THE INFLUENCE OF THE GRAIN SIZE OF MICROSTRUCTURE OF THE SURFACE LAYER MATERIAL OF A HYPERSONIC BODY ON THE PROPERTIES OF AIR PLASMA[1]

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Abstract

The flight of hypersonic bodies in the air is accompanied by intense processes of gas and body surface heating, its erosion and ablation. At the same time, temperature near the body surface and the intensity of these processes are higher, for greater density and pressure of the environmental gas.

The results of experimental investigations of properties of low-temperature air plasma initiated in air by the movement of hypersonic bodies with velocities close to the first cosmic velocity are presented. To intensify the processes and for studying the characteric features of the flight in extreme conditions, the model experiments were conducted in air in the normal initial state. The technique of X-ray and mm-wave diagnostics of plasma properties and microstructural analysis of hypersonic body material were utilized in the experiments.

1. Introduction

It is shown in this work that the size of the microstructure grain for the outer layer of the body influences the properties of the plasma with the condensing dispersion phase (CDP), which appear in the air with the movement of high-velocity bodies.

The investigations were made in the air with normal start conditions similar to work described in [1]. Through the experiment, the body, formed in the process of compression by products of detonation of cumulation shell-hole (CSH), moved between central transmitting and receiving high-frequency QDE's antennas [2,3] (zone plates Reley-Wood with the relative hole ≈1, diameter 40λ, were λ=0.004 m of wavelength).

The choice of radar frequency is governed primarily by two factors [4]. First, it is important to minimize the angular spread of the radar beam so that interference from multiple reflected signals caused by the presence of the walls of the firing range is reduced as much as possible. Musal [4] has shown that, for practical dimensions of evacuated ballistic ranges (diameters of not less than 1 meter), the radar frequency should be above 30 Gc/s. This ensures a useful operating range, free from interference, of about 3 meter. Second, the radar frequency should be near the plasma frequency of the ionized flow field in order to maximize the radar-plasma interaction. Reference to stagnation-point plasma frequencies [4] indicates that radar frequencies throughout the entire microwave spectrum up to 3000 Gc/s are of interest. With these considerations in mind, an initial choice of 75 Gc/s for the radar frequencies was made.

We used copper for the CSH. The form and the speed of the bodies were observed with the help of multipositioned impulse X-rayed survey along the ballistic path. The speed of the body was also observed with help of microwave radar. An artist's impression of the installation of the radar on the ballistic range is shown in Fig. 1. The coaxial beams from the antenna of the radar are directed through a dielectric window into an 1.5-meter-diameter ballistic-range tank. They are then deflected uprange by means of an expendable radar reflector centered on the flight axis. The backscattered signals from the projectile, which are "Doppler-shifted" due to the projectile motion, propagate back along the same paths to the radar antennas. The Doppler-shuffled signals are detected and recorded. The magnitude of signal is a measure of the radar cross section of the projectile at that particular range. The system is calibrated by transmission of a signal of known power and frequency from a known distance along the axis, which simulates in all respects a back scattered signal from a projectile in flight.

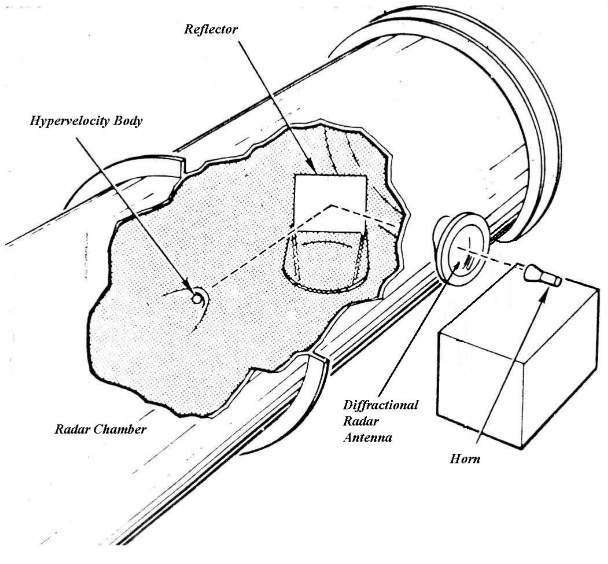

Fig.1. Head on CW Doppler radar.

The CW Doppler technique has been adopted for a number of reasons. The Doppler shift in the frequency of the backscattered signal from the projectile is of suf-

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ficient magnitude to make it possible to use the Doppler technique as a means of discriminating against the stationary background signal. A combination of CW nulling techniques, together with a simple band-pass amplifier, has been found to be very effective in the isolation of the Doppler signal from the stationary background signal. Because of the large Doppler shift (due to the high projectile velocity), it is quite practical to use a single klystron both as a transmitter and as a local oscillator. In addition, since the Doppler shift is used to discriminate against unwanted background signals, a single antenna for both transmission and reception can be used. The resulting unit is simple to construct, operate, and maintain. With CW operation of the radar, it is a simple matter to calibrate the radar accurately by the use of a phase-locked simulator.

The main disadvantage of a CW Doppler radar, namely the absence of range resolution, is unimportant in the present application. The exact location of the projectile at any instant of time is determined by spark-shadowgraph chronograph stations along the length of the ballistic range.

A photograph of the equipment is shown in Fig. 2.

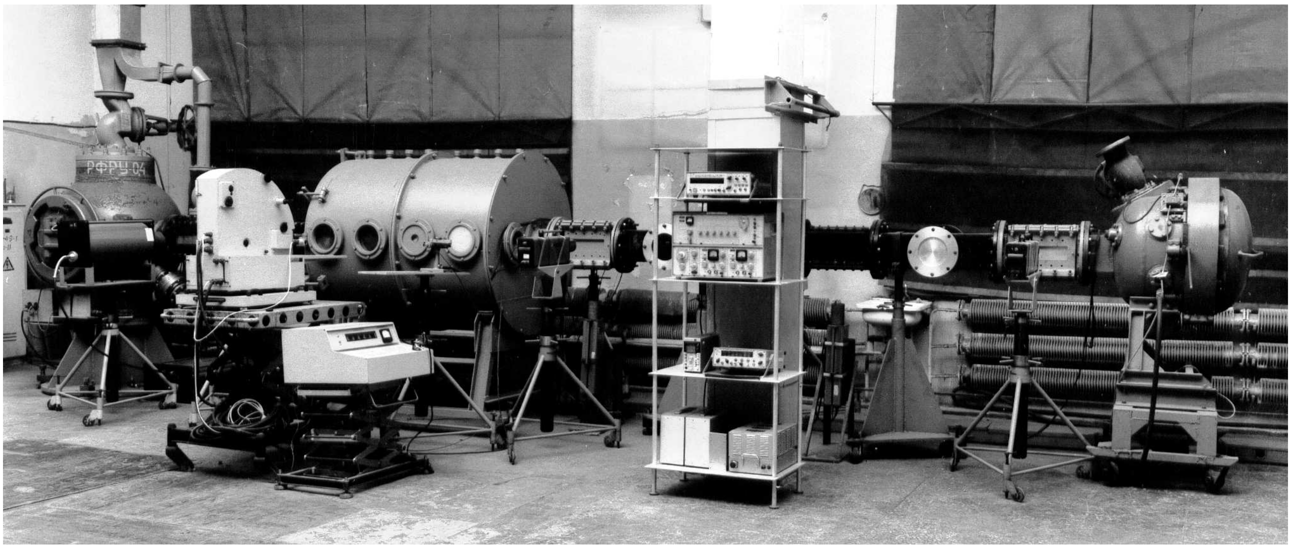


Fig.2. The experimental plant.

The radar chamber consists of a 3.5 meter-long tank, 1.5 meter in diameter, located at the middle of the ballistic range. The uprange end of the tank is lined with microwave absorbing material to minimize the effect of range wall reflections on the radar. The radar reflector, which is made of thin sheet aluminum, is suspended across the flight line at 45° to the flight axis. The supporting framework is designed to enable the sheet to be mounted easily and accurately in position. The sheet is replaced after each firing.

As a matter of convenience, the radars, the recording oscilloscopes, and the Doppler signal simulators are all placed at the same location near the dielectric radar window. The output of simulator is transmitted to the calibration point through low-loss circular waveguide. The calibration antenna with its associated waveguide is carried on a boom which can be pivoted to locate the antenna on the flight line at a known radar range, or along the side of the tank out of the line of fire and out of the main radar beam. The calibration point is approximately 2 meter from the radar reflector.

The time of body flight to the high-frequency section was several times longer than the time of relaxation of the local temperature of the body, taken from the equation of heat conduction:

$$t \approx \rho c_p L^2 \chi^{-1},$$

where ρ- density, c_p- specific heat, χ- the coefficient of specific heat of body material, L- the scale of irregular warning up of the material in the given condition, probably having the size similar to the size of the grain on the surface of the flying body.

The principle of the microwave plasma sounding, based on two off-axis zonel plates, is shown in Fig.3a, the amplitude masks of the three types of DQE's antennas with off-axis focus (a), off-axis FZP antennas (b) and off-axis rectangular FZP antennas, which were used in experimental investigations, is shown in Fig.3b.

The average size of the grain of microstructure of CSH was observed by it's length in three cross-sections on the microedges. The size of the grain was regulated by finding regimes of warmer CSH material. A metallographic sample was polished on a through-thickness plane parallel to the axis of symmetry. The grain boundary character distribution was characterized using orientation imaging microscopy. The observed trend was that the factor of "random" grain boundaries generally decreased with annealing while the grain size increased by less then a factor of 2.5.

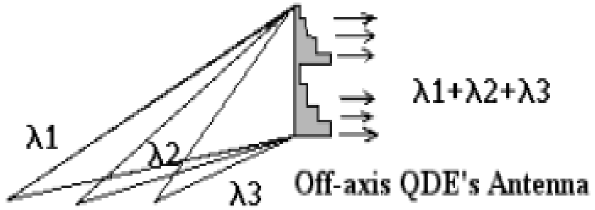
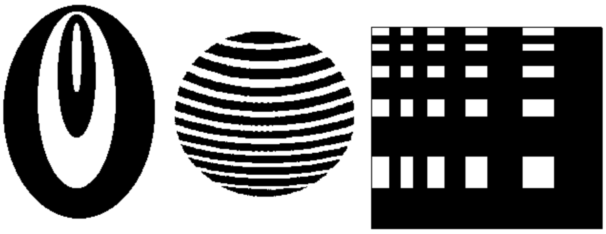


Fig.3a. The principles of the microwave plasma sounding with help of diffractional antennas.



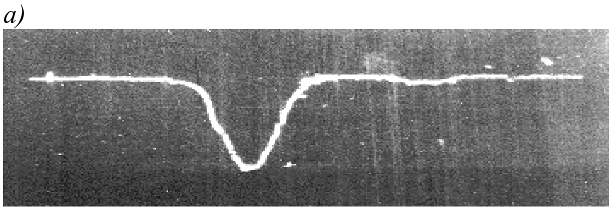
a) b) c)

Fig.3b. The amplitude masks of the DQE's mm-wave antennas with off-axis focus:
DQE's with off-axis focus (a), off-axis FZP antenna (b) and off-axis FZP antenna with rectangular zones (c).

2. Experimental results

In Fig.4, typical signals from the Cu and Al body are shown. Fig.5 shows the dependence of the time of existance of the plasma material with CDP on the size of microstructure grain of CSH material, which was obtained through processing of experimental data for the Cu body. While making the given dependence the data of three series of experiments were used, in which there were 10-15 experiments. The sizes of the CSH material were δ=7-10, 15-25, 80-100 micron. Taking account that the size of the grain on the inner surface of CSH is equal to the size of the surface on the body [5]. From this data, we can see that the size of grain structure on the surface of a high-velocity body greatly influences the electrophysical properties of plasma with CDP.

a)



b)

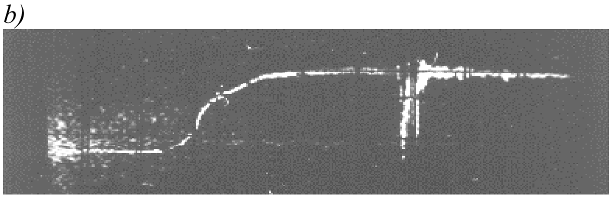


Fig.4. The typical signals from Cu-body (a) and Al-body (b).

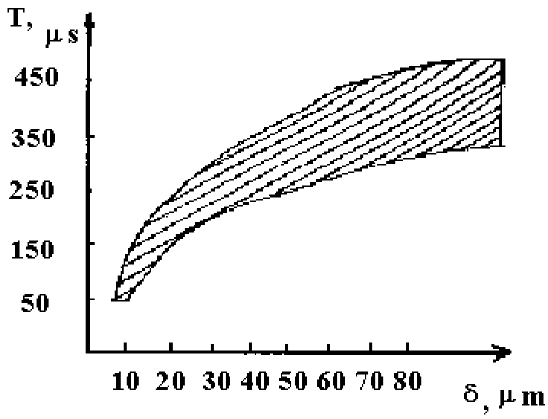


Fig.5. The dependence of the time of existance of plasma with the CDP on the size of microstructure grain of CSH material for Cu body.

The explanation of the discovered regularity, in our opinion, is the following: through the influence of heated plasma, the dynamic limit of fluidity which is an integral characteristic and determines the force of connection between the grain, is dependent on the grain size of body material which reduces creation of microcracks from thermostrain [6]. Alongside, the process of removing material from the body surface takes place as thermo-mechanical erosion.

Deformation and damage of the surface layer of the material become especially large when the temperature region of the half-firm condition is reached. In such a case, the deformation of body surface is probably caused by the movement of grains on the boundaries. This phenomena takes place with the temperature higher than 0.45T, where T – is the melting temperature of the material, which occurs at the given speed (~5 km/sec) for cooper.

The outer layer, which has lost it's mechanical density and is covered by cracks in all directions, is being removed by the stream of air. Also this process is not uniform, because the surface metal grains are being damaged to a different level, the damage of one grain leads to the damage of it's the neighboring grains.

Introducing the particles of metal into the CDP in the plasma track influence it's electromagnetic properties through thermoelectric emission from their surface. Thus the increasing of the grain size of metal microstructure on the body surface probably leads to the increasing of the charged particles in plasma.

Conclusion

Thus, the above mentioned results of the experiments show that while obtaining of plasma with CDP, appearing in the air though movement of high-velocity bodies and studying their electrophysical properties, it is necessary to take into account the influence of the microstructure of the surface of the body. This phenomena may be used, for example, to create remote quasistationary, impulse or moving reflection of microwaves. This impulse antenna is shown in Fig.6.

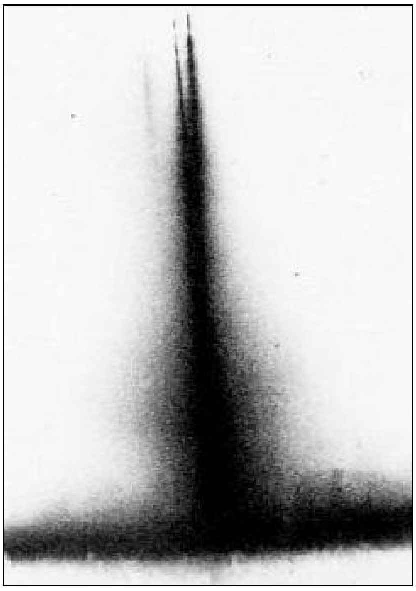


Fig.6. The plasma impulse antennas created in the air by a hypervelocity Al body.

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