§16. Calculation Model of Liquid Impedance Matching System for Wide Frequency Range ICRF Heating

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In ICRF heating experiments, we will apply MW level RF power to the LHD plasma in various heating methods and wide magnetic field strength operation. We designed and developed RF oscillator with wide band frequency range, 25 to 95MHz. These oscillators already achieved the RF power level more than 1MW in steady state operation[1]. In the steady state or long pulse ICRF heating, the plasma loading resistance changes gradually and/or suddenly in an L-H transmission. These result in the increase in the reflected RF power from ICH antenna. A liquid stub tuner can be a tool to solve above problem because it is allowable to move the liquid surface without RF breakdown. It utilizes a difference in RF wave length between liquid and gas.

We have already demonstrated that the liquid stub tuner can be used in high RF voltage more than 50kV in steady state operation and its dissipated power is less than 1% of the transmitted RF power. The successful movement of the liquid surface during RF operation is a prominent feature from the point of view of a feedback control to reduce a reflected RF power during ICRF heating[1]. We thought that the idea can be utilized to a phase shifter, which is sometimes called a line stretcher. Then we designed an impedance matching system consisting of the liquid stub tuner and the liquid phase shifter for wide frequency range ICRF heating.

Figure 1 shows a calculation model of the liquid stub tuner system and a conventional impedance matching system consisting of a line

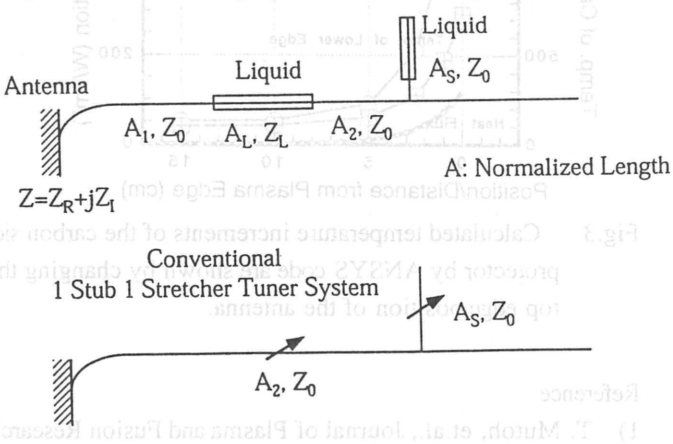

Fig.1 Calculation model of wide frequency range liquid stub tuner.

stretcher and a stub tuner. Here the antenna impedance is a complex resistance. The symbols of A_1 and A_2 are normalized length between antenna to the liquid phase shifter and between the liquid phase shifter and the liquid stub tuner, respectively. A_L is a normalized length of the liquid phase shifter. A_S is also a normalized length of the liquid stub tuner, which is a function of the ratio of the liquid and gas. Z_0 and Z_L are characteristic impedance of coaxial transmission line with gas and liquid, respectively. Here Z_0 is 50Ω and Z_L is 34Ω due to the relative permittivity, ε=2.72. Then RF voltage and current, V and I at the inlet of the liquid impedance matching system can be expressed by following relation.

$$\begin{pmatrix} V \\ I \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -j/Z_0/\tan A_S & 1 \end{pmatrix} \begin{pmatrix} \cos A_2 & jZ_0 \sin A_2 \\ j/Z_0 \sin A_2 & \cos A_2 \end{pmatrix}$$

$$\begin{pmatrix} \cos A_L & jZ_L \sin A_L \\ j/Z_L \sin A_L & \cos A_L \end{pmatrix} \begin{pmatrix} \cos A_1 & jZ_0 \sin A_1 \\ j/Z_0 \sin A_1 & \cos A_1 \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 \\ -jX & 1 \end{pmatrix} \begin{pmatrix} A & jB \\ jC & D \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix}$$

$$= \begin{pmatrix} A & jB \\ j(C-AX) & BX+D \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix}$$

Here, $X=1/Z_0/\tan A_S$

$$A=(\cos A_2 \cos A_L - Z_0/Z_L \sin A_2 \sin A_L)\cos A_1 - (Z_L/Z_0 \cos A_2 \sin A_L + \sin A_2 \cos A_L)\sin A_1$$

$$B=Z_0(\cos A_2 \cos A_L - Z_0/Z_L \sin A_2 \sin A_L)\sin A_1 + (Z_L \cos A_2 \sin A_L + Z_0 \sin A_2 \cos A_L)\cos A_1$$

$$C=(1/Z_0 \sin A_2 \cos A_L + 1/Z_L \cos A_2 \sin A_L)\cos A_1 + 1/Z_0(\cos A_2 \cos A_L - Z_L/Z_0 \sin A_2 \sin A_L)\sin A_1$$

$$D= -(\sin A_2 \cos A_L + Z_0/Z_L \cos A_2 \sin A_L)\sin A_1 + (\cos A_2 \cos A_L - Z_L/Z_0 \sin A_2 \sin A_L)\cos A_1$$

When the impedance at the RF antenna is expressed as follows,

$$V_R/I_R=Z_R+jZ_I,$$

then the impedance at the liquid impedance matching system can be expressed by following relation.

$$Z=\frac{V}{I}=\frac{AV_R+jBI_R}{I_R(BX+D)+j(C-AX)V_R}$$

$$=\frac{AZ_R+j(AZ_I+B)}{(BX+D-(C-AX)Z_I)+j(C-AX)Z_R}$$

References

1) Kumazawa,R., Mutoh, T., et al., Proceeding of 18th Symposium on Fusion Technology(1996), Vol.1, p.617.