Experiences with a visualisation of cavitating flows behind a micro-orifice

Branislav Knížat[1], Róbert Olšiak[2], Marek Mlkvik[3]

[1] Strojnícka fakulta STU v Bratislave, Ústav chemických a hydraulických strojov, Nám. slobody 17, 812 31 Bratislava, Slovenská republika, branislav.knizat@stuba.sk

[2] Strojnícka fakulta STU v Bratislave, Ústav chemických a hydraulických strojov, Nám. slobody 17, 812 31 Bratislava, Slovenská republika, robert.olsiak@stuba.sk

[3] Strojnícka fakulta STU v Bratislave, Ústav chemických a hydraulických strojov, Nám. slobody 17, 812 31 Bratislava, Slovenská republika, marek.mlkvik@stuba.sk

Abstract Cavitating flow of water behind a micro-orifice at high pressure gradients comes under phenomena of fluid mechanics the visualisation of which is a challenge. It requires a sophisticated apparatus as well as advanced methodology of the experiment and data processing. In the paper are described experiences with a construction and operation of the apparatus able to visualise flow at high speeds behind a microorifice. Presented are some results of experiments obtained with micro-orifices of diameters 0,350 mm and 0,580 mm. Described are some methods of processing and evaluation of flow images.

1 Introduction

Visualization is an important method of research of supercavitation flow behind a micro-orifice. Many parameters of flow may be observed: length, character of a collapse and an integrity of a cavitation cloud. Results may be related to cavitation effects, which are utilized in applications in different branches. The flow is characterized by a high pressure gradient and velocities up to 100 m/s. These facts make demands on the used device, especially on the camera and illumination method.

2 Experiment device

The base part is a Lichtarowicz cell [3]. It is adapted in a such manner, that through transparent walls it is possible to observe the flow within the cell. The aim of our experiments was a maximization of cavitation effects, so the development of a flow pattern of a jet impinging a solid perpendicular wall made of different materials was observed. We utilized a fact that the cavitation cloud itself has different optical properties as surrounding pure water. The whole test circuit is in the Fig. 1. It is composed of more independent parts (hydraulic part, optical part, data recording - DAQ system). A base part is a high speed camera Redlake Y3 and an illumination system of a micro – orifice.

The hydraulic part consists of (see Fig. 1): piston pump (P1) - 23.16 Lpm/1420 rpm, max. 130 bar; Lichtarowicz cell (LC); accumulator for pressure pulsation damping (A) – 1 L/HAB/Rexroth; vacuum chamber (VAC); vacuum pump (VP).

The DAQ system consists of (see Fig. 1): S1 piezorezistive pressure sensor p1 - BD Sensors/DMP 333/0 – 160 bar (relative); S2 thermocouple K – sensor of a water temperature at the jet input; S3 pressure sensor p2 - BD Sensors/Ni-Cr/; S4 force sensor (weigh of a vessel measurement); sensor of ultrasound vibrations Physical Acoustics/40 - 100 kHz; measuring amplifier; measuring PC; ultrasound system for sound speed measurement Controlotron / 1010DPI

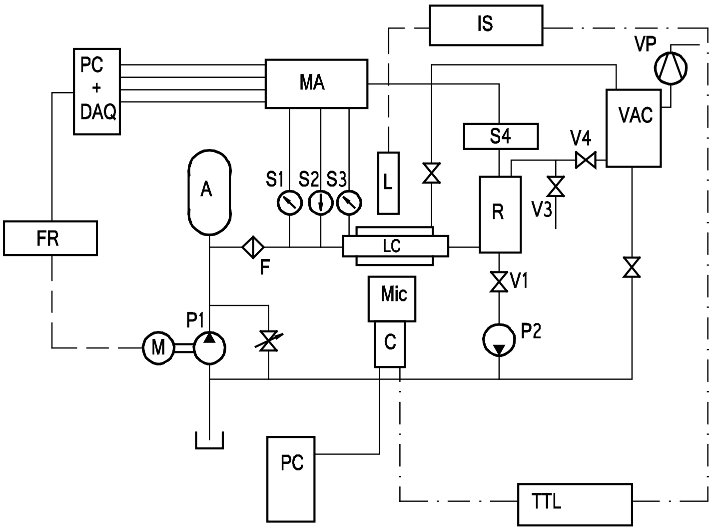

Fig. 1 Scheme of the test equipment. P1 – Primary (piston) pump, P2 – Secondary pump, LC – Lichtarowicz Cell, A – Acumulator, TTL – Generator of TTL signal, C – High Speed Camera, Mic – Microscope, L – Light, VAC – Vacuum vessel, VP – Vacuum Pump, S1, S2, S3, S4 – sensors, FR – Frequency Regulator, MA – Measuring Amplifier.

The system for visual data recording has following parts: high speed camera RedLake Y3; camera objective Nikkor 50 mm/Aperture f 1:1.2; illumination system Flashlamp NanoLite, High Speed Photosystem; Power Source for Flashlamp NanoLite, Ministrobokin, High Speed Photosystem, max. frequency 20 kHz, Flash duration 18 ns, Flash Energy 25 mJ, max. Flashcount 200; generator of synchronizing signal LG; PC with software for high speed camera.

In the Fig. 2 are snapshots of used micro orifices. The tests were carried out with two micro orifices with diameters 0,35 mm and 0,58 mm.

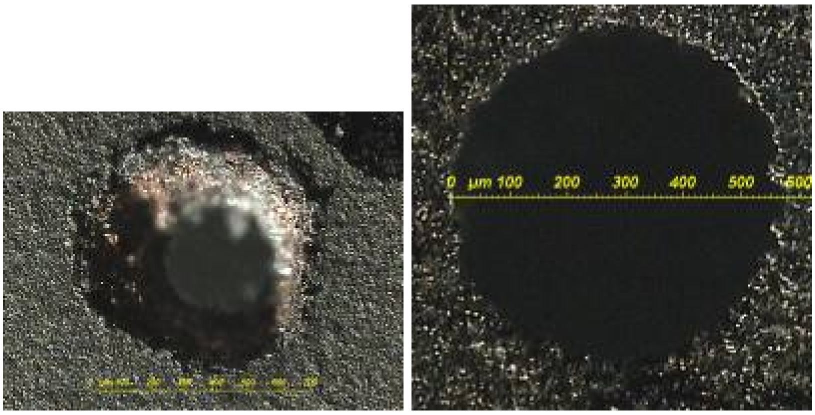

Fig. 2 Micro-orifice 0,350 mm (left) and 0,580 mm (right).

As it is clear from the snapshots, the orifices had different diameters from both sides and they were placed in a such manner that smaller diameter was oriented upstream. More materials of orifices were tested, but finally a hard alloy was acquitted well.

3 Selected experiment results

Many parameters of a cavitation cloud were interpreted from obtained snapshots, for example: a diameter of a collapse region D, thickness of a cavitation cloud s, etc. (see Fig. 3).

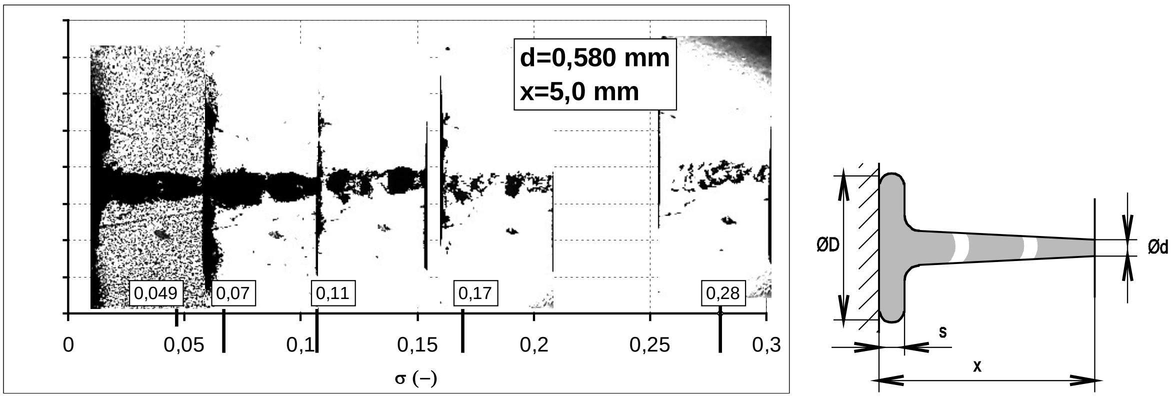

Fig. 3 Structure of a jet in a dependency on a cavitation number.

A base parameter used for estimation of intensity of cavitation is a cavitation number defined as follows:

$$\sigma = \frac{2(p_2 - p_v)}{v_2^2\,\rho} \tag{1}$$

where p_2 is a back pressure, p_v is a vapor pressure, v_2 is the exit velocity and ρ is a water density. In the Fig. 3 is then the shape of a cavitation cloud in dependence on a magnitude of the cavitation number. In the figure right is a scheme of a general structure of a cavitation cloud. The cloud is impinging the perpendicular wall (the distance between the orifice and the wall is denoted x) and the flow direction is from right to left.

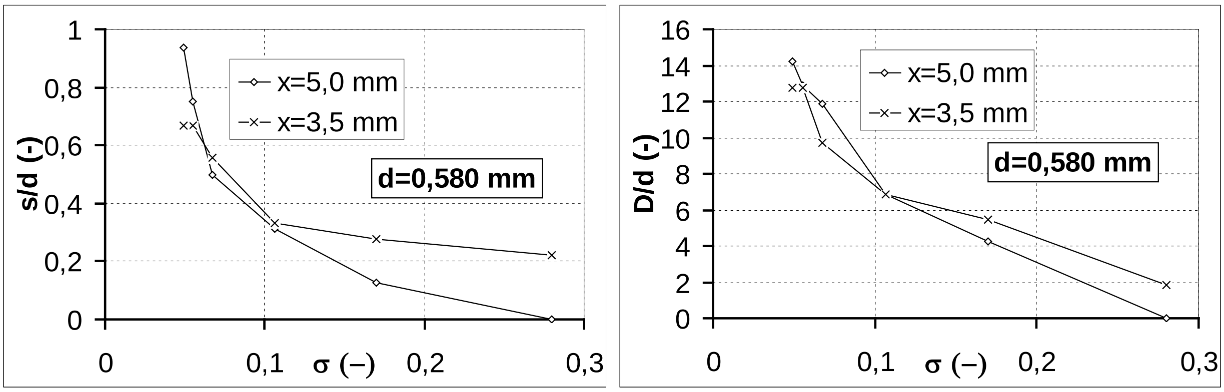

Fig. 4 Selected parameters of a cavitation cloud.

In the Fig. 4 are evaluated selected geometrical parameters of a supercavitation cloud in dependence on the cavitation number. These parameters are: non-dimensional cloud thickness s/d and non-dimensional diameter of the cloud collapse on the sample s/D; both are related to the orifice diameter. It is clear from the figures that with the decreasing cavitation number and with increasing cavitation intensity these parameters grow. The region of the cloud collapse (diameter D) on the perpendicular wall reaches at low cavitation numbers 15 multiple of the orifice diameter d. The cloud thickness reaches the value of the orifice diameter. The integrity of the cavitation cloud, which is influencing the destructive cavitation effects too, was also investigated from the snapshots.

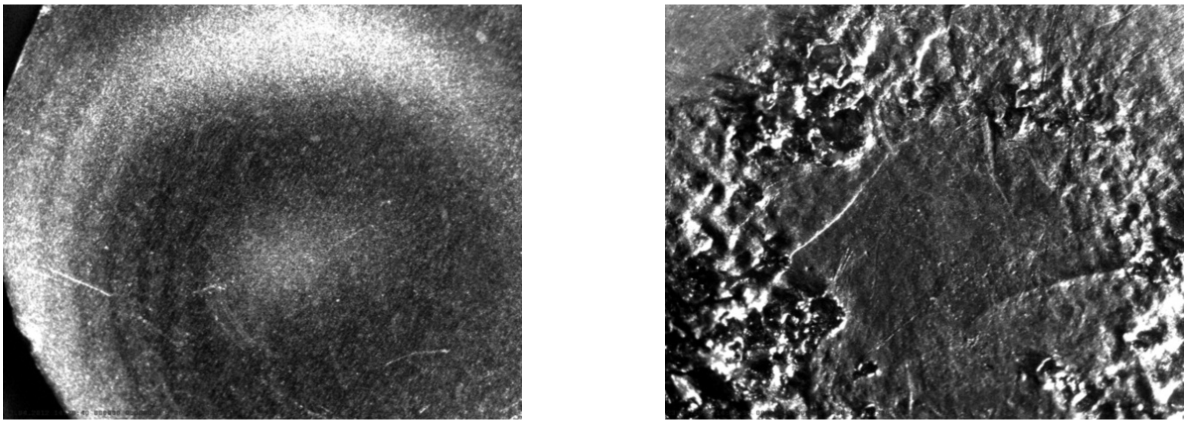

Fig. 5 Cavitation damage of samples. Left: copper, 20 min. Right: lead 5 min.

In the Fig. 5 is depicted an example of a cavitation damage of metal samples. The sample left is a copper after 20 min of exposing to cavitation. The right snapshot is a lead sample (the same configuration) after 5 minutes of exposing. Damaged region has a circular shape; the diameter corresponds to diameter D on the sketch in the Fig. 3 right.

4 Conclusions

The aim of the experiments was to find a configuration of parameters at which the cavitation effects are maximum. Such configurations were experimentally estimated; the experiments are actually still running. The destructive effects of the cavitation were presented on samples made from copper and lead. The visualization of cavitation cloud flow is a very powerful method in this research. It makes possible to find out how does the damaged region on the sample correlate with the shape of the collapsing cloud.

Acknowledgement This work was supported by the Scientific Grant Agency VEGA under number 1/0215/11.

Literature

[1] OLŠIAK R., KNÍŽAT B., MLKVIK M. Visualization Of Cavitating Micro Jets. Experimental Fluid Mechanics 2011, In *Proceedings of the International Conference*, November 22.-25., 2011, Jičín, Czech Republic.

[2] CHAVES H., KNAPP M., KUBITZEK A., OBERMEIER F., SCHNEIDER T. Experimental Study of Cavitation in the Nozzle Hole of Diesel Injectors Using Transparent Nozzles. In *SAE Paper 950290*, March 1955.

[3] KNÍŽAT B., OLŠIAK R., MLKVIK M. Collapse of a cavitation cloud behind a microjet. In *AEaNMiFMaE 2012, 25-27 April 2011*, Demänovská dolina.