vibrations etc. Detecting cavitation based on ultrasonic signal analysis is a challenge for hydraulic engineers worldwide. In addition to detailed theoretical preparation, research teams use advanced signal processing methods (see. [1]), recently including AI and neural networks as part of subsequent processing. However, a system with on-line processing is suitable for routine measurements during machine commissioning, operation optimization, etc., where is no time space for demanding post-analysis.

The OSC company has been using for field tests processing of water turbines instrument D400 developed by team of Prof. Taraba in Faculty of Electrical Engineering CVUT Prague. It is a

fully analogue measuring apparatus developed in the 1990s, but it still works reliably. Thanks to this apparatus, we have a very extensive database of cavitation measurements, which are also recorded together with vibrations and pressure pulsations in the measured machines.

In the paper, we also provide examples of parallel measurement comparison with two different digital sensing systems and ultrasonic emission evaluation.

Finally, an important note: The ultrasonic emission sensing described in this article is only an index measurement that indicates the relative intensity of the cavitation. It cannot be used to quantify the extent of surface damage over a specified time period.

2. Description of system D400

The analogue system D400 consist of following components:

- **Contact piezoelectric microphone** – see Figure 1. Advantage of the contact microphone is possibility to place it everywhere on the tested unit surface. An ultrasonic gel is used as the transmission layer between the machine surface and the microphone sensing area.



Figure 1. Piezoceramic contact microphone fixed by magnets on discharge ring

- **D400 evaluation unit**. This unit evaluates the modulation of the ultrasonic signal up to 500 kHz. Signal amplification is adjustable in the range of 0.1 to 3000 mV in ½ decade steps, analogue signal 0 ÷ 10 V is available on the output. Its frequency range is up to approx. 200 Hz.

The main advantage of this simple single channel device is its reliable function and easy interpretation of the results. Number of machines have been tested on a where it has been shown to reduce cavitation wear by reducing the operating range with cavitation.

3. Measurement experience

We perform cavitation measurements on Kaplan and Francis turbines and pumps. The following examples represent common measurement locations for cavitation emissions and typical behaviour of the respective water machines.

3.1 Horizontal Kaplan turbines

The advantage of horizontal Kaplan turbines in terms of measuring cavitation emissions is the free access to the discharge ring. The contact microphone must be installed at the top of the discharge ring. Horizontal Kaplan turbines are usually designed for low head installations and the runner diameter often represents a significant part of the total head. Therefore, conditions are most favourable for cavitation to occur at the top of the machine – see Figure 2.

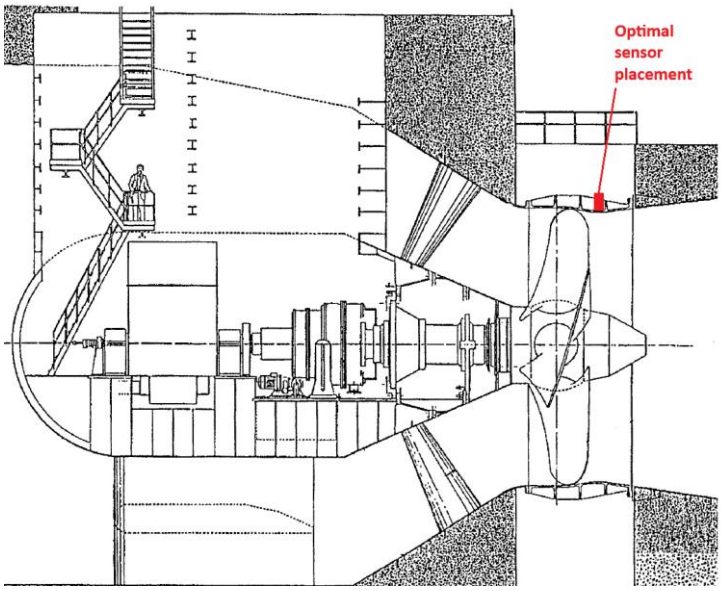


Figure 2. Installation of ultrasonic contact microphone on horizontal Kaplan turbine

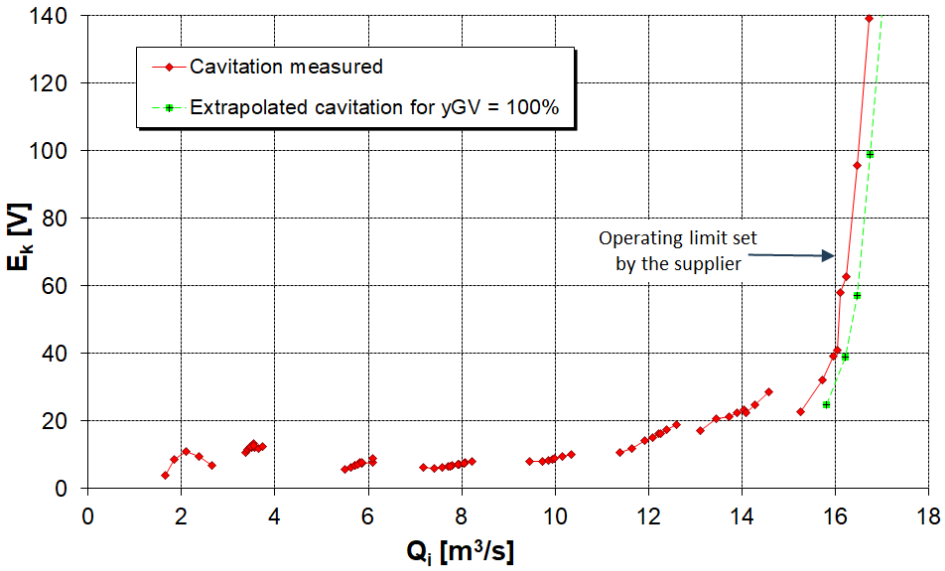


Figure 3. Cavitation emission scanned during the optimisation of HPP Augand

Typical result of cavitation measurement for Kaplan turbines performed during the acceptance tests of 6-blades Kaplan turbine with head approx. 31 m (see [2]) is presented in the Figure 3. This record was taken during the classic on-cam curve optimization. The machine operation was optimized to achieve maximum efficiency and thus production. However, for maximum machine opening, in this case, cavitation minimization was also taken into account at the cost of a slight reduction in efficiency and maximum achievable output. The working point of the machine must not be allowed to reach the area of steep increase in cavitation.

3.2 Vertical Kaplan turbines

Scan of cavitation emission in this case is usually a bit more complicated than by horizontal machines. The discharge ring is usually embedded in the concrete. This leaves access to the surface of the draft tube cone where the manhole is – see Figure 4. But access to this manhole is from the spiral case for low head units. That means the scan of cavitation on discharge ring or draft tube cone is impossible in this case.

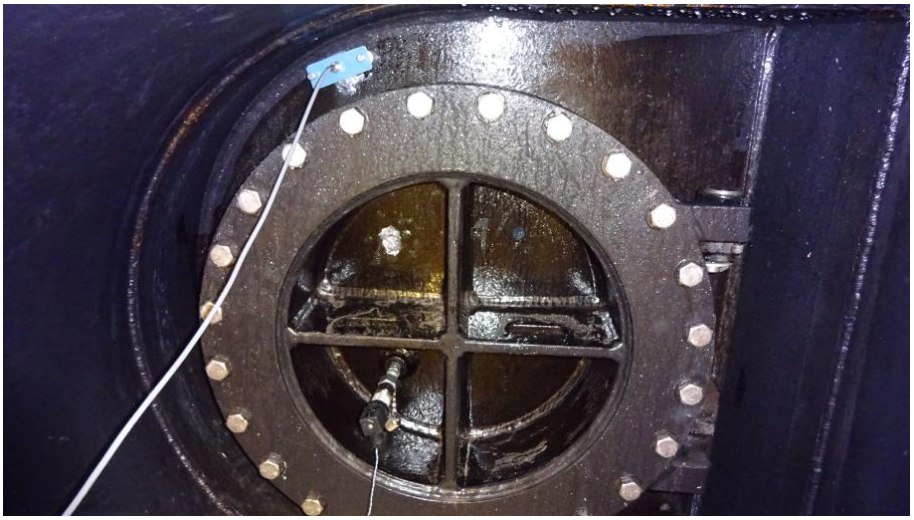


Figure 4. Ultrasonic contact microphone and pressure sensor on draft tube manhole

The results of operation optimization are very similar to the results presented in Figure 3 for good designed turbine according our experience. For units without access to suitable measuring points, only secondary manifestations of cavitation such as vibrations can be evaluated.

3.3 Francis turbines

In Francis turbines it is generally difficult to distinguish the cause of the ultrasonic emission. Francis turbines generally cavitate at different locations than Kaplan turbines - typically the trailing edges of the runner blades, the trailing edges of the distributor blades, or even the pre-distributor blades. These locations are usually poorly accessible. In addition, cavitation losses tend to be marginal compared to Kaplan turbines according to our experience. The sensor location should therefore be based on experience with observed cavitation wear. The sensor should be located downstream from the expected cavitation location so that at least some of the microbubbles are likely to implode on surfaces close to the contact microphone.

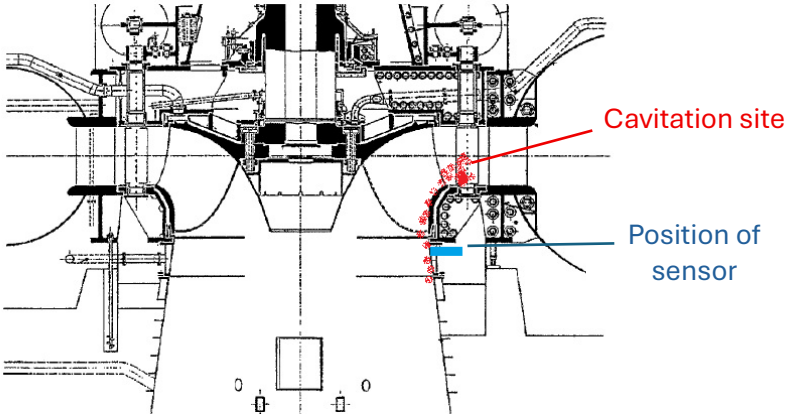


Figure 5. Example of sensor position on Francis turbine

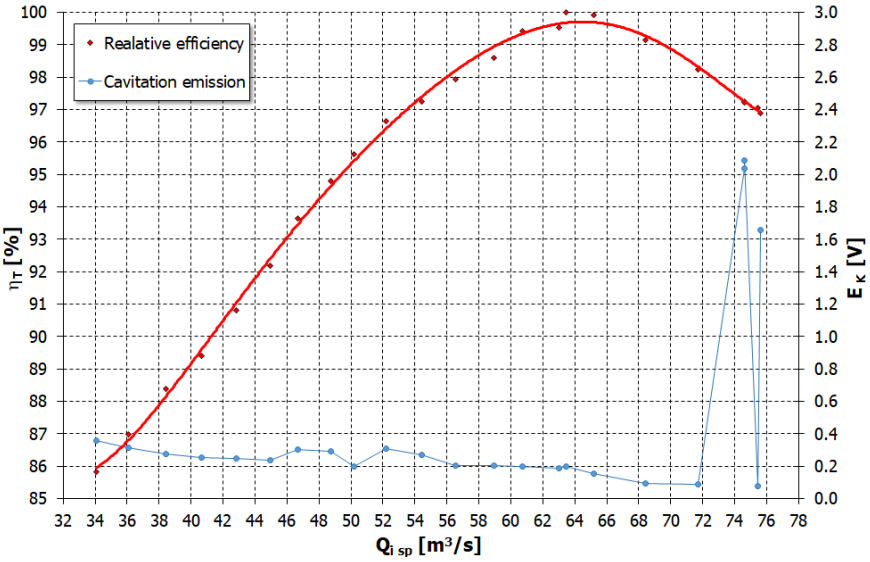


Figure 6.1 Efficiency and cavitation emission intensity on reversible turbine in HPP Ružín

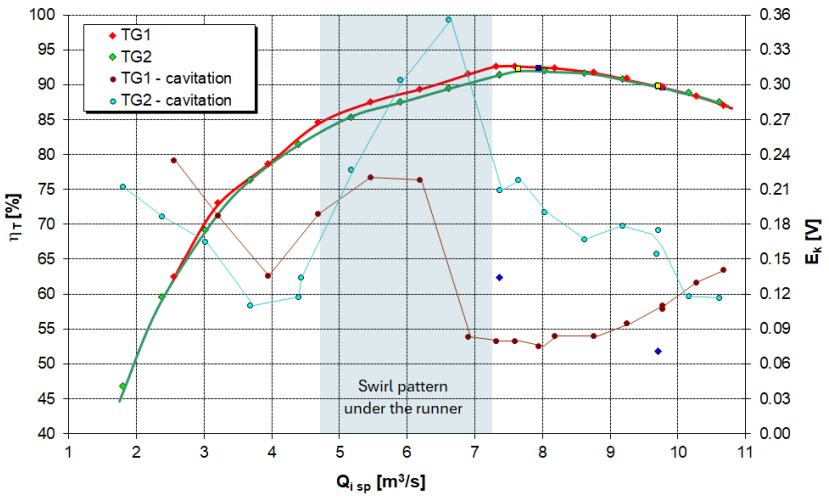


Figure 6.2 Efficiency and cavitation emission caused partially by vortex

Unlike Kaplan turbines, Francis turbines do not exhibit the typical steep increase in cavitation emissions when a certain flow rate is exceeded. Example of tests [3] is presented in Figure 6.1, such a phenomenon can occur, but even in the presented case, this phenomenon was not completely repeatable. When placing the sensor on draft tube cone, increased ultrasonic emission can often be observed for flow rates below 50% of the nominal value. In this case, it is not easy to distinguish whether it is cavitation or a side effect of the vortex under the runner – see Figure 6.2.

Since installing ultrasonic emission measurement is not difficult, our measurement team records this emission during larger measurements. But it is impossible to predict whether the results will be usable for optimizing machine operation.

3.4 Pumps

Cavitation often occurs in the suction section of pumps. The figure shows part of the open inlet section of the PSHP Čierny Váh pump with cavitation wear (see [4]), and the adjacent figure shows the installation of a contact microphone on the outer part of this cast iron piece in an accessible location as close as possible to the area of cavitation wear.



Figure 7. Cavitation damage of the surface in the suction section of the PSHP Čierny Váh storage pump



Figure 8. Contact ultrasonic microphone on the outer surface of suction section of storage pump

4. Comparison with digital systems

We had the opportunity to compare the measurement results of the D400 analogue device with two digital devices for cavitation scanning.

4.1 Dakel

The DAKEL technical diagnostics center focuses on applying diagnostic systems based on acoustic emission (AE) principles. In cooperation with Viktor Kaplan Institute of Brno Technical University,

we participated in a comparative test of the D400 analogue cavitometer and the experimental Kadet device – see [5].

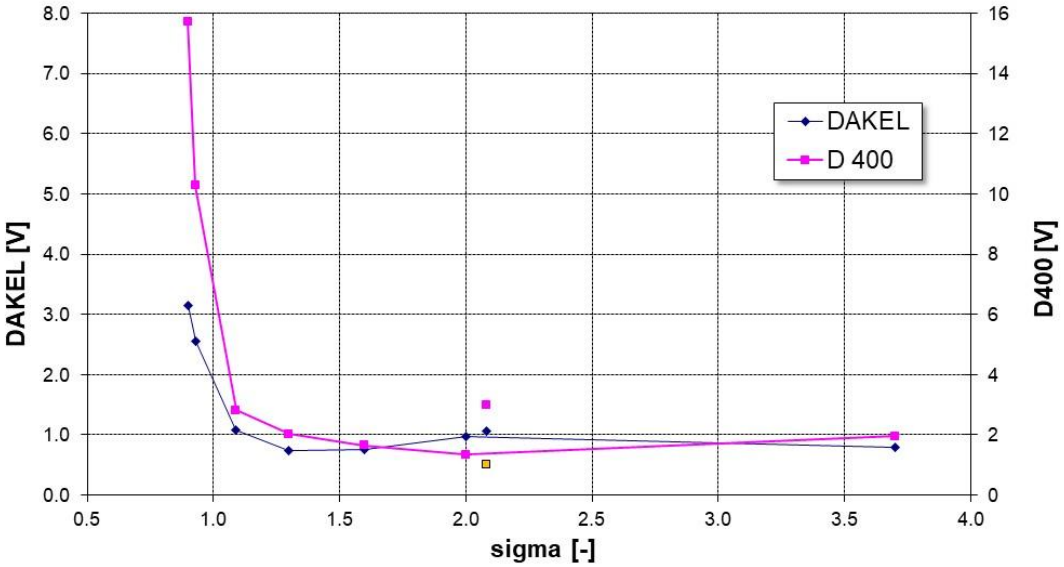


Figure 9. Results of comparative tests of D400 and Dakel Kadet instruments in laboratory

Test results of propeller turbine model in university laboratory are presented in Figure 9. The Dakel Kadet evaluated the RMS value of scanned signal in range 5 ÷ 200 kHz. As can be seen, analogue device reacts much more sensitively to increased cavitation. However, we must mention that the Dakel device is capable of evaluating a number of other signal characteristics; for this first device, RMS was selected for the output.

4.2 Digital system PULSE DAQ + Kistler sensors

Cavitation measurement at PSHP Čierny Váh was performed simultaneously by the power plant owner's (SE) measurement team using a digital system (see [6]) and the OSC measurement team using D400. The system used by SE consists of a contact microphone + analog amplifier Kistler and DAQ B&K PULSE. The measured data was subsequently processed, and several signal characteristics such as RMS, ENV, $AE_{p\text{-}p}$, etc. were evaluated. Measurements on draft tube were compared. The results from real unit are very similar as evident from Figure 10. The effect of aeration is particularly evident in both records.

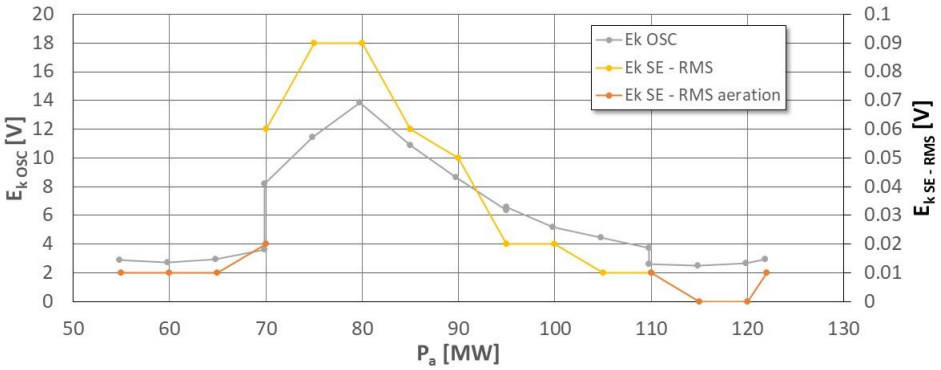


Figure 10. Results of comparative tests of D400 and digital instrumentation on Francis turbine

5. Conclusion

The experience presented here with a series of routine cavitation tests performed on various types of turbines can be summarized as follows:

- The best position for the sensor is downstream the cavitation site.
- Measuring cavitation in Kaplan turbines is of fundamental importance, as it can significantly extend the service life of the machine.
- Cavitation in Francis turbines is more difficult to measure; acoustic emissions may have other origins.

References

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