5. V. I. Polezhaev and A. I. Fedyushkin, "Hydrodynamic effects of concentration stratification in closed region," Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 3 (1980).
6. L. G. Napolitano, "Marangoni boundary layers," in: Proc. 3rd European Symp. on Material Science in Space, ESA, SP-142, Grenoble (1979).
7. G. K. Batchelor, "On steady laminar flow with closed streamlines at large Reynolds number," J. Fluid Mech., 1, No. 1 (1956).
8. P. Hartman, Ordinary Differential Equations, S. M. Hartman (1973).

EXPLOSION OF A SPHERICAL CHARGE IN A MAGNETIC FIELD

V. P. Korobeinikov and B. V. Putyatik UDC 534.222.2

The need to study the interaction of detonation waves with a magnetic field arises in research involving many phenomena, for example nonstationary flows of cosmic matter, as well as in practicall applications, for example in creating explosive MHD generators. Several problems involving explosions, taking into account the effect of a magnetic field for the case of a point explosion, are formulated and solved in [1].

The problem of an explosion of a cylindrical charge of condensed explosive in a gas in the presence of an external magnetic field is examined in [2]. In this paper we study the analogous problem for a spherical charge. The main difference, from the mathematical point of view, between this problem and the preceding one lies in the fact that its solution depends on two spatial coordinates (r, z in a cylindrical coordinate system) and time t, i.e., the problem becomes two-dimensional. The scheme for the flow that arises is shown in Fig. 1, where 1 denotes the products of the detonation, 2 denotes the contact surface, 3 denotes the shock-compressed gas, and 4 denotes the shock wave.

The interaction with the magnetic field occurs as a result of the motion of the electrically conducting gas, heated up by the shock wave, across the force lines of the magnetic field. The flow will differ from the spherically symmetrical flow that occurs in the absence of the field. In particular, the form of the contact surface bounding the detonation products and the form of the shock waves arising in the surrounding gas will become gradually distorted, stretching out along the force lines of the magnetic field.

The problem was solved in the approximation of small magnetic Reynolds numbers R_m (in the calculations $R_m \leqslant 0.1$); in addition, the deformations of the initial magnetic field were ignored. In taking into account radiation losses, we also used the approximation of volume emission. The detonation products are assumed to be electrically nonconducting [3] and nonemitting. The detonation wave is initiated at the center of the charge. Right up to the moment that the wave emerges onto the surface of the charge, the solution is self-similar and can be found separately. Then, it is already necessary to solve the complete system of two-dimensional equations of magnetogasdynamics, which have the form

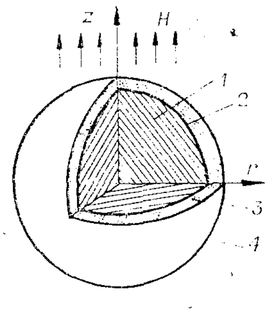

Fig. 1

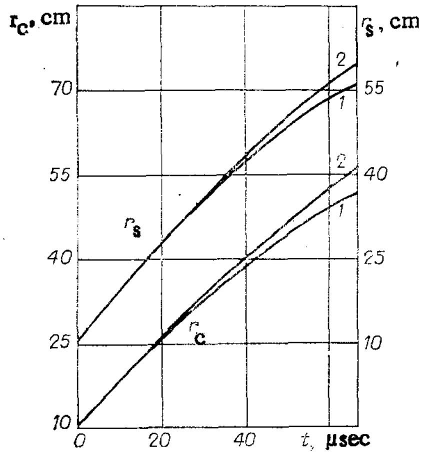

Fig. 2

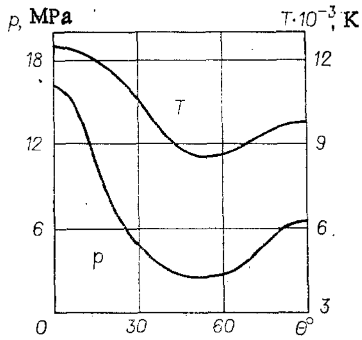

Fig. 3

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$$\frac{\partial\rho}{\partial t}+\frac{\partial(v\rho)}{\partial z}+\frac{1}{r}\frac{\partial}{\partial r}(ru\rho)=0,$$

$$\rho\frac{dv}{dt}+\frac{\partial p}{\partial z}=0,\quad \rho\frac{du}{dt}+\frac{\partial p}{\partial r}+\frac{\sigma uH^2}{c^2}=0,$$

$$\rho\left[\frac{de}{dt}+p\frac{d}{dt}\left(\frac{1}{\rho}\right)\right]=\frac{\sigma u^2H^2}{c^2}-4akT^4,$$

$$p=p(T,\rho),\ e=e(T,\rho),\ \sigma=\sigma(T,\rho),\ k=k(T,\rho),$$

where ρ is the density; u and v, velocity components along the r and z axes, respectively; p, pressure; e, internal energy; T, temperature; σ, electrical conductivity; k, Planck-averaged coefficient of absorption; H, intensity of the magnetic field; c, velocity of light; and a, Stefan–Boltzmann constant.

In view of the symmetry, the solution is sought in the region r > 0, z > 0 with the corresponding boundary conditions

$$r=0,\ u=0,\ z=0,\ v=0$$

and at infinity u = v = 0, $p = p_0$, $T = T_0$, where p_0 and T_0 are the initial pressure and temperature of the surrounding gas. For the initial data we chose the distributions of the gasdynamic quantities in the detonation products found beforehand by solving the self-similar problem of the detonation wave.

The problem formulated above was solved numerically by a finite-difference method (Wilkins' scheme) [4] using an artificial viscosity and mobile Lagrangian grids.

The jump in the electrical conductivity at the contact surface and the interaction with the magnetic field give rise to the appearance of a discontinuity of the tangential velocities on this surface. The last circumstance dictates the need for using two finite-difference Lagrangian grids: one in the detonation products and one in the gas surrounding them, which can slide relative to one another. This was incorporated into the program.

The calculations were performed for a hexogen charge with initial density of 1.8 g/cm^3. In calculating the thermodynamic functions of the materials, as well as the electrical conductivity and the coefficients of absorption, we used the data presented in [5-8] which take into account the real physical processes. The numerical procedure was first checked for the solution of a spherically symmetrical problem (H = 0) by comparing it with the corresponding one-dimensional calculation.

Figures 2 and 3 show some results of the calculation of one variant of the problem. The surrounding gas consisted of air with a pressure of $p_0 = 1.33\cdot10^4$ Pa and a temperature of T_0 = 300°K. The other initial data are as follows: radius of the charge, 10 cm; magnitude of the magnetic field, 100 kG. As noted above, the interaction of the flow with the magnetic field affects the form of the contact surface, separating the detonation products and the external gas, and the form of the shock wave that propagates into the surrounding gas. Figure 2 shows the laws governing the motion of the shock waves $r_s(t)$ and the contact surface $r_c(t)$ for two mutually perpendicular directions: z = 0 and r = 0, i.e., across the lines of force of the magnetic field (curve 1) and along them (curve 2). Figure 3 shows the angular distributions of the temperature and pressure near the contact surface in air at the time t = 48 μsec. The angles θ = 0 and θ = π/2 correspond to the values z = 0 and r = 0. It is interesting to note the nonmonotonicity of the distribution p and T as a function of angle. The curves have a minimum near the value θ = π/4. Figure 3 refers to the time when the contact surface is still nearly spherical (see Fig. 2). However, the nonuniformity of the distribution of the pressure as a function of angle later shows up and leads to a distortion of this form. We note that the greatest retardation of the detonation products occurs in a direction perpendicular to the lines of force of the magnetic field, i.e., for θ = 0, in accordance with the maximum pressure in Fig. 3.

The results of the calculations also reveal a strong tendency for the shock layer of the gas to slip relative to the detonation products. In a real experiment, the latter circumstance, together with the Rayleigh–Taylor instability, will apparently lead to a smearing of the contact surface.

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LITERATURE CITED

1. V. P. Korobeinikov, Problems in the Theory of a Point Explosion in Gases [in Russian], Nauka, Moscow (1973).
2. V. P. Korobeinikov, V. V. Markov, and B. V. Putyatin, "Propagation of cylindrical explosion waves taking into account radiation and the magnetic field," Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 4 (1977).
3. A. P. Ershov, P. I. Zubkov, and L. A. Luk'yanchikov, "Measurement of the profile of electrical conductivity in the detonation front for detonation of condensed explosives," Fiz. Goreniya Vzryva, 10, No. 6 (1974).
4. M. L. Wilkins, "Calculation of elastoplastic flows," in: Computational Methods in Hydrodynamics [Russian translation], Mir, Moscow (1967).
5. C. L. Mader, "Detonation properties of condensed explosives computed using the Becker–Kistiakowsky–Wilson equation of state," LA-2900, UC-4, Tid-4500 (1963).
6. N. N. Kalitkin, L. V. Kuz'mina, et al., "Tables of thermodynamic functions and transport coefficients of plasma," Preprint, Institute of Applied Mathematics, Academy of Sciences of the USSR (1972).
7. N. M. Kuznetsov, Thermodynamic Functions and Shock Adiabats of Air at High Temperatures [in Russian], Mashinostroenie, Moscow (1965).
8. I. V. Avilova, L. M. Biberman, et al., Optical Properties of Hot Air [in Russian], Nauka, Moscow (1970).

RELATIONS AT A COMBINED CONCENTRATION DISCONTINUITY IN A GAS CONTAINING SOLID PARTICLES

S. P. Kiselev and V. M. Fomin

UDC 532.529+533.6.011

A study is made of the flow of a mixture of gas and solid particles having discontinuities in the volume particle concentration m_2 when the gas flows through the discontinuities (combined discontinuities). There is a difficulty in describing such flows in that the conditions for using the two-liquid model $Z \gg l$ are not obeyed at the discontinuities, where Z is the characteristic scale in the change in mean flow parameters. This difficulty has been avoided [1] by replacing the region of discontinuity by a surface of discontinuity. With slight changes, this idea has been reproduced in all subsequent studies on combined discontinuities [2-8]. The continuous changes in gas parameters over the thickness of the discontinuity (much greater than the distance between the gas molecules) is replaced by a discontinuity of the first kind. A consequence of this is a physically unjustified increase in the entropy at the discontinuity [6], i.e., $[S] \sim [p]$. The physically correct conditions at the discontinuity were first used in [9] for the interaction of a shock wave with a porous half-space and a porous coating. Here the relations at the discontinuity have been derived on the assumption that the entropy is conserved when the gas flows into the porous material together with a Bord shock scheme for flow from it. These concepts were developed in [4, 10], where the surface force was introduced at the surface of discontinuity in the porosity, which acts on the gas and whose magnitude is chosen from the condition for the occurrence of given flow states at such discontinuities, which enables one to avoid the above entropy paradox. Similar concepts were partially used in [7] for the two-liquid model, where a surface force was artificially introduced that acts on particles at the combined-discontinuity surface.

Here we derive the relations at a combined discontinuity from the equations describing the flow of the gas at a discontinuity, which is an N-couple region, where N is the number of particles in the discontinuity. We calculate the surface force exerted by the gas on the particles.

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