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Abstract

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PULSE PRESSURES IN THE ZONE OF A SECONDARY EROSION FOCUS

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Cavitation erosion due to cavitation behind a model of a circular profile, on walls in contact with the ends of the model, is arranged in characteristic foci of greatest intensity. Near the model there are primary erosion foci, which at the stage $\lambda = l/d = 3$ (l is the length of the cavitation zone, measured from the model axis; d is the model diameter) have the form of tongue-shaped areas of destruction. At distances $\lambda = 4$ and $\lambda = 6$ there are secondary and tertiary foci in the form of local spots—clusters of pits over a comparatively small area (Fig. 1). A comparison of the location of the secondary erosion foci with the location and shape of the cavities of the cavitation zone can be made only from data of high-speed and ultra-high-speed photography of the cavitation zone, since the process of cavity development in these regions takes place in small volumes and at high frequency. The question arises as to the origin of the secondary erosion foci. According to existing hypotheses on the mechanism of erosion, the cause of destruction of solid bodies under cavitation is high pressure pulses on small areas, owing to the collapse of the bubbles of which periodic cavitation cavities consist ([1,2]). There are known works in which the kinematics of collapse and pressure pulses were investigated mainly for isolated bubbles produced by the spark method ([3,4]) and, more rarely, by flow cavitation ([5]). Pressure pulses were not measured directly, but indirectly, i.e., they were calculated from the results of measurements at some distance from the cavitation zone and the bubbles. According to such recalculations, the magnitude of the pulse pressures proved to be considerably smaller than the theoretical values and could not produce destructive stresses in the surface layers of materials under a single application of force. There is only one work ([5]) in which an attempt was made to measure pressure pulses directly in the zone of the primary erosion focus, and repeated investigations ([6]).

Table 1

Index in Fig. 3	Marking frequency, kHz	v_0, m/sec	f, Hz	S
	10	12	840	0.16

Fig. 1. Photograph of the cavitation zone (a) and erosion zone (b)

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Index in Fig. 3	Marking frequency, kHz	v_0, m/sec	f, Hz	S
	10	17	1250	0.17
	10	20	1540	0.17

The data presented in the present article were obtained as a result of the use of ordinary piezoelectric pickups (Fig. 2), positioned in the zone of the secondary erosion focus flush with the wall of the working chamber. In the present case the aim was not to make a pickup with the smallest possible dimension of the pressure-sensing element, since, according to investigations of erosion pits at the initial stage of destruction with the aid of an electron microscope (^{7}), the largest pit dimensions do not exceed $0.1\,\mu$ across. In our work the problem was posed of determining only the frequency of the pressure pulses. The experiments were carried out for three variants of the flow velocity, measured on the chamber axis (Table 1), but at one and the same cavitation stage $\lambda = 3$, since at the given λ the pickup was located in the zone of the secondary focus

erosion. The experiments were carried out in two variants of working chambers with cross sections of 6×25 mm^2 and 24×100 mm^2, with models $d = 6$ and $d = 24$ mm.

After amplification, the pressure pulses were recorded with a cathode-ray two-beam oscillograph, and spectrograms were taken on analyzers with frequency bands of 40 Hz–20 kHz and 7–300 kHz. On the oscillograms (Fig. 3) the pulses are arranged in groups with a period equal to half the Strouhal period

Fig. 1. Photograph of the cavitation zone (a) and erosion zone (b)

i.e., with a frequency obeying the Strouhal law for vortices in the absence of cavitation. This frequency is calculated by the formula $f = 2Skv_0/d$, where $S = 0.16$–0.17 according to our earlier studies (^{1}), and $k = 1.3$ takes into account the influence of the flow boundaries. The grouping of pulses is analogous to the grouping of ultrasonic-cavitation pulses investigated by Ingar and Richardson (^{8}). The halved period of the pulse groups shows that cavities detached from the zone of the primary erosion focus and moving with the flow are, at a certain instant, overtaken by a pressure wave formed by the disturbance of cavities on the other side of the model. This disturbance, as shown by studies using high-speed cinematography (^{9}), is produced by a sudden increase in the volume of the cavity, and not by its destruction and separation, as might have been expected.

Table 2

Fig. 2. Diagram of the pressure-sensor arrangement: 1 —mounting insert made of Plexiglas, 2 —barium titanate disk, 3 —cylinder, 4 —copper electrodes

Figure 2: Fig. 2. Diagram of the pressure-sensor arrangement: 1 —mounting insert made of Plexiglas, 2 —barium titanate disk, 3 —cylinder, 4 —copper electrodes

Index in Fig. 4	Working-chamber cross section, mm^2	Spectrometer range, kHz	f, kHz, $v_0 =$ 12 m/s	f, kHz, $v_0 =$ 17 m/s	f, kHz, $v_0 =$ 20 m/s
A	6×24	0.04-20	0.7-1.4	1.4-2.3	1.4-2.8
B	6×24	7-300	36.5	82	82
V	24×100	7-300	41	41	41

On oscillograms of individual pulses taken with a fast sweep (Fig. 3g), this consideration is confirmed by the steep front of the pulses. The velocity of motion of the pressure wave must be of the order of the speed of sound.

On type-A spectrograms one can distinguish frequencies (here and below, frequencies of the greatest amplitude) corresponding approximately to the Strouhal frequencies measured on the oscillograms (Table 2, Fig. 4a). On type-B spectrograms with a high-frequency band, high frequencies of 82 kHz at velocities of 17-20 m/s and 36 kHz at $v_0 = 12$ m/s are distinguished. On spectrograms V, taken with a working chamber 24×

× 100 mm^2, the highest frequency is 41 kc/s and does not change with the flow velocity. The twofold ratio of the high frequencies cannot be explained by the influence of the natural oscillations of the cavity itself, if it is regarded as a closed space and Minnaert's formula (10) is used, according to which the natural frequency of oscillation of a bubble is inversely proportional to its diameter. Under such an assumption there should be a fourfold ratio of the frequencies. Nor is it explained by the influence of the natural oscillations of the liquid column in the section from the sensor axis to the end of the working chamber. The frequency ratios are identical, but the frequency of the natural oscillations of the columns is approximately 10 times smaller than those recorded. More plausible is the assumption that explains the twofold ratio of the frequencies by the influence of the sizes of the bubbles of which the cavity consists. The sizes of the bubbles forming the cavity are determined by their stability and are not connected by a proportional dependence with the sizes of the cavities. At a lower velocity and with smaller disturbances in the flow, the bubble sizes may be larger than at high velocities. In this case the frequency of the pressure pulsations may be associated with the natural frequency of pulsations of the bubbles.

Fig. 3. a, b, c —oscillograms of pressure pulsations in the zone of the secondary erosion focus (see Table 1), d —oscillogram of pressure pulsations within one of the groups of impulses (time-marker frequency 50 kc/s)

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According to Minnaert’ s simplified formula $f = 0.64/d$ kc/s (d in cm), the diameter of the bubbles in the small working chamber should be $d = 0.64/f = 0.08$, and in the large chamber $d = 0.16$ mm, which approximately corres—

corresponds to the experimental data from the study of the cavitation zone by high-speed cinematography.

Conclusions. In the zone of the secondary erosion focus there are pressure pulsations occurring at frequencies on the order of ultrasonic ones. The steepness of the pressure-pulse front, as well as their high frequency, is explained by the natural pulsations of the bubbles that make up the cavitation zone. The cause exciting the pulsations of the bubbles is the pressure wave excited by caverns growing successively near the model. The results of the investigations may serve as confirmation of the vibration theory of cavitation erosion ([11,12]).

Fig. 4. Spectrograms of pressure pulses in the zone of the secondary erosion focus (see Table 2). $v_0 = 17$ m/sec. Scale for A: 1—44 ÷ 74, 2—88 ÷ 149, 3—177 ÷ 291, 4—354 ÷ 595, 5—707 ÷ 1000 Hz, 6—1.41 ÷ 2.38, 7—2.89 ÷ 4.7, 8—5.66 ÷ 9.5, 9—11.3 ÷ 19 kHz. Scale for B, C: 1—7 ÷ 15, 2—16 ÷ 32, 3—36 ÷ 70, 4—70 ÷ 103, 5—100 ÷ 200, 6—200 ÷ 292 kHz.

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