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Effect of Fast Heating of Ions in Multimirror Trap During Electron Beam Relaxation

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An idea of a multiple mirror fusion reactor originates from the early 70s [1]. In such a system, if plasma density is high enough, its expansion along the magnetic field becomes diffusion-like due to effective "friction force" between the magnetic field and plasma particles. The main advantages of this approach are technical simplicity, absence of density and beta limits. The experiments on multiple mirror plasma confinement are carried out at GOL-3 facility in Novosibirsk. The final aim of experiments carried out at the GOL-3 facility (Fig.1) is development of a multi-mirror fusion reactor concept [2]. In present configuration of the device [3], plasma with a density of $10^{20}\div10^{22}$ m^{-3} is confined in a 12-meter-long solenoid, which comprises 55 corrugation cells with mirror ratio B_{max}/B_{min}=4.8/3.2 T. The plasma in the solenoid is heated up to 2-4 keV temperature by a

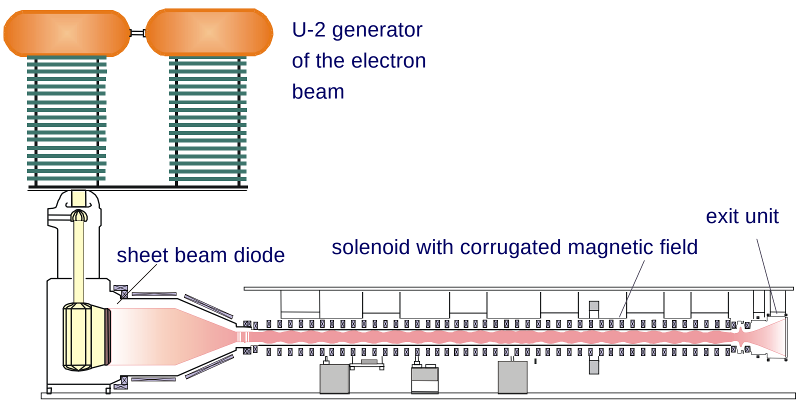

Fig.1. Layout of the GOL-3 facility.

high power relativistic electron beam (REB) (~1 MeV, ~30 kA, ~8 microseconds, ~120 kJ) injected through one of the ends.

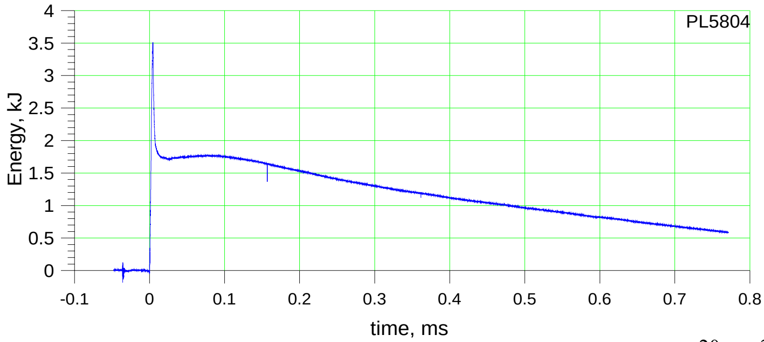

Fig.2. Energy stored in plasma with density of 8 10^{20} m^{-3}.

In the multi-mirror trap GOL-3 the plasma is heated as a result of interaction of high current relativistic electron beam with a dense (~$10^{21} m^{-3}$) plasma and confined in the trap (Fig.2). Besides, the experiments have shown that during the time when the REB was passing through the plasma, very strong suppression (by three orders of magnitude) of longitudinal electron heat conductance is observed. As a result, the electron temperature of 2-4 keV was obtained in the GOL-3. Results of electron temperature measurements by Thomson scattering are presented in Fig.3. Both the absolute value of the temperature and its inhomogeneous distribution along the device during ~5 microseconds could not be explained under assumption that the plasma energy is lost due to the classical electron heat conduction. To explain these experimental results, it was assumed in [6,7] that an abnormally high electron-scattering frequency caused by a strong turbulence occurring in the course of electron-beam injection into plasma reduces the longitudinal electron heat conductivity by two to three orders of magnitude, as compared to the classical conductivity.

The beam energy deposition is not uniform along the system. The axial profile of heating power and plasma pressure depends on local ratio of beam to plasma densities. Within the first meter of the plasma column, a sharp maximum of plasma pressure is observed, then it rapidly falls down and then the pressure continues to be decreased slower.

All the mentioned above phenomena result in high pressure gradients inside mirror cells along the magnetic field and macroscopic motion of the plasma. These gradients lead to two kinds of plasma macroscopic motions: local inside each cell and global along the system. Both these motions in a corrugated field lead to the electron energy transfer to ions much faster than the energy transfer due to binary collisions. As a result, electron and ion plasma temperatures up to 2-4 keV at density ~10^{21} m^{-3} are achieved and the value ntT~$(1.5\div3)\cdot10^{18}$ $m^{-3}s\cdot keV$ at T_i ~1 keV is attained.

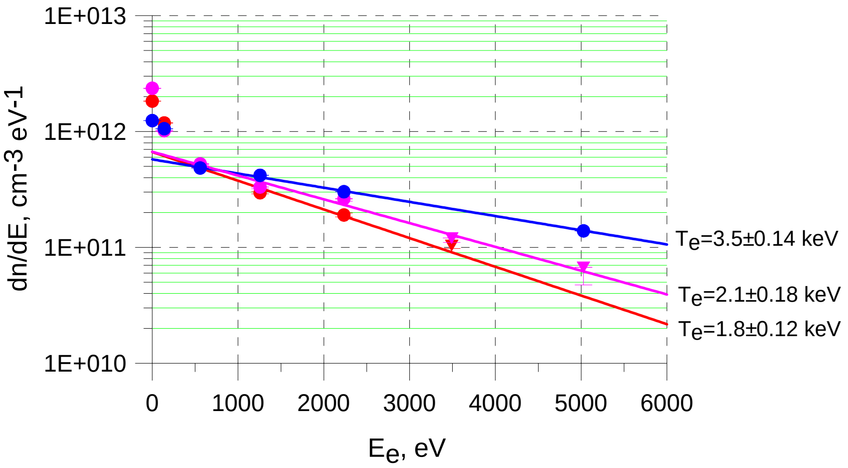

Fig.3. Results of measurements of electron temperature by Thomson scattering.

The mechanism of fast ion heating was studied in the experiments. Main points are the following. The non-uniform electron pressure should produce a longitudinal ambipolar electric field, which accelerates the plasma on both sides of the magnetic well toward the central plane of the cell, where the counter-propagating plasma flows collide. The kinetic energy of the accelerated plasma ions should depend on the magnetic field configuration, the total pressure drop, and the electron temperature profile along the cell.

The mean free path of the accelerated ions in these experiments is comparable to the cell length or is even longer. This means that the accelerated ion flows arriving from regions with a high magnetic field on both sides of the cell should mix in its central plane because of binary ion–ion collisions and/or because of the onset of turbulence in counter-propagating flows. The kinetic energy of the directed ion motion is, therefore, transformed into their thermal energy.

The mechanism for fast ion heating considered here should lead to the excitation of large-amplitude waves of the plasma density. Such density waves were measured directly by Thomson scattering.

The plasma motion along the axial direction through the multi-mirror system and redistribution of its parameters in the radius is accompanied by excitation of oscillations inside the hot part of the plasma column. This is clearly displayed by the signals of neutron detectors as this diagnostics most sensitive to the plasma parameters (see Fig.4). Period of oscillations agrees well with the predicted period for bounce oscillations. These oscillations make efficient exchange between populations of slightly trapped and slightly transit ions, therefore the plasma confinements in the multi-mirror system (which relies on relatively short free path length for ions) improves.

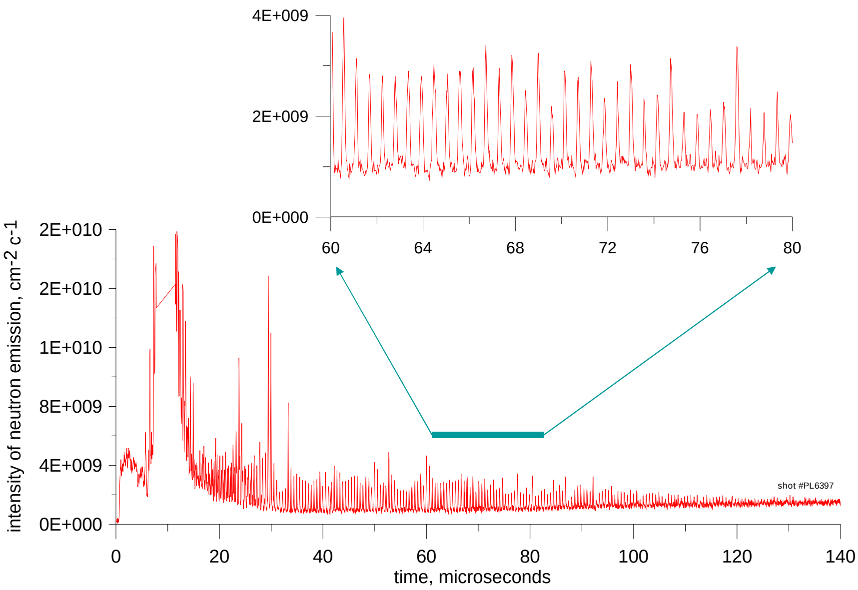

Fig.4. Initial phase of the neutron emission, there is almost no neutron flux during initial stage of the plasma heating. Then, approximately at the moment of emergence of the large density fluctuations, an intense neutron flash appears which is followed by a quasi steady neutron emission up to ~1 ms. Periodical oscillations of neutron emission are shown.

CONCLUSION

Electron and ion plasma temperatures up to 2-4 keV at density ~10^{21} m^{-3} are achieved due to collective processes in multi-mirror trap.

ACKNOWLEDGMENTS

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