§13. Development of Ex-vessel Impedance Transformer for ICRF Antenna in LHD

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There are three type of ion cyclotron range of frequencies (ICRF) antennas in the large helical device (LHD) referred to as Poloidal-Array (PA) antenna, Field-Aligned-Impedance-Transforming (FAIT) antenna and hand-shake form (HAS) antenna. Faraday shield were removed from a pair of PA antennas and the loading resistance R_p defined by the following equation was much increased.

$$P = \frac{1}{2} R_p (\frac{V_{max}}{z_c})^2$$

where P is the injected power from antenna, V_{max} is the maximum voltage on the transmission line with the characteristic impedance of z_c. HAS antenna has high performance in the heating efficiency in minority ion heating at the 0-π current phase [1], however the loading resistance is small and the maximum injection power is limited by the voltage on the transmission line. In LHD z_c is 50 ohm, and the interlock level of V_{max} is 35kV. Typical loading resistance of HAS antenna is 2Ω. This means maximum power is only 490kW. FAIT antenna has small antenna head, however the loading resistance is not so small due to the optimized in-vessel impedance transformer between antenna head and the feed-through. The injection power of more than 1.8MW is possible from one FAIT antenna [2], however typical loading resistance of FAIT antenna is 5Ω, therefore the power is limited to 1.2MW.

In order to increase the loading resistance, pre-matching is necessary. Pre-stub tuner is one of candidate, but the space is limited around the antenna port. In-vessel impedance transformer for FAIT antenna worked well. Therefore we designed ex-vessel impedance transformer for HAS and FAIT antennas. They are designed to be inserted in the transmission line outside of the vacuum vessel close to ceramic feed-throughs. The diameter of outer conductor is 241.2mm which is the same with that of transmission line, and the diameter of inner conductor is 185.6mm. This means that the characteristic impedance is 15.7Ω. The flange to flange length is 628mm and it is not enough for the perfect matching for the frequency of 38.5MHz but effective to increase the loading resistance. The outer conductor is made of aluminum but the inner conductor is made of stainless steel for the enough strength. To reduce the resistance copper was coated on the inner conductor.

Electromagnetic simulation was done with HFSS in order to estimate the increment of loading resistance and the electric field which cause the break-down. Small gap between inner and outer conductors of the ex-vessel impedance transformer means large electric field. In the simulation the loading resistances without ex-vessel impedance transformer were 2 and 5Ω for the HAS and FAIT antennas, respectively. The position of minimum voltage is important factor to determine the performance of the impedance transformer. ΔL is defined as the shifts of the minimum voltage position toward antenna without ex-vessel impedance transformer, where it is 0 in the case of the vacuum injection. The simulation was conducted with various assumable shifts. The output power is 1MW. In the typical case (ΔL=-5cm for FAIT antenna and 0 for HAS antenna), the enhancement factor of loading resistances are 2.68 times and 1.75 times for FAIT and HAS antennas, respectively. The electric field on the impedance transformer for the HAS antennas reaches to 18kV/cm in the case of ΔL=20cm. However, nitrogen with 0.3MPaG is filled between inner and outer conductors, therefore possibility of break-down is thought to be small.

The ex-vessel impedance transformers are attached to HAS antenna in 2014 before the 18th cycle in LHD experiments. The vacuum loading resistance was changed from 0.296Ω to 0.537Ω for lower port antenna, which were measured with a network analyzer. The increment factor was 1.81 times, which almost agrees with the calculated value of 1.71. The shift of maximum voltage position was 0.764m toward antenna, which also agrees with the calculated value of 0.752m. The loading resistance was compared between with and without the ex-vessel impedance transformer for lower HAS antenna changing the distance between antenna and the last closed flux surface as shown in Fig. 1. The upper antenna was turned off in order to avoid mutual coupling effect. In the figure, the loading resistances of lower FAIT antenna were plotted for the comparison. The ex-vessel impedance transformers are not attached to FAIT antennas, therefore the loading resistance was not changed. On the other hand, they were increased from 1.5 to 2 times for the lower HAS antenna, which agreed with the calculation. We installed the ex-vessel impedance transformer in FAIT antennas in 2015. The increase of the loading resistance is expected for FAIT antennas. As the result, the higher power injection will be possible.

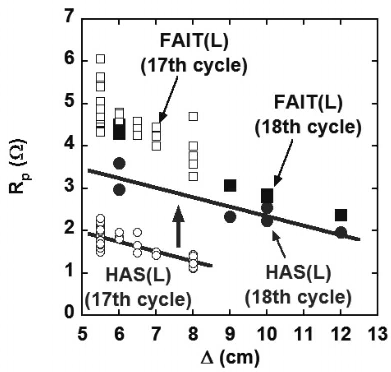

Fig. 1 Increase of the loading resistance by installing the ex-vessel impedance transformer in HAS antenna.

1) H. Kasahara, et al. : Proc. 38th EPS Conf. Strasbourg (2011) P2.099.
2) K. Saito, et al. : "Field-Aligned-Impedance-Transforming ICRF Antenna in the LHD", to be published in Fusion Eng. Des.