Influence of radial electric field on high-beta plasma confinement in the gas dynamic trap

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The GDT facility of the Budker Institute (Novosibirsk) is an axially symmetric linear machine of gas dynamic trap type [1]. Plasma confined in the GDT consists of two ion components: 100 eV maxwellian warm ions and 10 keV anisotropic fast ions which are produced by oblique injection of 4 MW power 17 keV energy neutral beams. Densities of warm and fast ions are $n_w = 5{\cdot}10^{13}$ cm^{-3} and $n_f = 2{\cdot}10^{13}$ cm^{-3} respectively, electron temperature is 100 eV, β parameter is up to 40% in the turning points region of the fast ions.

The plasma start-up is initiated by injection of hydrogen plasma along field lines from a mirror side during 3.1 ms. Consequently target plasma column with an initial temperature of 3–5 eV and a density of $\approx 5{\cdot}10^{13}$cm^{-3} is heated up by deuterium NB injection which provides the fast ion generation at the same time. A typical value of the trapped NB power is 2.5 MW.

Special biasing limiters were installed in the central cell of GDT device to control the electric potential in the plasma boundary. Limiters were located closely to mirror plugs on the radius of 14 cm in projection to the midplane along the magnetic field force lines. To control the radial potential in the core region of plasma column end plates consisted of 4 coaxial biasing

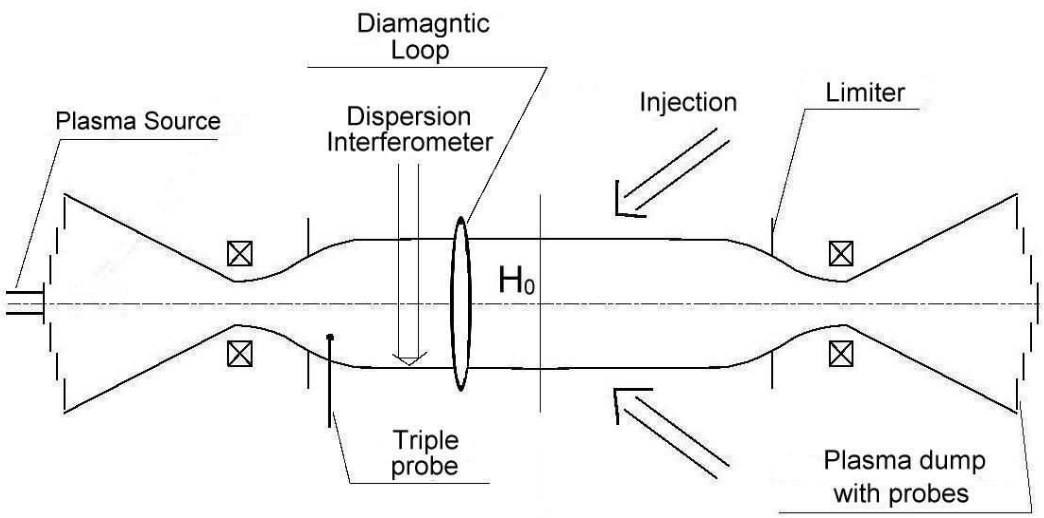


Fig.1 Schematic view of the GDT magnetic field configuration, location of limiters, plasma dumps, diagnostics, plasma source and neutral beams.

rings were used (see Fig.1).

One of the most important subjects of the GDT research program is MHD-stability and transversal transport of high pressure two-component plasma. Influence of radial electric field on the plasma confinement was demonstrated in previous experiments on the GDT [2]. It was observed in recent experiments that positive influence of radial electric field on plasma confinement always corresponds to «stepwise» distribution of biasing potential on limiters and plasma dumps.

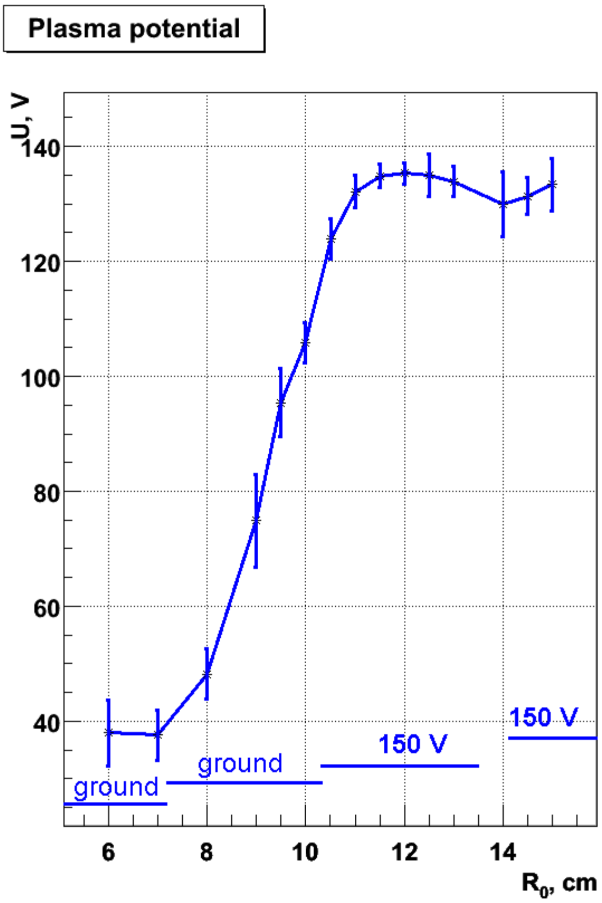
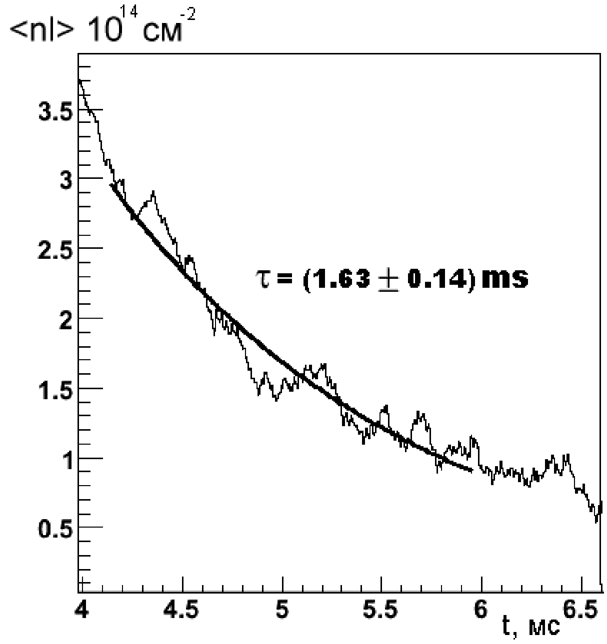


Fig. 2 Radial profile of floating potential in the central plane of GDT.

Figure 2 shows the radial profile of floating potential obtained by triple probe in the regime with biasing of limiter and outer ring of plasma dump by 150 V electric potential. The inner electrodes of plasma dump were grounded in this regime. Maximal value of the radial electric field calculated from this profile is about 25 V/cm. In experiments it was also shown that enhancement of plasma confinement time corresponds to the radial electric field in the range of 15 – 40 V/cm. A confinement time of warm plasma was measured by several diagnostics as end probes and dispersion interferometer. Figure 3 presents the time evolution of electron linear density measured after plasma source was switched off. According the results of special measurements electron temperature was approximately constant during the time of linear density monitoring. Characteristic time of the plasma decay was about $\tau_{MHD} = 1.6$ ms, which is in a reasonable agreement with confinement time calculated as axial gas dynamic flow time of warm plasma through the mirrors (τ_{GDT} = 1.3 ms). Confinement time of the fast ions was calculated from diamagnetic measurements, its magnitude was about 0.8 ms. This value is in a good agreement with electron drag time calculated taking into account measured parameters of warm plasma and fast ion population.

It is important to note that the special cusp and expander coils were turned off, therefore



measured after plasma source was switched off. Radial profile of plasma potential is «stepwise».

the magnetic field force lines in expander regions were straight making none contribution to the Rosenbluth-Longmire MHD stability criterion [3]. Summarizing results of measurements of plasma parameters in this regime we can draw the following conclusion: two-component plasma is MHD stable in spite of magnetic field configuration is unfavourable for MHD-stability. In comparison fig. 4 presents the time evolution of electron linear density measured after plasma source was switched off in regime with grounding of all electrodes – limiters and plasma dumps. Characteristic time of the warm plasma decay was 0.6 ms, which is two times lower than τ_{GDT}. Decay time of the fast ion diamagnetism was about 250 μs in this regime. This time is about three times lower than corresponding value in regime with «stepwise» profile of plasma potential. The circumstances mentioned above allow one to conclude that plasma became MHD unstable with «short circuit» connection of limiters and plasma dump electrodes.

One of the possible mechanism of MHD stabilization and decrease of transverse transport is sheared plasma rotation (see for example [4,5]). Difference of drift velocities between $R_0 \approx 7$ cm and $R_0 \approx 9$ cm is $\delta V_{dr} \approx 10^6$cm/s (see Fig.2). The external plasma layer ($R_0 \approx 9$ cm) makes one half of turn relatively to inner layer ($R_0 \approx 7$ cm) during the time of $\tau_{shear} \approx 30$μs. Typical

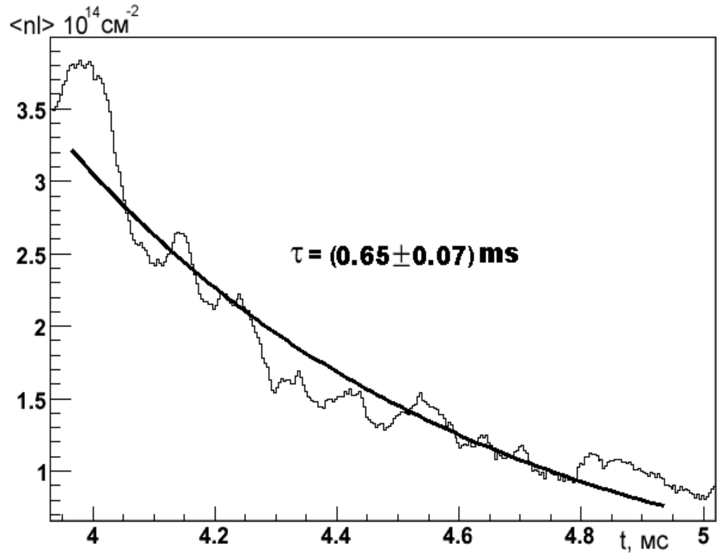


Fig.4 Time evolution of electron linear density measured after plasma source was switched off. Limiters and plasma dump electrodes are grounded.

time of flute instability can be roughly estimated as: $\tau_{MHD} \approx (W_{warm}/W_{fast})^{1/2} \cdot L/V_i \approx 15\mu s$, where W_{warm}, W_{fast} – are energy contents of warm and fast ion populations respectively, L – is length of GDT, V_i – is characteristic velocity of warm ions. Note that $\tau_{shear} \approx \tau_{MHD}$. It means that sheared plasma rotation could play an essential role as mechanism of MHD stabilization. Theoretical description of two component plasma MHD-stabilization in high β regime of the GDT operation is under construction at present time [6].

It is well known that sheared plasma rotation could drive instabilities and cause anomalous cross field transport of particles and energy. Measurements using special combined probe (see for example [7]) were carried out to study fluctuation induced transversal transport. It was shown in experiments that maximal value of particle flux density was about $2.7 \cdot 10^{14}$ cm$^{-2} \cdot$s^{-1} at the radius 9 cm. Characteristic confinement time which corresponds to this value is about 130 ms. This time is much higher that τ_{MHD}. Based on the measurements with combined probe one can conclude that cross field transport is negligible.

Summarizing results of experiments described above we can draw the conclusions as follows:

- sheared rotation can stabilize MHD modes of high β two-component plasma in the GDT experiment;
- fluctuation induced transversal transport does not play essential role in regimes with sheared plasma rotation.

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