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JT-60SA電子サイクロトロン波加熱電流駆動装置の2周波数化開発の進展
Progress in dual frequency system developments for electron cyclotron heating and current drive in JT-60SA

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An electron cyclotron (EC) heating (H) and current drive (CD) system is an important tool in JT-60SA (Super Advanced) for highly localized H&CD, and for start-up assist [1]. The millimeter wave frequency of 110 GHz, which was used in the previous JT-60U experiments, is used in JT-60SA in order to reuse the existing high-power millimeter wave components. In 2010, developments for realizing a dual frequency ECH/CD system were started. The second frequency was chosen to be 138 GHz considering both ECCD efficiency in typical experimental scenarios planned in JT-60SA [2] and gyrotron design parameters [3]. In 2012, short pulse (< 0.1 s) operation of the first dual frequency gyrotron for JT-60SA was carried out. The output power higher than 1 MW and 0.5 MW were obtained at 110 GHz and 138 GHz, respectively, with the oscillation efficiency (not including efficiency enhancement effect by collector potential depression) of higher than 30%, which is sufficiently high for long pulse operation at > 1 MW [3].

In 2013, the first long pulse operation of the dual frequency gyrotron was carried out. So far, we achieved oscillations of 1 MW for 10 s at both frequencies. Moreover, high efficiency of > 30% was obtained by optimizing an electron pitch factor for each frequency by changing anode voltage of the triode type magnetron injection gun before oscillation that is not possible by a diode type magnetron injection gun. The measured diffraction loss in the gyrotron is comparable level with the previous 110 GHz long-pulse gyrotron, which achieved oscillations of 1 MW for 70 s and 1.4 MW for 9 s, so far, as shown in Table. 1. Thus we expect that the dual frequency gyrotron has a long pulse capability of at least 1 MW for 70 s. The pulse length was limited by an increase in the pressure in the dummy load, so far, while it was saturated and the peak pressure during an oscillation was decreased shot by shot. Thus further pulse length expansion is possible.

Table. 1 Comparison of the diffraction losses (D_{loss}) in the gyrotron and the MOU of the previous 110 GHz long-pulse gyrotron (1-freq.), and the dual frequency gyrotron (2-freq.). Tentative power and pulse length achieved so far are also shown.

Gyrotron	1-freq.	2-freq.	
Frequency [GHz]	110	110	138
D_{loss} in gyrotron [%]	3.0	3.8	3.2
D_{loss} in MOU [%]	7.1	3.7	3.5
Power and pulse length	1MW, 70s 1.4MW, 9s	1MW, 10s	1MW, 10s

In the above long pulse operation, the diffraction loss in the matching optics unit (MOU) for 138 GHz was comparable level with 110 GHz and much lower than the single frequency gyrotron even though phase correcting mirrors optimized for only 110 GHz was used. Thus, it may be possible to use the same mirrors for both frequencies. However, detail evaluation of mode purities is required because the mode purity is an important parameter for both transmission loss and the beam quality launched into the tokamak. We will evaluate the mode purity in a long transmission line (~ 60 m) for both frequencies with high-power in near future.

Optical design of the launcher, which injects millimeter waves into the tokamak, has been carried out. In calculation, it was confirmed that the beam width in poloidal direction for 138 GHz was almost the same as that of the 110 GHz while the beam width in toroidal direction for 138 GHz was narrower than that of the 110 GHz.

Developments of transmission line and control system will be presented.

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[2] A. Isayama et al., Plasma Fusion Res. **7** (2012) 2405029.
[3] T. Kobayashi et al., Trans. Fusion. Technol. **63**, 1T (2013) 160.