Development and Performance of Electrostatic Deflector Insulators for the Chalk River Superconducting Cyclotron

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Abstract

The electrostatic deflector in the Chalk River superconducting cyclotron is in a dee, and has a single, fixed deflector electrode suspended from two insulators located above the midplane. One of them contains a high-voltage cable and a series water resistor to limit energy available to a spark and to isolate the high-voltage cable and dc power supply from rf pickup. The other insulator is a conventional cylindrical post. The insulators have been changed from the original design to make them less prone to thermal damage from rf heating. Details are given of the water system electrical performance and of insulator modifications and performance.

I. INTRODUCTION

Insulators are critical components in the electrostatic deflector for the Chalk River superconducting cyclotron [1]. They must provide electrical isolation for voltages up to 100 kV as well as support rigidly a cantilevered electrode structure. One of them is an integral part of the high-voltage input system that features high-resistivity flowing water [2]. These functions must be performed in magnetic fields up to 5 T while being heated by rf fields the order of ten watts, which leak into the dee cavity from adjacent accelerating gaps. (The maximum rf power for beam acceleration is 100 kW.) The temperatures of structures surrounding the insulators and of components of the deflector system reach 100 - 200°C when ion beams requiring large rf power are accelerated [3]. In this situation, the feed insulator as originally designed suffered distortion and other damage.

A small testing facility was built to study insulator performance. This facility uses a high-resistivity water system in common with the cyclotron and a similar high-voltage power supply, but does not have a magnetic field. Diagnostic instrumentation includes a high-voltage resistive divider to measure the voltage on insulator electrodes, a capacitive pick-up to detect electrical transients, an X-ray monitor, and circuitry to measure insulator surface currents. The surface currents are derived from the voltage across a 1 kΩ resistor between ground and the insulator anode, which is otherwise isolated from ground by a thin film of Kapton insulation. All insulators are tested to 95 - 100 kV.

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In this paper we give a brief description of the high-voltage supply system, describe the insulator geometries, and give an account of insulator development and performance. Our colleagues describe recent performance of the whole deflector system with emphasis on developments in electrode configuration and performance [4].

II. HIGH-VOLTAGE SYSTEM

Figure 1 shows schematically the layout of the deflector high-voltage system inside a dee of the cyclotron. Details are contained in reference 2. Briefly, a standard, flexible high-voltage cable enters the top of the water header. The outer conductor braid terminates at the header and a water seal is made to the cable dielectric with an O-ring. The cable is contained within a long Teflon tube, which extends down to the end of the coaxial feed insulator inside the insulator housing. The Teflon tube and cable are in turn contained within a copper tube that serves also as a vacuum envelope. High-resistivity water (typically 16 MΩ.cm) flows in the annular regions defined by the copper and Teflon tubes and the cable. At the end of the cable the water flow forms a series isolation resistor (typically about 30 MΩ), which makes connection to the deflector electrode.

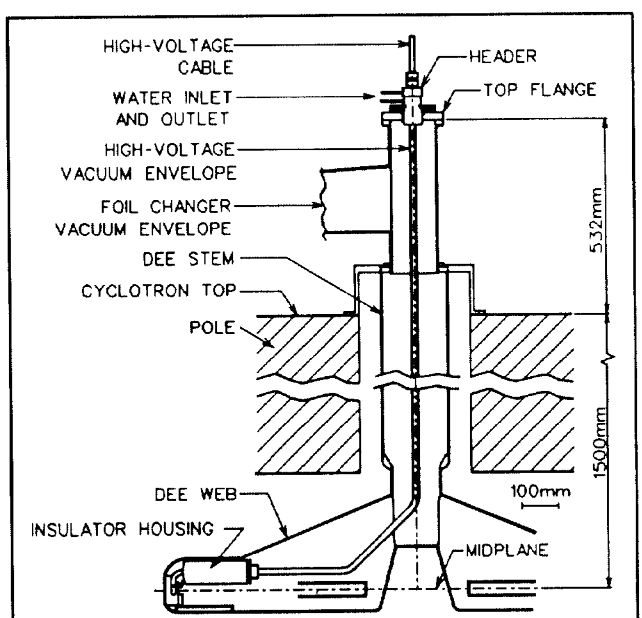

Figure 1 Schematic of the deflector high-voltage system in a dee.

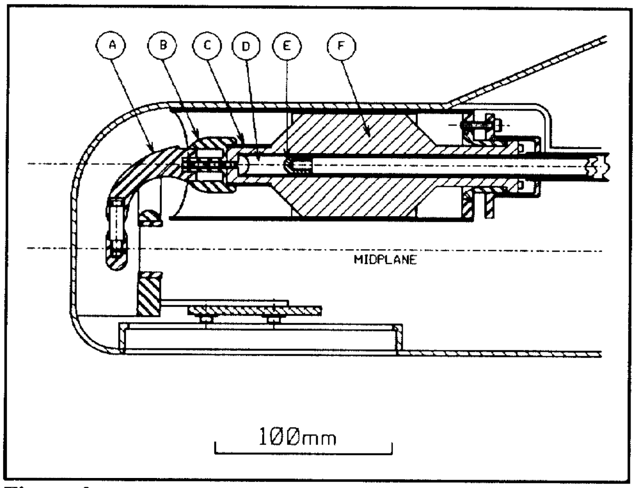

Figure 2 Cross section of a coaxial feed insulator. A - electrode hanger; B - cathode termination; C - boron nitride sleeve; D - water resistor; E - cable termination; F - insulator.

III. Insulator Configuration

Figure 2 is a cross section of the coaxial feed insulator mounted above the midplane in the dee, with some of the insulator features noted. (More details are in reference 2.) The insulator has a thin-walled, stainless steel cylinder (anode cylinder) shrunk onto it, to make good contact between insulator and housing. At the high-voltage cathode the insulator is fitted with a boron nitride sleeve to reduce secondary electron emission. Inside the insulator bore are the terminated, high-voltage cable, the water isolation resistor, and the Teflon tube. A hemispherical electrode, sealed to the insulator interior by a small O-ring, connects the high-voltage on the water resistor to the hanger of the deflector electrode structure. At the opposite end is another O-ring seal, between the flanges on the insulator and the copper vacuum envelope.

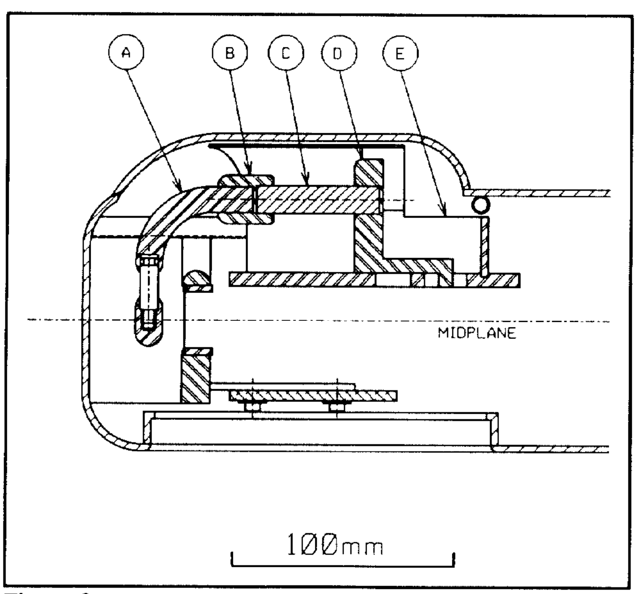

Figure 3 Cross section of a support insulator. A - electrode hanger; B - cathode termination; C - insulator; D - anode; E - housing.

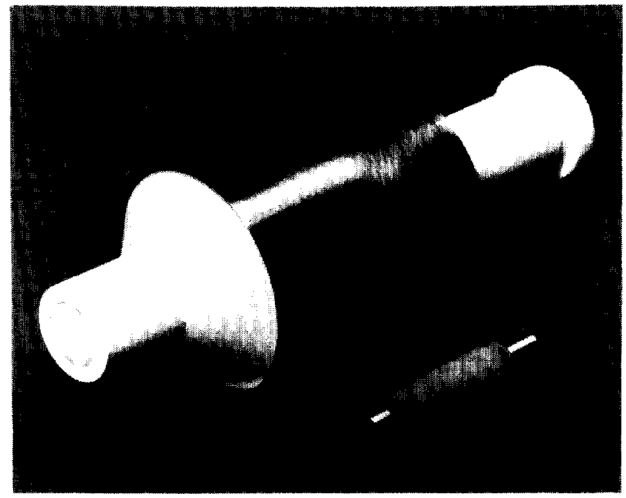

Figure 4 Photograph of a coaxial feed insulator and a support post insulator.

Figure 3 shows the post support insulator mounted above the midplane in the dee. Each end of the insulator is fitted with a thin, stainless steel cylinder (heat-shrunk on). The electrodes fasten to the insulator ends with set screws. The insulators are typically about 57 mm long and 12.7 mm in diameter. The distance between electrodes is 36 mm. This geometry is a change from the original support insulator design, which had two 25 mm long insulator posts parallel to the magnetic field. (See Figure 2 in reference 2.) Figure 4 is a photograph of a post support insulator and a coaxial feed insulator. The thin-walled, stainless steel cylinders are evident on both insulators.

IV. Development And Performance

A. Water Resistor

The water resistor is typically 20 mm long and the diameter is 11 mm. This resistor forms a voltage divider with the resistance to ground (typically about 1 GΩ) in the water between the Teflon tube and insulator wall. The output voltage is a few per cent smaller than the power supply voltage, provided that the leakage current is limited to the water. Additional leakage paths at the deflector electrode increase the voltage division ratio, with accompanying decrease in output voltage. At 100 kV the leakage current in the water path to ground is roughly 100 μA. The current through the isolation resistor may be larger at lower voltages because of the leakage currents at the deflector electrode. Figure 5 is a characteristic current-voltage plot for the isolation resistor in the cyclotron with the deflector electrode grounded. Measurements made in magnetic fields of 3.5 T were indistinguishable from those made with the field off. A 32 MΩ series resistor outside the cyclotron limits the voltage across the isolation water resistor to less than about 60 kV.

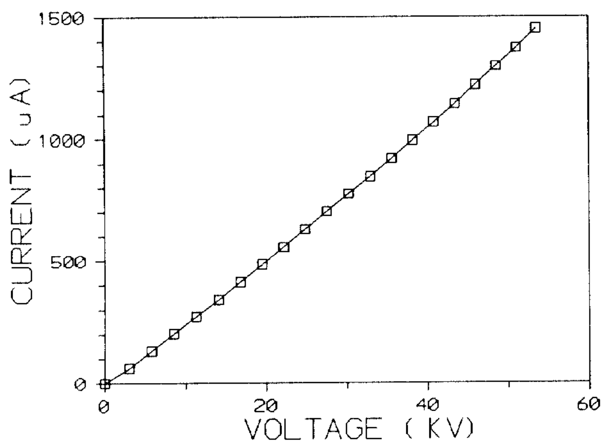

Figure 5 Current versus voltage across the isolation resistor.

B. Cylindrical Feed Insulator

The original design had Teflon as the major material and a boron nitride sleeve epoxied onto the cathode end. This insulator performed satisfactorily if its temperature did not rise appreciably. At elevated temperatures a gap of 0.5 mm would develop between the insulator and the anode cylinder, and the boron nitride sleeve would crack, causing deterioration in performance.

To obtain better thermal characteristics than those of Teflon, a Macor feed insulator was made, initially without a boron nitride sleeve, and studied in the test facility. The leakage current was higher than could be attributed to the water resistors alone. Installation of a boron nitride sleeve did not change this current. Subsequent measurements of leakage current along the insulator surface showed negligible surface leakage (much less than 1 μA). However, inspection of the insulator bore showed that the walls had become discoloured. The insulator bore then was fitted with a thin Teflon liner (1.4 mm thick), which was etched and epoxied onto the Macor wall. The liner covered the bore and the flange that mates to the copper vacuum envelope. Measurements then showed that the leakage currents varied essentially linearly with voltage over 95 kV (the power supply limit) and no significant leakage existed on the surfaces. Another Macor feed insulator was fabricated with a Teflon lining and a boron nitride sleeve. Both have given satisfactory service in the cyclotron in conditions where the original Teflon versions failed.

Surface leakage current measurements were made on one of the Macor insulators while it was in service in the cyclotron. The surface leakage was negligible and consequently not a contributor to the excessive leakage current that is experienced for deflector operation in the cyclotron [3].

Also, a Macor insulator was designed and fabricated, without a boron nitride sleeve, to supply cooling water to an appropriately modified deflector electrode [4]. The radius of curvature on the revised cathode termination was increased by over a factor of two near the insulator surface. This insulator has been successfully used in the cyclotron after development in the test facility.

Currently, alumina (99.5%) feed insulators are being developed. They have the boron nitride sleeve replaced by a layer of Cr_2O_3 to limit secondary electron emission at the vacuum-cathode-insulator interface [5]. These insulators still use a Teflon liner epoxied in place to keep water off any alumina surface. The Teflon liner is regarded as an important barrier for water containment in the event that the main insulator body cracks. The test facility results show these insulators to perform satisfactorily. None as yet has been installed in the cyclotron.

C. Support Insulator Post

Macor and alumina (99.5%), with and without a thin coating of Cr_2O_3, have been tested. Coated alumina performed the best. It showed negligible surface leakage up to the power supply limit of 95 kV in the test facility. By contrast, coated Macor exhibited increases in leakage current of 100 μA over a time period of 30 s at voltages above 75 kV. Also, performance varied with thickness of the Cr_2O_3 coating on the Macor posts.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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