High Density Operation of Potential Confinement in the GAMMA 10 Tandem Mirror

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Abstract

GAMMA 10 experiments have advanced in higher density operation up to $4\times10^{12} m^{-3}$ with substantial density increase due to potential confinement. The higher density plasma was obtained with a newly installed ICRF system and neutral beam injection in anchor cells.

Introduction

GAMMA 10 experiments attained doubling of density due to potential confinement with a 0.05 s duration [1]. After the experiment, larger density increase and longer operation of potential confinement were attained and were reported at the last EPS Conference [2]. Plasma densities on GAMMA 10 experiments were so far limited at about $2.5\times10^{12}cm^{-3}$ by some density limiting mechanisms. Recently higher density plasmas were attained with a newly installed ion cyclotron range of frequency (ICRF) system and neutral beam injection (NBI) in anchor cells and studies of potential confinement were extended into higher density region.

Attainment of High Density in GAMMA 10

The GAMMA 10 tandem mirror consists of an axisymmetric central cell, two anchor cells with minimum-B configuration located at both ends of the central cell, and axisymmetric two plug/barrier cells located outside the anchor cells. Plasma guns located at both ends initiate plasma production and a plasma is sustained by ion cyclotron rage of frequency (ICRF) heating in the central cell (RF2: 6.36MHz) and anchor cells (RF1: 10MHz) with hydrogen gas puffing in the central cell. A plasma confining potential is produced in the plug/barrier cell by fundamental electron cyclotron resonance heating (ECRH).

The central cell density and diamagnetism were increased 115% due to potential confinement with above heating systems [2]. However, it was difficult to increase the central cell density higher than about $2.5\times10^{12}cm^{-3}$ with and/or without potential confinement due to some density limiting mechanisms. This problem is not yet well understood, but we considered that the ICRF frequency for plasma production in the central cell is not high enough due to the requirement for simultaneous ion heating in the anchor cell. In order to overcome this problem, a new higher frequency ICRF system (RF3: 36-76MHz, ω/ω_{ci}~6 to 12) was installed and became operational recently. In addition to RF3, neutral beam injection (NBI) in anchor cells has become effective by reducing gas from the neutral beam injectors to the anchor cells.

The plasma in the central cell is sustained with RF1 and RF2. With application of RF3 power, the central cell density increased 30% as shown in Fig.1, where time evolution of a line density and RF3 power are shown during initial 100 ms. The central cell diamagnetic signal hardly changed with the application of the RF3 power. The central cell density could be increased without RF3 by a large amount of gas puffing in the central cell. However, in this case the diamagnetism decreased a large amount and this method can't be used for increasing in density on potential confinement experiments. When the RF2 power was increased the same amount of the RF3 power as power modulation of RF2, the diamagnetism increased with increase in the RF2 power but the density increase was slight due to some density limiting mechanisms as shown in Fig.2. So the application of RF3 is an effective method for increasing a central cell density and we obtained tools for controlling central cell density and diamagnetism. The density increase in Fig.1 is not so large, but this experiment was started very recently. We expect a large increase in central cell density with progress of wall conditioning and optimization of RF3 usage.

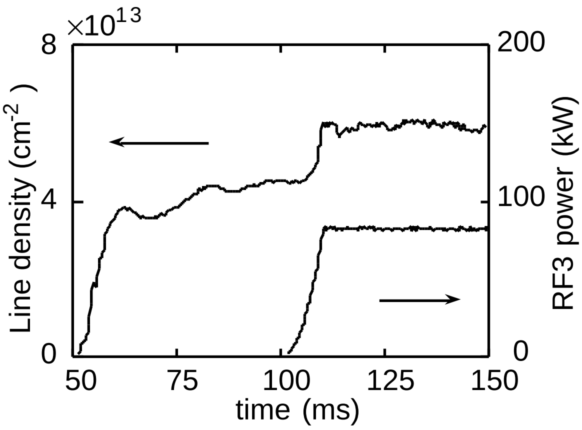

Figure 1 Time evolution of central cell line density and RF3 power during initial 100 ms.

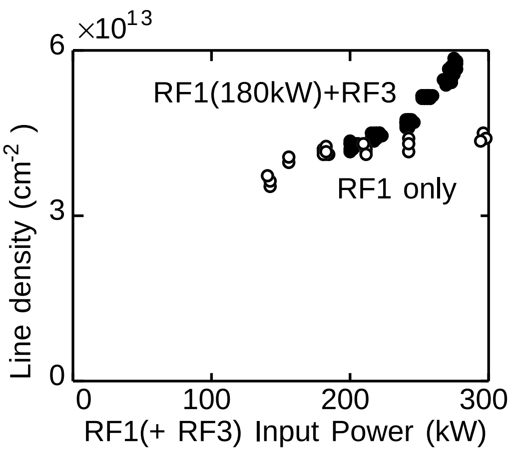

Figure 2 Central cell line density as functions of RF1(+RF3) input power for cases RF1 only (o) and RF1(180 kW)+RF3(•), where RF2 power was 150 kW. Absorption efficiencies for RF1, RF2, and RF3 were about 0.5, respectively.

Neutral beam injectors are installed at anchor cells. The maximum beam energy and equivalent neutral beam current of the injector are 25 keV and 50 A, respectively. The beam is injected at an angle 81.5 degree to the axis. Neutral beam injection in the anchor cell was not effective before. A line density of a typical anchor cell plasma is $4\times10^{12}cm^{-3}$. So the shine through beam is more than 90% of the initial beam and it caused a large amount of recycling gas. Then the plasma is disrupted by neutral beam injection due to the gas originated from the shine through beam. Recently new baffles were installed in the beam injector and dump tanks and the gas load to the anchor cell was much reduced and neutral beam injection (NBI) became effective with the reduction of gas load. The plasma density in an anchor cell increased 70% for 0.02 s with 25 kV-20 A NBI. Figure 3(a) shows time evolution of the line density in the east anchor, however, which starts to decrease during NBI. Figure 3(b) and 3(c) show the line density and diamagnetism in the central cell. The central cell density increases with the anchor NBI, but the diamagnetism decreases during NBI. The decrease in the diamagnetism is caused by charge exchange energy loss because gas load in the central cell increased with the anchor NBI. In order to reduce the decrease in the anchor density and central cell diamagnetism, a further reduction of gas load in the central cell is under way by controlling the puffing gas in the central cell.

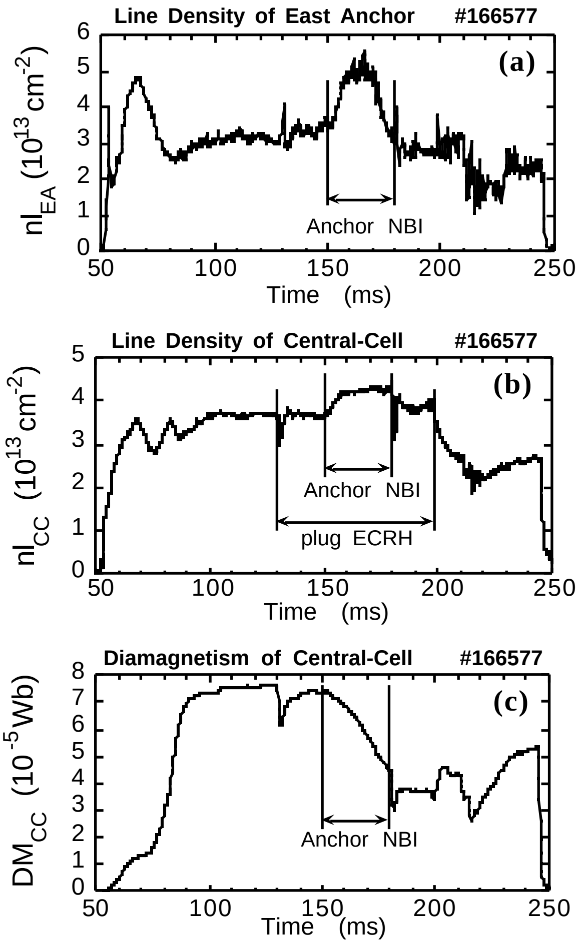

Figure 3 (a) Time evolution of east anchor line density (nl_{EA}), (b) Central cell line density (nl_{CC}), and (c) Central cell diamagnetism (DM_{CC}).

Potential Confinement of High Density Plasma

Potential confinement in GAMMA 10 advanced in higher density region. Experiments at higher densities were carried out with RF3 and NBI. Substantial plasma confinement were observed on the central cell plasma density up to $4\times10^{12}cm^{-3}$. Figure 4 shows the density increase due to potential confinement as a function of initial central cell density on the axis. As illustrated in the figure, filled circles indicate the central cell densities before potential confinement and filled triangles indicate those during potential confinement. The ion temperature on the axis and particle confinement time were 4.5 keV and 0.02 s for the data with the initial density of 1.2×10^{12} cm^{-3} and those were 3 keV and 0.01 s for the data with the initial density of 3.5×10^{12} cm^{-3}. Though the density increment decreased with initial plasma density, we expect a larger density increment at a higher density by optimization of heating scenario with respect to ECRH, ICRF heating and NBI.

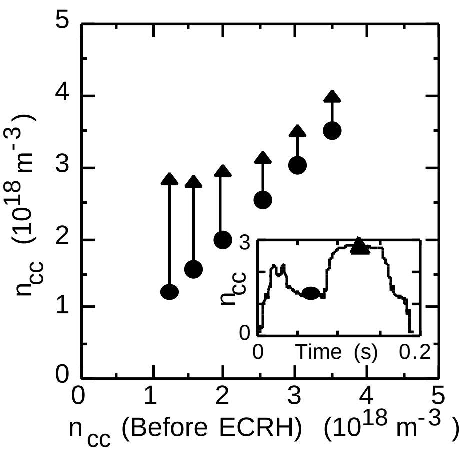

Figure 4 Central cell density (n_{CC}) before ECRH (•) and during ECRH (▲) as a function of n_{CC} before ECRH.

Summary

The potential confinement experiments in GAMMA 10 advanced in high density operation. A high density plasma was attained with the high frequency ICRF system and neutral beam injection in the anchor cell. A central cell density of 4×10^{12} cm^{-3} was attained with 15% density increase due to a potential confinement. The density is 50% higher than that attained without RF3 and anchor NBI.

[1] K.Yatsu, et al., Nucl. Fusion 39, No.11Y (1999) 1707.

[2] K.Yatsu, et al., 26th EPS Conf. on Contr. Fusion and Plasma Physics, Marstricht, 14-18 June 1999, ECA Vol.23J (1999) 461.