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THE CONTRIBUTION TO THE OPTIMIZATION OF DETONATION WAVE IN THE SHAPED CHARGE CONSTRUCTION

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The procedure of the theoretical optimization of the detonation wave profile in the shaped charge with conical metallic liner is shown as well as some results of experimental research on the possibility to realize practically a detonation wave of such characteristics. The calculation method of the optimum detonation wave profile at constant values of others construction parameters of the shaped charge is based on the criterion of the regular jet formation and maximum jet kinetic energy. To reach the highest jet penetrability, these criteria are enlarged with complementary conditions concerning the gradient of the jet velocity.

INTRODUCTION

In the shaped charge without a wave shaper the detonation wave profile is a priori determined and it cannot be changed. In this case a maximum performance of a shaped charge construction can be realized by the optimization of the form and the thickness of metallic liner. Meanwhile, for the shaped charge of the small and medium caliber in particular, the task of optimization of a detonation wave profile is stated more frequently. In practice, the problem is resolved by introducing a special-form wave shaper in the shaped charge.

THEORETICAL OPTIMIZATION OF THE DETONATION WAVE PROFILE

At the constant values of the construction parameters of the shaped charge with conical metallic liner only the variation of the wave shape is possible. But, only one possibility of all form variations will have the optimal detonation wave profile at each moment, which is a necessary and a sufficient condition to produce the jet of claimed characteristics.

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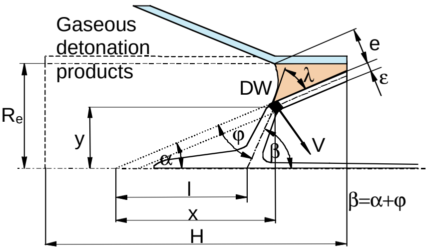
In other words, by initiating the detonation wave of an optimum form and its evolution along the shaped charge, in each point of the path line of the metallic liner, the most favorable conditions of the transfer energy from gaseous detonation products to liner will be achieved, providing the maximum jet performances.

Equations system

The phase of the metallic liner collapse (Fig. 1) and the phase of the collapsing mass collision and jet-slug formation (Fig. 2) have a primordial influence on the distribution of the shaped charge energy, and consequently on the jet parameters.



λ- Detonation wave attack angle
α - Liner cone apex half-angle
β - Collision angle
φ - Liner collapse angle

Figure 1 – General case of the no stationary liner collapse.

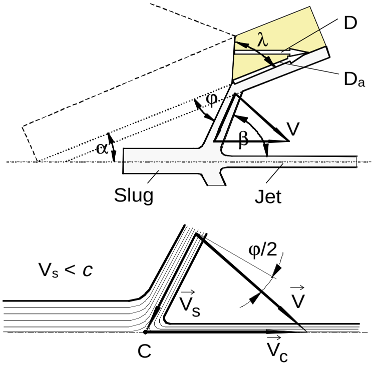


Figure 2 – Collapsing mass collision and jet-slug formation.

For the mathematical description of the phases given above, the analytical model of a two-dimensional metallic liner collapse for the general no stationary case and the equations of the hydrodynamic theory of jet-slug formation are used. Only the basic well-known equations of the Munroe's effect [1–4] are given in the paper.

The liner collapse angle φ is calculated on the basis of the Richter's equation:

$$\frac{1}{\varphi}=\frac{1}{\varphi_0}+K\frac{\rho\varepsilon}{e} \qquad (1)$$

where: φ_0 – is the free expansion angle of the gaseous detonation products, ρ – metallic liner density, ε – metallic liner thickness, e – explosive charge thickness, K – coefficient depending on the explosive type and the attack angle of the detonation wave λ.

The collapse velocity V is calculated by Taylor's equation:

$$V=\frac{2D\sin\left(\frac{\varphi}{2}\right)}{\sin\lambda} \qquad (2)$$

Velocity, mass and kinetic energy of the formed jet element are given by the equations:

$$V_j = D_a \left(1 - \cos\varphi + \sin\varphi \cot\frac{\beta}{2}\right) \tag{3}$$

$$\Delta m_j = \frac{1}{2}\Delta m (1 - \cos\beta) = \Delta m \sin^2\frac{\beta}{2} \tag{4}$$

$$\Delta E_{kj} = \frac{1}{2}\Delta m_j V_j^2 = \Delta E_k \cos^2\frac{\beta}{2} \tag{5}$$

This equations system with the optimization criteria is used for the determination of the optimum attack angle of the detonation wave.

Optimization criteria

The basic, starting criterion to reach the highest jet penetrability consists of the requirement for the maximum kinetic energy of the collapsed liner, i.e. of the jet.

The analysis of the influence of the detonation wave shape on the kinetic energy of the collapsed liner [5–7] shows that it is necessary in the shaped charge to generate the detonation wave of which profile is inclined, as much as possible, to the path line of the metallic liner cone. On the other side, by the inclination of the detonation wave, i.e. by decreasing the attack angle λ, the realised increasing of the liner collapse velocity leads to the critical conditions ($V_S > c$) where in the phase of the liner mass collision the jet existance is endangered. The mentioned criterion must be thus enlarged with a complementary condition concerning the existency of the coherent jet regular formation: $V_S \leq \Gamma c$ (Γ=1.23).

If these two criteria are satisfied in the optimization of the detonation wave profile the jet will be having the maximum velocity, i.e. kinetic energy. However, in some shaped charge constructions, particularly in the shaped charge with conical metallic liner where the liner thickness decreases from the top to the end of the basis of the cone, the jet of these characteristics will not have the maximum penetrability. This phenomenon is caused by a high value of the end part of the jet ($V_{jN} \gg V_{jmin} \cong$ 2300 m/s), by which the needed jet elongation at the given standoff distance is not possible.

To complete the method of the detonation wave optimization, the mentioned criteria must be enlarged with the following requirements:

- the velocity of the end part of the jet must be equal to the minimum jet velocity for penetration $V_{jN} = V_{jmin}$ =2321 m/s,
- the top of the jet for the given parameters of the shaped charge must have the maximum velocity $V_j(1) = V_{j0} = (V_{j0})_{max}$, which is in accordance with the basic criterion of the optimization, and
- the change of the jet velocity must be monotonous and decreasing (inverse gradient of the jet velocity) observing from the top to the end part of the jet, so that the first element has the velocity $V_j(1) = V_{j0} = (V_{j0})_{max}$, and the last $V_{jN} = V_{jmin}$ =2321 m/s.

NUMERICAL RESOLVING OF THE OPTIMIZATION TASK

Numerical resolving of the optimization problem of the detonation wave profile belongs to the inverse tasks of the detonics and is carried out in two phases. In the first phase the calculation of the optimum values of the detonation wave attack angle is performed for the local collapse conditions, and in the second the calculation of the inverse evolution of the detonation wave which in each point of the path line of the metallic liner cone satisfies this condition.

Determination of the optimum value of the detonation wave attack angle

In the preliminary analysis the general definition of the detonation wave optimum profile is given, which means that the detonation wave in each point of the cone path line has the optimum value $\lambda = \lambda_{opt} = \lambda^*$.

The angle λ^* is calculated using the system equations (1)–(5) beginning from the given jet element velocity and the local collapse conditions in the relevant point on the path line of the metallic liner cone. The calculation is carried out by a numerical iteration, introducing in the first approximation, the supposition of the frontal motion of the plane detonation wave for determining the initial value of the multi-factorial expression $\rho\varepsilon/e$ from eq. (1).

Inverse evolution of the detonation wave

In order to discribe mathematically the inverse evolution of the optimized profile detonation wave a discretization of the time t as independent variable is being performed, supposing that in finite time intervals the kinematic (D, D_a,D_a^x) and geometric (λ^*) characteristcs of the detonation wave change lineary. Thus, determining the optimum value of the attack angle $\lambda^*(j)$ in each point of the metallic liner cone path line j (j=1,2,3,…,M) for the actual negative time increment -Δt, it can be possible to determine in a particular moment -$t(i)$ the detonation wave profile of the optimum form given by the coordinates [$x(i,j)$; $y(i,j)$], according to the scheme in Fig 3.

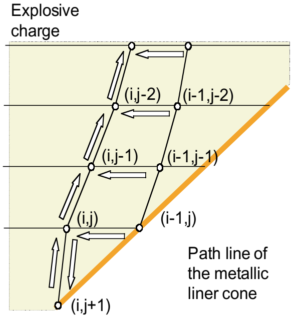


Figure 3 – Points determination flow on the detonation wave profile.

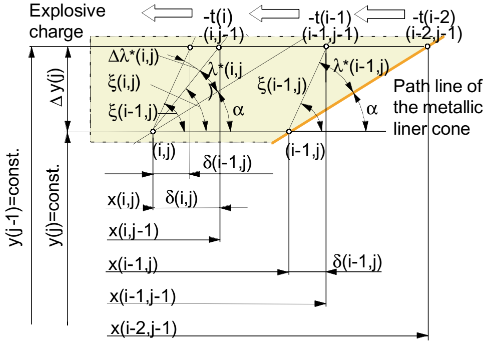


Figure 4 – Scheme of the change of the finite element of the detonation wave optimized profile.

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The inverse evolution of the detonation wave optimized profile, schematically shown in Fig. 4, during the movement from the point (i-1,j) with a known value of the attack angle $\lambda^*(i-1,j)$ to the point (i,j), at $y(j)=const.$, is defined by the system equations:

$$x(i,j) = x(i-1,j) + \Delta x(i,j) \tag{6}$$

$$\lambda^*(i,j) = \lambda^*(i-1,j) + \Delta\lambda^*(i,j) \tag{7}$$

The finite increments $\Delta x(i,j)$ and $\Delta\lambda^*(i,j)$ are given by the following equations:

$$\Delta x(i,j) = -D_a^x(i,j)\Delta t = -D_a(i,j)\cos\alpha\Delta t = -\frac{D\cos\alpha}{\sin[\lambda^*(i-1,j)]}\Delta t \tag{8}$$

$$\Delta\lambda^*(i,j) = \xi(i,j) - \xi(i-1,j) = \arctan\frac{\Delta y(j)}{\delta(i,j)} - \arctan\frac{\Delta y(j)}{\delta(i-1,j)} \tag{9}$$

where:

$$\xi(i,j) = \lambda^*(i,j) + \alpha \quad ; \qquad \xi(i-1,j) = \lambda^*(i-1,j) + \alpha \tag{10}$$

$$\delta(i,j) = \delta(i-1,j) + [\Delta x(i,j) - \Delta x(i,j-1)] \tag{11}$$

$$\delta(i-1,j) = x(i-1,j-1) - x(i-1,j) \tag{12}$$

RESULTS OF THE CALCULATION AND EXPERIMENTAL RESEARCH

The theoretical and experimental research on the optimization of the detonation wave profile is realized for the model of the medium caliber shaped charge. The construction and physical characteristics of the shaped charge model with conical metallic liner are shown in Fig. 5. Fig. 6 shows the calculated optimum profile and the realized profiles of the detonation wave in the experimental models of the shaped charge at the arrival moment to the metallic liner top. Making efforts to generate the detonation wave profile as closer as possible to the optimum profile, the several types of the wave shaper were tested [5–7], where the shape, dimensions, and kind of used material are varied. The results of the comparative research of the detonation wave form in the shaped charge with a special hemispherical wave shaper are given in the paper (Fig. 7).

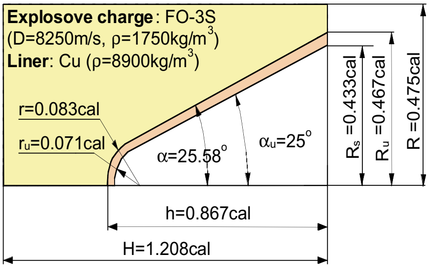


Figure 5 – Cross section of the shaped charge experimental model.

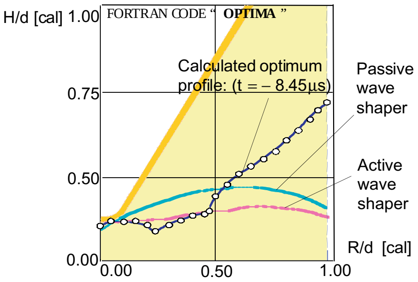
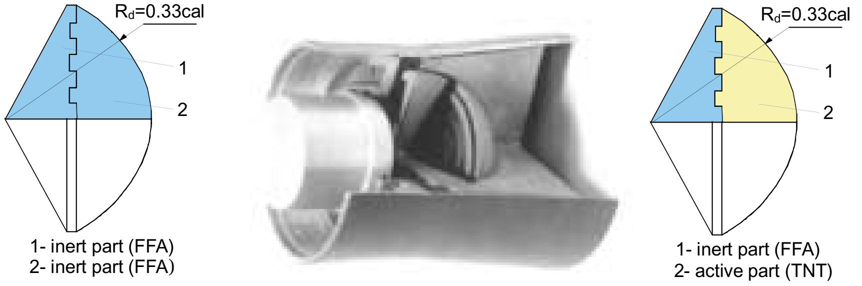


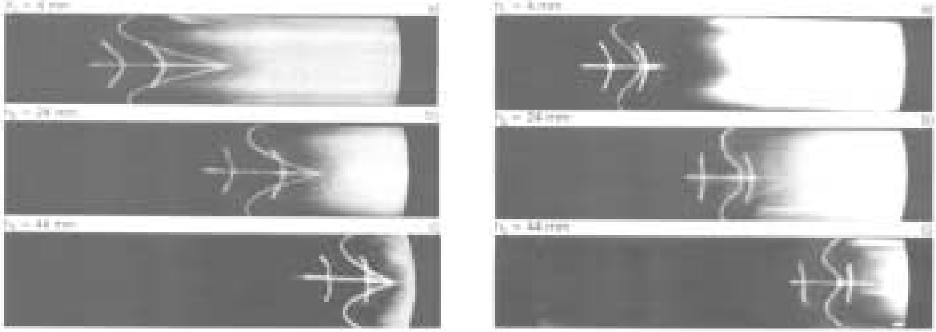
Figure 6 – Optimized and real profiles of DW at the arrival moment to the metallic liner top.



Hemispherical passive wave shaper.

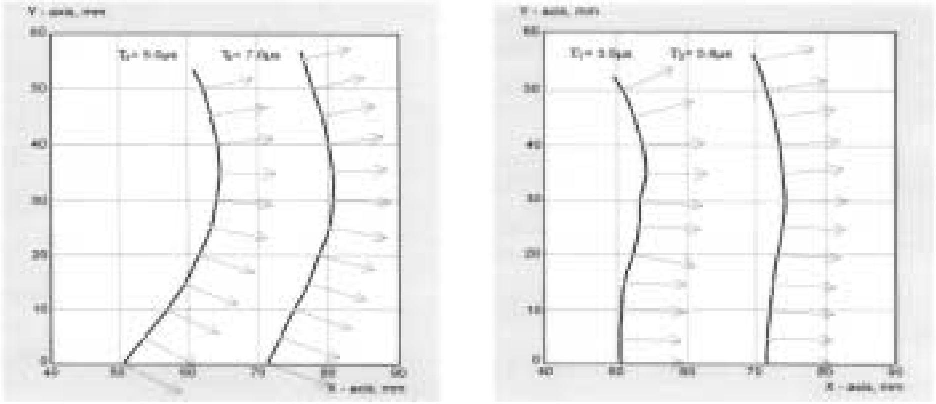
Model of the shaped charge with a hemispherical wave shaper.

Hemispherical active wave shaper.



Streak recordings of an emerging DW in the charge containing a hemispherical passive wave shaper.

Streak recordings of an emerging DW in the charge containing a hemispherical active wave shaper.



Real profiles and velocities of DW in the charge with a hemispherical passive wave shaper.

Real profiles and velocities of DW in the charge with a hemispherical active wave shaper.

Figure 7 – Results of the experimental research of the detonation wave profile in the shaped charge.

The recording realized by a high-speed camera in streak techniques [8,9] at recording speed V_r=10 mm/µs using the glass mask with engraved cross-shaped slots, and the processing of the results is realized by the theoretical and experimental method for the determination of detonation wave parameters, given in [9].

CONCLUSION

The explained method, with some suppositions, gives the possibility for theoretical optimization of the detonation wave profile in the shaped charge with conical metallic liner. The comparative analysis of the results of the experimental research (Fig. 6 and Fig. 7) shows that the active hemispherical wave shaper, which has a plane Mach wave in the central zone as a result, generates a detonation wave profile closest to the optimum theoretical profile.

The profile correction on the peripheral part of the detonation wave can be realized by two-component explosive charge (generator of the conical detonation wave), in which the central and peripheral charges of different detonation velocities are connected by area of strictly determined form.

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