Effect Of Limiter Biasing On Plasma MHD Stability In GDT

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Abstract: Radial electric field was found to have a strong effect on plasma performance in the gas-dynamic trap device. Minimisation of the radial field by radial limiter biasing results in significant increase of plasma energy and formation of a peaked profile of plasma density. In this regime, plasma beta as high as 0.4 has been measured in the turning points of fast ions produced by neutral beam injection.

1. Introduction

It was shown both theoretically and experimentally that radial electric field can significantly alter plasma MHD-stability. Influence of radial electric field may be crucial for plasma stability especially in the long axisymmetric mirror traps stabilized by remote MHD-anchors. In particular, estimate show that for the Gas Dynamic Trap (GDT) device [1], the radial electric field is essential comparing with magnetic field curvature effects [2]. Influence of the radial electric field on the MHD-stability has been studied in the GDT using a set of electrically biased radial limiters and segmented end walls. That enables us to control the radial profile of ambipolar potential and radial electric field, as well. General view of the GDT device is shown in Fig. 1. The GDT device has a 7m long axially symmetric central cell and outboard stabilizing cells attached from both ends. The plasma in the central cell is stabilized against curvature-driven flute modes by favorable contribution to the pressure –weighted curvature from the end cells In the experiments, the end stabilizing cell of expander-type with gradually decreasing magnetic field and that of the cusp-like were used.

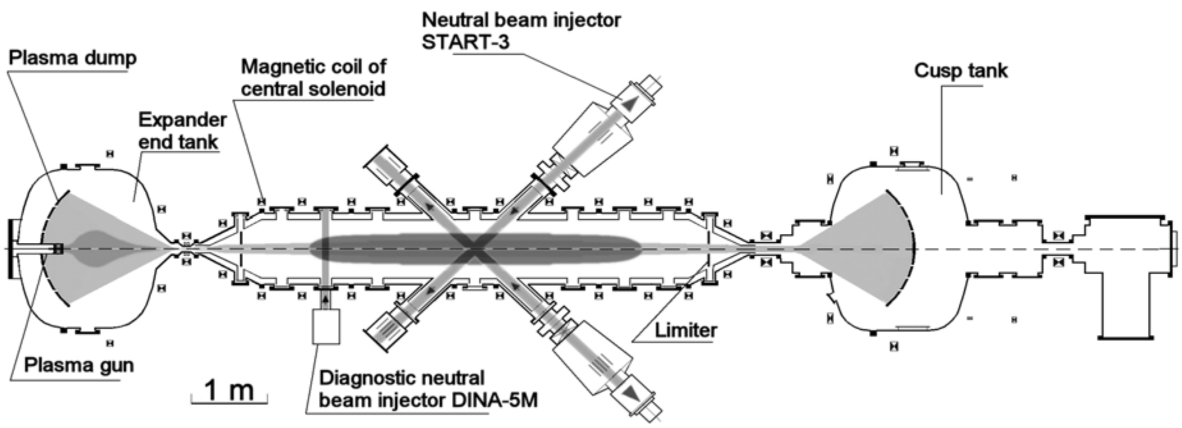

FIG. 1. General layout of GDT device.

2. Effect of limiter biasing on radial density profile.

In these experiments, the GDT plasma was heated up and fast ions were produced by injection of 6 deuterium neutral beams. The main parameters of the device are listed in Table 1.We used the deuterium beams instead of the hydrogen ones, which are routinely injected, in order to slightly increase the beam trapped fraction and obtain additional diagnostic capabilities. Total neutral beam current in excess of 250 equivalent atomic amperes was injected with an accelerating voltage 15-17 keV. The beam duration of each injector is set to 1 ms. About 2.6 MW have been trapped by the solenoid plasmas.

The initial plasma is produced by a ~3 ms pulse from a washer stack hydrogen-fed plasma gun. The gun is located in one of the end tank beyond the mirror throat. Under standard conditions, within ~3 ms, the plasma density reached 5-7 10^{19} m^{-3}, after that the gun current was terminated and the plasma begun to decay. The electron temperature of the gun-produced plasma (3-10 eV) was nearly constant across the radius. The radial density profile was well fitted by a Gaussian with characteristic scale length of 6-7 cm, which slightly changed with magnetic field strength in the gun. During the beam injection, significant broadening of the density profile has been observed. Further experiments revealed that this broadening, which was accompanied by considerable radial plasma losses, is associated with a plasma rotation caused by radial electric field. The electric field magnitude is determined by a drop of ambipolar potential (~150V on-axis value) across the plasma radius. To avoid the negative consequences of plasma rotation, a significant improvement has been introduced into plasma shot scenario. Namely, in these experiments we have employed a set of biased radial limiters (Fig. 2) and radially segmented end walls to control electric field in the plasma. The limiters were located closely to the end mirrors on the radii of 15 cm mapping onto the mid-plane. To control the radial potentials in the plasma core the four nested end plates have been used. While varying the electric field, the maximum in plasma energy and diamagnetism (Fig. 3) has been observed. This maximum corresponds to the radial limiter biasing ~150 V, while the radial end wall segments were electrically floated. The limiter potential in the optimum is essentially close to on-axis plasma potential at the end of the beam injection. In this case, when the radial potential drop was minimized, radial extent of the target plasma remained almost unchanged during the neutral beam injection, which indicates that no gross instability precludes the production of high-β, multi-component plasma in the gas dynamic trap configuration.

TABLE 1: Parameters of GDT device

Mirror to mirror distance	7 m
Magnetic field: at midplane in mirrors	Up to 0.3 T 2.5-15 T
Target plasma: density	5-7×10^{19} m^{-3}
radius at the midplane	0.10-0.15 m
Electron temperature	Up to 130 eV
NB energy	12.5 – 17.5 keV
NBs power	Up to 4.1 MW
Fast ion density (8 - 10 keV)	Up to 10^{19} m^{-3}
Maximal plasma ß	Up to 0.4

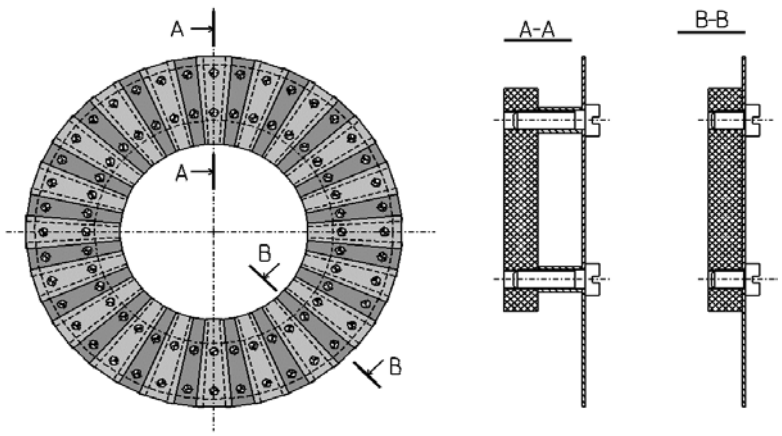

FIG. 2. Layout of segmented radial limiter.

Radial profile of the plasma potentials measured by a movable end-loss energy analyzer is shown in Fig. 4. This profile corresponds to the regime with the maximal plasma energy and β value. The potential drop from plasma axis to the limiter radius (r=15 cm) did not exceed 20 V, which is by the an order of magnitude less than that in the regime without the limiter biasing (≈200V).

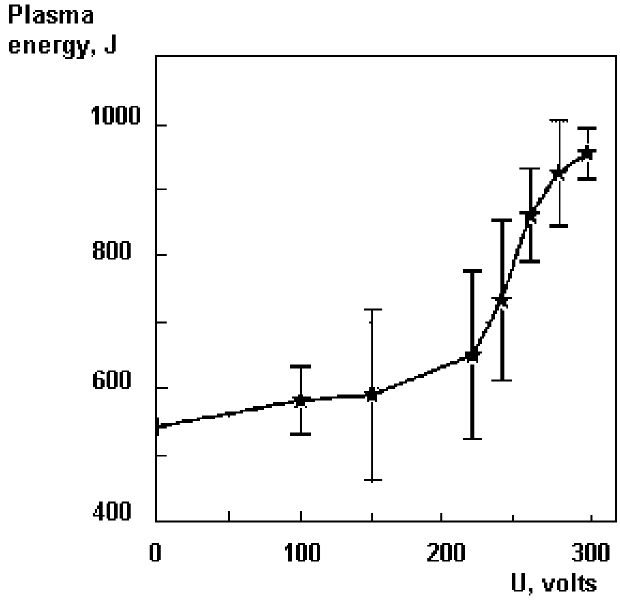

FIG. 3. Plasma energy vs potential on limiter.

3. Conclusions.

Summarizing, controllable limiter biasing significantly improved parameters of two-component plasma is GDT. Optimal potential profile in the plasma corresponds to vanishing of electric field in the plasma core. It was observed however that a formation of a potential dip near the limiter edge is also significant for further improvement of the plasma parameters. One of the conceivable mechanisms of the observed reduction of plasma losses in GDT is an interaction of the peripheral plasma with the conductive limiters. As it has been shown in [3], the short circuiting of the plasma currents flowing to the limiter decreases the grown rate of flute perturbations of the two-component plasma. The experiments, in which the azimuthal segments of the limiter were individually floating or electrically connected, have been carried out to prove this mechanism. Minimization of radial electric field has been obtained by using the end plates. It was observed that in the regime with the connected azimuthal segments, plasma energy is somewhat larger (~10%) that indicates significance of this mechanism.

Another possible mechanism is a sheared plasma rotation (see for example [4]). Radial profile of $E\times B$ drift velocity, which has been derived from the measured potential profile (Fig. 4), displays a difference of drift velocities between $R_0 \approx 12.5$ cm and $R_0 \approx 13.5$ cm of about $2.5\cdot 10^6$cm/s. The external plasma layer ($R_0 \approx 13.5$ cm) makes one turn relative the inner layer ($R_0 \approx 12.5$ cm) during $\approx 20\mu s$, which is comparable to characteristic time of flute perturbation in the GDT device. Therefore, it can be concluded that the sheared plasma rotation is significant for improvement of plasma MHD stability.

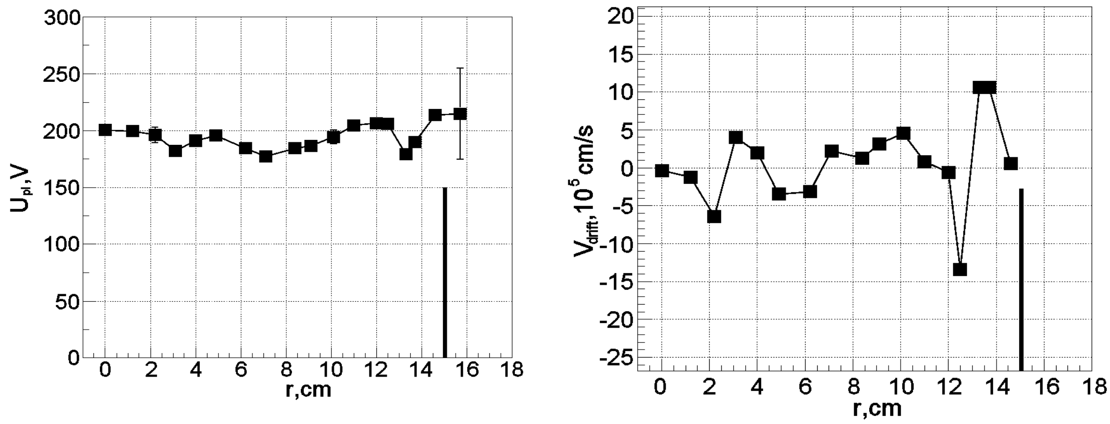

FIG. 4. Radial potentials (on the left) and the azimuthal rotation velocity profile derived from the potentials.

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