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Design of the High Voltage Test Bed for the KSTAR ICH Components

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Abstract

6 MW ICH(Ion Cyclotron Heating) power will be coupled to the plasma through ICH four strap antenna in KSTAR(Korean Superconducting Tokamak Advanced Research) in the frequency range from 25 to 60 MHz. There are two important factors in the design of KSTAR ICH system. One is the breakdown voltage in the transmission system which restricts the maximum transferable rf power to the ICH antenna and another is the heat dissipation arising from the ohmic loss during the long pulse operation. Maximum design values for the voltage and current in ICH system are 35 kV and 1 kA respectively and components are designed for the operation of 300 seconds. The test facility is designed to produce at least 35 kV/ 1 kA by applying low rf power up to 30 kW and high voltage/current test is performed on the vacuum feedthrough and other transmission components.

1. Introduction

ICRF(Ion Cyclotron Range of Frequency) fast wave and heating system is one of the powerful sources to heat plasma and to produce current-drive in nuclear fusion reactor nowadays and multi-megawatt ICRF power is used in all large tokamaks. 8 MW ICH power will be launched to ICH four strap antenna in KSTAR from the transmitter and 6 MW rf power be coupled to the plasma due to the rf ohmic loss in the transmission line and matching components.[1] Maximum transferable rf power to the ICH antenna is primarily restricted by the electrical breakdown at the transmission system. The breakdown voltage is dependent on the material and shape of the insulator as well as the geometrical factor such as the distance between high voltage line and ground. In addition, the heat removal is one of important design factor in long pulse operation and the heat load from rf ohmic losses should be removed. Maximum breakdown voltage and current in KSTAR is 35 kV and 1 kA respectively and components are designed for the operation of 300 seconds. A few experiment of high voltage test has been reported for the high voltage test of components[2]. The specifications of components are varied depending on the design of antenna and matching/tuning circuit, however. So it is necessary to test the KSTAR ICH components in the high voltage test bed in laboratory before they will be installed in KSTAR tokamak. The test facility is designed to produce 35 kV/ 1 kA by applying low rf power up to 30 kW and high voltage/current test is performed on the vacuum feedthrough.

2. Design of the high voltage test bed

The first necessity for high voltage test bed was a means to conveniently generate high voltage and high current up to 35 kV and 1 kA across a test fixture in a gas pressurized system. It also requires mechanically simple design and easy adjustable operation.

Impedances of shorted(Z_{short}) and open(Z_{open}) lines for the length of the transmission line, L is given by

$$Z_{short} = Z_0 \tanh(\Gamma L) \tag{1}$$

$$Z_{open} = \frac{Z_0}{\tanh(\Gamma L)} \tag{2}$$

where Z_0 is the characteristic impedance of the transmission line, Γ is the propagation constant. Γ is related to the distributed resistance, R by

$$\gamma = \frac{R}{2Z_0} + \frac{2\pi}{\lambda}$$

where λ is the wavelength. So the impedance at the tap position is expressed as

$$Z_{total} = \frac{1}{\frac{1}{Z_{short}} + \frac{1}{Z_{open}}} \tag{3}$$

When Z_{total} is matched to the Z_0 of the transmitter by adjusting lengths of short/open line and frequency, rf power can be delivered to the high Q resonator system consisting of parallel combination of the shorted and open line without reflected rf power. Test fixture for the high voltage test is positioned at the end point of the open line and the distance between the tap position and open end is fixed. The remaining control parameter is the line length from the tap position to shorted end and wave frequency. The real and imaginary part of impedance as a function of axial length of the shorted line(1/2 λ section) are shown in fig 1a. Note that it is very high Q system where Q value is as high as 6000 for R = 0.003 Ω. That means that the axial length variation should be controlled within mm range. When the total length is 3/4 λ, the length of shorted line has two roots depending on the frequency as shown in fig. 1b. As R is increased, the shorted line length which has to be varied is increased. In order to match the case that R is varied from 0.003 Ω to 0.3 Ω, the shorted line length should be increased more than 80 cm.

Fig. 2a is the schematic diagram of the high voltage test bed and the voltage/current distribution is shown in Fig 2b. 30 kV/ 600 A is produced with the rf power of 20 kW for R = 0.03 Ω. Total line length is about 7.5 m and its operating frequency range is from 27 to 55 MHz. The high voltage test section is positioned at the end of open line section(quarter wavelength) and high current test section is positioned around the tee point. Variable length of the stub tuner located at the end of half wavelength region is 1m and its position is finely controlled up to 1mm by using stepping motor. Shorted length is varied by moving the shorting plate and the finger stocks are attached at inner and outer periphery of the shorted plate. The surface of the inner and outer conductor are silver plated and its depth is above 20 um to reduce the electrical ohmic loss. The test bed is made of 9(3/16″) nominal diameter transmission line. All components are aligned in a straight line to avoid breakdown due to the curved structure. 3 atm. pressurized air is supplied to the high voltage bed through the gas barrier port. Voltage prove arrays are positioned in quarter wavelength region. The forward/reflected rf power is monitored by the directional coupler. The surface temperature of outer coaxial line is monitored by thermocouples and the temperature of the inner conductor is monitored by IR thermometer.

3. Test results

Fig. 3. shows the voltage as a function of the applied rf power. The voltage is nearly proportional to the square root of the rf power and 20 kV at the test section could be produced at the open position with P_{rf} = 9 kW. The operating frequency is 28.5608 MHz. Fig 4. show the time evolutions of the temperature at the outer conductor and the reflected rf power for P_{rf} = 4 kW without frequency tuning. The reflected power and the temperature are increased with the time. The rf ohmic losses generates the heat at the inner transmission line so that it induces the expansion of the

electrical length of the transmission line. The high voltage test bed is apart from the initial matched condition of the impedance. So the reflected rf power could be decreased by reducing the frequency to several kHz. High voltage test is performed on the vacuum feedthrough. It shows no damages up to 20 kV for 10 seconds.

4. Summary

Maximum breakdown voltage and current in ICH system for KSTAR ICH system are 35 kV and 1kA respectively and components should be designed for the operation of 300 seconds. The test facility is designed to produce at least 35 kV/ 1 kA by applying low rf power up to 30 kW and high voltage test performed on the vacuum feedthrough shows no damages up to 20 kV for 10 seconds.

References

1. B. G. Hong et al., 18th IAEA Fusion Energy Conference, Sorrento, Italy, 2000, p. 96.
2. S. W. Ferguson et al., 16th IEEE/NPSS symp. on Fusion Engineering, Champaign, Illinois, 1995, p. 837.

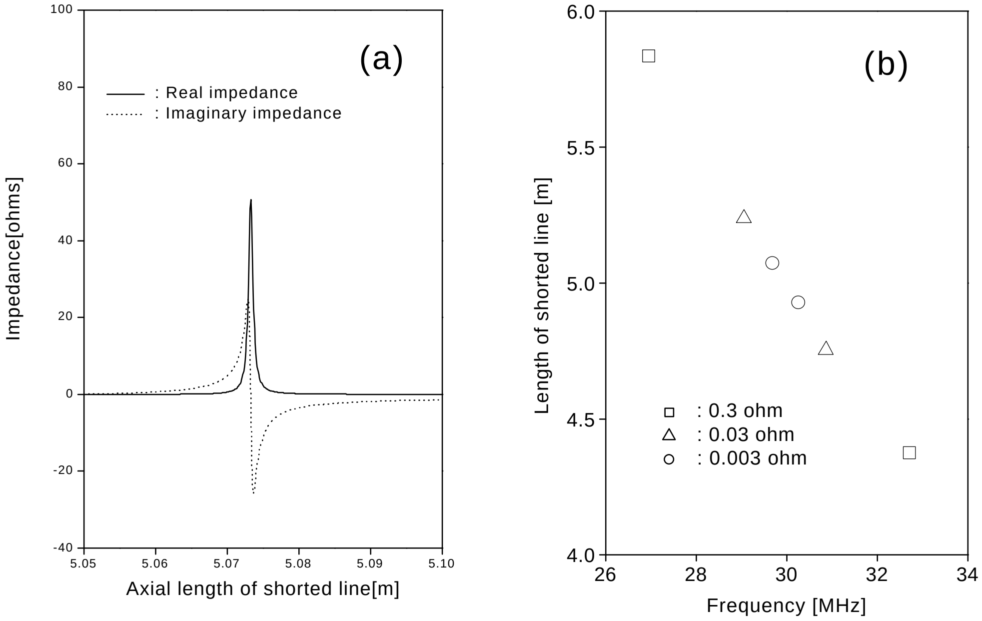

Fig. 1. Impedances vs. axial length of the shorted line for R=0.003 ohm(a) and length of shorted line vs. frequency (b).

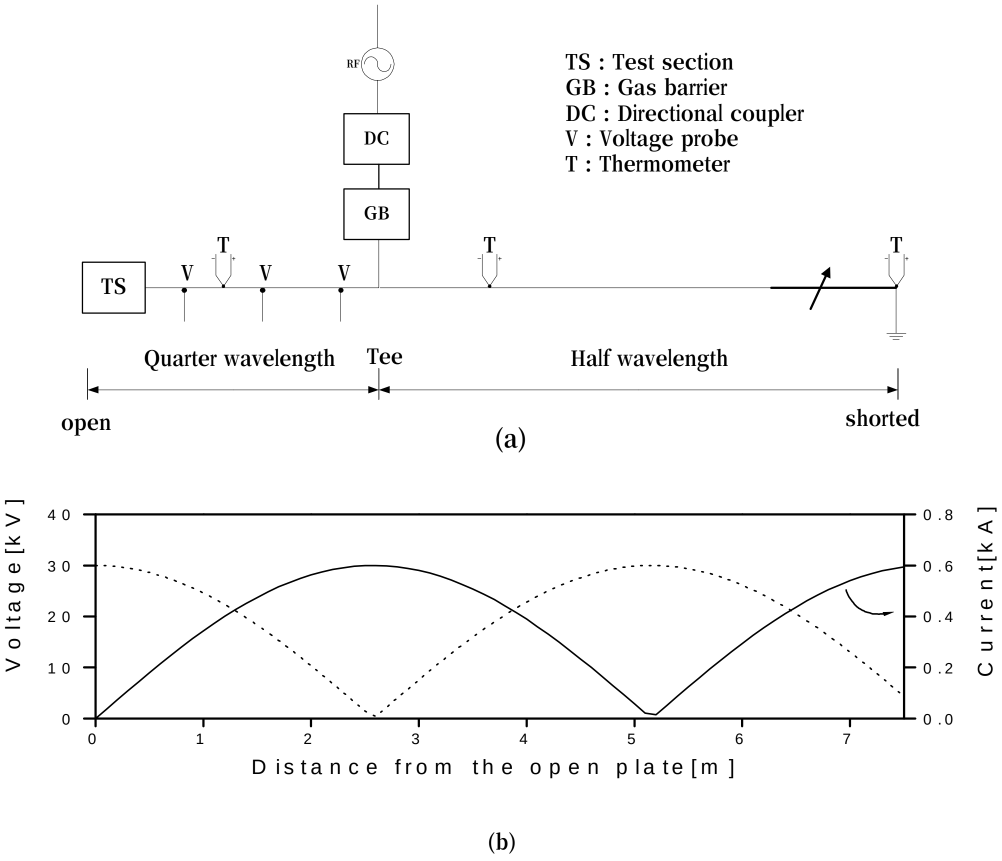

Fig. 2. Schematic diagram of the high voltage test bed(a) and the calculated voltage/current distribution on the transmission line for $P_{rf} \approx 20$ kW.

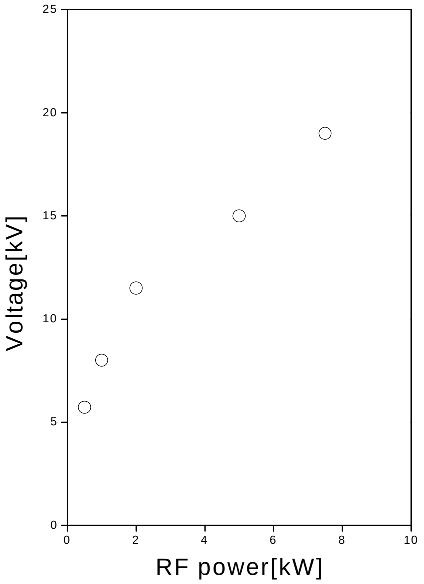

Fig.3. Voltage vs. rf power.

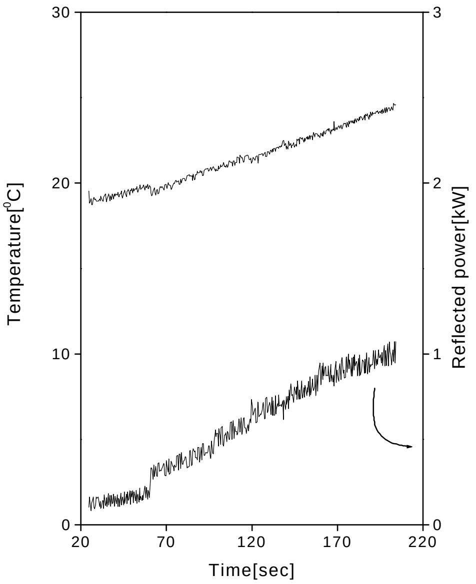

Fig. 4. The time evolutions of surface temperature of the transmission line and reflected power for P_{rf}=4 kW.