§16. Feedback Control of Liquid Impedance Matching System

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It is important to reduce the reflected RF power from the antenna to the RF generator during the long pulse ICRF heating in the viewpoint of protecting the high RF power vacuum tube. Therefore a feedback control of impedance matching using a liquid impedance matching system was carried out. Figure 1 schematically shows the liquid impedance matching system, which consists of a liquid phase shifter and a liquid stub tuner. The impedance matching can be acquired by changing the liquid surface levels in the wide frequency range, i.e. from 25 to 95MHz[1].

The key to lead to the successful feedback control is that the impedance can be correctly calculated at a point A using a reflection coefficient $|\Gamma|\exp(i\phi)$ measured by the directional coupler. $|\Gamma|$ is the amplitude of the reflection coefficient and ϕ is the phase difference between the reflected wave and the forward wave. The liquid surface levels are determined using the impedance at A so that the impedance matching is perfectly obtained. First of all, the electric lengths of L_1, L_2, L_3 and L_4 must be known, because the mechanical length is not always accurate.

To determine the length of L_1 and L_2 the reflection coefficients $|\Gamma|\exp(i\phi)$ was measured changing the liquid surface level S_2 at fixed S_0 and S_1. As the impedance at the antenna side of liquid stub tuner must be same in the first and second trials as,

$$\frac{1}{Z_f^C}-\frac{1}{Z_f^{ST}}=\frac{1}{Z_s^C}-\frac{1}{Z_s^{ST}}=\frac{1}{Z^B}=\text{constant}. \qquad (1)$$

where subscripts f and s mean the first trial and the second trial respectively. The impedance $Z_{f,s}^C$ is a function of L_1 with $|\Gamma_{f,s}|\exp(i\phi_{f,s})$ and the impedance $Z_{f,s}^{ST}$ is a function of L_2 with the liquid surface level $S_{2f,s}$. The lengths of L_1 and L_2 can be determined by using the real part and the imaginary part of the equation (1). Then the liquid surface level S_1 was changed at fixed S_0 and S_2. L_3 was determined. Finally the liquid surface level S_0 was changed at fixed S_1 and S_2 and the length L_4 could be found.

Using the electric lengths of L_1, L_2, L_3 and L_4, the impedance at a point A could be calculated with the reflection coefficient at the directional coupler. Then the optimal shifts of S_0, S_1 and S_2 was determined for the feedback control using the condition that the real part of the impedance at the generator side of the stub tuner, which was derived from the impedance Z^A, must be same as the specific impedance of the transmission line, which is 50Ω, and that the imaginary part must be zero. But it is not necessary to change three parameters independently for this condition, so in this experiment the parameters S_0 and S_1 were changed as $\Delta S_0=\Delta S_1$. The experiment, which is not a real time feedback control yet, could be performed at the small RF power in the absence of the plasma.

Figure 2 shows how the liquid lengths approach to the matching point. The axis of ordinate means the length of the liquid in the liquid stub tuner (l_stub) and the axis of abscissa means the total length of the liquid in the liquid phase shifter (l_shifter). The contour lines were calculated from $|\Gamma|$ and ϕ in many trials changing S_0, S_1 and S_2 to meet the condition $\Delta S_0=\Delta S_1$. In fourth trial the parameters reached the region where the reflected power is under 1% of the forward power. Theoretically, however, in the second trial there must be no reflection. The reason seems to be the reading error of measured phase difference. If the phase difference is larger by 5° than that of the first trial, the parameters reach the region where the reflected power is under 1% of the forward power in the second trial.

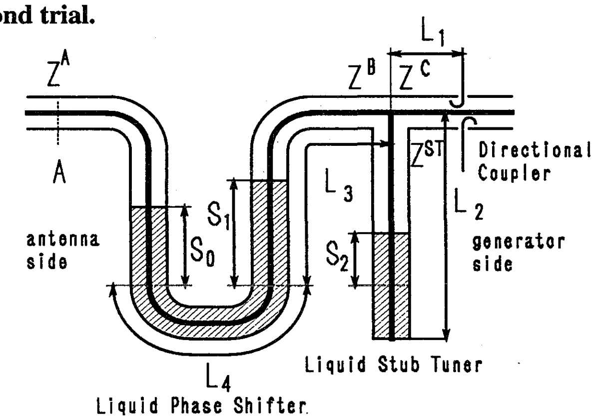

Fig. 1 The liquid impedance matching system.

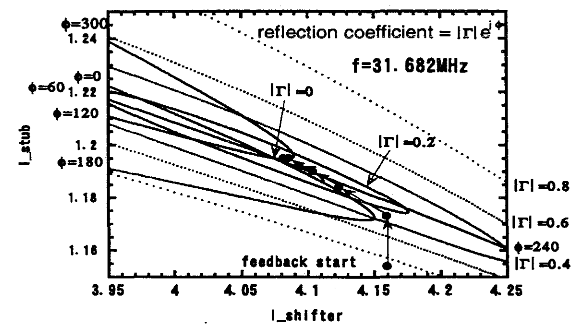

Fig. 2 Trajectory of l_stub and l_shifter.

Reference

[1] Kumazawa, R., et al. To be published in the proceeding of 13th Topical Conference of Application of RF power to Plasmas (1999).