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COLD-GAS FUELING EXPERIMENTS IN THE GAS-DYNAMIC TRAP

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1. Introduction

The Gas-Dynamic Trap (GDT) is a long axisymmetric mirror confinement system with the high mirror ratio [1,2]. The plasma confined in the GDT is of two-component. One component is a collisional warm «background» plasma with the ion and electron temperatures of 5-120 eV and density of $(1\text{-}15)\cdot 10^{13}$ cm^{-3}. For this component the ion mean free path of scattering into the loss cone is less than mirror-to-mirror distance that suggests the gas-dynamic regime of confinement. The 45° Neutral Beams (NB) injection creates the second plasma component that is fast ions with energies of 2-15 keV and the density up to 10^{13} cm^{-3}. For this component the ion mean free path of scattering into the loss cone is much greater than mirror-to mirror distance. Consequently the regime of confinement is appeared to be mirror for this component. The main objective of the GDT experiments is the studying of the basic physical phenomena underlying the project of a 14 MeV neutron source for the irradiation testing of the fusion materials [3].

As it was shown in the recent experiments on the Gas-Dynamic Trap [4], application of the plasma gun to fuel the plasma during the NB-heating causes an additional heat flux into the gun muzzle, which is comparable to collisional losses through the mirrors. Furthermore the GDT plasma gun requires a 5-12 MW power supply. The last imposes restrictions on the use of the plasma gun in a neutron source in regimes of steady state operation. That motivated the using a gas-puffing as an alternative way for the bulk plasma fueling in the GDT under NB-heating.

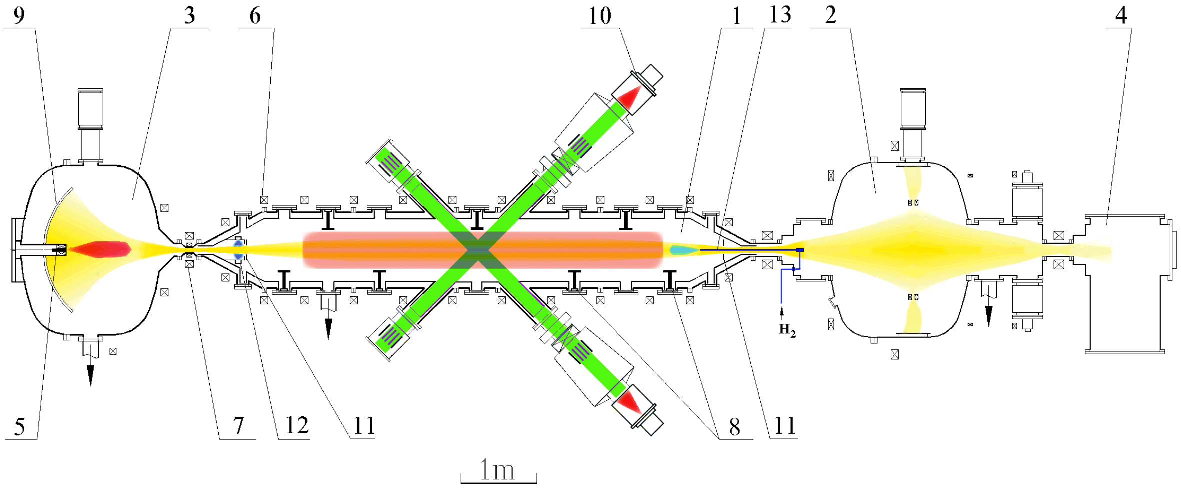

***Figure 1** The GDT layout.*
1--central cell, 2--cusp cell, 3--expander cell, 4--end-tank, 5--plasma gun, 6--solenoid coils, 7--mirror plug, 8--Ti-evaporators, 9--plasma dump, 10--NB-injectors, 11--limiters, 12--gas-box, 13—gas inlet tube.

The two methods of cold-gas-injection were realized in the GDT. The special gas-box was used for uniform H_2 injection into the bulk plasma at the plasma boundary. Alternatively on-axis injection of cold gas was carried out using of special injection tube located in the region behind the turning point of the fast ions. This method also allowed us to simulate particularly the effects of the pellet injection, which is planned to be used in the projecting GDT-based neutron source.

The main objectives of the cold-gas-fueling experiments in the Gas-Dynamic Trap were as follows:

- testing this method as an alternative robust approach to plasma fueling in the GDT;
- study of the warm background plasma radial density profiles for different conditions;
- investigation of a particle and energy balance of the warm plasma fueled by gas-puffing;
- demonstration of the possibility of cold-gas-fueling in regimes of steady-state operation;
- study of charge-exchange losses of the fast ions during NB-heating.

2. Gas-Box Experiment

The gas-box is a 40 cm length and 21 cm diameter stainless steel tube, located behind the turning region of the fast ions. Location of the gas-box is shown in Figure 1. The radius of the projection of the gas-box outlet onto the central plane is 15 cm. The design of the gas-box allowed us to perform the gas puffing on the azimuth uniformly with the gas input rate was $10\text{-}10^3$ atom Amperes depending on the gas pressure in the control valve. These values of puffing rate were enough to maintain the plasma density within a wide range of experimental conditions.

It is important to note that for the plasma with density of $(1\text{-}5)\cdot 10^{13}$ cm^{-3} and temperature of 70-100 eV, typical for GDT experiments, the penetration length of hydrogen atoms is estimated as 1 cm. This value was also obtained using special Monte-Carlo simulations. In these simulations the processes of hydrogen recycling from the stainless-steel gas-box were taken into account. Thus, the question of gas particles penetration into the plasma core is essential for the peripheral gas puffing as a method of plasma fueling in the GDT.

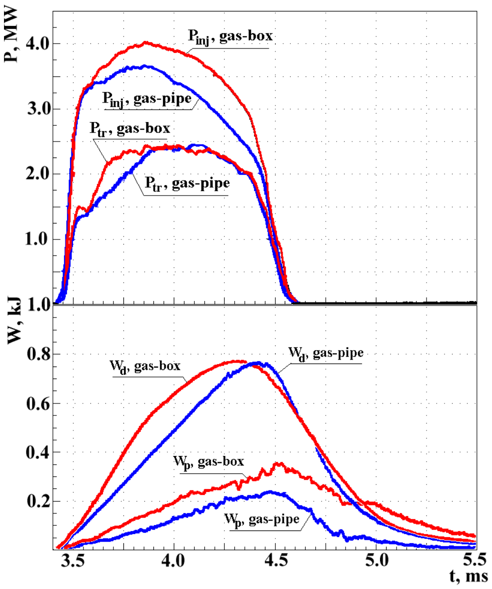

Figure 2. *Typical values of injected and trapped NB power along with data of diamagnetic measurements («gas-pipe» corresponds to on-axis gas puffing).*

A typical scenario of the gas-fueling experiment is as follows:

1. plasma gun turns on, the time of the plasma gun operation is 2.8 ms;
2. 0.3 ms before the plasma gun turns off, the gas puffing starts, the duration of the gas-puffing is about 10 ms;
3. 0.1 ms after the plasma gun turns off, the NB injection starts, the time of the NB operation is 1.1 ms.

According to the scenario, plasma gun only creates an «initial» background plasma as a target to neutral beams.

The time evolutions of injected and trapped NB power along with the data of diamagnetic measurements are shown in Figure 2. Figures 3 and 4 present the typical radial profiles of the plasma density and electron temperature at the midplane of the central cell at puffing rate of about

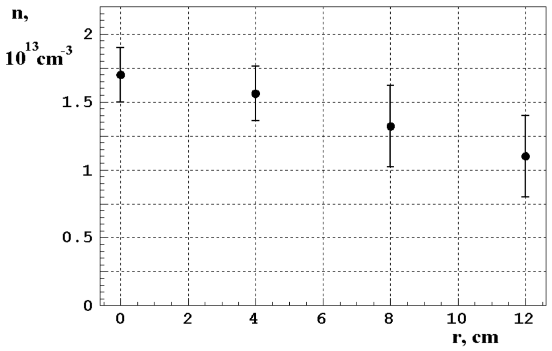

Figure 3 *Radial profile of the plasma density*

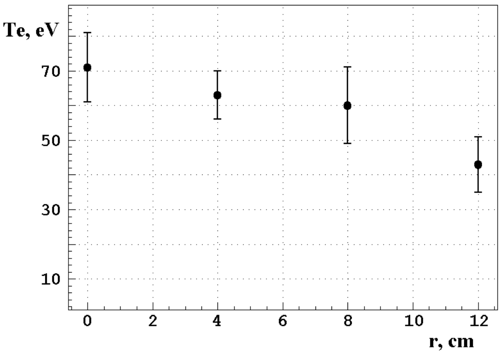

Figure 4 *Radial profile of the electron*

300 atom Amperes. Note that the maximum of the plasma density is located at the axis.

Investigations of the energy balance of the two-component plasma heated by the NBs were carried out at puffing rate of 300 atom Amperes. Table 1 presents the results of these investigations. Note that transverse losses to limiters dominate the energy balance of the warm plasma.

The possibility to realize regime of steady-state operation was studied in the special experiment with 3 ms of NB operation. The pair of neutral beams located at the opposite side of the GDT device was sequentially switched on. Figure 5 presents the time evolution of injected and trapped NB power in these experiments. Note that the ratio of injected NB power to the trapped one is almost constant during 3 ms NB injection. This result along with the plasma density and temperature measurements, performed in peripheral regions by means of a triple probe, indicates that the density of target plasma during period of NB injection remains constant.

3. On-axis gas-puffing experiment

According to results of the experiments mentioned above the main disadvantage of the peripheral gas injection is relatively high transverse losses. These losses are caused apparently by interaction of the dense plasma that is generated by gas ionization at the plasma boundary with limiters. It is possible to overcome this disadvantage by use on-axis gas injection in the region between the mirror plugs and turning points of the fast ions. This possibility can be realized by pellet injection. Special on-axis gas injection system was created to simulate particularly effects of pellet injection and to solve experimentally the tasks listed in the «Introduction». The main element of this system is quartz pipe that is inserted into the central-cell from the cusp-cell through the mirror plug (see Fig.1). The length of this so-called gas-pipe is about 500 mm, diameter is 4 mm. The pipe is oriented precisely along magnetic axes of the GDT. Pulsed gas valve was used to control the time and rate of the gas-puffing.

NB injected power	3.6 ±0.1MW
Trapped power	1.8±0.1 MW
Drag power	850±50 kW
Longitudinal losses:	
calculated	210 kW
measured	250±40 kW
Losses to limiters	540±50 kW
Gas ionization losses	50 kW

Table 1*. Results of the energy confinement study in the gas-box experiments at gas puffing rate of 300 atom Amperes*

The first experiment with on-axis injection of cold hydrogen indicates high efficiency of this method and shows its advantages. The effective energy content of a two-component plasma exceeds 800 J for NB power up to 3.5 MW. This value is very close to

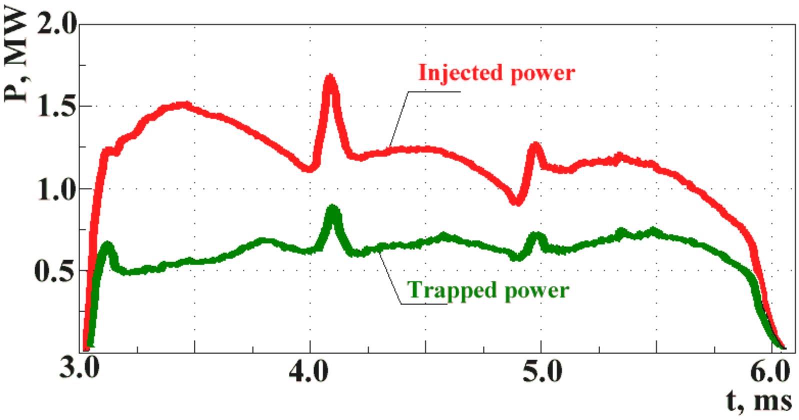

Figure 5 *Time evolution of injected and trapped NB power in experiments with 3ms NB-injection*

the plasma energy content in experiments performed previously using the plasma gun for fueling and with essentially higher NB power (see Fig.2). At the same time energy content of the fast-ion population was considerably higher, that indicates higher heating efficiency of the bulk plasma. Note that the power of charge-exchange losses during on-axis gas injection was 150 kW that is negligible in comparison with trapped NB power in this regime (see Fig.2). An experiment to demonstrate the possibility of steady-state operation was also successfully carried out in this regime.

4. Conclusions

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

- the injection of cold hydrogen with the puffing rate of a few hundred atom Amperes in GDT plasma heated up by the NBs allows us to obtain a plasma with the radius of 15-17 cm and the maximum on-axis density of $(1.5\text{-}20)\cdot 10^{13}$ cm^{-3};
- the possibility of steady-state fueling was demonstrated in the 3 ms experiments;
- charge-exchange losses of the fast ions was about 150-200 kW that is negligible in comparison with 2 MW trapped NB power;
- cross-field energy losses are dominant in the energy balance of the two component plasma fueled by cold gas in experiments with peripheral gas injection.

Acknowledgements

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