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A REVIEW ON CAVITATIONS IN HYDRAULIC TURBINE USING VIBRATION, NOISE AND ACOUSTIC EMISSION

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Abstract: *This Paper represents a review of a case study on experimental investigation has been carried out in order to evaluate the detection of cavitation in actual hydraulic turbines. The methodology is based on the analysis of structural vibrations, acoustic emissions and hydrodynamic pressures measured in the machine. The proposed techniques has been checked in real prototype suffering from different types of cavitation. In particular, Kaplan. First, a brief description of the general features of cavitation phenomenon is given as well as of the main types of cavitation occurring in hydraulic turbines. The work presented here is focused on the most important ones which are the leading edge cavitation due to its erosive power, the bubble cavitation because it affects the machine performance and the draft tube swirl that limits the operation stability.*

Keywords – *Cavitation, hydraulic turbines, Kaplan Turbine, structural vibrations.*

I. INTRODUCTION

A review of an experimental investigation has been carried out in order to evaluate the detection of cavitation in actual hydraulic turbines. The methodology is based on the analysis of structural vibrations, acoustic emissions and hydrodynamic pressures measured in the machine. The proposed techniques were checked in real prototypes suffering from different types of cavitation. In particular Kaplan Turbine has been investigated in the field. First, a brief description of the general features of cavitation phenomenon is given as well as of the main types of cavitation occurring in hydraulic turbines. The work presented here is focused on the most important ones which are the leading edge cavitation due to its erosive power, the bubble cavitation because it affects the machine performance and the draft tube swirl that limits the operation stability. This paper discusses the measurements of acoustic emission, vibration, and noise on a two-bladed Kaplan turbine. Parallel to conventional measurements, images of cavitation structures were recorded. It was discovered that a correlation exists between the acoustic emission, vibration, and noise on one side, and topology, type, and extent of cavitation structures on the other side. Finding deterministic links between the acoustical signal and the cavitation structures could lead to improvement of the monitoring and control of hydraulic machines.

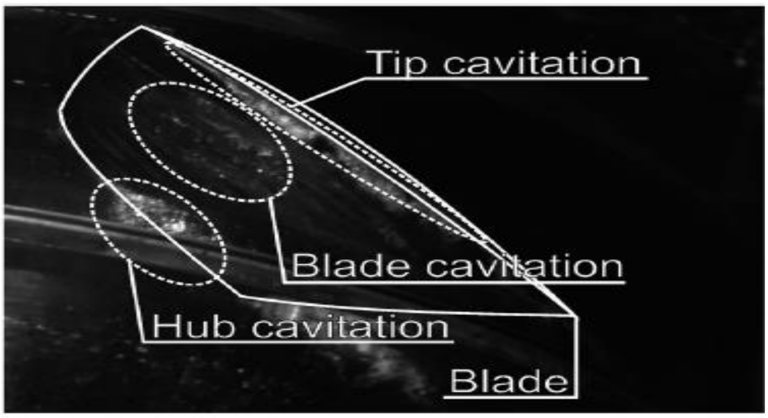

Fig. 1.1. A typical image with noted places of cavitation occurrence on the blade.

II. LITERATURE REVIEW

Xavier et. al has been studied "Detection of cavitation in hydraulic turbines" to evaluate the detection of cavitation in actual hydraulic turbines. The methodology is based on the analysis of structural vibrations, acoustic emissions and hydrodynamic pressures measured in the machine. The proposed system techniques have been checked in real prototypes suffering from different types of cavitation. low frequency spectral content can also be used in certain cases. The results obtained for the various types of cavitation found in the selected machines are presented and discussed in detail in the paper.

Sulo et. al has studied "Vibration Analysis of Cavitation in Kaplan Water Turbines" The real-time detection of cavitation risk is increasingly important, and even narrow cavitation-free power ranges can be utilised in load optimisation. Higher derivative signals x (3) and x (4) calculated from acceleration signals are very suitable for detecting impacts. This paper introduces a generalised moment τ σ M p α which is defined by three parameters the sensitivity of the moment improves when the order p of the moment increases, especially when short sample
time τ is used. In this study, sufficently good results were obtained with moments where the order of derivation $\alpha = 4$, $p \approx 4$, and $\tau = 3$ s. The moment can be analysed first, and it is then possible to obtain the cavitation index
if the moment value exceeds the threshold. Data compression is very efficient as the detailed analysis only requires the feature values of the appropriate samples.

III. CAVITATION AND DETECTION TECHNIQUES

Cavitation is defined by Knapp et al. as the condition when a liquid reaches a state at which vapour cavities are formed and grow due to dynamic pressure reductions to the vapour pressure of the liquid at constant temperature. In a flowing liquid, these cavities are subjected to a pressure increase that stops and reverses their growth, collapsing implosively and disappearing. The violent process of cavity collapse takes place in a very short time of about several nanoseconds and results in the emission of large amplitude shock-waves, as demonstrated by Avellan and Farhat. A high-speed reentrant liquid micro-jet directed towards the boundary can also occur for cavities collapsing close to a solid surface. If the amplitude of the resulting pressure pulse is larger than the limit of the material mechanical strength, a hollow or indentation of several micrometers called pit will be formed on the surface. If an accumulation of pits takes place in a narrow area, the material is finally eroded and mass loss occurs due to the repetitive action of the cavity collapses.

Cavitation detection is based on the previous understanding of the cavity dynamics and its location inside the machine. This knowledge has been gained from flow visualizations and measurements in laboratory devices such as a high-speed cavitation tunnel and a reduced scale turbine test rig. The main techniques are the study of the high frequency spectral content of the signals and of their amplitude demodulation for a given frequency band. Moreover, low frequency spectral content can also be used in certain cases. The results obtained for the various types of cavitation found in the selected machines are presented.

3. MAIN TYPES OF CAVITATION

3.1. Leading Edge Cavitation

See in Figure 3.1. It takes the form of an attached cavity on the suction side of the runner blades due to operation at a higher head than the machine design head when the incidence angle of the inlet flow is positive and largely deviated from the design value. It can also occur on the pressure side during operation at a lower head than the machine design head when the incidence angle is negative. If unstable, this is a very aggressive type of cavitation that is likely to deeply erode the blades and to provoke pressure fluctuations.

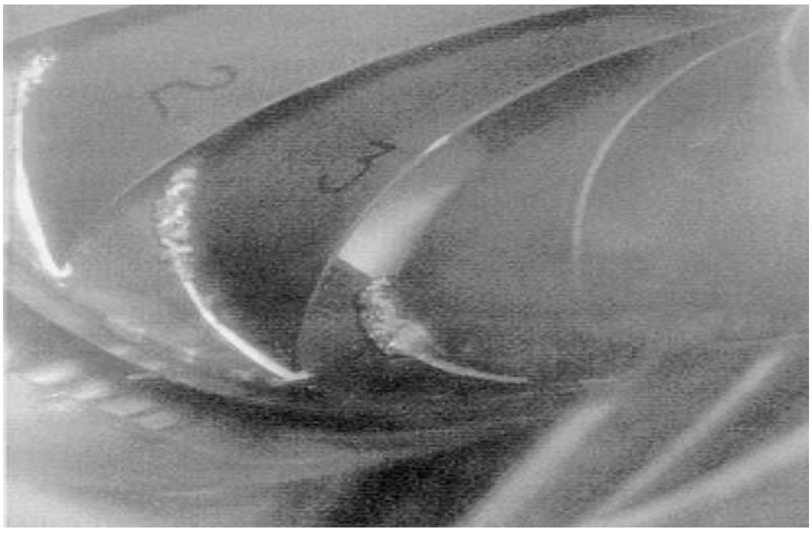

Fig. 3.1. Leading edge cavitation

3.2. Travelling Bubble Cavitation

See in Figure 3.2. It takes the form of separated bubbles attached to the blade suction side near the mid-chord next to the trailing edge. These travelling bubbles appear due to a low plant cavitation number sp and they grow with load reaching their maximum when the machine operates in overload condition with the highest flow rate. This is a severe and noisy type of cavitation that reduces significantly the machine efficiency and that can provoke erosion if the bubbles collapse on the blade.

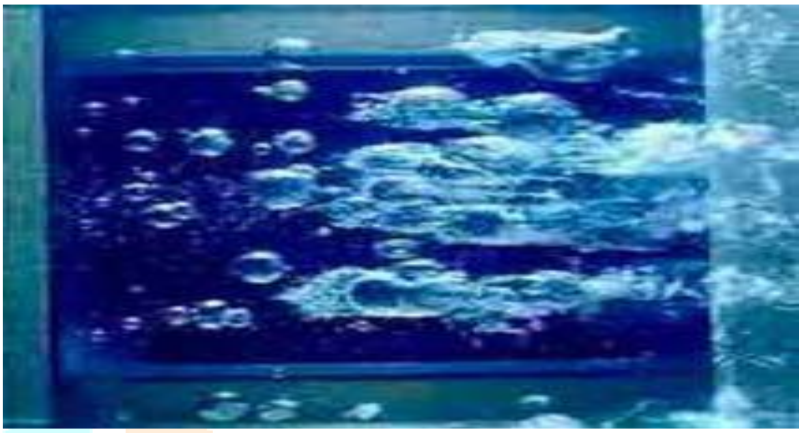

Fig.3.2. Travelling bubble cavitation.

3.3. Draft Tube Swirl

It is a cavitation vortex-core flow that is formed just below the runner cone in the centre of the draft tube. Its volume depends on sp and it appears at partial load and at overload due to the residual circumferential velocity component of the flow discharged from the runner. This vortex rotates in the same direction as the runner at part load and in the opposite direction at overload. From 50% up to 80% of the best efficiency flow rate, the vortex core takes a helical shape and presents a precession rotation at 0.25–0.35 times the runner rotating speed. In this case, circumferential pressure pulsations are generated at this low frequency. This provokes large bursts of pressure pulses in the draft tube causing strong vibrations on the turbine and even on the power-house. Beyond the best efficiency point the vortex is axially centered in the draft tube cone.

3.4 Inter-blade vortex cavitation

This is formed by secondary vortices located in the channels between blades that arise due to the flow separation provoked by the incidence variation from the hub to the band. They can attach to the intersection of the blade inlet-edge with the crown or mid-way of the crown between the blades close to the suction side. Only if their tip is in touch with the runner surface they can result in erosion. These vortices appear at partial load operation and yield a high broadband noise level. They can also appear and capitates at extremely high-head operation ranges because the sp is relatively low. In this case, they become unstable and cause strong vibrations.

IV. TESTING INSTRUMENTS AND CONDITIONS

Experiments were performed at the low head closed-loop test rig for Kaplan turbines. Model tests were performed ac- cording to ice 60193 standard 17. The flow rate was measured with an absolute accuracy of ±0.16% of the measured value Venturimeter calibrated with volumetric method and ±0.20% of the measured value electromagnetic flow meter. The head was measured with an uncertainty of less than ±0.1% of the measured value.

4.1. Acoustic Emission Sensor.

For the detection of the high- frequency noise, an acoustic emission sensor Kistler 8152A1 was used. It contains a piezoelectric element that detects acoustical waves in solids with a frequency ranging from 50 kHz to 400 kHz ±10dB. The sensor was mounted according to ASTM E 650-85 standard 18. It was connected to the signal-conditioning device, a Kistler AE-Piezotron Coupler 5125A, which contains the sensor's current supply, the amplifier, a two-pole Butterworth high- pass 50 kHz cutoff frequency , and low-pass 1 MHz cutoff frequency filters.

4.2. Hydrophone.

A Bruel and Kjær B & K type 8103 high- frequency hydrophone was used. It can be used for sound measurements with a frequency ranging from 0.1 Hz to 180 kHz. ±12.5dB. The hydrophone was connected to the charge amplifier B&K-type 2635. The hydrophone was submerged in a small container filled with water and attached to the outside surface of the draft tube. The acoustical signal was transmitted from the flow field, through the Plexiglas and water to the hydrophone. To improve the amplitude resolution of the high-frequency component before A/D conversion, the low-frequency signal up to 2 kHz was removed with an analog filter KEMO VBF42.

4.3. Accelerometer.

A Bruel and Kjær type 4393 accelerometer was used. It has a flat from 0.1 Hz to15 kHz. The typical mounted resonance frequency is 55 kHz. The calibration curve was considered so that the vibrations could be measured almost up to the accelerometer resonance region frequency range 30 – 50 kHz ±7 dB. Despite this deficiency, the results were similar to those of the acoustic emission and hydro- phone measurements. The accelerometer was connected to the amplifier B&K-type 2635.

4.4. Data Acquisition.

The acoustic emission, hydrophone, accelerometer, and trigger signals were simultaneously sampled at a 12-bit resolution with a 1 MHz sampling rate for 20 s to pre- serve the full frequency range of each transducer for further analysis. To avoid the possible aliasing phenomenon, the sampling frequency was at least five times higher than the observed frequency range. PC-based sampling was carried out simultaneously over four channels using a National Instruments PCI-6110E A/D converter card. Data sampling and post-processing were performed with software developed in LABVIEW on 2×10ˆ7 samples of complete acquired signal from each transducer.

4.5. Model Turbine Operation Conditions

The present study concentrates on the most severe cavitation conditions, i.e., at the operating point with a full turbine discharge and a minimum full-size turbine operating head. Cavitation measurements were performed at a fixed model turbine head 5.4 m ,flow rate 0.44 m3 /s , and rotational speed 900 rpm . Only the cavitation number was changed by adjusting the absolute pressure in the turbine draft tube. The definition of the cavitation number as used in water turbine testing is

$$\sigma = \frac{H_b - H_s - H_v}{H}$$

Where Hb is the atmospheric pressure, Hs is the suction head, Hv gives the vapor pressure of water, and H is the net head applied to the turbine. At first, a negative suction head was achieved by applying over- pressure in the draft tube measuring points with cavitation number higher than 4.6 in, then a vacuum pump was used to achieve positive suction head up to the point of full impeller cavitation. In this way, the full range of cavitations' conditions was tested. The setting level of the machine is the distance Hs indicated in that determines the pressure field in relation to the vapour pressure threshold. For instance, bubble cavitations' can appear even at the best efficiency point of the machine because it has a strong dependence on this level. Thus, the cavitations' coefficient of a hydraulic turbine depends on this parameter. A water turbine is designed to have the maximum efficiency for a given head and flow rate, but it can also operate at off-design points.

V. EXPERIMENTAL SETUP

Experiments were first conducted on a four-bladed Kaplan turbine model with specific speed nq= 3.21 and nominal outside diameter of 350 mm. The Reynolds number was held constant during the experiment Re =2.6×10ˆ6 based on the blade tip velocity and the blade chord length. Because of the distorted signals from noise, the measured acoustic signals from the four-bladed turbine show an unclear cavitation trend from the interaction of multiple blades. This un- clear trend is also demonstrated from the visual measurements. In order to isolate the cavitation features, a two-bladed Kaplan turbine was therefore constructed from the original four-

blade con- figuration by removing two blades. The two-bladed turbine has, of course, higher specific speed than the original. The efficiency of the two-bladed turbine certainly deviates from the original design. However, a similar cavitation condition and phenomena would be expected with the same revolution speed, guide vane opening, flow rate, cavitation number, and lower head as for the original four-bladed turbine.

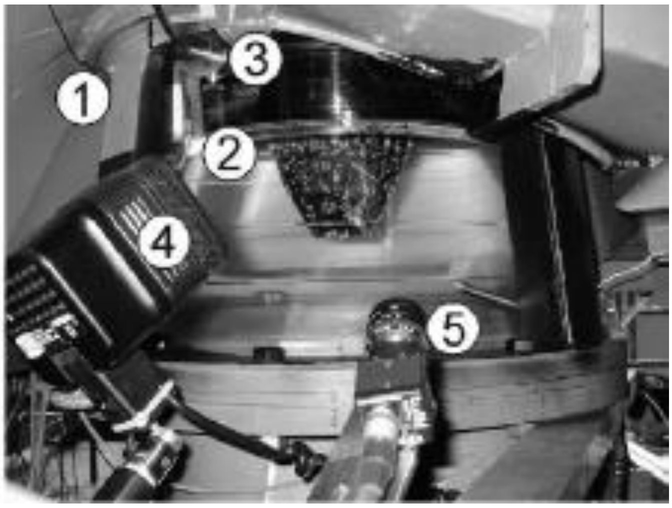

Fig.5. Experimental setup: 1. accelerometer, 2. hydrophone, 3. AE sensor, 4. stroboscopic light, 5. camera.

Because of the physical nature of cavitation, sensors with a large frequency range were used. The acoustic emission sensor and accelerometer were mounted on the flange in the horizontal plane at the beginning of the suction tube. The hydrophone was mounted on the suction tube close to the impeller. Actual positions of the sensors, stroboscopic light, and the charge-coupled device camera.

VI. RESULT AND DISCUSSION

For the acoustical emission measurements, the frequency range plays no role for the cases with higher cavitation numbers. Both signals in the frequency ranges of 60–120 kHz and 180–300 kHz begin to rise at approximately=3.4, where cavitation first occurs. A maximum of both signals is reached at = 1.9. After that, the amplitude of the signals drops significantly until a local minimum is reached at = 1.5. The amplitude of the signal with the frequency range 180 – 300 kHz drops slightly slower in this region, probably because the majority of the Eigen frequencies of the pressure waves that are emitted during the cavitation cloud collapse also lie in this range 12, 13. At even lower cavitation numbers 1.5, both signals rise again.

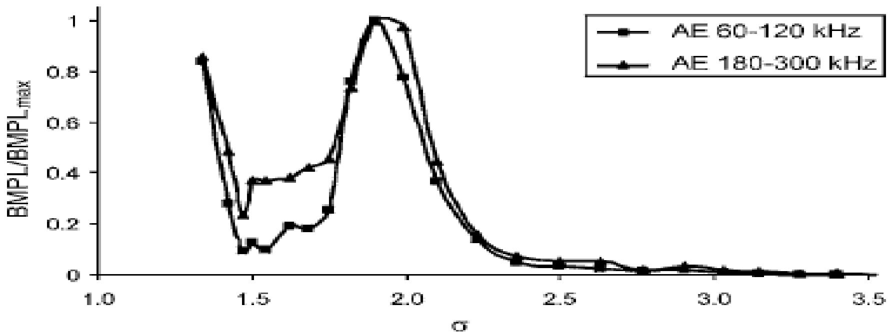

Fig.6. Results of measurements with acoustical emission sensor.

VII. CONCLUSION

Cavitation can present different forms in hydraulic turbines depending on the machine design and the operating condition. As a result, high vibration levels, instabilities and erosion can occur this invalidates the machine operation and provokes damage.

The types of cavitation of major interest in hydraulic turbines are the inlet leading edge cavitation, the outlet bubble cavitation and the draft tube swirl, which have been described after introducing the basic cavitation phenomena.

The inspection of single images revealed that different cavitation types exist at various positions on the turbine blade as a function of cavitation number. This fact indicates a possible explanation of the variation of acoustic emission, noise, and vibration based on the topological structure and the position of cavitation.

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