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Studies of Magnetic Surface Control and Electron Orbit Loss in Heliotron DR

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Abstract

Magnetic surface control by $n/m = 1/1$ helical windings and electron orbit loss measurement by stellarator tetrode method have been carried out in Heliotron DR. Magnetic island of $m = 1$ is effectively corrected by $n/m = 1/1$ helical windings but $m = 2$ like island structure is remained uncorrected. Electron confinement is observed to be deteriorated for high pitch angle electrons at the outboard side of the torus and also improved by inward shift of the magnetic axis.

Keywords:
heliotron, torsatron, magnetic surface, magnetic island, stellarator diode method, stellarator tetrode method, drift orbit, loss cone, alpha particle

1. Introduction

Magnetic surface control is a key technique and very important for helical fusion devices. Previously, we compensated the perturbing earth filed in Heliotron DR by using a large (2.8 m × 2.8 m) helmholtz coil system [1]. However, such a coil system produces undesirable extra components simultaneously. In the present experiment, we have used $n/m = 1/1$ helical windings for compensating the earth fields.

Studies of alpha particle confinement in helical fusion reactors are also important. To simulate motion of alpha particles experimentally, we previously studied behavior of energetic (E < 1 keV) electrons at relatively low magnetic field intensity (B ~ 500 G) in Heliotron DR using the newly developed stellarator tetrode method [2]. In this method (Fig.1), a transparent mesh screen is set at a poloidal cross section. The electron current collected by the screen (I_S) normalized by the emission current from the gun (I_B) gives an indicator for electron confinement and it goes to unity when electrons are well confined. In this experiment, the electron gun had a mesh anode and electrons were launched in all directions. We observed that with increase of the bias voltage E, electron confinement was deteriorated only at the outboard side of the torus.

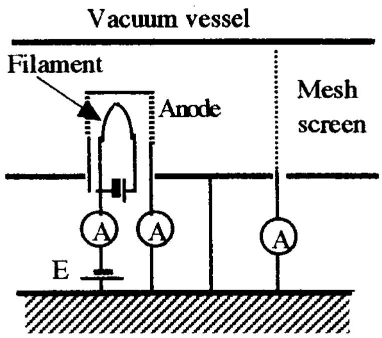

Fig. 1 Principle of stellarator tetrode method for electron confinement study.

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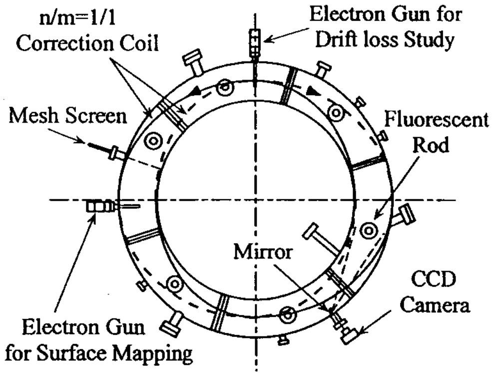

Fig. 2 Experimental set up for magnetic surface and electron confinement studies.

This result was explained by increase of electron population with higher pitch angles.

In the present experiment, we have used the electron gun which has a small beam extracting hole. Thus, we can launch electron beams at defined pitch angles.

2. Experimental Procedure

The Heliotron DR is a conventional $l = 2$ heliotron/torsatron device (major and minor radii of the helical coil are 90 cm and 13.5 cm, toroidal pitch number is 15) [3]. The experiments were carried out at low magnetic field of B ~ 500 G, and the base pressure in the vacuum vessel was kept at $p < 5\times10^{-7}$ torr. Figure 2 shows the experimental setup. Two electron guns (3 mm dia.) are used for magnetic surface mapping and electron confinement study. The anodes are stainless steel pipes with extracting holes of 0.5 mm diameter. The filaments are tungsten wires (0.1 mm dia.) and negative bias voltages E are applied against to the anodes (E = 200 V for surface mapping, ~ 800 V for confinement study). Both guns are rotatable around their axes so that electron pitch angles are variable. They are attached to horizontal ports and are movable in major radius direction. The fluorescent rod for surface mapping is 3 mm diameter and is coated with P-15 phosphor material. It is scanned in a poloidal cross section at a toroidal angle of 156° from the electron gun.

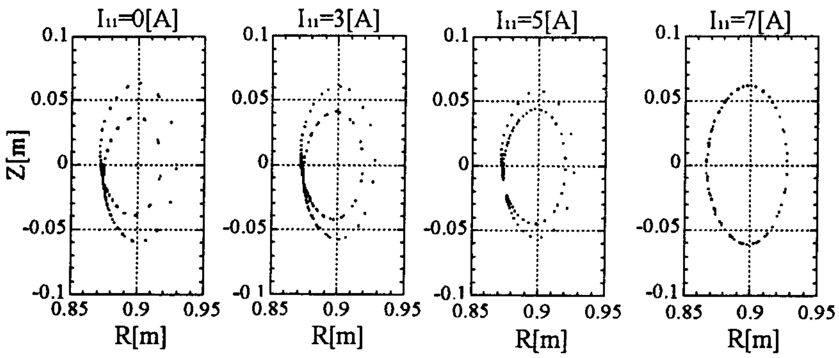

Fig. 3 Computed magnetic surfaces (B = 500 G) under the horizontal earth field of 0.3 G plus n/m = 1/1 helical coil currents I_{11}.

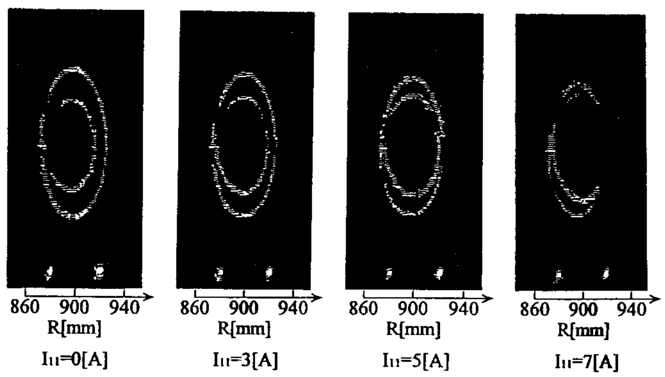

Fig. 4 Measured magnetic surfaces (B = 500 G) for different n/m = 1/1 helical coil currents.

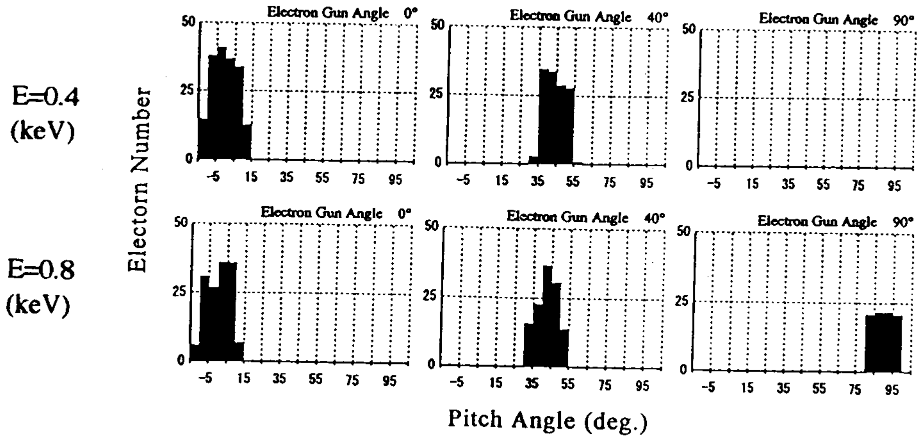

Fig. 5 Relation between electron gun angle and electron pitch angle (B = 500 G, anode diam. = 3 mm).

The n/m = 1/1 helical windings are wounded along the torus at a minor radius of r = 18 cm in which currents of 0 ~ 20 A are fed from a DC power supply. The transparent screen for electron confinement study is made of tungsten mesh (transparency, T = 93%).

3. Results and Discussions

Figure 3 shows computed magnetic surfaces (B = 500 G) under the influence of horizontal earth field of 0.3 G and a superimposed n/m = 1/1 helical coil current I_{11}. The effect of earth field is fully compensated by the current of I_{11} = 7 A, which is ~ 1/7 of the current needed for the large helmholtz coil system. Figure 4 shows magnetic surfaces measured at B = 500 G. The m = 1 magnetic island (mainly due to the earth field) is fairly corrected by I_{11} = 7 A, but m = 2 like island structure is still remained suggesting existence of error fields other than original earth field. Correction of the m = 2 like island is under way using n/m = 2/2 helical windings.

To investigate experimentally electron confinement, we have to know the relation between electron gun angle and electron pitch angle at the anode hole. Figure 5 shows this relation calculated for the electron gun used in the experiment. Electron beams with high pitch angles are not extracted from the anode hole for E = 400 V, but the pitch angles almost coincide with the gun angle for E = 800 V. This result has been confirmed experimentally and the bias voltage in the present experiment is set at E = 800 V. In Fig.6, the normalized screen current, I_S/I_B is plotted as a function of the pitch angle for different launching positions R. Although the electron confinement depends mildly on the pitch angle, it is deteriorated at high pitch angles at the periphery region of the outboard side of the torus. This result is consistent with that of previous experiment in which electrons are launched in all directions. Effect of the magnetic axis shift has been examined and confinement improvement has been observed with inward shift of the magnetic axis. This result agrees qualitatively with the numerical calculation [4].

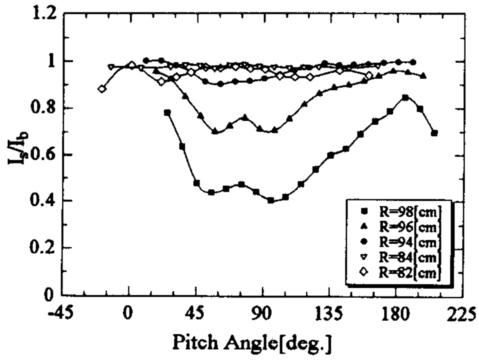

Fig. 6 Normalized screen currents I_S/I_B versus electron pitch angle for different birth points R.

4. Summary

Magnetic island of m = 1 has been corrected effectively by using n/m = 1/1 helical winding but m = 2 like island structure is still remained. The stellarator tetrode method with defined electron pitch angle has shown that electron confinement is deteriorated at high pitch angles at the outboard side of the torus and is improved by inward shift of magnetic axis in consistent with numerical calculation.

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