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Development and Fabrication of Folded Waveguide Antenna for the Large Helical Device

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Abstract

We report a development and fabrication of an folded waveguide (FWG) antenna to produce and heat the plasma via ion Bernstein wave on the Large Helical Device (LHD) in the ion cyclotron range of frequency (ICRF). This antenna is 428 mm in height, 1050 mm in width and 3950 mm in length with 23 vanes and 24 folds. It will be installed to the horizontal vacuum port with an inclination angle of 38.9° for the RF electromagnetic field to be parallel to the magnetic field line at the last closed magnetic flux surface. It is housed in the LHD vacuum port with 1m movable distance, when it is not used. It can launch an ion Bernstein wave from a lower magnetic field side. The resonant frequencies are determined from the previous experimental results using Type-III antenna on Compact Helical System (CHS). This antenna can deliver RF power in the wide frequency range of 25 to 64 MHz. It can produce and heat the plasma in the wide magnetic field operation on LHD. As an another feature, the wave number can be changed by replacing an array of polarization plates, which was experimentally demonstrated.

Keywords:
helical system, folded waveguide antenna, ion Bernstein wave heating

1. Introduction

We report a development and fabrication of a folded waveguide (FWG) antenna, which is scheduled to be installed to the Large Helical Device (LHD) in 1998. It can launch RF power in ion cyclotron range of frequency (ICRF) in an accessible size to fusion experimental device, because it is designed to lower a cut-off frequency by folding a waveguide antenna [1]. The LHD is an $l=2/m=10$, Heliotron/Torsatron device in National Institute for Fusion Science (NIFS). ICRF heating is planned to be applied to the LHD plasma at moderate power level, 3 MW with steady state (30 min) and at higher power, 12 MW in 10 sec operation. For these purpose, we are researching and developing several engineering requirements such as a feedback control for a temporal change of plasma loading resistance [2], an RF power transmission system and an steady-state RF Oscillator etc. We succeeded in achievement of a steady state high RF power operation such as 1.6 MW/5000 sec in the RF oscillator with a wide band frequency, 25–95 MHz [3, 4]. We also verified that the RF power transmission system is good enough for MW level power transmission in steady state, which is composed of a stub tuner, a newly developed liquid stub tuner, a ceramic feed-through [4]. On the other hand, we have designed and fabricated two types of antennas; one is a pair of fast wave

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launching antennas and the other is a folded waveguide (FWG) antenna. The fast wave antenna is installed in the outer and higher magnetic field side[5] and the FWG antenna is installed in outer and lower magnetic field side[6].

The FWG antenna is designed to launch an ion Bernstein wave (IBW), which heats electron via Landau damping process. This heating scheme has been demonstrated to produce and heat the plasma by using Type-III antenna in CHS[7]. In Japan-US collaboration, the preliminary experiment demonstrated that RF power capability of the folded waveguide antenna can be evaluated to be several MW in the density range, more than 10^{19} m^{-3} [6]. In section 2, we describe principal parameters of the folded wave guide antenna. In section 3, the resonant frequencies are calculated and determined for the optimal plasma production condition inferred presumed from CHS experiment. In section 4, RF electromagnetic field pattern is discussed. In section 5, we summarize.

2. Folded Waveguide Antenna

A schematic drawing of a folded waveguide (FWG) antenna is given in Fig.1. A folding of waveguide can be realized by vanes, which are standing from a ceiling and a bottom plate of FWG antenna. The polarized direction of an RF electromagnetic field is opposite to adjacent folds. The polarization plates are attached to the exit in order to launch the RF field in a smaller wave number spectrum, which will be discussed in the section 4.

Figure 2 shows a schematic drawing of side view of the FWG antenna and LHD device. The size of the antenna is 1050 mm in width, 428 mm in height and 3950 mm in length. It will be installed to the horizontal vacuum port of LHD device as shown in Fig.2. The antenna is housed in a cylindrical vacuum container with 1300 mm in diameter. The antenna position can be changed in the range of 1150 mm and can be drawn back and housed in the extension LHD vacuum port when it is not used. The front configuration of the antenna fits to the last closed magnetic flux surface. The position of the concave with the largest curvature moves in the poloidal direction. The exit of the antenna is divided by 23 vanes and forms a waveguide with 24

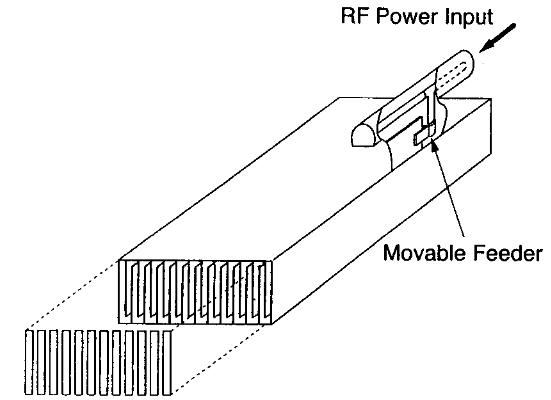

Fig. 1 Schematic drawing of folded waveguide antenna with polarizing plates and RF power feeder.

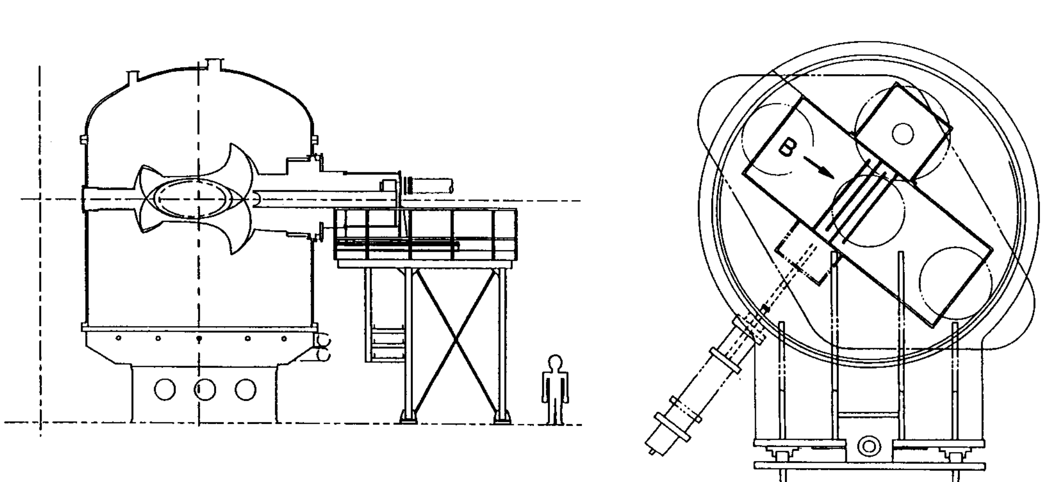

Fig. 2 Install of folded waveguide antenna to the Large Helical Device.

folds. The slanting angle is 38.9 degrees so that the excited RF electromagnetic field is perpendicular to the magnetic field line just inside the last closed magnetic flux surface. Lateral water cooled carbon protectors are furnished on both sides of the antenna. The polarization plates are also water cooled.

RF power is fed through a ceramic feed-through with an outer diameter of 240 mm, which is a cone type one similar to the Prinston (PPPL) type. This was tested in 40 kV/30 min and 58 kV/10 sec and verified as a reliable component. The temperature increase due to dielectric loss is moderate even in 40 kV/30 min operation. RF power is supplied through a coaxial transmission line located on the FWG ceiling to an end of the vane at the back side of the antenna. The vane is selected in the second one from the central one. RF power is fed there from the movable conductor connected to the inner transmission line as shown in Fig.1. When we adopted the RF feeding position at the central vane, odd modes of higher harmonic resonance condition would not have been achieved. The impedance matching can be primarily obtained by adjusting the feeding position along the vane for the variable plasma loading resistance.

3. Resonant Frequency of FWG Antenna

We calculated resonant frequencies of FWG antenna to design an optimal frequency for the ion Bernstein wave heating based on the experimental results on CHS. The end of the antenna is open as shown in Fig.1, so the resonant condition is expressed in the following equation,

$$L(m) = [(4f/c)^2 - (2m/a)^2]^{-1/2}$$

Here, L, f, c, m and a are a length, a frequency, a light velocity, a mode number and a virtual width of the antenna, respectively. a is used a=24 (folds)×H, H=0.428 m. Figure 3 shows a relation between an antenna length and a resonant frequency in various mode number; m=1,2,3 and 4. In plasma production experiments in CHS, the plasma with an average electron density of middle of 10^{18} m^{-3} could be sustained near $\omega/\omega_{ci}=1$, where ω and ω_{ci} is an applied angular frequency and an ion angular gyration frequency on the magnetic axis, respectively. We adopted the frequencies from 24 to 64 MHz in the experimental magnetic strength range, 1.5 T to 4 T operation. When we choose the antenna length as 3.95 m, the resonant frequencies are determined to be 24.2, 35.6, 49.0 and 64.0 MHz, respectively. The plasma will be able to be produced in the magnetic strength of 1.5 T operation, which is scheduled to be operated in the 2nd cycle in 1998.

4. RF Field Pattern

The sharp wave spectrum is desired to effectively heat the plasma, specially electrons via Landau damping process. We measured RF field pattern emitting from the exit of the antenna. As described in the previous section, we can change the RF field pattern by a different combination of polarization plates. When we adopted the alternative array of polarization plates, the RF electromagnetic field is in phase with the adjacent one. Figure 4 shows RF field pattern measured by a magnetic probe. This experiment was carried out in a proto-type FWG antenna, which was fabricated in the

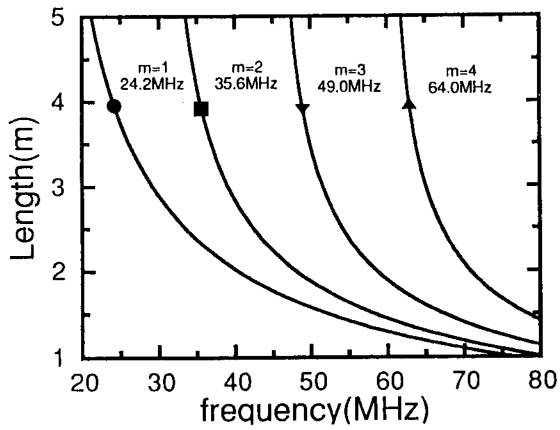

Fig. 3 Resonant frequencies of folded waveguide antenna with various modes, m=1,2,3 and 4.

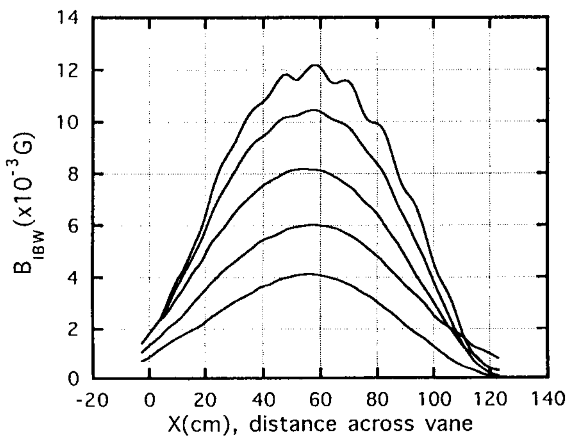

Fig. 4 RF electromagnetic field pattern with smaller wave number with an array of alternative polarizing plates.

proceeding of the real antenna and made of aluminum. That was almost a same size with the real antenna except for the terminated back plate, so the resonant frequency is higher than the real antenna. The probe was scanned in the mid plane across vanes from 0 to 1200 mm as shown in Fig. 4. The measured RF field is parallel to vanes. This RF electromagnetic field can efficiently excite an ion Bernstein wave, when the antenna is located for vane to be perpendicular to the magnetic field line as shown in Fig. 2. Figure 4 shows RF magnetic field pattern measured in the case RF power of 1 W with the frequency of 50 MHz. Five solid lines are in different scanning positions, 25 mm, 50 mm, 100 mm, 150 mm and 200 mm away from the front of the antenna, respectively, which can be refered to the smaller $k_{\parallel}$ mode. On the other hand, Fig. 5 shows RF field pattern in the case of the larger $k_{\parallel}$ mode. In this mode, two adjacent exits are masked by the polarization plates in three positions, where the measured RF electromagnetic field becomes to zero as shown in Fig. 5. Two standing RF wave is exited along the direction of the vanes. In this case, the frequency and applied RF power are same as the case of the smaller $k_{\parallel}$ mode. The peak RF magnetic field is almost same as that in smaller $k_{\parallel}$ mode. It should be noted that total emitting RF energy is smaller by about 30% in the larger $k_{\parallel}$ mode than in the smaller $k_{\parallel}$ mode. The resonant frequency is 60 MHz in m=3 mode with the array of alternative polarization plates, which is same as in the case in Fig. 4. The RF magnetic field pattern shows a larger $k_{\parallel}$ mode as seen in Fig. 5.

In the FWG antenna, we will be able to choose various launching modes;

(1) the smaller and larger $k_{\parallel}$ with a low frequency, such as $k_{\parallel}=2.6$ m^{-1} and $k_{\parallel}=10.5$ m^{-1} in f=24.2 MHz,
(2) the smaller and larger $k_{\parallel}$ with a high frequency, such as $k_{\parallel}=2.6$ m^{-1} and $k_{\parallel}=10.5$ m^{-1} in f=64.0 MHz.

Needless to say, the intermediate wave spectrum with the intermediate frequency can be chosen by selecting the array of polarization plates and mode number, m.

5. Summary

We designed, developed and fabricated the folded waveguide (FWG) antenna to produce and heat the plasma via ion Bernstein wave on the Large Helical Device (LHD) in the ion cyclotron range of frequency (ICRF). This antenna is 428 mm in height, 1,050 mm in width and 3,950 mm in length with 23 vanes and 24 folds. It will be installed to the horizontal vacuum port with an inclination angle of 38.9° for the RF electromagnetic field to be perpendicular to the magnetic field line at the last closed magnetic flux surface. It is housed in the LHD vacuum port with 1m movable distance, when it is not used. It can launch an ion Bernstein wave from a low magnetic field side. The resonant frequencies are determined from the previous experimental results using Type-III antenna on Compact Helical System. This antenna can deliver RF power in the wide frequency range of 24 to 64 MHz. It can produce and heat the plasma in the wide magnetic field operation on LHD. As an another feature, the wave number can be changed by replacing an array of polarization plates, which was experimentally demonstrated.

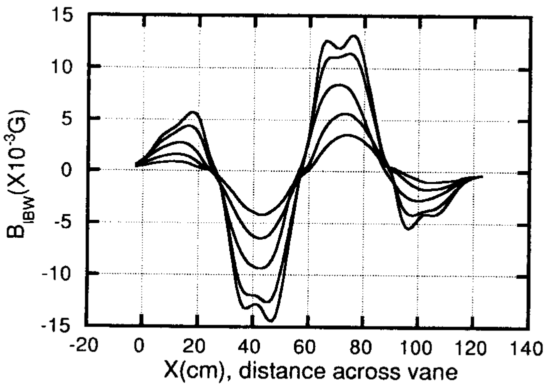

Fig. 5 RF electromagnetic field pattern with larger wave number with an array of controlled polarizing plates.

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