Advanced experiments on Field-Reversed Configuration at Osaka

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ABSTRACT

Confinement, heating and compression experiments of Field-Reversed Configuration (FRC) plasma have been conducted in an FRC experimental machine at Osaka. The FRC formed in a quartz tube with a high voltage θ-pinch system is translated into a confinement region with quasi-steady magnetic field, and expands by a factor of 100. Separation of the confinement region from the formation part makes it convenient to mount some additional components. In order to investigate the power input by the application of a fast-rise magnetic pulse, magnetic fluctuation is measured. High power neutral beam injectors have been installed for heating. An axial magnetic compression experiment has been also done, looking for a new compression scheme that has a possibility to heat the plasma and to improve confinement properties.

INTRODUCTION

The FRC has obtained a promising position as a unique candidate for the D-^{3}He fusion core plasma. The point of scope in the FRC physics design for reactor is based on the following intrinsic ability: extreme high β core, natural divertor around the core and a shape control by its transmovement. In order to realize a FRC reactor with the aid of this ability, various kinds of novel experimental techniques are required to improve plasma properties. In the present status of the FRC research, it is especially demanded to develop additional heating method, equilibrium control way for confinement improvement and some sustainment technique. In our FRC machine FIX at Osaka [1], the large volume FRC plasma (~0.5m^3) can be contained in a stainless-steel vacuum vessel with a quasi-steady field equipped with mirror fields at its both ends. It is, then, relatively convenient to install the various optional equipments around the plasma corresponding to many experimental requirements. In the following, our experimental activities are introduced as for the developments above.

EXPERIMENTAL APPARATUS

The FIX machine consists of the formation and the confinement regions as shown in Fig.1. In the formation region, an FRC plasma is produced by the field reversed theta pinch method. The formed FRC plasma is injected along a magnetic guide field into the confinement chamber, which is made of stainless steel and just takes a role of flux conserver. The magnetic pressure difference between the confinement and the formation fields enables the translation action with equilibrium profile change. When the injected FRC with super sound velocity bounces off at the downstream mirror, shock wave occurs to thermalize the plasma [2]. The separatrix length is limited by two mirror points of ~0.15T, and the mirror ratio can be chosen to be 1~10. Confined plasma parameters are listed in Table 1. The following experiments are done in this region.

CORE PLASMA CONFINEMENT

For particle transport, it is thought that the particles across the separatrix flow along the open magnetic field line to the mirror ends, and hence the confinement is not considered to be governed by the core plasma property only. The present empirical particle confinement scaling $\tau_N \sim R^2 / \rho_i$ (R;major radius, ρ_i;ion gyro radius) predicts the confinement time $\tau_N \sim 50\,\mu s$ against our FRC plasma, but the experiment shows the better value of $\tau_N \sim 200\,\mu s$. Compared with other machines, the FIX-FRC plasma has two considerably different parameters: the small density and the large mirror ratio. The reduction of the density by the injection into the lower magnetic field retards the diffusion across the closed field line. In the formation region, the mirror ratio is restricted to a factor of 1.5 because it influences the formation stage. The FIX machine is operated under a relatively large mirror ratio (~4) in the confinement region against the one (~1.1) in the formation region. The mirror is expected to play an important role not only in the equilibrium but also in the confinement conditions. The relatively large mirror ratio may produce good confinement properties.

MAGNETIC PULSE APPLICATION

The experiment of a magnetic pulse application to the FRC has been performed for heating study. A pair of half turn coils with the radius of 0.33m is placed in a stainless chamber coaxially at the midplane. The crowbarred discharge of the capacitor bank (3.3μF,35kV) connected to each coil produces the magnetic field of 0.07T at the geometrical axis with the rise time 2.5μs. It is found that the volume increases and some amount of power is to be input [3]. This effect might be caused by excitation of plasma waves. Then, magnetic fluctuations of B_z, B_θ, B_r inside the FRC are measured by search coils at an axial distance of 1.2m from the coil. The frequency to be measured is selected with a bandpass filter. As shown in Fig.2, the waveforms of the probe signals indicate the different ones from the applied pulse. The appearance time of the fluctuation signals are delayed 8.5μs after the initiation of the applied pulse, and thus the fluctuation must be a sort of plasma wave. Similar fluctuation as these has been also detected during the reflection and the rethermalization phase of the injected FRC.

NEUTRAL BEAM INJECTION

Although neutral beam (NB) injection is used on a number of tokamak experiments to heat the plasma and to drive the current, NB injection experiment on FRCs has not been done yet. For the first time, three NB injectors are attached to the FIX machine as illustrated in Fig.1. Two are called by "near-axial injector" and the other is "oblique injector". The role of the two near-axial injectors is some tool to search for heating method and for potential control of the FRC via escape of high energy beam ions. As the electron temperature of the FRC is less than 100eV, these NB beams may heat only electrons [4]. On the other hand, the oblique injector is intended to offer the seed current of the equilibrium sustainment. The ratio of the vertical and the parallel velocity components of the beam ions is designed to be outside the loss cone of the mirror field. The beam ions with high energy are to be trapped, although their orbits extend near to the chamber wall. These neutral beam injectors have a possibility to modify the internal structure and bulk parameter. The experiment will start in the last of this year.

AXIAL MAGNETIC COMPRESSION

In the FRX-C/LSM facility, a high-power magnetic compression was accomplished by increasing the axial confinement field. The successful heating is obtained, while the confinement time decreases [5]. The decrease may be caused by the reduction of R in the scaling. Equilibrium state of the translated FRC is affected by the external magnetic field shape and the separatrix length is determined by the distance between the mirror points. In order to avoid the poor confinement in this radial compression, the axial compression is done in our experiment by only shortening this distance. By this operation, the plasma length will become short but the plasma radius may increase. According to the scaling law, τ_N is expected to increase in the case of our axial compression.

To realize the axial magnetic compression, we install an additional compression coil to raise the strength of the magnetic field at a certain section of the confinement region next to the upstream mirror. For the adiabatic compression, the rise time of the compression field should be longer than the axial Alfvèn transit time and shorter than the confinement time. Since such a fast-rise magnetic field is not able to penetrate into the stainless vacuum chamber, this additional 6 turn coil is set inside the chamber as presented in Fig.1. When the FRC becomes a quiescent state, this coil is energized by the crowbarred capacitor bank (30kJ) with the coil current risetime of 35μs, to produce the compression field of ~0.15T. Thus the mirror distance is changed from 3.4m to 2.4m.

The time evolution of the separatrix radius is estimated from the excluded flux measured by the magnetic probe array just inside the flux conserver wall. As magnetic probes near the compression coil pick up not only the excluded flux but the compression field, the separatrix radius cannot be determined around the compression coil. In Fig.3, the time change of the separatrix radius at a distance of 1.2m from the coil is shown for a typical shot. The separatrix radius begins to increase from 248μs against the application time of 240μs, and the increment at peak compression is about 7%. The decay rate of the radius is, however, almost same before and after compression. The separatrix shape before and after the compression is shown in Fig.4. The separatrix radii increase at all positions. Although the separatrix near the compression coil cannot be measured, it is probable that the part of the FRC under the coil is pushed into the downstream direction and the shortened FRC expands in the downstream side without any deleterious effect on the plasma confinement.

SUMMARY

A plasma wave has been excited in an FRC plasma with β~1 by application of a fast rise magnetic pulse. This may lead us to a new scheme for heating. High power neutral beam injectors have been already installed to search for another heating method. Finally, it is found that the axial distance of the FRC can be reduced without any deterioration by the axial compression experiment. This fact could promise that the equilibrium control and the power input to the FRC can be done to look for the favorable confinement condition.

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	separatrix radius	separatrix length	electron density	pressure balance temperature	magnetic field	particle confinement time
formation region	0.04m	0.9m	$5\times10^{21}m^{-3}$	450eV	1T	50μsec
confinement region	0.2m	3.5m	$5\times10^{19}m^{-3}$	150eV	0.04T	200μsec

Table1 Plasma parameters in formation and confinement regions

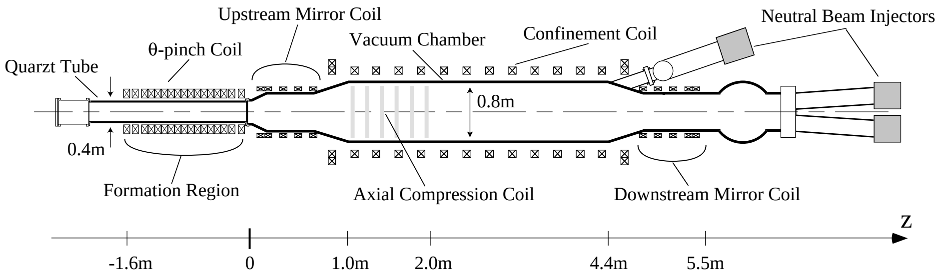


Fig.1 Schematic drawing of FIX and other experimental equipments

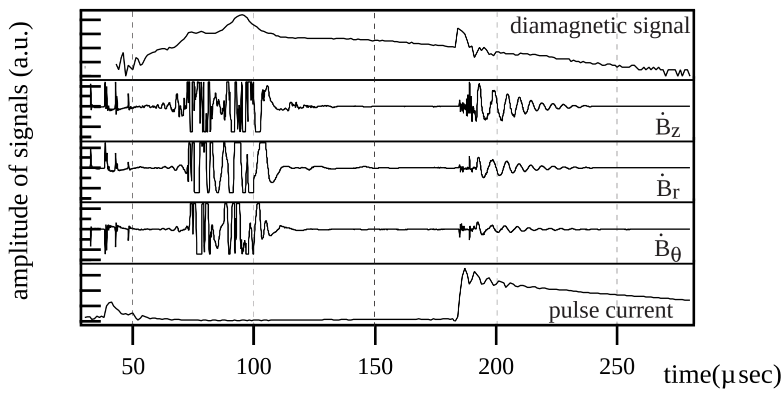
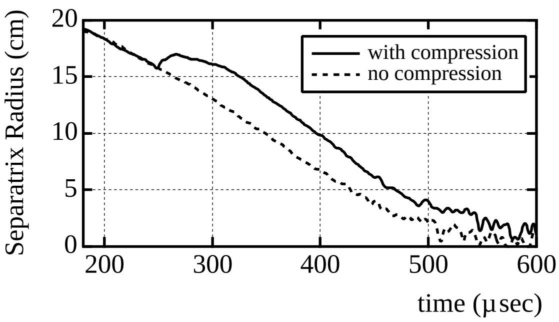


Fig.2 Time evolutions of B_z,B_θ,B_r against fast-rise magnetic pulse



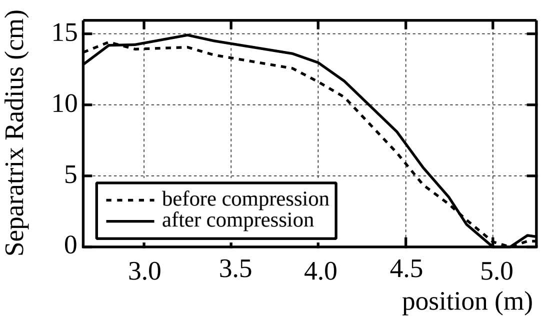


Fig.3 Typical time histories of separatrix radii with and without compression

Fig.4 Cross sectional FRC shapes before and after compression