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Heating and Confinement of Dense Plasma in Multimirror Trap GOL-3

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1. Introduction.

Open traps (mirror systems) of different type for hot plasma confinement are studied now in some groups [1-5]. Facility GOL-3 is a multimirror trap.

Multimirror confinement of a hot dense plasma in a long open trap was proposed in [6,7] and is considered as alternative approach to nuclear fusion [8]. The multimirror trap consists of a set of mirrors which are connected to each other at their ends and have full length L which exceeds the mean free path of the particles λ. If, at the same time, the mirror cell length $l<\lambda$ then the longitudinal confinement time increases essentially compared to classical single mirror trap (see review [9]).

This paper covers our new experiments with multimirror magnetic system on the GOL-3 facility. Main aims of the experiments were: study of multimirror confinement of a dense hot plasma; gradual improvement of the facility in order to reach broader range of operational parameters with macroscopically stable plasma.

2. GOL-3 Facility.

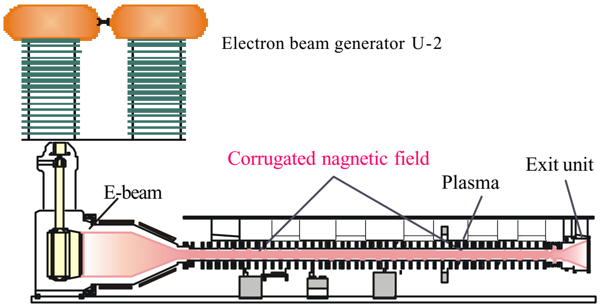

Fig.1. Layout of the GOL-3 facility

GOL-3 facility (Fig.1) is a long open trap intended for study of heating and confinement of a relatively dense (10^{21}-10^{23}m^{-3}) plasma in axisymmetrical magnetic system [1]. The magnetic system consists of coils for transport and shaping of the electron beam, a 12-meter-long solenoid and an exit unit (which includes plasma creation system, expander and exit receiver of the beam and plasma). Solenoid consists of 55 cells of 22 cm each with $B_{\max}/B_{\min}$=5.2/3.2T. Preliminary deuterium plasma of (0.2-5)$\cdot 10^{21}$ m^{-3} density is created by

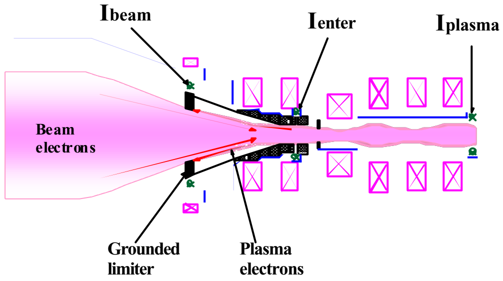

Fig.2. New configuration of the electron beam compressor

a special linear discharge along the whole device length. Axial distribution of the plasma density is formed by a set of fast gas-puff valves.

The plasma heating is provided by a high-power electron beam (1 MeV, 30 kA, 8 μs) with total energy content of 120-150 kJ. Main plasma diagnostics include magnetic measurements, 1.06 μm Thomson scattering, visible and VUV spectroscopy, VUV linear detector array, 1.15 μm interferometry, neutron detectors of different types, CX neutrals, etc.

The sertain modernization of the facility was performed last year. The main goal of the modernization consisted in increasing of power density in the heated electron beam. For that purpose the cathode of E-beam generator was reduced that caused decreasing the beam cross-section by half with the invariable total energy content and respective increasing of specific plasma parameters. Also the carbon limiter enclosed the reverse plasma current (Fig.2) was mounted in the compression chamber for the improvement of plasma stability.

3. Macroscopic stabilization of the dense plasma in the multimirror trap

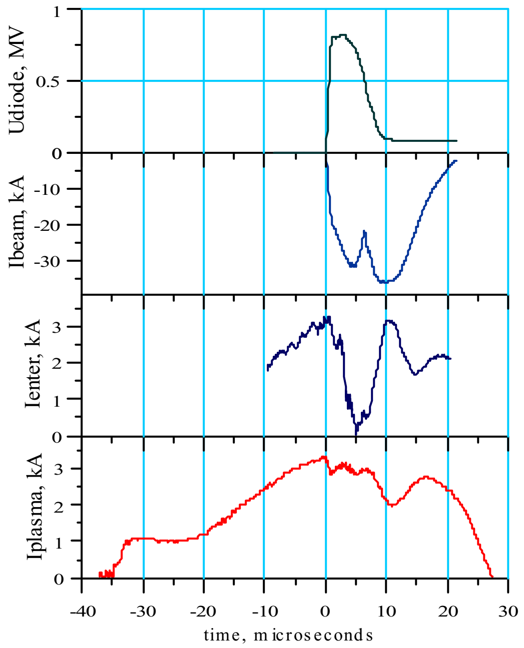

Fig.3. Waveforms of diode voltage, current in vacuum and net current in compressor and plasma column.

The special efforts are required for providing of stability at the real experimental conditions of the GOL-3 facility. As shown later the kink (Kruscal - Shafranov) instability is most dangerous for plasma confinement in our case. For it's suppression the plasma current directed towards the electron beam is created by the special source mounted in exit unit device. The waveforms of some currents in the shot with plasma density in the center of mirror (z=6 m) $4\cdot10^{21}m^{-3}$ is shown in fig.3. Plasma source (switched on at moment -35 μs) drives a current along all 12-meter plasma column. The waveform of current at z=255 cm is marked on fig.3 as Iplasma. Up to beam injection (moment '0') the radial distribution on plasma density (measured by Thomson scattering) is practically uniform. That fact pointed to uniform distribution of current density across plasma column cross-section and means that some part of current encloses to the limiter across magnetic force lines. At the moment 0 µs the electron beam is generated. Amplitude of beam current (Ibeam) achieves 35 kA in 5µs. In contrast in the plasma filled part of compression chamber the current direction is reverse and value of current (Ienter) don't exceed 3 kA in the moment '0'. During beam injection this current and as current in the trap chamber (Iplasma) are not changed drastically. The such a current dynamics is necessary to macroscopic stability of plasma column. If this condition is not satisfied, the kink instability appears that results to beam and plasma transverse energy losses in a few microseconds. Thus the confinement of hot plasma with density up to $4\cdot10^{21}$m^{-3} is achieved as a result of modernization of multimirror trap GOL-3.

4. Increase of energy confinement time of plasma in multimirror trap.

Creation of macroscopically stable plasma resulted in improved confinement of dense plasma in the multimirror trap. Initial deuterium puffing in the discharge chamber provided peak of gas concentration $4\cdot10^{21}$ m^{-3} in the central part of a trap. After heating of the plasma and redistribution of particles over the device length the average density of plasma in the chamber is of ~ $(0.7\text{-}1)\cdot10^{21}$ m^{-3}. A comparison of confinement time of plasma in various modes of facility operation is shown in Fig.4. As one can see, in a mode with the improved confinement and the increased beam energy density the confinement time of plasma is sufficiently increased. In this case a value of $n\tau_E \sim 10^{18}$ m^{-3}s corresponds to theoretical confinement time in multimirror trap in optimum conditions. According to value of plasma pressure and recent measurements[10] the average ion temperature is 1-1.5 keV. Dense hot plasma confined in GOL-3 trap, is a remarkble source of fusion neutrons. In Fig. 5 the neutron flux from of D-D reactions is shown. These results

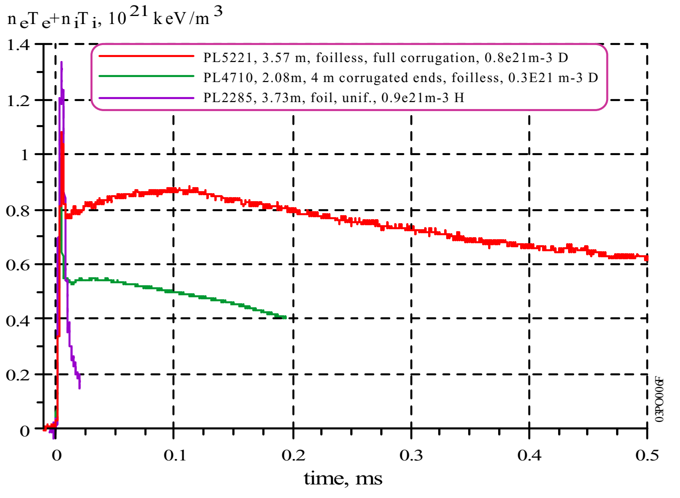

Fig.4.Waveforms of the plasma pressure at different magnetic configurations

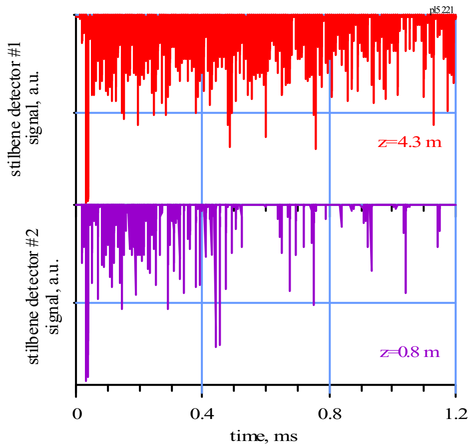

Fig.5. Fusion neutron emission registered by digital PSD stilbene detectors

are obtained by new neutron diagnostics - stilbene detector with digital pulse shape discriminations (digital PSD). This diagnostics, additionally to (n-γ) separation, allows to determine a spectrum of neutrons. In the experiment this spectrum corresponds to 2,45 MeV D-D neutrons. As one can see from the figure, the neutron flux, appropriated the plasma with T_i = 1-2 keV and n~ 10^{21} m^{-3}, exists during for~ 1 ms in the central part of a trap (z=4.3m). Near the edge of a trap (z=0.8 m), smaller life time is observed, that indirectly confirms to prevalence of longitudinal losses in comparison with transverse ones.

5. Conclusion

As a result of transition to total corrugation and increasing energy density in heating electron beam, parameters of plasma in the multimirror trap GOL-3 are essentially increased.

Macroscopical stability of the plasma with density (1-4) 10^{21} m^{-3} in system with magnetic confinement is achieved.

The value $n\tau_E \sim 10^{18}$ m^{-3} s at ion temperature (1-2) keV is obtained.

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