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EXPERIENCES ON CAVITATION DETECTION METHODS

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Abstract: Cavitation is in most cases harmful and undesired phenomenon in fluid power systems. When actions for preventing cavitation are considered, it is essential to recognise the existence of cavitation and location of cavitation inception point.

In fluid power components and systems cavitation can occur in various locations where the access for measuring instruments is limited. Therefore, the existence of cavitation is often very difficult to detect. In addition, very high speed of the cavitation phenomenon makes the task difficult.

At the Institute of Hydraulics and Automation several cavitation detection methods have been studied. The existence of cavitation can be detected either directly or indirectly. Indirect detection can be done by monitoring steady-state flow properties and with high-speed pressure transducers or accelerometers the cavitation-induced shock waves can be recorded. Measurement of frequency spectrum of acoustic pressure reveals also the presence of cavitation. When flow visualisation is possible to arrange, cavitating flow can be observed directly. In addition, an ultrasonic transmitter-receiver has been tested for direct cavitation detection.

The above-mentioned equipment has been used in several cavitation studies at the IHA and promising results have been obtained.

Keywords: Cavitation, Detection methods

1 INTRODUCTION

Cavitation is a term used to describe a process, which includes nucleation, growth and implosion of vapour or gas filled cavities. These cavities are formed into a liquid when the static pressure of liquid for a reason or another is reduced below the vapour pressure of the liquid in current temperature. When cavities are carried to higher-pressure region, they implode violently and very high-pressure shock waves can occur.

Cavitation is in most cases harmful and undesired phenomenon in fluid power systems. Due to the various effects on fluid power systems, cavitation is to be avoided as much as possible. When actions for preventing cavitation are considered, it is essential to recognise the existence of cavitation and location of cavitation inception point.

Detection of cavitation can be done directly only by verifying the existence of cavities. Direct detection is possible by observing visually the population of developed cavities in flow passages. However, fluid power components encompass usually complicated constructions and cavitation can occur in various locations where the access for visualisation instruments is limited. In addition, very high speed of the cavitation phenomenon makes the task difficult. Due to restrictions of direct detection of cavities, various indirect methods can be used. In these indirect methods the measurements are typically targeted to the shock waves generated by cavity implosions.

When detecting cavitation from an operating machine, environmental disturbances make the indirect measurements difficult. Indirect measurement methods are especially useful if the measurement data from non-cavitating circumstances is available. Cavitation generates typically high frequent vibration from which the existence of cavitation can be recognised.

In the past research, several methods for cavitation detection have been studied. Grätz [1] and Riedel [2] have studied steady-state flow properties in cavitating orifices. They have obtained parameters by which cavitation occurrence in orifices can be estimated. Wiklund and Svedberg [3] and Myllykylä [4] have studied the pumping capability of various pumps. They have recorded remarkable reduction in pump outlet flow when suction line of pump suffers cavitation. Eich [5] has studied cavitation noise in cavitating orifice flow and recorded acoustic pressure along with visual inspection of flow. He concluded that acoustic method revealed cavitation inception before visual detection of cavities. Eich found out that at the inception of cavitation the first responses in acoustic pressure are seen at high frequencies (>20kHz). Backè and Berger [6] have used accelerometers in their jet-cavitation studies. They found out that signal from accelerometer indicated the cavitation prior to change in steady-state flow properties. Visual inspection in cavitating orifice flow have been used by several authors (e.g. Kleinbreuer [7], Eich [5]). In these studies, relatively slow cameras have been used. High-speed photography has been used in cavitation research in water tunnels (e.g. Knapp et al [8]). Slow cameras reveal the presence of cavitation but only high-speed photography give detailed information on cavity size and velocity.

2 TEST APPARATUS

At the Institute of Hydraulics and Automation, IHA (Tampere University of Technology) several cavitation detection methods have been studied and promising results have been obtained. In the studies, a controlled cavitation was created with a cavitating-jet apparatus, which is based on cavitation due to reduction of static pressure head at high velocity flow in an orifice. The test installation of the cavitating-jet apparatus is presented in figure 1. Cavitation starts when static pressure head at high velocity flow reduces in the vena contracta of the jet and a cloud of cavities is ejected around the emerging jet.

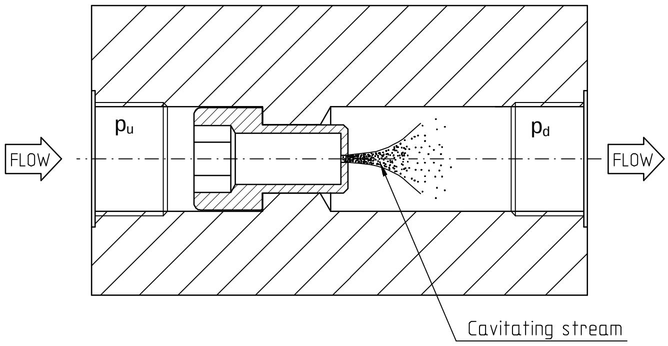


Figure 1. Controlled cavitation was created with a cavitating-jet apparatus.

In the following, the studied detection methods are described and the results of the experiments are presented.

3 MONITORING OF STEADY-STATE FLOW BEHAVIOUR

The presence of cavitation can be detected by monitoring steady-state flow behaviour of a fluid power component. When pressure downstream from a valve is reduced sufficiently, flow rate does not increase with the increasing pressure drop across the valve. This phenomenon is typically referred as “saturation” or “choking”. By measuring the characteristic curve of a valve, a cavitating range can be determined. An example of a characteristic curve is presented in figure 2. In the figure, the flow saturates to the value of 6.5 l/min, when downstream pressure is 75 bar.

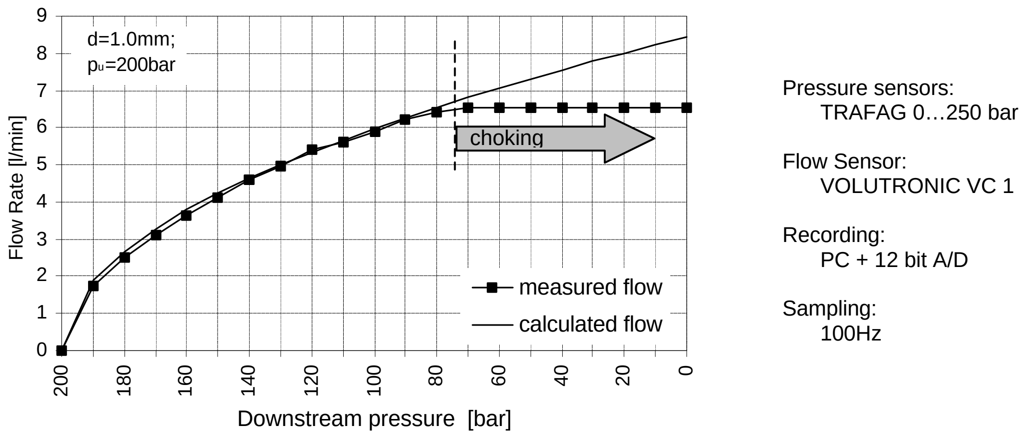


Figure 2. Characteristic curve of a circular orifice.

In addition, in the case of pumps, cavitation in suction line reduces the efficiency of the pump. When pressure is reduced in the suction line, pump chambers do not fill completely due to air-release in suction line. Measurement of the flow rate on pump outlet reveals the reduction in pump flow and hence cavitation. [3, 4]

4 HIGH-SPEED MONITORING OF PRESSURE AND VIBRATIONS

When detecting cavitation indirectly, the question is typically about measuring the shock waves induced by cavity implosions. Cavity inception is at first seen in very high frequencies, and therefore very fast transducers are needed. Shock waves can be recorded in the cavitating fluid with high-speed pressure transducers. The propagation of shock waves continues from fluid to the surrounding component body and measurement of the acceleration of the component surface reveals the presence of cavitation. In figure 3, high-speed pressure transducer is used to record pressure peaks due to cavitation. In the left, no cavitation is present and only pump fluctuations can be seen. In the second figure, cavitation has just incepted and when cavitation has developed extensively (in the right), the pressure peaks get higher.

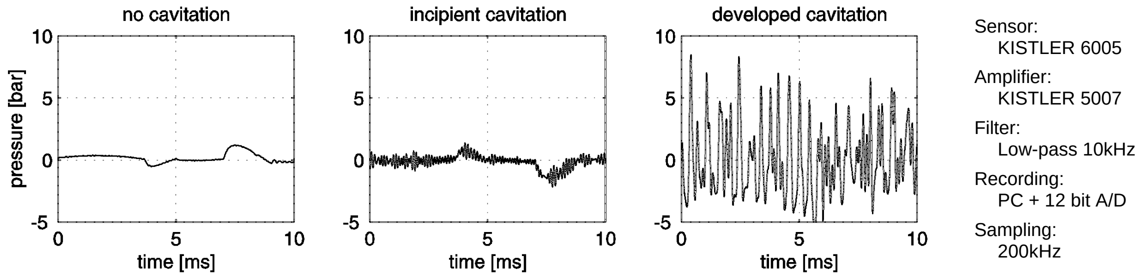


Figure 3. Pressure in downstream chamber of the test block. Cavitation intensifies from left to right.

In the figure 4, the vibration (acceleration) of the test block surface is presented. Very similar results to the figure 3 can be seen. The difficulty in acceleration measurements is the isolation of disturbing vibration sources of the component.

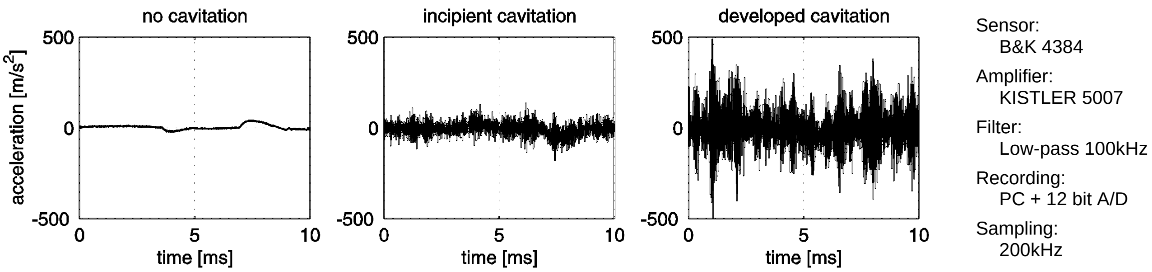
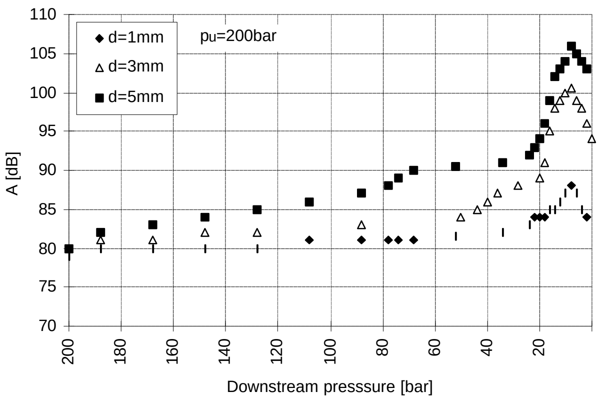


Figure 4. Acceleration of the test block surface. Cavitation intensifies from left to right.

5 MONITORING OF ACOUSTIC PRESSURE EMISSION

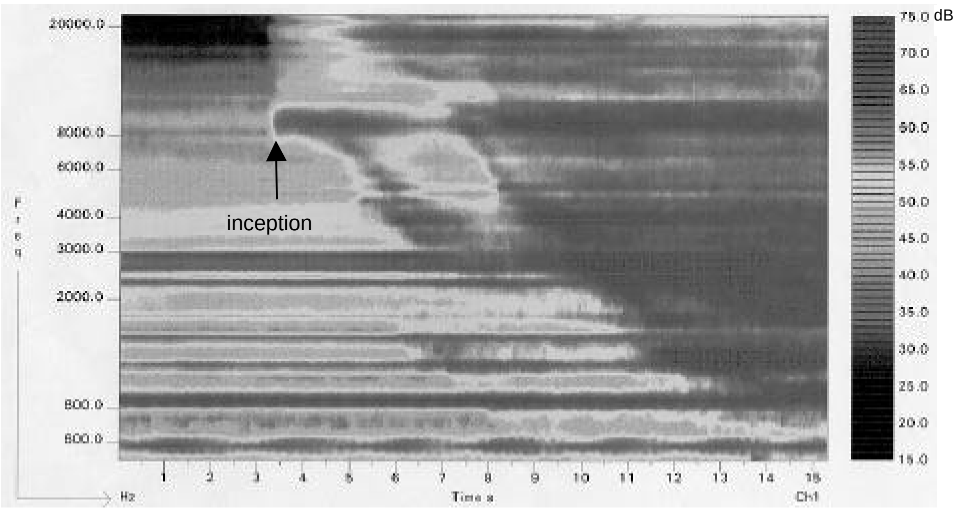
Cavitation produces broad band high-frequent noise. Noise is emitted when the cavities collapse violently and high pressure peaks are generated. Incipient cavitation may not be audible to human ear but developed cavitation can be identified from distinct sizzling or crackling noise. Using microphones and sound level meters, also incipient cavitation can be recorded. The acoustic pressure measured from the cavitating-jet device with various orifice sizes is presented in figure 4. When flow is cavitation free, the noise level remains quite constant and is mainly due to background noise. When cavitation is well developed acoustic pressure increases rapidly.



Sound level meter:
TES –1350
Frequency weighting:
A
Range:
65 – 130 dB
Accuracy:
±2dB
Recording:
manual

Figure 5. Acoustic pressure measured outside of cavitating jet apparatus.

More information is obtained when cavitation noise is measured with wide range of high frequencies. Moreover, if results are plotted as frequency spectrum the inception and development of cavitation can be seen clearly. Frequency spectrum of acoustic pressure measured from the cavitating-jet apparatus is presented as 3D-chart in figure 6. At the time of 3s, the inception of cavitation is clearly seen in sudden increase of acoustic pressure at high frequencies (> 8 kHz). When cavitation is developing, acoustic pressure extends to the lower frequencies as well. Same kind of trends can be seen when frequency spectrums of pressure and vibration measurements are analysed.



Microphone:
B&K 4135, ¼” free-field microphone
Sound level meter:
B&K 2231
Filter:
Low-pass 20kHz
Recording and analysing:
Larson-Davis 4-channel frequency analyzer
Plotting:
Ids Nvision data visualisation software

Figure 6. Frequency spectrum of acoustic pressure. Cavitation is developing when downstream pressure is decreased with time.

6 DETECTION OF CAVITIES BY ULTRASONIC METHOD

Detection of cavitation can be based on attenuation, reflection or scattering of ultrasonic waves (frequency: 20…10MHz) from cavities. The laboratory experiment in question was based on reflection of ultrasonic waves from a cloud of cavities. The specific acoustic impedance in cloud of cavities is less than in oil, providing that the volume of cavities is large enough. Then ultrasonic wave reflects partly from the cloud and a reflection pulse is seen on receiving sensor.

The test installation of the ultrasonic detection method is presented in figure 7. A T/R-type ultrasonic sensor was used to transmit and receive ultrasonic burst signal.

The T/R-sensor used in the test was primarily designed for distance measurements and it had a narrow beam. The velocity of oil flow was high and the measuring distance was large, which caused beam deflection and the reflected waves did not hit the receiver. Hence, the signal was not detected reliably. Although this laboratory experiment was not successful, positive experiences with ultrasonic sensors have been obtained from field tests carried out in operating hydraulic machinery.

Sensor for this kind of application should have wide beam and the Doppler-shift should be considered when designing the bandwidth of the sensor. In addition, the geometry of the oil chamber and the location and orientation of the sensor should be optimised in order to avoid reflections from the chamber walls.

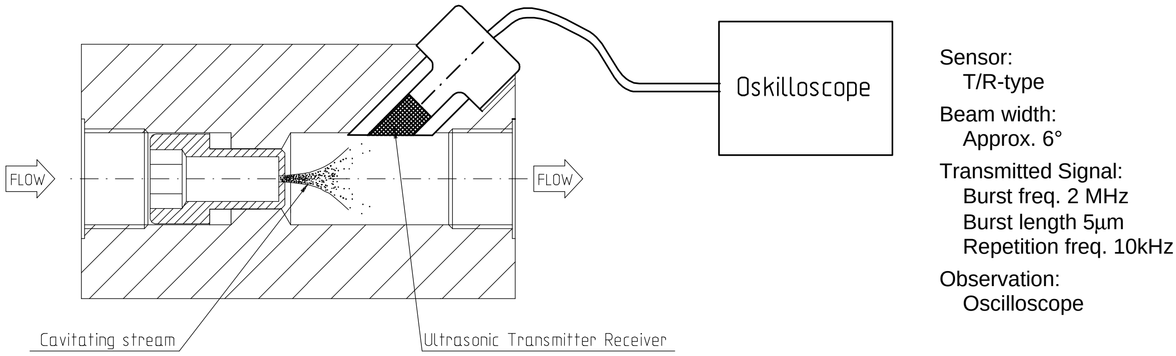


Figure 7. Ultrasonic transmitter/receiver at the cavitating-jet apparatus.

7 DETECTION OF CAVITIES BY FLOW VISUALISATION

Direct detection of cavitation is possible with flow visualisation. Gas or vapour filled cavities can be detected visually only if the fluid is somewhat transparent and visual devices can access the cavitating flow region. Visual observation of cavities was studied in the cavitating-jet device as well (figure 8). Sapphire-windows were mounted at the cavitating flow. When lighting and observation is done both through one window the light does not scatter from the cavities and visualisation is poor. Two windows are needed in order to get successful visualisation of cavities. However, arrangements for two visualisation windows are often difficult. In the test system, light to the downstream chamber was supplied through one window and observation was done through another window. Light scattering from the cavities was optimised by mounting the windows in 140° angle.

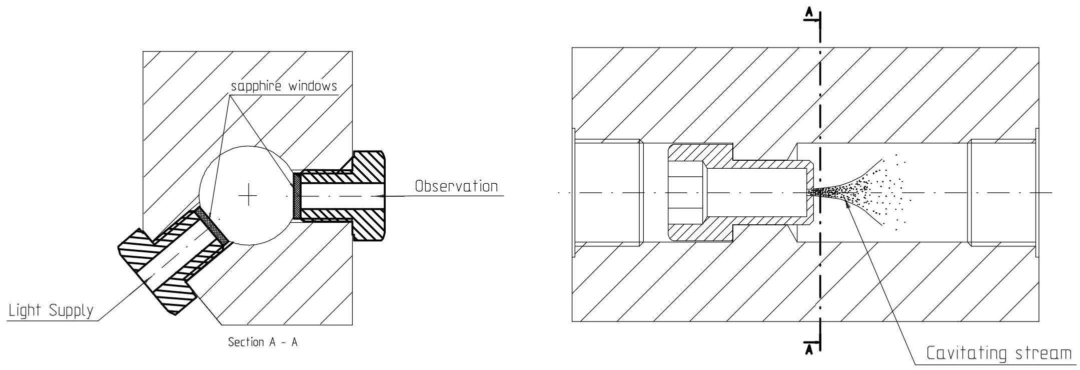


Figure 8. The arrangement of flow visualisation in the cavitating-jet apparatus.

At first, the chamber was lit by halogen light and observation was carried out with human eye, camera or video camera. A photograph of cavitating jet emerging the orifice is seen in figure 9. The population of cavities is seen as a homogenous foggy jet due to relatively long exposure time. The measurement of the intensity of light scattered from the cavities gives information of the intensity of cavitation.

When pulse light and high-speed photography is implemented, the motion of cavities can be arrested. This enables, for example, the analysis of the cavity size distribution. In the test installation a xenon-discharge light and CCD-camera was used. A close-up view of cavitating flow is presented in figure 9. A population of cavities can be seen clearly in the oil flow.

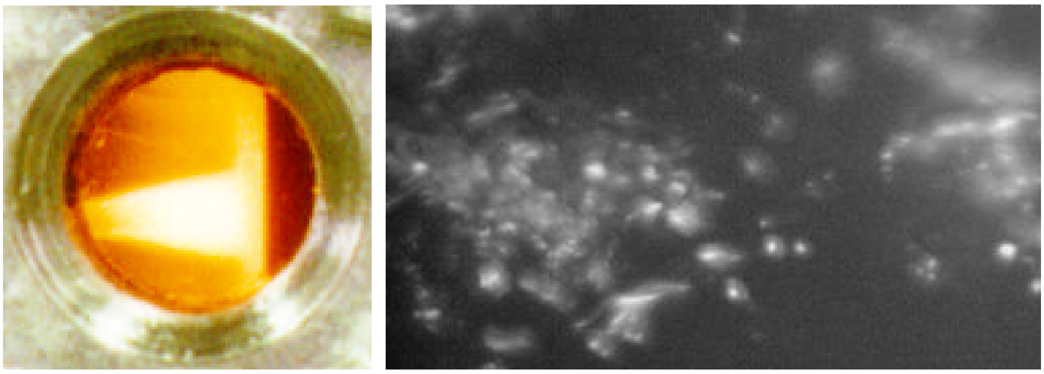


Figure 9. Photographs of cavitating oil flow. Left: halogen light and film-camera. Right: Close-up view with xenon-discharge light and CCD-camera.

8 CONCLUSIONS

Several cavitation detection methods have been studied in laboratory conditions. Promising results have been obtained from the experiments.

Direct detection of cavitation is possible only if measuring or detecting instruments can access the cavitating region of flow passages. This is quite difficult task due to the fact that cavitation phenomenon is typically very local. Detection of cavitation can be done directly only by verifying the existence of cavities. Visual observation of the cavities in flow passages can be done successfully if the light can be scattered from the cavities. This requires minimum of two visualisation windows. Observing the behaviour of ultrasonic waves can reveal the existence of cavities. High flow velocity causes the deflection of ultrasonic waves, which sets requirement for wide beam sensor.

Due to the difficulties in direct detection methods, several indirect methods can be considered. In indirect methods, the measurements are targeted to the shock waves generated by cavity implosions. The shock waves propagate relatively far and the sensor placement is not so limited than in direct measurements. In the paper, cavitation was detected indirectly with pressure sensors, accelerometers and acoustic instruments. Results showed that the inception of cavitation is first seen as high frequent pulsation. When cavitation develops, pulsation extends to the lower frequencies as well. Measurements of pressure, vibration and acoustic pressure with sufficient high and wide bandwidth are efficient cavitation detection methods.

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