

MINIMIZATION OF THE ENTROPY JUMP DURING COMPRESSION

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1. Dynamical methods of acting on a substance during their comparatively easy realizability afford the possibility, in principle, of approximating the isentropic nature of compression up to high pressures [1]. To do this, a shock of the required pressure amplitude is transformed in some manner into a series of successively impinging shocks, whose total amplitude equals the initial value.

One of the methods of compression pulse transformation is to set up a layered spacer in front of the substances being compressed (see Fig. 1 with block 1, spacer 2, checking layer 3, damper 4, copper M1, iron M2, titanium M3, polyethylene M4, copper M5, iron M6, $h_i = 5$ cm, $h_i = 1$ cm, $i = 2, \dots, 6$). Passing through the layer of materials that possess different dynamical stiffnesses, the shock decomposes into a series of shock and rarefaction waves that interact mutually and with the contact surfaces. Consequently, a step compression pulse that changes with time passes into the obstacle control layer.

Compared with a shock of equal amplitude, such a pulse will cause a smaller entropy increment in the control layer of the substance [2].

Transformation of the pulse, concentrating or stretching it over the obstacle, can be controlled by altering the thickness of the spacer layers, and consequently, a large or small entropy increment can be obtained. The greatest possible entropy jump for this set of materials assures the least temperature increment under compression, and therefore, the least reduction in the strength characteristics of the control layer material. Moreover, the domain achievable for dynamical loading in temperature-pressure coordinates is extended to the limit, which is important for a number of practical applications [2].

The variational methods ordinarily used to find the optimum in similar cases here oblige substantial simplification of the model of the dynamical compression process itself [3, 4]. The coordinates of the optimum are hence determined to an accuracy not exceeding the accuracy of the simplified model.

An approach is used in this paper that does not constrain the complexity of the model and allows its easy replacement. The analysis performed below illustrates this approach in an example of a sufficiently complex model of the process for which the traditional optimization methods are inapplicable.

2. Let us consider a one-dimensional hydrodynamic model of the shock propagation process over a layered obstacle. According to [5], its mathematical description is a system of quasilinear partial-differential equations. The system is closed by the Osborne equation of state [6] and is solved numerically by using a difference approximation [7]. The process was computed up to emergence of the shock on the free surface of the obstacle.

The model described was considered as an object being optimized that has an input function h_i (the thickness of the spacer layers) and the output functions $p(x, t)$ and $\rho(x, t)$ (pressure, density).

The entropy increment in each cell of the obstacle control layer was computed by means of the output functions. To do this, an equation [8] was used with a power-law potential [9]

$$\Delta S \equiv \frac{S - S_0}{c_V} = \ln \left\{ \frac{p - \rho_0 a^2 \left(\frac{\rho}{\rho_0} - 1 \right) \left(\frac{\rho}{\rho_0} - 1 \right) \left(\frac{\rho}{\rho_0} \right)^{(2b-1)}}{c_V T_0 \rho_0 \gamma_0 \exp \left[\gamma_0 \left(1 - \frac{\rho_0}{\rho} \right) \right]} + 1 \right\}, \quad (2.1)$$

where c_V is the specific heat, S_0 is the initial entropy, T_0 is the initial temperature, γ_0 is the Gruneisen parameter, and a and b are material constants [8].

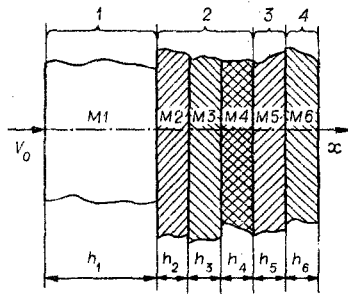


Fig. 1

TABLE 1

h_2 , cm	h_3 , cm	h_4 , cm	K	T, °K
0	0	0	1,40	2100
1,00	1,00	1,00	1,24	1800
0,20	0,24	2,36	0,94	1100

TABLE 2

Initial point, cm			Optimum point, cm			K
h_2	h_3	h_4	h_2^*	h_3^*	h_4^*	
1,00	1,00	1,00	$0,20 \pm 0,05$	$0,24 \pm 0,05$	$2,36 \pm 0,05$	0,94
1,00	1,00	0,45	$0,24 \pm 0,10$	$0,30 \pm 0,10$	$2,67 \pm 0,25$	1,01
1,00	0,50	0,25	$0,22 \pm 0,05$	$0,40 \pm 0,10$	$2,60 \pm 0,22$	0,99
0,50	1,00	2,00	$0,24 \pm 0,15$	$0,38 \pm 0,10$	$3,07 \pm 0,80$	1,03

It is assumed that the compression process can be characterized by the maximal value of the entropy increment in time and in control-layer thickness, i.e., the criterion characterizing the process as a whole was selected in the form

$$K = \max_t \left\{ \max_x \{ \Delta S(x, t) \} \right\}. \quad (2.2)$$

Taking account of (2.1) and (2.2), the criterion can be considered an implicit function of the input variables

$$K = \varphi(h_i), \quad i = 1, \dots, n. \quad (2.3)$$

It is impossible to establish the form of the function (2.3) for our problem since the system allows only a numerical solution and we are free of the assumptions simplifying the model. Moreover, the nature of the hypersurface K in the space of the variables h_i is not known, and the number of variables n can vary from problem to problem.

Under these conditions it is expedient to use a nonlinear simplex method [10] to find the optimum of K. The method was combined with the idea of transferring the input variables into a normalized space [11] and was modified so as to allow application of inequality-type constraints.

3. The listed composite parts of the general optimization problem were programmed in separate functionally interrelated modules so that their set forms a system that adapts to the hypersurface of the criterion (2.3) during the computation. The following are the basic interacting modules: The object being optimized is the numerical solution program of the system (see Sec. 2) that permits obtaining the output functions $p(x, t)$, $\rho(x, t)$ by means of the input parameters h_i ; the criterial module that computes the value of K by means of the output functions by using (2.1) and (2.2); the optimizing automaton whose basis is the algorithm of the simplex method [10] that permits computation of those new input parameters by means of a number of previous values of h_i and K, that should diminish the value of the criterion according to the logic of the automaton.

The minimum possible value of K and its corresponding parameters h_i^* was computed in an iterative manner during cyclic operation of this system, whereby the optimal thicknesses were found for a given shock velocity and the layer materials selected.

4. The nature of the hypersurface (2.3) and the clarification of the possibilities of the algorithm of the problem were computed for a preliminary study under the conditions displayed in Fig. 1 and a collision velocity of $V_0 = 4$ km/sec. The quantities h_2 , h_3 , h_4 were optimized.

The optimal thicknesses obtained as a result of the computation turned out to equal

$$h_2^* = 0.20 \text{ cm}, \quad h_3^* = 0.24 \text{ cm}, \quad h_4^* = 2.36 \text{ cm}.$$

A comparison of the computed values of the criterion and temperature in the control layer M5 is presented in Table 1 for different spacers.

The temperature was calculated from the formula [8]

$$T = T_0 \exp [\gamma_0(1 - \rho/\rho_0) + \Delta S].$$

It follows from Table 1 that the optimal structure substantially reduces the entropy increment (and the temperature) in the control layer as compared with a uniform thickness distribution, and even more so by comparison with a shock without spacers.

In order to eliminate the determination of the local minimum and to verify the uniqueness of the optimal structure, the descent to the optimum was carried out from different initial points. The results are presented in Table 2. Low accuracy in localization of the minimum was selected to reduce the calculation time. It follows from Table 2 that a search for the optimum from additional initial points results in practically the same optimal structure. This affirms the globality of the minimum achieved and the unique dependence of K on h_i to the investigated range of their variation.

The normal nature of the descent trajectory being observed during the optimization permits a judgment on the absence of gullies and singularities on the hypersurface (2.3) (at least for the initial conditions under consideration). Hence, for a small number of layers in the spacer the approach elucidated can result in a simplified computation by using rapid and less tedious search methods in the optimizing automaton, that use smoothness of the criterion.

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LITERATURE CITED

1. G. A. Adadurov, "On the development of dynamical action methods on a substance," in: Abstracts of Reports of the Second All-Union Symposium on Pulse Pressures [in Russian], VNIIFTRI Akad. Nauk SSSR, Moscow (1976).
2. L. V. Al'tshuler, E. A. Dynin, and V. A. Svidinski, "Hydrodynamic methods of low-temperature compression of solid hydrogen," *Pis'ma Zh. Eksp. Teor. Fiz.*, **17**, No. 1 (1973).
3. V. A. Ogarkov, N. P. Purygin, and S. V. Samylov, "Simple model of layered systems to obtain high body speeds," in: Detonation. Critical Phenomena. Physicochemical Transformations in Shocks [in Russian], Chernogolovka (1978).
4. S. Kaliski, "Rendering the explosion compression isentropic by a 'soft' layer effect," *J. Tech. Phys.*, **17**, No. 3 (1976).
5. B. L. Rozhdestvenskii and N. N. Yanenko, *Systems of Quasilinear Equations* [in Russian], Moscow (1968).
6. *High-Speed Shock Phenomena* [Russian translation], Mir, Moscow (1973).
7. R. D. Richtmaier, *Difference Methods of Boundary-Value Problem Solutions* [Russian translation], Inostr. Lit, Moscow (1961).
8. V. A. Zhdanov and A. V. Zhukov, "Thermodynamically complete equations of state of metals (solid phase)," *Prikl. Mekh. Tekh. Fiz.*, No. 5 (1978).
9. E. A. Shchegolov, "Equations of a solid body isotherm," in: *Materials of the Fourth Scientific Conference on Mathematics and Mechanics* [in Russian], Pt. II, Tomsk. Gos. Univ., Tomsk (1974).
10. A. I. Boyarinov and V. V. Kafarov, *Optimization Methods in Chemical Technology* [in Russian], Khimiya, Moscow (1975).
11. L. P. Ruzinov, *Statistical Methods of Optimizing Chemical Processes* [in Russian], Khimiya, Moscow (1972).