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EQUATION OF STATE OF DETONATION PRODUCTS OF COMPACT EXPLOSIVES

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The behavior of detonation products (DP) of compact explosives is described satisfactorily in a number of cases by the equation of state [1-3]

$$p = f(\rho)T + \varphi(\rho), \tag{1}$$

which takes account of the molecule interaction in a broad range of variation of the temperature T and density ρ. In a number of cases the functions $f(\rho)$ and $\phi(\rho)$ are selected in simplest form. Thus a simple dependence of the pressure p on the density

$$p = A\rho^n \tag{2}$$

is proposed in [2] to describe the DP properties in the neighborhood of the Jouget point. The equation of state

$$p = B\rho T + A\rho^n \tag{3}$$

with three constants is examined in [1]. The equations of state (2) and (3) have a limited range of applicability. If the numerical values of A, n, B are chosen such that the error would be least in the neighborhood of the Jouget point, then it will grow noticeably with distance from it along the isentrope. The flinging properties of explosives are described better and the parameters of the normal detonation wave (DW) worse for another choice of constants. In order to increase the accuracy of describing DP behavior in the neighborhood of the Jouget point under isentropic expansion and moderate compressions, a number of equations of state [4-6] of the type (1) was created with different functions $f(\rho)$ and $\phi(\rho)$ containing around 10 constants. The rise in their accuracy is achieved by noticeable complication. It is characteristic for the mentioned equations of state of the DP that the numerical values of the major part of the parameters therein are determined individually for each explosive.

Let us consider one of the methods for finding the functions $\gamma(\rho)$ and $\phi(\rho)$ for (1)

$$p = (\gamma(\rho) - 1)\rho E + \varphi(\rho). \tag{4}$$

A physical experiment permits determination of the dependence of the velocity D of the normal detonation wave, the mass flow rate u behind the wave front, and the calorific value Q of the explosive on the initial density ρ_0 ahead of the detonation wave front. We will use these dependences to set up the form of the functions $\gamma(\rho)$ and $\phi(\rho)$ and to determine the numerical values of the parameters in them.

The conservation laws on a strong discontinuity with instantaneous liberation of internal energy Q have the form

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$$\rho(D-u)=\rho_0(D-u_0),\quad p-p_0=\rho_0(D-u_0)(u-u_0),$$
$$E-E_0=0{,}5(u-u_0)^2+p_0(u-u_0)/\rho_0(D-u_0)+Q,$$
$$D=u+c,\quad c^2=\left(\frac{\partial p}{\partial\rho}\right)_S. \tag{5}$$

For a given equation of state (4) the system (4) and (5) determines the line of the Jouget points on which all the thermodynamic quantities and velocities depend on ρ_0. Let us introduce the concept of a crystalline or greatest possible explosive density ρ_{0K} under normal conditions and a normal detonation wave velocity D_K in an explosive with this density. Let us use ρ_{0K} and D_K to go over to dimensionless variables

$$\Delta=\rho_0/\rho_{0K},\quad \delta=\rho/\rho_{0K},\quad W=D/D_K,$$
$$M=u/D_K,\quad Z=c/D_K,\quad \Pi=p/\rho_{0K}D_K^2, \tag{6}$$
$$\Phi=\varphi/\rho_{0K}D_K^2,\quad J=E/D_K^2,\quad K=Q/D_K^2.$$

For simplicity we shall consider $u_0 = 0$, $p_0 = 0$, $E_0 = 0$ in (5). After having gone over to the dimensionless variables (6), the equations (5) become

$$\delta=W\Delta/(W-M),\quad \Pi=WM\Delta,$$
$$J=0{,}5M^2+K,\quad W=M+Z,\quad Z=\left(\frac{\partial\Pi}{\partial\delta}\right)_S. \tag{7}$$

Let us write (4) in dimensionless variables

$$\Pi=(\gamma-1)\delta J+\Phi. \tag{8}$$

The system of six equations (7) and (8) contains nine functions of Δ: Π, δ, J, W, M, K, Z, γ, Φ. The system becomes definite if any three of the nine mentioned functions of Δ are given, i.e., are defined without utilization of (7) and (8).

Let us introduce the index of adiabaticity N

$$N=\left(\frac{\partial\ln p}{\partial\ln\rho}\right)_S. \tag{9}$$

Going over to dimensionless quantities and using (5) and (7), we obtain

$$N=Z^2\delta/\Pi. \tag{10}$$

Let us eliminate Z and M in (7) and (10)

$$\delta=\Delta(N+1)/N,\quad \Pi=W^2\Delta/(N+1),$$
$$J=\frac{W^2}{2(N+1)^2}+K,\quad \left(\frac{\partial\Pi}{\partial\delta}\right)_S=\left(\frac{WN}{N+1}\right)^2. \tag{11}$$

Let us find an exprssion for the derivative $(\partial\Pi/\partial\delta)_S$. To do this, we use the thermodynamic equation

$$\left(\frac{\partial\Pi}{\partial\delta}\right)_S=\left(\frac{\partial\Pi}{\partial\delta}\right)_J+\left(\frac{\partial\Pi}{\partial J}\right)\left(\frac{\partial J}{\partial\delta}\right)_S. \tag{12}$$

It follows from the main thermodynamics equations that along the isentrope

$$\left(\frac{\partial J}{\partial\delta}\right)_S=\frac{\Pi}{\delta^2}. \tag{13}$$

Let us substitute expressions for the derivatives

$$\left(\frac{\partial\Pi}{\partial\delta}\right)_J=\frac{d\Phi}{d\delta}+(\gamma-1)J+\delta J\frac{d\gamma}{d\delta}, \tag{14}$$

$$\left(\frac{\partial\Pi}{\partial J}\right)_\delta=(\gamma-1)\delta \tag{15}$$

into (12) and let us eliminate $(\partial J/\partial\delta)_S$ by using (13)

$$\frac{d\Phi}{d\delta}+(\gamma-1)J+\delta J\frac{d\gamma}{d\delta}+\frac{(\gamma-1)\Pi}{\delta}-\left(\frac{WN}{N+1}\right)^2=0. \tag{16}$$

Using (8) we eliminate J in (16). We consequently obtain