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Abstract

Full Text

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HYDROMECHANICS

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OBTAINING HIGH-VELOCITY GAS JETS

(Presented by Academician Ya. B. Zel' dovich, 17 VII 1964)

To obtain high-velocity gas jets and strong shock waves in gases, a device was developed and investigated; it is shown schematically in Fig. 1. A charge of explosive (1) with a plane detonation-wave front accelerates a metal plate (2), which together with a spherical segment (3) forms a compression chamber filled with the working gas (4). At the top of the chamber there is an orifice closed by a thin diaphragm (5), beyond which is a vacuum outlet tube (6).

After the plane detonation wave reaches the plate, the latter is accelerated and compresses the gas toward the top of the chamber. Investigation of the conditions for obtaining high-velocity gas jets showed that the principal role is played by the acceleration of the gas in the narrow gap formed between the front wall of the chamber and the compressing plate as the plate approaches the top of the chamber. The mass velocity of the gas is close to the phase velocity of motion of the point of contact between the plate and the chamber, which is several times greater than the flight velocity of the plate. Compression is effected by several strong shock waves; as a result of their passage the temperature and pressure of the gas increase, so that the gas is transformed into a high-temperature plasma of high density. After rupturing the diaphragm, this plasma exits through the orifice at the top of the chamber. Immediately after leaving the chamber, the plasma occupies a small part of the tube; then its unsteady expansion into the vacuum occurs. The velocity of the luminous plasma jets in the glass outlet tube was measured with a slit photochronograph. Fig. 2 gives a typical photochronogram. When the experiments were repeated, the velocity was reproduced with an accuracy of $±$5%.

Figure 2

Figure 2: Figure 2

Fig. 1. Schematic of the device for obtaining high-velocity gas jets. Typical dimensions are indicated in millimeters.

Fig. 3 shows the dependence of the jet velocity on the type of working gas. The maximum velocity was obtained with hydrogen and is equal to 90 km/sec. A characteristic feature of the experimental results is the weak dependence of the jet velocity on the type of gas and its density. Thus, changing from hydrogen at 1 atm to xenon at 0.5 atm, i.e., changing the density by a factor of 32, reduces the velocity by ~30%. At different initial pressures of air in the working chamber, from 10 to 760 mm Hg, the jet velocities proved to coincide within the limits of experimental scatter and the accuracy of the measurements.

If the mass of the diaphragm (5 in Fig. 1) is no more than 5% of the mass of the gas, its presence, irrespective of the material, has no effect on the velocity obtained. Increasing the mass of the diaphragm to 20% of the mass of the gas reduces the velocity by ~40%. In the experiments, diaphragms were usually used–

of lavsan with a thickness of 8 μ, whose mechanical strength is utterly negligible in comparison with the pressure of the compressed gas.

The material (steel, copper, aluminum) and thickness of the compressing plate (2 in Fig. 1) over a wide range of parameters do not affect the jet velocity, provided that different plates are accelerated to one and the same velocity.

Fig. 2. Photochronogram of the motion of an air jet in the glass exit tube of the device shown in Fig. 1. x is the distance along the tube axis, t is time, 1 is the jet front; 2 is the reflection-wave front; 3 is a plug at the sealed end of the tube; 4 are scale marks.

When plates less than 1 mm thick are used, the jet velocity decreases severalfold, apparently as a result of the loss of integrity of the plate and mixing of the explosion products with the working gas. In this work, aluminum plates 1.5 mm thick were used for the most part.

The radius of curvature R of the front wall of the chamber (3 in Fig. 1) has a decisive influence on the jet velocity. Under the conditions of the experiments performed, the optimal radii of curvature were found to be $R = 60 \div 80$ mm.

The maximum jet velocity was obtained with an internal diameter of the exit tube of 8 mm. When the tube diameter was increased to 28 mm or decreased to 3 mm, the velocity decreased by $\sim 30\%$.

A twofold decrease in the jet velocity due to friction during motion through a tube 8 mm in diameter occurs over a length of ~ 50 cm.

Figure 3

Figure 3: Figure 3

Fig. 3. Dependence of the jet velocity u on the density of the working gas ρ. Curves a and b correspond to chamber radii of curvature of 60 and 40 mm. $1, 2, 3$ –hydrogen, helium, air at 1 ata; 4 –xenon at 0.25 ata; 5 –xenon at 0.5 ata.

All the experiments described above were carried out with an air pressure in the exit tube of $10^{-1} \div 10^{-2}$ mm Hg. If the exit tube is filled with gas at high pressure, the velocity of motion of the jet decreases, and a strong shock wave travels through the gas. Figure 4 shows the velocity of the shock wave in the air filling the exit tube as a function of its initial pressure. At pressures below 10 mm, the velocity is practically independent of the pressure. The velocity of a shock wave in air under normal conditions is 40 km/sec.

The maximum velocity obtained with cumulative charges ($^{1-3}$) does not exceed the velocity obtained by the method described here. In this case, a hypersonic cumulative jet (velocity > 60 km/sec) is formed when the volume is evacuated to a residual pressure of 10^{-3} mm or less, while increasing the pressure to 1 mm reduces the velocity to ~ 30 km/sec (^{3}). Comparison of these data with the results of the present work (Fig. 4) makes it possible to conclude that the method described here produces gas jets substantially

···of substantially higher density. It should also be noted that supervelocity cumulation and the method described differ in another respect: in the first case the metal (or its vapor) is accelerated, while in the second it is the gas, so that one can obtain, for example, a jet of hydrogen.

Fig. 4. Dependence of the jet velocity u on the pressure p of the air filling the outlet tube. In the chamber–air at 1 ata.

The temperature behind the front of a shock wave moving at a velocity of 40 km/sec in air taken under normal conditions is 8.6 eV ($1 \cdot 10^5$ °K). The pressure in this case is $2 \cdot 10^4$ ata, and the number of ions in 1 cm^3 is about $4 \cdot 10^{204}$. If the wave is reflected from the closed end of the tube, the temperature, pressure, and density of the plasma increase still further. Upon impact deceleration of a hydrogen jet with a velocity of 90 km/sec, the temperature is ~ 18 eV^5. Thus, the described method makes it possible to obtain a high-temperature plasma of high density.

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Note: Figure translations are in progress. See original paper for figures.