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SHORT COMMUNICATION

Magnetogasdynamic Control of Burning Rate of Condensed System

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ABSTRACT

Presents the results of modelling combustion products of solid propellant flow. The product of combustion is the ionized gas occurring in a channel with current conducting walls, when a part of the channel is in the external homogeneous magnetic field, oriented in such a way that the ponderomotive force, occurring in the flow region, is opposite to the flow. This results in gas deceleration and increase of static pressure. For the condensed systems, whose mass burning rate is in direct proportion to the environment pressure, the static pressure increase causes increase of mass burning rate. The basic parameters have been determined by numerical simulation. The nature of their influence on the process of combustion in a cylindrical channel has also been determined. The study revealed that a ten-fold increase of burning rate is possible at moderate values of the parameter of magnetogasdynamic interaction.

NOMENCLATURE

σ	Electrical conductivity, A/B·m
U	Velocity vector of gas flow, m/s
$m_0(P^{\nu})$	Mass burning rate, kg/m^2·s
$m = (U,n)$	Gas mass velocity, kg/m^2 s
(U,n)	scalar product of the velocity vector U by the external normal n to the surface, m/s
t	Time, s
P	Pressure, Pa
ρ	Density, kg/m^3
h	Total gas enthalpy, J/kg
B	Vector of magnetic induction of external field, N/A m
j	Vector of current strength density, A/m^2
f	Vector of ponderomotive force density, N/m^3
V	Volume, m^3
F	Surface, encompassing volume V, m^2
γ	Index of gas adiabatic curve
ν	Power index for mass burning rate
S_H	Parameter of magnetogasdynamic interaction
n	Vector of external normal to the surface F

Indices

o	Input cross-section and
e	Output cross-section.

1. INTRODUCTION

It is important to know how to control the combustion products flow of solid rocket propellant, mainly on account of operating conditions of a rocket motor when it becomes necessary to provide a required diagram 'thrust-time' as well as when controlling the thrust in a given direction. The existing methods of control of combustion of solid propellants in combustion chambers of rocket motors are mainly based on the mechanical principles. On their realisation, the units of the operating mechanism are exposed to the intense thermochemical and erosion effects of a high temperature multiphase medium.

The physicists are familiar with a principle of power effect of the external magnetic field on the flow of a conducting medium. This principle has multifunction

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application in different devices, such as magnetohydrodynamic generators, pumps, flow meters and so on[1,2]. The authors propose to use the above-mentioned power effect of magnetic field in two aspects, First, to control the mass burning rate of solid propellants, whose combustion products are the ionized gas with electrical conductivity, σ. Secondly, to deflect the combustion products flow from a longitudinal axis of the flowing channel, that may have extensive applications in the control of the direction of jet thrust of airborne vehicles.

2. CONTROL OF MASS BURNING RATE

This communication describes the axis symmetric flow of an ideal ionized gas in the channel with the velocity vector, U in the cylindrical coordinate system (x,y,z), where x denotes the flow direction along the channel axis, $U = (u_x,0,0)$. The part of the channel is in the homogeneous magnetic field (Fig. 1), oriented in such a way that the vector of magnetic induction has only a radial component $B = (0,B_y,0)$. In the input

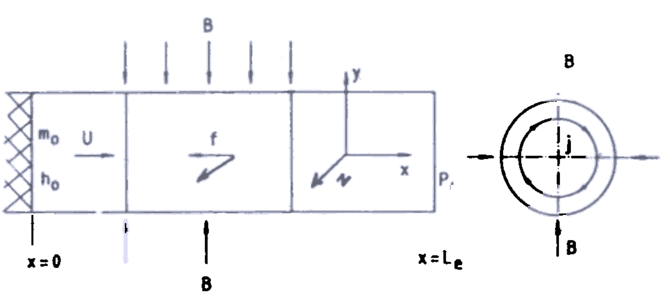

Figure 1 Scheme of flow region.

section of the channel, the mass burning rate is given as the pressure power function $m_0(P^\nu)$ and the total gas enthalpy, h_0 is given as well; and in the output section of the channel the pressure of environment P_e is given. In the absence of external electric field[2,3], the vector of the current strength density, j has a circular component $j = (0,0,j_z)$, $j_z = \sigma\, u_x B_y$, and the ponderomotive force, f is directed against the flow and equals $f=(f_x,0,0)$, $f_x = -j_z B_y$

Here, $j = \sigma[U \times B]$ and $f = [j \times B]$

Therefore, the application of external field results in flow deceleration and pressure increase in the region adjacent to the burning surface. Since the burning rate of solid propellant is directly proportional to the environment pressure, the pressure increase gives rise to the increase of mass burning rate.

Numerical simulation of the process under study is based on the integral Euler equations[4] in the approximation of magnetogasdynamics[2], when the magnetic Reynolds number $Re_H << 1$.

$$\frac{\partial}{\partial t}\int_V \rho dV + \oint_F m\, dF = 0,\quad m = (U,n)$$

$$\frac{\partial}{\partial t}\int_V \rho U\, dV + \oint_F (Pn + mU)\, dF = \int_V f\, dV$$

$$\frac{\partial}{\partial t}\int_V \rho E\, dV + \oint_F \left(E + \frac{P}{\rho}\right) m\, dF = 0$$

where $m = \rho(U.n)$ is mass gas velocity; $E = \frac{1}{\gamma-1}\frac{P}{\rho} + \frac{|U|^2}{2}$ is full energy of gas volume; $(U.n)$ is scalar product of velocity vector U by the vector of external normal n.

As the initial conditions, the stationary solution of Eqns (1)-(3) is used in the absence of the external field, and the boundary conditions are as follows:

$$x = 0 \quad m = m_o\,(P^\nu)$$

$$E + \frac{P}{\rho} = h, \tag{5}$$

$$x = L_e \quad P = P_e \tag{6}$$

For the numerical solution of the set of Eqns (1)-(3) the authors have used the Godunov-Kolgan method[5,6], and the procedure of realisation of boundary conditions (4)-(6) for all possible modes of flow is based on the solution of the problem of an arbitrary discontinuity[7].

The calculations were made for the combustion products with the characteristics: $\gamma = 1.2$, $\sigma = 50$ A/B m at $h_o = 4$ MJ/kg, $\nu \in (0,0,8)$ and at the external pressure $P_e = 0.1$ MPa.

A typical stationary distribution of the flow parameters is shown in Fig. 2. In the initial state the gas flow is a subsonic one with the Mach number $M_x = 0.82$ (dashed line) at constant level of pressure being equal to P_e. When applying the external field the flow is decelerated and the pressure increases by a factor of more than 20, thus magnifying the mass arrival of combustion products. As a result, after applying the magnetic field region the mode of flow changes, which becomes a sound one.

The analysis of stationary solution obtained from the balance analogs of Eqns (1)-(3) has shown that the

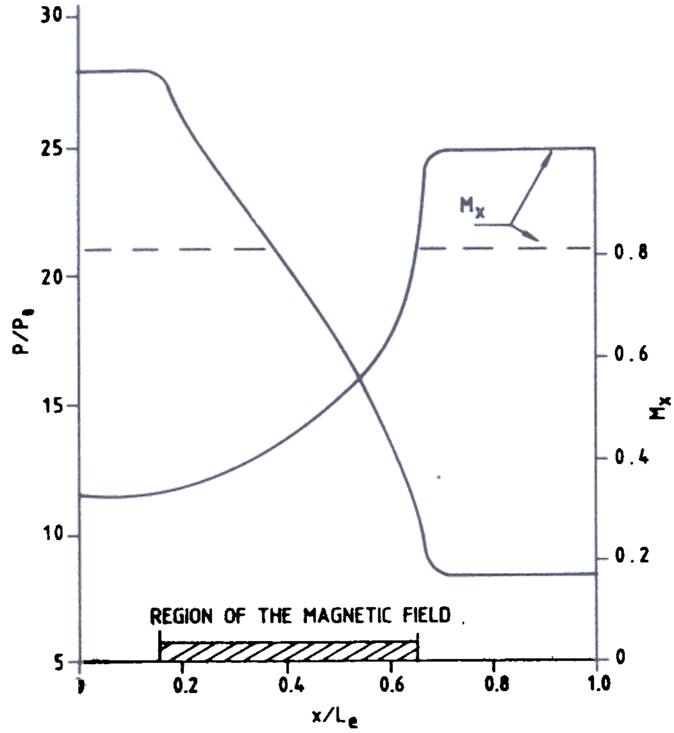

Figure 2. Typical stationary distribution of flow parameters.

relative mass arrival, m_H/m_0 (the ratio of mass burning rate with the availability of magnetic field m_H and without it m_0) depends on the power index, ν and the parameter of magnetogasdynamic interaction, S_H, which determines the relationship between magnetic and inertial forces and equals

$$S_H = \frac{\sigma \; |B|^2 v_H}{m_0 F_c}$$

where V_H is the volume of the external magnetic field and F_c is the transverse cross-sectional area of channel. The results of the investigation of the influence of the parameters S_H and ν on the relative mass burning rate of solid propellant, are presented in Fig. 3. It should be noted that more than ten-fold increase of mass arrival is possible for $\nu > 0.6$ at average values of the parameter S_H.

4. CONCLUSIONS

The communication describes a principle feasibility of the use of force action of the external magnetic field to control the mass burning rate and direction of motion of combustion products of solid propellant. It should be noted that in practice the proposed noncontact method of control will be highly efficient, since, in its use, the elements will be lacking which directly interact with high temperature combustion product flow. Besides, the efficiency of the method can be increased by introducing in the gas flow, special ionizing additions resulting in several times increase of electrical conductivity.

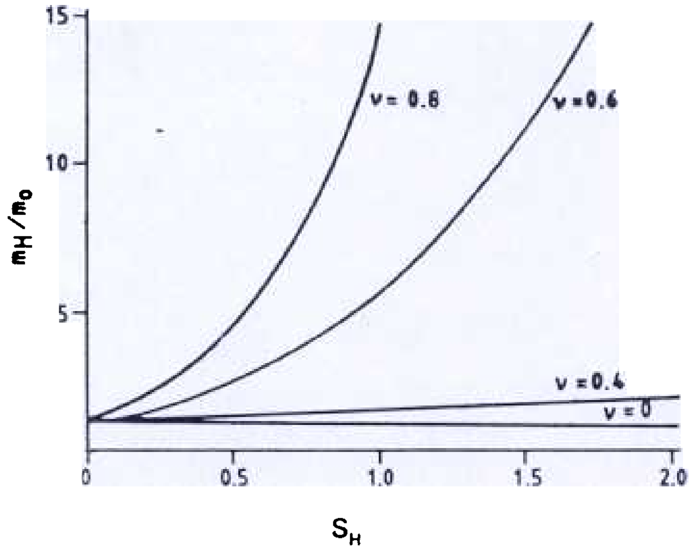

Figure 3. Influence of S_H and ν on relative mass burning rate of solid propellant.

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