LOCAL MEASUREMENTS OF PLASMA BETA IN GDT USING MSE DIAGNOSTIC

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ABSTRACT

The measurements of the radial profile of β for two-component plasma were performed on the gas-dynamic trap using the MSE diagnostic. The maximal value of magnetic field perturbation (ΔB/B) was 0.2 allowing to estimate the β as 40%. The profile radius was ≈7 cm, which is only slightly greater than the fast ion gyroradius mapped onto the GDT midplane. The possible mechanisms of a steep plasma pressure profile is under consideration.

I. INTRODUCTION

The Gas-Dynamic Trap (GDT) is a long axisymmetric mirror system with the high mirror ratio (Fig.1) for confinement of two-component plasma [1]. One component is a collisional target plasma with ion and electron temperatures up to 120 eV and density up to $1.8 \cdot 10^{20} m^{-3}$. The mean free path of scattering into the loss cone for the target plasma ions is much less than mirror-to-mirror distance, that suggests the gas-dynamic regime of confinement. The second component is a fast ion minority with the mean energy of 5-10 keV and density up to 10^{19} m^{-3}, which is produced by 45° neutral beam (NB) injection. The fast ions are confined in the mirror regime so that their turning points correspond to the mirror ratio of 2.

Stable confinement of fusion-energy ions with high density and small width of angular distribution in axially symmetric magnetic field is the critical issue for feasibility of the neutron source based on a gas dynamic trap [2]. Accordingly, study of the fast ions confinement and MHD-stability of two-component plasma with a high pressure plays a dominant role in the experimental program on GDT. Measurement of axial and radial profiles of plasma pressure (or plasma β) near the fast ion turning points are important, because these determine spatial profile of neutron flux in the testing zones of the projected GDT-based neutron source [2]. First results of the measurements of the perturbed magnetic field in GDT can be found in [3]. Present paper reports on the measurements of β radial profile in GDT device.

II. PRINCIPLES OF MSE DIAGNOSTIC

Stark effect is a well known phenomenon of energy level degeneracy breaking of an atom in an external electric field. In the frame of reference of a fast atom moving in a transverse magnetic field, the Lorenz electric field **E=1/c[v×B]** appears, which causes energy levels splitting. For a hydrogen (and hydrogen-like) atom the resulting Stark splitting is of the first order by the electric field thus

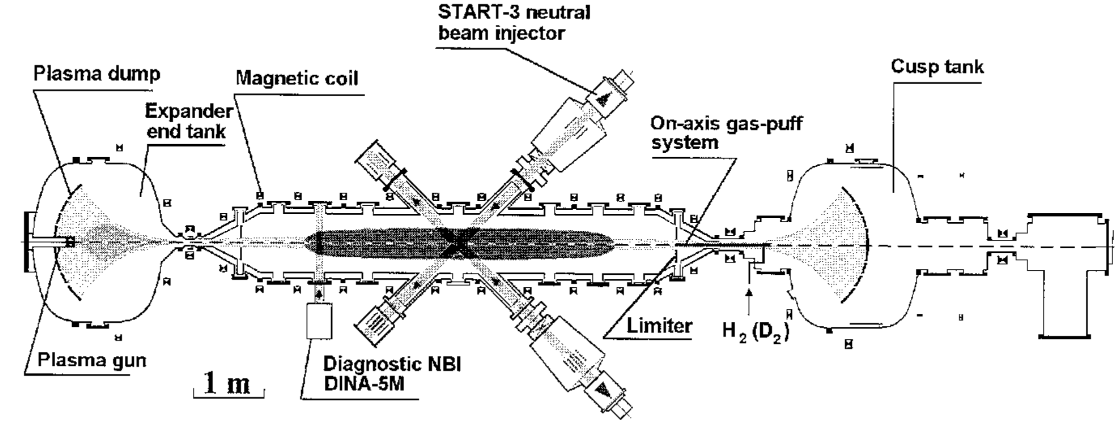

Fig. 1 The GDT layout.

providing a robust method of magnetic field measurement. In GDT experiment, the H_α line emitted by diagnostic beam atoms was chosen to conduct MSE measurements. For typical conditions of GDT experiment other effects (namely, Zeeman splitting, fine structure of atom energy levels, and other relativistic corrections) contribute to the line splitting negligibly comparing to the Stark splitting. Thus the model employing only this effect was used for data processing. Magnetic field value was determined by fitting a model profile to a measured spectrum. Knowing the perturbation of the magnetic field in plasma $\Delta B/B = (B_{vacuum} - B_{plasma})/B_{vacuum}$, one can estimate in paraxial approximation $\beta \approx 2\Delta B/B$.

III.MSE DIAGNOSTIC SETUP ON GDT AND MEASUREMENTS

The MSE diagnostic on GDT (Fig.2) comprises the neutral beam injector DINA-5M [4] and registration system [5].

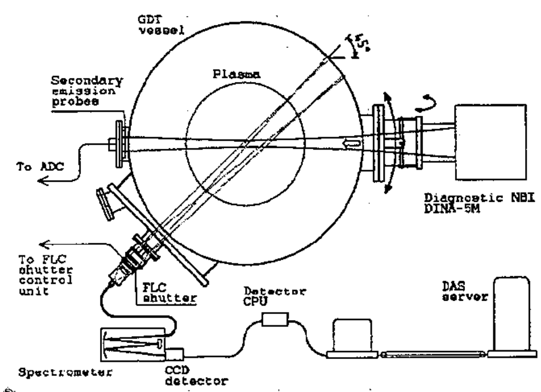

Fig. 2 MSE diagnostic layout.

Main parameters of the diagnostic injector are presented in Table 1. The NBI was mounted at an alignment unit (see Fig.2) to provide a capability of changing the beam direction. In the experiments described here the beam was directed horizontally.

Table1 The parameters of DINA-5M injector.

Type of ion optical system	Focusing
Energy of injection	40 keV
Extracted ion current (hydrogen)	Up to 7 A
Pulse duration	200 μs
Focal length	1.3 m
Beam radius at focal plane	2 cm
Current density at focal plane	0.25 A/cm^2

Two diagnostic ports could be used for observation, as shown in Fig.2. The upper port corresponds to the angle Θ=22.5° between the beam and the viewing chord, the lower one corresponds to the angle Θ=45°. The choice of the latter observation geometry for experiments was motivated by a better achievable spatial resolution (4.5×1.5 cm along the viewing chord and in the perpendicular plane resp.), which is essential for magnetic field profile measurements. The temporal resolution was 200 μs, as it was determined by the beam duration.

Registration system of the MSE diagnostic consists of the lenses assembly, optical shutter (employing ferro liquid crystal technology, FLC) and a spectrometer with attached CCD detector, which was controlled by PC. The GDT cross section, where the diagnostic was located, corresponds to the area of fast ion turning points (mirror ratio R=2). Accordingly, the plasma pressure and the magnetic field perturbation level are maximal at this location.

Hydrogen target plasma in the presented experiments was produced by a plasma gun pulse of ≈2.8 ms duration (see Fig.1). The fast ion population was created by deuterium beam injection. No gas-puff was used to maintain target plasma particle balance during the NBI pulse. Therefore, the measurements were done during the target plasma decay. Plasma MHD stability was provided by expanders (see Fig.1) and a set of biased limiters. The total NBI power was up to 3.9 MW, the beam duration was set to 1 ms. Typical target plasma parameters at the end of heating NBI pulse were as follows: electron temperature 100 eV, density $3\cdot10^{19}$ m^{-3}. The parameters of fast ion population for this regime were measured in previous experiments [6]. On the basis of their measured values one can estimate the pressures ratio $P_{fast\ ions}/P_{target} \approx 10$ and β~30% in the turning point area.

Diagnostic beam injector was fired at 4.3 ms, which corresponds to the heating pulse end, in order to measure the maximal value of β. For calibration of the spectrometer dispersion two bright plasma lines were used: H_α at 656.28 nm and CII at 657.81 nm. The Doppler-shifted beam emission line, which undergoes the Stark splitting, was visible in the same wavelength range without re-adjustment of the spectrometer. To improve the signal-to-noise ratio we summed up several experimental spectra (up to 10) in the series of shots with reproducible parameters.

IV.EXPERIMENTAL RESULTS AND DISCUSSION

The measured radial profile of the $\Delta B/B$ ratio is shown in Fig.3. Radial error bars are defined by the spatial resolution, errors in B_{plasma} measurements are due to several factors, namely: difference between plasma pressure in a set of shots used in the calculation; instability of the injection energy; uncertainty in the dispersion calibration; signal-to-noise statistics. The final accuracy of MSE measurements was estimated as 10%, which was cross-checked also by calculation of the statistical deviation between separated sets of shots.

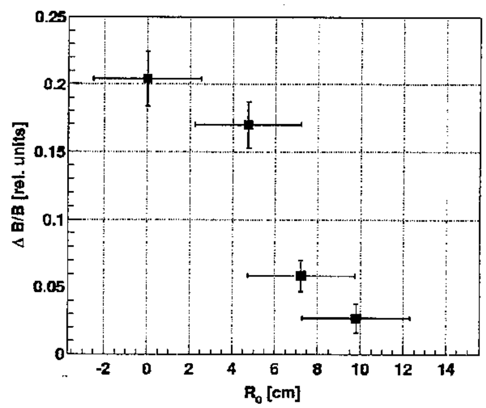

Fig. 3 Magnetic field perturbation profile vs radius mapped onto the GDT midplane.

The ΔB/B value of 0.2 measured on the axis, allows to estimate perpendicular plasma β as 40%. The rough estimation made above is close to the experimental result.

The interesting feature of the profile in Fig.3 is the small radial width $R_{1/e}\approx 7$ cm (mapped to the GDT midplane), which is only slightly greater than a deuteron gyroradius $\rho_i\approx 5.6$ cm, calculated for the magnetic field of 0.25 T and the mean energy of fast ion of 10 keV. The possible relevant mechanisms are under consideration.

On the basis of the results discussed here, one can draw the following conclusion.

- The on-axis value of ΔB/B=0.2 was measured by means of MSE diagnostic on GDT under conditions of target plasma decay. That allows to estimate β as 40% in paraxial approximation.
- The ΔB/B profile is significantly narrower in comparison with the target plasma profile, its radius $R_{1/e}\approx 7$ cm is close to an deuteron gyroradius calculated for mean energy of 10 keV.

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