INITIAL PLASMAS AND DIAGNOSTIC ENERGY CONTENT IN HELIOTRON J

S. Besshou [1], **K. Aizawa** [1], **K. Hanatani** [2], **K. Kondo** [1], **T. Mizuuchi** [2], **K. Nagasaki** [2], **Y. Nakamura** [1], **M. Nakasuga** [1], **T. Obiki** [2], **H. Okada** [2], **F. Sano** [2], **M. Wakatani** [1], **W. L. Ang** [1], **T. Hamada** [1], **K. Ichikawa** [1], **Y. Ikeda** [1], **H. Kawazome** [1], **T. Kobayashi** [1], **Y. Liu** [1], **S. Maeno** [1], **Y. Manabe** [1], **H. Shidara** [1], **Y. Suzuki** [1], **M. Takeda** [1], **T. Takamiya** [1], **K. Tomiyama** [1], **O. Yamagishi** [1], **Y. Ijiri** [2], **K. Sakamoto** [2], **T. Senju** [2], **M. Shibano** [2], **K. Toshi** [2], **K. Yaguchi** [2]

[1] *Department of Fundamental Energy Science, Graduate School of Energy Science, Kyoto University, Japan*
[2] *Institute of Advanced Energy, Kyoto University, Japan*

This report describes the behavior of the initial plasmas in Heliotron J since July 2000. Hydrogen plasmas has been successfully produced by electron cyclotron resonance heating (ECH) (53 GHz, $P_{ECH} \leq 400$ kW, $\Delta t \leq \ \leq 50$ ms). The stored energy was measured with the diamagnetic double loops as a function of magnetic field strength (0.61 T< <B> axis < 1.44 T). The value of $W_p \approx 0.7$ kJ, which corresponds to $\langle\beta\rangle \approx 0.2$ %, was obtained by the second harmonic ECH at <B> axis ≈ 0.95 T with the input power 400 kW, $1/2\pi = 0.18$ m and <R> axis = 1.20 m. The values of $W_p \approx 0.8$ kJ and $\langle\beta\rangle \approx 0.1$ % were obtained at <B> axis ≈ 1.44 T by the off-axis fundamental ECH. Preliminary magnetic configuration scan with the vertical field coils controls the plasma position (1.1 m < <R> axis < 1.3 m), the rotational transform, etc. The configuration effects on the energy content are discussed.

1. Introduction

Recently many theoretical optimization studies have been done for stellarators [1-3]. However, there are still uncertainties in the theoretical optimization studies, particularly for the anomalous transport. In a medium size experimental device (major radius ~ 1.2 m), in order to allow experimental flexibility and easy access to the plasma, a continuous helical field coil is employed for Heliotron J [4-6]. Here the configuration produced by an L = 1/M = 4 continuous helical field (HF) coil with pitch modulation of $\alpha = -0.4$ has been chosen; where the helical coil winding law is defined as $\theta = \pi + (M/L)\phi - \alpha \sin\{(M/L)\phi\}$ [4]. Here $\theta(\phi)$ is a poloidal (toroidal) angle variable. One of the reason to choose a negative value of α is to produce a magnetic well in the entire plasma region. The magnetic well is necessary to suppress the pressure driven instabilities up to $\langle\beta\rangle \geq 3$ %. Another advantage of negative α is that the bumpy field component (toroidal mirror ratio) is easily controlled to reduce the neoclassical transport. Schematic of the device is shown in Fig. 1. The coil system is composed of an L = 1/M = 4 continuous helical coil, two types of toroidal coils and three pairs of vertical coils. Device parameters are, R = 1.2 m, $\langle a\rangle \leq 0.2$ m, $B_o \leq 1.5$ T, $\iota/2\pi = = 0.3 - 0.8$ with low magnetic shear, and 1.5 % magnetic well depth at the plasma edge.

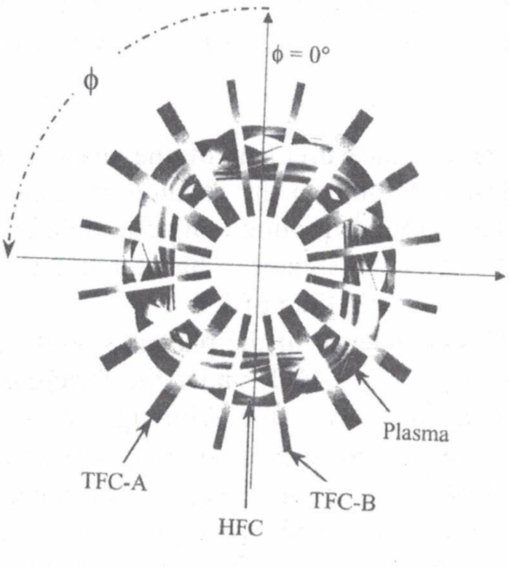

Fig. 1. Schematic of Heliotron J.

2. Experimental Results

Hydrogen plasmas have been successfully produced by the second harmonic ECH (53.2 GHz, $P_{ECH} \leq 400$ kW, $\Delta t \leq 50$ ms), after the careful examination of the vacuum magnetic surfaces by using a directed low energy electron beam [6]. The TE$_{02}$ mode waves generated by three gyrotrons were injected through smoothed oversized waveguides. A time trace of typical ECH plasma is shown in Fig.2. In this shot the toroidal averaged magnetic field strength at axis, <B> axis, is 1 T for the standard magnetic configuration (STD) with $\iota/2\pi = 0.56$, <a> = 0.18 m, and <R>axis = = 1.2 m. Diamagnetic signal shows that a stored energy of 0.38 kJ is obtained with the input power about 400 kW. Soft X-ray flux, measured with $1.5\mu m$ aluminum filter, also shows the production and the formation of ECH plasma.

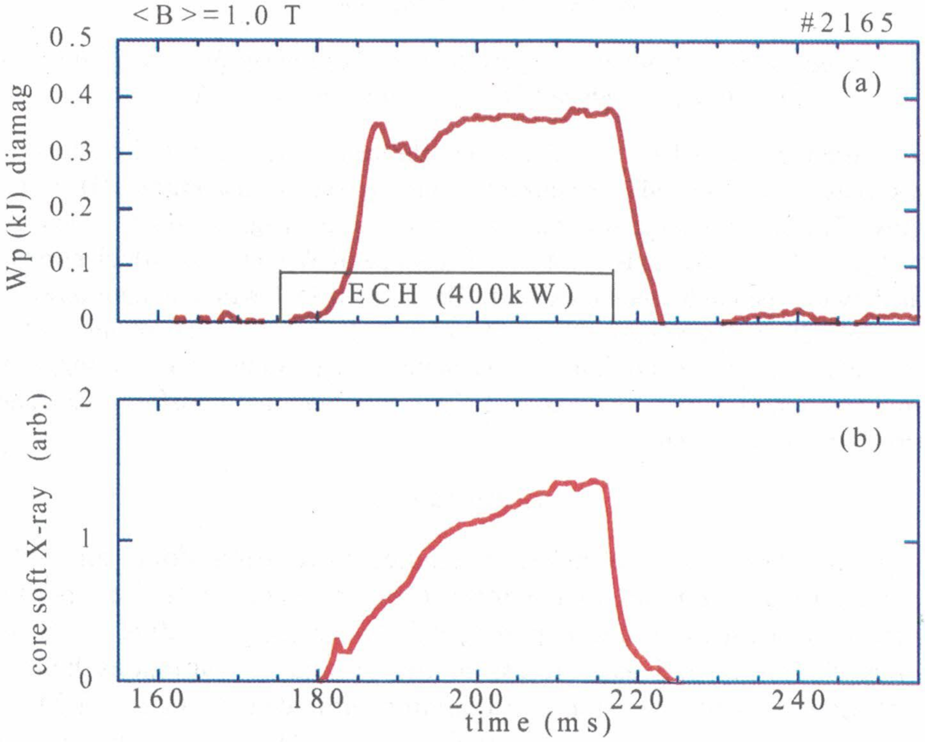

Fig. 2. Time history of ECRH plasma at averaged magnetic field strength <B> *axis* = 1.0 T in the Heliotron J standard (STD) configuration, (a) diamagnetic stored energy Wp, (b) soft X-ray flux with 1.5µm aluminum filter.

We used a diamagnetic double loop method for the measurement of the plasma-stored energy. Two concentric diamagnetic loops enclose a plasma column in the vacuum chamber. The merit of this method is a high ability to cancel out the background rippling magnetic field and the effect of eddy current to measure relatively small diamagnetic signals. The stored energy is measured with the typical noise of ± 0.02 kJ at the rippling magnetic field of 1 T.

To investigate the plasma heating window, the B- dependence of the plasma stored energy was measured in the magnetic field strength, <B> axis =0.61 T - 1.44 T, under the different gas-puffing conditions with the STD magnetic configurations in many cases. Although the density control was not optimized, the peak value of Wp ≈ 0.7 kJ, which corresponds to $\langle\beta\rangle \approx 0.2$ %, was obtained by the second harmonic ECH at <B> axis ≈ 0.94 T as shown in Fig. 3. The obtainable stored energy decreases from 0.95 T to 1.2 T. However the plasma stored energy again increases with the magnetic field strength from 1.3 T to 1.44 T. Fig. 4 shows the time history of the stored energy at 1.44 T, indicating stored energy of 0.8 kJ and $\langle\beta\rangle \approx 0.1$ % were obtained by the off-axis ECH.

Fig. 5 shows the stored energy Wp measured with the diamagnetic double loop as a function of the magnetic field strength. Here, all the data obtained during this experimental period ($P_{ECH} \approx$ ≈ 100 - 400 kW) are plotted. In the intermediate magnetic field strength (1.2 T - 1.3 T), we detected the finite signals in the stored energy of 0.08 - 0.04 kJ in off-axis ECH. In the higher magnetic field

(<B> axis > 1.35 T), we found the effective heating window. Here, the fundamental resonance condition (|B| = 1.9 T) appears only outside of the plasma half radius. The other heating mechanisms are also under study. In the low magnetic field strength with about 0.63 T, we have tried the third harmonic resonance heating. Plasma production and heating were not observed in this experimental series as shown in Fig. 5.

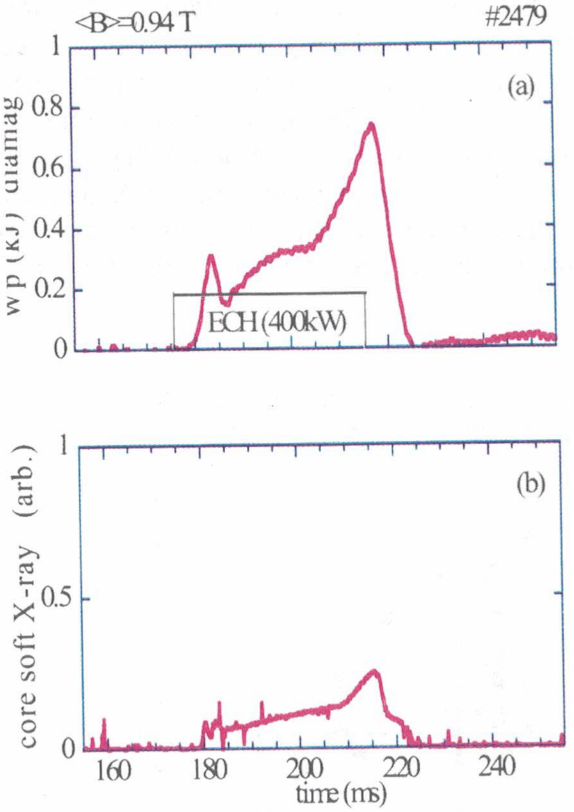

Fig. 3. Time history of ECH plasma at the magnetic field strength <B> *axis* = 0.94 T, (a) Wp, (b) soft X-ray flux.

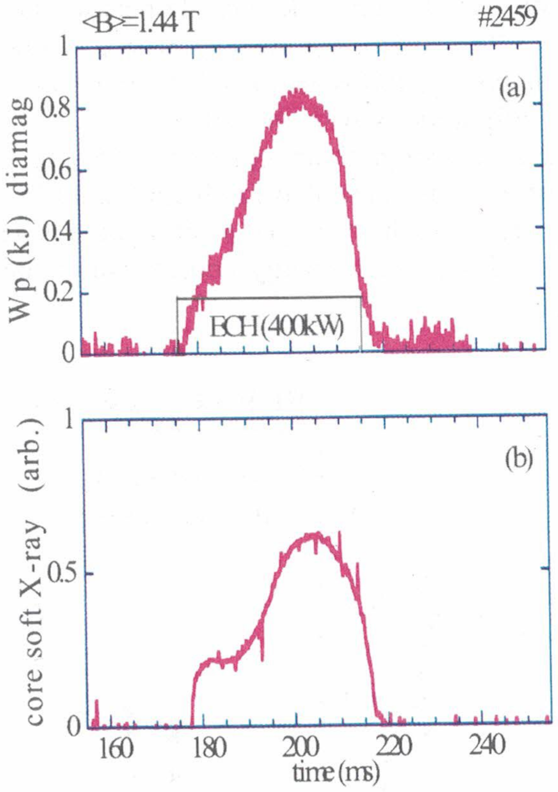

Fig. 4. Time history of ECH plasma at the magnetic field strength <B> *axis* = 1.44 T

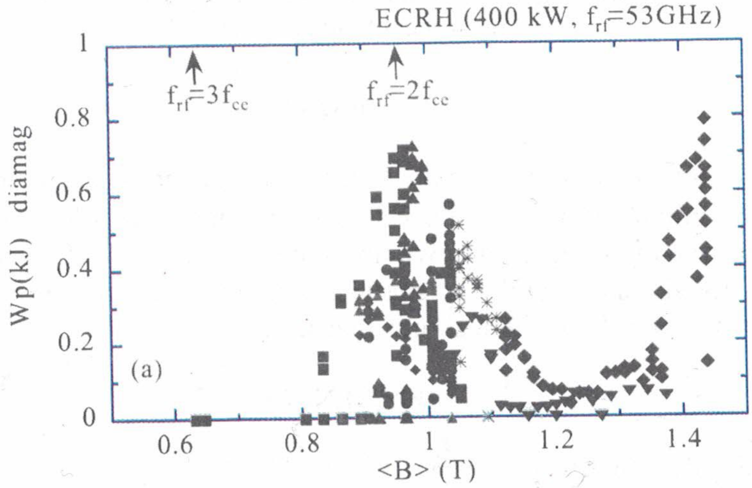

Fig. 5. Dependence of the diamagnetic stored energy of the magnetic field strength on *axis*.

The VUV spectra show the Fe and Ti besides light impurities (C and O). The level of the total radiation loss estimated from bolometers is less than 20 % of the input power. The observed VUV spectra indicate that the plasma of $T_e > 300 - 400$ eV was created, while the accurate temperature measurement is in preparation. Measured toroidal plasma current (< 1 kA) has a possibility to change the rotational transform for the low shear system.

Preliminary magnetic field configuration scan was done with exciting the additional vertical field coils. In this scan, the plasma position (1.1 m< <R> axis < 1.3 m), the rotational transform ($0.45 < \iota/2\pi < 0.65$), the average plasma radius (0.15 m < <a> < 0.21 m), and the magnetic well depth at average minor radius of 10 cm (0.0 - 1.0 %) change at the same time. For each magnetic field configurations with the <R> axis (1.15 - 1.16 m and 1.22 - 1.25 m), we have scanned the magnetic field strength on axis from 0.85 T to 1.1 T to match the second harmonic ECH at 0.95 T. Gas puffing was controlled to obtain higher Wp. Fig. 6 shows the dependence of the diamagnetic stored energy on the averaged position of axis. Here all data obtained during this configuration scan are plotted. The high-energy content was obtained for the basic configuration with <R> axis = = 1.2 m.

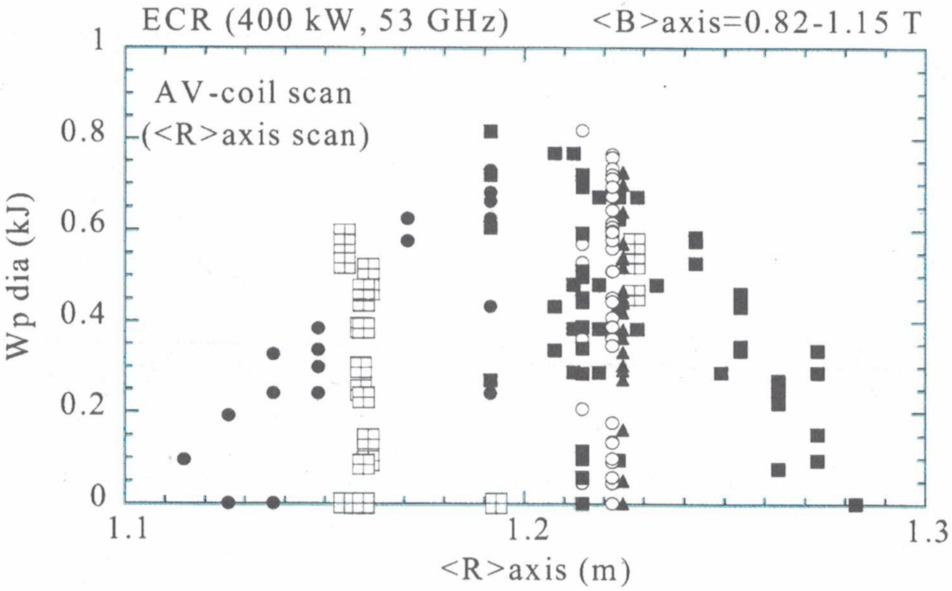

Fig. 6. Dependence of the diamagnetic stored energy on the average radial plasma position of axis (the vertical field coil scan).

3. Summary

Confinement experiments in Heliotron J have successfully begun to study the optimization physics since July 2000. The initial ECH (53 GHz, 400 kW) plasmas with Wp ≤ 0.8 kJ and $\langle\beta\rangle \leq 0.2$ % were produced in the two effective heating windows at 0.95T and 1.44 T. The sensitive dependence of the diamagnetic stored energy on the magnetic configuration is encouraging to get experimental insights into the optimization of the helical-axis plasmas.

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ПЕРШІ ЕКСПЕРИМЕНТИ З ПЛАЗМОЮ В ГЕЛІОТРОНІ J

С. Бесшоу, К. Аізава, К. Ханатані, К. Кондо, Т. Міцуучі, К. Нагасакі, Й. Накамура, М. Накасуга, Т. Обікі, Х. Окада, Ф. Сано, М. Вакатані, В. Л. Анг, Т. Хамада, К. Ічікава, Й. Ікеда, Х. Кавазоме, Т. Кобаяші, Й. Ліу, С. Маено, Й. Манабе, Х. Шідара, Й. Сузукі, М. Такеда, Т. Такамія, К. Томіяма, О. Ямагіші, Й. Іджірі, К. Сакамото, Т. Сенджу, М. Шібано, К. Тоші, К. Ягучі

У роботі описано поведінку плазми в Геліотроні J, починаючи з липня 2000 р. Водневу плазму було отримано з використанням ВЧ-нагрівання на електронному циклотронному резонансі (ЕЦР) (53 ГГц, $P_{ЕЦР} \leq 400$ кВт, $\Delta t \leq 50$ мс). Накопичена енергія вимірювалася за допомогою подвійної діамагнетичної петлі як функція напруженості магнітного поля (0.61 Тл < <B> axis < 1.44 Тл). Значення Wp ≈ 0.7 кДж, що відповідає <β> ≈ 0.2 %, було одержано при нагріванні на другій гармоніці ЕЦР при <B> axis ≈ 0.95 Тл із вхідною потужністю 400 кВт, $l/2\pi = 0.18$ м і <R> axis = 1.20 м. Значення Wp ≈ 0.8 кДж і <β> ≈ 0.1 % було отримано при <B> axis ≈ 1.44 Тл за допомогою позаосьового фундаментального ЕЦР. Положення плазми (1.1 м < <R> axis < 1.3 м) та обертальне перетворення силових ліній магнітного поля змінювалися за допомогою котушок вертикального магнітного поля. У роботі обговорено вплив змін у магнітній конфігурації на енерговміст плазми.