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Prospects and tasks of sound vision application for diagnostics and visualization of cavitation and turbulent flows in medium and large diameter fittings

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Abstract. The possibility of using sound vision to solve the problems of visualization and diagnostics of caviation and turbulent flows arising during the operation of pipeline valves is considered. The available methods of realization of sound vision are analyzed. A block diagram with the reconstruction of a holographic image is proposed. The diagram could visualize the picture of the cavitation flow. It is shown that it is most promising to develop such circuit and technical solutions that could form a complete picture of the flow in dynamics with the ability to digitize it for further analysis.

1 Introduction

Cavitation and cavitation destruction are the most dangerous phenomena that occurs during the operation of pipeline fittings. To study and prevent it, experts have proposed many methods, from analyzing critical threshold values for the onset of cavitation noise to studying optical phenomena in transparent pipes [1-22]. However, none of the methods makes it possible to completely visualize the picture of the cavitation region, which can be very different, and the emerging regions can be variants from the bubble region to developed stationary areas of cavitation, Figure 1.

At the same time, thanks to the development of digital methods of signal processing and sound measurement, new approaches to solving this problem can be proposed. One of the promising ways to display the picture of turbulent and cavitation flow can be considered sound vision and approaches to creating holographic and 3D images, implemented by modern means of processing sound signals with their subsequent visualization. Unfortunately, these methods are not yet used to study this type of cavitation-hazardous equipment such as pipeline fittings.

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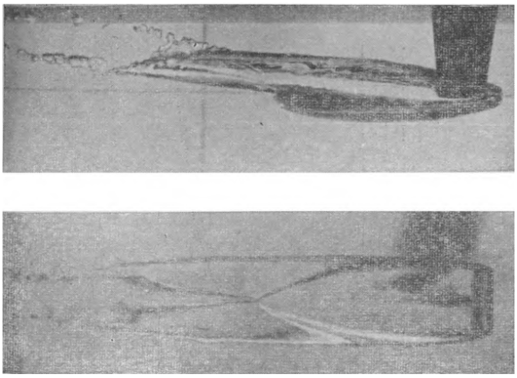
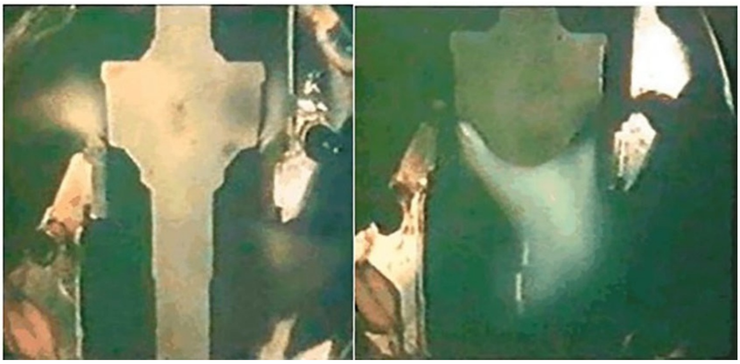


Fig. 1. An example of a stationary cavitation area arising behind the working body [4].

This task is especially serious for high-pressure control valves and valves of medium and large diameters, most often used for large-scale industries (pulp and paper industry, oil refining, etc.), industrial and thermal power engineering, Figure 2.



a b

Fig. 2. Valve seat outlet with wet steam with cavitation; Water 20°C, $p_1 = 9$ bar, $p_2 = 1$ bar.
a) “Normal Open” (FTO); b) "Normal closed" (FTC).

2 Methodology

Sound imaging tools are designed to obtain a visual image of various objects through the use and analysis of sound waves. The basis of sound vision equipment is the acoustic image converter (AIC).

To obtain an image close to optical, the observed changes in the flow pattern of the working medium are irradiated with acoustic waves. The waves, reflected from the phase interface, fall on the PAI target, where an acoustic pressure distribution in the reflected signal is formed, close to the pressure distribution at the phase interface. At the outputs of individual cells of the PAI target, potentials will be distributed accordingly.

In accordance with this, PAIs, which can be used for hydroacoustic measurements in pipeline fittings, differ significantly from similar devices used in other areas of ultrasonic technology, because must have high sensitivity and resolution and maintain their characteristics and parameters under conditions of high pressure and significant noise interference and vibration. It is especially important to note the requirements for the operation of PAI in conditions of cramped channels of complex cross-section, characteristic of the flow sections of pipeline fittings.

Taking into account the need to obtain the required depth and sharpness and resolution and to prevent specular reflection of rays from phase interfaces, certain frequencies are used in sound vision systems. According to some estimates, it is most promising to use frequencies of the order of 1-3 MHz. In this case, despite the strong spatial attenuation of the signal (for example, for uncontaminated Newtonian liquids (water with minor soluble impurities, for which the attenuation coefficient can be 10 dB/m), an image of the object can be obtained.

To obtain an image, acoustic waves reflected from an object can be focused using a converging lens onto the image plane. In other cases, the image may be obtained using one or more highly directional beams of a receiving antenna scanning the surface of an object. The image is formed sequentially and element by element in the time required for the beam to survey the entire surface of the observed object. For this reason, when observing an object moving relative to the PAI, due to a change in distance during the acquisition of a complete image, the beam may become defocus and the image quality will deteriorate. To avoid this, the change in the distance between the object and the PAI during image formation should not exceed 10-15%, which corresponds to a certain relative movement speed of no more than 10 m/s, characteristic of flow speeds in industrial pipelines.

The modern approach also involves the possibility of creating holographic or 3D images to clarify the characteristics of the phenomenon (object) under study. Hydroacoustic holography uses the interference of vibrations to obtain a visual image of the emerging phase region in the phenomenon (based on the principle of wave reflection from the phase interface). The observed object is irradiated with acoustic vibrations of a certain frequency and the waves reflected from it arrive at the surface of the PAI. At the same time, vibrations called a reference wave are applied to this surface. As a result of the resulting interference of the received reflected and reference oscillations, electrical oscillations are formed at the outputs of the PAI elements, carrying information about the distribution of not only the amplitudes, but also the phases of the waves reflected from the surface of the observed object, which makes it possible to recreate its three-dimensional image.

If you visualize the received signals and record the resulting picture, for example, on a display, a hologram is formed - a diffraction grating consisting of alternating dark and light stripes. By illuminating the hologram with coherent oscillations, it is possible to restore the image recorded in the hologram, i.e. obtain a three-dimensional image of an object.

When reconstructing an image, the reference wavelength λ_2 may differ from the wavelength λ_1 used to form the hologram. Moreover, if the hologram was obtained for an object located at a distance r_1 from the PAI surface, the reconstructed image will be visible to an observer at a distance r_2 from the hologram according to the relation

$$r_2 = r_1 \lambda_1 / \lambda_2 \tag{1}$$

Thus, an image obtained in a liquid medium using acoustic waves can be restored using light waves in the form of a regular visual image of the area (object) being studied.

When choosing the operating frequency of a holographic system, the influence of the relative movement of the object and PAI during the formation of the hologram on the quality of the latter is taken into account. If during the formation of the hologram the phase of the signal reflected from the object changes by λ/4 or more, the diffraction rings will be blurred, and the reconstructed image will be blurred or will not be obtained at all. So, for example, with a relative speed of movement of the medium of 5 m/s and the formation of a hologram in 150 μs, the full period of oscillations should last at least 600 μs and, therefore, the frequency should not exceed 250 kHz.

The advantages of holography over sound vision are higher information content and image quality; large field of view and depth of field; better resolution. However, these advantages are achieved by a more complex signal processing and image restoration system.

3 Results

A generalized block diagram of a hydroacoustic holographic system, which can be used as a basic option for calculating cavitation areas during valve operation, is shown in Figure 3.

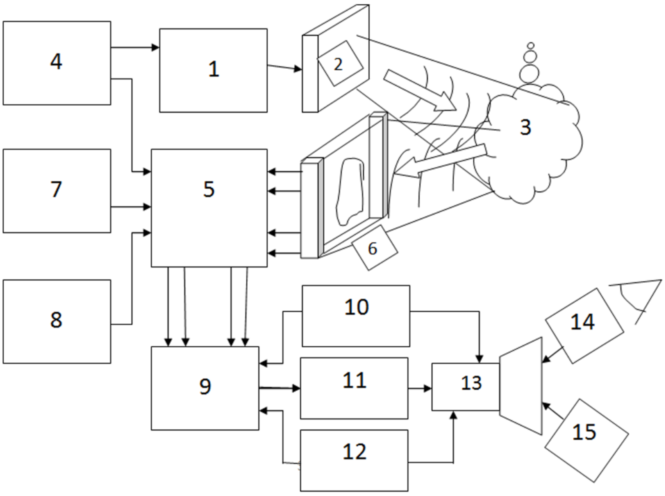


Fig. 3. Generalized block diagram of a hydroacoustic holographic system. 1 - generator; 2 - radiating antenna; 3 - observed object; 4 - synchronization block; 5 - multi-channel signal processing unit; 6 - receiving antenna; 7 - reference voltage generator; 8 - range gating block; 9 - channel switch; 10, 12 - scanners; 11 - video amplifier; 13 - display; 14 - optical system; 15 - laser.

The system works as follows. The observed area is irradiated by vibrations with a frequency of 250 kHz and the acoustic waves reflected from it arrive at a matrix-type receiving antenna, the dimensions and number of elements of which are determined taking into account the required field of view angle and angular resolution. Thus, with the adopted operating frequency, field of view angle of 400 and angular resolution of 0.40, the antenna aperture should be about 1 m, the number of elements in the PAI matrix should be 100x100. In this case, up to 50 interference fringes can be recorded on the hologram.

Electrical signals taken from the antenna elements are pre-amplified, and after that electrical reference vibrations are introduced into them. Interference occurs directly in the receiving path, and not on the surface of the antenna, which simplifies the design of the equipment. Phase-sensitive detectors distinguish phase differences between mixed oscillations and produce voltages at their outputs proportional to these differences. The range gating circuit allows signals coming from only the target object to pass through. Switching of the channels of the receiving path occurs synchronously with the raster scanning of the beam of the reproducing tube along the coordinate axes x, y.

A hologram from the screen is used to directly restore an image or take a snapshot of it for later restoration. In direct reduction, the indicator can be a special cathode ray tube with a target made of a material in which local changes in the refractive index occur under the influence of electrons incident on the target. The distribution of refractive indices on the target surface after a full cycle of polling the channels of the receiving path displays a hologram of the observed object. When a target is irradiated by a source of reference vibrations (laser), its rays will be refracted and reflected, modulating in phase in accordance with the law inherent in the hologram. The image of the object is observed in an optical device. To obtain images of large areas with minimal time, a holographic system with a large aperture can be used.

Modern hydroacoustic technology can be used to solve problems related to the determination of cavitation areas and its possible development above critical values. Can be defined:

- quantitative characteristics and assessment of the cavitation area, the concentration of the cavitation "cloud" and the distribution of changes in the cavitation pattern of the flow of the working medium;
- coordinates and elements of motion of the cavitation area;
- the position of the working body of the valve relative to the cavitation area and its condition were monitored;
- The behavior of the cavitation area was studied, its migration was monitored, and information was obtained about the processes in this area.

Quantitative assessment tools are an automated system for obtaining data on the presence of a cavitation area and statistical processing of information. The system may include locators, echo integrators, a computer and output devices. Signals coming from the locators are processed in an echo integrator, the output of which generates a signal proportional to the volume of the cavitation region. Next, it enters a computer that provides cavitation classification. With a significant development of the cavitation area, when the echo signal is created simultaneously by many areas of cavitation, the signal at the integrator output will be proportional to the volume of such an area. Such output signals from the echo integrator will need to be processed on a computer, after which the final result, containing information about the features of the cavitation areas, can be output for further analysis or data presentation.

Means for detecting cavitation areas are based on the principles of sonar and noise direction finding. To better ensure obtaining a cavitation picture of the flow of the working medium through the fittings, it is advisable to install combined locators with viewing in the vertical and horizontal planes. For these purposes, locators with independent horizontal and vertical viewing paths operating at different frequencies can be used.

Locators can also be used to monitor the position and condition of the valve working body. The operation of these means can also be based on the principles of hydroacoustics. Their condition and movement can be compared with the development features of cavitation areas, while their condition and operating parameters are monitored. This is accomplished by continuous comparison of current information about the movement of the cavitation area and the position of the working body relative to this area.

For these purposes, in addition to the cavitation area locators, a separate probe may be provided, reflecting the echo sounder measurement of the stroke of the valve working body. Such a probe can also be connected to a locator. Requires installation of an additional acoustic antenna. The generation of probing pulses, force processing and display of the received echo signals from the working element are carried out by the corresponding locator paths.

Reinforced probes make it possible to study additional parameters related to the characteristics of the flow of the medium, for example, temperature and other quantities. Currently, there is a tendency to increase the number of measured parameters and use computers to process the received information.

New means for monitoring the behavior of the resulting turbulence inside the valve channels can be hydroacoustic tags, in particular, during the electrolysis of small quantities of the medium with the formation of bubble tags or special elements in the working body, allowing long-term monitoring of changes in the state of cavitation areas. The operation of such tags is based on the principles of stronger reflection of locator signals from the tag, which makes it possible to better determine incipient turbulence and cavitation in the working environment. In this case, a significant improvement in the quality of tracking the first stages of turbulence growth can be achieved.

4 Conclusion

The problems of improving the quality of cavitation recognition, diagnosing and visualizing the cavitation pattern in fittings can be solved using technical means of sound imaging and the development of specialized solutions suitable for use in conditions of both stationary and pulsating turbulence, and cavitation, which usually occurs in the operation of high-pressure fittings. pressure and fittings of large diameters. The main hydroacoustic means for achieving these goals can be sonar and noise direction finding devices, modified for the conditions of use in the channels of pipeline fittings. Further tasks and prospects for the development of sound imaging in pipeline fittings will be associated with a better understanding of the characteristics of cavitation and the adaptation of the used sonar devices, as well as recognition, display and visualization tools for the purpose of identifying harmful turbulent and cavitation phenomena and creating a three-dimensional picture of these phenomena that can be easily analyzed

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