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Extraction of Runaway Electrons from a Helical Device to Utilize as an Electron Source

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Abstract

The purpose of this study is to use helical device as an electron source. For this purpose, it is necessary to extract runaway electrons from the outside of the magnetic surface to the out of a helical device. To extract runaway electrons, the coils other than the helical and the vertical coils are required. It was clarified that extraction of runaway electrons is possible without influence on the magnetic surface when these additional coils are set up all around the device [1]. In this paper, we researched the influence of the extraction coils on the magnetic field when those coils are set up partly. And, to make an electron source which can supply up to 10 keV electrons, we researched the extraction of 10 keV electrons which has maximum drift velocity. 10 keV electrons can be used for sterilization etc.

Keywords:

helical device, extraction, runaway electron, electron source, divertor

1. Introduction

In this study, we added extraction coils [1] to a helical device for extracting runaway electrons. The feature of extraction coils is that the coils can be set up partly. Another type of additional coils to extract charged particles is the type with octapole coils [2]. But octapole coils can not be set up partly.

If runaway electrons can be extracted from helical device partly, another device supplied electrons is connected only at the extraction area. Therefore the system with helical device is made more compact than the case of extracting electrons from all around helical device.

But if extraction coils are set up partly, the coils cause disturbance on magnetic field. So, we investigated the influence of the disturbance about two type extraction coils. Additionally we investigated the extraction power with each type coils.

2. Calculation Method

We calculated the values of the magnetic force on each grid points by numerical integration [3] with the magnetic force which is generated by each small pieces of coil [4,5]. The values on other points are calculated by interpolation method with the values on the grid points [6].

On magnetic line of force, the unit vector of tangent direction, $\vec{e}_t$ is defined $\vec{e}_t = \vec{B}/B$. Accordingly, $d\vec{x}$ on the line satisfies eq. (1).

$$d\vec{x} = \vec{e}_t ds = \frac{\vec{B}}{B} ds \tag{1}$$

Therefore, the form of magnetic line of force can be known by solving this expression with *Runge–Kutta* Method [7]. ds in eq. (1) satisfies eq. (2).

$$ds = \sqrt{dx^2 + dy^2 + dz^2} \tag{2}$$

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A charged particle orbit can be determined by solving *Guiding–Center* Equation [8] with *Runge–Kutta* Method.

$$\frac{d\vec{x}}{dt} = \vec{v}_{\parallel} + \frac{1}{2}\frac{mv_{\perp}^2}{qB^2}\frac{gradB \times \vec{B}}{B} + \frac{mv_{\parallel}^2}{qB^2}\frac{\vec{\rho} \times \vec{B}}{\rho^2} \qquad (3)$$

$\vec{\rho}$ in eq. (3) is the curvature radius of $\vec{B}$.

3. Calculation Model

Two helical coils are set up in the model which we calculated. The helical coils' major radius R, minor radius a and helical winding pitch m are R = 500 mm, a = 50 mm and m = 12. Figure 1 shows the other coils' arrangement on $r - z$ plane in cylindrical coordinate (r, ϕ, z).

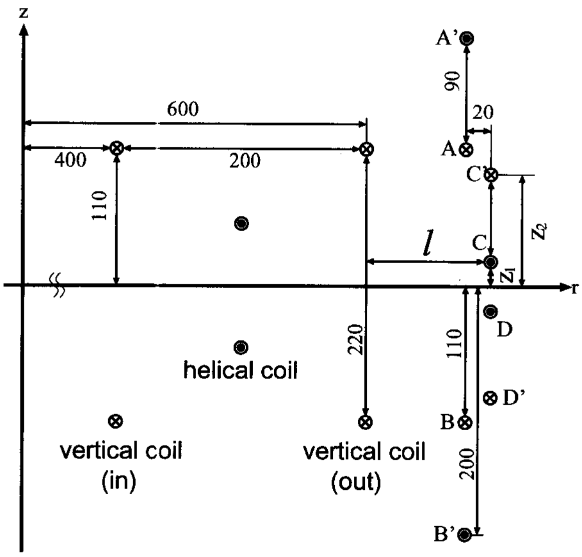

Fig. 1 Coils' arrangement.

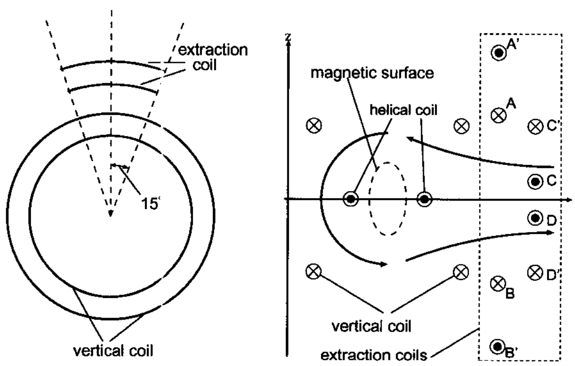

Fig. 2 Coils geometry and magnetic line of force on $x - y$ plane and poloidal plane.

On Fig. 2, left figure shows coils geometry with extraction coils set up partly on $x - y$ plane. And right figure shows the magnetic field generated by the extraction coils. Coil C and D in Fig. 2 generate the magnetic force line to extract electrons. Coil A, B, C' and D' cancel the influence of coil C and D on the confinement area.

When the extraction coils are set up partly, coil A and A' are connected, and the other coils are too. And the coils exist from -15 degrees to 15 degrees on ϕ direction in cylindrical coordinate. Because it is possible to extract almost 10 keV electrons from the outside of the confinement area in the two cycles of magnetic field on toroidal direction [1].

In this study, we investigated three cases; one case is setting up extraction coils all around toroidal direction and the other cases are setting up extraction coils partly, TYPE I, TYPE II. The first case and TYPE I have same combination of l, z_1 and z_2 in Fig. 1, and TYPE II is improved TYPE I for suppressing the influence on the confinement area Table 1 shows the combination of l, z_1 and z_2.

The current of helical coils is 2000 A, strength of the magnetic force on the center of the magnetic surface becomes 0.02 T. The values were decided for confinement electrons up to 10 keV in magnetic surface. Other coils currents are shown in Tables 2 and 3.

Table 1 Combination of l, z_1 and z_2.

	l	z_1	z_2
TYPE I coils	40 mm	20 mm	90 mm
TYPE II coils	60 mm	30 mm	80 mm

Table 2 Ratio of current.

coil	ratio to helical coil current
vertical coil (inner)	−0.500
vertical coil (outer)	−0.625
coil C,D	0.800

Table 3 Ratio of coil A and B current.

coil	ratio to helical coil current
set up all around	−0.538
TYPE I	−0.600
TYPE II	−0.348

We calculated only about vacuum static magnetic field. Because it is for clarifying the influence of the extraction coils.

4. Results

Figure 3 shows magnetic surfaces with the extraction coils. In the case of TYPE I, the radius of the magnetic surface reduces to 1/3 of the one with extraction coils set up all around device. Because disturbance in magnetic field is caused by extraction coils.

When the extraction coils are set up all around device, disturbance in magnetic field isn't caused. But, when extraction coils are set up partly, disturbance is caused, because the coils don't exist uniformly. Therefore, the magnetic surface decreases.

There are three methods to suppress the influence of extraction coils; (1) enlarge l (2) enlarge z_1 (3) decrease the difference of z_1 and z_2. (1) and (2) make the influence of the extraction coils smaller by keeping away these coils from the magnetic surface. (3) makes coil C and C' to cancel each other magnetic forces by setting up nearer.

The extraction coils of TYPE II was improved by the three methods. Figure 4 shows strength of the magnetic force on z direction generated by the extraction coils. With TYPE II extraction coils, the peak becomes the half, and the radius of the magnetic surface becomes the twice.

It means that the influence of the extraction coils can be suppressed by the three methods. But, the methods may decrease the extraction power. So we investigated the orbit of 10 keV electrons from 100

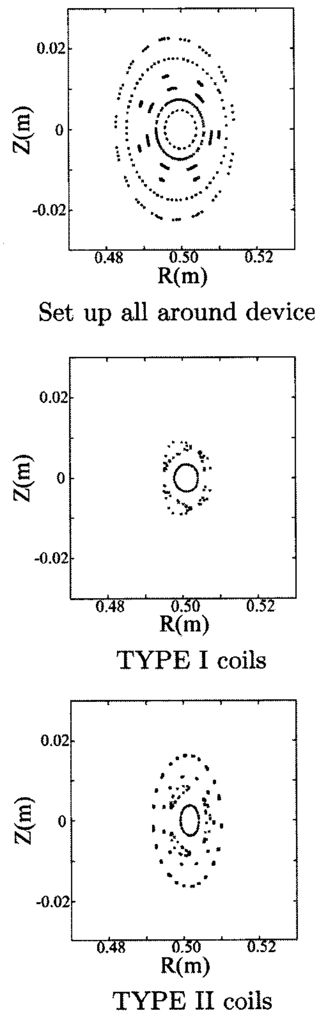

Fig. 3 Magnetic surface with extraction coils.

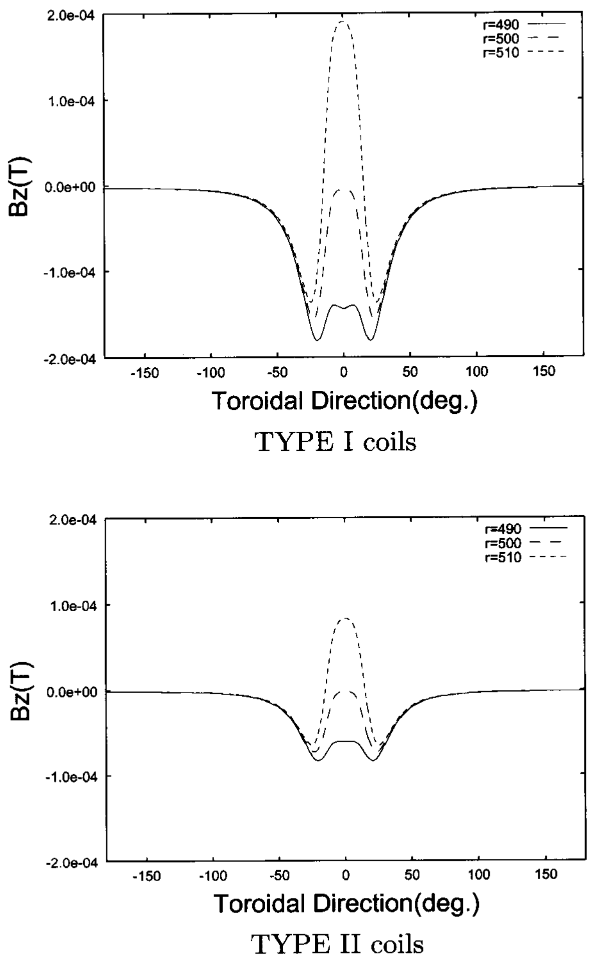

Fig. 4 Influence by extraction coils.

initial points near the outside of confinement area to the outside of the device or the wall of the vacuum vessel. We assumed that the inside wall of vacuum vessel is R = 400 mm, the upper and lower side wall are $z = \pm 110$ mm, and the outside wall of the area without extraction coils is R = 600 mm. And we didn't consider the support structures of helical coils. Additionally we also investigated the orbit of the inside of the confinement area. Table 4 shows those results.

With the extraction coils of TYPE I, 83 % of the electrons were extracted. It is almost same value in the case of extraction coils set up all around the device. With the TYPE II coils, only 24 % of electrons were extracted.

Figure 5 shows the distribution of the points where non-extracted electrons hit the wall of the vacuum vessel on toroidal direction with TYPE II coils. Most of the electrons hit the wall near the area where the extraction coils are set up. It shows that the electrons were pulled to the wall by the extraction coils, and the half of the electrons hit the wall in the area without extraction coils. So, if the area with extraction coils becomes more larger, the half of electrons in the outside of the confinement area may be able to be extracted.

Table 4 Orbit of 10 keV electrons.

	ratio of extracted electrons	maximum average radius
set up all around	100%	14.0 mm
TYPE I	83%	1.73 mm
TYPE II	24%	11.8 mm

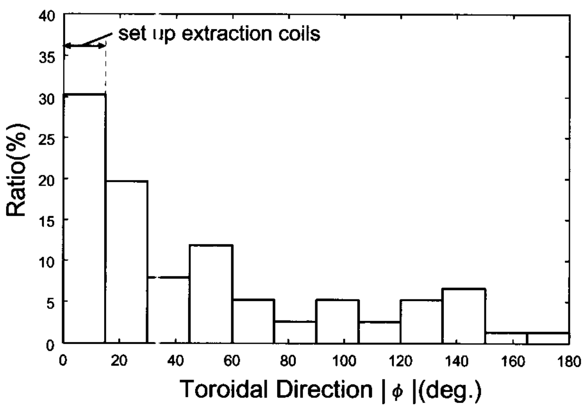

Fig. 5 Distribution of the points where the non-extracted electrons hit the wall of the vacuum vessel with TYPE II coils.

5. Conclusions

In the case of extraction coils set up partly, the disturbance by the coils reduces magnetic surface very much. But if the disturbance will be suppressed, the extraction power will be also decreased.

A solution for the problem is setting up TYPE II coils in longer area. But, by this solution, runaway electrons cannot be extracted completely. Because many electrons hit the wall in the area where extraction coils are set up. Therefore it is need that the new methods to suppress the influence on the confinement area without decreasing the extraction power.

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