12. I. A. Vasil'eva, "Boundary condition for plasma concentration in a magnetic field," Radiotekh. Élektron., 5, No. 12, 2015 (1960).
13. I. I. Litvinov, E. D. Lyumkis, and S. S. Filippov, "Nonequilibrium and overheating instability in a pulsed xenon discharge," in: Fourth All-Union Conference on Physics of Low-Temperature Plasma. Abstracts of Papers [in Russian], Vol. 2, Inst. Fiz., Akad. Nauk UkrSSR, Kiev (1975).
14. D. V. Sivukhin, "Drift theory for motion of charged particles in electromagnetic fields," in: Problems in Plasma Theory [in Russian], Vol. 1, Gosatomizdat, Moscow (1963).

# INVESTIGATION OF THE CHARACTERISTICS OF THE IONIZATION CHAMBER AND THE PROPERTIES OF THE FLOW OF A GAS-DISCHARGE ION SOURCE

V. E. Nikitin, L. V. Nosachev, and V. V. Skvortsov

UDC 533.9

A gas-discharge ion source with volumetric ionization [1] is an effective device for creating flows of a rarefied plasma, which, with high values of the specific impulse, can be used as reactive jets [2], and which, with low velocities of the flow, find application in experiments on ionospheric aerodynamics, carried out with the aim of modeling the interaction between an aircraft and the ionosphere [3,4]. When such a source is investigated as a device for creating a reactive jet, along with metals (cesium, mercury), gases are used as its working substance: xenon, argon, and nitrogen, which (as well as helium) are used as the working substance of a gas-discharge source and in experiments on ionospheric aerodynamics. Therefore, the study of the characteristics of such a source working on gases is of considerable interest.

The aim of the present work was an investigation of the characteristics of a gas-discharge ion source and the flow of plasma set up by it. High values of the principal parameters of the source (the ionic current, the coefficient of the use of the working substance, expenditures for the production of one ion, i.e., the cost of the ions, the energy efficiency) can be obtained only with the realization of determined conditions of the burning of the discharge in the ionization chamber. Here it is important to know the distribution of the potential of the plasma, determining the losses of ions in the chamber, and the form of the distribution function of the electrons, on which the efficiency of the ionization of neutral atoms depends. In experiments on ionospheric aerodynamics, the ion source must set up a flow of synthesized plasma with relatively low (~100 eV) energies of the directed motion of the ions with the required concentration in the working part of the flow. The characteristics of such flows in the absence of a magnetic field have been discussed in [3, 4]. However, for problems of ionospheric aerodynamics, there is also required the study of the parameters of the flows of a synthesized plasma propagating in magnetic fields with an intensity up to several hundred oersteds.

The investigations were made with a source with a diameter of 10 cm, a schematic diagram of which is shown in Fig. 1 (1 is the gas inlet; 2 is the cathode; 3 is the anode; 4 is the shielding grid; 5 is the accelerating grid; 6 is the ion beam; 7 is the neutralizer; 8 is the electromagnet; and 9 is the shield). The process of the efficient conversion of a neutral gas to a plasma, whose ionic component subsequently obtains the required velocity in the ionic optical system, takes place in an ionization chamber with a directly heated electron emitter. An electromagnet is used to create an intrinsic magnetic field in the ionization chamber of the source. The current $I_s$ through its coil, equal to 1 A, corresponded to the intensity of the magnetic field at the axis of the chamber, equal to 15 Oe.

---

Zhukovskii. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 1, pp. 56-61, January-February, 1977. Original article submitted January 12, 1976.

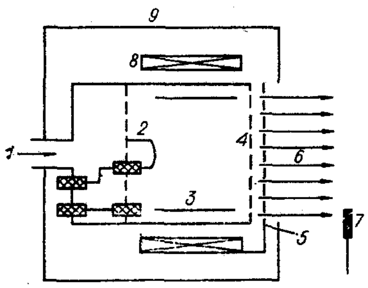


Fig. 1

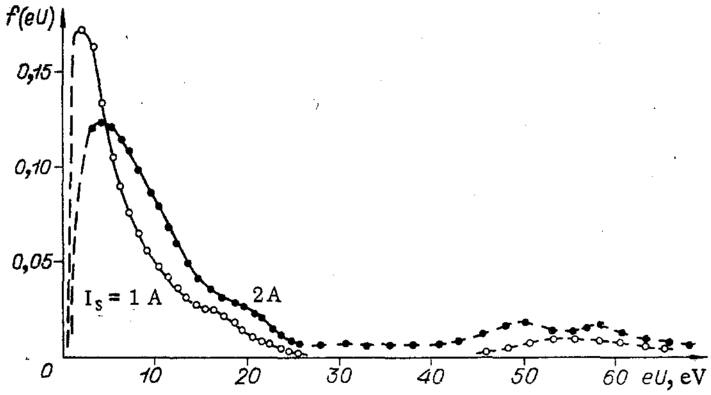


Fig. 2

Measurement of Parameters of Plasma in the Ionization Chamber

The distribution of the potential of the plasma with respect to the anode $U_a$ was recorded in [5]. The concentration of charged particles was determined using separate flat and cylindrical probes. With an analysis of the probe characteristics using the usual method [6], it was found that the electronic part of the characteristic curve in semilogarithmic coordinates is not rectilinear, i.e., in the investigated range of conditions in the ionization chamber, there is a deviation of the energy distribution function of the electrons from a Maxwell distribution. In this case, the concentration was determined using the Dryuvestein method [7], making it possible to obtain the distribution function with respect to the second derivative of the probe current. The latter was found on an electronic computer by numerical differentiation of the probe characteristic; the scatter of the values of the second derivative in the range of energies 0-70 eV did not exceed 30%.

The presence in the plasma of electrons with a large energy is the reason for the additional maxima of the distribution function (Fig. 2, where eU is the energy of the electrons). In comparison with the results of [8], obtained for mercury vapors, the δ-function in the energy distribution of the primary electrons is not realized.

The form of the distribution of the potential of the plasma over the radius with respect to the anode $U_a$ depends to a considerable degree on the value of the intensity of the magnetic field (Fig. 3). With small intensities, the value of $U_a$ is positive over the whole volume of the plasma, i.e., there is a negative anode drop, studied in the absence of a magnetic field in [9]. A rise in the intensity of the magnetic field leads to the appearance of a positive anode drop and to a decrease of the potential ($U_a < 0$) in the preaxial zone. Under these conditions, it is not possible for the ions to reach the anode, and maximal values of the coefficient of the use of the working substance are attained. The value of the error in determination of the potential of the plasma by the thermoprobe method with constant values ofthe incandescence current of the thermoprobe did not exceed ±0.5 V.

The maximal values of the concentration of charged particles in the plasma lay at the level $(1-2)\cdot 10^{11}$ $cm^{-3}$; under these conditions, no distorting effect of a relatively weak magnetic field on the electronic part of the probe characteristic is observed with the conditions under consideration.

Characteristics of an Ion Source in Xenon with High Specific Impulses

An investigation of the characteristics of an ion source as a device for creating a reactive jet was made using argon, nitrogen, and xenon as working substances. Among them, xenon, having a low value of the ionization potential and a high mass number, is the most suitable substance for the most efficient work of the device.

Table 1 gives some characteristic data in the investigated range of parameters: The mass flow of xenon corresponded to 225-425 mA of the equivalent ionic current; the anode voltage was 30-40 V. The maximal values of the ionic current $I_i$ exceeded 370 mA; the density of the ionic current, referred to the area of the openings in the grids of the ionic-optical system, attained 18 $mA/cm^2$; the coefficient of the use of the working substance $\eta_m$ had values in the range 0.6-0.9.

TABLE 1

| | | | | | |
|---|---|---|---|---|---|
| $I_i$, mA | 207 | 233 | 306 | 347 | 374 |
| $\eta_m$ | 0,92 | 0,62 | 0,81 | 0,82 | 0,88 |
| $E_a$, eV/ion | 540 | 420 | 450 | 440 | 500 |
| $\eta_n$ | 0,8 | 0,82 | 0,84 | 0,85 | 0,84 |

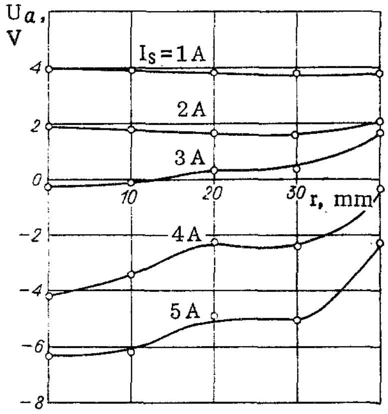


Fig. 3

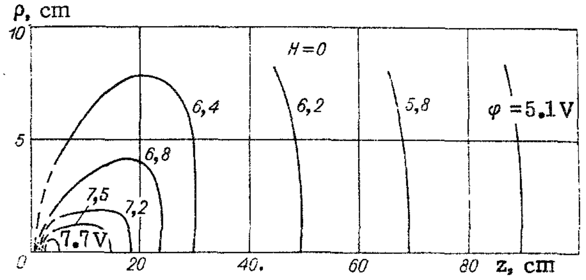


Fig. 4

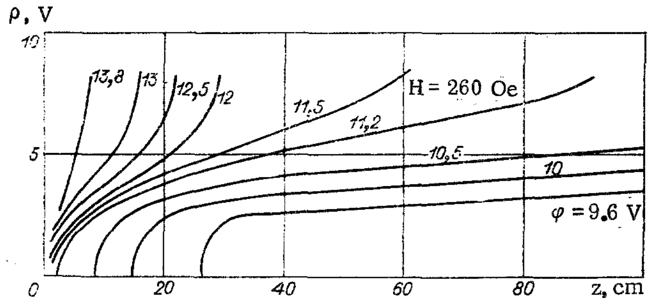


Fig. 5

The experimental data are given with a transparency of the grids of the ionic-optical system around 0.38; therefore, the value of the discharge of the ions $E_a$ did not drop below 420 eV/ion. With an accelerated voltage, equal to 5000 V, the energy efficiency of the source $\eta_n$, equal to the ratio of the power in the ion beam to the total power supplied, was 0.8-0.85. The values of the specific impulses of the reactive jet, set up by the source, calculated by taking account of the value of the coefficient of the use of the working substance, lay in the range 5000-7500 sec.

Characteristics of Jet of Ion Source in Experiments on Ionospheric Aerodynamics

The parameters which, in experiments on ionospheric aerodynamics, must be satisfied by the flows of a synthesized plasma set up by ion sources are discussed in [3, 4]. In the present work, an investigation was made of the characteristics of a flow of rarefied plasma with the resultant energy ~100 eV, with its propagation in a longitudinal magnetic field with an intensity up to 700 Oe, simulating the magnetic field of the earth.

The parameters of the flow of a rarefied plasma were measured with multielectrode probes (measurement of the energy distribution of fast and slow ions, the temperature of the electrons, the concentration of slow ions); there were also used flat Langmuir probes (determination of the concentration of fast ions and the temperature of the electrons) [4, 10], thin cylindrical probes (measurement of the temperature of the electrons in the presence of a magnetic field), and thermoprobes (measurement of the potential of the electrical field in a flow of plasma) [11].

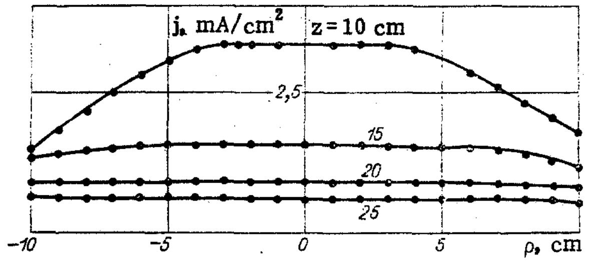


Fig. 6

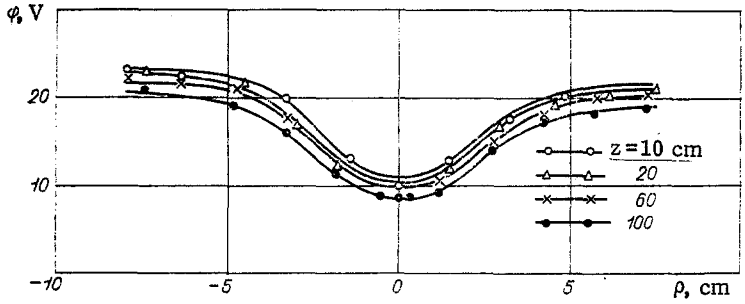


Fig. 7

The potential in the flow of plasma was determined from the result of an analysis of the characteristics of cold and heated probes, using a method proposed in [11], where an analysis was made of the errors arising with the use of thermoprobes in a flow of rarefied plasma. For the conditions under consideration, the values of the errors with determination of the potential of the plasma are ±0.3 V.

A thermoprobe was used to measure the distribution of the potentials in a flow of plasma without a magnetic field and with an external magnetic field. The energy of the helium ions in the flow was 70 eV. The experimental data were used to construct pictures of the equipotential electrical field in a flow of rarefied plasma with H = 0 and 260 Oe, shown in Figs. 4 and 5 (ρ is the distance from the axis of the flow in a radial direttion; z is the distance from middle of the ion source along the flow). The difference in the pictures of the equipotential field in a flow with an external magnetic field and without it is due to the character of the motion of the charged particles of the flow.

Without a magnetic field, the flow of plasma set up by a gas-discharge ion source diverges (Fig. 6, where j is the density of the ion current) and has an angle of its half-aperture of 15°. Therefore, to assure quasineutrality with H = 0, the electrical field is so directed that the electrons are held in the jet in the zone of maximal density of the ions at the axis of the flow at the outlet of the ion source. The imposition of a longitudinal magnetic field leads to the focusing of the ion jet and to a considerable increase in the concentration of charged particles in the working volume of the ionospheric aerodynamic tube. Figure 7 shows the change in the distribution of the potential of the plasma φ along the length of the jet with H = 520 Oe, with a concentration of ions at the axis of the flow equal to $2 \cdot 10^{9}$ $cm^{-3}$. A longitudinal magnetic field hinders the neutralization of the ion jet due to a weakening of the diffusion of the electrons across the magnetic field. Under these conditions, the electrical field arising near the neutralizer and in the jet should promote the motion of electrons over the radius of the jet.

As a result of investigations of the distribution of the potentials in a flow with an external magnetic field it has been established that a rise in the intensity of the electrical field leads to an increase in the gradient of the electrical field over the cross section of the jet. With intensities of the magnetic field greater than 300 Oe at the outlet from the ion source, there arises an electrical field, which leads to debunching of the ions and their departure from the grid of the ionic-optical system. With a rise in the intensity of the magnetic field, there is also an increase in the depth of the drop in the potential of the plasma at the axis of the jet. The longitudinal gradient of the electrical field in a flow of a rarefied plasma with an external magnetic field is approximately 0.04 V/cm.

The investigations showed that the gas-discharge ion source under consideration has high energy characteristics and is effective for obtaining a jet of rarefied synthesized plasma with parameters satisfying conditions simulating the flight of aircraft in the ionosphere. The introduction of a flow of synthesized plasma into a longitudinal magnetic field, modeling the magnetic field of the earth, has been realized, and the gradients of the potentials along the jet of plasma in this field have been determined.

The authors express their thanks to G. L. Grodzovskii for his interest in the work and for his fruitful discussion of the questions touched on in the article.

## LITERATURE CITED

1. M. D. Gabovich, Plasma Sources of Ions [in Russian], Izd. Naukova Dumka, Kiev (1964).
2. H. R. Kaufman and P. D. Reader, "Experimental performance of ion rockets employing an electron-bombardment ion source," in: Progress in Astronautics and Rocketry, Vol. 5, New York–London (1961).
3. S. D. Hester and A. A. Sonin, "A laboratory study of wakes of ionospheric satellites," AIAA J., 6, No. 6 (1970).
4. V. V. Skvortsov and L. V. Nosachev, "Investigation of the structure of a wake behind spherical models in a flow of rarefied plasma," Kosmich. Issled., 6, No. 2 (1968).
5. M. D. Gabovich, O. A. Bartnovskii, and Z. P. Fedorus, "Potential drop at the axis of a discharge with the oscillation of electrons in a magnetic field," Zh. Tekh. Fiz., 30, No. 3 (1960).
6. O. V. Kozlov, An Electrical Probe in a Plasma [in Russian], Izd. Atomizdat, Moscow (1969).
7. V. L. Granovskii, An Electric Current in a Gas [in Russian], Izd. GITTL, Moscow (1952).
8. W. B. Strickfaden and K. L. Geiler, "Probe measurements of the discharge in an operating electron bombardment engine," AIAA J., 1, No. 8 (1965).
9. B. N. Klyarfel'd and N. A. Neretina, "The anode region in a gas discharge with low pressures," Zh. Tekh. Fiz., 28, No. 2 (1958).
10. L. V. Nosachev and V. V. Skvortsov, "Investigation of the slow ions of a rarefied plasma using a multielectrode probe," Uch. Zap. Tsentr. Aéro-gidrodinam. Inst., No. 3 (1973).
11. E. M. Netsvetailov, L. V. Posachev, and V. V. Skvortsov, "A glued probe in a flow of rarefied plasma," Zh. Tekh. Fiz., 44, No. 12 (1974).

# NATURE OF SIGNAL EXTRACTED FROM A TOTAL ELECTROMAGNETIC PULSE

V. V. Ivanov, Yu. A. Medvedev, B. M. Stepanov, and G. V. Fedorovich

UDC 538.561

§1. It is well known [1] that gamma rays passing through air excite electromagnetic fields by currents produced by Compton electrons that are formed during the interaction of gamma quanta with the atoms and molecules of air. In the idealized case of an isotropic source and a homogeneous medium this field is present only in the current zone; however, in actuality there is always some asymmetry present which leads to radiation of electromagnetic waves.

In [1, 2] the fields are computed for the current zone as well as the wave zone for a gamma-ray pulse that damps exponentially in time; here the nature and origin of the spatial asymmetry in the distribution of the radiating currents were not specified. The model problem of fields excited by a pulsed gamma-ray source, located at the plane boundary of the half-space formed by an ideal conductor and homogeneous air, is solved in [3]. The problem for an isotropic source in inhomogeneous air is investigated in [4] without considering the effect of the underlying surface. In [1-4] the air density is normal or close to it. The

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 1, pp. 61-68, January-February, 1977. Original article submitted March 17, 1976.