NUMERICAL STUDY OF PROCESSES PROCEEDING IN A TWO-CHAMBER HURLING UNIT

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The influence of apparatus parameters on gasdynamic processes in the working gas is studied. The possibility is shown of reducing the maximal pressure without noticeable loss of kinetic energy of the body being hurled.

The operation of multistage, multichamber, gasdynamic apparatus used to accelerate bodies has been studied sufficiently completely relative to the possibility of raising the hurling velocity [1, 2]. Two-stage units, particularly light-gas units, in which the hurling is accomplished by a light gas compressed by a piston set in motion by the working gas [1-3], havebeen studied in greatest detail. Two-stage units are of interest also from the viewpoint of the possibility of controlling the gasdynamic parameters of the working gas during the hurling. The influence of its parameters on the time dependence of the pressure in the working gas is investigated in the present paper for one of the possible versions of such an apparatus. The unit to be studied is shown schematically in Fig. 1. Here 2 is the domain occupied by the working gas, the hurling body of mass M_2, while the space 1 is filled with a neutral gas being compressed because of the motion of the piston of mass M_1 subjected to pressure in the working gas. The presence of chamber 1 permits diminishing the peak value of the pressure in chamber 2 under definite conditions, and then increasing it during the reverse motion of the piston M_1 as compared to the case in which the piston M_1 is replaced by a blind wall. Since the oscillating motions of the piston M_1 can damp out slowly, rises in the working gas entropy caused by the shocks being generated by this piston can occur during the whole working process. Consequently, the time dependence of the pressure at the bottom of the body being hurled takes a form shown qualitatively by curve 2 in Fig. 2, in contrast to curve 1, which corresponds to the case of no chamber 1 (the classical Lagrange problem [4]). Therefore, by varying the relationship between the volumes of the working and buffer chambers, and the masses of the bodies being hurled and acting as buffer, we obtain the possibility of controlling the dependence P(t) within definite limits. Computations of the appropriate gasdynamic problem were performed for a quantitative study of the process described.

The system of equations governing the problem is written in dimensionless form as follows:

$$\frac{\partial u}{\partial t} = -\frac{\partial P}{\partial m}, \quad u = \frac{\partial R}{\partial t}, \quad v = \frac{\partial R}{\partial m},$$
$$\frac{\partial \varepsilon}{\partial t} + P\frac{\partial v}{\partial t} = \frac{\partial q}{\partial t}, \quad \frac{du}{dt} = \frac{M}{M_2}P, \tag{1}$$
$$\frac{du}{dt} = \frac{M}{M_1}\Delta P, \quad \varepsilon = Pv(\gamma - 1).$$

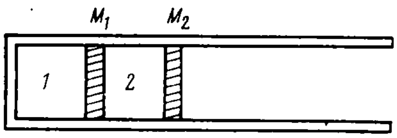

Fig. 1. Diagram of the apparatus being computed.

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TABLE 1. Comparison of Peak Values of Pressure, Final Kinetic Energy of the Body Being Hurled, Efficiency of the Hurling Process for Different Variants of the Computation for $\gamma_2 = 1.2$; 5/3

No.	γ_2	P_N/P	E_{KN}/E_K	η_N/η	R_1/R_2	M_1/M_2
1		1(P=0,153)	1(E_K=1,03)	1(η=0,240)	0	0
2		0,736	0,670	0,639	6	0,6
3	1,2	0,780	0,772	0,737	4	1,0
4		0,827	0,924	0,890	2	1,6
5		0,874	0,981	0,953	1	2,5
11		1(P=0,133)	1(E_K=0,70)	1(η=0,547)	0	0
12		0,692	0,823	0,790	6	0,4
13	5/3	0,741	0,909	0,862	4	0,6
14		0,815	1,000	0,941	2	1,0
15		0,865	1,029	0,968	1	1,6

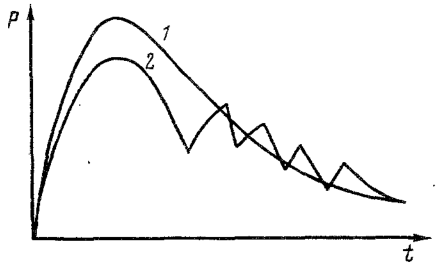

Fig. 2. Qualitative time dependence of the pressure on the body being hurled: 1) without additional elements; 2) for the unit presented in Fig. 1.

We give the law of energy release by the expression

$$\frac{\partial q}{\partial t} = at \exp(-t/t_*). \tag{2}$$

The actual dimensional gasdynamic quantities of the problem are related to the dimensionless quantities thus: $u_p = u_0 u$, $v_p = v_0 v$, $P_p = P_0 P$, $\varepsilon_p = \varepsilon_0 \varepsilon$, $m_p = m_0 m$, $t_p = t_0 t$, $R_p = R_0 R$, where the characteristic quantities satisfy the relationships

$$\frac{u_0}{t_0} = \frac{P_0}{m_0}, \quad u_0 = \frac{R_0}{t_0}, \quad v_0 = \frac{R_0}{m_0}, \\ \varepsilon_0 = P_0 v_0, \quad m_0 = M/S_0. \tag{3}$$

Let us present the boundary and initial conditions for the system of equations (1)-(2):

$$\begin{gathered} t = 0, \quad u(R) = 0, \quad v(R) = v_1, \quad P(R) = P_1, \\ \varepsilon(R) = \varepsilon_1, \quad 0 \leqslant R \leqslant R_1, \\ u(R) = 0, \quad v(R) = v_2, \quad P(R) = P_2, \\ \varepsilon(R) = \varepsilon_2, \quad R_1 < R \leqslant R_2, \\ P(R) = 0, \quad v(R) = 0, \quad R_2 < R \leqslant R_3, \\ t > 0, \quad u(R) = 0, \quad \partial u(R)/\partial t = 0, \quad R = 0. \end{gathered} \tag{4}$$

System (1)-(2) with the boundary conditions (4) was approximated by a finite-difference scheme of first-order accuracy [5] with pseudoviscosity. Since the scheme is centered relative to the density, pressure, and internal energy, then a fictitious pressure point was introduced to give the boundary condition on the piston M_2 being hurled, and this permits expressing the pressure at the point of piston location by interpolation, by using the piston M_2 momentum and motion equations written for that point of the Lagrangian mesh where the position is:

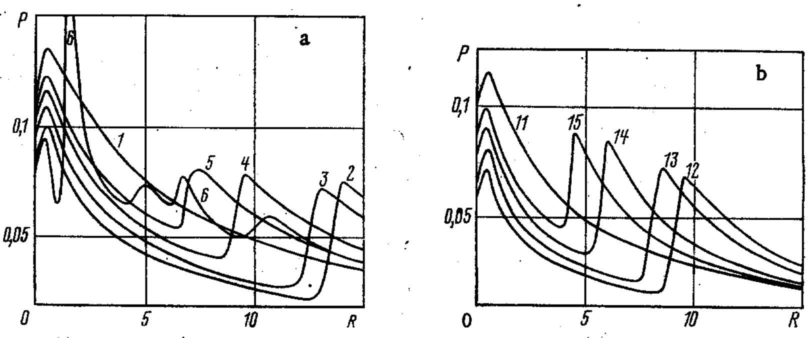

Fig. 3. Dependence of the pressure on the body being hurled on its location for different versions of the computation for $\gamma_2 = 1.2$ (a) and $\gamma_2 = 5/3$ (b).

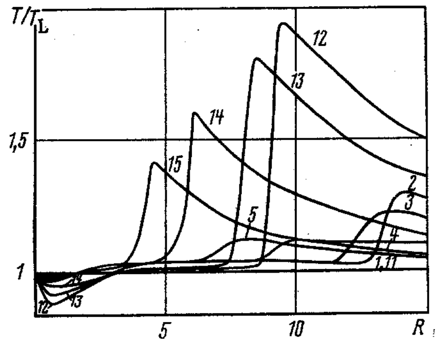

Fig. 4. Ratio T/T_L of the temperature on the body being hurled to the temperature on the body in the case of the Lagrange problem for different versions of the computation.

$$P_{j+1}^{n} = \frac{2P_{j+\frac{1}{2}}^{\bar{n}}}{2 + Mh/M_2}.$$

The expression obtained contains the piston mass as a parameter which goes over into the condition on the gas–vacuum interface in the limit case of equality to zero, and into the condition on a fixed wall as $M_2 \to \infty$. An analogous condition is used on the left piston. The accuracy of the computation was verified by the agreement of the magnitude of the total system energy with the quantity of energy introduced from the source at a given time. The problem formulated in difference form was programmed for FORTRAN for the Minsk-32 electronic computer, and the mean time of computation of any variant was around 40 minutes of machine time.

The computations of the problem were performed for $K_2 = M/M_2 = 0.295$; $R_2 = 1$; $R_3 = 15$; $P_2 = 0.0001$; $v_2 = 1$; $\gamma_2 = 1.2$; 5/3; $P_1 = 0.01$; $\gamma_1 = 5/3$; the quantity $K_1 = M_1/M_2$ varied between the limits $K_1 = (0.01\text{-}10)K_2$, and R_1 between the limits $R_1 = (1\text{-}6)R_2$. The mode of energy insertion was given by the constant of the source (2), $t_* = 10$.

The results of computing certain variants are presented in Table 1. All the quantities here are referred to their values corresponding to the solution of the Lagrange problem [4], where their maximum values are taken for P.

It is seen that a noticeable effect of reducing the peak pressure in a system with relatively small losses in the kinetic energy of the piston being hurled occurs for variants with masses M_1 and M_2 of similar magnitude. This strongest interaction of pistons is similar to that observed in traditional light-gas two-stage ballistic apparatus [3]. Losses in the hurling velocity increase substantially in the range of heavier masses M_1 since the buffer piston does not succeed in returning the working-gas energy during the process. When M_1/M_2 is considerably less than 1, the peak pressure in the channel rises abruptly because of the formation and multiple reflection of shocks, exactly as in standard two-stage systems with a light piston [2]. It should be noted that sufficiently high pulse pressures occur in the buffer chamber 1 during the hurling; however, their acting time is small, and the total gas energy in the chamber 1 is hence around 2-13% of the working gas energy.

Values of the pressure on the piston being hurled are displayed in Fig. 3a and b for its different locations in the tube. The numbers on the graphs correspond to the numbers of the version in the table. In contrast to the usual behavior of the pressure curve in the Lagrange problem 1 the curves 2-5 and 12-15 have two quite definite peaks in the cases presented, which are lower in amplitude. Exactly as in cases 1 and 11, the former correspond to an increase in pressure during heating of the working gas (piston motion to the opposite side), and the latter to a compression wave being formed during return motion of the buffer piston. The behavior of the pressure on the body being hurled is shown by the number 6 in Fig. 3a for the variant of a light buffer piston $K_1 = M_1/M_2 = 0.16$, which forms a sufficiently strong shock and a number of waves of substantially lower amplitude. The ratios T/T_L of the temperature on the piston being hurled to the temperature on the piston for the classical Lagrange problem are shown in Fig. 4 for the versions 2-5 and 12-15. It can be seen that the presence of the shocks in the working gas causes a twofold rise in the temperature.

It should be noted that despite the action of the compression wave on the piston being hurled, the time dependence of its coordinate has the form of a smooth curve in the whole range investigated for the mass M_1 and the length of the chamber 1.

In conclusion, let us note that the use of several buffer chambers and pistons can significantly extend the possibilities of controlling the gasdynamic processes in the working chamber; however, systematic investigations here require performing extensive computations because of the abrupt rise in the number of governing parameters.

NOTATION

u	is the gas flow rate;
P	is the pressure;
ε	is the specific internal energy;
v	is the specific volume;
t	is the time;
R	is the coordinate;
$m = \int dR/v$	is the Lagrange coordinate;
M	is the mass of working gas;
γ	is the adiabatic index;
ΔP	is the pressure difference on the buffer piston;
q	is the source function;
a	is the normalizing constant;
t_*	is the characteristic time of energy insertion corresponding to the maximum of the source function;
h	is the spacing on the mass mesh;
η	is the efficiency, the ratio between the final kinetic energy of the body being hurled E_k to the total system energy;
R_1	is the length of chamber 1;
R_2	is the length of chamber 2;
S_0	is the tube section.

The subscripts are:

0	characteristic quantities of the problem;
p	dimensional quantities;
1	quantities in chamber 1;
2	quantities in chamber 2;
n	number of the time spacing;
j	number of the mesh mode;
N	number of the variant.

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