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Design and Development of Electron Cyclotron Heating and Current Drive System for JT-60SA

JT-60SAに向けた電子サイクロトロン加熱・電流駆動装置の設計と開発

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Design and development of high-power long-pulse electron cyclotron heating and current drive system for JT-60SA have been progressed. High power transmission test using newly developed components with a waveguide inner diameter of 60.3 mm was carried out. A conditioning operation was progressed to 5 s with an output power of 0.5 MW, so far, within a few weeks without significant trouble. The other progress was made to develop the dual frequency system with an additional frequency of 137.6 GHz in order to enhance operation regime. Output power higher than 1 MW with oscillation efficiency much higher than 30% was obtained for preliminary design of a dual frequency gyrotron for both 110 GHz and 137.6 GHz.

1. Introduction

Electron cyclotron Range of Frequency (ECRF) heating and current drive system plays important roles for super-conducting tokamak, such as for localized electron heating and current drive, for stabilizing neoclassical tearing modes (NTMs), for assisting plasma start-up, and for wall cleaning. In JT-60 Super-Advanced (JT-60SA), an ECRF system is specified as injection power of 7 MW, flat top pulse length of 100 s with a millimeter wave frequency of 110 GHz [1]. In order to satisfy the above requirements, design and development of ECRF system have been carried out by improving the previous ECRF system in JT-60 [2, 3]. Recently, an application of a dual frequency ECRF system in JT-60SA was discussed [4, 5], and a design of a dual frequency gyrotron has been started. In this paper, present status of ECRF system design is described in Sec. 2. Progresses in high-power long-pulse millimeter wave generation and transmission experiments are shown in Sec. 3 and design of a dual frequency gyrotron is described in Sec. 4, and progresses on ECRF system design and developments toward JT-60SA are summarized in Sec. 5.

2. Status of ECRF System Design

Conceptual design of ECRF system had been carried out, and the design has been revised in order to be consistent with the latest design of JT-60SA. Since many systems are installed in the torus hall, especially near the JT-60SA tokamak, design of layout of transmission line, launcher and stages is one of the important issues. Since the conceptual design of the ECRF launcher was finished, we have started to design the layout of stage of launcher and transmission line by using CATIA. Figure 1 shows a present model of the ECRF system in the torus hall. The structure of the stages and space for maintenance are under discussion.

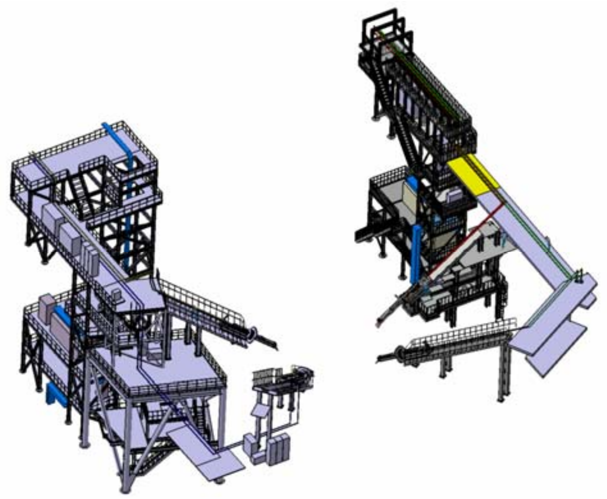

Fig.1. Present model of ECRF system in the JT-60SA torus hall.

3. High-power Long-pulse Experiments

In 2010, we achieved an oscillation of 1 MW for 31 s by using an improved gyrotron, of which mode converter was revised to reduce diffraction loss in the gyrotron [6]. However, the transmission line used to test the gyrotron limited the pulse length up to 31 s (~30 MJ). In order to achieve pulse length of 100 s by reducing mode conversion loss at miter bends, we revised the transmission line by increasing inner diameter of waveguide from 31.75 mm to 60.3 mm. Moreover, protection jackets of bellows of inlet and outlet of matching optics unit (MOU), which was significantly heated by diffracted waves, was developed. After these improvements, we restarted to operate the gyrotron, and pulse length reached to 5 s so far at output power of ~0.5 MW without any significant troubles.

4. Dual Frequency Gyrotron Design

A dual frequency ECRF system has been designed, in which the most challenging task is the development of a dual frequency gyrotron. From a view point of plasma experiments in various experimental conditions, an additional frequency between 130 GHz and 140 GHz in addition to 110 GHz is useful for extending operation regime of the ECRF system in JT-60SA, and the frequency of 137.6 GHz was selected from discrete frequencies of gyrotron oscillation modes to satisfy suitable experimental condition. At this frequency, the thickness of CVD diamond windows (2.291 mm) used as an output window of a gyrotron and a torus window is thicker by 4/3 than that of the previous one (1.715 mm). The oscillation modes for 110 GHz and 137.6 GHz are $TE_{22,8}$ and $TE_{27,10}$, respectively, with the cavity radius of 22.84 mm. The radius is slightly larger than that of the previous cavity (19.8 mm) operated at $TE_{22,6}$, and the cavity heat load was reduced from ~1.2 kW/cm^2 to ~0.8 kW/cm^2 for 110 GHz. Figure 2 shows a rf output power and efficiency of the newly designed gyrotron cavity for both 110 GHz and 137.6 GHz. The output power and efficiency at the window will be slightly lower than these values due to diffraction and Ohmic losses in the gyrotron. It was clarified that an output power higher than 1 MW is obtained with oscillation efficiency much higher than 30% for both frequencies even with relatively low electron pitch factor of 1.1. A quasi-optical mode converter was designed using LOT/Surf3d code [7]. The Gaussian like patterns were obtained at the output window for both frequencies and the beam center was placed at the center of the output window. The design of other parts of the gyrotron is the same as that of the improved 110 GHz gyrotron for JT-60 and 170 GHz gyrotron for ITER [8]. The design of the gyrotron was finished and fabrication has been started in Toshiba Electron Tubes and Devices Co., Ltd. The new gyrotron will be delivered by the end of March, 2012, and conditioning operation will be started from April, 2012.

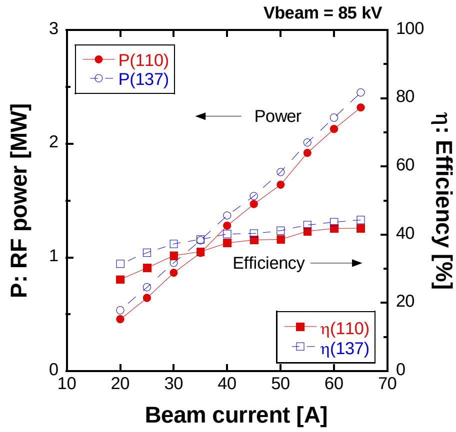

Fig.2. Simulation result of beam current dependence of generated rf power and efficiency of the newly designed gyrotron cavity. The cavity magnetic field was optimized to obtain the highest efficiency with the electron pitch factor and beam voltage of 1.1 and 85 kV, respectively.

5. Summary

The design of ECRF system has been progressed in the system layout in torus hall.

Transmission line with 60.3 mm waveguide components was installed for reducing mode conversion loss at miter bends, and conditioning operation was progressed to 5 s at the output power of 0.5 MW without any significant troubles. An oscillation of 1 MW for 100 s at 110 GHz, which is required in JT-60SA, is expected to be demonstrated in the near future.

For extending operation regime of the ECRF system in JT-60SA, a dual frequency gyrotron was designed, and fabrication has been started. The new gyrotron will be tested by improving transmission line for broadband frequency.

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