§18. Liquid Stub Tuner for Feedback Controlled Impedance Matching System in ICRF Heating

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We developed a liquid stub tuner for a feedback controlled impedance matching system in an ion cyclotron range of frequency(ICRF) heating. The liquid stub tuner contains a liquid in the short-ended co-axial transmission line. During ICRF heating plasma loading impedance changes gradually with density or abruptly in L-mode to H-mode transition. Needless to say, the impedance matching is always achieved by shifting short-ends of stub tuners and/or changing length of the phase shifter. It is, however, dangerous to move the short-end of the stub tuner or the sliding joint of the phase shifter during high power ICRF heating pulse such as in MW level. The liquid stub tuner works as the conventional stub tuner by changing its liquid level without shifting its short-end, because an RF wave length in the liquid is different from that in the filling gas. This idea is also applicable to the liquid phase shifter.

A function of the liquid stub tuner is illustrated in Fig.1. RF voltage is V_1 and RF currents are I_1 and I_2, respectively at its T-junction. RF current, I' flows to the liquid stub tuner and RF current is I_t at the short-end of the liquid stub tuner. A relation among V_1, I' and I_t is formulated in following equation;

$$\begin{pmatrix}V_1\\ I'\end{pmatrix}=\begin{pmatrix}\cos\beta l & jZ_0\sin\beta l\\ j/Z_0\sin\beta l & \cos\beta l\end{pmatrix}\begin{pmatrix}\cos\beta_G & jZ_G\sin\beta_G l_G\\ j/Z_G/\sin\beta_G l_G & \cos\beta_G l_G\end{pmatrix}\begin{pmatrix}0\\ I_t\end{pmatrix}=\begin{pmatrix}E & Fj\\ Gj & H\end{pmatrix}\begin{pmatrix}0\\ I_t\end{pmatrix} \quad (1)$$

Here, Z_0 and β are a characteristic impedance of a coaxial line and RF wave number, respectively. Z_G and β_G are a characteristic impedance and RF wave number in the liquid, respectively. I' is calculated by eliminating I_t in a following equation;

$$I'=-jH/FV_1 \quad (2)$$

RF current, I' follows Kirchhoff's law at the T-junction. Therefore

$$I_1=I'+I_2=-jH/FV_1+I_2 \quad (3)$$

On the other hand, the relation between RF voltage and current in a conventional stub tuner is expressed as follows;

$$\begin{pmatrix}V_1\\ I_1\end{pmatrix}=\begin{pmatrix}1 & 0\\ -j/Z_0/\tan\beta l & 1\end{pmatrix}\begin{pmatrix}V_1\\ I_2\end{pmatrix} \quad (4)$$

We obtain a following relation between the liquid and the conventional stub tuners by comparing eq.(3) and eq.(4),

$$\frac{1}{Z_0\tan\beta l}=\frac{1-Z_G/Z_0\tan\beta l\tan\beta_G l_G}{Z_0\tan\beta l+Z_G\tan\beta_G l_G} \quad (5)$$

Figure 2 shows calculated results of eq.(5) where the permeability of the liquid used in this calculation is 2.7. The abscissa is a ratio of the liquid height to the total length of the liquid stub tuner, $l_G/(l+l_G)$ and the ordinate shows how the liquid stub tuner works as the conventional stub tuner, βl in this figure. Three cases are calculated in different liquid stub tuner length. When the normalized length of the liquid stub tuner, $\beta(l+l_G)$ is 0.3, the liquid stub tuner works from 0.3 to 0.5. The changeable normalized length becomes larger with the liquid stub tuner length.

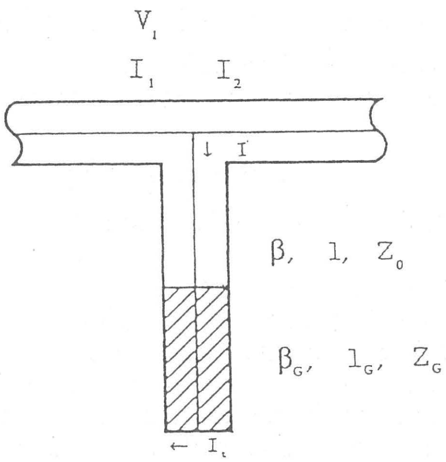

Fig.1 Schematic drawing of liquid stub tuner.

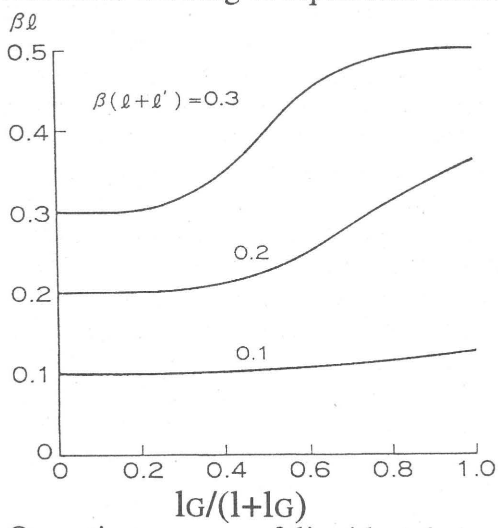

Fig.2 Operating ranges of liquid stub tuner with various length.