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Operation with a High Pressure Plasma in the Central Solenoid of AMBAL-M

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At present, behavior of a collisionless hot plasma in long solenoids is studied experimentally on the ambipolar mirror machines GAMMA-10 [1] and AMBAL-M [2], and also on the open mirror trap HANBIT [3]. In these experiments important for optimization of the central solenoid plasma of an ambipolar fusion reactor, MHD-stability, transverse transport and plasma heating methods are studied. Essential for a central solenoid of ambipolar traps is its ability to confine a plasma with considerable values of relative plasma pressure $\beta = 8\pi p/B^2$. Now on the central solenoid of the fully axisymmetric, ambipolar trap AMBAL-M the experiments are underway on increasing the plasma pressure in the solenoid.

The ambipolar trap AMBAL-M now consists of a central solenoid and an end system attached to it (Fig.1). The hot plasma in the solenoid is accumulated from a thermally insulated, turbulent plasma stream generated by a gas-discharge plasma source, located before a solenoid magnetic throat. Ions are heated by the Kelvin-Helmholtz instability of a nonuniformly rotating plasma column, and electrons are heated mainly by the axial current flowing along the plasma. MHD stability is provided by line-tying into the source. Using this method, the plasma in the solenoid was obtained with 6 m length, ~0.4 m diameter, on-axis density $\sim 2\cdot 10^{19}$ m^{-3}, electron temperature ~50 eV and ion temperature ~250 eV.

Further plasma density increase in the solenoid was achieved using hydrogen puffing into the plasma through a gas-box near the entrance solenoid throat. With the optimized hydrogen puffing rate ~80 Torr·*l*/s, the solenoid plasma density increased to $\sim 6\cdot 10^{19}$ m^{-3} with simultaneous growth of the plasma energy content. Enhancement of the total plasma energy during the hydrogen puffing is explained by fast turbulent heating of cold ions and electrons originating from hydrogen ionization, from the operating plasma source.

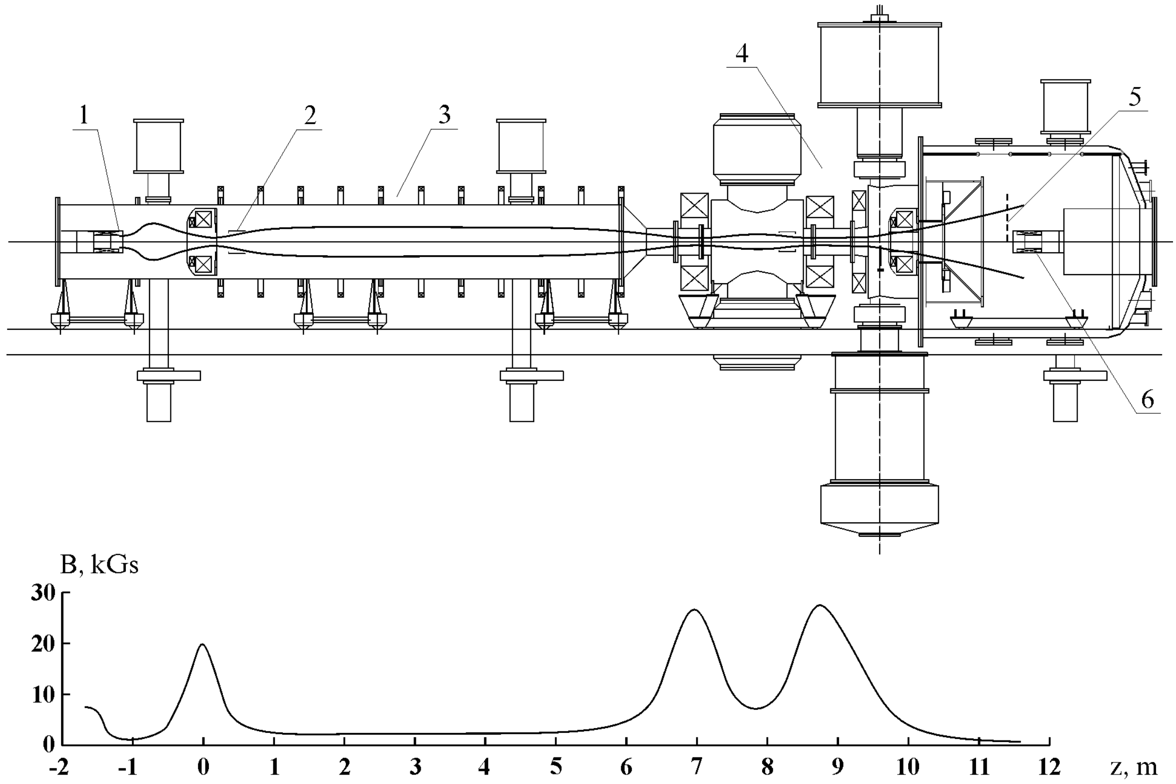

Fig.1. Side view of the magnetic system and vacuum chamber of AMBAL-M. 1 – gas-discharge plasma source, 2 – gas-box, 3 – solenoid, 4 – end system, 5 – position of end-loss analyzers, 6 – second plasma source. Magnetic field line starting from the plasma source ($z = -155$, $r = 6$ cm) is shown. Below is given the magnetic field profile at the axis.

Plasma parameters in this high-density regime were measured in the solenoid. The plasma density radial profile measured by Langmuir probes and multichord attenuation of a diagnostic neutral beam of 10 keV hydrogen atoms is shown in Fig.2. The plasma density near the axis is ~$6 \cdot 10^{19}$ m^{-3}. The ion temperature was measured by a grid end-loss analyzer,

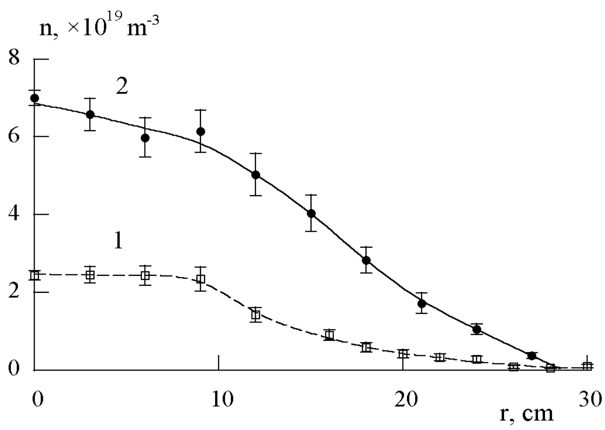

Fig.2. Radial profile of the plasma density in the solenoid.
1 –without gas, 2 –with hydrogen puffing.

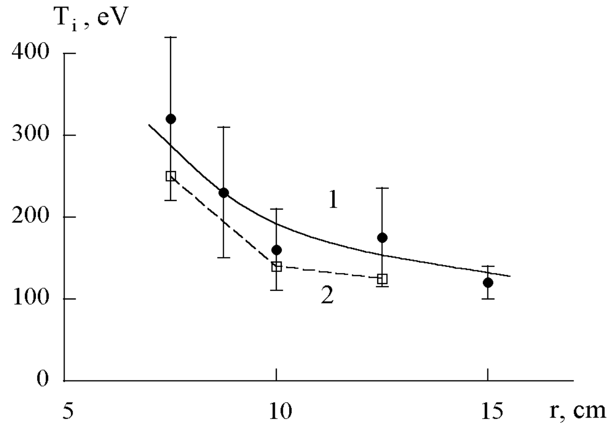

Fig.3. Radial profile of the ion temperature matched to solenoid.
1 –without gas, 2 –with hydrogen puffing.

and the maximum value in the solenoid was estimated as ~250 eV (Fig.3). The ion temperature was also measured by Doppler broadening of the H_α line emitted from the plasma perpendicularly to the solenoid axis. The obtained spectrum is presented in Fig.4, and the ion temperature extracted from this spectrum is also about 250 eV. The electron temperature distribution was measured by a triple probe and by attenuation of a diagnostic beam of fast argon atoms. The maximum electron temperature was achieved at the axis and with hydrogen puffing it decreased from 45 to 30 eV. Thus, the presented plasma parameters with gas puffing at the 0.2 T magnetic field in the solenoid, yield β~0.15 near the axis.

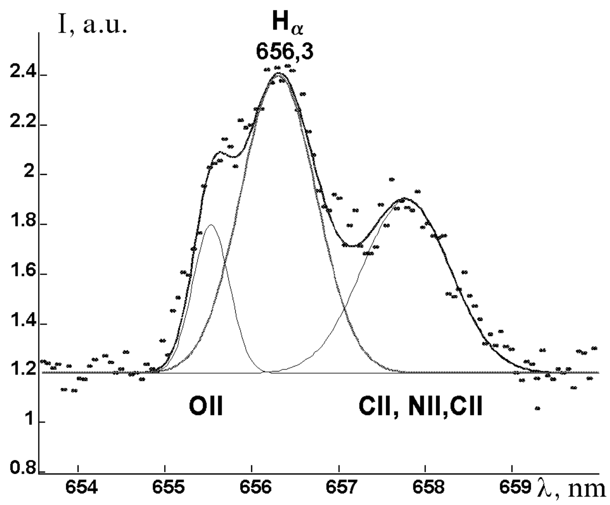

Fig.4. Spectrum of the plasma emission near the H-α line.

The plasma parameters obtained with hydrogen puffing were used to achieve high β by reducing the magnetic field strength. Experiments demonstrated that when the magnetic field in the solenoid was decreased from 0.2 T to 0.1 T, the plasma density, electron and ion temperatures decreased insignificantly, hence the β value increased approximately four times. The measured plasma density, ion and electron temperatures gave estimate $\beta \approx 50 \pm 10\%$ in the core region 15 cm in diameter, in the regime with reduced field and gas puffing.

As it was mentioned above, the flute MHD instability is stabilized by strong line-tying of the plasma into the plasma source. But as the plasma pressure increases, there will develop the ballooning instability, which is caused by the ability of the finite-pressure plasma to bend the magnetic field. Its perturbations are localized in the regions of the unfavorable field line curvature, and therefore this instability can develop even with the ideal line-tying at the ends. Numerical analysis carried out for the AMBAL-M solenoid using the conventional ballooning stability equation [4] showed that for the plasma rigidly tied in the throats, the marginal instability will start at high β values ~0.8–0.9. However, in a real plasma line-tying is not perfectly rigid and the line-tying point is located outside the throat, which reduces the critical β to ~0.5–0.6. Thus, for the AMBAL-M solenoid the maximum β value limited by the ballooning instability is expected to be in the range from 0.5 to 0.9. At present the experiments are carried out on further enhancement of β and determination of the critical β value.

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