NEW TYPE OF CHARGE-EXCHANGE PARTICLE ANALYZER

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To determine the ion temperatures of plasmas in modern thermonuclear facilities, neutral particles (neutrals) are often used, which are formed in the plasma by the interaction of ions with neutral particles, which are always presented in the apparatus. Measuring the energy of the formed particles can determine the temperature of the plasma.

For this, the neutrals are ionized in one way or another and the energy and mass composition of neutral fluxes are determined with help of various analyzers.

At present, neutrals are passed through an ultrathin (20-200 angstrom thick) carbon foil for ionization. After the passage of the foil, neutral, positively and negatively charged particles are contained in the particle flux. In a laboratory plasma, positive ions are usually used for measurements [1, 2].

In this paper, we describe an instrument in which the ionizing of charge exchange neutrals are fulfilled when they are scattered on the surface of a solid [2, 3].

Fig.1. Ionizer of "blinds" type

Ionizer of “jalousie” type, which uses this principle, is a set of Ta plates 5 mm wide, located at a distance of 2 mm from each other. Those plates are mounted in a cylindrical body. The photograph of the ionizer is shown in Fig.1.

The scheme of operation of such ionizer is shown in Fig.2. The flow of neutral particles from the plasma D^0 falls between the plates of the ionizer and is reflected from them. Positive ions D^+ are sent to the electrostatic analyzer.

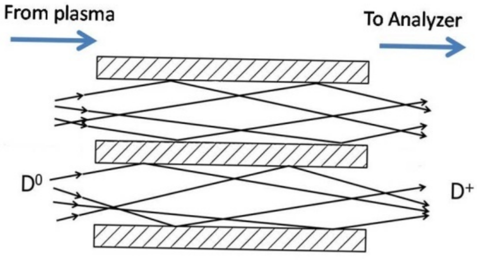

Fig.2. The scheme of the ionizer.

The scheme of the Charge Exchange Particle Analyzer (CEPA) is shown in Fig.3, and its photograph is shown in Fig.4.

The flux of neutrals hits ionizer 1. The energy of positively charged ions is measured by an electrostatic analyzer 2. The ions are detected by the detector 3. The magnetic screen 4 is simultaneously a vacuum volume of the CEPA. The CEPA is connected to the installation through the flange 5. The detector in this device is the Channelnetron. To reduce the size of the instrument in the direction of the ion flux from the electrostatic analyzer, the outgoing particle flux is rotated as it is shown in Fig. 5. The particles from the analyzer pass through the diaphragm 1 to the conical diffuser. Scattered particles pass through diaphragm 2 onto the Channelatron.

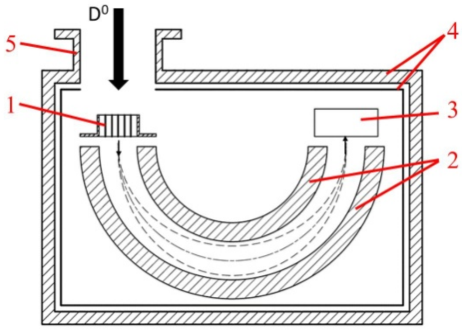

Fig.3. The CEPA schematic diagram

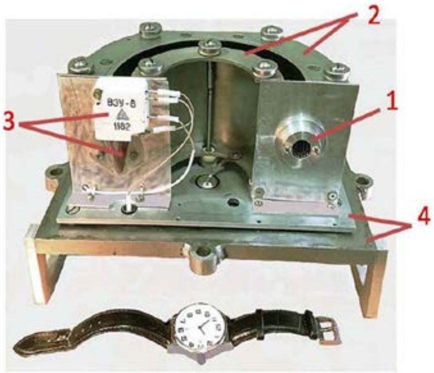

Fig.4. The CEPA photo

1 - ionizer, 2 - electrostatic analyzer, 3 - detector, 4 - magnetic shield, 5 - inlet nozzle.

The energy distribution of ions in the plasma $f_i(E)$ is related to the distribution of ions leaving the electrostatic analyzer $f_a(E)$ by the relation

$$f_i(E) = f_a(E) / \eta(E) \qquad (1)$$

where $\eta(E)$ is the efficiency of CEPA registration.

If $f_i(E) \sim e^{-\frac{E}{T}}$, where T is the plasma ion temperature we have

$$T = \frac{E_1 - E_2}{ln(f_i(E_1) / f_i(E_2))} \qquad (2)$$

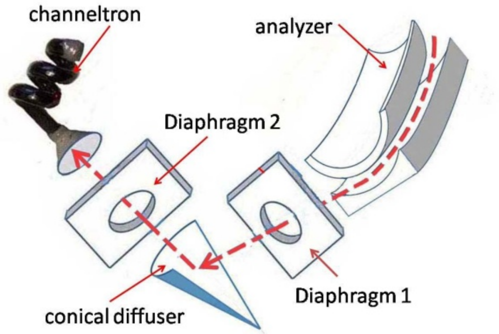

Fig.5. Detector unit.

For the following we represent the quantity $\eta(E)$ in the form

$$\eta(E) \sim E^{\alpha} \qquad (3)$$

The CEPA works as follows. A potential, which varies from 0 to the maximum value during some time t, is applied to the analyzer plates. Accordingly, during the same time, the detector signal also changes. At T-10, this value was 20 or 50 ms. Thus, during the operating pulse of the installation (~ 1c), the plasma temperature was measured every 20 or 50 ms.

To calibrate the device (determine the value $\eta(E)$), we used the fact that in the ohmic mode of tokamak operation, the Artsimovich formula [4]

$$T(0)=(1.3\pm 0.14)\frac{\left(IBR^2<n>\right)^{1/3}}{A_i^{1/2}} \tag{4}$$

in the steady state ("plateau" mode) describes the plasma temperature on its axis with an accuracy of 11%. Here I (kA) is the plasma current, B (kG) is the value of the toroidal magnetic field, R (cm) is the large radius of the tokamak, <n> (10^{13} cm^{-3}) is the average plasma density.

Data for 52 spectra were used for calibration. As a result, it was found that $\alpha = 2.10 \pm 25\%$, which leads to an error in determining the ion temperature $\pm 10\%$.

Figure 6 compares the ion temperature calculated by the Artsimovich’s formula, determined by formula 2 and measured by the method of resonance spectroscopy (CXRS). The "plateau" in this discharge begins approximately 500 ms. It can be seen from the figure that the values of the ion temperature, determined by three different methods, practically coincide.

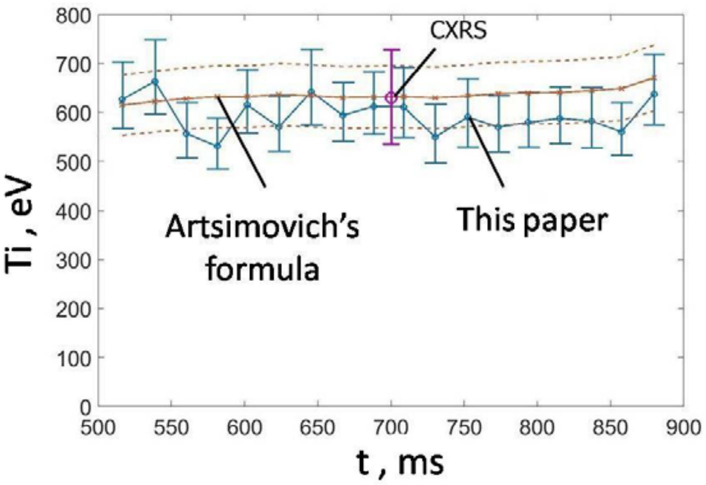

Fig.6. Comparison of the ion temperatures determined by different methods.

In Figure 7 one can see the comparison of the ion temperatures determined by the same three methods in a discharge in which the sequential injection (approximately every 40 ms) of 5 deuterium pellets (starts at 550 ms) and electron-cyclotron heating (starts at 600 ms). Each pellet contains about 2.10^{19} deuterium atoms. The same figure shows the data on the electron temperature. It can be seen from the figure that in this case the temperatures measured by the described method and with the aid of CXRS coincide, with accuracy up to measurement errors. The fact that under these conditions the ion temperature on the "plateau" does not practically change coincides with the fact that the electron temperatures for 500 ms and 800 ms are practically the same.

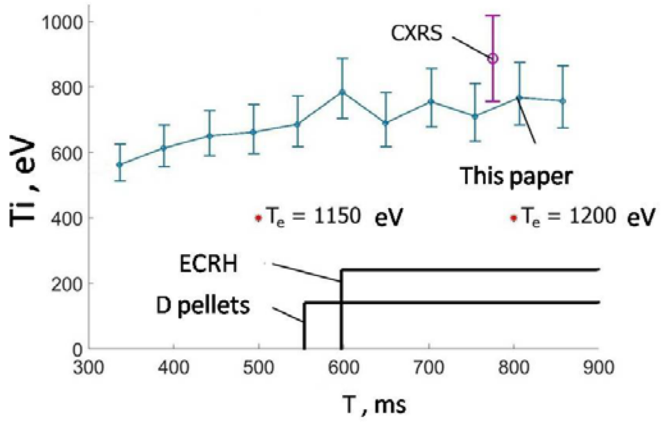

Fig.7. Ion and electron temperatures in a discharge with electron-cyclotron heating and pellet injection

The sensitivity of the proposed analyzer increased by almost 10 times in comparison with the analyzer, in which ionization of the charge-exchange particles was carried out on carbon foil 50 Å thick. The replacement in the device of the detector - the secondary electron multiplier on the microchannel plates by the channel multiplier allowed to significantly reduce the background from hard X-rays. In addition, the minimum energy of the analyzed particles decreased to several tens of electron volts and it became possible to analyze the neutrals of any chemical elements. All this makes it promising to use the proposed method for investigating scrape-of-layer plasma and plasma in a divertor.

In conclusion, we consider it our pleasant duty to express our gratitude to V.A. Krupin's group for presenting data on the ion temperature (CXRS) and the V.M.Trukhin's group for presenting data on the electron temperature.

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