NEUTRAL BEAM SYSTEM OF THE GAS DYNAMIC TRAP

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Within this report we summarize the technical and experimental effort made on high power neutral beam injector system (NBI) and diagnostics neutral beam injector (DINA-5M) which was installed at Gas Dynamic Trap device (GDT) last year. Basic components of NBI-systems and DINA are reviewed. Recent experimental results support the concept of the neutron source based on the gas dynamic trap.
KEYWORDS*: gas-dynamic trap, neutral beam injector, neutron source.*

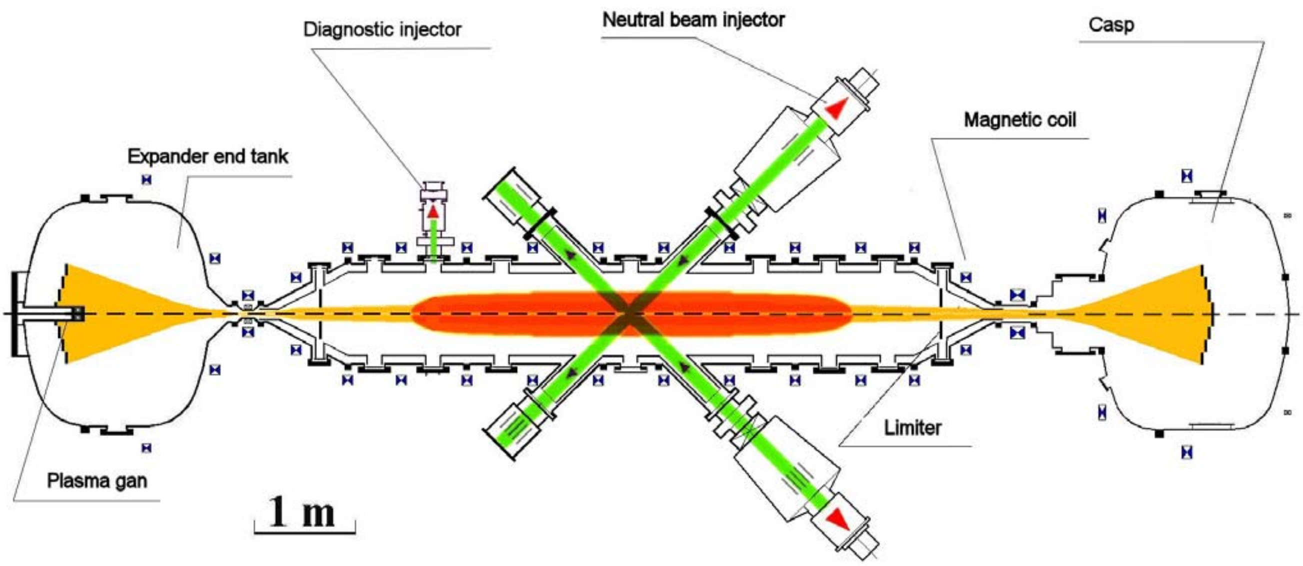

Fig.1 *The GDT layout.*

I. INTRODUCTION

The gas-dynamic trap [1] is an axisymmetric magnetic-mirror system for confinement of warm collisional (so called “target”) plasma and fast ions with the mean energy much bigger than the “target” plasma temperature. Possible fusion application of the GDT were analyzed in [2]. Based on the GDT concept, a high-power generator of thermonuclear neutrons with energies of 14 MeV can be built to study materials properties [3]. Ideas to use open confinement system as a neutron generator were also proposed in [4].

The neutral beam injection is used for plasma heating in a GDT. Fast ions with the mean energy of 9 keV and the maximum density of $5*10^{19}$ m^{-3} were produced by injection of deuterium or hydrogen neutral beams into collisional warm plasma with the electron temperature up to 250 eV and the density of $2*10^{19}$ m^{-3}.

In 2009 both the main GDT systems and diagnostics were substantially upgraded: plasma was heated and fast ions were produced by eight focused neutral beams. Neutral beams with the total current in excess of 300 atomic amperes were injected with the accelerating voltage of ~22 kV. NBI pulse length is set to 5 ms. About 4.5 MW of incident beam power was trapped by the plasma in the central GDT cell. In order to measure radial profile of plasma beta, we used the Motional Stark Effect (MSE) diagnostic [5] comprises a 50-keV, 5-A diagnostic neutral beam injector with beam 1/e radius about 1 cm at the focal plane and angular divergence about 0,5°.

II. EXPERIMENTAL SETUP

The GDT layout with neutral beam systems is shown in Fig. 1. The vacuum chamber consists of a cylindrical central cell 7 m long and 1 m in diameter and two expander tanks attached to the central cell at both ends. A set of coils mounted on the vacuum chambers produce an axisymmetric magnetic filed with a variable mirror ranging from 12.5 to 75 when the central magnetic filed is set to 0.3 T. The basic parameters of the device and the plasma parameters typical for the operational regime are listed in Table I.

The plasma was heated and fast ions were prodused by eight deuterium or hydrogen neutral beams. Neutral beams with total current more than 300 equivalent atomic ampers are injected with the accelerating voltage of ~22 kV. The beam duration of each injector is set to 5 ms. About 4.5 MW of incident beam power is trapped by the plasma in the central GDT cell.

The initial plasma is produced by a ~3 ms pulse from a washer stack hydrogen-fid plasma gun. The gun is located in one of the end tanks beyond the mirror throat. Under the standard conditions, within ~3 ms, the plasma density reaches 5 to $7*10^{19}$ m^{-3}. After that the gun current is terminated and the plasma begins to decay. The electron temperature of the gun-produced plasma is 3 to 10 eV and nearly constant across the radius. The radial density profile is well fitted by a Gaussian with characteristic scale length of 6 to 7 cm and it's changed slightly with magnetic filed strength in the gun.

TABLE I. The Parameters of GDT Device.

Parameter	Value
Mirror to mirror distance	7 m
Magnetic field	
at midplane	0.3 T
in mirrors	2.5 to 15 T
Target plasma density	1.5 to $3*10^{19}$ m^{-3}
Radius at the midplane	6 to 7 cm
Electron temperature	Up to 250 eV
NBI accelerating voltage	22 keV
Beam current in neutrals	300 eq. A
Total injection power	6 MW
Beam pulse duration	5 ms
Injection angle	45^0
Fast ion density	$5*10^{19}$ m^{-3}
Mean energy of fast ions	10 to 12 keV

III. RESULTS AND DISCUSSION

At present the upgrade of the GDT HNBI system for increase the plasma electronic temperature up to 300 eV have been completed. New high power neutral beam injector with accelerating voltage up to 25 kV START-5F [6] have been created for the new GDT HNBI system. The total beams power is up to 10 MW and pulse duration is 5 ms. Ion-optical system has beam geometrical focusing for current density increasing in the beam focal point. The START-5F layout is shown in Fig. 2.

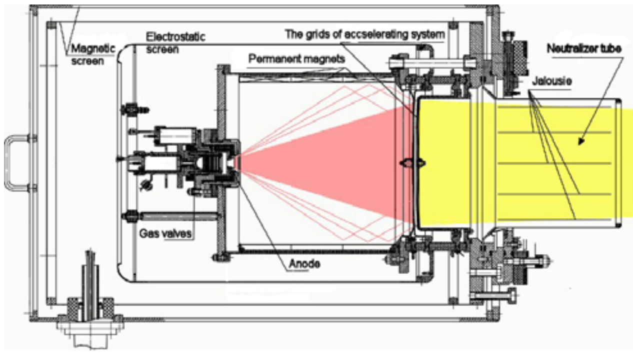

Fig.2 *Ion source and neutralizer layout START-5F*

The ion current of 50 A is routinely extracted from the plasma emitter and accelerated up to 25 keV by a multi-aperture four-electrode ion optical systems. Each molybdenum electrode (grid) of the ion-optical system (IOS) has more than 3300 holes with 2.5 mm diameter inside the 200 mm aperture. The holes form the regular hexagonal structure with accuracy better than 10 μm. The transparency of hexagonal structure is 53%.The grids were spherically shaped with the curvature radius of 240 cm corresponding to the desirable focal length. The beam 1/*e* radius is about 4.5 cm at the focal plane. It corresponds to the 0.02 radian beam angular divergence. The focal length is about 200 cm. The equivalent current density of 1 A/cm^2 is achieved in the beam focal point.

In order to measure the radial profile of plasma beta in the turning point region the MSE diagnostic is used. The MSE diagnostic at the GDT comprises a 50 keV, 5 A diagnostic neutral beam injector and a registration system. The spatial resolution is determined by the beam size and by the viewing angle of the observation system. It was found to be 4.5 cm along the viewing chord and 1.5 cm in the perpendicular plane, correspondingly. The temporal resolution is 200 μs, as it is set up by the duration of the diagnostic beam. The basic parameters of the DINA-5M are listed in Table 2.

TABLE 2. The Parameters of DINA-5F.

Parameter	Value
Work gas	H_2
Beam energy	50 keV
Beam current in neutrals	~2.5 eq.A
Operated pulse length	5 ms
Grid material	Molybdenum
Grid diameter	110 mm
Grid hole diameter	4 mm
Focal length	1600 mm
Exp. neutral beam divergence	~0.5°
Ion species composition	$H^+:H_2^+:H_3^+$=90:7:3

IV. CONCLUSIONS

Minimal angular divergence of 9 mrad and neutral beam current density >250 mA/cm^2 in focal point were achieved on the DINA-5M diagnostic hydrogen beam. These parameters allowed to apply effectively this beam for the spectral MSE diagnostic on GDT. Using of new power supply system enabled to increase the injection pulse duration up to 5ms.

The development of a new power supply system and using of a more transparent ion optical system allowed to increase the parameters of the START-5F neutral beam injector as up to 24-25 keV in energy and up to 40-50 atomic amperes in the beam current. The angular divergence of the neutral beam is 20 mrad. The upgrade of the GDT neutral beam heating system has allowed to increase injection power up to 9 MW.

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