§16. Development of CW High Power Transmission Line Components

Kubo, S., Shimozuma, T., Yoshimura, Y.,
Nishiura, M., Igami, H., Takahashi, H., Ohkubo, K.

The development of the high power, and long pulse millimeter wave transmission component is inevitable for the high temperature steady state plasma confinement experiment in the LHD. In order to accommodate high power of the order of 1 MW, long pulse or CW transmission with high reliability, the evacuation of the system and the developments of the corresponding components are necessary. In addition to the three 1MW class 77 GHz gyrotrons, one more 1 MW class 154 GHz gyrotron is developed under the collaboration between NIFS and Plasma Research Center, Univ. of Tsukuba. The main objective of introducing 154GHz gyrotron is to achieve higher electron temperature at higher plasma density regime by second harmonic X mode heating scenario. Total injected power of ECRH into LHD exceeded 4.6 MW in FY2012. Four corrugated 3.5 inch waveguide transmission lines have been evacuated using several developed components so far. These experiences are utilized to develop corrugated waveguide components with other inner diameter(2.5 inch and 60.3 mm inner diameter) for the test of high power at 110 GHz in JAEA and at 70 GHz in Kyoto Univ.

Transmission mode analysis using burn pattern

The analysis method of the series of burn patterns in a corrugated waveguide taken at several distances from the high power injection are further developed to minimize errors in the measured and calculated burn patterns in several distances. This method is in particular effective during the building up transmission line, since, the burn pattern needed to optimize the waveguide coupling from matching optics uint (MOU) relies on the tilt in case of larger diameter and offset in case of small waveguide. Minimizing the transmission loss of the corrugated waveguide system is important for the stable and reliable transmission of high power millimeter waves as well as transmitting with high efficiency. The optimizing the coupling of the gyrotron output to the corrugated waveguide system is crucial to excite as higher purity of HE_{11} mode as possible. The compact diagnostics of the mode purity and utilizing such diagnostics to optimize the coupling are required. A set of linear polarized modes which is more suitable for describing the transmission modes coupled from the gyrotron output, since the gyrotron output is linearly polarized. The method is to deduce the contents of transmission modes from several burn patterns in the waveguide. These burn patterns are used to retrieve the power ratio and phase differences of undesired modes to a main $LP_{01}(HE_{11})$ mode. This method utilizes the linearity and orthogonality of each mode inside the waveguide. The great merit of this method is that the power flux going through each plane can be assumed to be conserved and resultant burn pattern can be reproduced using relatively few modes near fundamental one. Based on the orthogonality of waveguide modes, the amplitude fractions and the phase differences are adjusted to reproduce the observed burn patterns. It is also investigated how resolution of the measured burn pattern affects the accuracy of the deduced mode contents and phase difference. The resolution is one of the key parameters for the observation as well as the analysis. Original observed data is the burn pattern, but due to the inhomogeneity of the paper surface, material or wetness the fine structure are not necessarily reflects the mode amplitude there. This method of analysis is further refined to determine the unique consistent mode purity contents and phase differences between selected low order modes by minimizing the errors between calculated and real burn patterns. In this process, the function of the solver in MS-Excel is utilized to minimizing the errors [1)].

Transmission components for 154 GHz gyrotron

Several transmission components for 154 GHz are newly developed and installed on LHD. The power monitor is designed and fabricated as almost a duplication of that for 77 GHz. The difficulty in using short wavelength is in the smallness of the sub-waveguide components and accompanied fabrication tolerance. The matching of the transmission wavenumber $k_z = \frac{2\pi}{\lambda_0}\sqrt{1-(\frac{\lambda_0}{2a})^2}$ along the sub-waveguide and that of the mirror surface $k_z = \frac{2\pi}{\lambda_0}\cos\theta$. Here, λ_0 is the wave length in vacuum, a is the larger size of the rectangular sub-waveguide and θ is the injection angle of the miter bend surface. May be due to this difficulty, the power monitor for 154 GHz used during the 16th experiment campaign did not show a monitor signal in proportion to the real transmitted power. The modification of the power monitor is underway. The mitre bend polarizers which had been used originally used for 168 GHz developed by General Atomics are used for 154 GHz. The control of the polarizer angle is performed by recalculating the necessary polarizer rotation taking the frequency difference in to account. The arc detector/temperature monitor mount at the LHD window is duplicated from the design of that for 77 GHz. The quasi-optical mirrors near the injection antenna installed inside is newly designed to allow water cooling capability. These mirrors are fabricated from the Cu-SUS diffusion bonded plate which is used for the first wall in LHD, to reduce ohmic loss of mirror by front surface Cu, but keep enough structural strength and reliability of the water cooling channel by SUS as back side.

1) K. Ohkubo, *et al.*, FUSION SCIENCE AND TECHNOLOGY **62** (2012)389-402.