Chapter 2
Experimental Setup

2.1 GAMMA 10

Plasma experiments have been carried out in GAMMA 10, which is a minimum-B anchored tandem mirror with outboard axisymmetric plug and barrier cells [5,10,11,18,19,29-33]. A schematic view of the magnetic coil set and a part of the produced magnetic flux tube of GAMMA 10 is illustrated in figure 2-1. GAMMA 10 has an axial length of 27 m, and the total volume of the vacuum vessel is 150 m^3. The central cell has a length of 6 m and a limiter with a diameter of 0.36 m, and the magnetic field intensity at the midplane is 0.405 T with a mirror ratio of 5.2. The target plasmas initiated with both ended magnetoplasma dynamic (MPD) guns are produced and sustained by fast Alfvén waves. The fast waves are launched in the central cell with a four-plate-element antenna to generate rotating electromagnetic fields (9.9 and 10.3 MHz with 40 kW being supplied from the east and the west sides of the central cell, respectively). The fast waves are then mode-converted into slow waves [28] and cyclotron-damped near the midplane in the minimum-B anchor regions so as to sustain MHD stability of the GAMMA 10 plasmas. Slow waves from standard double half-turn antennas with 6.36 MHz and 60 kW are employed for producing ion cyclotron heated (ICH) bulk hot ions with an averaged ion temperature T_i of a few keV in the central cell. The ICH produced hot ions then heat bulk electrons due to slowing down processes [10,11].

Neutral beam injections (NBI; 25 keV, 20 A) are prepared for producing hot ions in the central cell and anchor regions. For the present purpose in this thesis, gas puffing from an NBI port without fast neutral beams is employed for reducing ICH produced hot ions in an anchor region due to charge exchange losses so as to degrade the MHD stability condition. In fact, after the gas puffing, it is found that the MHD destabilization phenomena take place due to a decrease in the anchor diamagnetism; that is, sawtooth oscillations are found in the following originally developed X-ray detector signals.

Electron-cyclotron-heating systems (ECH; 28 GHz, 150 kW) are prepared for producing plasma-confining potentials in the plug and barrier regions, and also for direct electron heating in the central cell. Plug/barrier ECH systems are set up for the potential formation and this system consists of four gyrotrons with the frequency of 28 GHz; this frequency correspond to the fundamental ECH at the plug (B=1 T) and the second harmonic ECH at the barrier (B=0.5 T). Plug ECH produces warm electrons for the plug potential. Barrier ECH produces magnetically trapped hot electrons in the barrier region; consequently, thermal-barrier potential is formed between the warm plug electrons and the colder central cell electrons in order to heat selectively the plug electrons.

Pumping system is composed of six turbo molecular pumps (three pumps with pumping speed of 2500 l/s, three pumps with 1500 l/s), eight helium cryosorption pumps and liquid helium cryopanels (two panels for anchor Neutral Beam Injector (NBI) tanks with 4.0×10^5 l/s, two panels for end-mirror tank with 9×10^5 l/s). The base pressure of less than 5×10^{-8} Torr is maintained by above pumping system.

2.2 Plasma Production

The method of Plasma production in GAMMA 10 has a high potential mode and a hot ion mode.

The aim of the high potential mode is to obtain high ion confining and deep thermal barrier potentials. After starting up the plasma with the plasma gun, the plug/barrier ECH are applied for producing the ion confining and the thermal barrier potentials. The ICH is carried out for ion heating in the central cell and anchor cells. The typical plasma parameters on the axis are as follows: electron density 3×10^{11} cm^{-3}, ion temperature 600 eV, electron temperature 150 eV, ion-confining potential 1.5 kV.

The hot ion mode has intention of achieving high ion temperature and large stored energy. After starting up the plasma with the plasma gun, the ICH is applied for heating the ions in the central cell and the anchor cells. Furthermore, additional heating ECH for producing the confining potential formation is applied to improve the plasma confinement. The typical plasma parameters on the axis are as follows: electron density 2×10^{12} cm^{-3}, hot ion temperature 4.0 keV, electron temperature 100 eV, ion-confining potential 0.5 kV.

2.3 Diagnostics

Electron temperatures are measured by X-ray diagnostic systems, which are constructed by pulse height analyses (PHA) and absorption method. X-ray diagnostic systems are newly developed and characterized as described in chapter 5.

The absolute values of the central cell potential Φ_C and the barrier potential Φ_B at the thermal barrier midplane are directly measured by heavy ion, Au^0, beam probes [34].

The plasma line density is measured by a microwave interferometer. The radial density profile is obtained by radial scanning of the interferometer.

Hot ion temperature is basically estimated from plasma diamagnetism. The temperature is checked by the result of charge exchange neutral particle analyzer (CX-NPA).

The atomic hydrogen H_α emission is measured radially in order to determine the ionization source of the plasma.

An electrostatic ion energy spectrometer array containing five spectrometer units [31] is utilized for end loss ion diagnostics. The arrays are placed on the end walls of the GAMMA 10 tandem mirror. The radial positions of the five spectrometer units in one spectrometer array are mapped along the magnetic flux tubes into the central cell plasma radius r_c of 2.6, 5.3, 8.2, 11.2, and 14.6 cm with a spatial resolution of 0.25 cm. The ion spectrometer arrays are installed around the magnetic axis (r_c=0) horizontally and vertically in each end region. These spectrometer signals are employed for the confirmation of plasma rotation (i.e. ion motion) viewing from both ends when the X-ray sawtooth signals appear (see chapter 6).