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Experiments on High-β Plasma Confinement in Gas Dynamic Trap

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The Gas Dynamic Trap (GDT) is an axisymmetric plasma confinement device with the high mirror ratio variable in the range of 12.5-100. To provide MHD stability of the entire plasma axisymmetric min-B cells are attached from both ends of the device. The plasma confined in the central cell is essentially collisional and contains hot ion minority produced by oblique injection of high-power neutral beams (NBs) into the relatively cold target plasma. The plasma in the external stabilizing cells are fed by bulk plasma losses from the central cell. Main objective of the GDT research program is to generate plasma physics database for the GDT-based neutron source for material irradiations [4].

Studies of low beta (5-10%) plasma confinement in GDT are reported elsewhere[1-3] Main parameters of the GDT device are listed in Table1. Recently, plasma parameters in the GDT experiment were significantly improved with higher injected NB power. The injected current of each of six NB injectors were equalized by their increasing to 37 eq. A. (as it was for the better injector), for 15.5 -17keV energy thus providing full injection power of up to 4.3MW. Due to the equalizing the injected currents and beam energies for the injectors located at different azimuths high enough axial symmetry of the injection was achieved and thus disturbances and induced losses of the target plasma during the initial stage of neutral beam heating were minimized. Plasma energy in the regimes with increased injection power increased more than 1.5 times in comparison with that previously achieved. In stable regimes of confinement with cusp end cell [3] and when titanium was deposited onto the first wall, heating up of bulk electrons to temperatures of 120eV was observed. Reduction of charge-exchange losses and increase of target plasma temperature enabled to increase the density of fast ions with the mean energy of 5-8keV to 10^{13} cm^{-3} near the turning points. Measurements of energy losses from the bulk plasma during the heating indicated that for the mirror ratio of 12.5 these are dominated by longitudinal losses through the mirror as expected. In optimal regimes maximal plasma β of up to 25-30% was obtained. With increasing mirror ratio from 12.5 to 45 global energy lifetime for the target plasma heated up by NBI became noticeably less than that theoretically calculated for the given plasma parameters (Fig.2).

Table 1. The parameters of GDT experiment

Magnetic field at midplane	**0.22 T**
Total length	**11m**
Trapped NBI power	**2.2-2.6 MW**
Fast ion energy content	**600-800 J**
Target plasma energy	**170-230 J**
Target plasma density	**$10\text{-}13\times10^{13}$ cm^{-3}**

On axis distribution function of the energetic ions locally measured at the midplane of GDT is shown on Fig.1. Relaxation of the fast ions in the target plasma was simulated using Monte-Carlo code which incorporates classical Coloumb collisions. Simulation results were find to be in reasonable agreement with the experimental data on the fast ion distribution over energies and pitch angles. The measured fast ion energy content, with an accuracy of ±10%, close to that predicted by the code for the given parameters of target plasma.

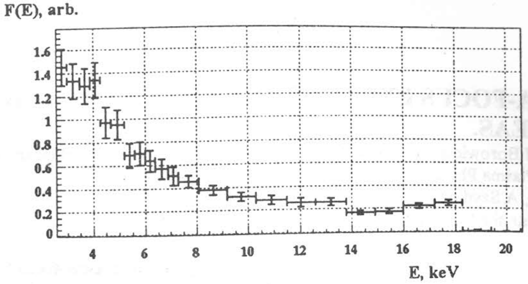

Fig1. Fast ion distribution over energies measured at plasma center.

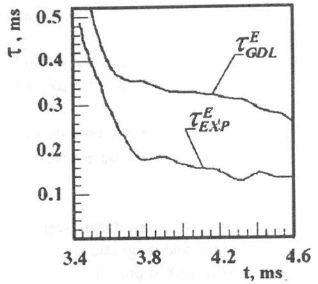

Fig.2 Global energy lifetime of target plasma for mirror ratio 45.

Conclusions.

Plasma β in GDT central cell was increased up to 30% with higher NB power. Measurements of local distribution of fast ions over energies and pitch angels indicate that there were no noticeable anomalies in fast ion slowing down and scattering. For mirror ratio of 12.5, energy losses from the target plasma are dominated by longitudinal ones. With increasing mirror ratio to 45 it was observed that energy lifetime of the target plasma is about 2 time less than that determined by longitudinal losses through the mirrors. Additional channel of energy losses can be characterized by corresponding lifetime which is estimated to be ≈ 30 $_{Bohm}$ for the representative shot parameters. In this estimate of the effective plasma temperature is calculated including contribution from fast ions. Exact mechanism of enhanced transverse losses is not identified so far. It is believed that the extra energy losses during NB injection would be caused by residual asymmetry of beam current of injectors installed at different azimuths that still exists. Nevertheless, it should be emphasized that these losses are tolerable when scaled to the operational parameters of the GDT-based neutron source [4].

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PLASMA-FOCUS EXPERIMENTS ON PF-1000 FACILITY - NEW IDEAS.

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In this paper we present the research carried out with a megajoule plasma-focus facility (PF-1000).
The goals of the experiment were defined as follows:

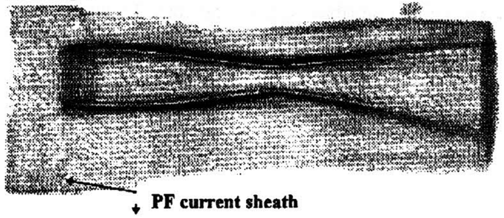
1. Using of powerful plasma-focus as a driver of staged plasma liner composition.
2. Examine various features of focused discharges with a mixed gas (H+Ar) when enhanced energy losses would change the dynamics of composition.

The PF-1000 machine was a mather type. The anode and the cathode radii are 5 cm and 7.5 cm, respectively. The condenser bank consisted of 288 × 4.6 μF, 40 kV capacitors.
Operating parameters of PF-1000 were:

- V_{max}=25 kV and with a mixture (H_2+ 20%Ar) a gas filing up to 3.7 Torr.
- V_{max}=25 kV, hydrogen pressure up to 5 Torr for liner experiment.

1. Plasma-focus liner experiment.

The high current PF plasma sheath, being accelerated during some microseconds in coaxial accelerator, could deliver its kinetic, thermal and magnetic energy to coaxial liner, positioned on the accelerator top, in rather short perid, and to provide appropriate initial conditions for fast inner implosion.
PF current sheath imploded onto agar foam liner (diameter 20 mm, 15 mm lenght, 200 μg/cm or 5.4 mm, 15-20 mm lenght, 250-280 μg/cm), produced for „ANGARA" (TRINITI) double liner implosion program [1].
Measurements of dI/dt and V(t) were done to evaluate the total active power in discharge circuit. Visible light streak camera with radial slit at the liner middle were used for current sheath and liner dinamics investigation. Time integrated X-ray pinhole camera (10-20 μm. Be) allowed to analize soft X-ray radiation intensity during sheath - liner contact and the composition implosion.
After hydrogen current shell coming to the 20 mm liner the external margin of foam plasma becomes to expand during ~100 ns till 22 mm, after that it implodes to axial rod with specific velocity ~2 cm/μs. The liner plasma reflects from the rod with almost the same velocity after implosion. Variations of imploding liner plasma radiation in optic band with specific period ~ 0.4 μs are registered Fig.1.



PF current sheath

Fig.1

2. Plasma-focus argon experiment.

The interest in the study of high-energy density states of plasmas, and associated radiative collapse phenomena induced more intensive studies during the last decade, especially research on the plasma focus operation with heavy gases /2,3/.
A filtered soft X-ray pinhole camera was employed to record time-integrated pinch images. X-ray sensitive film was used to register pictures behind a of 100μm in diameter, which was covered with Be filter of 20μm in thickness. The side-on camera had two pinholes of 100 μm in diameter covered with the Be foil of 10 μm and 25 μm, respectively.
Observations were carried out with a streak-camera slit in the radial (Fig.2) and axial (Fig.3) directions. When current sheath reaches the end of the inner electrode, then it collapses and moves axially, simultaneously. It was estimated, from the streak-camera photographs, that the average radial velocity of the plasma sheath was ~ $1.3 \cdot 10^7$ cm/s and an average axial velocity (at r = 0) was ~ $1.8 \cdot 10^7$ cm/s. Exemplary streak photographs are shown in Fig.2. It can easily be seen that the features of radial motion have been different.

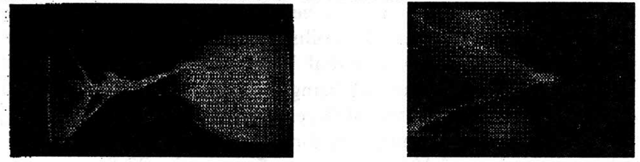


Fig.2. Streak-camera pictures taken through a slit in the radial direction:
a) for Ar+H mixture, b) for pure hydrogen

As shown in Fig.3, by means of the streak camera with a slit along the axis, there was relatively fast (~ $1.8 \cdot 10^7$ cm/s) motion of plasma sheath in the axial direction, and slow (~ $4 \cdot 10^6$ cm/s) motion of an evaporated electrode material.

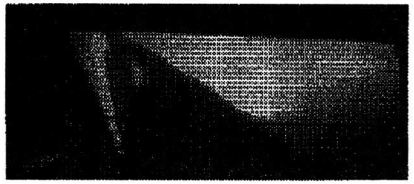


Fig.3. Streak-camera photograph obtained with the slit oriented in axial direction.

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