CONFINEMENT AND MHD STABILITY OF HIGH-BETA ANISOTROPIC PLASMA IN THE GAS DYNAMIC TRAP

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Abstract
The paper summarizes recent results from the gas dynamic trap (GDT) linear system in Budker Institute (Novosibirsk, Russia) after upgrade of heating atomic beam system and main magnetic field power supply. Modernized heating beam system allowed to inject six 18 keV hydrogen or deuterium beams to the central GDT cell providing 3.8 MW in the 5 ms pulse. Two additional focused 25 keV beams are arranged to fire 1.2 MW beams in the compact mirror section attached to the GDT central cell. Increase of the beam pulse enabled to confine plasma with anisotropic ions with the mean energy of 10 keV and maximal beta exceeding 0.4 in a stationary regime. Background plasma electron temperature was also significantly increased in these experiments. The effect of strong decrease of MHD interchange mode increment and influence of the sheared radial flux zone on transverse transport were studied.

1. Introduction

Main goals of plasma studies in the gas dynamic trap (GDT) linear system in the Budker Institute Novosibirsk Russia [1] are accumulation of physical background necessary for projects of neutron source for material treatment and development of technologies essential for future applications in fusion schemes like D-He^3 and p-B^{11} [2]. A GDT-based neutron source acting as a driver in the nuclear waste burner [3] is also considered as a perspective approach.

The schematic layout of GDT experimental facility is presented on Fig.1.

Our previous experiments [4] with 1 ms beam injection have demonstrated sustainment of anisotropic plasma with beta approaching 0.4.

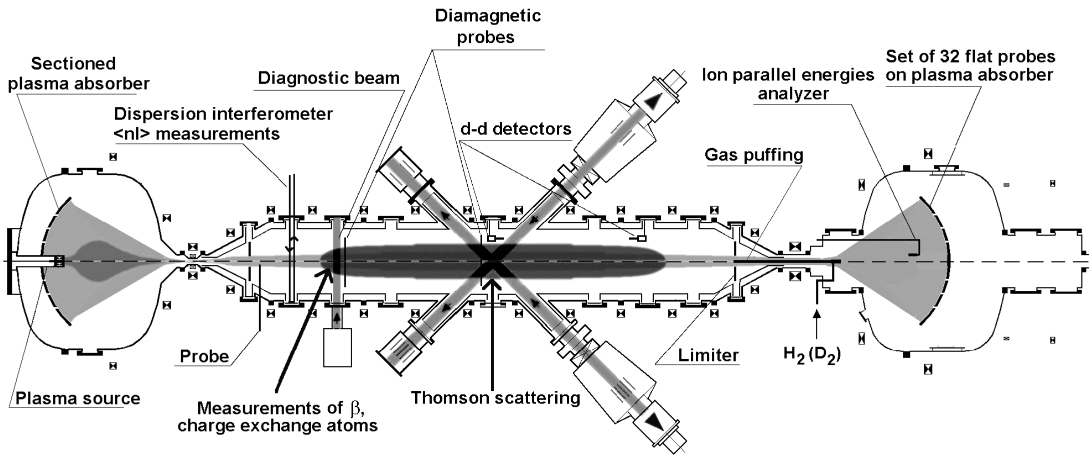

Fig.1 GDT experimental layout.

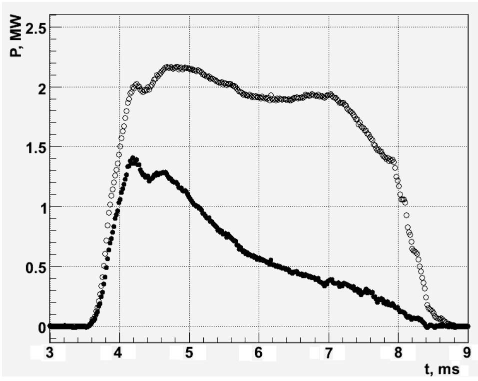

Fig. 2 Injected (o) and trapped (•) power in «decay» scenario with increased duration of atomic injection to GDT.

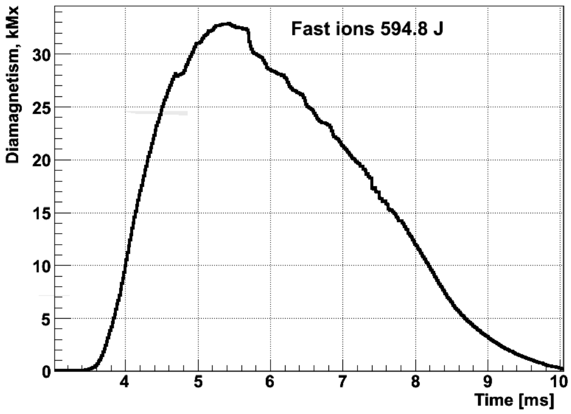

Fig. 3. Fast ions diamagnetism vs time in «decay» scenario.

This paper summarizes recent results of experiments on the Gas Dynamic Trap facility after upgrade of heating atomic beam system and main magnetic field power supply.

2. Study of fast ions accumulation and confinement.

First experiments of fast ions accumulation in GDT with 5 ms NB injection duration were successfully carried out. According the estimations and computer simulation results the fast ions distribution function in these conditions becomes close to equilibrium one because the characteristic energy lifetime defined by ions drag on target electrons $\tau_E \approx 700$ µs is much smaller than injection duration. In those experiments two work scenarios were investigated: «decay» scenario and experiments with additional gas puffing to the axis of GDT device used for plasma particles balance maintenance.

Temporal sequence of GDT systems work in «decay» regime was the following: warm target plasma was injected to the central cell the plasma generator. After plasma generator switching OFF, the neutral beam injection system was switched ON. Therefore, atomic beams were injected to plasma in the stage of its exponential density decreasing due to plasma flow through the mirrors. Perfect illustration of this process is the Figure 2 where the power trapped to plasma (which is proportional to linear target plasma density) in comparison with total neutral power beams power is presented.

In the Fig. 3 the plasma diamagnetism in this regime is shown. On the initial stage of injection rising of diamagnetic signal is observable, the value of this signal is

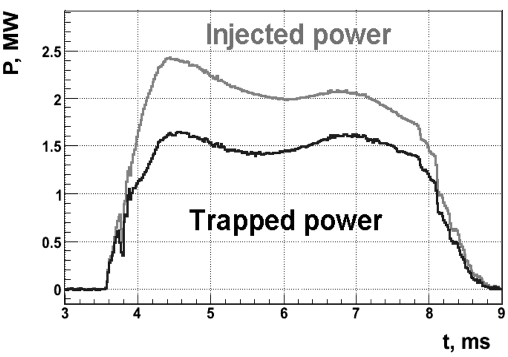

Fig. 4. Injected and trapped power in scenario with additional gas puffing and increased duration of atomic injection to GDT

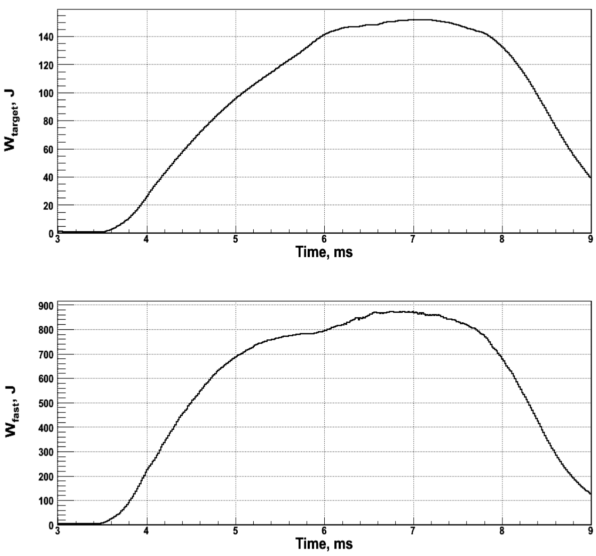

Fig. 5. Energy content of target plasma (top) and fast ions (bottom) in experiment with the additional gas puffing.

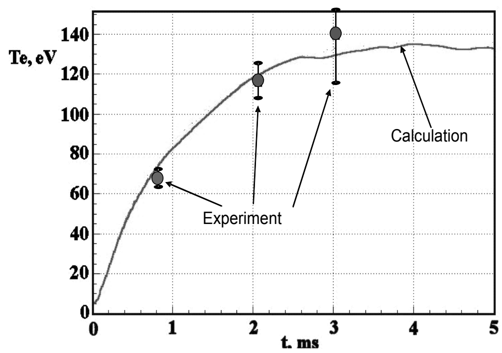

Fig. 6. Electron temperature measured by Thomson scattering at radius 4 cm and simulation result. The time scale is after NBI start (3.5 ms).

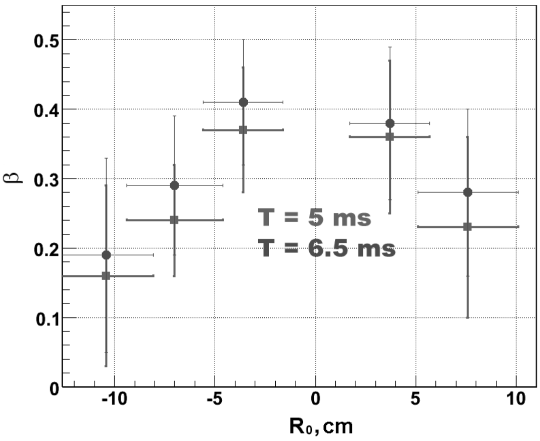

Fig. 7. The β radial profiles in a turning point of fast ions measured at the moments t=5 ms (■) and t=6.5 ms (●).

proportional to energy stored in fast ions. Then the fall of diamagnetism during 3 ms can be observed. It's important to note that the characteristic MHD-instability development time in view of mentioned plasma and magnetic field parameters can be estimated as few tens of microseconds. Basing on results of first experiment with increased atomic injection duration we can draw that plasma is stable relate to MHD-modes at injection times about 5 ms. Accordingto Thomson scattering diagnostics averaged electron temperature was about 120 eV. Temperature was measured in the time moment of 2 ms after injection start (5.5 ms in Figs. 2 and 3).

For better accumulation of fast particles, for plasma particles balance maintenance during long injection and for obtaining and investigations anisotropic plasma with maximal energy content and pressure the scenario with gas puffing to the GDT axis was realized. Gas was injected by means of special capillary (see Fig. 1) installed on the trap end after plasma generator switching off. As a result quite dense target plasma with maximal density up to $2x10^{14}$ cm^{-3} and radius about 4-5 cm was obtained.

In the figure 4 temporal dependencies of the injected and trapped power are presented, the figure 5 shows the energy content of target plasma and fast ions measured by diamagnetic loops. It is observable that the accumulation of fast ions takes place during all the injection time. The maximal value of the fast ions energy content is about ~ 900 J in this regime. The electron temperature achieves 140 eV at radius 4 cm and agrees with the numerical simulation that assumes only the classical gas-dynamic losses of target plasma in the real conditions of GDT experiment (see Fig. 6). The on-axis electron temperature in this regime is about 100 eV due to cooling by injected gas.

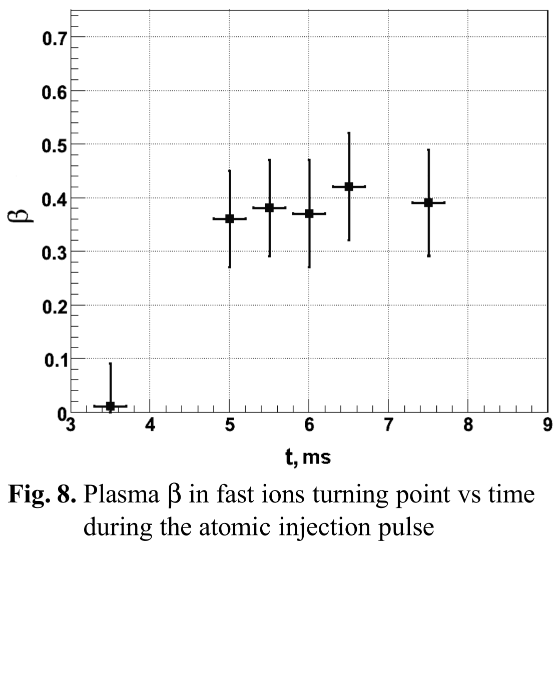

Fig. 8. Plasma β in fast ions turning point vs time during the atomic injection pulse

The confinement and dynamic of the anisotropic plasma in GDT was investigated by modernized MSE-diagnostics. Figure 7 presents the β radial profiles measured in moments of 5 ms and 6.5 ms during injection pulse (NBI operates from 3.5 to 8.5 ms). On-axis value of the β parameter versus time during the injection is shown in Fig. 8. As it is seen, the formation of compact fast ions distribution with the characteristic radius ≈ 8.5 cm occurs on the initial stage of NBI injection in the first millisecond, and has altered negligibly during NBI operation.

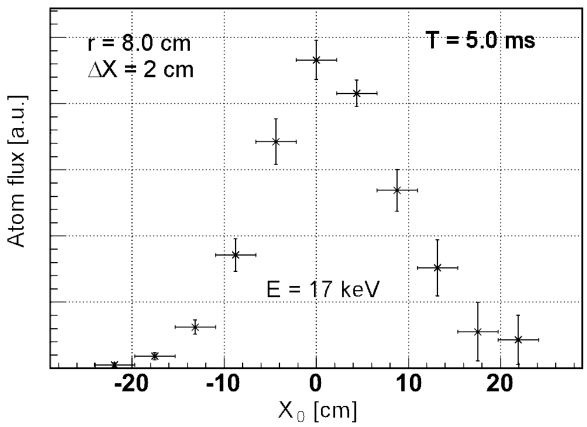

Fig.9 Transverse profile of charge-exchange atom flux.

Figure 9 demonstrates the transversal profile of charge-exchange atom flux measured by atom energy analyzer [5] at the moment of 5 ms. This atom flux corresponds to fast ion density in observed points. Locality of these measurements was provided by registration of atomic flux formed as a result of fast deuterium atoms charge exchange on an artificial target. This target was created by diagnostic hydrogen beam. For atoms with energies of 17 keV (see Fig.9), which is close to injected one, the characteristic profile radius is equal to 8 cm and closes to one measured by MSE diagnostic (Fig.7). The measurement of profile for other moment t=4÷6 ms during NBI operation gives the same result with characteristic radius of about 8 cm. The measurements of atoms with energies of 10÷17 keV also confirm the conclusion about formation of stable stationary population of anisotropic plasma with hot ions and maximal β about 0.4 observed in GDT experiment. The maximal density of fast ions in the turning point region was estimated as 2×10^{13} cm^{-3} in these experiments.

4. Conclusions

- The first stage of the GDT upgrade program is competed. The new power supply system for eight neutral beams has been installed and allows to increase total injection power up to 10 MW with duration of 5 ms and 25 keV injected atoms energy. The magnetic field strength has been increased up to 0.35T in the midplane of GDT and up to 12T in the mirrors.
- The first GDT-upgrade experiments with the injection power more than 3 MW, duration of 5 ms and 18 keV of injected atom energy were successfully made.
- The stationary confinement regime of two component plasma with β more than 40%, with electron temperature higher than 100 eV, warm ions density of 2×10^{14} cm^{-3} and fast ions density of 2×10^{13} cm^{-3} was realized and studied in the GDT experiment with increased 5 ms duration of NBI.

5. References

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