Impact load measurements with a PVDF pressure sensor in an erosive cavitating flow

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Abstract. A PVDF pressure sensor was used to measure the pressure peaks due to the collapse of cavitation bubbles in the high-speed tunnel of the LEGI laboratory. It was flush mounted on a stainless steel disk in the most erosive area of the test section. The recorded data were post-processed in order to get the impact load spectra for different velocities at constant cavitation number. The results are presented as cumulative histograms of peak rate and maximal impact load for different flow velocities of the high-speed tunnel.

1. Introduction

Cavitation is one of the main issues in turbomachinery since it may be responsible for efficiency losses, vibration and erosion. When a cavitation bubble collapses close to a surface, a microjet and a pressure wave are usually created, which impact the surface on a very small area and can deform and/or erode it. It has been shown from pitting tests that the impact area is of the order of tens or hundreds of micrometers in diameter (see for example, Franc et al [1]).

Moreover, the pressure pulse resulting from the collapse of a cavitation bubble is characterized by a large amplitude, of the order of 100 MPa (Wang et al [2]) or more (> GPa) (Momma et al [3]), and a very short duration measured typically in microseconds or even nanoseconds (Wang et al [4]).

Because of these extreme characteristics, it is very difficult to measure such pressure pulses whereas an accurate knowledge of their features is essential in view of damage prediction. So experimenters have developed special pressure sensors able to resist to cavitation erosion and with a high resonance frequency suited to the small duration time of the phenomenon.

Franc et al [5] measured the pressure pulse signal in a cavitation loop with a commercial pressure sensor (PCB 108A02) and showed that their sensor was not optimal for such measurements because of its limited resonance frequency.

Several authors use piezoelectric polyvinylidene fluorine (PVDF) films because of their high mechanical resistance and high resonance frequency. Momma et al [5] developed a PVDF pressure sensor and measured impact loads in a cavitating jet apparatus. Their PVDF transducer was mounted on a stainless steel support and protected on top by polyamide tapes from water and cavitation damage. Wang et al [1] recorded the impulsive pressure generated by cavitation bubble collapse with a single PVDF sensor and an array of PVDF sensors.

The purpose of the present work is to measure the impact loads due to cavitation bubble collapses in a cavitation loop with a PVDF sensor flush mounted in the region of maximum damage. Measurements were conducted at different flow velocities in order to investigate the effect of velocity on the flow aggressiveness at constant cavitation number i.e. for geometrically similar cavitating flows. Details on the facility and the pressure sensor are given in section 2. Section 3 is devoted to presentation of the results and the conclusion.

2. Experiments

2.1. Experimental Facility

The experiment was carried out in the high-speed tunnel of the LEGI laboratory, described in [5], generally used for cavitation erosion tests on samples made from different materials. In cavitating conditions, a cavity develops in the test section, which generates small vapor structures that collapse and may erode the sample. Erosion appears as a ring whose dimensions, minimum radius (R_{min}) and maximum radius (R_{max}), depend on the cavitation number. Present tests were carried out at a constant value $\sigma = 0.9$ of the cavitation number that leads *to* $R_{min} \approx 21\,mm$ *and* $R_{max} \approx 26\,mm$ on average. The same value of cavitation number as in [1] was chosen with the aim of comparing pitting tests and pressure pulse measurements.

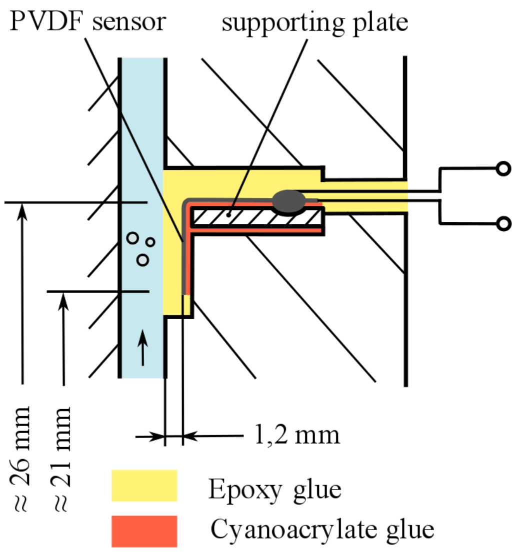

Figure 1. Detail of the mounted PVDF Sensor.

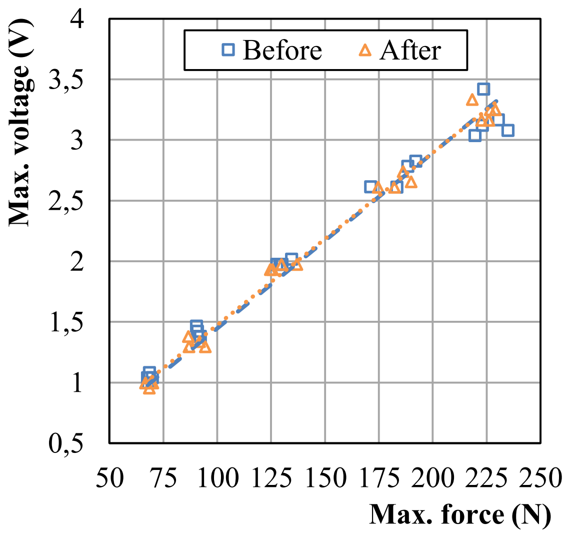

Figure 2. Calibration curve of the mounted PVDF sensor before (blue square and dashed line) and after (orange diamond and dotted line) experimentation.

Cavitation impacts are concentrated between the minimum and the maximum radius. A 28 µm thick commercial PVDF (DTI-028K/L – Measurement Specialties, Inc.) sensor was placed in this area and mounted on a cavitation stainless steel disk (AISI 304 L), as shown in figure 1. The active area of the PVDF sensor was cut from 12 mm x 30 mm to 12 mm x 5 mm approximately. At first, the PVDF sensor was fixed on an adjusted supporting plate made from polymethyl methacrylate (PMMA) and then glued on the disk by cyanoacrylate glue (Loctite Super Attak Power Flex Gel). Finally, the hole was filled with epoxy glue (Bison Epoxy 5 minutes) and the 1.2 mm thick upper layer was used to protect the sensor from cavitation damage.

2.2. Calibration of the sensor

The piezoelectric PVDF sensor delivers a voltage *V* proportional to the force *F* or pressure *P* applied on its active surface. So a calibration curve *F=f(V)* or *P=f(V)* is necessary for estimating the force or the pressure applied on the sensor from the measured voltage. In the present work, force is preferred since pressure is far from being uniformly applied on the sensitive surface of the sensor.

A ball drop test technique was used for calibration. A stainless steel ball is dropped on the homemade sensor, including its protective layer on top, from a known height h_1 and the height h_2 of the first rebound is measured. On the same time, the voltage is recorded as a function of time using the 8-bit Bus-Powered USB digitizer NI USB-5132.

The mean force on the transducer is calculated from a momentum balance:

$$F = \frac{m(V_1 + V_2)}{\tau}$$

where V_1 is the velocity just before the impact on the sensor, V_2 the rebound velocity just after impact, m the mass of the stainless steel ball and τ the duration of the impact. Both velocities V_1 and V_2 can be expressed as $V_i = \sqrt{2gh_i}$ (g gravity acceleration). The impact duration τ was read on time axis of the calibration signal. The ratio between the maximum force and mean force is determined from the shape of the calibration signal.

The calibration curve in figure 2 was plotted from five calibrations settings characterised by different heights and stainless steel balls diameters, each one including four runs. It showed a good reproducibility. Furthermore, the performance of the sensor before and after the experiments is not changed significantly, which proves that the sensor is not damaged by the cavitating flow in spite of its high aggressiveness.

2.3. Acquisition and processing of the data

The impulses generated by the cavitation were registered by the PVDF sensor connected directly to a digitizer (NI-USB 5132) and the signal acquisition was made by a LabVIEW virtual instrument control at the highest sampling rate of 50 MS/s. The high-speed cavitation tunnel, disc, digitizer and computer were grounded to limit noise.

The acquisition time was ajusted according to the cavitation erosion potential, which depends on the flow velocity (upstream pressure) of the cavitation tunnel. As a consequence, for a flow velocity of 22 and 34 m/s the acquisition time was 50 s and for 44.7, 54.8, 63.2 and 70,7 m/s it was 30 s.

The recorded data were post-processed by using two parameters: a threshold, depending on noise of each signal, and a locking time of 10 µs. So if one peak is detected, any other fluctuation of the signal during the following 10 µs is ignored in order to avoid multiple counting for one impact.

3. Results and conclusion

The results of the post-processing are presented in figure 3 as cumulative histograms. For the different flow velocities, cumulative peak rates in peaks per unit surface area of the PVDF sensor and per unit time are displayed as a function of the maximal impact load. The maximal impact load in newtons was determined from the maximal voltage in volts using the calibration.

The results show that the impact load increases as flow velocity increases. Also the peak rate increases with flow velocity. Concave parts of the spectra at high amplitude for each flow velocity suggests a limit value for the maximal impact load. Results at low amplitude are dependent upon the threshold used for filtering the noise.

As a conclusion, the use of PVDF pressure sensors appears to be an accurate technique for measuring the aggressiveness of a cavitating flow. In the present work, measurements have been made up to a maximum flow velocity of 71 m/s (25 bar) which corresponds to a flow of high aggressiveness. The final objective is to correlate these measurements with cavitation damage in order to propose a method of prediction of damage based on impact load measurements.

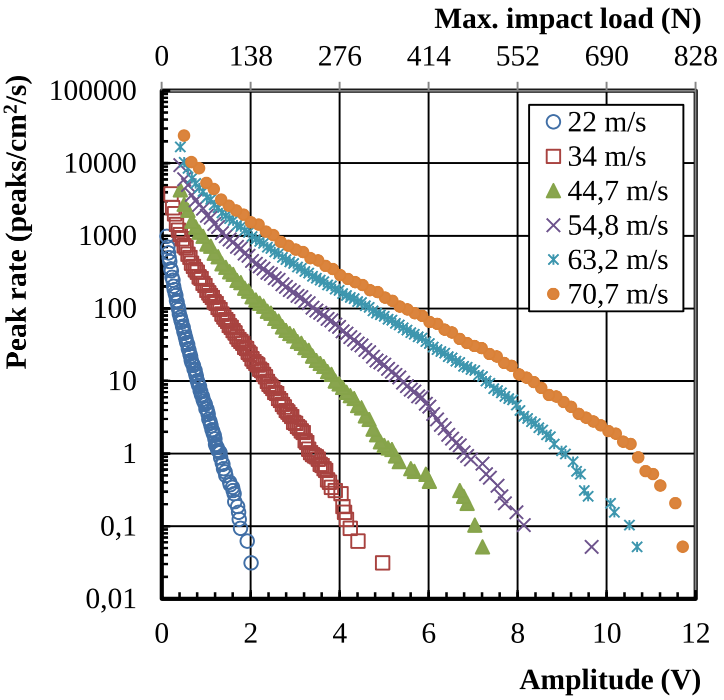

Figure 3. Impact load spectra at different flow velocities.

Acknowledgments
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References

[1] Franc, Jean-Pierre, Michel Riondet, Ayat Karimi, and Georges L. Chahine. "Material and Velocity Effects on Cavitation Erosion Pitting." Wear 274–275 (January 2012): 248–59.
[2] Wang, Yi-Chun, and Yu-Wen Chen. "Application of Piezoelectric PVDF Film to the Measurement of Impulsive Forces Generated by Cavitation Bubble Collapse near a Solid Boundary." Experimental Thermal and Fluid Science 32, no. 2 (November 2007): 403–14.
[3] Momma, T., and A. Lichtarowicz. "A Study of Pressures and Erosion Produced by Collapsing Cavitation." Wear 186–187 (August 1995): 425–36.
[4] Wang, Yi-Chun, Ching-Hung Huang, Yung-Chun Lee, and Ho-Hsun Tsai. "Development of a PVDF Sensor Array for Measurement of the Impulsive Pressure Generated by Cavitation Bubble Collapse." Experiments in Fluids 41, no. 3 (August 24, 2006): 365–73.
[5] Franc, Jean-Pierre, Michel Riondet, Ayat Karimi, and Georges L. Chahine. "Impact Load Measurements in an Erosive Cavitating Flow." Journal of Fluids Engineering 133, no. 12 (2011): 121301. doi:10.1115/1.4005342.
[6] Momma, T., and A. Lichtarowicz. "A Study of Pressures and Erosion Produced by Collapsing Cavitation." Wear 186–187 (August 1995): 425–36.