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Inventory Controlling Experiment of Translated Ultra High beta Plasmas without Stored Energy Loss

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Introduction

A field-reversed configuration (FRC)[1] plasma has only poloidal magnetic field and is confined in a basically simple solenoidal magnetic field. The structure of the FRC is quite simple, like a vortex, and therefore it has a magnetic null inside its separatrix. These properties make the average plasma beta, the plasma pressure normalized by the solenoidal magnetic field pressure $\langle\beta\rangle = B_w^2/2\mu_0$ extremely high, up to 0.9. Owing to this high beta feature, possibility of achieving a neutron-lean reactor using advanced fuels D-^{3}He was considered[2].

Another significant feature of the FRC is that the plasma can be translated from the quartz formation region to the metal confinement region along the guide magnetic field. Translation of FRCs have successfully demonstrated in several facilities since the early 1980s[3-4]. FIX (FRC Injection experiment) device consists of a quartz formation region and a metal confinement region. The FRC produced in the FIX can be translated with the velocity of about 0.1 ~ 0.2 m/μsec.

Translating a FRC plasma into the background neutral gas pre-filled in the metal confinement region is equivalent to the injection of a warm neutral (molecular) beam end-on into the FRC. Based on this concept, We try to control the FRC inventory without significant energy loss by translating into the neutral gas technique. In FIX case the warm neutral beam is equivalent to a 150~300eV neutral D_2 beam injection.

Experimental setup

A schematic drawing of FIX device is shown in fig.1. The FRC is produced in the quartz formation region using the negative bias theta pinch method and then translated into the metal confinement chamber, where it is confined, by a gradient in the solenoidal guiding field. A 1 m long and 0.31 m inner diameter theta pinch coil contains a 0.27 m inner diameter quartz discharge tube. The FRC plasma is formed in this quartz discharge tube. The fuel gas D_2 is introduced by two gas puff systems. Typical parameters of the FRC in formation region are an electric density n_e of 5×10^{21}m^{-3}, a pressure balance temperature T_{tot} of 300~400eV and x_s ($=r_s/r_w$, where r_s is the separatrix radius and r_w is the wall radius) of 0.35. Independently driven mirror coils are installed at both ends of the main coil. The FRC is ejected from the formation region into the confinement region by unbalanced operation of these mirror coils. The axial velocity of translation is about 0.1~0.2 m/μsec. The confinement region is made of 6 mm thick stainless steel and has a straight section with a length of 3.4 m and a radius of 0.4 m. Both end of the straight section are tapered to a 0.5 m

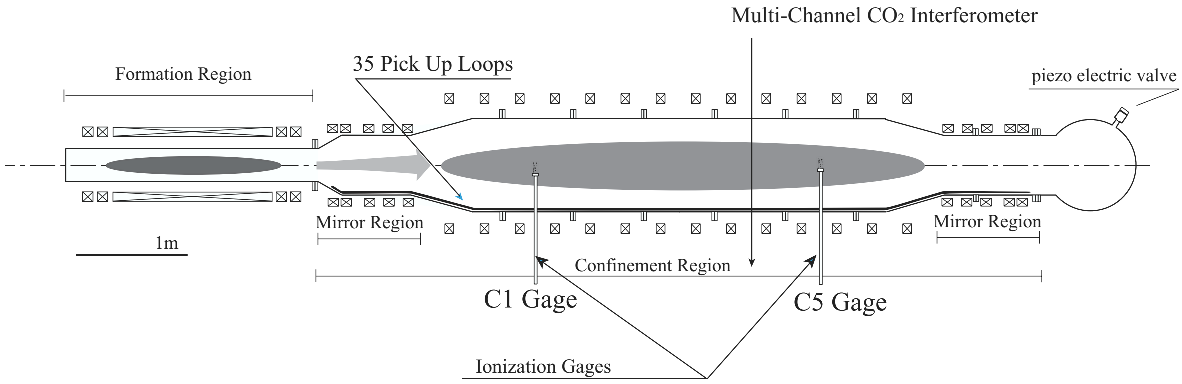

Fig.1 Schematic drawing of experimental setup

inner diameter, and have strong magnetic mirror fields there. Typical strength of the magnetic field is 0.04 T in the confinement region, 0.13 T in the upstream mirror region and 0.15 T in the downstream mirror region.

Typical parameters of the FRC in confinement region are n_e of $3x10^{19}m^{-3}$ and T_{tot} of 100~200eV. The FRC radii are estimated from data of 35 chs magnetic pickup loops installed inside the metal confinement chamber. The CO_2 laser interferometer is installed near the mid-plane of straight section to measure the line integrated density of the FRC. The plasma temperature T_{tot} is calculated from the radial pressure balance equation. Two ionization probes are using for estimate the neutral gas diffusion in the confinement chamber. These ionization probes are installed on the FIX machine axis only for the gas diffusion measurement. The time response of the ionization probe is shorter than several ten micro second. They are pull up on the chamber wall side when the FRC plasma is produced. A piezo electric valve is set on the end of the downstream mirror section and is introduce the background neutral gas into the confinement chamber. The typical results of the background gas diffusion measurement is shown in Fig.2. Fig.2(a) shows the time revolution of neutral gas density measured with the C1 ionization probe. Fig.2(b) shows that with the C5 ionization probe. Time sequence of the FRC production is shown in Fig.2(c). The formation of a FRC plasma is not affected very much, however a small amount of the background neutral gas come into the formation region when the FRC is produced. The warm neutral D_2 beam injection equivalent to the energy of 240eV and the fueling the particle number of $2.6x10^{18}$ are expected under

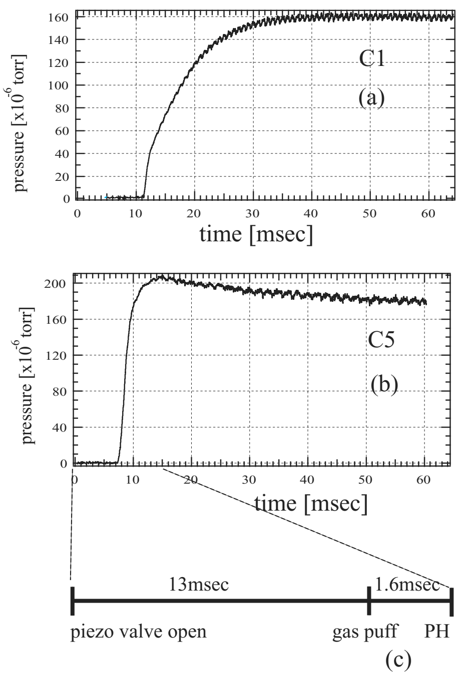

Fig.2 (a) Time revolution of neutral gas pressure at C1. (b) Time revolution of neutral gas pressure at C5. (c) Time sequence of neutral gas injection experiment. Time origine is the time of piezo valve openinng in each graph.

the condition of an FRC translation velocity v_z~$1.5x10^5$ m/sec and the deuterium background pressure ~$2x10^{-2}$ Pa.

Experimental Results

The time history of separatrix shapes of normal translation are shown in Fig.3(a). Fig.3(b) shows the time history of the separatrix shapes of translation into the D_2 neutral background gas. Both of these are calculated from averaging the each 10 shots. The velocity of translation into the neutral gas is observed to be faster than that of normal plasma shot. The velocity after the first reflection (2nd pass) of the background gas shot become slower than that of normal plasma shot. The rethermalizations [5] are observed on the reflection process on both shot. In the back ground gas shot case radial -plasma expansion after the first reflection is observed obviously. Thus the rethermalization efficiency may be better when the FRC is translated into background gas. The comparisons of plasma parameters between normal shots and background gas shots are shown in Fig.4. Each trace shows the time evolution averaged about 10 shot. The time evolution of FRC volumes are shown in Fig.4(a), those of the total temperature are shown in Fig.4(b), those of the particle number inside the FRC are shown in Fig.4(c) and those of the total energy inside the FRC are shown in Fig.4(d). Red lines show the data of the background gas shots and blue lines shows the normal shots in Fig.4. About $6x10^{18}$ of D_2 particles are expected to be penetrate translated FRC under the condition of pre fill D_2 pressure ~ $3x10^{-2}$ Pa and the translated FRC radius ~ 0.1m. The increase of the particle number at the first pass is consistent to that. After the first reflection particle number increase to ~125% of that of normal shot. More neu-

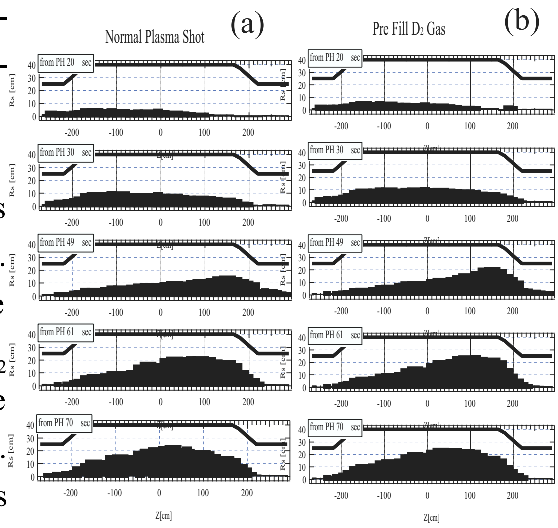

Fig. 3 (a) Time history of the separatrix shape of the normal FRC translation. (b) Time history of the separatrix shape of the FRC translated into the neutral D2. Both (a) and (b) graphs include the data of time from 20 sec, 30 sec, 49 sec, 61 sec and 70 sec.

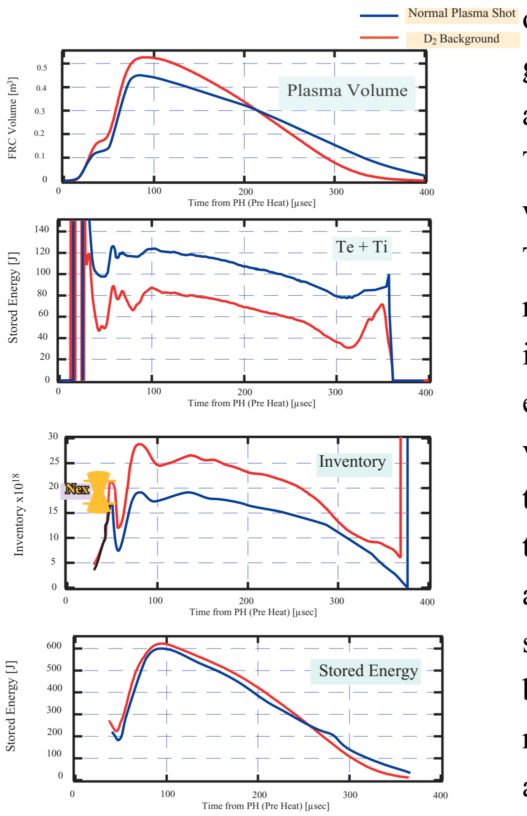

Fig.4 Time revolutions of plasma parameters.
(a) FRC volumes.
(b) Total temperature T=Ti+Te.
(c) Particles inside the separatrix.
(d) Energy inside the FRC.
Blue lines show the data for translation into the deuterium background. Red lines show the data of normal plasma operation.
All lines are averaged data of 10~12 shots data.

trals are considered to be captured by fatter FRC which grow radially on their 1st pass. The mean free path of deuterium ionization (λ_i) is about 8cm under the typical FIX-FRC parameter. The translated FRC length about 3.5m is long enough compare with the λ_i. Supposing that all of the warm neutral beam energy changes the energy inside the FRC, the increase of energy after 1st pass expected to be ~200J. The increase of the plasma energy is observed to be about half of it or less. The mean free path of hot ions on the charge exchange is about 9cm. Hot ions escape from FRC by charge exchange are calculated to be negligible small. An ion mean free path is about 50cm ~100cm. It is not negligible for FRC scale. Thus the escaping hot ions may be the cause of the energy loss of 1st pass. Fig.5 shows the translation velocity and the total energy of the FRC. In this case rethermalization efficiencies are calculated to be 60% (normal plasma shot) and to be 55% (into gas background). The energy of FRC on 1st pass is increased because the particle number and the translation velocity is increase. Thus the total energy at the time after first reflection also increase.

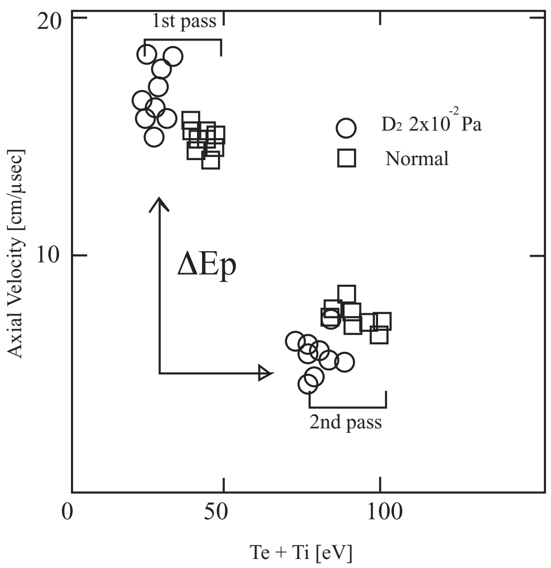

Fig.5 Axial FRC velocity. Circles show the data of normal plasma shot. Rectangles show the data of translation into the neutral deuterium.

Summary

An FRC translation experiment into the dense neutral gas has carried out. The FRC is translated with gathering almost all the neutral particles along its path. The FRC radius grows fat and its volume increases to be 120%. The first pass velocity into the background gas is faster than that of normal shot. The rethermalization efficiency under the back ground gas condition is almost equal to that of normal shot. Thus the total energy inside the FRC tends to be increase. FRC inventory can be controlled by pre-fill gas pressure without significant energy loss.

References

[1] Tuszewski, M., Nucl.Fusion 28, 2033 (1988).
[2] Momota, H., et al., Fusion Technol. 21, 2307 (1992).
[3] D.J.Rej, et al., Phys. Fluids 29, 852 (1986).
[4] H.Himura, et al., Fusion Technol. 27, 345 (1995)
[5] Himura et.al , Physics of Plasmas 2, 191 (1995).