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EXPERIMENTAL RESEARCH OF CAVITATION IN CHANNELS OF VERY SMALL SCALES

EXPERIMENTÁLNY VÝSKUM KAVITÁCIE V DÝZE VEĽMI MALÝCH ROZMEROV

Abstract

This paper deals with defining of experimental methods and with description of an experimental setup used in research of fluid flows in jets and other orifices of very small scales. The jet used in the experiments has an axissymetric shape with circular cross-section. The experimental setup used for experiments consists of these basic parts: a device used for microscopic visualization and capturing of image of the liquid flow in small scale channels, a digital image data acquisition system and a system of image data manipulation, a system for parallel acquisition and manipulation with other experimental data.

Abstrakt

Príspevok sa zaoberá definovaním experimentálnych metód a opisom experimentálneho zariadenia na výskum prúdenia tekutiny v dýzach a clonách veľmi malých rozmerov (v zmysle hydraulickom). Dýza, prúdenie v ktorej je cieľom experimentálneho výskumu má osovo symetrický tvar s kruhovým prierezom. V ďalšom uvedená a krátko opísaná základná štruktúra experimentálneho systému: zariadenie na mikroskopickú vizualizáciu a snímanie obrazu prúdiacej kvapaliny v kanáloch veľmi malých rozmerov, systém digitálneho záznamu a ďalšieho spracovania video dát, systém na paralelný zber a záznam ďalších experimentálnych dát.

1 INTRODUCTION

Publications, where researchers presenting results of their work are most often focused on the fluid flow in channels of very small scales (e.g. in channels which belong to microfluidics devices due to the characteristic hydraulic dimension [1], [3], [4]), where the cross section of the channel is of a non-circular shape (rectangular, square, trapezoidal….). This shape is surely a result of the used manufacturing technology, most often technologies also used in manufacturing of semiconductors, MEMS components etc.: lithography, microlithography, etching (wet process, dry process)[4]. The jet used for the experiments in this paper has an axissymetric shape with a circular cross-section (more or less circular). The model of the jet was created by cast in plexiglas and we used the same technology for manufacturing of other shaped orifices (fig. 1). Characteristic dimensions of these hydraulic parts are in scale of tens and hundreds of micrometers. Shapes and dimensions of our micro-orifices can be seen in figure 1.

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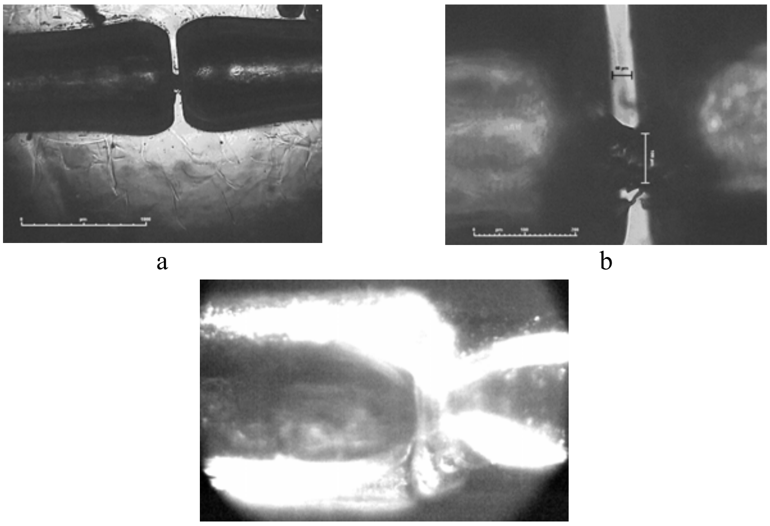

a b

c

Fig. 1 Pictures of micro-orifice (a,b) and micro-jet (c)

In the next part of the paper there are described experiments focused on the analysis of cavitation beginning and continuance by a high speed flow through the jet of a microscopic scale, which is pictured in figure 1,c . The diameter of the straight part of the channel is 0,8 mm, diameter of the orifice is 0,1 mm. The channel is cast into plexiglas. In the place of the orifice two holes are drilled from the side into plexiglas. These holes are used for installation of optical fibres used for illumination of the orifice area.

2 STRUCTURE OF EXPERIMENTAL SYSTEM

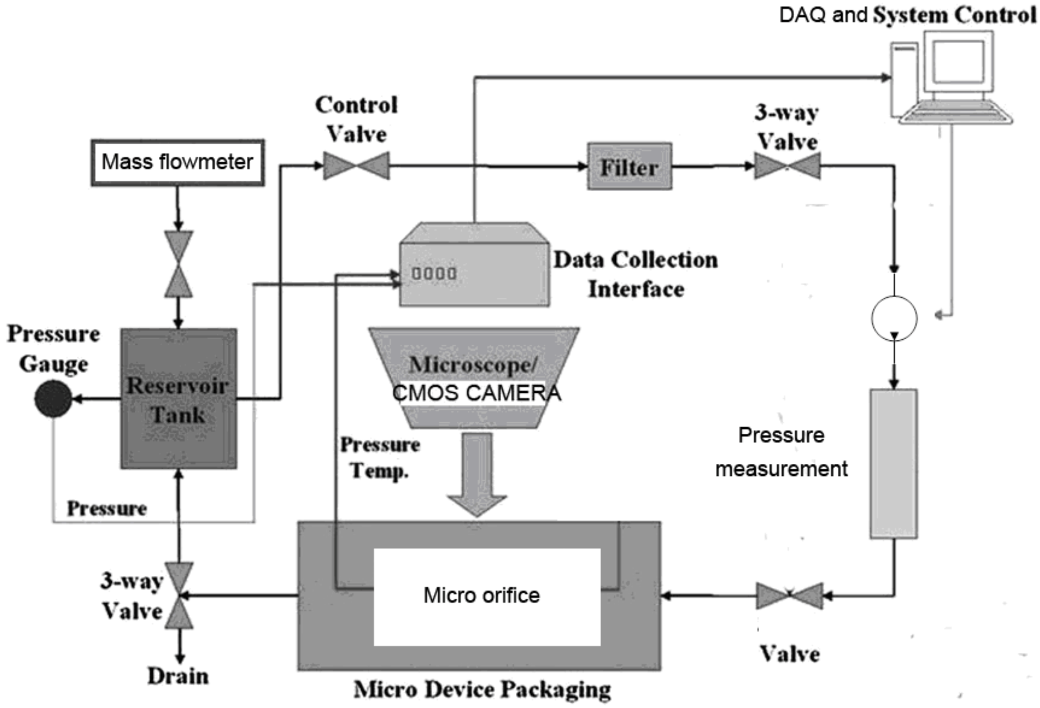

Fig. 2 Diagram of experimental system used for research of cavitation phenomenon in channels of very small scales

The block scheme describing structure of experimental system is pictured in figure 2.

- The whole experimental system consists of four functional subsystems and each subsystem is modular:
- The model of the investigated micro jet (micro orifice) placed on a carrier unit made of a transparent material
- The hydraulic part of the experimental system, consisting of a source of hydraulic fluid on the inlet part of the channel and vacuum recipient on the outlet.
- The optical system used for flow visualization, record and manipulation with visual data connected with an illumination modul.
- DAQ & Control system used for measuring of physical parameters, transmission, archiving and manipulation with non-visual data.

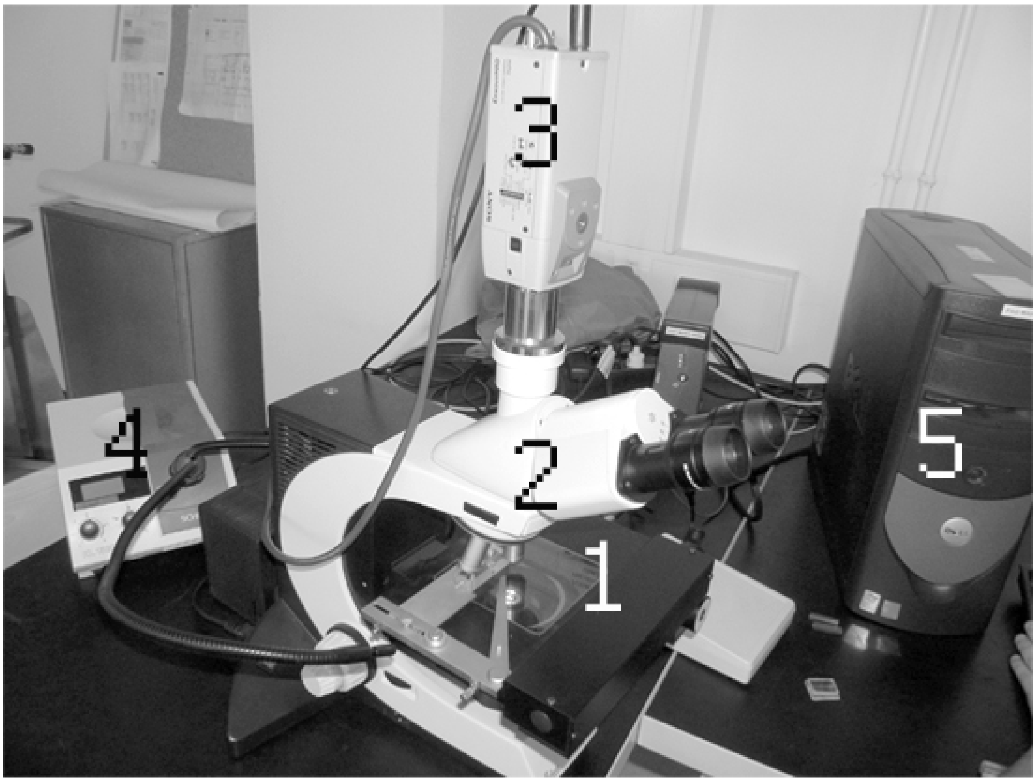

Fig. 3 Main parts of the used measuring system

The real visage of the experimental system is pictured in Fig. 3. The base of the system for visualization of the chosen hydraulic phenomenon (in this case cavitation on the jet exit) consists of a hydraulic device, which is based on LEICA microscope platform (Fig. 3, pos. 2). A traversable table is modified for mounting of the input/output ports with a watched microchannel, including the supply and outlet of fluid (fig. 3, pos. 1). The camera can be attached to the microscope (Fig. 3, pos. 3). It is possible to attach any digital camera with a chip size 1”. Two cameras were used in the experiment described in this paper:

1. for capturing of the stationary phenomenon a color CCD camera SONY VAWE was used, which is connected to the measuring PC through an additional PCI frame grabber card.
2. For capturing of the non-stationary phenomenon a monochromatic digital, high speed camera REDLAKE Y3 with CMOS chip is connected to the system. Y3 camera has its own memory, so the videosignal is transmitted to the PC through the universal serial bus (USB) or through the GIGA Ethernet card. The measuring computer of WORKSTATION class is running under Windows OS and is equipped with a multifunctional measuring card used for measuring hydraulic parameters: pressures, flow rates and others. The maximum amount of measured parameters is 32 (Fig. 3, pos. 5). This measuring card also establishes synchronization of the captured visual and non-visual data.

Very important for the quality of pictures in visualization of cavitation phenomenon in hydraulic channels of very small scales is illumination of the examined volume. Adequate illumination is very strongly determined by used material of the microfluidic device and also by the used technology of manufacturing. There are two methods of illumination which can be used on the described device. Methods of illumination can be divided according to the physical base of illumination source or according to the intensity and the method of illumination of examined volume [5]. During experiments it is very useful to use multiple illumination methods, for example, a combination of light sources listed in the table below.

Tab. 1 Illumination of examined Channel

Illumination type	Direction of light	wavelength	usage
Continual microscopic light source	From side of channel, from top, fibre optics	Adjustable temperature and wavelength	Channels with non-transparent base
Fluorescent light (continual)	From bottom (backward projection)	White light	Channels with transparent base

The DAQ system is designed for parallel capturing of visual data and hydraulic and thermodynamic parameters of a fluctuant liquid: the pressure of the liquid on input and output collectors, temperature in input and output collectors. For measuring of pressure in selected points of the microfluidic device two types of sensors are used. For measuring of the static pressure miniature piezoresistive pressure sensors are used with a silicon membrane manufactured by the MEMS technology [2]. For measuring non-stationary pressure pulsations a piezoelectric pressure sensor is used with a rustless isolation membrane. The sensor is manufactured with integrated measuring electronics (the measuring amplifier is powered by the power circuit, the measured signal is superposed on the supply voltage, so called ICP technology). Signals are measured by a universal measuring card with sequential A/D conversion with the maximum sample rate 1.2MHz. For the experiment control, recording and analysis of measured data a measuring software is used, created in developing environment LabView from National Instruments company. In the measuring setup any desired parameter can be set by the block oriented programming environment.

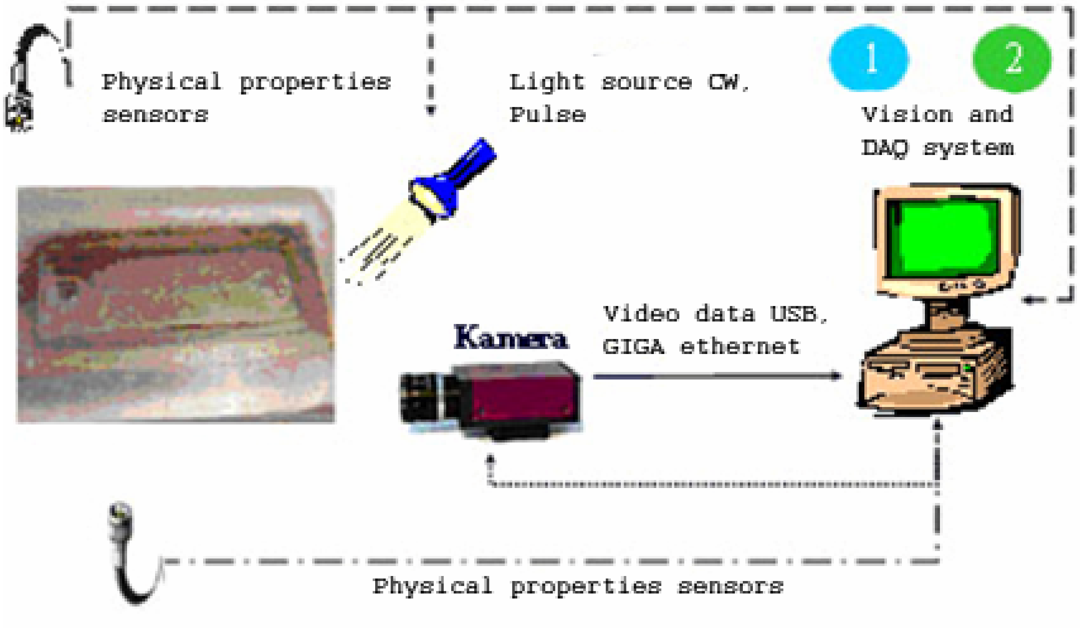

Fig. 4 DAQ and Control modul concept

For measured data analysis, synchronization between capturing visual and measured data is critical. There were two methods tested during the experiment:

- synchronization by the powerful DAQ measuring card. Through the output data line the synchronization impulse is connected to the driving collector of the camera (only digital camera). The synchronization pulse is then generated by the run of measuring software (Fig. 4).
- The pulse is generated by the digital camera (camera is set as a master), measuring card and DAQ software are set as slaves.

Experimental data recorded by one of the used methods can be presented together using the proper software, even when the character of data is different. It is important to note that during the experiment a large volume of data is recorded, especially video data. The file with recorded video sequence of length 2,5 seconds has 4GB of data (Fig. 5). Further manipulation with data of size in tens of GB requires a fast hardware and effective algorithms.

3 REALIZATION AND RESULTS OF THE EXPERIMENT

The experiment is focused on description of the used channel by basic hydraulic parameters. In addition to video capturing of the orifice area, the pressure in the inlet port of the channel was measured (a piezoresistive sensor of absolute pressure, 0-6 Bar, 0-10 Volt, manufacturer BD Sensors). The pressure in the outlet port is assumed to be atmospheric one. Because of a very low flow rate in the channel, the absolute method of measuring was used: weighting of the overflowed fluid in a specified time. Measured regimes are defined by parameters in Tab. 2. In each measured regime a video sequence of cavitation cloud behind the orifice at specified conditions was also captured. Pictures were digitally processed for better identification of cavitation structures.

Tab. 2 Measured values

p_{abs}[bar]	Q[g/min]	Picture number
3,869	67	5a
4,075	72,5	5b
4,548	76	5c
5,268	83	5d
5,848	91,5	5e

p_{abs} – absolute pressure in the microchannel input port [bar],

Q – mass flow rate [g/min],

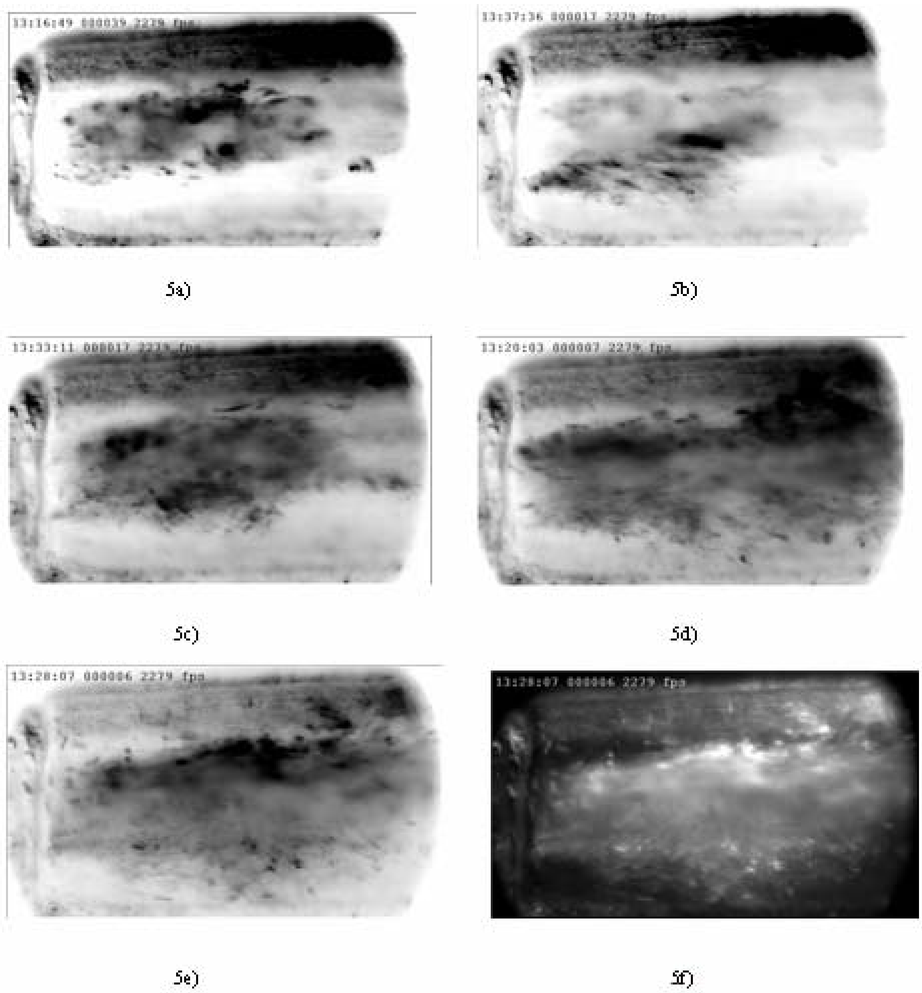

Fig. 5 Pictures captured by a high speed camera 5f) unchanged record, 5a) to 5e) Pictures after digital processing

4 CONCLUSIONS

The use of a high speed camera in combination with microscope and adequate illumination is very helpful in research of fluid flow in channels of all sizes. In figures 3a,b,c,d,e can be seen that even in the small space inside a microchannel, where a simple flow is assumed, a very complicated flow with number of vortexes can develop as a result of high speeds. The video sequence clearly shows that the cavitation cloud is of a very dynamic structure, pulsing and changing its shape and size in frequency higher than 2KHz. The video frequency in this experiment was 2279 fps. Even this high frequency cannot capture continual changes of the cavitation cloud. The video then can show only a series of isolated states, but not transitions between these particular states. Even at the frequency over 5000 fps the transitions was not continuous enough. It is clear that more precise observations will require a higher frequency of capturing multiple times. This can be achieved by reducing of video resolution. Then the electronics of camera will be capable of processing more pictures at the same data rate. For this purpose, the microscope optics must be adapted to provide less zoom. Then, the whole cavitation cloud will be contained in the frame/window with reduced resolution.

The frequency of capturing is only one of influences which determines the quality of the video. Time of exposition is also very important factor which has a very strong influence on sharpness of the pictures. To “freeze” the motion, this time must be set to value less than 10µs for conditions of our experiment. For exposition short like this, a very intensive illumination is necessary. Illumination is reached by laboratory light source with fibre optics. Through these fibres the light is conducted to the area of the cavitation cloud. It can be testified that the problem of illumination is handled on a very good level and the system of illumination does not need to be changed in the near future.

Processing of captured video data or static pictures can be very helpful for research. It is shown in fig. 3e and 3f. Both are created from one picture. But in fig. 3e the picture is inverted into negative image and its histogram is little bit manipulated. Even this simple change showed the structure on the cavitation cloud which was in original picture barely visible. Of course, there is a lot of different ways to process the image and all of them are useful in different situation. Very helpful is using of correlation functions to visualize the velocity field of the flow in the plane or in the whole volume. But in microchannels only the flow in the plane can be visualized.

At the end, I want to note that the mentioned measurements were used primary for checking of the experimental system and for acquiring some knowledge which can be used for later experiments. This data can also help to orient direction of our further research. It is necessary to mention that it is important to tune both the DAQ and visualization part of system and also hydraulic circuit used as the flow source for microfluidic experiments. In this time the manufactured source of pressurized liquid and technology for creating pressure take off directly from the cavitation cloud area. Measuring secondary data as the acoustic or ultrasound emission is strongly considered. Parallelly with above mentioned activities, the technology for manufacturing microchannels of better quality is being developed.

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