A Review on Liquid Stub Tuner For Impedance Mathing

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Abstract— ***Plasma* is a variable load. It is a fourth state of matter. The plasma impedance varies over a wide range. This requires impedance matching with RF generator that is normally of 50 Ohm. An ion cyclotron range of frequencies (ICRF) system is an important system to heat plasmas and to drive anon-inductive current infusion devices. ICRF system will deliver 6 MW of RF power to plasma with a long-pulse length operation up to 300s. Therefore, high-power RF transmission components are required to transmit a MW level of RF power continuously in the ICRF heating and current drive systems. For impedance matching network consists of stub tuner and phase shifter. A conventional stub tuner has moving arrangement. At high power moving arrangement is not suitable because of high current flowing through it. Finger contacts are used to make electrical contacts between different conductors Finger contact may burn due to high localized current. To avoid this problem, liquid stub tuner is the best option for the impedance matching. A liquid stub tuner makes use of the difference between the RF wave lengths in liquid and in gas due to the different relative dielectric constants. It is to be very reliable RF component for high power transmission systems. Changing the height of the liquid in the phase shifter varies the phase.**

***Index Term*- Liquid stub tuner, ICRF heating, LHD**

I. INTRODUCTION

Ion cyclotron range of frequency (ICRF) heating on the large helical device is characterized by high power up to 12 MW and steady state operation for 30 min. Ion cyclotron heating has been established as one of the heating schemes in nuclear fusion research and its use in steady state plasma heating in various devices is being considered. The optimal technology for steady state ion cyclotron range of frequency heating has not been firmly established. The LHD is a helical device (with a major radius of 3.9 m and a minor radius of 0.6 m) with superconducting coil windings (l=2, m=10). The main purpose of physical research is to investigate current less and disruption-free plasma. Research and development for steady state ICRF heating has been carried out in recent years: A high rf power transmission system consisting of stub tuners, a ceramic feed through, and an ion cyclotron heating loop antenna has been developed. In addition, steady state operation of a rf oscillator has been achieved at a power higher than 1 MW. A liquid stub tuner has been proposed as an innovation. It demonstrated high performance in real use in experiments. The liquid stub tuner makes use of the difference between the rf wavelengths in liquid and in gas due to the different relative dielectric constants. The liquid stub tuner has been experimentally proved to be a reliable rf component for high power transmission systems. Test results have quantitatively demonstrated that it can be used at high rf voltage: 61 kV for 10 s and 50 kV for 30 min. Furthermore, the liquid surface can be shifted under high rf voltage without breakdown, which suggests that it can be employed as a feedback control impedance matching tool to keep reflected rf power at a low.

To satisfy high power transfer from the transmitter to the antenna, the transmission line size is 9 inch. Its outer conductor diameter is 230 mm, and inner conductor diameter is 100 mm. The characteristic impedance is 50 Ω. To satisfy the CW operation, the inner and the outer conductor must be cooled by the pure water. a DC breaker must be used in order to isolate the grounds between RF transmitter and the antenna. Normally a stub tuner is used for traditional matching system. The stub tuner is a short-circuited coaxial transmission line with a changeable length. Because the metal contact finger of conventional stub tuner is seriously damaged sometimes.

In tokamak experiments, ICRF heating is now accepted as a reliable heating tool. In Heliotron and stellrator systems, however, ICRF heating has not always demonstrated successful heating. ICRF heated plasma has often suffered from impurity problems. Recently ICRF heating has been successfully applied in the compact helical system and Wendelsten.

In this article, a liquid stub tuner is proposed as an innovation component. A liquid stub tuner is superior to a conventional stub tuner because it has no sliding contact. Therefore, it is important to demonstrate that the liquid stub tuner can withstand a high rf voltage in long pulse operation and that its surface can be shifted during the application of high rf voltage without rf breakdown. Typical response time may not be fast enough to respond to L – H transition; however, the liquid stub tuner will be useful in ICRF heating experiments at high rf power. The principle and the characteristic of the liquid stub tuner will be explained in Sec.II. Sec. III, the experimental setup will be described. In Sec. IV, experiment results are given. In Sec. V, we will discuss experimental dat and an advanced method.

II. PRINCIPLE & CHARACTERISTICS

A liquid stub tuner is proposed as a new component of an impedance matching circuit. The impedance matching circuit is located between the ICRF heating antenna and the rf oscillator and generally consists of a conventional stub tuner, a liquid stub tuner, and a phase shifter. The liquid stub tuner contains a liquid as shown in Fig.1. Its use is based on the difference between the rf wavelength in liquid and in gas due to the different relative dielectric constants. The liquid stub tuner is able to be used as a conventional stub tuner by changing the liquid surface level. without shifting the electrical short end. Needless to say, impedance matching is always attained by shifting the short ends of conventional stub tuners and/or by changing the 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, because 1KA of rf current flows there in MW level heating. Therefore a liquid stub tuner will be superior to the conventional one.

A function of the liquid stub tuner is illustrated in Fig. 1. Rf voltage is V1 and rf currents at the junction are I1 and I2, respectively. A r current, I’ flows to the liquid stub tuner and rf current is I_t at the short one end of the liquid stub tuner. The relation between them is formulated in the following equation:

Rf voltage and rf current on the liquid surface can be calculated using the following equation

$$\begin{matrix} V1 \\ I' \end{matrix} = \begin{matrix} \cos 2\pi ALS & jZL\sin 2\pi ALS \\ \frac{j}{ZL}\sin 2\pi ALS & \cos 2\pi ALS \end{matrix} \qquad (1)$$

ZL and ALS are the characteristic impedance and the length normalized by rf wavelength in the liquid.rf voltage and rf current at the junction can be calculated from the following matrix

$$\begin{matrix} V1 \\ I' \end{matrix} = \begin{matrix} \cos 2\pi AGS & jZ0\sin 2\pi AGS \\ \frac{j}{Z0}\sin 2\pi AGS & \cos 2\pi AGS \end{matrix} \qquad (2)$$

and AGS are the characteristic impedance of a coaxial transmission line and the length normalized by rf wavelength in the gas region, respectively.

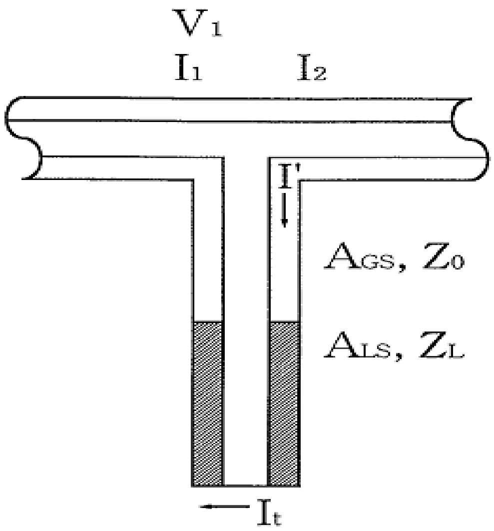

Fig. 1. Schematic drawing of liquid stub tuner, Liquid stub tuner is connected at a T junction of transmission line. End is electrically terminated [1].

Combining of equation (1) and (2)

$$\begin{matrix} V1 \\ I' \end{matrix} = \begin{bmatrix} \cos 2\pi ALS & jZL\sin 2\pi ALS \\ \frac{j}{ZL}\sin 2\pi ALS & \cos 2\pi ALS \end{bmatrix} *$$

$$\begin{bmatrix} \cos 2\pi AGS & jZ0\sin 2\pi AGS \\ \frac{j}{Z0}\sin 2\pi AGS & \cos 2\pi AGS \end{bmatrix} * \begin{bmatrix} 0 \\ I\ t \end{bmatrix} \qquad (3)$$

$$= \begin{bmatrix} B & jC \\ jD & E \end{bmatrix} * \begin{bmatrix} 0 \\ I\ t \end{bmatrix} \qquad (4)$$

B= cos2πAGS cos2π ALS –Z0/ZLsin2πAGS sin2πALS,

C= ZLcos2πAGS sin2πALS+Z0 sinπ2AGS cos2πALS,

D= 1/Z0 sin2πAGS cos2πALS+1/ZL cos2πAGS sin2π ALS,

E= -ZL/Z0 sin2πAGS sin2πALS+cos2πAGS cos2π0ALS.

I’ is calculated by eliminating It in the following equation

I’ = jH / FV1

RF current I’ obeys kirchhoff’s law at the T-junction therefore,

It = I’+I2

If the conventional stub tuner shunted at the input of the load is compared to the liquid stub located at the same position, following equation is hold true for the same electrical effect [1]

$$\frac{1}{\tan 2\pi AGS} = \frac{1-\frac{Z0L}{Z0G}\tan 2\pi AGS \tan 2\pi ALS}{\tan 2\pi AGS + Z0L/Z0G \tan 2\pi ALS} \qquad (5)$$

Liquid stub configured to have AL and AG as the portion of liquid and gas results in the same electrical effect with the conventional stub having length A.So A in the equation (5) can be called normalized effective stub length.

III. FABRICATION

To test the liquid stub tuner concept, a 260cm long liquid stub tuner has been fabricated , consisting of a 104mm inner copper conductor and a 240mm outer aluminum conductor as shown in

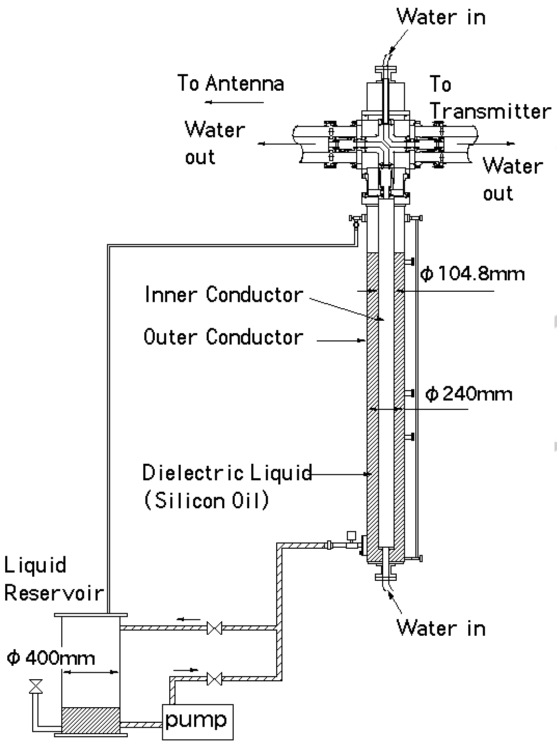

Fig.2 Schematic drawing of liquid stub tuner with rf voltage measured ports, consisting of 240mm of coaxial transmission line. Liquid surface height can be changed by pump and valves[1].

Fig.2.cooling water flows inside the inner conductor and the outer conductor is surrounded by a water-cooled copper tue. Silicon oil is used as the liquid. It has been selected because of the low vapour pressure and the low dielectric loss. The vapour pressure is less than 0.1 Torr even at 240°C. The dielectric constant €L is 2.72 and the dielectric loss tangent tanơ is $1*10^{-4}$ to $3.3*10^{-4}$ in the frequency range of 10 – 100MHz.The liquid surface level can be shifted by the use of an oil pump and valves, as shown in Fig.2. The liquid stub tuner is equipped with electrostatic probes to measure rf voltage and a thermocouple to measure the liquid temperature. At the top of the liquid stub tuner, a gas stop has been installer to isolate it from other transmission lines. It utilizes the difference of radio frequency wavelengths in gas and in liquid due to the different relative dielectric constants. The liquid (i.e. oil silicon) is filled between inner conductor and outer conductor. By using a pump to control the liquid level, the parameters of this matching system can be changed. Since there are no mechanically moving parts, it will work more reliable. Due to the CW operation, the inner and outer conductor of the liquid stub tuner must be cooled by pure water.

IV. EXPERIMENTAL SET UP

A schematic drawing of the research and development of experimental setup is shown in Fig. 3. The rf oscillator system consists of three stages of amplifiers: IPA(4kw) , DPA(100kw), FPA(2MW), in the frequency range of 25-95MHz.

In this experimental setup, rf power is transmitted to a dummy load or R&D experimental setup through a coaxial switch. The experimental setup is sometimes changes, so this system is very convenient. A rf power of several Watt is applied to the R&D experimental setup from one port of the coaxial switch. An impedance matching is acquired by adjusting positions of the liquid surface and the conventional stub tuner. The rf oscillator is tuned to maximize power at the frequency for which the system is matched.

A double stub tuner system has been adopted as an impedance matching circuit. The transmission system consists of coaxial transmission line components, whose characteristic impedance is 50Ω and which are in the same configuration as the liquid stub tuner. Cooling water flows inside the inner conductor for steady state rf power operation. The stub tuner on the rf oscillator side is a conventional one with a sliding contact. The liquid stub tuner has been arranged on the rf antenna side in the double stub tuner system as shown in Fig. 3.

To use a phase shifter, the phase different between two ICRF antennas can be changed. The phase difference can be changed from 00 to 3600. Because of CW operation and high power RF transfer, the phase shifter needs water-cooling and 3 atm. nitrogen gas filled also. In order to transfer RF power to antenna, a feedthrough must be used to separate the vacuum. Because of a high power RF transfer, 9 inch in diameter of a feedthrough is chosen. The ceramic part of the feedthrough is difficult to make it in china, it is considered to buy this feedthrough in other laboratory.

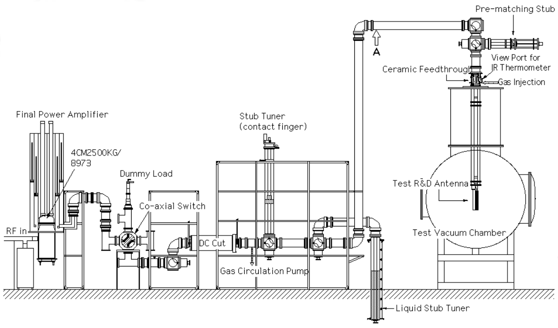

Fig. 3 Experimental set up diagram of liquid stub tuner for impedance matching[1].

At the beginning of the R&D experiment, a conventional stub tuner is used there; however, it is damaged in steady state operation at a relatively low rf voltage(20kv). An rf current of about 400 ampere make a hole in the outer conductor at the movable sliding contact. In spite of careful design and fabrication, a conventional stub tuner could not withstand steady state operation even at a relatively low rf voltage, so it has been replace with a liquid stub tuner. A prematching stub tuner is located near a ceramic feedthrough in order to reduce the rf standing wave. The performance of the ceramic feedthrough is another matter of the great importance for high power and steady state ICRF heating, the R&D results of which are described in other papers [2].

Rf power is transmitted to the impedance matching circuit and the rf antenna through the coaxial switch and the dc break in the transmission system. When the transmission system can withstand a high rf voltage, a large rf power can be transferred. How much RF power is delivered to the RF antenna is deduced by a following equation[1]

$$\mathrm{PRF} = \frac{1}{2}\mathrm{R}\left(\frac{\mathrm{VRF}}{50}\right)\left(\frac{\mathrm{VRF}}{50}\right) \qquad (6)$$

In the Ion Cyclotron Resonance Frequency (ICRF) range, the characteristic impedance of the coaxial transmission lines and the output impedance of the transmitter are 50 Ω and the plasma loading of the loop antenna is in the 0.5 – 5Ω range. It is necessary to match the antenna loading to 50Ω by adding a matching system. Normally a stub tuner is used for traditional matching system. The stub tuner is a short-circuited coaxial transmission line with a changeable length. Because the metal contact finger of conventional stub tuner is seriously damaged sometimes, we develop a liquid stub tuner for HT-7U. It utilizes the difference of radio frequency wavelengths in gas and in liquid due to the different relative dielectric constants. The liquid (i.e. oil silicon) is filled between inner conductor and outer conductor. By using a pump to control the liquid level, the parameters of this matching system can be changed. Since there is no mechanically moving part, it will work more reliable. Due to the CW operation, the inner and outer conductor of the liquid stub tuner must be cooled by pure water.

V. CONCLUSION

For the high power rf component a liquid stub tuner , it is very reliable and easy to operate compared to the conventional stub tuner. There is no distortion of reflected power during the liquid level is raised. The maximal rf voltage is determined by fitting measured rf voltages to the standing wave distribution using the value of voltage standing wave ratio. It is conclude that to adopt the liquid stub tuner as a reliable stub tuner for the impedance matching circuit of ICRF heating on large helical device (LHD).And to develop a system equipped with a mechanism which can move the liquid surface faster. It will make the matching work simpler, more convenient and more accurate.

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