REDUCTION OF CAVITATION ACTION ON A SURFACE BEING TREATED BY DIMINISHING THE GAP

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UDC 532.529.6:621.034.4-8

The nature of the collapse of cavitation bubbles is examined for different gaps between the specimen and the ultrasonic emitter. A method is proposed for reducing the cavitation action on the surface being treated by diminishing the gap to values on the order of the maximal diameter of the cavitation bubbles. A formula is found to compute the gap domain with lowered cavitation action. The results obtained can be utilized in the realization of ultrasonic technological processes associated with the action on cavitationally unstable materials.

The action of acoustic cavitation on solid surfaces is utilized extensively in different ultrasonic technological processes [1, 2]. However, in a number of cases ultrasonic treatment in the cavitation mode results in damage to the materials being treated or to superposition of coatings if they are not cavitationally resistant, for instance, during the ultrasonic cleansing of light contaminations from surfaces of large-scale articles, radio electronic apparatus, etc.

A less aggressive action can be assured due to the production of precavitation modes [3]. But the absence of cavitation impacts and acoustic microflows caused by collapsing and fluctuating cavitational bubbles in this case makes impossible, say, the qualitative cleansing of different slots, pores, and micrononcontinuities of the surface being treated. Other methods of preventing the destruction of an article surface by cavitation require additional apparatus, to saturate the working fluid by gases, to raise the working temperature almost to boiling (let us note that raising the working fluid temperature yields an ambiguous result: cavitation erosion can both be reduced and raised depending on specific conditions [4, 5]), and do not assure shielding of the ultrasonic emitter surface from destruction.

Due to the cavitational erosion of ultrasonic emitters and waveguides, the oscillator system is taken out of resonance, the amplitude of the emitting surface oscillations drops, and the efficiency and lifetime of the ultrasonic transducers diminish significantly. The diminution of the oscillation amplitude results in nonuniformity of the treatment, reduction of the volume and number of the cavitation domains.

We obtained an expression to determine the domain of gaps with reduced cavitation action on a surface being treated. The mechanism for its reduction in the gaps is described.

It is known [6] that the influence of cumulative fluid microjets (Fig. 1a) predominates for gaps δ between the surface being treated and the ultrasonic emitter that are so much greater than the maximum cavitation bubble diameter D_{max}. Under the condition $\delta \sim D_{max}$ [6-9] the article is treated principally by radial microjets (Fig. 1b). Such microjets directed parallel to the surface being treated exert a substantially smaller effect on it as compared with cumulative fluid microjets that make impact on the surface being treated at a velocity >100 m/sec (an order greater than the radial jet velocities). The mentioned factors result in a reduction in the cavitation action on the surface being treated as δ diminishes to the value $\sim D_{max}$. Therefore, ultrasonic treatment of cavitationally unstable materials by radial microjets of fluid substantially reduces the probability of their cavitation damage.

It is evident from the construction (Fig. 1) that $\delta = \ell_1 + \ell_2$. The solid surface exerts influence on the process of cavitation bubble collapse for distances less than $2.5D_{max}$ from

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Applied Physics Institute, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 58, No. 6, pp. 986-990, June, 1990. Original article submitted November 22, 1988.

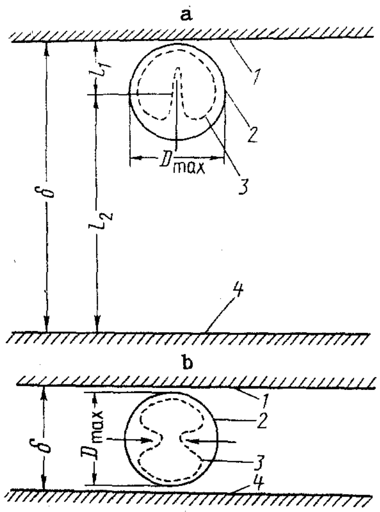

Fig. 1. Diagrams for the collapse of cavitational bubbles for different gaps δ, m, between the surface being treated and the ultrasonic emitter [a) $\delta \gg D_{max}$, b) $\delta \sim D_{max}$]; 1) surface being treated; 2) cavitation bubbles at the initial time; 3) shape of the cavitation bubble at the initial time; 3) shape of the cavitation bubble in the collapse stage; 4) ultrasonic emitter; directions of fluid microjet motions shown by arrows.

its center to this surface [10, 11]. The distance ℓ_1 at which the bubble exerts an action on the surface being treated by a cumulative fluid microjet will be within the limits

$$0{,}5D_{\max} \leqslant l_1 < 2{,}5D_{\max}. \tag{1}$$

Moreover, for a cavitation bubble to exert action on the surface being treated and not on the ultrasonic emitter surface, the condition $\ell_1 < \ell_2$ should be satisfied.

To assure ultrasonic treatment of an article by radial fluid microjets, it is necessary that the cavitation bubble experience the simultaneous action of two solid surfaces, that being treated and that emitting. And if the bubble is at a distance ℓ_1 from the surface being treated, determined by the relationship (1), then the radial microjets will be formed at distances ℓ_2 less than $2.5D_{max}$, i.e.,

$$\delta = l_1 + l_2 < [0.5D_{\max}(1-5) + 2.5D_{\max}] = (3-5)\,D_{\max}. \tag{2}$$

We take the formula [12]

$$D_{\max} = 0.8\,(1 - P_0/P_A)(P_A/\rho)^{1/2}/f \tag{3}$$

as the basis for finding D_{max}. However, in the developed cavitation mode this formula is not valid since it is already impossible to utilize the values of ρ and c for the unperturbed fluid in this case (these quantities diminish, i.e., the fluid wave drag in the cavitation mode can be reduced substantially). Moreover, this formula does not take account of the influence of the solid boundary surfaces on the process of bubble growth, etc.

In this connection, we introduce a coefficient k in (3)

$$D_{\max} = k\cdot 0.8\,(1 - P_0/P_A)(P_A/\rho)^{1/2}/f. \tag{4}$$

We determined the coefficient k experimentally by means of high speed movie photography (up to $2.5\cdot 10^6$ frames/sec) of the cavitation bubbles in the gap between the ultrasonic emitter and the specimen in water with an equilibrium gas content (a 2-4% total gas content) at an 18-20°C water temperature. The cinematography was realized on an installation assembled on the base of a high-speed photographic recorder SFR in light transmitted through a microscope [6]. For A = 5-25 μm, f = 15-45 kHz the value of the coefficient k is 0.1-0.2. Therefore, by substituting the values of ρ and c for unperturbed water and the value k = 0.1-0.2 for the coefficient, we obtain real values of D_{max}.

The spread of the coefficient (3-5) in (2) and the difference in the values of D_{max} as a function of specific conditions [the spread in the coefficient k in (4)] can result in a change in the upper bound of the minimal cavitation effect zone, i.e., the value of the gap starting with which (as the gap diminishes) the cavitation action is lowered. Consequently, to assure a stable mode of fluid radial microjet formation, we select the value three for the coefficient in (2) and 0.1 for the coefficient k in (4).

Let us convert (4) in application to cavitationally unstable materials. Since an increase in the hydrostatic pressure results in a significant rise in the cavitation action [4], the condition $P_0 \ll P_A$ will be satisfied for $P_0 \sim 1$ atm.

Then assuming $c = 1.5 \cdot 10^3$ m/sec (for water), and $P_A = 2\pi\rho c f A$, we obtain from (4) and (2)

$$\delta < \delta^* (\text{m}) = 23.3\, [A\,(\text{m})/f\,(\text{Hz})]^{1/2},$$

or in a form convenient for practical computations

$$\delta < \delta^* (\text{mm}) = 2.3\, [A\,(\mu\text{m})/10f\,(\text{kHz})]^{1/2}. \tag{5}$$

The quantity δ^* in (5) indeed determines the upper bound of the domain of gaps with reduced cavitation action. For instance, we obtain $\delta < \delta^* \simeq 0.5$ mm from (5) for $A \simeq 10^{-5}$ m, $f \simeq 2 \cdot 10^4$ Hz for water.

The data obtained agree with the experimental results [13] where in all cases a stable reduction in the cavitation action on the specimen [14-17] is observed for A = 6.5-25 μm, f = 21.7 and 41.9 kHz in the domain of the computed gaps.

It can analogously be shown that for slot gaps $<\delta^*$ the cavitation action diminishes on not only the surface being treated but also on the ultrasonic emitter.

The deductions of this paper can be utilized not only in the case when the working gap boundaries are the surface being treated and the surface of the ultrasonic emitter but also for gaps formed by two unstable surfaces being treated cavitationally (for example, when cleansing several articles simultaneously in an ultrasonic field) or by an unstable surface being treated cavitationally and the surface of the working space with fluid. As earlier, it is expedient to place the working surfaces at distances $\delta < \delta^*$, governed by (5), whose domain of application is the following: A = 5-25 μm, f = 15-45 kHz, the working fluid is water with an equilibrium gas content (total gas content is 2-4%) at an 18-20°C temperature, the solid boundary surfaces are planes, and the sounding time is 1-2 min, when performing qualitative ultrasonic treatment of articles without their cavitational damage.

Therefore, the results obtained permit determination of the domain of gaps with a stable reduction in the cavitation action on the surface being treated, that must be taken into account for optimization of ultrasonic treatment of cavitationally unstable materials.

NOTATION

δ, gap size; D_{max}, maximal diameter of a collapsing cavitation bubble; ℓ_1, ℓ_2, distances between the center of the cavitation bubble and the surface being treated and the second solid wall; P_0, hydrostatic pressure; P_A, amplitude of the ultrasonic pressure; ρ, fluid density; f, frequency of the ultrasonic oscillations; c, speed of sound in the fluid; A, amplitude of the displacement of the emitting surface; k, a coefficient; and δ^*, upper bound of the domain of gaps with reduced cavitation action.

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THERMODYNAMIC CHARACTERISTICS OF THE SUPERCONDUCTING METAL-OXIDE $Bi_2Sr_2CaCu_2O_y$ IN THE LOW TEMPERATURE DOMAIN

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UDC 537.312.62

Results are presented of an experimental investigation of the specific heat of the superconducting metal-oxide $Bi_2Sr_2CaCu_2O_y$ in the 40-230 K range on whose basis the temperature dependences of the thermodynamic functions and the Debye temperature are computed.

An experimental investigation of the specific heat of superconductors is one of the important questions of the problem of the physics of superconductivity. With the discovery of high-temperature superconductivity (HTSC) this problem became still more urgent since the nature of the phenomenon has not been revealed and much that is contradictory is present in published data on the HTSC properties, including the specific heat. There is very little

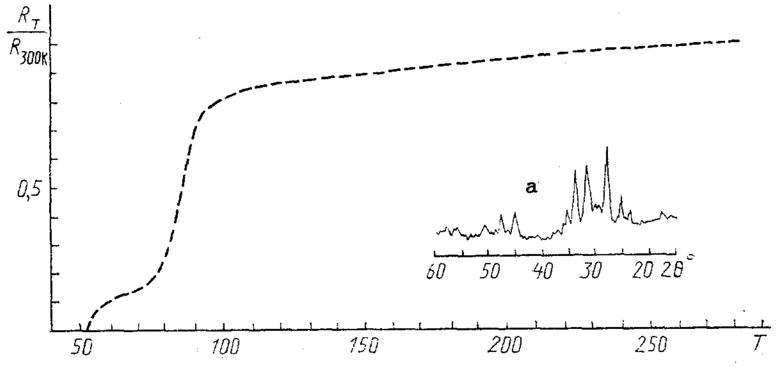

Fig. 1. Temperature dependence $R_T/R_{300\,K}$ for the superconducting metal-oxide $Bi_2Sr_2CaCu_2O_y$: a) x-ray diffraction pattern of this specimen. T, K; θ, deg.

Institute of Solid-State and Semiconductor Physics, Academy of Sciences of the Belorussian SSR, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 58, No. 6, pp. 990-994, June, 1990. Original article submitted June 30, 1989.