ELECTROSTATIC DEFLECTOR HIGH VOLTAGE SYSTEM FOR THE CHALK RIVER SUPERCONDUCTING CYCLOTRON

C.R. Hoffmann and C.B. Bigham
Atomic Energy of Canada Limited, Research Company
Chalk River Nuclear Laboratories
Chalk River, Ontario, Canada K0J 1J0

Abstract

The extraction system for the Chalk River superconducting cyclotron has a single fixed electrostatic deflector located in a dee. High voltage is fed from the top of the cyclotron, down the dee stem and through the dee top interior to connect to a coaxial support insulator for the deflector electrode. The body of this insulator contains a limiting series resistor in the form of a short column of high resistivity flowing water. This resistor effectively eliminates rf pickup in the feed cable and isolates the deflector electrode from the power supply and cable during a spark. Maximum design voltage for the system is 100 kV.

Introduction

The distinguishing features of the electrostatic deflector high voltage system in Chalk River's superconducting cyclotron[1] stem from the deflector being located in a dee. As shown in Fig. 1, which is a photograph of the dee that contains the deflector, two semicylindrical bulges on the top surface are required to provide adequate space for the support insulators and their housings. Access to this region is from the top of the dee stem. Figure 2 is a photograph of the deflector showing the insulator housings that fit under the bulges in the dee surface. The high voltage deflector electrode is suspended from two stainless steel hangers attached to the insulators. The longer housing contains the coaxial insulator to which a high voltage cable connects, as will be explained in later sections.

Details of the high voltage feed system within the cyclotron have changed considerably since model studies were made[2]. The intention was to use a custom-made, semi-rigid coaxial cable, which had copper conductors, Teflon dielectric and was vacuum tight. An isolating resistor made from a string of 2 watt carbon resistors immersed in oil was at the top of the cyclotron. DC high voltage tests outside the magnet showed the cable and coaxial insulator geometry to be acceptable, but tests in the cyclotron magnet with rf power turned on showed the semi-rigid cable to be vulnerable to damage because it was long enough to be resonant in the operating frequency range of the cyclotron. The design of the system was reviewed and altered to provide resistance that would dampen the cable resonances and allow use of a standard flexible high voltage cable that was easily removable. The idea of using a water isolating resistor that could be located near the deflector electrode developed from discussions during a visit to Oak Ridge National Laboratory[3]. The water resistor fulfills both functions of damping cable resonances and isolating the deflector electrode from the cable and driving power supply when sparking occurs.

Details of the high voltage system that was developed, installed and operated in the cyclotron are presented in sections following.

General Layout

Figure 3 schematically displays the high voltage system inside the dee. At the top is a stainless steel header that is fastened to the top flange of a section of the foil changer vacuum envelope[4], which mates to the top of the dee stem. An O-ring provides the vacuum seal between header and top flange. A copper tube (13.84 mm inside diameter, 1 mm wall thickness) brazed onto the header forms a vacuum envelope that extends down to the coaxial insulator housing in the dee. Within the envelope are the high voltage cable and the water passages to form the

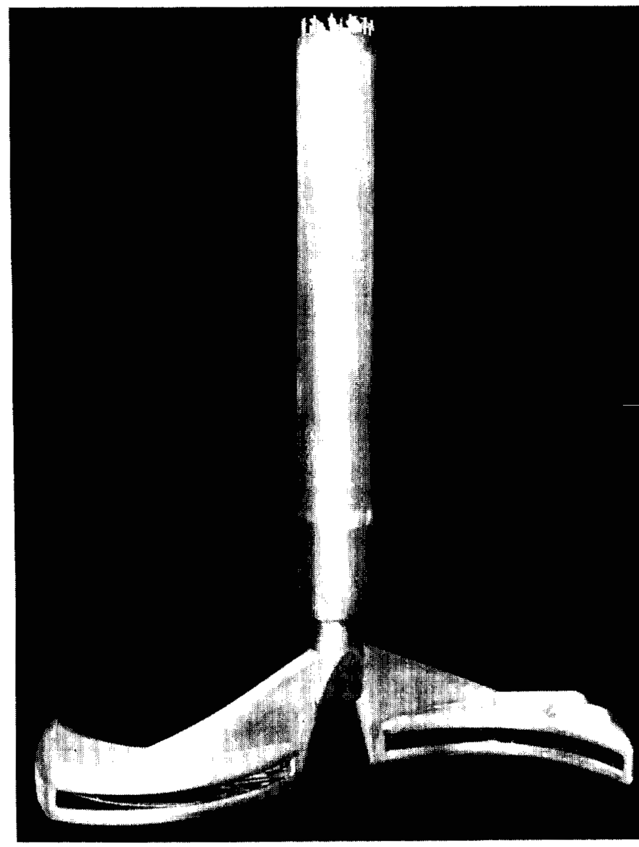

Fig. 1 Photograph of a pair of dees and their centre conductor dee stem. The dee on the right, with the semicylindrical bulges on the top surface, houses the deflector.

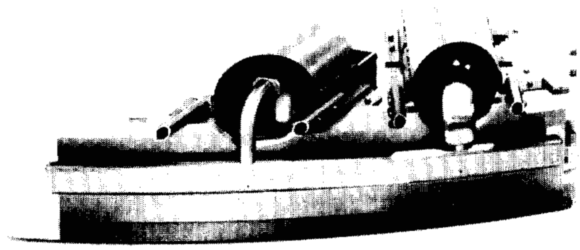

Fig. 2 Photograph of the electrostatic deflector showing the deflector electrode suspended from the support insulators.

CH2387-9/87/0000-1567 $1.00 © CCC
PAC 1987

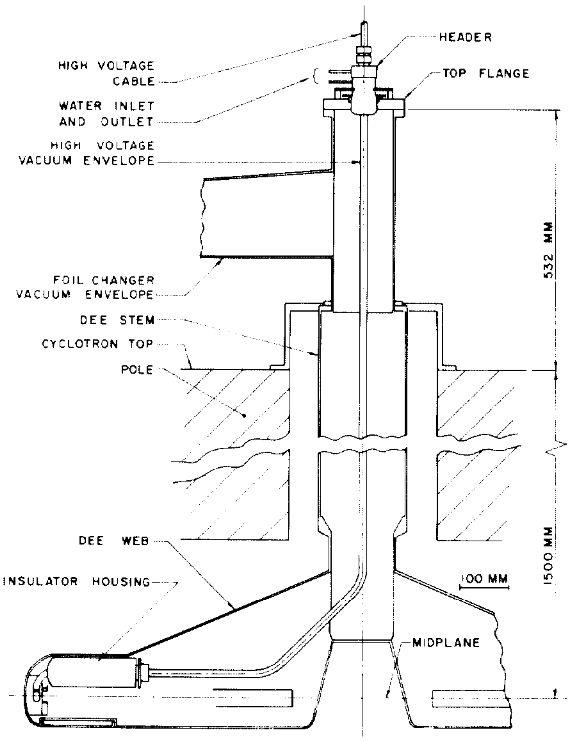

Fig. 3 Schematic layout of the electrostatic deflector high voltage system inside the dee stem and dee.

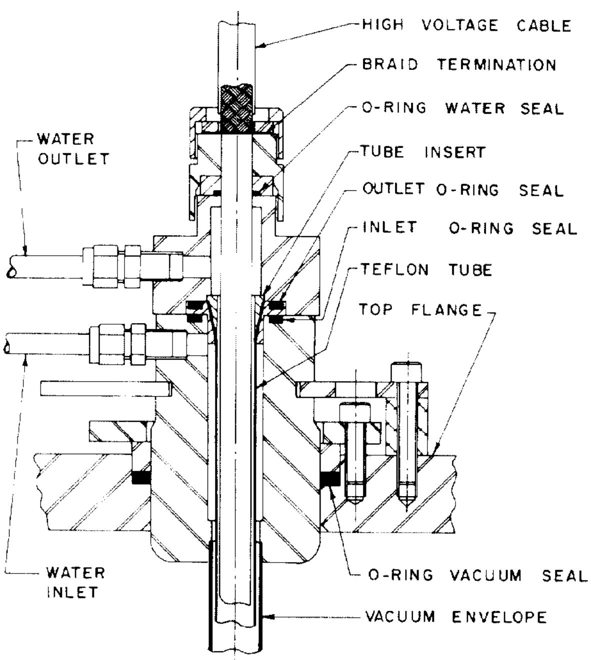

Fig. 4 Cross section view of the water header.

isolation resistor. The distance from the top of the header along the copper tube to the end of the water resistor is 2.57 m. The envelope tube is mounted on the dee stem inner wall (offset into the page in Fig. 3) and has precise bends to fit into the narrow opening in the dee web. An O-ring provides a vacuum and water seal to the coaxial insulator body.

Water Header

Figure 4 gives a cross section of the water header. A standard flexible high voltage cable[5] (polyethylene dielectric of diameter 8.9 mm) enters at the top. The cable outer conductor braid is terminated by capture between a washer and the header body. A water seal is made to the dielectric with an O-ring. This seal has been tested up to 1000 kPa pressure without leaking. Nominal maximum operating pressure in the system is 600 kPa. No special preparation of the dielectric surface was required after removal of the cable braid to make the seal. The cable is contained within a long Teflon tube (12.7 mm outside diameter, 0.76 mm wall thickness), which extends down into the body of the coaxial insulator. Water flows toward the insulator core in the annular region between the copper vacuum envelope and Teflon tube and away from the insulator core in the annular region between the cable and the Teflon tube. A typical water flow is 2 L/min. The water is supplied from a small, commercially available, high purity, deionized water system[6]. Water resistivity measured at the header outlet is greater than 16 MΩ•cm.

Coaxial Insulator

Figure 5 shows details of the Teflon coaxial support insulator. The Teflon tube extends to within a few mm of a hemispherical electrode, which seals to the inside of the insulator with an O-ring and connects to one of the support hangers for the electrostatic deflector electrode. Inlet water, flowing between the Teflon tube and insulator body, turns around at the end of the insulator interior to enter the region of the isolating water resistor. This resistor is formed from a column of water 20 mm long

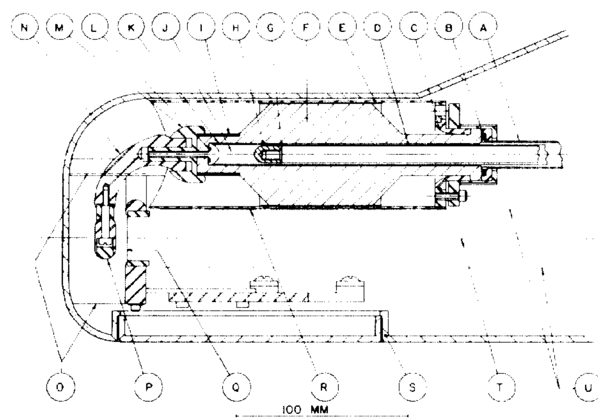

Fig. 5 Cross section view of the coaxial support insulator and deflector system inside the dee. A - high voltage cable vacuum envelope; B - O-ring seal between vacuum envelope and insulator; C - electrical stress relief collar; D - high voltage cable dielectric; E - thin-walled cylinder; F - Teflon insulator; G - cable dielectric O-ring water seal; H - cable centre conductor termination; I - boron-nitride sleeve; J - isolation resistor water column; K - Teflon tube; L - O-ring seal for hemispherical electrode, high voltage connection to deflector electrode; M - electrical stress relief collar; N - deflector electrode hanger; O - tungsten sparking plates; P - stainless steel deflector electrode; Q - tungsten septum; R - coaxial insulator housing; S - dee envelope; T - midplane; U - vertical dee gap edges.

between the hemispherical electrode and a copper termination for the cable inner conductor. The copper termination threads onto the cable dielectric and seals to it with an O-ring to prevent water leaking through the centre conductor passage in the cable.

A significant leakage resistance to ground exists in the annular water passage between the Teflon tube and insulator body. This length of water (≈ 159 mm) connects the deflector electrode to the copper vacuum envelope. The outer surface of the Teflon tube in this region has two sets of machined grooves(0.25 mm deep by 1 mm wide) orthogonal to one another. One set consists of eight linear grooves equally spaced about the tube circumference and the other set consists of 15 rings spaced 12.7 mm apart.

Typical calculated values of isolation and leakage resistances for water resistivity of 10 MΩ•cm are 20 MΩ and 1.5×10^3 MΩ respectively. These two resistances form a voltage divider that reduces the voltage supplied to the deflector electrode by about 1% compared with that appearing at the end of the cable termination. These resistance values and division ratio have been verified by measurements at low voltages (< 1 kV). These features at high voltages are discussed in the next section.

The insulator body has an overall axial length of 165.3 mm and a main body diameter of 60 mm press fitted into a stainless steel, thin-walled cylinder. Two 45°conical sections transfer this diameter down to 24 mm. The hole on axis within the insulator is 13.1 mm in diameter. The insulator is tightly clamped inside a cylindrical stainless steel housing, which also defines the ground plane. On the high voltage output end is a boron nitride sleeve (1.5 mm wall thickness), which is vacuum potted into place after the Teflon surface has been suitably etched. The minimum path length measured along the surface between metal structures in contact with the insulator is 50 mm.

The deflector electrode hanger is rigidly attached to the insulator through a stress relief collar that is threaded onto the high voltage electrode contacting the water resistor. The hanger is held in position on the shaft of the collar with set screws and has a position adjustment range of 5 mm. The radius of curvature of the collar edge overhanging the boron nitride sleeve is 1.5 mm. The largest calculated electric fields occur in this region. The use of boron nitride at this location is based on earlier development work[2] in which such a sleeve was used to overcome voltage limitations from insulator charging.

Access to the insulator for cleaning and other maintenance or adjustments is through a hatch in the bottom surface of the dee. The cable and Teflon tube are easily removed from the top.

Performance

The electrostatic deflector system is driven by a well regulated 100 kV, 1 mA dc power supply through a cable approximately 25 m long, 10% of this length being in the cyclotron. During initial operation deionized water was supplied from a large water system which services the whole accelerator facility. Water resistivity was typically about 5 MΩ•cm. Under these conditions the operation of the system was limited to 60 kV maximum voltage because leakage current in the water could exceed 1 mA. Through using various filters on the inlet line of the water header it was shown that the leakage current was dependent on water resistivity. With installation of a high purity water system dedicated to the deflector to increase resistivity the leakage current was reduced to ≈ 1 mA at 100 kV.

A dominant feature of the dependence of leakage current on voltage is that it is non-linear. At voltages below ≈ 25 kV and above ≈ 60 kV the dependence is approximately linear with equivalent resistances of 600 MΩ and 60 MΩ respectively for water resistivity ≈ 14 MΩ•cm. At lower values the equivalent resistances change inversely with water resistivity. It is planned to examine this behaviour in more detail later.

Evidence that 99% of the voltage set on the power supply is actually appearing on the deflector electrode is indirect. All of the beams extracted from the cyclotron have used electric fields that are close to the calculated values, and beam position responds to changes in voltage. It is planned to build a jig to measure output voltage from an identical water resistive divider directly to confirm that output voltage is as expected.

The deflector system has sustained damage when the rf system was inadvertently operated without water flowing for the deflector isolation resistor. Enough heat was generated to melt the cable dielectric. The coaxial insulator body was distorted and the boron nitride sleeve shattered. These latter events are believed to have happened in the same heating incident. However, the deflector was operated routinely, below 60 kV, for several months after this event and failed with onset of large leakage currents (not related to water quality) when the system was operated at 80 kV for a few days. Evidence of sparking on the coaxial insulator was confined to the region of the broken sleeve.

At present (1987 February) the cyclotron is shut down for maintenance and repairs. The coaxial insulator is being repaired. The high voltage power supply to drive the system is being upgraded to 125 kV, 4.8 mA.

Acknowledgment

It is a pleasure to acknowledge supporting effort from J.E. Anderchek, R.J. Kelly, D.G. Hewitt, J.F. Mouris and D.R. Proulx and the contributions of K.A. Dobbs during insulator development work.

References

1. C.B. Bigham, W.G. Davies, E.A. Heighway, J.D. Hepburn, C.R.J. Hoffmann, J.A. Hulbert, J.H. Ormrod and H.R. Schneider, Nucl. Instr. and Methods, A254, 237 (1987).
2. C.R. Hoffmann, Proceedings of the Ninth International Conference on Cyclotrons and their Applications, Les Editions de Physique, 497 (1981).
3. S.W. Mosco, private communication (1984).
4. C.R. Hoffmann, R.I. Kilborn, J.F. Mouris, D.R. Proulx and J.F. Weaver, IEEE Trans. Nucl. Sci., NS-32, 2986 (1985).
5. The high voltage cable is Belden No. 8870 manufactured by Belden Corporation.
6. Barnstead Nanopure System, Model D3798.