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The Initial Experiment in Heliotron J

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1. Introduction

Based on the Heliotron E experiment and the recent progress on theoretical understandings [1], the helical axis heliotron configuration is proposed as an advanced heliotron configuration by introducing the idea of local quasi-isodynamic optimization for good particle confinement and the concept of well stabilization for MHD instabilities. The Heliotron J device has been designed and constructed as a concept exploration device for this configuration [2, 3]. It is possible to produce a wide range of helical-axis configurations with various combinations of helicity, toroidicity and bumpiness in the magnetic field spectrum. The investigation of plasma confinement and the study of divertor related physics and technology are the prime objectives of the Heliotron J experiment. This paper reports the results from the initial operation of the Heliotron J device after a short description of the device.

2. The Heliotron J Device

Figure 1 shows a schematic view of the Heliotron J device. The device parameters are the major radius of 1.2 m, the averaged minor radius of 0.1–0.2 m, the maximum magnetic field strength of 1.5 T (on the magnetic axis), the rotational transform of 0.3–0.8 with low shear. The coil system consists of an L=1/M=4 continuous helical field coil (HFC) with pitch modulation of –0.4, two types (TFC-A and TFC-B) of 16 (8+8) toroidal field coils and three pairs of poloidal coils (inner (IVFC), outer (AVFC) and main (VFC) vertical field coils). The two types of toroidal coils with individual power sources enable us to change both the bumpiness and the rotational transform. The vertical coils provide a shift of the plasma position, which changes the magnetic well depth as well as the bumpiness.

The bumpiness is a key component for improving the high-energy particle confinement as well as the reduction of the neoclassical transport. In the standard configuration, the local quasi-isodynamic structure can be formed at the straight section of the torus. Most of deeply trapped particles are located at the position where the magnetic axis looks straight. The gradient of the magnetic field strength becomes small there, thus suppressing the ∇B-drift of ripple trapped particles. According to a numerical calculation, the prompt orbit loss rate of collision-less ions decreases from 20 % down to a few percent at the half radius when β increases to 2 %. The trapped particles are well confined as localized banana or superbanana particles. The calculation has also revealed that a slight radial electric field in the level of L-mode can reduce the loss rate down to less than 10 %.

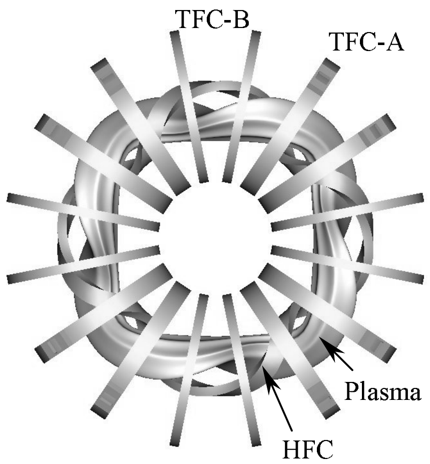

Fig. 1 A schematic view of the Heliotron J device. The poloidal coils are not drawn.

One can produce the magnetic well in the whole confinement region, which is necessary to suppress the pressure driven instability at high β. The magnetic well about 1.5 % is formed at the boundary region of the standard configuration. The stability β limit, determined by the interchange instability, is expected around 4 %. When increasing β, the magnetic well becomes deeper, and the edge rotational transform decreases, leading to the shear stabilization.

The final assembling of the device was finished at the end of October 1999 and we succeed to obtain the first plasma by 53GHz ECH at ≈ 1T during the commissioning operation.

3. Experimental Confirmation of the Field Topology

In stellarator/heliotron devices, the magnetic field configuration for the plasma confinement can be produced only by using the external coils. If the accuracy of the coil alignment is not enough, the resulting error fields spoil the magnetic surfaces and the plasma confinement property. Even if the accuracy is good enough, mechanical restrictions in the construction of the coil system (ex. a finite size of the feeder, etc.) and magnetic materials around the device, which are used for magnetic shielding of diagnostics or heating equipments, can cause error fields. Therefore, experimental verification of closed nested magnetic surface formation in the vacuum (no plasma) condition is an important experimental task.

The measurement of the field topology for the confinement region in Heliotron J has been performed by using the beam-fluorescence method. The goal of this experiment is to evaluate magnetic surface shape, quality, and rotational transform profile for different magnetic configurations of Heliotron J. Figure 2 schematically shows the experimental setup. A small electron gun emits a low energy (≤ 100 eV) electron beam along the field line. The beam diameter at the gun exit is about 0.5 mm. The electron beam goes around the torus many times along the field line and makes a drift orbit surface, which is close to the magnetic surface where the electron gun is positioned. The electron gun is inserted from a top port of the device and the gun position can be vertically (Z-direction) changed from the equatorial plane of the torus up to Z = 30 cm. The position of the electron beam is detected by scanning a fluorescent rod in a poloidal cross section. The fluorescence light image is taken with a CCD camera. The scanning system of the fluorescent rod is designed to cover the whole area of the magnetic surfaces for the standard configuration of Heliotron J by a combination of linear motion and rotation (see Fig. 3).

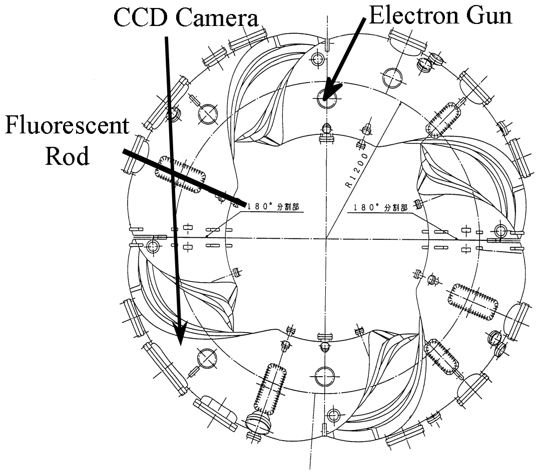

Fig. 2 Experimental Setup for Vacuum Magnetic Surface Mapping.

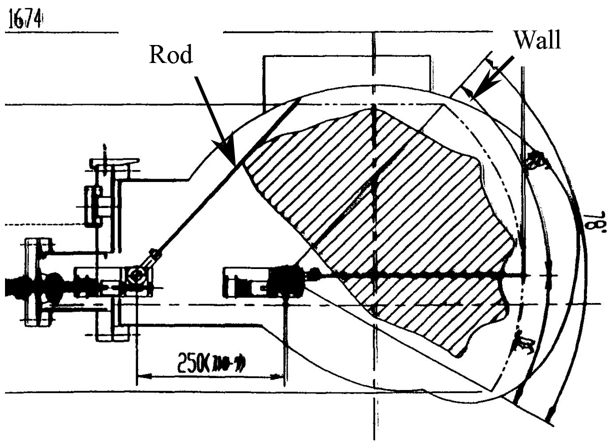

Fig. 3 Fluorescent rod scanning system. The shaded area is the outermost magnetic surface in the standard configuration.

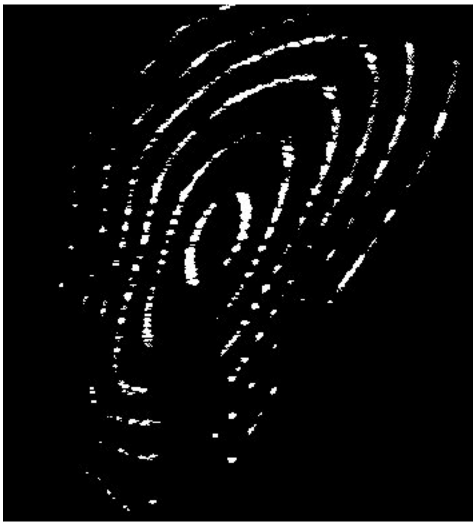

Fig. 4 An example of the fluorescent image. (before view-angle compensation)

Figure 4 shows the initial mapping results for two different configurations; the helical coil current I_{HFC} = 24 kAT, the main vertical coil current I_{VFC} = 21 kAT, the toroidal coil currents $I_{TFC\text{-}A}$ = 15 kAT and $I_{TFC\text{-}B}$ = 4 kAT, the auxiliary vertical coil current I_{AV} = 0 kAT, the inner vertical coil current I_{IV} = 0 kAT, and the gun positions are Z_{Gun} = 50, 100, 150, 200, 250, 300 mm. As shown in Fig. 4, a set of closed magnetic surfaces is observed. (Note that the scale of these figures is not calibrated yet.) By changing AV and/or IV fields, the modifications of magnetic surfaces are observed. For example, it is observed that the position of the surfaces is outward shifted by adding AV field. These modifications are qualitatively consistent with the field calculation.

Since the magnetic field strength in these conditions is about 500 G, it must be taken into account at least the effect of the earth magnetic field for quantitative comparison with the calculated magnetic surfaces. The basic mode of the earth magnetic field is n=1/m=1. This is off-resonance condition for the rotational transform of these two configurations and no large magnetic island will be appeared. However, the earth magnetic field will cause tilting of the surfaces and some modification of the shape. The detailed analysis is under going.

4. The Initial Plasmas in Heliotron J

Current-less plasmas have been produced successfully by 53.2 GHz ECH using two gyrotrons (G2 and G4) at B ~ 1.0 T. The TE_{02} axisymmetric mode generated by the gyrotron is transmitted by a waveguide system, and launched into the vacuum chamber from the outside of the torus through a smoothed waveguide of 2.5” diameter. The total launched power is ≤ 300 kW, and the pulse duration is ≤ 50 ms. Since the TE_{02} mode is considered as a mixture of O- and X-modes, the single pass absorption is not high, and the remaining power would be absorbed after the multi-reflection from the chamber wall, resulting in the uniform power dis-

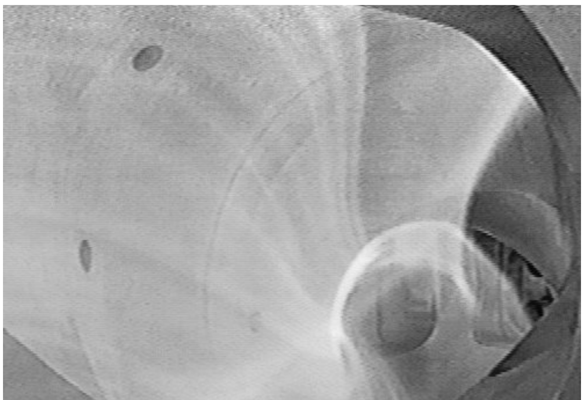

Fig. 5 A tangential view of ECH plasma measured with a CCD camera.

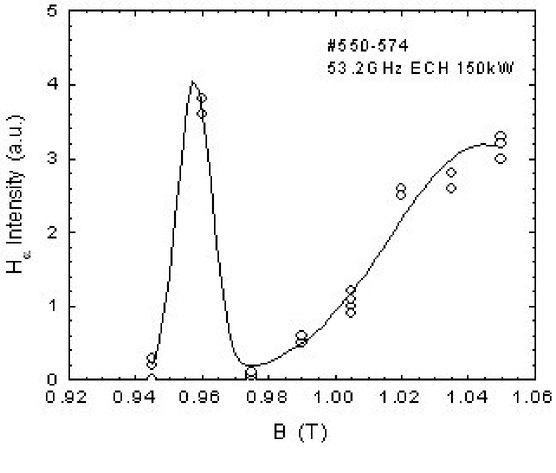

Fig. 6 Dependence of H_α emission on magnetic field strength. The field configuration is kept constant.

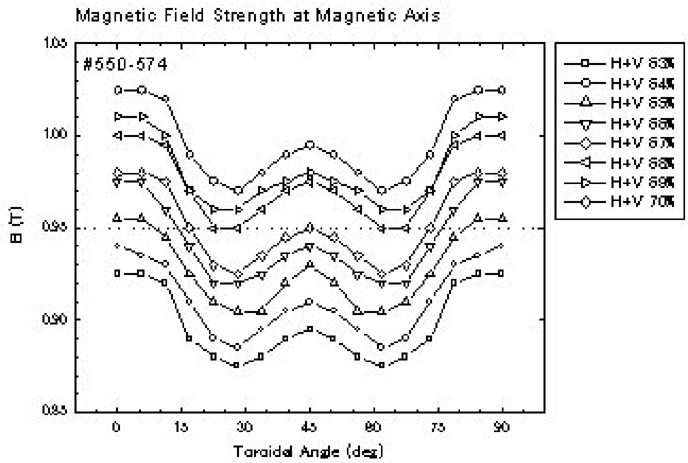

Fig. 7 Magnetic field strength on the magnetic axis in the toroidal direction. The field strength is scanned with the field configuration kept constant.

tribution. A tangential view of the plasma shape measured with a CCD camera has shown that the plasma boundary is clearly defined by the helical-axis flux surface (Fig. 5). Scanning the field strength the investigation of the accessible field regime has been performed. Figure 6 shows the $|B_{axis}|$ dependence of the H_α emission. The field configuration is kept almost constant in this scan. The plasma production is possible at two magnetic field regimes, which is different from that in conventional plane-axis heliotrons. This may be related to the location of the resonant layer for the 2nd harmonic X-mode. The magnetic field has two maxima a toroidal pitch as shown in Fig. 7. At B = 0.96 T, the resonant layer crosses the magnetic axis at the poloidal cross-section of tokamak-like mod-B structure (φ = 0°). On the other hand, at B = 1.05 T, it crosses the magnetic axis at the poloidal cross-section of saddle-type mod-B structure (φ = 22.5°).

From the viewpoint of edge plasma structure, the tangential images show an interesting feature. As shown in Fig. 5, some stripes with different brightness exist in the edge. Since the width and position of these stripes are affected by change of the magnetic field components, this stripe structure in the visible light image should be a reflection of the edge field structure. Since $\langle\beta\rangle$ of this plasma is low enough, it is interesting to compare this stripe pattern with the vacuum field structure. By assuming the high intensity emission in the SOL plasma, the calculated edge field structure can reproduce the similar stripe structure to that in the camera image. In heliotron/stellarator device, especially a low-medium $\iota/2\pi$ and low shear device, it is important to experimentally know the change of field structure due to the plasma current and/or $\langle\beta\rangle$-effect. In the edge region, however, it is not easy to get 3-D data on the change of field structure. The visible image might become one effective method for this purpose by using additional information such as edge temperature and density profiles.

5. Summary

The construction of the Heliotron J device has been completed, and the initial experiments (the field topology measurements and the ECH current-less plasma productions) have successfully started since December 1999. After the installation of plasma diagnostics, ECH experiments will be re-started in July 2000. The dependence of plasma confinement properties on the field configuration will be investigated in detail.

References

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