CLOSURE PROPERTIES OF CAVITIES FORMED BY ELECTRICAL EXPLOSIONS

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Experimental and theoretical studies (see, for example, [1-3]) show that even weak departure from a spherical shape of a vapor gas cavity (VGC) leads to asymmetric closure of the cavity due to the fact that a surface of a real VGC is not an ideal sphere, but always has deformed (convex or concave) regions. These surface defects do not influence the kinematics of the cavity when the cavity boundaries move at low velocities. However, at times close to the minimum when the velocity of motion of the boundaries attains high magnitudes (according to the assumptions of a number of authors [4], it can attain and even exceed the velocity of sound in the fluid), these nonuniformities in the surface can be reason for the appearance of jets or flows of fluid piercing the cavity. As a result of this, either the cavity separates into several parts, subsequently pulsating independently, or its shape changes considerably.

In connection with the fact that the intensity of the secondary shock wave finally depends on the shape of the bubble [5, 6], the purpose of the present work was to investigate the evolution of the shape of cavities by electrical explosions at all stages of expansion and collapse, including times close to the minimum. The latter circumstance is extremely important, for, since dynamics of the final stages of the motion of the cavity are not determined, the acoustical radiation accompanying its motion also remains indeterminate, and in the final analysis, the force characteristics of the electrical explosion also remained undetermined.

The cavities were generated by an electrical explosion in an open chamber, filled with distilled water and having on both sides illuminators for photographing the VGC in transmitted light. The distance from the axis of the discharge to the chamber walls exceeded by more than a factor of 5 the maximum VGC radius, which permitted neglecting the effect of the boundary surfaces on the development of the cavity [7]. The parameters of the discharge circuits were as follows: The charging voltage of the storage battery was $U_0 = (1\text{-}4)\cdot 10^4$ V, the capacitance was $C = (0.01\text{-}3)\cdot 10^{-6}$ F, the inductance was $L = (3.4\text{-}3.8)\cdot 10^{-6}$ H, and the magnitude of the interelectrode gap was $l = (1.2\text{-}30)\cdot 10^{-3}$ m. The VGC was photographed with the help of a high-speed SFR-2M camera in the photodetecting regimes and time frames. In order to investigate the behavior of the cavity, at the time the minimum volume was attained, the object was magnified with the help of a special attachment and a time magnifier.

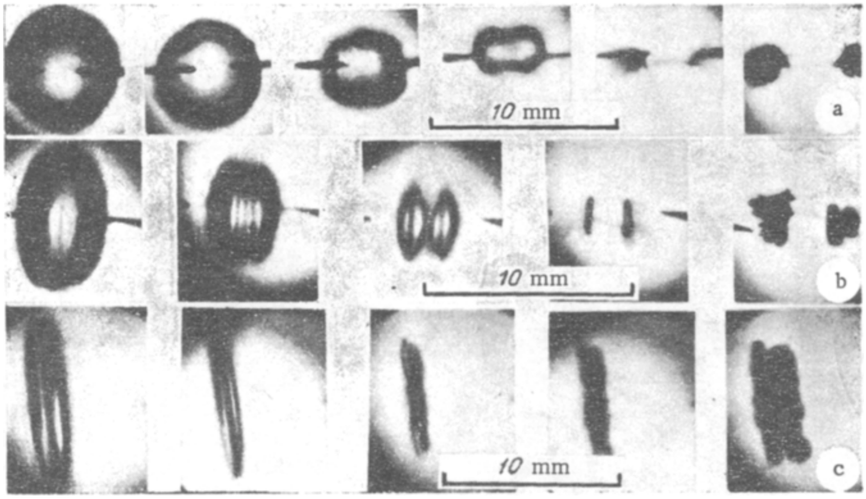

Fig. 1

Nikolaev. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 3, pp. 60-64, May-June, 1981. Original article submitted April 10, 1980.

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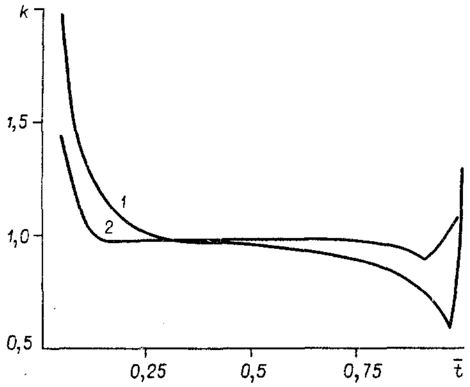

Fig. 2

The motion picture frames of the final stages of the process of closure of the electrical explosion cavities for different discharge regimes (the moving picture frames of the process of the development of cavities of different geometrical shapes are presented in [8]), as well as the time dependence of the contraction coefficient k, consisting of the ratio of the meridional diameter $d_{\parallel}$ of the VGC and the equatorial diameter $d_{\perp}$, are presented in Figs. 1 and 2, respectively. The time between frames (Fig. 1) is $8.3 \cdot 10^{-6}$ sec. Analysis of the results obtained shows that a general property of spherical cavities (necessary condition for their formation is $W_T/l \geqslant 1$ kJ·m^{-1} [8], where W_T is the electrical energy liberated in the discharge channel) is that with expansion (we are talking about the first cycle of expansion and collapse of the VGC) as the ratio W_T/l increases, the cavity at earlier stages acquires a spherical shape. Thus, for the regime $W_T/l \approx 1$ kJ·m^{-1}, the cavity acquires a spherical shape at $\bar{t} = 0.12$ (where $\bar{t} = t/T$ is a dimensionless time, T is the pulsation period of the cavity), and for $W_T/l = 0.4$ kJ·m^{-1}, at $\bar{t} = 0.25$. Having attained at the maximum an almost spherical shape (Fig. 2, curve 2), the cavity retains it up to the time $\bar{t} = 0.85$, then contracts primarily along the axis of the electrodes ($\bar{t} \approx 0.85$–0.92). This leads to the fact that in locations of greatest curvature in the surface of the VGC, a ring-shaped jet of fluid forms, separating the cavity into two parts perpendicular to the electron axis. As a result of this, two bubbles are formed with an improper geometrical shape, connected by a bridge. Therefore, the conclusion that the spherically shaped electrical explosion cavities retain their symmetry up to the point at which they attain their minimum dimension [8] is not quite correct.

Closure of a VGC for $W_T/l = 0.4$ kJ·m^{-1} occurs in the same manner. However, in this case, the cavity already immediately after the maximum begins to acquire the shape of an ellipsoid whose long axis is perpendicular to the electrodes (Fig. 2, curve 1). At the time $\bar{t} = 0.97$, a ring-shaped jet is formed, penetrating into and separating the cavity into two parts in the same direction. As experiments have shown, the process of closure of an almost spherical VGC, described above, is characteristic for $0.4 \leqslant W_T/l \leqslant 5$ kJ·m^{-1}. With an increase in the ratio W_T/l, the nonsphericity is less strongly manifested. Thus, for $W_T/l = 30$ kJ·m^{-1}, the cavity retains a shape close to spherical not only at the second pulsation, but also at the third.

When the energy liberated per unit length of the channel decreases to ~0.1 kJ·m^{-1} (which corresponds to ellipsoidal cavities), the VGC closes primarily along the axis of the electrodes, transforming at the final stages into a torus (see Fig. 1c).

Further decrease in W_T/l, as shown in [8], leads to the fact that the cavity acquires a cylindrical shape, which becomes very unstable as the minimum is approached.

The instability of the boundary of the cavity, stemming from the presence of defects in the boundary (depressions and protuberances) at times close to the minimum (see Fig. 1a-c), should be noted. However, these are not the defects that have the large effect on the dynamics of the VGC, since in all experiments for $0.4 \leqslant W_T/l \leqslant 5$ kJ·m^{-1}, the jets were formed perpendicular to the axis of the electrodes.

The behavior of electrical explosion cavities described above can be explained by the fact that at the time of their formation (which is taken as the time that liberation of energy into the discharge channel ceases), the cavity always has a shape close to cylindrical,

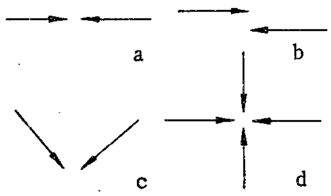

Fig. 3

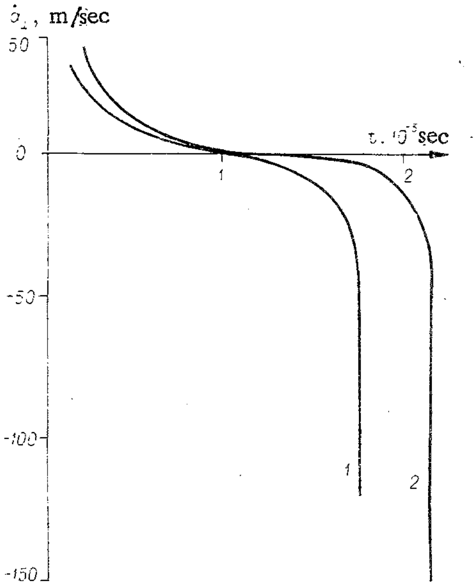

Fig. 4

which is caused by the method generating the VGC itself. The presence of electrodes leads to the fact that initially the discharge channel expands primarily in the direction perpendicular to the axis of the electrodes (the latter hinder the motion along the axis). In this case, the greatest momentum is transmitted to the fluid in the direction indicated above, which in the final analysis must lead to a difference in the radii $a_\perp$ and $a_\parallel$, namely, the radius in the direction perpendicular to the axis of the electrodes $a_\perp$ must exceed somewhat the radius along their axis $a_\parallel$.

Thus, a comparison of $a_\perp$ and $a_\parallel$ for five discharge regimes showed that the difference in the values of the radii, when the cavity attained the maximum volume although not large, still constitutes 5%. In correspondence with the results of a numerical solution of the problem of closure of an almost spherical cavity in the fluid [3], the conclusion we have arrived at follows unavoidably.

Indeed, specially conducted experiments showed that any position of the electrodes relative to one another, as well as the use of an additional system of electrodes (Fig. 3), has no effect on the closure scheme. It follows from this that the factor determining the nature of the collapse of the VGC can be taken as the distribution of the hydrodynamic characteristics in the starting phases of the active stage of the discharge, depending on the boundary conditions on the form of the end faces of the electrode surfaces.

Two systems of electrodes, placed in mutually perpendicular directions (Fig. 3d), which permitted attaining at the initial stage a cavity that did not have a cylindrical shape, were used as an additional experimental check on the influence of the initial shape of the VGC on the dynamics of its closure. Such a VGC could be obtained by conducting simultaneously a discharge in two mutually perpendicular, nonintersecting directions. As expected, in this case, the closure scheme of the VGC changed.

Analysis of the kinematic characteristics of the cavities shows that a decrease in the quantity W_τ/l increases the asymmetry of the closure process (a difference of the time dependences of the radii $a_\perp$ and $a_\parallel$ is observed), as well as the rate of closure of the VGC (Fig. 4). Thus, for the regime $W_\tau/l = 1$ kJ•mole^{-1}, $\dot{a}_\perp^{max} \approx 120$ m/sec, $\dot{a}_\parallel^{max} \approx 40$ m/sec; for $W_\tau/l =$ 0.4 kJ•m^{-1}, $\dot{a}_\perp^{max} \approx 160$ m/sec, $\dot{a}_\parallel^{max} \approx 53$ m/sec. In the second case, the cavity at the final stages has a much large curvature on the surface, which leads to an increase in the velocity of the jet $\dot{a}_\perp^{max}$. The experimentally determined values of the jet velocity confirm the results of the numerical solution of the problem of collapse of an almost spherical cavity in the fluid [3]. It should not be forgotten that the values of the rate of collapse of VGC at the minimum, obtained in the present work, are approximate, since in view of the instability of the shape of the cavity it is extremely difficult not only to fix clearly its boundary at times close to the minimum, but also to distinguish the minimum itself. Nevertheless, the data obtained permit analysis of the evolution of electrical explosion cavities and clarification of the relationship between the nature of their closure and their generation. In addition, a factor determining the closure scheme of the VGC is the compression factor of the cavity at the maximum, stemming from the initial distribution of hydrodynamic parameters.

This character of the closure of electrical explosion cavities complicates the statement and solution of the problem of calculating the acoustical emission, accompanying the post discharge stage of the electrical explosion, since even for spherical cavities the problem must be solved in a two-dimensional space. The acoustical emission of such dumbbell-shaped source has a directed action which cannot be taken into account in commercial use of the electrical explosion. On the other hand, this fact somewhat complicates, in a number of cases, the use of electrical explosion cavities for an experimental check of the applicability of existing theoretical models, as well as for modeling other explosive processes or cavitation phenomena with the help of an electrical explosion.

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