Development of Liquid Matching Components for KSTAR ICRF System

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1. Introduction

An ion cyclotron range of frequencies (ICRF) system is an important method to heat plasmas and to drive a non-inductive current in fusion devices. High-power RF transmission components are required for transmitting MW levels of RF power continuously in the ICRF heating and current drive system [1]. Key performance factors are maximum voltage and current without breakdown for a long pulse operation [2, 3]. Steady-state relevant technologies need to be developed in the area of transmission components such as insulators and matching devices. If the high RF power (MW level) is to be transmitted, the coaxial transmission line must withstand the high RF voltage (> 35 kV) for a long time. Conventional matching components, a phase shifter and stub tuner, have some problems due to difficulty in fabricating a straight coaxial line, a local temperature increase, and insulation breakdown for long-pulse operation under high power. To solve such problems, we developed matching components using liquid, instead of gas, for the insulating dielectric medium [4]. The liquid matching components, a liquid phase shifter and a liquid stub tuner, can be used reliably in continuous high-power RF facilities since they don't have sliding contact and can withstand high RF voltage (> 40 kV). They are made of 9-3/16″ nominal-diameter aluminum transmission line. The results of the developments will make an ICRF system a key element for steady-state, high-performance operation of fusion devices.

2. Development of liquid matching components

The liquid matching components contain liquid between the inner and the outer conductors of the coaxial transmission line. If the liquid level is changed instead of shifting the electric short-end, the phase of the wave can be shifted based on the difference between the RF wavelength in the liquid and gas due to the different relative dielectric constants. The conventional matching components are easily damaged in steady-state operation at relatively low RF voltages. An RF current of about 400 A made a hole in the outer conductor at the movable sliding contact [4]. It is dangerous to move the sliding joint of the conventional matching components during high-power ICRF heating because the RF currents of 1 kA will be present in the MW level heating. Therefore, the liquid matching components will be superior to conventional matching components.

The liquid matching components were made of 9-3/16″ nominal diameter aluminum transmission line. Silicon oil with a relative dielectric constant of 2.74 was used as the liquid. It was selected because of its low vapor pressure and low dielectric loss. The vapor pressure was less than 0.1 Torr even at 240 ℃. The dielectric constant, ε_r, was 2.74, and the dielectric loss tangent, tanδ, was 10^{-4} to 3.3×10^{-4} in the frequency range of 10 ~ 100 MHz at 25 ℃, as shown in **Table. 1.** The asterisk in Table 1 means that the data are available when the silicon oil contains under 50 ppm of water.

Table 1. Characteristics of silicon oil (dimethyl polysiloxane).

Specific Gravity (25℃)	0.965
Viscosity (25℃)	100 mm^2/s
Vapor Pressure (<260℃)	<0.1mHg
Specific Heat (25℃)	0.36 cal/g·℃
Thermal Conductivity (25℃)	3.8×10^{-4}cal/ cm·sec·℃
Resistivity*	> 1×10^{14} Ω·cm
Dielectric Strength*	> 50 kV/2.5 mm
Dielectric Constant (50 Hz)*	2.74
Dielectric Loss (tanδ)*	< 0.0001
* mean in Table 2 : Water < 50 ppm	

The speed of motion of the liquid surface was 1.8 cm/sec, which corresponded to 0.42 degrees/sec at 30 MHz. The liquid matching components were equipped with electrostatic probes to measure the RF voltage, two thermocouples for the liquid temperature, and a humidity sensor to measure the humidity in the coaxial transmission line. The schematic diagram of a RF test stand with liquid matching components is shown in **Fig. 1.**

The level of the liquid can be changed from 0m to 5.6m for liquid phase shifter and 2.8m for liquid stub tuner, which corresponds to 3.6m and 1.8m mechanical length variation at 30 MHz, respectively. Voltage probes are calibrated by applying a low RF power.

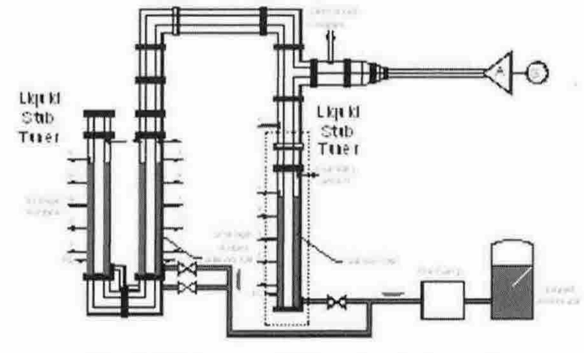

Fig. 1. High power RF test stand schematic

3. RF Test of the liquid matching components

The RF power test of the liquid matching components were accomplished at f = 30 MHz by using the experimental apparatus shown schematically in Fig. 1. The liquid matching components were connected to a pressurized transmission line. The matched line section from the liquid stub tuner to the liquid phase shifter were pressurized with N_2 gas at 3 kgf/cm^2 to increase the stand-off voltage. The matching circuit was connected to the RF transmitter through a dual directional coupler. During the RF pulse, temperatures of the liquid were measured by using 3 thermocouples, and the temperature of the outer conductor of the liquid matching components was measured by using an equipped thermocouple.

The line voltages, and the forward and the reflected powers were also measured. The reflected RF power was increased on a long-pulse, high-power test of the liquid matching components because the temperature of the transmission line components increased. Frequency feedback control was used to reduce the reflected power. **Figure 2** shows the RF voltage and current distribution from the liquid phase shifter to the liquid stub tuner when an RF power of 22.5 kW was applied for 30 seconds at 30 MHz. The zero position is at the open end of the liquid phase shifter. The maximum voltage at the boundary of the liquid and gas exceeded 35 kV. The maximum current in liquid region was higher than 1.1 kA. The average peak voltage of the standing wave was 35.8 kV during 30 seconds. The RF voltage of 35.8 kV is equivalent to a 1.54-MW transmission power to an antenna with a 6-Ω/m expected plasma loading.

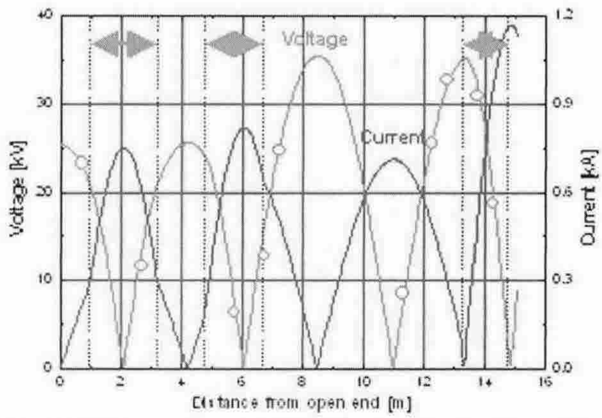

Fig. 2. Voltage and current distributions of the liquid matching components

4. Conclusion

High-power RF liquid matching components were designed and fabricated for the KSTAR ICRF system. A RF power test of the liquid matching components were performed at f = 30 MHz; a stand-off voltage of 35.8 kV(average) was achieved for a long pulse of 30 seconds. We confirmed that the RF liquid matching components could be satisfactorily used for long-pulse, high-power matching components.

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