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Features of MHD activity in beam-heated plasma in multimirror trap GOL-3

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1. Introduction

Multimirror approach to plasma confinement [1] is studied at the GOL-3 facility in Novosibirsk [2]. Deuterium plasma is heated up to 1-2 keV ion temperature (at ~10^{21} m^{-3} density) by a high power relativistic electron beam. Energy confinement time is ~1 ms that is in agreement with theory predictions. The plasma heating and confinement in the GOL-3 facility are determined by several linked collective processes, which lead to a high-level turbulence and large modulation of plasma parameters. Fast plasma heating and suppressed axial heat transport during the heating phase result in some observed features of the plasma behaviour, which includes motion of the plasma and MHD activity.

In this paper we are discussing two separate effects. The first effect is a periodical structure of a neutron emission from the GOL-3 plasma. The second one is dynamics of currents, which indicate a possible existence of *m*=1 tearing mode in GOL-3.

GOL-3 is the only one facility in the class of multimirror confinement systems. The plasma of $10^{20}\div10^{22}$ m^{-3} density is confined in a 12-meter-long solenoid, which consists of 55 corrugation cells with B_{max}/B_{min}=4.8/3.2 T. The relativistic electron beam for plasma heating has the parameters: energy ~0.9 MeV, current ~25 kA, duration ~8 μs, ~120 kJ per pulse. Main features of the beam-plasma interaction are the following.

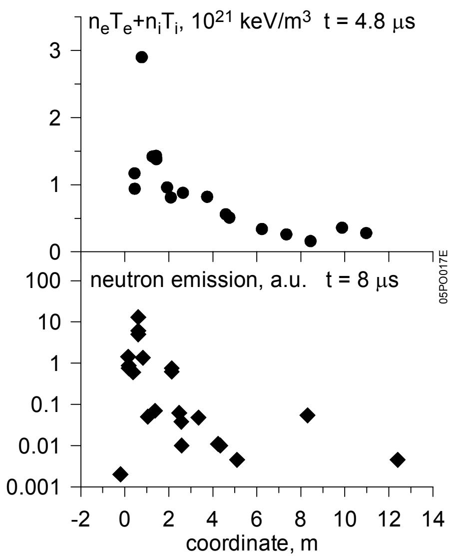

Fig.1. Top - diamagnetism at a peak of heating (single shot), bottom - peak of neutron signal (one dot per shot).

- The beam-plasma interaction efficiency depends on the ratio of the beam density to the plasma density, i.e. on the local magnetic field.
- The beam energy release is nonuniform over the plasma length (see Fig.1).
- The effective electron collision rate exceeds the classical binary collision rate by a few orders of magnitude. This causes significant decrease of the

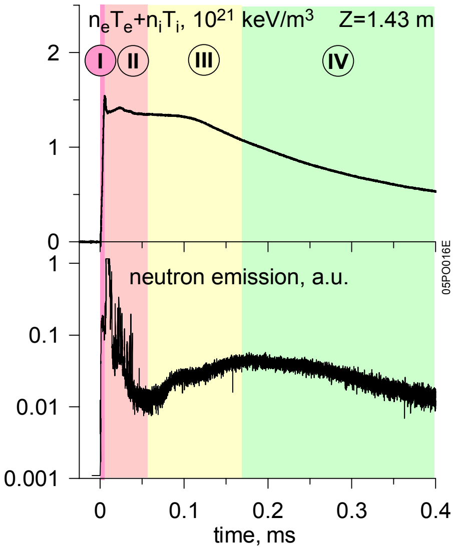

Fig.2. Diamagnetism (top) and neutron signal (bottom). I - beam injection, II - oscillation phase, III - temperature levelling, IV - cooling.

plasma conductivity and axial heat transport coefficients [3].

All the plasma lifetime can be approximately split into four periods (see Fig.2). Next Section will specifically discuss some features of Phase II.

2. Features of neutron emission

Neutron diagnostics of the GOL-3 facility consist of several subsystems. All data discussed in this paper was obtained with compact detectors with plastic scintillator, which were placed directly on the vacuum vessel wall at different locations along the device. Detector with BGO scintillator monitored hard bremsstrahlung and gammas. Figure 3 shows typical waveforms of D-D neutron emission at different coordinates. Upper curve corresponds to detector placed near the beam accelerator and it shows dynamics of hard bremsstrahlung. Other curves correspond to neutron emission from the plasma. Two features should be mentioned. The first one is some delay of large-amplitude peaks in the signals at coordinates 0.5-3 m, i.e. in the section with largest ion temperature. Such delay of start of neutron emission is natural for the existing mechanism of fast ion heating. The second feature is a phase with strongly modulated periodic oscillations of neutron flux. Sometimes as much as over 100 oscillations are detected in a shot (Fig.4).

Period of mentioned oscillations is close to l/v_{Ti} (transit time through the corrugation cell). The oscillations exist during the period of large axial gradients of the plasma pressure. The most probable interpretation is a "whistle"-like mechanism. During the plasma expansion through the corrugated magnetic system, a part of transit ions can be trapped in the cell of the multimirror trap and then a kind of "resonator mode" with grouped

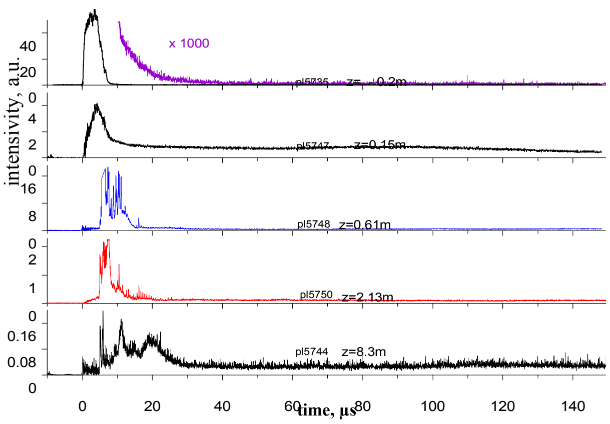

Fig.3. Neutron emission at different coordinates.

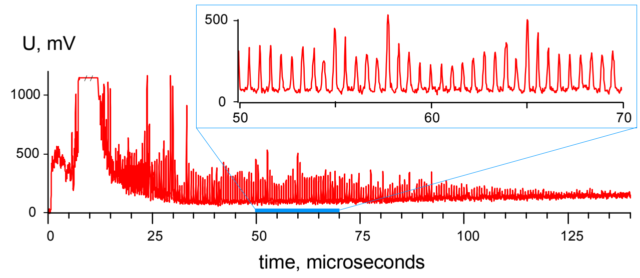

Fig.4. Periodic oscillations of neutron flux.

particles may develop in that cell. This group of trapped particles propagates through the cell and bounces from the high field edges of the cell. Depending on the direction of movement of these particles in respect to the stream velocity, we will observe modulation of neutron signal. This modulation exists whilst the pressure gradient is high enough to maintain amount of ions in that particle group. Then modulation gradually decays and neutron signal becomes more equilibrium. Oscillations in the adjacent cells differ in phase and in period. Sometimes two concurrent processes with slightly different periods are observed in one signal (see Fig.5). Such situation can be naturally explained as phase locking of oscillations in two adjacent cells (with slightly different ion temperature).

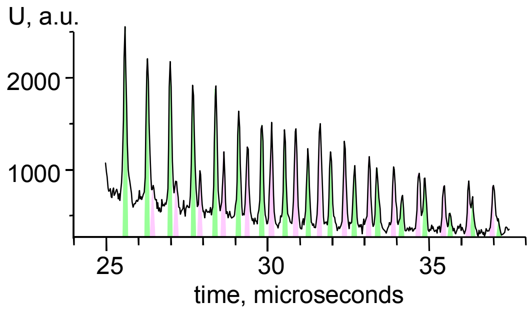

Fig.5. Evidence of two concurrent processes.

3. Tearing-like dissipation of axial currents

The main efforts in the experiments at the GOL-3 facility during the last few years were targeted for the search of the regimes, which are stable in respect to global kink modes. As a result, the conditions for the beam-plasma system stability were found [4]. The beam current is also an additional perturbation which the electron beam introduces in the plasma. The current value of 20-30 kA is high enough for generation of a considerable azimuthal magnetic field. Moreover, as is shown in [4], the safety factor $q=(H_z/H_\varphi)\cdot(2\pi r/L)$ (where H_z and H_φ are the axial and azimuthal components of the magnetic field, r and L are the plasma radius and length) equals to 0.3-0.5 at the axis. Such case should result in the stability loss for the beam-plasma-system.

A physical model for evolution of the helical structure of the magnetic field was initiated at GOL-3 in 2004. This model is similar to ones used in a tokamak physics except for the cylindrical geometry. Initial conditions include the beam current and a counter-directed plasma discharge current and a plasma return current (see [4]). First results of simulation show fast degradation of a nested current structure due to a tearing-like m=1 process - see Fig.6.

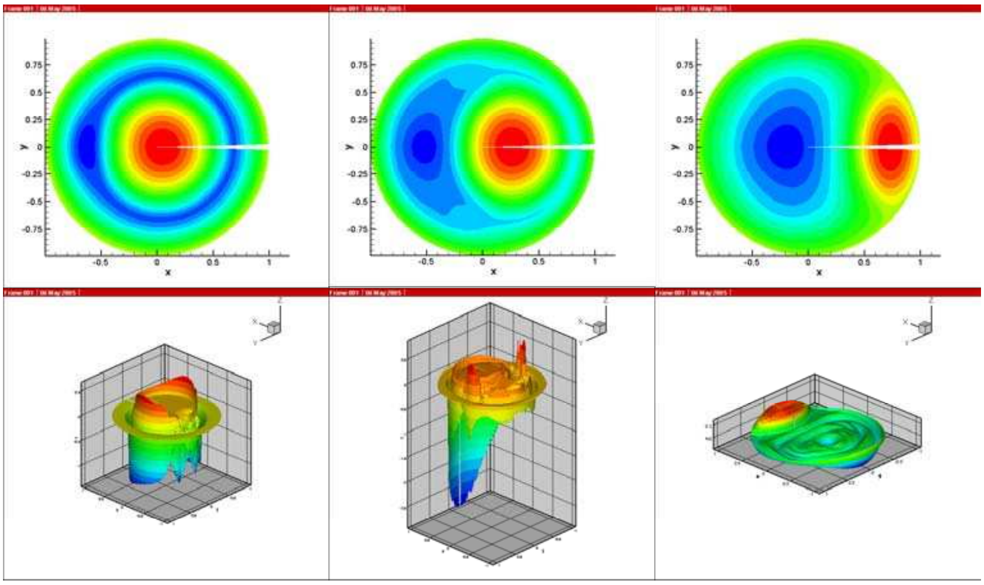

Fig.6. Results of 2D simulation. Top: azimuthal magnetic field, bottom: current density distribution for time 7.2 μs, 11.5 μs and 26 μs (left to right).

4. Summary

Axial profile of emission of D-D neutrons is peaked in the region of peak plasma pressure. At some time after the end of the beam injection the local neutron emission becomes highly modulated. Modulation of neutron signals can exist for several tens of oscillation periods. Such modulation can be attributed to a “whistle”-like mechanism, which can exist in a plasma with locally trapped ions due to plasma flow along the magnetic field and local (within the field corrugation cells) pressure gradients. Existence of particle exchange between groups of transit and trapped ions in the corrugated magnetic field is one of important evidences of the multimirror confinement.

Another discussed feature is the dynamics of the sheared structure of the magnetic field, which is initially formed during the beam injection phase with $q(0)\sim0.3$. After the end of the beam injection the sheared structure of the magnetic field exists for a relatively short time and then decays. Evolution of plasma currents was modelled with 2-D MHD code, which shows close similarity of core plasma dynamics to the well-known Kadomtsev model for sawteeth in tokamak.

References

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