§1. ECRH System Upgrade and Performance Confirmation

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Eight gyrotrons with six 88.9 mm and two 31.75 mm corrugated waveguide transmission lines are routinely operated in ECRH system in LHD. ECRH system is mainly used for the experiments of high electron temperature plasma production and sustainment. In these experiments, higher and stable power injection, and better power deposition control are required. The recent efforts for the upgrades of the system are the evacuation of the corrugated waveguide system for higher power transmission capability, and confirmation of the beam injection position.

As for the higher and stable power injection, the evacuation of the waveguide transmission system is effective. Stand-off power against the arcing inside waveguide can be much higher in the vacuum ($< 10^{-2}$ Pa) than in the air. The two 31.75 mm corrugated waveguide lines are originally designed to be evacuated, since the power density is high and evacuation is necessary for 1 MW HE_{11} mode transmission. In contrast, the original 88.9 mm waveguide system were designed to operate in the atmospherric pressure for its lower power density with 1 MW HE_{11} mode. However, it appeared that a small contamination of higher mode other than HE_{11} mode can lower the power threshold of arcing. Even with several efforts to reduce higher mode, careful alignments of the matching optics unit and waveguide axis, the reduction of the number of miter bends, improvements of the corrugation gap in the miter bends, etc, the threshold power for the transmission without arcing in the air is limited below 350 kW. Once the arcing occurs, not only the damage of the transmission components at the arcing, but also the damage on the gyrotron due to excess power reflection back to the cavity become serious problem. These arcing also degrades the stability and reliability as a heating system during experiments. So, we decided to improve the 88.9 mm waveguide line to be evacuated below 10^{-2} Pa step by step.

The original 88.9 mm lines were equipped o-ring seals to be air tight at each connection between components, but not enough tight to be evacuated. First evacuation trial of one of the 88.9 mm waveguide lines is performed by just pasting pads for vacuum where leakage is found. The vacuum level barely reached to 10^{-2} Pa. At the time of the second line improvement, all seal mechanisms including those of the first trial line are exchanged to attain higher vacuum. As the result of these improvements, the base pressure of both first and second 88.9 mm evacuated lines reached to 10^{-4} Pa. These evacuation greatly contributed to the stable and reliable and higher power operation of the ECRH system all over the 10th experimental campaign.

The antenna beam alignments and its controllability are another keys for the physics experiment. All the antennas installed in the LHD are designed to focus the injection beams and control the injection angle so that the power deposition profile is controlled depending on the experimental purposes. The antenna mirror systems are designed using the Gaussian optics code. Antenna performances were checked with low power source before installation on LHD. The alignments of the mirror setting were checked only by He-Ne laser after installation on LHD. In order to confirm the hot beam performance inside the LHD vacuum vessel, beam patten measurements and injection angle controllabilities are checked. The beam pattern measurements have been performed with thermal paper or liquid crystal plates outside of the vacuum vessel, so far, since they easily give direct information on the required position. A new method adopts infra-red camera measuring the temperature rise of a Kapton sheet target set inside the vacuum vessel. The Kapton is adopted due to several preferable characteristics for measuring beam pattern in side vacuum vessel. Adequate absorption for microwave is required to measure the beam profile from temperature rise, but not burned out even with focused high power beam. Good emissivity for infra-red region, adequate thermal capacity and conductivity are also necessary for the precise estimation of the beam pattern. In addition, unflamable and dust free natures are especially important for in vessel measurement. Reference lines and ticks is formed by weaving a thin nichrome thread on the screen. These were utilized to correct and calibrate the viewing angle distortion of the infra-red images. In such a way, the method of high power beam measurement in the vacuum vessel is established and the beam quality, alignment and its controllability are confirmed inside the vacuum vessel for almost all ECRH antenna. Figure 1 is the photo showing the measuring configuration of the beam from U-port antenna.

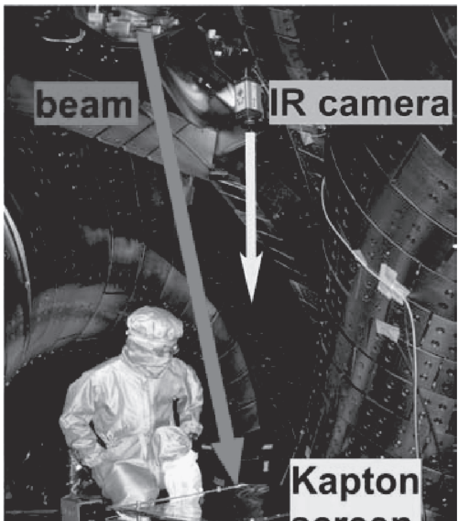

Fig. 1. Photo showing the configuration of the beam patten measurement inside LHD vacuum vessel. Taraget screen of Kapton is placed on the mid-plane of the LHD.