Electrical and Thermal Analysis of Alumina Insulator for the KSTAR ICRF Transmission Line

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1. Introduction

An ion cyclotron range of frequency (ICRF) system is widely applied to plasma heating and current drive for fusion devices. In this system, a development of high power RF transmission components is necessary for transmitting MW levels of RF power continuously. However, it may be limited by some reasons such as a high voltage breakdown on dielectric insulators in the ICRF transmission line [1, 2]. If an arc breakdown frequently occurs on dielectric insulators by high voltage, an effectively transmitting high RF power to the plasma is difficult by reflected RF power. Generally, a Teflon insulator has developed for KSTAR ICRF system due to relatively lower dielectric loss [2]. Even though Teflon insulator has this advantage, the breakdown often occurs by several reasons such as temperature, operating time, partial breakdown, arc discharge, treeing, and tracking etc [3]. Therefore, an alumina insulator is needed for our system, since it may give damage less than Teflon insulator. So, an electrical and thermal analysis of alumina insulator is necessary for this experiment.

This presentation will give an installation of RF test system for the electrical and thermal analysis of alumina insulator in the transmission line, will show an E-field distribution of alumina insulator using 3D E-field simulation, and will present a calculated dielectric loss and a temperature difference using a predicted ICRF condition.

2. Methods and Results

2.1 System setup of RF test circuit

The RF voltage test on the alumina insulator in the transmission line was accomplished at around 42.9MHz using the experimental apparatus shown schematically in Fig. 1. The alumina insulator is placed at the end of the test section which is 1/4 wavelength position of operating frequency, and its end is electrically opened. It means that the voltage at the insulator position become maximum. It is connected to the matching circuit through the transmission with three voltage probes of which sampling are around -75.8dB at 42.82MHz. Its operating range of frequency is around 42.9MHz.

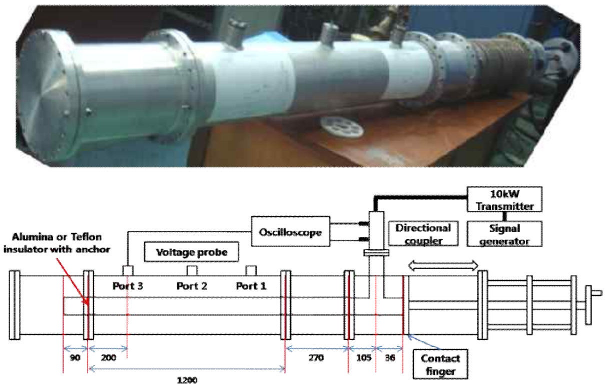

Fig. 1. Experimental setup and schematic drawing

2.2 Results of RF test

The RF test on the alumina insulator was conducted. The results of it are described in Table I. Depending on dielectric loss data from each company's specification the order of its value is almost same. It means that if the experimental condition is similar, the increscent of temperature on the alumina insulator may become comparable value. However, the temperature results of each insulators show the different value. It is due to the difference of dielectric loss of the insulator by several reasons such as treatment of alumina powder by company, processing method of making alumina insulator, and the insulator aging by the operating condition etc.

Table I: Conditions of frequency, RF voltage on alumina insulator and temperature at atmospheric pressure for 600 seconds (B/A=Before/After). In this case, Type 1 is made by slip casting method from company A, Type 2 is formed by cold isosstatic pressing method from same company, and Type 3 is manufactured by slip casting method from company B.

Alumina Insulator	Frequency [MHz]	Voltage [kV]	Temperature [℃] (B/A)
Type 1	42.82	3.99	41.3 (24.3/65.6)
Type 2	42.855	4.14	22.5 (17.4/39.9)
Type 3	42.96	4.62	4.3 (14.8/19.1)

2.3 3D electrostatic simulations

To analyze the electric field on the alumina insulator in the transmission line, it was computed by using the commercial FEM 2D code (Quick Field). In this presentation, a calculation of 3D electrostatic field has performed by CST EM Studio. It can give the more exact simulation results in a non-symmetrical geometry compared 2D simulation. The results of 3D E-field simulation using measurement data are shown in Fig. 2. As of this result, an average of electric field strength on alumina insulator is around 0.05 MV/m.

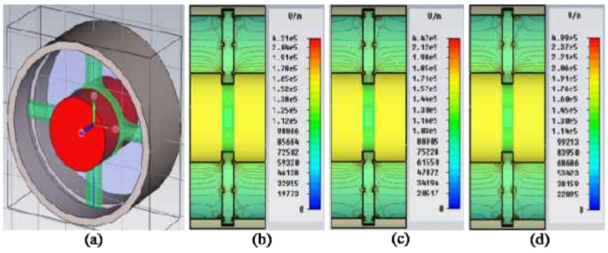

Fig. 2. A 3D electrostatic field simulation for alumina insulator in ICRF transmission line, (a) is 3D modeling for the insulator, (b) is simulation result of Type 1, (c) is the result of Type 2, and (d) is the result of Type 3.

2.4 Calculation of dielectric loss and temperature

On applying the RF voltage, the real power loss in a volume of dielectric material in electric field might be calculated by tanδ and an temperature difference on the dielectric material can be also computed by the real power loss due to tanδ. It means that tanδ of dielectric material would be easily calculated by those things as mentioned above. By the results of RF test on alumina insulator and simulation of average electric field strength on it, temperature difference is figured out using predicted ICRF condition and Table II show this result. Therefore, a suitability of the dielectric material for ICRF experiment can be determined through it.

Table II: Calculation of temperature difference using computed dielectric loss and ICRF condition

Alumina Insulator	Frequency [MHz]	Time [sec]	Voltage [kV]	△T [℃]
Type 3	30.8	60	30	14.02

3. Conclusions

A RF voltage test on alumina insulator in transmission line was performed to analyze the electrical and thermal properties of it. And then, 3D electrostatic field simulation was conducted, and 3D E-field distribution of the insulator was computed. So, a real dielectric loss of insulator can be calculated. Using its results, we will be able to predict the suitability of alumina insulator for ICRF experiment.

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