STABILITY OF THE MOTION OF METAL PLATES DRIVEN BY THE GRAZING DETONATION OF A FLAT CHARGE

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UDC 534.222.2

Deribas et al. [1-3] have investigated the dynamics of the launching of plates by grazing detonation of a high-explosive layer. The onset of instability during the motion of the plate can affect the operating efficiency of a planar explosive magnetic generator [4] and the accumulation of a shock-compressed gas slug under the conditions of colliding plates in an acute-angle geometry [5].

In the present study the motion of a plate behind a detonation front propagating along a flat overlay high-explosive charge at a detonation rate greater than the sound velocity in the plate material is investigated by pulsed x-ray photography and by Fourier analysis of the x-ray photographs.

The experimental arrangement is shown in Fig. 1. A flat charge of high-explosive plastic 1 is overlaid on the driven plate 2, which is mounted "with overhang" on the walls 3 of a three-piece cell with backing 4. A flat detonation-wave generator 5 and an electric detonator 6 are set up on the initial part of the charge. A PIR-600 pulsed x-ray camera 7 is used for recording; it is set up so that the direction of radiation is parallel to the plane of the driven plate and perpendicular to the direction of propagation of detonation and to the plane of the airtight film casette 8. The initiation time of the x-ray pulse is synchronized with the instant of passage of the detonation front at a definite position along the charge by the installation (at that position) of a contact sensor 9, which triggers the x-ray apparatus.

The walls of the channel are made of vinyl plastic 1 mm thick; the backing and the driven plate are made of aluminum. The driven plates have thicknesses d = 0.2, 1, 1.5, and 2 mm. The inside width of the channel is 40 mm, the gap h between the driven plate and the backing is varied from 4 mm to 40 mm. The rate of detonation of the high explosive is 7.3 ± 0.1 km/sec and the thickness of the charge is 4.5 mm. It follows from [5] that the time required for the entire cross section of the channel to be filled with gas is 3-5 μsec after the start of the process in the presence of stable accumulation of the shock-compressed gas before the line of contact of the driven plate and the backing. Consequently, in order to prevent the transient shock configuration before the contact line from influencing the flight dynamics of the plate, the contact sensor is installed at a distance of 100 mm from the beginning of the channel.

Upon detonation of the charge, the plate is driven onto the backing. When the detonation front reaches the position of the contact sensor, the latter closes, and an x-ray pulse is initiated. As a result, the profile of the driven plate is recorded on the film in the casette.

Figure 2 shows typical photographs of experiments with plates of thickness 1 mm driven onto a backing of thickness 2 mm with gaps h = 4.5 mm and 16 mm (Fig. 1a and 1b, respectively): 1) layer of undetonated high explosive; 2) plate driven inside the channel; 3) backing; 4) "edges" of the driven plate, i.e., the parts that project beyond the walls and remain motionless after the passage of detonation. Point A indicates the position of the detonation front and the turning point of the plate; point O gives the position of the contact line. The position of point A is determined at the place where the plate begins to move relative to the horizontal. The arithmetic-mean values of the path angle $\langle\delta\rangle$ are calculated from the measurement results (for gaps $h \gtrsim 11d$). Figure 3 (points 1 and the solid curve) shows $\langle\delta\rangle$ as a function of the natural logarithm of the ratio of the explosive mass to the mass of the driven plate ($r = \rho_{ex}d_{ex}/\rho d$, where ρ_{ex} and d_{ex} are the density and thickness of the high-explosive layer, and ρ is the density of the plate). Also shown are the values of the path angle estimated according to semiempirical equations for the launching of a plate [1] (points

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Krasnoyarsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 162-165, March-April, 1991. Original article submitted February 13, 1989; revision submitted April 23, 1989.

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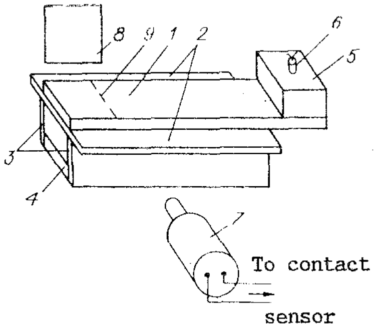

Fig. 1

2 and the dashed curve). The discrepancies between the experimental and calculated values of the path angle do not exceed 10%.

Figure 4 shows the instantaneous vaules of the angle δ as a function of the coordinate x (x is the distance from the turning point A along the surface of the plate): 1) $r = 1.56$; 2) $r = 1.13$. The rms error of determination of the instantaneous angles $\delta(x)$ is not greater than 0.6°. The horizontal dashed lines indicate arithmetic-mean angles $\langle\delta\rangle$ for both cases. The path angle increases abruptly in the vicinity of point A, corresponding to the acceleration stage of the plate, where it turns through the maximum angle. (It has been shown [3] that the plates achieve acceleration at distances of 5-10 thicknesses from the turning point.) Subsequently, with increasing x, $\delta(x)$ varies in the form of stochastic oscillations. The nature of the oscillations depends on r. Table 1 gives the arithmetic-mean values of the absolute deviation $\langle|\Delta\delta|\rangle$ $(\Delta\delta(x) = \delta(x) - \langle\delta\rangle)$ and the dispersion measure $\eta = \langle|\Delta\delta|/\langle\delta\rangle\rangle$ for various ratios r. The small values of $\delta(x)$ in the plate acceleration stage are ignored in the calculations. It follows from these data that the instability of motion of the driven plates disappears when r is decreased (d is increased). The nature of the motion of the driven plate and the backing after the contact line 0 (see Fig. 2) depends on the size of the gap h. If h is just adequate for the plate to turn through the maximum angle in the acceleration stage ($h \lesssim 5$ mm) (i.e., if there is not sufficient room for the completion of one whole cycle of oscillations during the motion of the plate to the contact line), the interface between the backing and the driven plate has a continuous stable form (see Fig. 2a). If $h \gtrsim 15$ mm, the stability of the interface is upset, so that cavities and "pockets" occur at the interface [4] (see Fig. 2b). It is therefore apparent that the unstable behavior of the flow at the interface after the contact line is a consequence of the development of instability in the motion of the driven plate.

The onset of instability of the contact boundary brings about a change in the gasdynamic flow regimes in the gap before the contact line. It has been shown [5] that when the gap h is increased to a critical value h_*, which occurs at $h \approx 15$-18 mm for an aluminum backing and a ratio $r = 2.33$, the stable accumulation of a shock-compressed gas slug ceases, and the flow exhibits a detached, pulsating behavior. With a further increase in h, accumulation does not occur at all. It is evident from the foregoing results that the change in the regime of stable accumulation of a shock-compressed gas slug as h increases is attributable to the development of oscillations during the motion of the plate in the gap and, accordingly, to losses of stability of the interface between the colliding plates. In this case the shock-compressed gas "collapses" in the cavities after the contact line.

The spectra of the oscillations of δ relative to $\langle\delta\rangle$ (without regard for the small angles δ in the acceleration stage) are obtained from the experimental data (see Fig. 4) for various ratios r by means of the fast Fourier transform. The spectra have a multimodal structure with three distinct characteristic frequencies. The spectra for the cases $r = 1.56$ (points 1 and the solid curves) and $r = 1.13$ (points 2 and the dashed curves) are shown in Fig. 5, where a_n and b_n are the coefficients of the Fourier series expansion

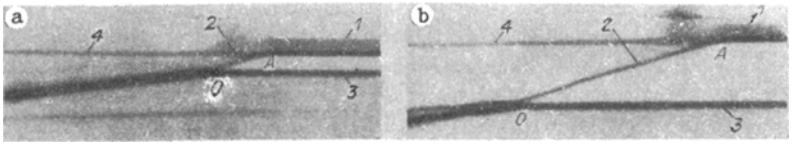

Fig. 2

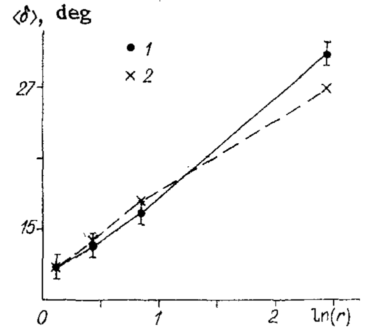

Fig. 3

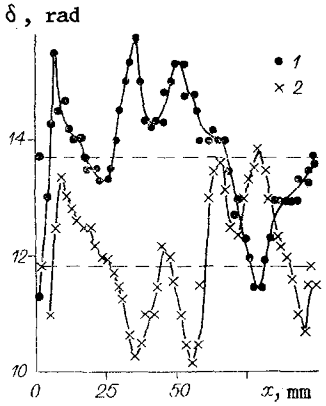

Fig. 4

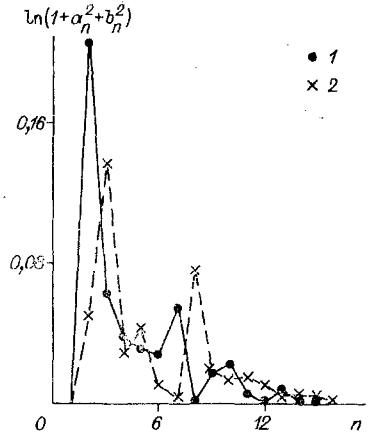

Fig. 5

TABLE 1

r	$\langle\lvert\Delta\delta\rvert\rangle$, deg	η
2,33	1,17	0,065
1,56	1,07	0,072
1,13	0,96	0,079

TABLE 2

r	ω^1, mm^{-1}	ω^2, mm^{-1}	ω^3, mm^{-1}
2,33	0,12	0,30	0,53
1,56	0,03	0,19	0,29
1,13	0,06	0,13	0,22

$$\delta(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos \omega_n t + b_n \sin \omega_n t) \quad \text{at} \quad \omega_n = \pi n/l$$

[ℓ is the baseline on which the measurements of the instantaneous angle $\delta(x)$ are performed; x varies from 0 to ℓ]. Three characteristic harmonics ω^1, ω^2, and ω^3 are clearly perceptible on the spectra. We note that the error of determination of $\langle\delta\rangle$ does not affect the form of the Fourier spectrum, because it merely alters the constant component, i.e., influences only the amplitude of the zeroth harmonic. A statistical analysis by the procedure given in [6] shows that all three peaks are significant at the 95% confidence level. This fact indicates that all three modes do actually exist and are not attributable to random measurement errors. The latter statement follows from physical considerations. Inasmuch as the peaks in Fig. 4 are fairly sharp, the error of determination of $\delta(x)$ can be reduced to shifts of the peaks along the horizontal by $\Delta x \simeq 2$-4 mm. The period of the corresponding maximum-frequency harmonic is approximately 12 mm. In view of the low probability of mutual agreement between the errors of determination of $\delta(x)$, they cannot possibly have any significant influence on the ω^3 mode. The probability of such an influence on the ω^2 and ω^1 modes is even lower. The characteristic frequencies are given in Table 2 for various ratios r. The ratio $\omega^3/\omega^2 \approx 1.5$-$1.8$ for all r. We notice a general decrease in the characteristics frequencies with decreasing r (as the thickness of the driven plate is increased, its motion becomes more stable).

In summary, the fast Fourier transform can be used effectively in analyzing the dynamics of the motion of metal plates. When a plate is driven by a grazing detonation wave, the spectrum of oscillations of the path angle exhibits three characteristic frequencies, whose values are determined by the launching parameters. The oscillation of the driven plate has the effect of destabilizing the interface after the line of contact with the backing. The frequency and amplitude of the path-angle oscillations increase with the ratio of the explosive mass of the high-explosive charge to the mass of the driven plate.

The authors are grateful to A. Yu. Babushkin, A. G. Beloshapko, S. G. Popov, and Yu. D. Shishkin for conducting the x-ray experiments.

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