ANGULAR CHARACTERISTICS OF AN IONIC ORIENTATION TRANSDUCER UNDER LABORATORY CONDITIONS

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One of the main modes of control for a space vehicle is that for the orientation, since this precedes all other modes (course correction or descent). In particular, considerable importance attaches to providing stability relative to coordinate axes related to the flight velocity vector. Transducers of various types are used, one of which is an ionic orientation transducer, which records the number of ions in the upper atmosphere entering the corresponding receiving device [1, 2].

The components of a transducer of this type are the sensing element SE, which detects the ions in the incident flow, and the electronic unit, which transforms the signals from the SE into control signals for the engines, these being proportional to the deviation of the axis of the sensing element from the direction of the flight velocity vector.

In the form examined here, the sensitive element in the ion transducer is a hollow tube, within which there are (Fig. 1a) the following: the collector vessel 1 in the form of a cylinder of diameter 40 mm and length 70 mm, which is cut along the generators into four identical sections with set of grids 2 with diaphragm, which together provide for generating an ion flux of diameter 20 mm at the collector. They also cut off the electrons from the surrounding space, modulate the ions with a fixed frequency (to provide collector-current amplification), and suppress the dynatron effect at the collector. The diameter of the leading surface 3 in this form is about 110 mm. Because of design considerations, the entrance hole of the SE is displaced relative to the center of the leading surface by 15 mm. The electrodes in set 2 are grids in which the cell size is 0.8×0.4 mm and the wire diameter is 30 μm. The distance between the grids is about 0.7 mm.

The working principle is that the ion flux at the collector is redistributed if there is any change in orientation of the vehicle (and correspondingly in the orientation transducer rigidly attached to it) either laterally or horizontally, and this produces a signal from the electronic system to the vehicle control gear.

The ionic component of the ionosphere is selected on the basis of the closely collimated flux of these particles in the coordinate system linked to the vehicle, which moves with velocity v_0, which satisfies the condition $v_0 \gg \sqrt{2kT_i/M_i}$, where T_i and M_i are the temperature of the thermal motion and the mass of the ions correspondingly, while k is Boltzmann's constant.

A major advantage of an ionic orientation transducer is the short response time (fraction of a second) to any change in angular position. Therefore, this transducer provides rapid orientation of the vehicle on the flight velocity vector.

The output signal U_θ (or U_ψ) is dependent on the angle of rotation (angular characteristic) in the pitching plane θ as shown in Fig. 1b (that for the course plane ψ is analogous). The linear part of the characteristic BC is used to orient the vehicle, while parts AB and CD are used to trap the incident ion flow. The sum of all parts AD is the transducer view zone. The output signal on the linear part BC varies over the range ±6 V and is maintained at this level on the saturation parts AB and CD.

Various external factors can influence the operation under real conditions: the production of a potential on the body of the vehicle when the main and correcting engines operate, the formation of a pad of neutral particles ahead of the surface, etc. These changes in the external conditions may distort the paths of the ions in the incident flow near the detector and cause changes in the output signals. It is therefore important to be able to simulate

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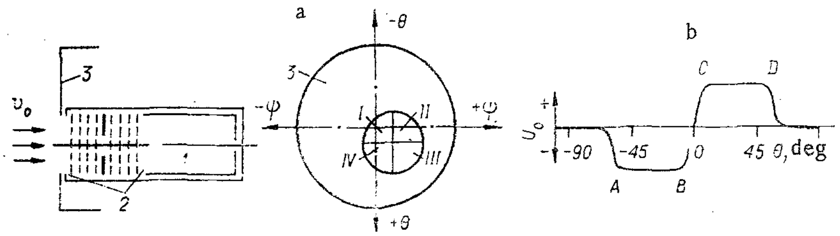

Fig. 1

the effects of these various factors on the angular characteristic under controlled laboratory conditions, since it is much more difficult to make such studies in flight.

For such purposes one needs a flow of low-density plasma whose parameters are close to the natural ones as regards charged-particle concentration, particle velocity, and temperature.

These conditions have been realized in an ionospheric wind tunnel [2, 3], which is a vacuum chamber of diameter 1.5 m and length about 10 m. Within it there is a plasma flow, a coordinate-setting system, the object, and means of diagnosing the flow parameters. A system of vacuum pumps provides a pressure at the level of 1×10^{-3} N/m^2 in the chamber with the source working.

The plasma flow is generated by a source providing ionization of the working substance (nitrogen) by electron impact [4, 5] (Fig. 2a). The production of the ion flow is as follows. In the discharge between the cathode 1 and anode 3 in the ionization chamber 2 a plasma is produced, whose potential is close to that of the anode. The ion-optical system IOS 4 accelerates the ions from the ionization chamber. The flow of low-density plasma reproduces the conditions of flight in the ionosphere as regards the major parameters, and this is produced by combining the accelerated ions with electrons emitted from the heated tungsten filament 5.

The distribution of the potential along the length (Fig. 2b) shows that the energy of the ions in the flow is determined by the difference in potential of the plasma between the ionization chamber I and in the flow of synthesized plasma II, i.e., the ion speed can readily be adjusted by varying the anode potential. Also, a source of this type enables one to vary the other flow parameters over wide ranges: charged-particle concentration (by varying the degree of ionization of the plasma in the source chamber), electron temperature, and plasma potential in the flow (by varying the heating and position of the neutralization filaments).

Table 1 gives the values of the basic parameters such as the charged-particle concentration N, the speed of the directional ion motion v_0, and the electron temperature T_e in the ionospheric tube and in the ionosphere at heights of 100-200 km. The values show that the ionospheric tube enables one to reproduce the flight conditions at these heights and to examine the characteristics of the ionic orientation transducer. The diameter of the flow at the object (about 3 m from the source) is about 1 m. When the experiments are performed, the transducer is set up on the platform in the coordinate-setting system, which enables one to move it along the tube over a distance of 1.5 m and to provide rotation in course and pitch angles by ±90°.

This tube was used in examining the effects of various external factors on the output characteristic of the orientation transducer, including the potential of the transducer body, the surrounding gas pressure, the method of mounting a transducer on the vehicle, etc.

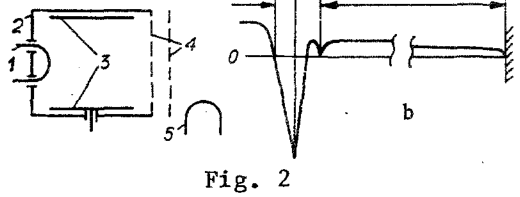

Fig. 2

TABLE 1

Parameter	Ionosphere 100—200 km	Laboratory apparatus
N, 1/cm^3	10^3—10^6	10^3—$5\cdot10^6$
v_0, km/sec	~8	4—10
T_e, °K	1000—3000	1500—4000

Measurements have been made [2, 3] on the effects of the vehicle body potential on the angular characteristics of the transducer, and these show that the geometry of the electric field in the space-charge layer around the transducer plays a considerable part. The effects of the potential on the characteristics are explained by the interaction of the ions in the incident flow with the electric field of the layer and by the unsymmetrical position of the hole in the SE relative to the boundary of the layer.

In previous studies [3], the space-charge layer was produced only by the leading surface of the transducer 3 (Fig. 1a). Under real conditions, the motion of the ionospheric ions is influenced by the charge layer formed directly around the vehicle. Therefore, there may be differences in angular characteristics between transducers set up at different points on the leading surface of the vehicle.

We have examined how various ways of mounting a transducer relative to the vehicle body influence the dependence of the signals U_θ and U_ψ on the body potential U_k.

The part of the vehicle body was simulated either with a grid screen of diameter 500 mm covered with vacuum thermal insulation VTI or else by means of a metal screening disk of diameter 600 mm. The VTI was a layer of insulating material fitted with wires arranged in the form of a grid with a cell size of 10 × 10 mm. The wire diameter was about 0.1 mm. The screens were mounted on the transducer in such a way that the center of the entrance hole in the SE coincided with the center of the screen.

Figure 3 shows to scale the various forms of mutual disposition of the transducer 1 and screens 2 covered by the VTI 3 or without it. In the form shown in Fig. 3a, the transducer is in the flow without a screen, which simulates for example the disposition of the transducer at a certain distance from the vehicle. In Fig. 3b, the metal screening disk is located at the same level as the leading surface of the transducer, which corresponds to the condition where the transducer is placed fairly far from the edge of the vehicle surface. In Fig. 3c, we show schematically the disposition of the screening surfaces for which the surface of the vehicle is covered with the VTI in the region of the transducer as is the part of the SE projecting above the vehicle surface. In the form shown in Fig. 3d, one simulates the method of setting the ionic transducer at the edge of the leading surface of the vehicle, which is of interest for certain conditions of use for these transducers.

Figure 4 shows the effects of body potential U_k on U_θ and U_ψ for each disposition of the transducer and screening surfaces (Fig. 3). The points on the graphs relate to the signals U_θ in the pitch channel θ, while the crosses relate to U_ψ in the course channel ψ. The vertical lines show the standard deviations in the measurements, which in most cases were 15-20% of the signals. All the relationships shown in Fig. 4 were obtained at zero angles of deviation of the FE axis in pitch and course angle. In the experiments, U_k was varied from +8 to —30 V relative to the walls of the vacuum chamber (the potential on the unperturbed plasma in the region of the transducer was about 10 V). The charged-particle

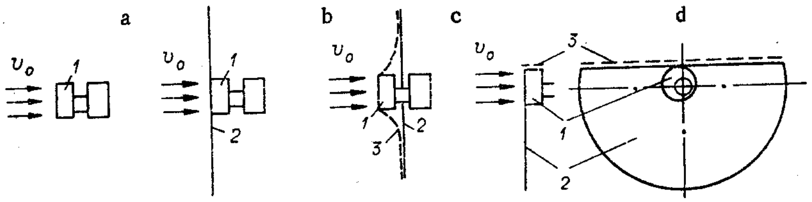

Fig. 3

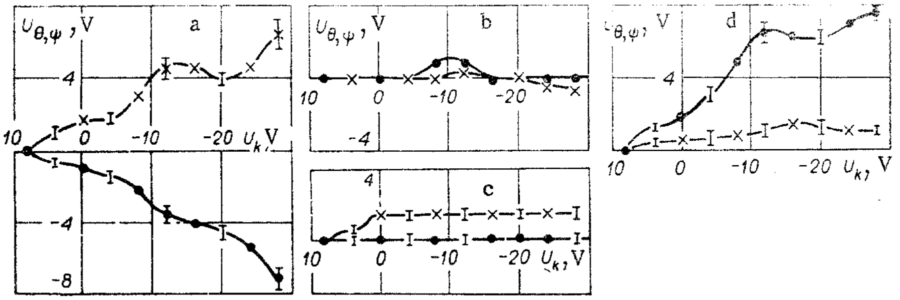

Fig. 4

concentration in the flow was 10^{10} m^{-3}, while the energy of the directional motion of the ions on emerging from the source was 15 eV. In all cases, the screening surfaces and the metallic filaments in the VTI had the same potential as the body of the transducer.

If there are no screening surfaces or VTI on the transducer (Fig. 3a), any change in body potential produces signals on both channels (Fig. 4a), which is [2, 3] due to the unsymmetrical disposition of the entrance hole in the SE relative to the symmetry axis of the space-charge layer around the transducer, and the magnitudes of these signals may exceed the magnitude of the useful signal for large negative values of U_k.

The use of a metallic screening disk at the same level as the leading surface of the transducer (Fig. 3b) causes the electric field in the space-charge layer around the transducer to be close to the field in a planar layer. This produces a substantial reduction in the distortion of the ion paths in the incident flow in the layer and correspondingly reduces the effects of U_k on U_θ and U_ψ (Fig. 4b).

In the case of Fig. 3c, the projecting part of the SE and the screen are covered with the VTI, and then there is no dependence of U_θ on U_k, while there is only a slight effect on U_ψ (Fig. 4c). If the VTI is removed while leaving the screen in the previous position, there are increases in U_θ and U_ψ when U_k varies. Also, with the system of Fig. 3c the effects of the body potential on the transducer signals are more marked than those in Fig. 3b. These results show that advancing part of the transducer above the surface of the vehicle produces an inhomogeneous electric field in the layer around the transducer. However, the presence of the VTI on the transducer and screen tends to balance out the effects of this field.

Figure 4d shows results on the position of the transducer shown in Fig. 3d. In that case, the effects of U_k on the signal in the pitch channel are more important than those in the course one. This relationship agrees satisfactorily with views on the effects of the disposition of the space-charge layer relative to the input hole of the SE as regards the dependence of U_θ and U_ψ on U_k. In fact, in that case the space-charge layer has a larger curvature on the screen cutoff side, which leads to more marked curvature of the ion path in the direction of the collectors III and IV (Fig. 1a), which is perceived by the transducer as deviation of the SE axis in the positive pitch direction. Correspondingly, U_θ (Fig. 4d) is of positive sign. At the same time, U_k has appreciably less effect on U_ψ, because the field distribution in the layer remains close to symmetrical with respect to the $\pm\psi$ axes.

Therefore, these results show that an ionospheric wind tunnel can be used to compare various ways of installing an ionic orientation transducer on a vehicle and to choose the best setting from the viewpoint of minimum effect of the vehicle body potential on the output signals. Also, these results confirm the previous suggestion [3] on the effects of the space-charge layer electric field geometry on the output signals.

These results also show that it is effective to use ionospheric tubes to examine the effects of various flight factors on the characteristics of measuring equipment used in orbital flights.

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INITIAL DISEQUILIBRIUM IN SUPERSONIC FLOW OF LOW-DENSITY ARC PLASMA

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Much attention is currently being given to nonequilibrium processes in supersonic flows of supercooled plasma. Particular interest attaches to the conditions for nonequilibrium population of excited atomic and ionic states in the plasma-forming body. The working bodies are usually gases in experiments, while in theoretical calculations they are the vapors of readily ionized metals, which are recognized as promising working bodies for plasma-dynamic lasers, particularly lithium vapor. For example, population inversions have been observed in supersonic plasma flows for the levels of hydrogen [1] and helium [2], and lasing has been obtained in supersonic plasma jets of argon [3] and hydrogen [4]. In all the experiments, the plasma flow was from an electric-arc source into a low-density medium under stationary conditions [1, 2] or quasistationary ones [3, 4].

Studies on the parameters of the plasma in low-density supersonic jets produced by electric-arc sources have also shown that there is marked thermal and ionization disequilibrium in the flow beginning with the end of the nozzle [5] and in the plasma-source arc chamber [6].

The substantial initial disequilibrium in the plasma produced by an arc discharge (an arc plasma) complicates examining the variation in parameters during the subsequent expansion. At present, in spite of extensive studies such as [7], methods of estimating arc-plasma parameters remain very complicated.

Here we present an engineering method of estimating the parameters of a thermal plasma formed by a dc arc discharge at a pressure in the source chamber not exceeding 10^5 Pa and a temperature T_0 of $2\text{-}20 \times 10^3$ °K. The estimates are compared with experimental data.

The method involves the following assumptions:

1) The plasma is assumed to be ideal and of two-temperature type and consisting of electrons, ions, and atoms with Maxwellian velocity distributions and with temperatures T_e for the electrons and T_0 for the heavy particles (atoms and ions);

2) the plasma parameters are homogeneous in the arc-discharge region;

3) the ionization equilibrium in the plasma corresponds to the electron temperature T_e; and

4) the difference between T_e and T_0 is due only to the electric field.

In this formulation, the state of the plasma in the electric field of the arc can be described by a system of equations for a thermodynamically equilibrium plasma together with a relation specifying the nonisothermal nature of the plasma as determined by the electric field strength E. Finkelnburg's equation [8] is used for this purpose, which reflects the balance of the energy acquired by the electrons in the electric field and the energy they lose in elastic collisions with heavy particles.

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