Study of the MHD−stability of the multicomponent plasma with the finite beta confined in the Gas−Dynamic Trap

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1. Introduction

The Gas−Dynamic Trap (GDT) is a long axisymmetric mirror system with the high mirror ratio [1,2] for confinement of two−component plasma. One component is a collisional "background" (or "target") plasma with ion and electron temperatures up to 130 eV and density up to 1.8×10^{14} cm^{-3}. The ion free path of scattering into the loss cone is much less than mirror−to−mirror distance for this component that suggests the gas−dynamic regime of confinement [1]. The second component is the population of fast ions with energies of 2−17 keV and density up to 10^{13} cm^{-3} [4], which is produced by 45° neutral beams (NB) injection. The fast ions are confined in the mirror regime having their turning points at the mirror ratio of 2.

The main objective of the GDT experiments is the investigation of the basic physical phenomena underlying the project of a 14 MeV neutron source for different purposes including the irradiation testing of fusion materials [3]. One of the most important tasks is the study of the MHD−stability of multicomponent plasma with high beta confined in the GDT. However carrying out the experimental study of MHD−stability using the fed washer−stack plasma gun as a source of particles for background plasma during NB injection pulse encounters some noticeable problems. The main of them is that the plasma gun provides a considerable gain in the safety factor which is enough for the plasma MHD−stability. This was proven experimentally. That motivated the applying an on−axis gas−puffing for background plasma fueling under NB−heating [5].

The main objectives of experiments to study the plasma MHD−stability were as follows:

- Achievement of the high plasma beta in experiments with applying the on−axis gas−puffing for the plasma fueling
- Investigation of conditions of the plasma MHD−stability in the regime with the cusp anchor
- Study of the influence of the plasma radial electric field on the stability
- Investigation of the plasma energy balance in a stable regime of confinement

2. Experiments with on−axis gas−puffing and cusp stabilizer

The design of the gas−puff system is described in [5]. A typical scenario of experiment using this method of plasma fueling was as follows:

1. plasma gun generates the initial background plasma, the duration of it's operation was 2.9 ms
2. the NB injection starts after the plasma gun turns off
3. the gas−puffing starts simultaneously with the NB injection

The most dangerous instability for GDT plasma is the flute instability mode m=1; all higher modes are stabilized by the FLR effects [6] under condition of the GDT plasma. Therefore the definition of the safety factor relative to the curvature driven flute instability for the regime with the cusp stabilizer must be as follows:

$$Q=dW_{cusp}/(dW_{fi} + dW_{pl}) \quad (1),$$

where dW_{cusp}, dW_{fi} and dW_{pl} − flute mode energy perturbations (abs. values) for the cusp

plasma, fast ions population and background plasma in the central cell respectively.
Although the safety factor (1) was much greater than unity in the described experiments we observed an instability after the plasma gun turned off. This indicates that plasma column rotation as a potential energy reservoir for MHD−instability provides a stronger destabilizing effect than stabilizing effect of regions with the favorable curvature of magnetic field force lines in agreement with (1).

3. Experiments with the cusp turned off and biasing limiters

The scenario of the experiments was as described in sec.2. The cusp and expander coils were turned off so the magnetic field force lines in expander regions were straight making a zero contribution in the safety factor (1). Limiters located closely to mirror plugs on the radii of 15 cm (in projection to the midplane along the flux tubes) were biasing by potential of 0−300 V. With the limiters potential varied between 0 V and 280 V we observed instability after the plasma gun turned off similar to the experiments with U_{lim}=0 and the cusp turned on (sec.2). Increasing U_{lim} up to 300 V allowed us to obtain the stable regime of confinement. In this regime the highest up to now for GDT value of plasma energy content of 1020 Joules was achieved. Corresponding to this value of plasma beta was estimated as 25%. The radial distributions of the plasma electron temperature and density are shown on Fig.1 and Fig.2.

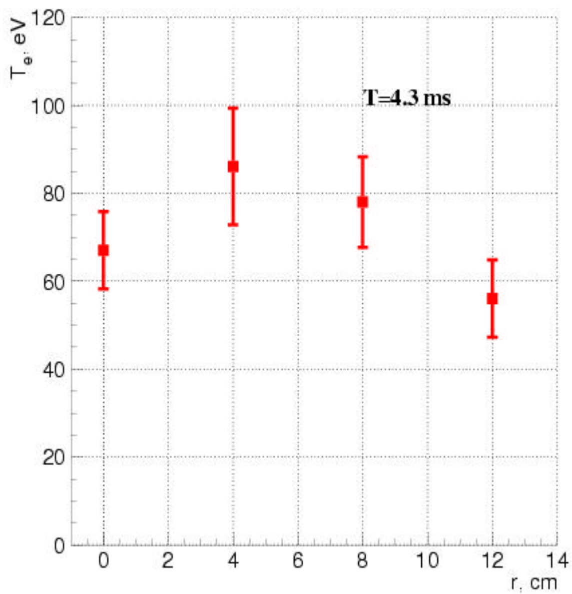

Figure 1 Radial profile of the electron temperature

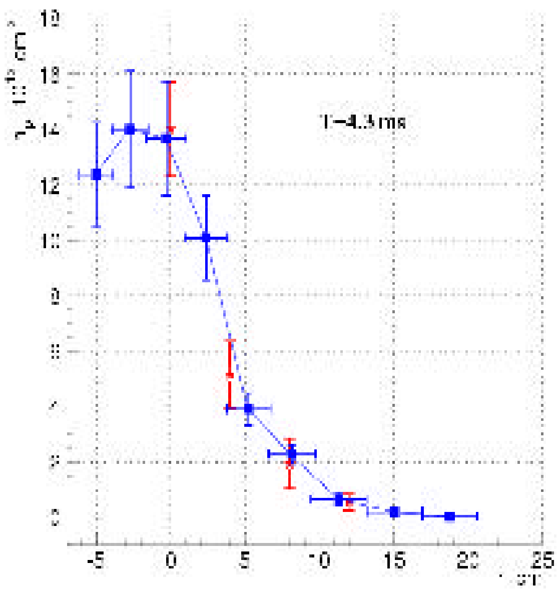

Figure 2 Radial profile of the plasma density

The T_e profile was measured by thomson scattering system, N_p profile was measured by thomson scattering and by the diagnostic based on the neutral beam injector DINA−5 [7] (helium beam was used). The measurements were carried out at t=4.3 ms. This time moment corresponds to the peak value of the plasma energy content. Note that the radial width of the density distribution (≈4.5 cm) is noticeably less than the one in experiments with the gas−box [5]. The results of an analysis of the plasma energy balance are presented in the Table1.

The Fig.3 illustrates the plasma energy content W_d and trapped NB power P_b dependence on the limiter potential. On the Fig.4 the plasma energy content averaged by a large number of shots as a function of limiter potential is shown. The drop at the value U_{lim}~260 could be interpreted as a transition across the stability boundary.To test this a simple estimation can be made: the plasma ambipolar potential difference between the midplane and the wall along a field line is ~5T_e [1]; taking into account the difference of T_e between the maximum (4 cm) and the limiter radius (15 cm) dT_e=55 eV, we obtain $\Delta\varphi\approx$275 V, that is close enough to the experimentally measured value mentioned above. The presented experimental results allow to make the conclusion that biasing limiters decrease the radial electric field in the plasma and consequently decrease the increment of the MHD−instability flute mode.

NB injected power	4.3 ± 0.2 MW
NB trapped power	2.8 ± 0.1 MW
Drag power	1.0 ± 0.1 MW
Longitudinal losses	400 ± 50 kW
Losses to limiters	400 ± 100 kW
Charge−exchange losses	150 ± 30 kW
Gas ionization losses	50 ± 25 kW

Table 1 Results of the energy confinement study in the experiment with the on−axis gas−puffing

The most probable mechanism of stabilization in such a conditions is due to line tying effect in the plasma halo, which is being in direct contact with the limiters. As it was shown experimentally and numerically calculated the fast ions density in peripheral flux tubes is noticeable. Thus the plasma heating power due to electron drag in that flux tubes is high enough for the mentioned stabilizing effect to arise. To test this hypothesis we have conducted experiments with the varied NB turn−off time. The observations have shown that the instability arises right after neutral beams turn off. In order to investigate this effect more carefully the special experiment with limiters divided on several sections azimuthally is planned to be realized.

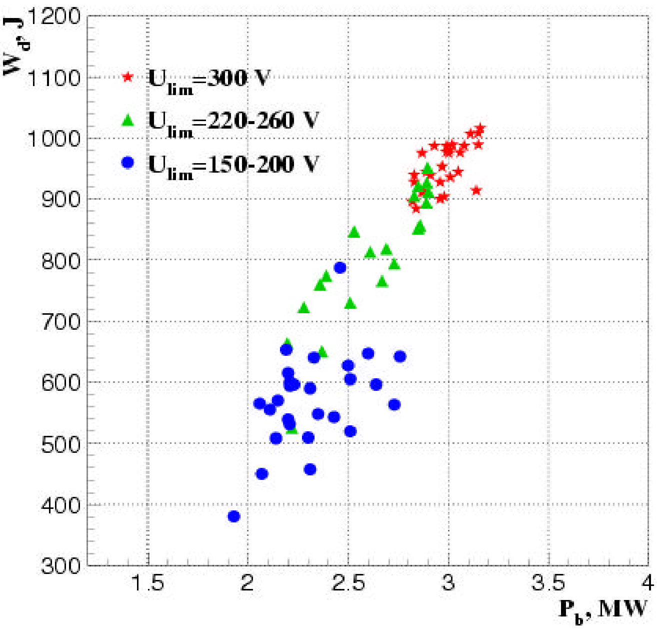

Figure 3 Plasma energy content and trapped NB power with varied limiters potential U_{lim}

4. Conclusions

On the basis of the results presented above we can draw the following conclusions:

- the plasma fueling using on−axis gas−puffing under NB injection allow to obtain a plasma with maximum density of $1.8 \cdot 10^{14}$ cm^{-3} and beta ≈25%
- rotation of the plasma caused by the E×B drift leads to the rise of MHD−instability in regimes of operation with the plasma gun turned off
- the destabilizing effect of the electric field can be decreased by biasing limiters; value of U_{lim}~260 volts corresponds to the transition across the stability boundary
- the probable mechanism of stabilization in the described experiments is due to line−tying effects in the peripheral plasma interacting with the limiters

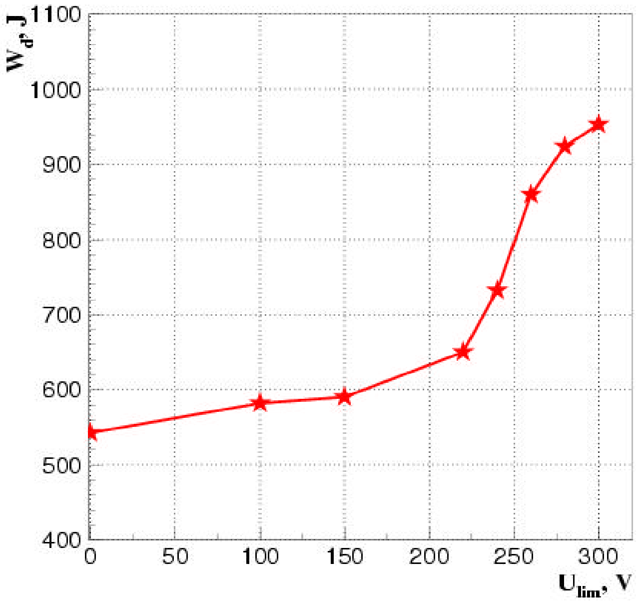

Figure 4. Plasma energy content as a function of limiter potential

Acknowledgments

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