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CUTOFF OF A SHAPED-CHARGE JET

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The process of cutoff of low-velocity areas of a shaped-charge jet with the help of a reverse-action shaped charge adjacent to the base of the shaped charge and having an axial channel where the shaped-charge jet passes is considered. The operation of the cutoff device and the shaped charge is synchronized by choosing an appropriate thickness and material of the cutoff device liner. An engineering method for synchronization of operation of the cutoff device and the shaped charge is proposed. Recommendations on choosing the cutoff device are given for a particular case of practical interest.

Key words: *shaped charge, shaped-charge jet, cutoff of the shaped-charge jet, cutoff device.*

Operation of a shaped charge (SC) generates a high-velocity shaped-charge jet (SCJ) whose velocity is 9–10 km/sec in the head section and 2.0–2.5 km/sec in the tail section (in the case of conical copper liners). The SCJ mass is 10–20% of the initial mass of the liner [1]. The main part of the shaped-charge liner is transformed to a tamper moving with a velocity of 0.5 to 1.0 km/sec. There is no clear boundary between the SCJ and the tamper: after implosion of the liner and formation of the tail part of the SCJ, the material continues to exhaust from the tamper. As a result, the SCJ forms a hole choked by the tamper, and a "tail" projecting from the target is seen.

A particular case of a cutoff device is a cylindrical flare near the liner base [2]. The flare cast into the high explosive (HE) prevents spalling at the liner base and increases the velocity of the tail part of the SCJ. Implosion of the cylindrical flare can destroy the SCJ, which has not yet left the zone of its action. A bulge is formed on the tail part of the SCJ owing to interaction of the high-velocity jet from the flare with the tail part of the SCJ escaping from the base of the conical liner.

Low-velocity parts of the SCJ and the tamper were cut off by a device, which was a shaped charge with a reverse action (cutoff device). A sketch of this device is shown in Fig. 1 (α_0 and α_1 are the angles of the cutoff device and SC liners, respectively, δ_0 and δ_1 are the thicknesses of the cutoff device and SC liners, respectively, d is the SC diameter, and a is the maximum thickness of the HE layer in the cutoff device). The cutoff device and SC are separated by a cylindrical bushing surrounded by the HE charge. If this bushing is absent, the cutoff device prevents implosion of the SC liner base and drastically decreases the SC penetration depth. The bushing length necessary for the cutoff process depends on the angle of the SC liner and reaches $0.2d$ for high liners. SCJ cutoff occurs owing to its deceleration on the cutoff device liner.

Figure 2 shows the space–time diagram of the SCJ cutoff process. The time of cutoff device implosion is calculated from the moment when the detonation wave arrives in a specified cross section of the cutoff device to the moment of liner implosion in this cross section on the charge axis. The minimum time needed for implosion of the cutoff device liner is chosen as the cutoff time t_0. As a result, there remains a high-velocity part of the SCJ of length l_{jet}.

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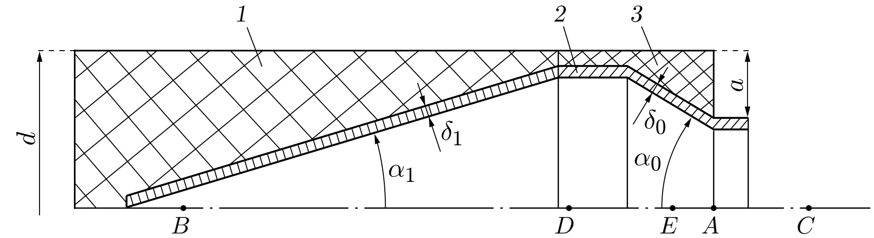

Fig. 1. SCJ cutoff scheme: shaped charge (1), cylindrical bushing surrounded by the HE charge (2), and cutoff device (3).

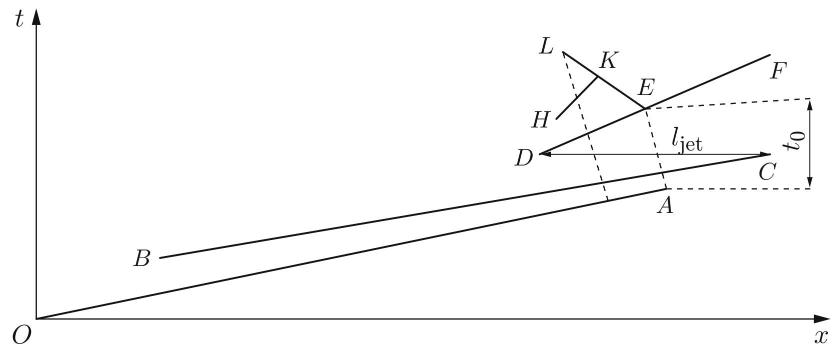

Fig. 2. Space–time diagram of SCJ cutoff: the lines show the motion of the detonation wave of the HE charge (OA), motion of the head part of the SCJ (BC), motion of the tail part of the cutoff SCJ (DF), motion of the point of cutoff device implosion along the charge axis (EL), and motion of low-velocity parts of the SCJ, which did not pass through the cutoff device (HK).

The geometric parameters of the cutoff device (see Fig. 1) were chosen from experiments. Commercial copper liners with angles $\alpha_0 = 45$ and $50°$ were used for the SC. In the case of a cylindrical liner of the cutoff device ($\alpha_0 = 0$), the maximum mass flux to the axis is reached, but only partial cutoff of the SCJ occurs in this case, because the SCJ leaves the cutoff device as if it were a drawing nozzle. The cumulative effect of the cutoff device is enhanced with increasing α_0, and SCJ cutoff becomes more complete. At high values of α_0, the radius of the remaining jet increases because of the insufficiently large flux of the cutoff device mass to the axis. The rate of implosion of the cutoff device liner depends on the ratio of the HE mass to the cutoff device liner mass and is determined by the dimensionless parameter $\eta = \rho_{\text{HE}} a/(\rho_0 \delta_0)$ (ρ_{HE} is the density of the HE in the cutoff device and ρ_0 is the density of the cutoff device material). With increasing the parameter η, the rate of implosion of the cutoff device liner also increases; as a result, SCJ cutoff becomes more complete. The ratio of the cutoff device and SC liner masses is determined by the dimensionless parameter $\mu = \rho_0 \delta_0/(\rho_1 \delta_1)$. With increasing this parameter, the radius of the remaining jet decreases. The length l_{jet} of the jet remaining after the cutoff procedure decreases with decreasing cutoff time t_0. If the velocity of the head part of the jet V_{head} is insufficiently high, then the SCJ does not have enough time to leave the cutoff device. In calculating the jet length l_{jet}, we used the dimensionless parameter $\bar{t}_0 = t_0 V_{\text{head}}/d$. SCJ stretching during its motion to the target depends on the ratio of velocities of the tail (V_{tail}) and head (V_{head}) parts of the jet. The finite length of the SCJ and the penetration depth h were calculated on the basis of the dimensionless parameter $\bar{V}_{\text{tail}} = V_{\text{tail}}/V_{\text{head}}$. The geometric parameters of the cutoff device were chosen from experiments with the aim of reaching the most complete cutoff of the SCJ, which is observed at $\alpha_0 = 45°$, $\mu > 1$, and $\eta > 1.7$. When the cutoff device hits the SCJ, ejection of the SCJ material occurs, and a typical "hat" is formed at the SCJ end (Fig. 3).

Below we consider an example of using the SCJ cutoff procedure for the case of practical interest. A shaped charge with a high aluminum liner forming a large-diameter hole was used (Fig. 4). The SC was located at a distance of $4d$ from the steel target. SCJ cutoff was performed by a cutoff device with an iron liner. The kinematical parameters of the SC and the cutoff device were calculated by an engineering method [1, 3], which allows the effect

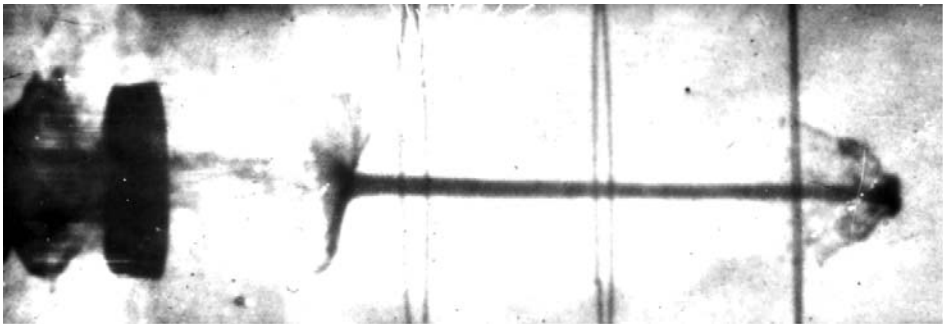

Fig. 3. X-ray photograph of the SCJ after the cutoff procedure [$\alpha_1 = 50°$ and $\delta_1 = 0.02d$ (copper); $\alpha_0 = 45°$ and $\delta_0 = 0.03d$ (iron); $d = 56$ mm; 40/60 TNT/RDX is used as the HE].

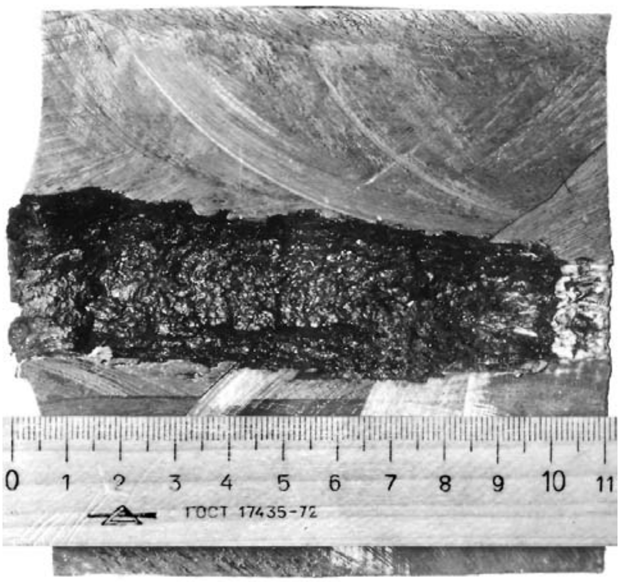

Fig. 4

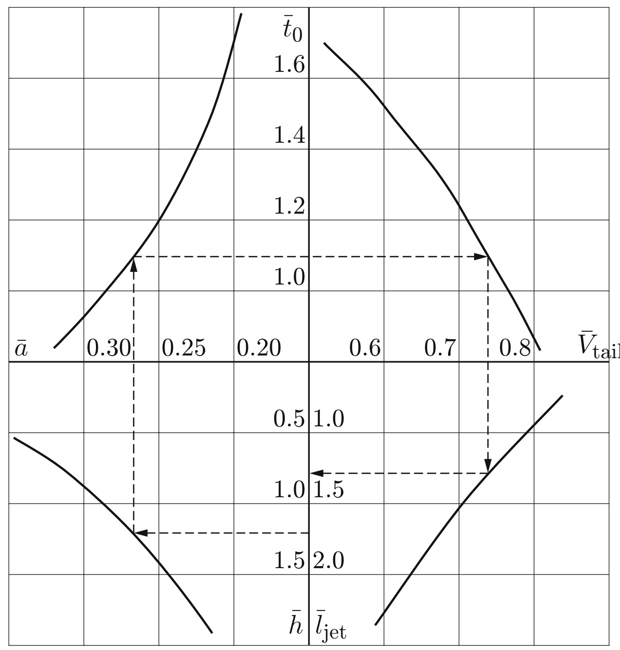

Fig. 5

Fig. 4. Hole in a steel target (St. 20 steel) formed as a result of the action of an SC with an aluminum liner [$\alpha_1 = 21°$ and $\delta_1 = 0.05d$ (aluminum); $d = 56$ mm; 40/60 TNT/RDX is used as the HE].

Fig. 5. Nomogram of SC and cutoff device operation [$\alpha_1 = 21°$ and $\delta_1 = 0.05d$ (aluminum); $\alpha_0 = 45°$ and $\delta_0 = 0.03d$ (iron); $d = 56$ mm; 40/60 TNT/RDX is used as the HE].

of the end-face rarefaction wave in the cutoff device to be taken into account. The calculated results are plotted in Fig. 5 ($\bar{a} = a/d$, $\bar{l}_{jet} = l_{jet}/d$, and $\bar{h} = h/d$, and h is the SC penetration depth). The value of h was also calculated by the method described in [1]. Engineering methods usually involve the notion of a critical velocity at which the SCJ ceases to penetrate through the target: at the jet–target interface, the SCJ does not create a pressure necessary to move the target material apart. For the SCJ and target made of steel, the critical velocity can reach 2–4 km/sec [1]. At the moment, there are no reliable data on the threshold velocity of the aluminum SCJ at which the strength of the steel target should be taken into account. The calculated velocity of the head part of the aluminum jet V_{head} is 12 km/sec, and the velocity of the tail part of the jet V_{tail} exceeds 6.5 km/sec. The penetration depth of a high-velocity aluminum jet was calculated with the use of the hydrodynamic theory; the strength of the steel target was ignored. For obtaining a high-velocity SCJ forming a hole with a depth $\bar{h} = 1.2$, it is necessary to use a cutoff device with a size $\bar{a} = 0.27$, which implodes during the time $\bar{t}_0 = 1.1$ and ensures the velocity of the tail part of the SCJ $\bar{V}_{tail} = 0.74$; in this case, the cutoff device generates an SCJ with a length $\bar{l}_{jet} = 1.3$.

The experiments performed provided data on cutoff of low-velocity parts of the SCJ. An engineering method was developed, which allows one to estimate the cutoff device parameters for particular applications (cutoff of low-velocity parts of the SCJ, cutoff of the tamper and cleaning of the hole, identification of the low-gradient part of the SCJ, which is a long-range striker, etc.).

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