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USE OF OPTOELECTRONIC SYSTEM FOR THE FREQUENCY ANALYSIS OF CAVITATING FLOW

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Abstract: *Cavitation can be observed in many hydraulic systems and its effects can do great harm. Basic problem with cavitation is its observation. This article continues the topic of optoelectronic system registering the shape of cavitation cloud. The aim of this paper is to analyse the possibility of broadening the use of that system, i.e., using it for the purpose of the frequency analysis of cavitating flow. The system assumes that cavitation leads to diffusion of lasers light on the vapor bubbles. Signals obtained from photodetectors is subjected to frequency analysis. Obtained results are promising - in our opinion, frequency analysis of cavitation flow can be treated as interesting source of additional information on parameters of cavitation.*

Key words: *cavitation, cavitating flow, frequency analysis, optoelectronic system.*

1. INTRODUCTION

One of the most interesting topics in the area of fluid dynamics is cavitation. The phenomenon itself consists in a formation of vapor bubbles (cavities) in a fluid, under the influence of pressure drop below the saturated liquid pressure [1-3].

Cavitation can be observed in many different hydraulic systems and, generally, it plays a negative role in the hydraulic machineries, as in many kinds of devices, systems, and constructions, like propellers, pumps, control valves, spillways or engines, cavitation causes noise, vibrations, damage, as well as a loss of efficiency [4-6].

One of the problems appearing when dealing with research on cavitation is observation of the phenomenon itself, not only its effects. There are many systems provided for that purpose, their review can be found e.g. in [7]. The most common method is high-speed photography [8-10]. Other methods proposed in the literature on the subject include i.a. digital holography [11], Particle Image Velocimetry (PIV) [12], X-ray imaging [13] and laser Doppler anemometry [14].

Laboratory stand construction, equipment availability as well as examined machinery, determine the choice of the method that will be the most suitable for the specified problem. Other important aspects are financial abilities, as well as measurement accuracy and usefulness of the obtained data [7, 15]. In many cases, the use of the sophisticated and expensive methods is not always reasonable. That was our motivation to propose the method allowing research on cavitating flow with the use of simple methods, both financially and computationally undemanding.

The first paper in the series presented the optoelectronic system registering the shape of cavitation cloud [15]. The second article presented the validation of results of numerical simulations of cavitating flow in a convergent-divergent nozzle with the use of the proposed system [16]. The results of the experiments shown in these works proved that the proposed optoelectronic system could be regarded as an inexpensive alternative to traditional methods of cavitation observation.

The aim of this paper is to analyse the possibility of broadening the use of that system, i.e., using it for the purpose of the frequency analysis of cavitating flow.

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2. MATERIALS AND METHODS

The basic idea of the measurements bases on the assumption that cavitation leads to diffusion of lasers light on the vapor bubbles; diffused light can be then measured with the use of photodetectors. The construction of used system bases on lasers (Huey Jann Electronic HLDPM12-655-5) and photoresistors (GL5616D 10k/1M), playing the role of photodetectors. These are placed in four rows along the length of the flow channel/cavitation chamber (i.e., Plexiglas pipe with the internal diameter of 50 [mm]) - symmetrically in pairs. To obtain information on the cavitation character, signal from each photoresistor was being registered using digital oscilloscope (EZ Digital DS1080C). The idea of the measurements is shown in Fig. 1.

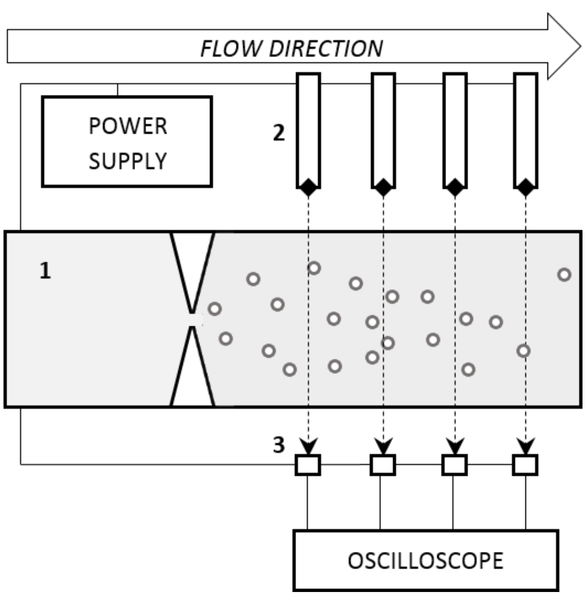

Fig. 1. Scheme of the measurements:
1 – cavitation chamber, 2 – lasers, 3 – photoresistors.

Used laboratory stand is shown in Fig. 2. Its detailed description can be found in [17], although in the context of this study, key information are as follows:

- the cavitation inducer can be a replaceable converging-diverging nozzle,
- there is a possibility of controllable change in flow velocity.

Fig. 2. Laboratory stand with cavitation chamber shown in enlargement [16].

The cavitation chamber with mounted optoelectronic devices (i.e., lasers and photoresistors) is shown in Fig. 3.

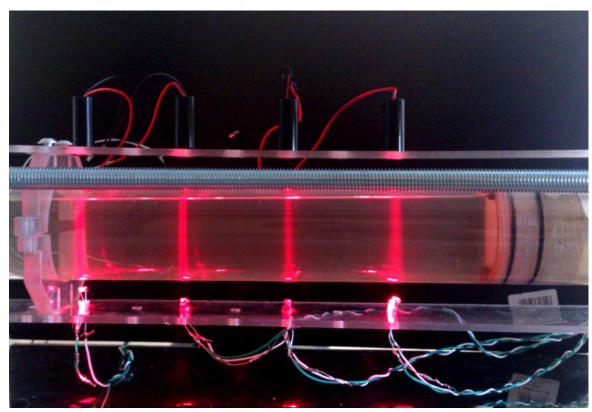

Fig. 3. The cavitation chamber with mounted lasers and photoresistors.

The experiment was performed for flow velocity equal to 0.3 [$m \cdot s^{-1}$] and with the use of converging-diverging nozzle with the following dimensions:

- angle of converging section: 45°,
- angles of diverging section: 45°,
- throat diameter: 3 [mm],
- throat length: 6 [mm].

The scheme and dimensions of the nozzle used in the experiment is shown in Figure 4.

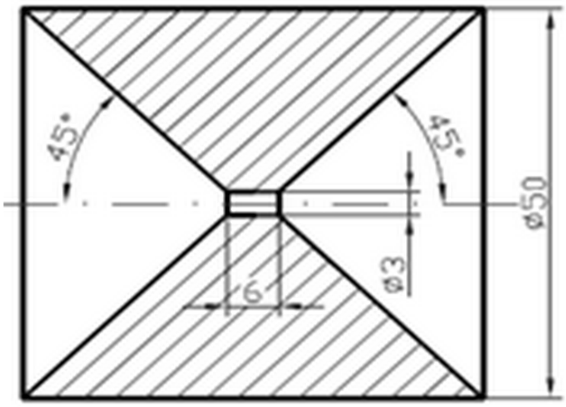

Fig. 4. Converging-diverging nozzle used in the experiment [16].

The measurement procedure was as follows:

- the cavitation chamber was filled with water;
- the whole system was switched on and calibrated - this step included inter alia adjustment of pairs of lasers and photoresistors;
- the water flow was forced and, after stabilization of flow velocity, voltage signals for all photoresistors were registered and their frequency analysis using Fast Fourier Transform (FFT) was performed.

3. RESULTS

The results of the described experiment, i.e., signals obtained from each photoresistor in the frequency domain, are presented in Fig. 5 a, b, c and d (numbering of photodetectors increases with distance from inducer, i.e., sensor number 1 is the one located next to the nozzle, while the sensor number 4 is the most distant).

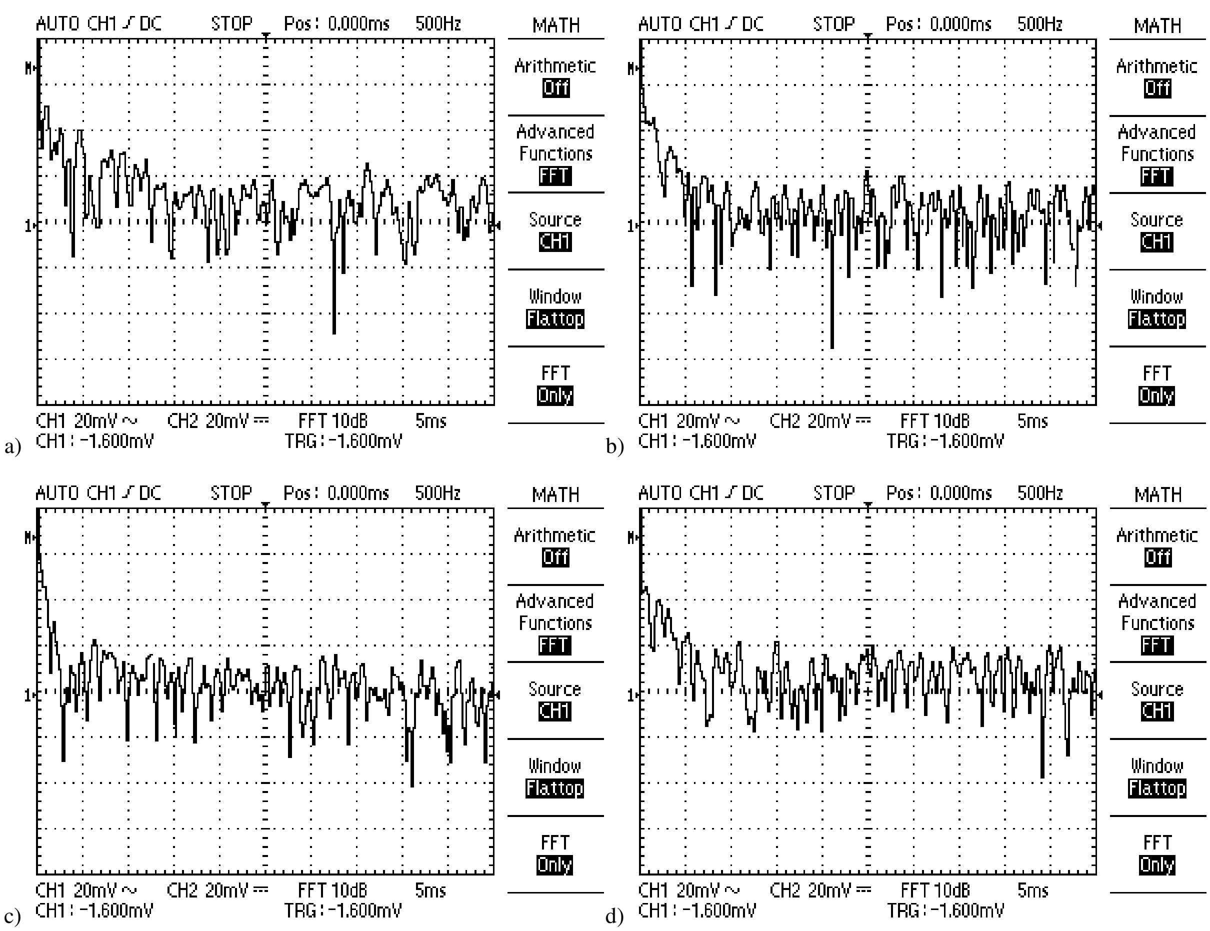

Fig. 5. The frequency spectrum obtained for the first (a), second (b), third (c) and fourth (d) photoresistor, counting from the nozzle.

FFT analysis cannot be properly analysed in a context of its usefulness without comparison with cavitation cloud observed as it is. That is why Fig. 6 shows exemplary photograph of cavitating flow captured with a high-speed camera (a), and images being the result of image processing of the whole series of high-speed photography images, i.e., so called variability maps (methods of obtaining such maps are described in detail in [9]) – Fig. 5 b and c. It should be noted that images shown in Fig. 6 were obtained with the same experiment conditions as those shown in Fig. 5.

It should be noted that although basic comparison of high-speed photographs with FFT images is difficult, as these photographs are quite a little contrast, variability maps give us useful information on the intensity of cavitation along the length of the chamber, and in a consequence - a possibility of reference to information about the position of the photoresistors.

a)

b)

c)

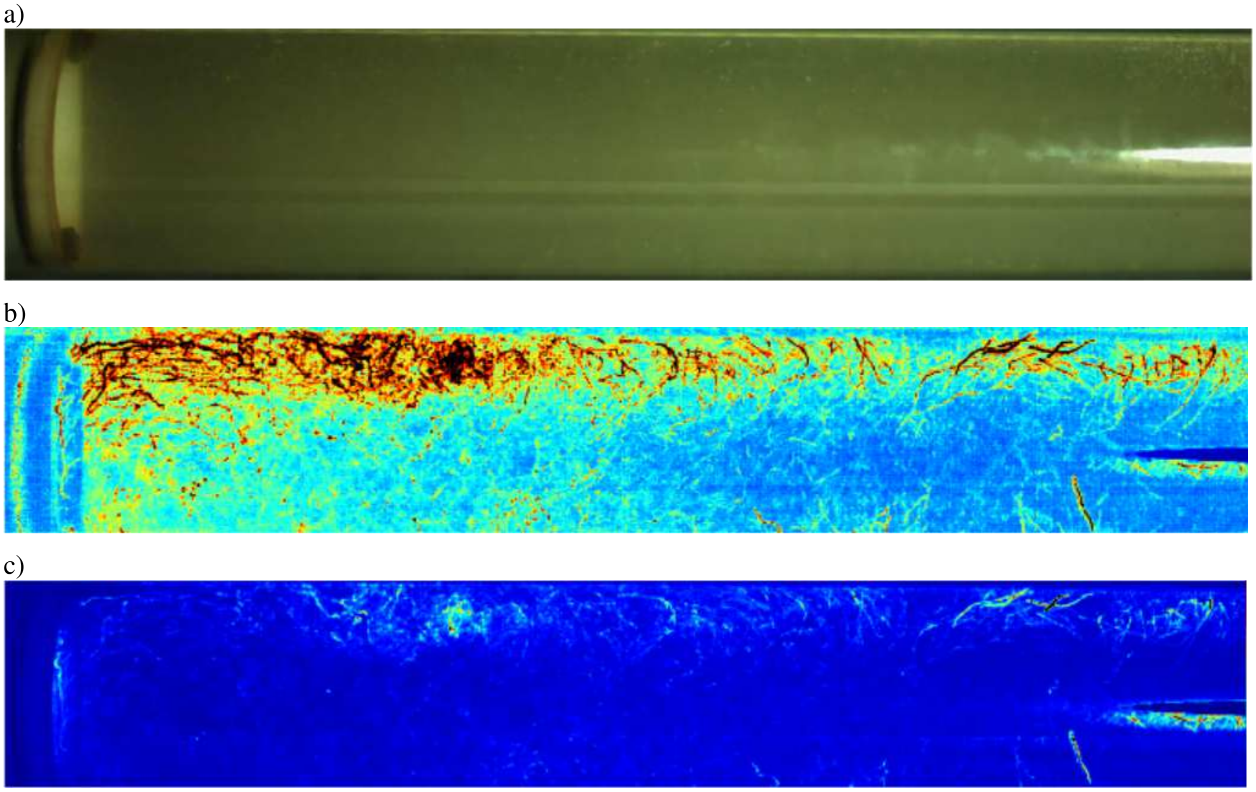

Fig. 6. Exemplary photograph of cavitating flow captured with a high-speed camera (with lasers turned off), as well as two variability maps (b and c) obtained based on image processing of the whole series of those images [9].

4. DISCUSSION

The obtained frequency spectra are similar to each other, what is rather surprising, as the direct observation of the cavitation cloud, as well as variability maps obtained based on the analysis of the same flow (Fig. 6 b and c), suggested that they would differ more. It can lead to the conclusion that the FFT analysis of the signals registered using designed optoelectronic system is not as promising as basic analysis of these signals, which was proven to be quite useful in [9], [15] and [16].

However, a more detailed analysis of the obtained spectra leads us to the following observations:

- spectrum obtained from the first sensor (shown in Fig. 5 a) has the flattest shape, what can be explained by the fact that cavitation near the nozzle is unstable – Fig. 6 b and c confirms that observation;
- spectra obtained from the second (Fig. 5 b) and the third (Fig. 5 c) sensors are very similar, what is consistent with the results obtained in [15], where the attenuation rate in the middle of cavitation cloud is almost constant – Fig. 6

(especially Fig. 6 b) also confirms that observation;
• spectrum obtained from the fourth sensor (Fig. 5 d) shows the decrease of signal in lower frequencies – that is also consistent with the data from [15], as this sensor is located at the end of the cavitation cloud, where attenuation rate noticeably decreases – it can also be noticed in Fig. 6 b and c.

5. CONCLUSIONS

The main conclusion that can be drawn based on our study is as follows – although, as stated above, frequency analysis of cavitating flow is not as promising as straightforward analysis of these signals, in our opinion this approach should not be neglected, as the further research on it may reveal the potential of this method. This is indicated by the fact that other publications considering the frequency analysis of the cavitation phenomenon, albeit based on different signals, gave promising results [18, 19].

As this is the last of the series of three papers, let us draw some conclusions based on all three papers:
• the new system, based on optoelectronic devices, allowing cavitation diagnostics, was designed, constructed and tested;
• proposed system is simple in implementation and financially undemanding thanks to the simple principle of operation;
• proposed approach to cavitation research appears to be useful especially for the fast recognition of appearing problems, in cases when use of more sophisticated and expensive equipment is not reasonable;
• the new method should be further investigated, both in the context of comparison to other methods of cavitation observation and improving the quality/accuracy of the results achieved with the use of it.

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Utilizarea sistemului optoelectronic pentru analiza de frecvență a fluxului cavitativ

Rezumat: Cavitația poate fi observată în multe sisteme hidraulice, iar efectele sale pot dăuna foarte mult. Problema de bază a cavitației este observarea acesteia. Acest articol continuă subiectul sistemului optoelectronic care înregistrează forma norului de cavitație. Scopul acestei lucrări este de a analiza posibilitatea de a lărgi utilizarea sistemului respectiv, adică de a-l utiliza în scopul analizei de frecvență a fluxului cavitativ. Sistemul presupune că cavitația duce la difuzia luminii laserelor pe bulele de vapori. Semnalele obținute din fotodetectori sunt supuse analizei de frecvență. Rezultatele obținute sunt promițătoare - în opinia noastră, analiza frecvenței fluxului de cavitație poate fi tratată ca o sursă interesantă de informații suplimentare despre parametrii cavitației.

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