PLASMA HEATING AND CONFINEMENT IN THE GOL-3 MULTIPLE MIRROR TRAP

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Experiments on plasma confinement in a multiple mirror configuration are carried out at GOL-3 facility in Novosibirsk. Feature of experiments at this facility is high plasma density (up to $5{\cdot}10^{21}$ m^{-3}). High ion temperature (up to 2 keV) essentially differs the regime with multimirror configuration from previously studied plasma heating by the E-beam in a uniform magnetic field. Physical mechanism of effective heating of plasma ions, substantially dependent on corrugation of the magnetic field is discussed. In this paper the new experimental data from the GOL-3 facility are presented and the main attention to a stage of ion heating is addressed.

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1. GOL-3 FACILITY AND EXPERIMENTAL CONDITIONS

GOL-3 facility 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 [1,2].

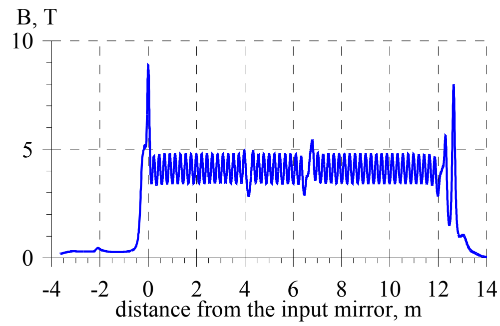

Fig.1. Configuration of the magnetic field

Plasma is confined in a solenoid with corrugated (multumirror) field which consists of 55 cells with H_{max}/H_{min}= 4.8/3.2 T (Fig.1). Plasma is heated by ~120 kJ (~8 µs) E- beam. Vacuum diode for electron beam generation is placed at Z= -4 m (Z is a distance from the input mirror). Recently the plasma heating was improved by additional compression of the E-beam that gives increasing beam current density in the plasma. Collective plasma heating by E- beam results in T_e~2 keV at ~10^{21} m^{-3} density [3]. High T_e exists for ~10 µs. To this time T_i reaches 1-2 keV. Then electron temperature rapidly decreases to below 100 eV. Ion temperature keeps at the high level. Energy confinement time in this configuration is ~1 ms at initial density of deuterium $2{\cdot}10^{21}$ m^{-3}.

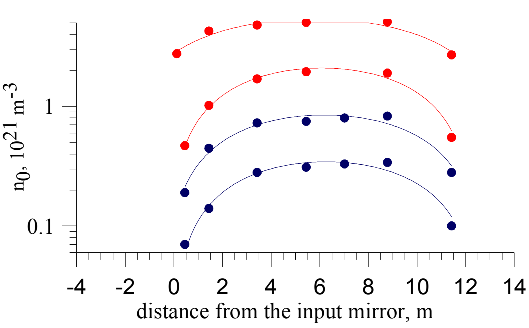

Fig.2. Axial distribution of the initial deuterium density (n_0). Several typical regimes of operation are shown

Dynamics of ion temperature measured by Doppler broadening of D_α spectral line is shown in Fig.3. Maximum temperature is about 2 keV in a short time after the beam injection ends and is ~1.5 keV for at least 0.25 ms. After this time the Doppler measurements become impossible due to growth of plasma density and domination of Stark broadening.

Figure 4 shows the neutron and X-ray count rate for stilbene detector. Digital pulse shape discrimination (dPSD) was used for analysis of stilbene detector signals with high count-rate. Generation of DD neutron emission starts during injection of the electron beam in the miltimirror trap. Duration of the neutron emission exceeds 1 millisecond.

This fast ion heating can be explained by collective phenomena in the plasma as a result of features of interaction of the high-power electron beam with the plasma in corrugated magnetic field.

2. HEATING PHASE

The model for an explanation of the fast ion heating in a multimirror trap was proposed. It take to account the following: a) nonuniform plasma heating (which depends on the n_b/n_p ratio, i.e. on the local magnetic field); b) suppression of heat transport during the beam-plasma interaction that enables to create of a large pressure

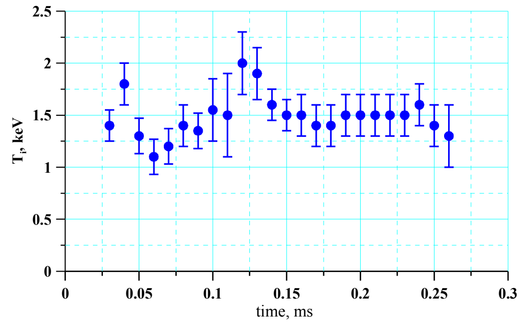

Fig.3. Dynamics of ion temperature. Initial density is 0.3 10^{21} m^{-3}. Z=2 m

gradients; c) collective acceleration of plasma flows from the high-field part of corrugation cells to cell's 'bottom'; d) thermalization of opposite ion flows. The model predicts the occurrence of strong modulation of density and speeds of ions in cells of a trap after several microseconds of beam injection.

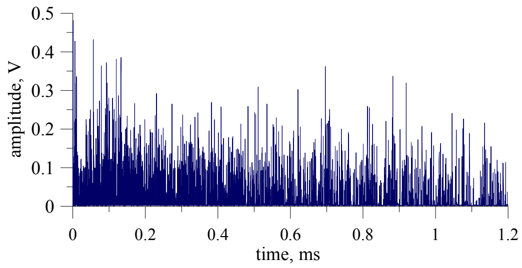

Fig.4. Waveform of signal of digital PSD stilbene detector of fusion neutrons (Z=4.3 m); Initial deuterium density is $1.9{\cdot}10^{21}$ m^{-3}

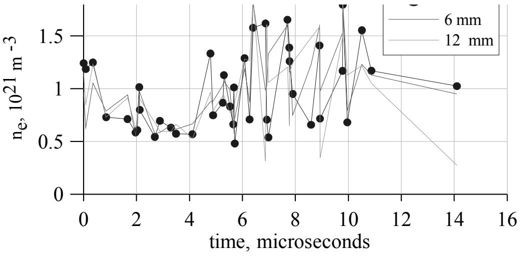

Fig.5. Results shot-by-shot measurements of the radial profile of the plasma density by Thomson scattering

A set of special experiments was carried out at GOL-3 facility in order to study this mechanism of ion heating. A Thomson scattering system (10 J, 1.06 μm) was used in order to measure 8-point radial distribution of the plasma density with 1-mm-spatial resolution. Shot-to-shot spread of plasma density is below 10% during several first microseconds of the beam injection. Then density spread becomes larger, up to δn/n ~ 40% (Fig.5).

In the experiments the intensity of neutron emission was measured by "local" detector which was placed on various distances from an input mirror (Fig.6). There are

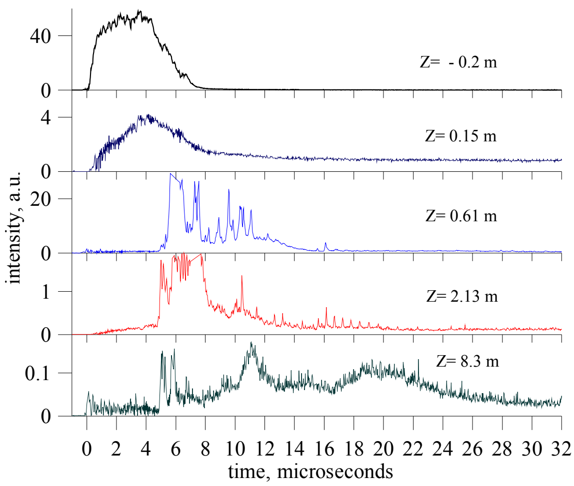

Fig.6. Measurements of the neutron flux by "local" detector. At Z= -0.2 m detector registered bremstrahlung of the beam only. n_0=$1.9{\cdot}10^{21}$ m^{-3}

some features in the received data. There is almost no neutron flux during the initial stage of the plasma heating. Then approximately at the moment of emergence of the large density fluctuations an intensive neutron flash appears which is followed by a quasy steady neutron emission up to ~1ms. Observed plasma behaviour confirms the suggested mechanism of fast collective heating of ions in a beam-plasma system in a corrugated magnetic field.

There is a strong dependence of intensity of neutron flux and the shape of a pulse on the co-ordinate Z. Pressure of plasma in these time intervals is peaked also at distance of 0,5-1 m from an input mirror. The features of behaviour of plasma may be result of hot plasma flow in axial direction from the region with maximal heating.

3. DIRECT MEASUREMENT OF RADIAL *q*-PROFILE

The possible mechanism of occurrence of density modulation and additional plasma heating may be also connected with formation of helical structure of the magnetic field on the device and the subsequent internal tearing mode excitation. This structure of the magnetic field naturally originates from the fact that the beam

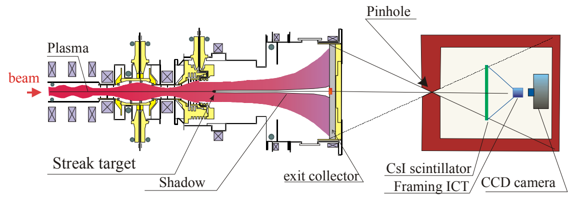

Fig.7. Scheme of exit unit of GOL-3 facility and diagnostics for q-profile measurements

current in the plasma core flows in the direction, which is opposite to artificial compensating return current. Special experiments by direct measurement of a structure of rotary transformation μ=1/*q* were carried out ($q=(H_z/H_\varphi){\cdot}(2\pi r/L)$, where H_z and H_φ - longitudinal and azimuthal magnetic field, *r* and *L* - plasma radius and column length) (Fig.7). For this purpose the X-ray footprint of the beam on a collector was imaged by a fast-frame pinhole detector. The narrow graphite bar was placed into the beam cross-section. Rotation of the magnetic field was

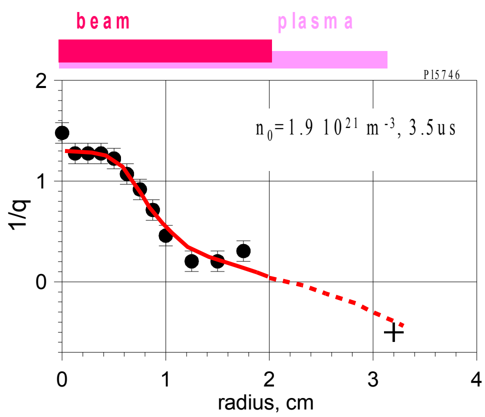

Fig.8. Result of direct measurement of q- profile

measured by the displacement of print of the beam shadow on the collector. frame pinhole detector. The narrow graphite bar was placed into the beam cross-section. Rotation of the magnetic field was measured by the displacement of print of the beam shadow on the collector. Results show (Fig.8), that during the beam injection the helical magnetic field is formed in the plasma column, and value of the factor q in the centre of plasma is less than unity. Shear of the magnetic field, resulting from partial compensation of the beam current is observed. Sheared structure of the magnetic field can improve the plasma stability and affect mode structure.

4. CONCLUSION

Fast ion heating up to ~2 keV is observed in the multimirror trap GOL-3 with plasma density of ~ 10^{21}m^{-3}. Experimental evidence of sheared structure of magnetic field is obtained. These phenomena are consequences of collective interaction of E-beam with the plasma and they lead to improvement of plasma heating and confinement.

5. ACKNOWLEDGEMENTS

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НАГРЕВ И УДЕРЖАНИЕ ПЛАЗМЫ В МНОГОПРОБОЧНОЙ ЛОВУШКЕ ГОЛ-3

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Эксперименты по нагреву и удержанию плазмы в многопробочной ловушке проводятся на установке ГОЛ-3 в Новосибирске. Особенностью плазмы в этой ловушке является ее относительно высокая (до $5\cdot10^{21}$ м$^{-3}$) плотность. Нагрев плазмы релятивистским электронным пучком в многопробочной ловушке существенно отличается от нагрева в простом соленоиде тем, что наблюдается увеличение ионной температуры вплоть до 2 кэВ. В работе обсуждается механизм быстрого нагрева ионов и представляются новые экспериментальные результаты, полученные на установке ГОЛ-3.

НАГРІВАННЯ Й УТРИМАННЯ ПЛАЗМИ В БАГАТОПРОБКОВІЙ ПАСТЦІ ГОЛ-3

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Експерименти по нагріванню й утриманню плазми в багатопробковій пастці проводяться на установці ГОЛ-3 у Новосибірську. Особливістю плазми в цій пастці є її відносно висока (до $5\square10^{21}$ м$^{-3}$) густина. Нагрівання плазми релятивістським електронним пучком у багатопробковій пастці істотно відрізняється від нагрівання в простому соленоїді тим, що спостерігається збільшення іонної температури аж до 2 кэВ. У роботі обговорюється механізм швидкого нагрівання іонів і представляються нові експериментальні результати, отримані на установці ГОЛ-3.