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ESTIMATION OF THE TEMPERATURE ON THE HUGONIOT ADIABAT BY USING THE "MIRROR IMAGE" RULE

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Existing methods of computing the temperature of a solid body compressed by a shock, which require tedious calculations, are approximate to some degree or other. This is associated both with the inaccuracies in giving the potential and the magnitudes of its governing coefficients and with the selection of the equation of state. In practical computations, the approximation $\Gamma/V = \Gamma_0/V_0$ is often used, where Γ is the Grunhausen coefficient, V is the volume, and the subscript zero refers to the initial state of the substance [1, 2], and the "mirror image" rule also. The foundation for this rule is the law for doubling the mass flow rate of a substance u_H in an unloading wave [3, 4] which has been established experimentally for not too high pressures p_H in the shock.

In many papers [4–7], the agreement between the unloading isentrope and shock compressibility curve in p–u-coordinates is used to evaluate just one of the Riemann integrals governing the shape of the isentrope on the p–V plane. This procedure permits giving an estimate of the magnitude of the volume increment of the material because of the irreversible shock heating after unloading to zero pressure:

$$\Delta\hat{V}_{\text{res}} = \hat{V}_{\text{res}} - V_0 - \int_0^p \left(\frac{du_H}{dp}\right)^2 dp - \Delta V_H. \qquad (1)$$

However, within the framework of the same "mirror" approximation, it is possible to write a second Riemann integral also for the energy E:

$$\Delta\hat{E}_{\text{res}} = \hat{E}_{\text{res}} - E_0 = \Delta E_H - \int_0^p p\left(\frac{du_H}{\partial p}\right)^2 dp. \qquad (2)$$

Since (1) and (2) for the residual parameters are formally equivalent, the question occurs as to which describes the thermodynamics of shock compression best.

Both the true and the "mirror image" residual quantities admit of expansion in Taylor series at low pressures. For deviations of these parameters it is possible to obtain

$$\Delta V_{\text{true}} - \Delta\hat{V}_{\text{res}} \sim p^3 \sim \Delta V_{\text{true}},\ \Delta E_{\text{res}} - \Delta\hat{E}_{\text{res}} \sim p^4,$$

from which it follows that the "mirror" approximation for the energy (2) best describes the thermodynamics of shock compression. The use of (1) results also in substantial inaccuracies in computing the shape of the "mirror" isentropes [7].

It is possible to arrive at the same deduction by comparing the thermodynamic consequences of the integrals (1) and (2) with the extensively used approximation Γ/V = const. As in [8], the thermodynamic equality

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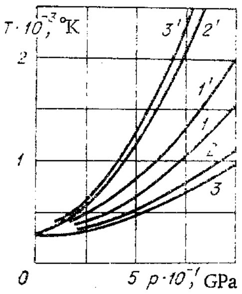

Fig. 1

$$T_H \frac{dE_{\text{res}}}{dp} = T_{\text{res}} \left(\frac{dE_H}{dp} + p \frac{dV_H}{dp} \right) = T_{\text{res}} \frac{d\sigma}{dp}$$

can be used to compute the temperature on the Hugoniot adiabat, where σ is the area bounded by the shock adiabat and the Rayleigh line on the p−V plane; let us note that the residual internal energy was estimated in [8] by using a combination of "mirror" quantities:

$$\Delta E_{\text{res}} = \frac{\sigma}{1 + \dfrac{\sigma - \Delta \hat{E}_{\text{res}}}{\beta \Delta \hat{V}_{\text{res}}}}, \quad \beta = \left(\frac{\partial E}{\partial V} \right)_{p=0}. \tag{3}$$

Results of computations for copper are represented in Fig. 1, where it is assumed that the shock velocity D is related linearly to the mass flow rate $D = C + Su$ ($C = 3.94$ km/sec, $S = 1.489$), and the coefficient of volume expansion and the specific heat are constant $\alpha = 5.5 \cdot 10^{-5}$ deg^{-1}, $c_p = 410$ J/kg · deg. For this case the curves 1, 1' and 2, 2' yield dependences of T_{res} and T_H on the pressure obtained by using (1) and (2), respectively, by means of the formula

$$\Delta \hat{E}_{\text{res}} = \frac{C^2}{4S^2} \left[1 + x + \frac{1}{4} \ln(1 + 4x) - \sqrt{1 + 4x} \right], \quad x = S \frac{pV_0}{C^2}. \tag{4}$$

The Riemann integral (2) for the energy yields a result in the "mirror" approximation which is substantially closer to the consequences $\Gamma / V = \text{const}$ (curves 3 and 3') than the volume integral (1) used extensively in thermodynamic computations; temperatures close to 3 also follow from (3). In those cases when the selection of the "mirror" approximation corresponds to the nature of the problem posed, Eq. (4) can be used to obtain simple and reliable estimates of the shock compression temperature.

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