CONVERSION FROM SHOCK TO ISENTROPIC COMPRESSION

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New and promising problems in the physics of high pressures have been recently under discussion. These include problems of obtaining superconductors, metallization of dielectrics, and particularly the production of metallic hydrogen and others.

The experimental research necessary for the solution of these problems is limited by the maximum pressures attainable with contemporary laboratory equipment. These pressures, obtained by static compression, do not exceed several hundred kilobars in static compression[1].

Yet the solution of the problems indicated above calls for pressures exceeding several megabars. Pressures up to 10 Mbar can be obtained at present in shock waves by using explosives. There is, however, one circumstance that limits the use of shock waves in many problems of high-pressure physics.

The processes in shock waves entail a change of entropy. The substance behind the shock wave is therefore strongly heated. This makes the degree of compression of the substance in the shock wave much lower than under static compression at the same pressures.

Thus, when solving the problems indicated above, where the decisive factor is in essence not the pressure applied from the outside by the degree of compaction of the substance, the advantages afforded by shock waves that produce high pressures are to a considerable degree illusory.

A promising possibility in this connection is the conversion of shock-wave compression into isentropic compression[2]. It then becomes possible to obtain with the aid of shock waves a high compression of matter, not attainable in modern laboratory practice.

We consider therefore the problem of propagation of a shock wave in a medium with variable acoustic characteristic, and then determine the law that this characteristic must satisfy in order to convert shock-wave compression into isentropic compression.

We use an equation of state of the type given by L.D. Landau and K.P. Stanyukovich, in the form of a sum of two components that characterize the elastic properties of a cold body and the thermal pressure of the atoms [2]. The argument of the exponent of the volume in the elastic component is assumed to be equal to 3, and the Gruneisen coefficient is assumed equal to 2. For simplicity, we consider a substance with a variable specific volume $V_0$, but at a constant initial speed of sound $c_0$ and a constant Grueisen coefficient.

Since the shock wave produces a variable entropy, it is convenient to carry out the calculations in Lagrangian coordinates, taking the mass m per square centimeter between the input surface and a given point as the coordinate. Then the equations of motion take the form

$$(\partial v/\partial t) = (c^2/V^2)(\partial V/\partial m), \tag{1}$$

[1] There are data on static compaction of glass and quartz at a pressure exceeding 2 Mbar [1].

[2] At not too high a temperature, the isentrope in a solid is close to the isotherm.

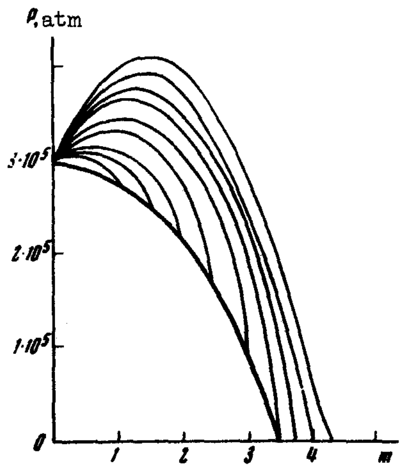


Fig. 1

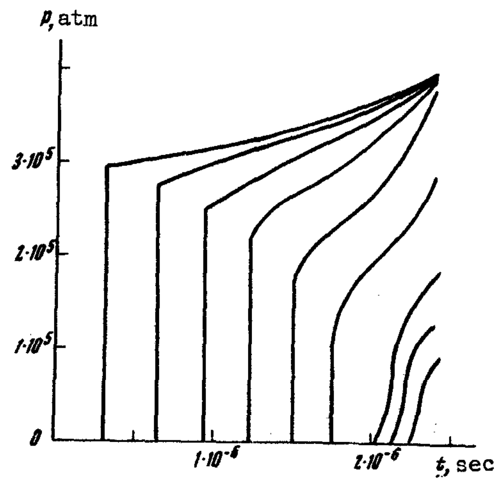


Fig. 2

Fig. 1. Distribution of the pressure as a function of the mass.

Fig. 2. Time dependence of the pressure for m = 0.52, 1, 1.53, 2, 2.5, 2.95, 3.52, 3.75, and 4 (from left to right, respectively).

$$\partial V / \partial t = \partial v / \partial m, \tag{2}$$

where V is the specific volume, v the velocity, and $c^2 = (\partial P/\partial \rho)_{S=\text{const}}$ (S is the entropy). The equation of the Hugoniot adiabat assumes the very simple form

$$P_f = (c_0^2/V_0)\,[(V_n - V_f) \;/\; (2V_f - V_0)], \tag{3}$$

where $R_f$ and $V_f$ are the pressure and specific volume on the shock wave front.

We express with the aid of this equation the velocity of the shock-wave front and the velocity of the substance on the front.

The distribution of the density as a function of the mass is assumed to be

$$\rho_0 = \rho_i\,[1 - (m/m_0)^2]^{-1}. \tag{4}$$

This form is highly arbitrary. All that matters is that the density must increase as the wave propagates, and that the expansion in powers of $m/m_0$ must not contain a linear term. In the concrete calculations we assume $m_0 = 5$ deg/cm$^2$.

The shock wave is excited by detonating a sufficiently thick explosive layer in contact with the medium at m = 0, so that the pressure on the compressed substance is constant.

The initial change of pressure in the shock-wave front is described by the expansion

$$P_f = P_0\,(1 - 1{,}46(m_f/m_0)^2). \tag{5}$$

The calculations were performed with a computer using an explicit difference scheme [3] and led to the following results (Figs. 1 and 2):

When the density is increased the shock-wave amplitude vanishes at m = 3.5 deg/cm$^2$. The succeeding compression is isentropic. Figure 2 shows the compression curves for this case as a function of the time for different points.

We have thus shown that the conversion of shock-wave compression into isentropic compression is feasible in principle.

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[2] L.D. Landau and K.P. Stabyukovich, Dokl. Akad. Nauk SSSR 46, 399 (1945).
[3] Kh.S. Kistenboim and G.S. Roslyakov, Chislennoe reshenie odnomernykh zadach o vzryve (Numerical Solution of One-dimensional Explosion Problems), MGU, 1971.