§7. Improvement of Real-Time Impedance Matching System for the ICRF Long Pulse Heating

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For a long pulse discharge we had conducted two methods of impedance matching in ICRF heating in LHD to reduce the reflected power caused by the change of antenna impedance [1]. One was manual frequency control. By this method, the reflected power fraction initially decreased. However, the frequency was limited to within the allowable bandwidth of the amplifiers without tuning; therefore, the reflected power eventually increased. Therefore this method was insufficient. Another method was automatic feedback control utilizing a trial-and-error method by using liquid stub tuners. Since this method has the risk of increasing the reflected power fraction by incorrectly shifting the liquid height, it is useful only for very slow variations in antenna impedance. Moreover, it took some time to reduce the reflected power fraction because the liquid stub tuners have to be controlled one by one.

Since the above-mentioned methods have limitations, a new real-time impedance matching method was required. Since fine impedance matching through the use of a prediction method has been established for short pulse discharges in the LHD [2], the reflected power fraction was expected to be kept low during a long pulse discharge by the application of this method to real-time feedback control.

Figure 1 shows the real-time impedance matching system using the prediction method. It consists of the liquid stub tuners, a directional coupler, 3dB couplers, a phase detector, diodes, an analog-digital converter (ADC), a computer, motor drivers, and pulse motors. The signals of the forward and reflected waves are measured by the directional coupler. The waves' signals are divided by 3dB couplers. One signal is rectified by a diode and the other signal is input to the phase detector. The outputs of the phase detector, the rectified forward and reflected wave amplitudes, and the liquid height voltages are converted to a digital signal by the ADC. Then a computer calculates the antenna impedance and the liquid heights are predicted so as to achieve an impedance matching. Pulses are sent to the motors via motor drivers as determined by the calculation.

The feedback experiments were conducted by attaching a variable resistor to the outlet of stub tuners at a power of less than 1W. The frequency was set to 38.47MHz, which is the standard frequency of the LHD plasma experiment. Figure 2 shows the result of the experiment. Resistance changed between 3Ω and 6Ω. Without feedback control reflected power fraction ratio P_r/P_f reached 13.5%, but by adjusting liquid lengths L_2 and L_3, it was kept low under 1%.

Since this system was verified to be useful, we utilized it for long pulse plasma discharges. In 2006 we achieved the world record of input energy of 1.6GJ by using this system.

Figure 3 shows the liquid lengths and the reflected power fraction ratio of 7.5U ICRF antenna which contributed most to the 1.6GJ input energy. Liquid lengths were adjusted and reflected power fraction ratio was kept low under approximately 1%. A calculation showed that the ratio would have reached up to 70% as shown by dashed line without feedback control.

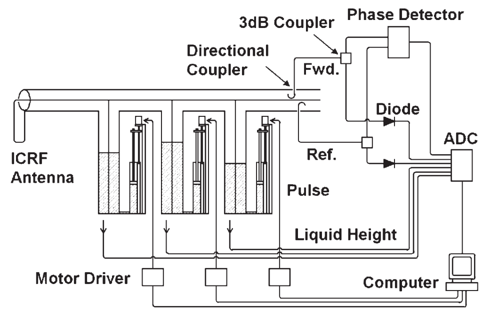

Fig.1 Real-time impedance matching system.

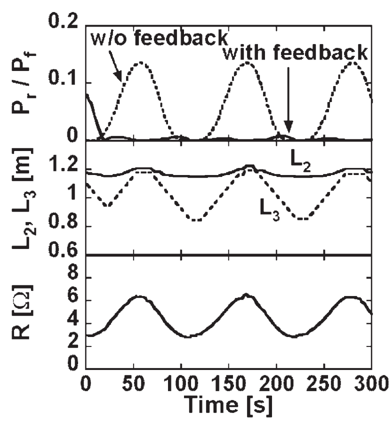

Fig.2 Result of impedance matching with variable resistance.

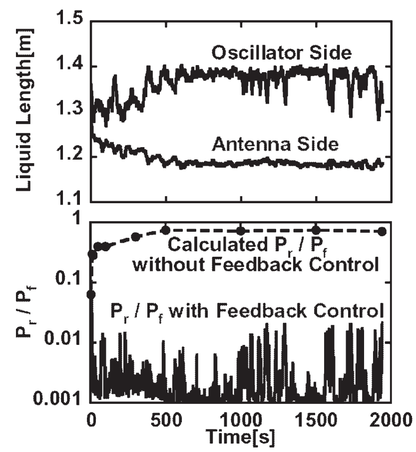

Fig.3 Impedance matching during the long pulse discharge of the 1.6GJ input energy.

References

1)Saito, K, et al.: Long Pulse Discharge with ICRF Heating in LHD, in: Proc. of 32nd EPS Plasma Physics.
2)Saito, K. et al.: Fine Impedance Matching by Use of Liquid Stub Tuners in ICRF Experiment on LHD, J. Korean Phys. Soc., submitted for publication.