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Study on Confinement of Particle and Trapped Magnetic Flux in FRC

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Abstract

Confinement times of plasma particle and trapped magnetic flux in FRC experiments were compared with those obtained in 1-D classical MHD transport simulations. This revealed an MHD scaling of the confinement which indicated that the transport of particle and trapped flux was classical and depended much on a plasma aspect ratio ε. In order to verify the scaling, constructed was FTHX device, purposes of which were to generate plasmas of large ε up to 15 and to increase T_e by axial injection of intense-pulse ion beams. Preliminary results of the plasma formation in the device were obtained recently. Life time of FRC plasmas was 70~80μs.

Keywords:

FRC, high beta, plasma formation, classical transport, confinement scaling, aspect ratio, further heating

1. Introduction

A field reversed configuration (FRC) has intrinsic features, i.e. pure poloidal magnetic field confinement, open field configuration outside the separatrix of plasma, and extremely so high plasma beta as more than 0.9, a value of which is fixed uniquely from a condition of plasma equilibrium. These features are surely promising potential of the FRC for a fusion burning plasma as shown in the D-^{3}He fuel reactor designing [1].

However, transport mechanisms of FRC plasmas have been remained almost unclear. The study on the transport mechanisms is therefore most urgent and important issue to be address in FRC researches.

Early works in the researches proposed a particle confinement scaling of r_s^2/ρ_i (r_s: separatrix radius, ρ_i: ion gyro radius evaluated in external field outside the plasma) [2]. Experimental results fairly agreed with this scaling in a range of the plasma aspect ratio ε (= $\ell_s/2r_s$, ℓ_s: plasma length) of 4~8 [3]. However as experimental facts, decay times of particle inventory (τ_N) and trapped flux (τ_ϕ) were almost classical for the plasmas of ε = 15~20 as seen in Fig.1.

Considering this fact, a confinement scaling of the particle and trapped flux was deduced from a 1-D MHD classical transport simulation [4]. In order to verify this scaling, constructed was an experimental device FTHX (FRC Transport and Heating Experiment). Purposes of this experiment were to realize a plasma of large ε up to 15 and to further heat plasma electrons by the axially injection of intense and longpulsed ion beam in an energy range of 50keV and in a power range of 50MW. Details of the pulse ion beam diode are described in Ref. [4]. Preliminary results of plasma formation in FTHX is reported in Sec.3.

2. Confinement Scaling in FRC

Grounded on the fact mentioned above, we numerically simulated the transport of the plasma particle and trapped flux in FRCs using the 1-D MHD

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transport model just like those used in Ref. [5] and [6]. This model assumed a cross section of magnetic surface on the separatrix was a rectangular shape. The simulation dealt with only radial transport, considering particle flows on magnetic surfaces in the axial direction and the Barn's condition of 2-D plasma equilibrium. Plasma resistivity was assumed to be uniform and classical (Spitzer's one η_0).

In the applications of this simulation to experimental plasmas, we used measured values of plasma parameters (r_s, ℓ_s, and electron temperature T_e) and a ratio α (= τ_ϕ/τ_N) of trapped flux decay times to particle inventory decay times.

The simulations were done for experimental plasmas, each of which was typical in 10 experiments and plasma parameters of which are seen Ref. [4]. Plotted in Fig.1 are those ratio ***h*** of simulated particle confinement times to experimental ones. This figure is same for the case of flux decay times since both are coupled by α. As shown obviously in Fig.1, the experimental confinement time of plasmas is almost classical ($f(\alpha)\mu r_s^2/4\eta_0$, $f(\alpha)$~0.3 for α = 1) for ε = 17~20 and decreases as plasmas becomes fat (i.e. as ε becomes smaller). This result indicates that ***h*** correlates strongly to plasma elongation as shown by a following hitting curve to data points as a function of $2r_s/\ell_s$ (= 1/ε).

$$h = (1 + 1.2\times10^3\left(\frac{2r_s}{l_s}\right)^{2.7}) = (1 + 1.2\times10^3\varepsilon^{-2.7}),$$

Values of h are 3.5 and 16 respectively for ε = 10 and 5, and are nearly unity for ε = 20 which satisfies an assumption of the model ($r_s \ll \ell_s$). This confinement scaling indicates that the transport mechanism of the particle and trapped flux in the FRC is basically classical and the confinement anomaly (***h***-1) in experiments as compared with the 1-D classical may be attributed to some 2-D transport effect, which is out of the transport model. It also indicates that it is necessary for the improvement of the confinement to increase ε and r_s, and to increase T_e.

From the scaling, r_s and ℓ_s dependence of the confinement time in a case of T_e = 100eV and α = 1 is obtained in Fig.2, in which shown are confinement times evaluated using experimental values of r_s and ℓ_s for FRX-C and NUCTE and using expected values for FTHX. This Figure indicates that the effect of r_s on the confinement saturates in the both experiments.

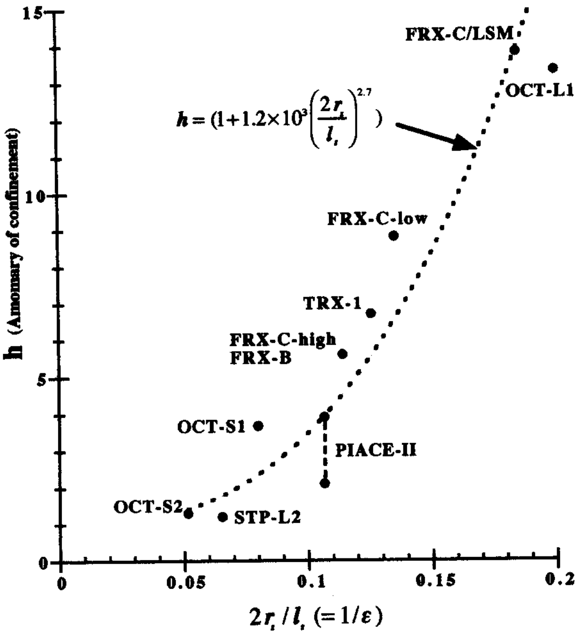

Fig. 1 Ratio ***h*** of 1-D classical confinement time to experimental one versus $2r_s/\ell_s$ (= 1/ε).

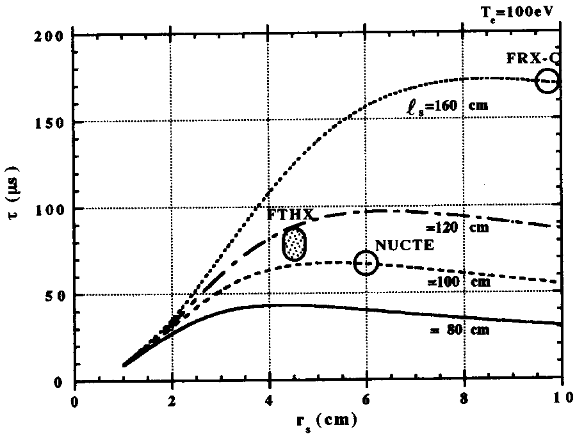

Fig. 2 Dependence of confinement time on r_s inferred from the confinement scaling for ℓ_s of 80, 100, 120, and 160cm.

3. Experimental Results

A full schematics of FTHX is shown in Fig.3. A pinch coil is 22cm in diameter and 1.5m in length. Diameter of parts of 12cm long at both coil ends is 20cm to make larger field of a mirror ratio of 1.1 on the coil axis. Total energy of the main bank is 24kJ at charging voltage of 50kV. The main pinch field rises to 5.1kG in 1.6μs at 45kV charging. Bias field is 330G. Locations of diamagnetic flux probes are shown in

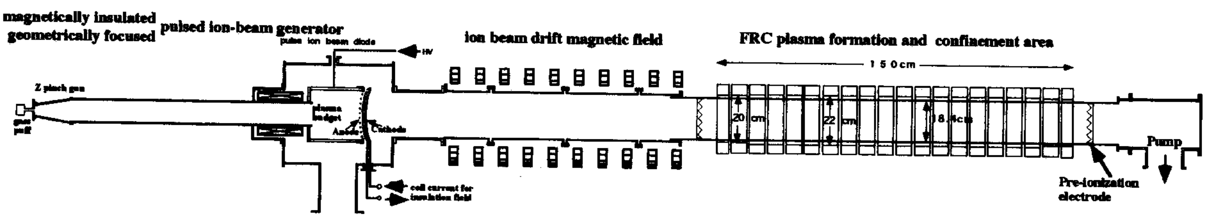

Fig. 3 Full schematics of FRC Transport and Heating Experiment device (FTHX).

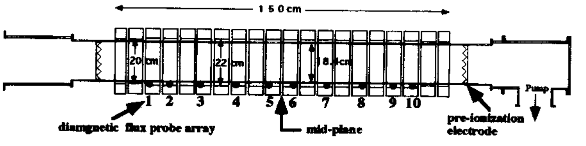

Fig. 4 Location of diamagnetic flux probes (ch.1~ch.10).

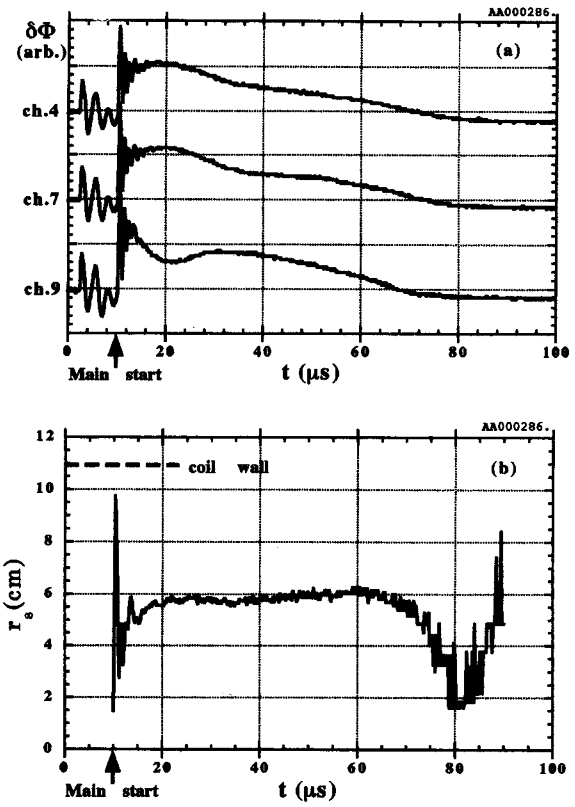

Fig. 5 (a) Diamagnetic flux signals of ch.4, ch.7, and ch.9, (b) separatrix radius at a position of ch.4.

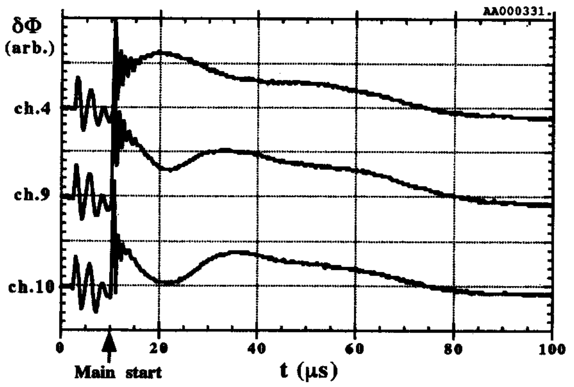

Fig. 6 Diamagnetic flux signals of ch.4 and of ch.9, ch.10 at positions near mirror field.

Fig.4. Filling gas of deuterium is 17mTorr and is ionized by z-discharge current.

Diamagnetic flux signals ($\delta\Phi$) are almost axially symmetrical. Signals of $\delta\Phi$ at ch.4, 7, and 9 are shown in Fig.5(a). Life time of plasmas is $70\sim80\mu s$. A plasma radius r_s in Fig.5(b) is inferred from $\delta\Phi$ and external field at ch.4. A value of x_s ($= r_s/r_w$) is almost constant in time and is 0.50~0.55, where r_w is the coil radius. In Fig.6 are shown $\delta\Phi$ at ch.4, 9, 10. These signals show that plasmas expand up to the position of the both mirrors and continue to push the mirror field during all the plasma life time. The length of plasmas does not, therefore, decrease in time (no axial shrink). Also, the radius is axially uniform and values of x_s is much larger than those (~0.4) in usual experiments due to the axial compression by the mirror field. All evidences mentioned above indicate that the configuration of plasmas is, so-called, that of the mirror field confinement. Intuitively saying, this phenomena is attributed to a cause that the confinement field pressure decays faster than the trapped flux and the particle inventory and energy decay.

4. Summary

The purpose of FTHX is to verify a classical MHD scaling of confinement time of the plasma particle and trapped flux.

As preliminary results, plasma configuration life time is 70~80μs. Measurement of axial profile of diamagnetic flux signals shows that plasma expands axially up to mirror field at both pinch coil ends, plasma length does not decrease in time (no axial shrink), and that x_s is 0.5~0.55 which is larger than x_s of 0.4 in usual FRC experiments. Faster decay of the field pressure than decay of the plasma energy and the trapped flux causes the mirror field confinement.

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