DEVICE FOR PLASMA DIAGNOSTICS
WITH A MULTICOMPONENT BEAM
OF FAST NEUTRAL PARTICLES


An active method for the diagnostics of a high-temperature plasma by means of beams of fast neutral particles has been successfully tested in the last few years [1-5]. The method is very promising, does not involve a direct contact with the plasma, is characterized by high resolution in time and space, and enables plasma-parameter measurements in a range in which measurements with other techniques are difficult.

As has been shown, e.g., in [1], measurements of the relative attenuation of neutral particle beams passing through a plasma can be used to obtain the time-dependent pattern of the principal plasma parameters, namely $n_i$, the ion density; $n_n$, the density of the neutral component; and $T_e$, the electron temperature.

The present article describes a device for the diagnostics of a hydrogen plasma with a three-component neutral beam ($H^0$, $H_2^0$, and $He^0$) having an energy of several kiloelectronvolts. The simultaneous use of three beams increases both the accuracy and reliability of the results of a diagnostic test. The use of a beam of hydrogen atoms enables measurements of the ion density in a hydrogen plasma. Once the ion density is known, one can evaluate the electron temperature of the plasma from the relative attenuation of the helium beam. The attenuation of the beam of fast hydrogen molecules provides additional information on the electron temperature or, in the case of a low degree of plasma ionization, on the density of the neutral component.

Light atoms can be recommended for testing for several reasons. First, one can obtain a very high time resolution with light atoms, because the resolution is basically determined by the time of flight of the test particles in the plasma; second, light atoms facilitate ionization measurements in the neutral beam portion which was attenuated by interactions with the plasma, and thus, one considers stripping reactions in the gas because the corresponding cross section assumes its maximum in the case of light atoms; third, one can use a magnetic analyzer with a high mass dispersion which is also greatest for light particles [6].

Experimental Setup

Figure 1 shows schematically the setup described. A multicomponent beam of neutral particles with an energy of several kiloelectronvolts is generated in a neutral particle source 1 which comprises a usual high-frequency ion source $f = 50-70$ MHz; power of the discharge $P = 100$ W. The charge exchange of the ions in the source takes place within the channel.
of an accelerating electrode 3 \((l = 60 \text{ mm}, d = 2.5 \text{ mm})\) and involves the gas which flows in from the source. This arrangement made it possible to simplify the source and to reduce its size, because, first of all, it was no longer necessary to use a charge-exchange chamber and, hence, a huge vacuum system, and second, because it was possible to simplify the supply circuit for the high-frequency generator (the generator is on ground potential). In order to obtain a vacuum of about \(5 \times 10^{-5} \text{ mm Hg}\) in the volume following the accelerating electrode, a single TsVL-100 pump sufficed during the operation of the source.

At a distance of about 0.5 m from the source, the equivalent current of neutral hydrogen atoms (measured with the current of secondary electrons which are knocked from the retractable target 7 by the neutral atoms) reached 80 \(\mu\text{A}\) at a beam diameter of about 0.5 cm.

The electric field between the accelerating electrode 3 and the chamber walls stops the ions which do not participate in the charge-exchange process; this leads to a shielding of the neutral beam. A capacitor which deflects the ions in the transverse direction is provided for the same purpose. The neutral beam which was attenuated by the interaction with the plasma is once more separated from the charged particles which enter into the beam from the plasma, and passes into stripping chamber 13. This chamber has the form of a gas-delay line, i.e., it consists of a set of concentric stainless steel rings which are closely spaced (spacing about 2 mm). The internal ring diameter increases gradually toward the chamber outlet (from 6 to 14 mm) and creates an aperture angle of not less than 4-5° for viewing the center section of the plasma. The chamber has a length of 12 cm. The pressure is of the order \((1-5) \times 10^{-4} \text{ mm Hg}\). Air is used as the stripping gas.

The set of concentric rings is isolated from the housing by means of Teflon sleeves. By adjusting the potential applied to the stripping chamber, the ions generated by stripping reactions in the neutral beam can be transferred from one energy interval into another to which the electrostatic ion-energy analyzer 15 and the magnetic mass analyzer 18 are adjusted. This facilitates the adjustment of the entire system when one switches to a beam with a different energy.

The electrostatic ion-energy analyzer, in which a cylindrical capacitor \([8]\) with an aperture angle of 127°17' is used, serves for separating particles with a certain, well-defined energy from the ion beam.

During the operation of the stripping chamber, the pressure in the analyzer amounts to \((3-6) \times 10^{-5} \text{ mm Hg}\).

The mass resolution of the monoenergetic ion beam takes place in the magnetic analyzer 18 which consists of sectors and has an aperture angle of 60°. A collector 20 for regulating the current of the ion beam leaving the electrostatic analyzer is provided in the chamber of the analyzer.

The ion beams are recorded with ion-electron converters 21. The dispersion of the magnetic analyzer amounts to about 43 mm per proton mass. Therefore, small-size 16B photomultipliers can be used without connecting light guides. The aperture of the target relative to the center of the plasma device is not less than 3°. In calculating the aperture angle, the focusing effect originating from the charged particles was taken into account. The focusing effect depends upon the angle of the cylindrical capacitor which has an aperture angle of 127°17' \([8]\).

In order to simplify the adjustment of the entire system, a d.c. signal modulation of the multiplier photocathode is used; the modulating frequency is 500 kHz. The modulating high-frequency voltage has an amplitude of not more than 10-15 V and is applied to the photocathode rather than to a modulating grid which is usually provided for this purpose \([9]\). Application of