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Design of Conductive Ceramic Acceleration Tubes for Compact Fusion Neutron Generators

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1. Introduction

Acceleration tubes used in fusion reaction neutron generators are usually cylindrical tubes that accelerate deuterium ions by DC high voltage [1].

Vacuuming the inside of the acceleration tube, and applying voltage to electrodes on both ends of it creates an inclination of the field inside the acceleration tube, which accelerates the charged particles. To prevent insulation from being destroyed at any moment by continuously increasing the applied voltage, split the acceleration tubes into zones to make it into insulator – conductor – insulator - conductor.... structures and use them to distribute voltage uniformly to each conductor. As such, by dividing the acceleration tubes into several electrodes, the field inside them becomes much more uniform, allowing more stable operation.

In addition, the fluctuation of beam current consisting of charged particles can be forced to maintain a uniform field to some extent by distribution resistors, which increases the internal voltage.

As such, the acceleration tube consists of insulators such as ceramics and glass, multi-stage electrodes consisting of aluminum, titanium and stainless steel, and a number of distribution resistors to force equal division of the field (Fig. 1.).

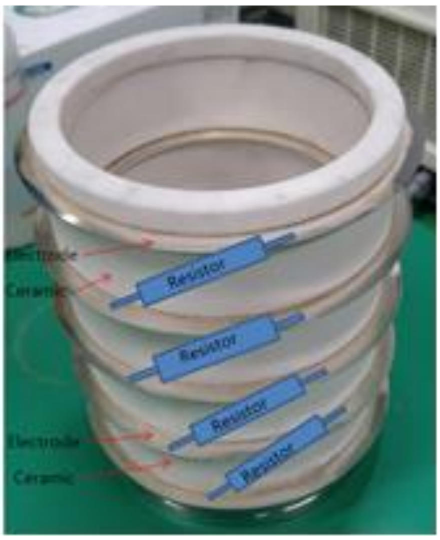
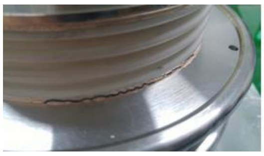


Fig.1. Appearance of the acceleration tube consisting of ceramics, electrodes, and distribution resistors.

Brazing for metal-ceramic bonding is used to produce high voltage acceleration tubes available in vacuum, with larger acceleration tubes and higher junctions, the more likely the problem is (Fig. 2).


(a) Lack of filler


(b) Excess of filler


(c) Crack on Brazing

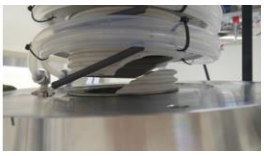

(d) Ceramic break

Fig.2. Types of failure to build acceleration tubes.

In this paper, we propose acceleration tubes that use conductive ceramics (adjustable resistivity from 10^7 ohm-cm to 10^{10} ohm-cm) instead of ordinary ceramics (resistivity $>10^{13}$ ohm-cm) as ceramic insulators that make up the acceleration tubes.

The conductive ceramic acceleration tubes have the advantage of reducing the junctions of the brazing to improve the fabrication. 2. The voltage distribution is continuous, so as to obtain a more even continuous field than the multi-stage electrodes. 3. No additional distribution resistors were required, 4. The built in distribution resistance can be adjusted so that the distribution resistance effect can be obtained arbitrarily.

2. Conductive ceramic

Ceramic is a material widely used in many fields (resistivity $>10^{13}$ ohm-cm) with excellent mechanical, chemical and thermal durability and also with great electrical resistance. Ceramics with these properties include Al_2O_3, Y_2O_3, etc. By adding a small amount of micro-size SiC less than 1 um to Al_2O_3 ceramics, the mechanical properties of Al_2O_3 ceramics can be increased and resistivity reduced to a certain level at the same time. The Engineering Ceramics Laboratory of the Korea Institute of Machinery and Materials announced that if S_iO_2 is added with 10 to 15 volumetric SiC, resistivity of 10^{13} ohm-cm or more can be adjusted to

10^7 ohm-cm or below [2]. Commercial ceramic manufacturer MacTech also confirmed that this conductive ceramic can be manufactured.

3. Design of conductive ceramic acceleration tubes

3.1. Conventional acceleration tube

The acceleration tube used in high-flux/movable neutron generator under development by the Korea Atomic Energy Research Institute(KAERI) have four voltage distribution resistors and five electrode-ceramic junction surfaces as shown in Figure 3. The voltage distribution resistors used seemed to be too large to play a role as the voltage distribution resistors, but the resistance with a value of 1 G ohm was used due to the limitations of size and power rates.

The dividing stages of the acceleration tube are four, the inside and outside diameter of the ceramic is approximately 12 cm and 17 cm (thickness 2.5 cm) and the ceramic length of each stage is 3.7 cm.

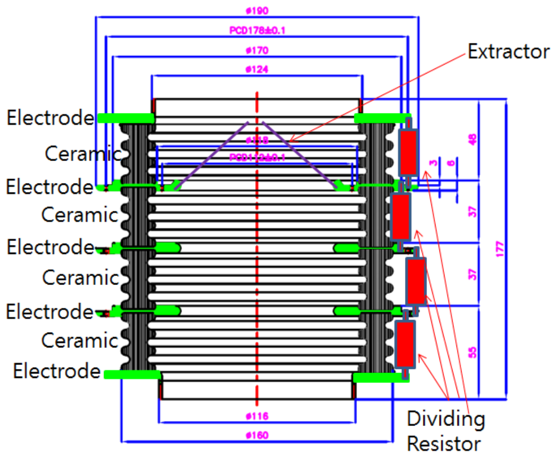


Figure 3. Structure of KAERI acceleration tube used in the neutron generator. (Four distribution resistors and five electrode-ceramic brazing junctions are visible).

3.2. Voltage Distribution Resistance Calculation

Since the voltage distribution resistors currently used are 1 G ohm per unit, the total resistance is 4 G ohm, which tends to be too large to efficiently perform the role of voltage distribution resistors. Ideally, 40 to 80 M ohm, which is 10 to 20 times larger than 4 M ohm, the circuit impedance (200kV/50 mA = 4 M ohm) at a maximum acceleration energy of 200 keV and a beam current of 50 mA, is desirable, but considering the heat dissipation and the heat load generated by this power((200 kV)^2/(40 ~ 80 M ohm) = 0.5 kW ~ 1 kW), the total power has been decided at 50 W with 800 M ohm.

The resistance of an object is given as shown in formula (1) (see Figure 4.).

R = (ρ. L) / A ------------------------------ (1)

where, R is the resistance, ρ is the resistivity of the material, L is length of the object, and A is the cross section of the object.

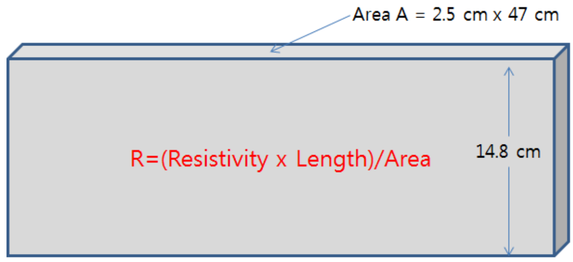


Figure 4. Calculate the resistance of an object (Resistance R = (Resistivity x Length) / Area).

The thickness of the ceramic acceleration tube is 2.5 cm, average circumference 47 cm, and length 14.8 cm. Therefore, the resistivity to make the resistance 800 M ohm is about 7 x 10^9 ohm.cm. In other words, if SiC of 10% to 15% is properly combined in S_iO_2 to create a ceramic with a resistivity of 7 x 10^9 and the acceleration tube is constructed, even if the electrode for the joining of the Extractor is constructed as shown in Figure 5, the brazing junctions are reduced to three sides (reduce from five sides to three) and the production failure rate decreases. At the same time, there are many advantages mentioned in the introduction.

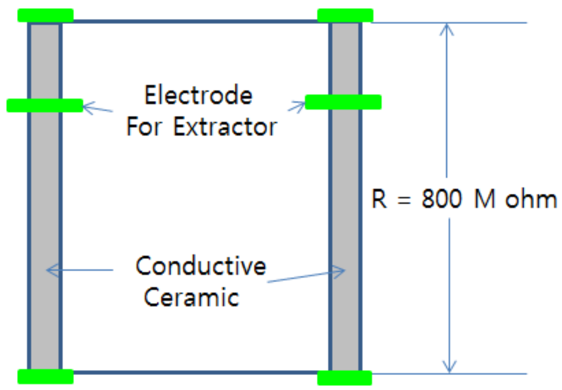


Fig. 5. Structure of conductive ceramic accelerators.

4. Conclusions

Acceleration tubes with conductive ceramic were designed. The ceramic thickness of the designed tube was 2.5 cm, internal diameter 12 cm, external diameter17 cm, length 14.8 cm, resistivity 7 x 10^9 ohm.cm, and the resistance was 800 M ohm. Brazing junctions were reduced to three junctions from five including bottom, top and extractor bonding electrodes, making acceleration tubes easier to fabricate.

In addition, the continuous voltage distribution effect, rather than the single discontinuity, could be obtained so that the continuous field was more uniform than the multi-stage electrodes. No additional distribution resistors were needed, and the built in distribution resistance could be adjusted so that the distribution resistance effect could be obtained arbitrarily.

However, it is necessary to check the vacuum properties, uniformity of built in resistance, resistivity controllability, temperature characteristics of resistivity values and brazing properties of the conductive ceramic experimentally.

REFERENCES

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[2] Ha-Neul Kim, Hyun-Myung Oh, Young-Jo Park, Jae-Woong Ko, and Hyun-Kwuon Lee, " Fabrication and Characteristics of Al2O3-SiC Ceramic Composites for Electrostatic Discharge Safe Components", J. Korean Powder Metall. Inst., Vol. 25. 2, 144-150, 2018.

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