MODEL STUDY OF AN ELECTROSTATIC DEFLECTOR CONFIGURATION WITH AN INTERMEDIATE ELECTRODE

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ABSTRACT

As part of a development program for electrostatic deflectors in the Chalk River superconducting cyclotron, an alternative electrode configuration has been studied, which has a set of electrodes between the high-voltage electrode and sparking plates of the traditional deflector geometry. These intermediate electrodes are driven by an independent power supply at half the deflector voltage and have a series water resistor for isolation. They grade the potential between main electrode and sparking plates and reduce the maximum energy available to main electrode sparks occurring along the magnetic field lines. A model was built and tested in a modest magnetic field of 0.5 T.

1. INTRODUCTION

The first element in the extraction system for the Chalk River superconducting cyclotron[1] is an electrostatic deflector, located in one of four dees. The electrode configuration is the traditional one of a negative, high-voltage electrode and a grounded septum, which bound the extracted beam path in the midplane. A cross section of this configuration is shown schematically in Fig. 1(a). Above and below the high-voltage deflector electrode are sparking plates, to provide refractory surfaces that resist spark damage. Insulators off the midplane support the deflector electrode.[2] One of the insulators contains a column of high-resistivity flowing water that isolates a spark from the energy stored in the high-voltage cable and power supply,[3] and provides a source of cooling to the deflector electrode.[4] The present status and recent developments of this system are reported in a companion paper at this conference.[5] One of the remaining challenges in this system is to develop the deflector system to the point of reliable operation at voltages above 90 kV and apertures greater than 5 mm.

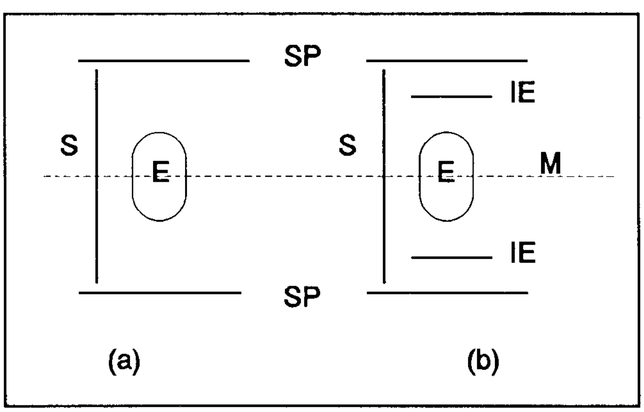

Fig. 1 Schematic of the deflector electrodes, (a) traditional arrangement, and (b) with intermediate electrodes (IE). E - deflector electrode; M - cyclotron midplane; S - septum; SP - sparking plates.

Work at Chalk River has followed several avenues in pursuit of better deflector performance. While development of the existing electrode design progressed, a study was undertaken to assess the potential reduction in deflector voltage requirements that could arise if magnetic elements following the deflector in the extraction path were altered to obtain more magnetic deflection of the beam.[6]

Also, other electrode geometries were investigated in the search for reliable, higher voltage operation. This paper reports work on a model study of an alternative electrode configuration illustrated schematically in Fig. 1(b). This configuration has electrodes placed at an intermediate position between the deflector electrode and the sparking plates of the conventional deflector configuration. This intermediate electrode system is described in the following sections along with the high-voltage system and insulators required; results are given for operation of a model in a 0.5 T magnetic field.

2. INTERMEDIATE ELECTRODE

As shown in Fig.1 the configuration studied here is basically the traditional deflector geometry, with a pair of planar electrodes added in the gaps between sparking plates and deflector electrode. These electrodes (IE) are held at a common potential that is half that of the main deflector electrode (E). The intermediate electrode segments divide the vertical space between deflector electrode and sparking plates in half. Consequently, the intermediate electrodes define the potential at their locations to be 50% of the original gap potential (between electrode E at 100% and a sparking plate SP), rather than about 75% without the electrodes, as predicted by two-dimensional electrostatic calculations. This grading of the gap potential significantly reduces the electric field on the deflector electrode, and presumably any resulting field emission of electrons. The intermediate electrodes are wide enough to have all of the magnetic shadow of the deflector electrode fall on them. (The magnetic shadow is defined by the magnetic field lines that pass through the deflector electrode.) Because the charged particles of a typical spark are confined by the magnetic field lines, the intermediate electrodes will intercept all sparks originating at the main deflector electrode, and as a result the maximum energy available to particles in the spark is limited to half of what it would be without the intermediate electrodes. This should lead to reduced sparking damage.

2.1. Intermediate Electrode Model Deflector

Figure 2 shows the cross section of the model. Cross-section dimensions are full size, but the model length is 20% of the deflector in the cyclotron. The metal components are stainless steel, and electrical surfaces are polished. The sparking plates (A) cover the pole tips of the magnet and are insulated from their surroundings with thin layers of Kapton. Each sparking plate is connected to ground through a 1 kΩ resistor, to monitor leakage current. The pole tips fit into the top and bottom surfaces of a vacuum chamber that enclose the model. The vertical gap between sparking plates is 76 mm. Insulator posts (B) are alumina (99.5%), coated with Cr_2O_3 for reduction of secondary electron emission.[7] Their length is 10 mm. The septum plate (D) is wide, to support the sparking plates against the magnet pole tips and vacuum chamber walls. The gaps between septum and intermediate electrodes are 5 mm, and the gap between septum and deflector electrode is 6 mm. The high-voltage connection to the intermediate electrode (E) is made on a metal post (G), which slips into a high-voltage termination. A high-voltage connection is made to the deflector electrode (E) at a hole in the end of the electrode. Insulator F is identical with insulator B, but has a length of 6 mm. The edges of the intermediate electrodes facing the septum have a 1.5 mm radius.

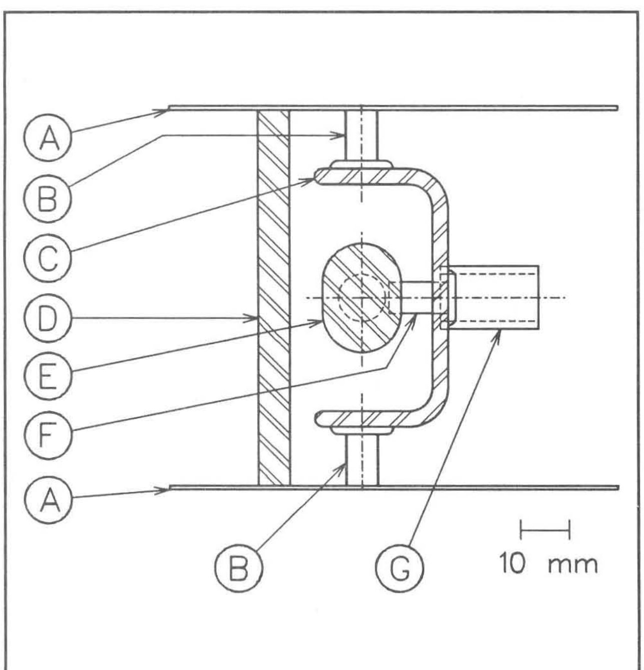

Fig. 2 Cross section of the model intermediate electrode. A - sparking plates; B - insulator; C - intermediate electrode; D - septum; E - deflector electrode; F - insulator; G - metal post.

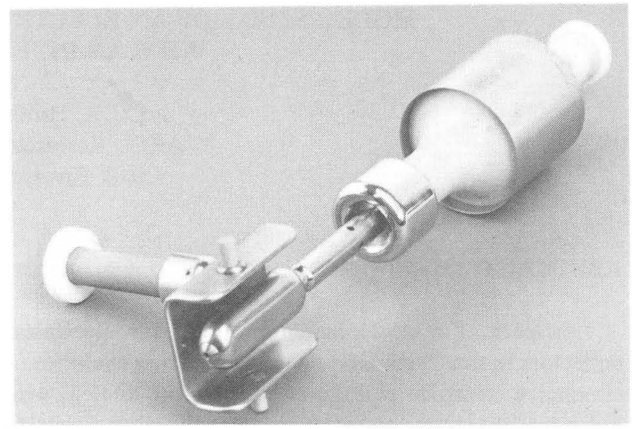

Fig. 3 Photograph of the intermediate electrode model.

Figure 3 is a photograph of the model and the feed insulators that provide high voltage to the electrodes. The electrode assembly fits between the poles of the magnet and the insulators fit into appropriate housings attached to the walls of the vacuum chamber. The chamber walls, sparking plates, and septum form the ground plane.

2.2. High-Voltage System

Figure 4 gives the basic electrical configuration. The

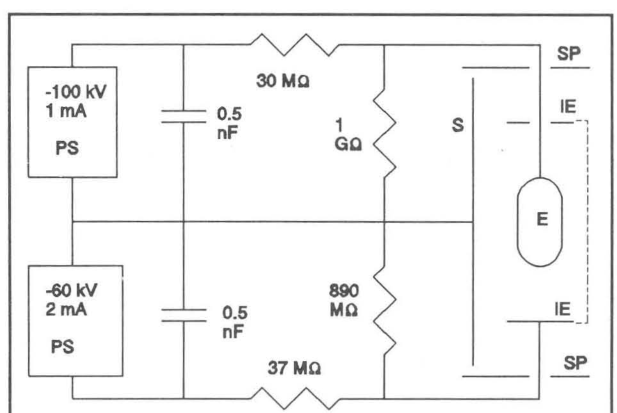

Fig. 4 Schematic of the system to supply high voltage to the model deflector electrode and the intermediate electrodes.

major features are the power supplies, the isolation resistors, and the electrode configuration. The power supplies are standard switching units with small energy storage. They are usually operated from a control module that maintains a two-to-one ratio between their output voltage settings, with the smaller voltage on the intermediate electrode. The resistors shown in Fig. 4 are formed in flowing water in the interior of the custom-designed insulators. The high-voltage feed insulator for the deflector electrode has been described previously.[2,3)]

2.3. Feed Insulator

High voltage to the intermediate electrode is supplied through the bore of an alumina (99.5%) insulator that contains a column of flowing, high-resistivity water. The insulator is 15.9 mm outside diameter and is 36 mm long between the cathode and anode terminations. Figure 5 displays the insulator cross section. It has similar water circuitry to the feed insulator used for the main deflector electrode. A Teflon sleeve (B), vacuum-epoxied to the alumina, separates the water from contact with the alumina and provides a barrier to possible water leaks if the alumina body should crack. One end of the sleeve has an electrode (C) sealed into it with an O-ring (D), and the other end of the sleeve has a flange to seal for vacuum and water. The outer surface of the alumina (F) is coated with a thin layer of Cr_2O_3, to reduce secondary emission of electrons near the cathode end (A) of the insulator.[7)] The high-voltage cable (L) is contained within a thin-walled Teflon tube (K), which in turn is within the insulator bore and the interior of a standard-size length of copper tubing (J) (inside diameter 7.9 mm; wall thickness 3.5 mm). Water flows to and from the insulator bore in the annular regions formed by the insulator/tubing, the Teflon tubing (inside diameter 6.7 mm and wall thickness 0.4 mm) and the high-voltage cable (dielectric diameter 6.0 mm). Tubing and cable of these dimensions is readily available commercially. The isolation resistor (E) formed between the end of the cable and the output voltage termination is 10 mm long. The whole insulator assembly is mounted on a flange (H) and sealed to the vacuum chamber wall (G). Three sets of O-rings (I) provide sealing. The metal post (G) in Fig. 2 fits into the end of terminal (A).

3. PERFORMANCE

Figure 6 gives the current-voltage characteristic for the isolation resistor in the intermediate electrode feed insulator. The water resistor performed reliably at the maximum voltage applied across it of -57 kV.

The intermediate electrode deflector model was installed in a small vacuum chamber inside the poles of a dc magnet. X-rays were monitored outside one of the chamber ports, and leakage currents were monitored for the sparking plates and the deflector electrode feed insulator surface. Also, the septum plate was isolated with Kapton and the current collected on it was measured. Current and voltage from the power supplies were measured with precision digital panel meters. The vacuum pressure was typically $1x10^{-4}$ Pa, and the resistivity of the water to the insulator isolation resistors was in the range of 12 to 14 MΩ•cm.

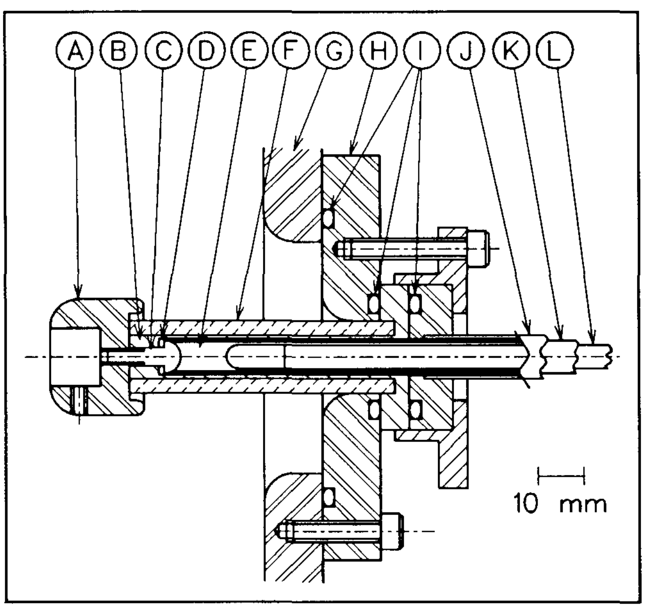

Fig. 5 Schematic of the high-voltage feed insulator for the intermediate electrodes.

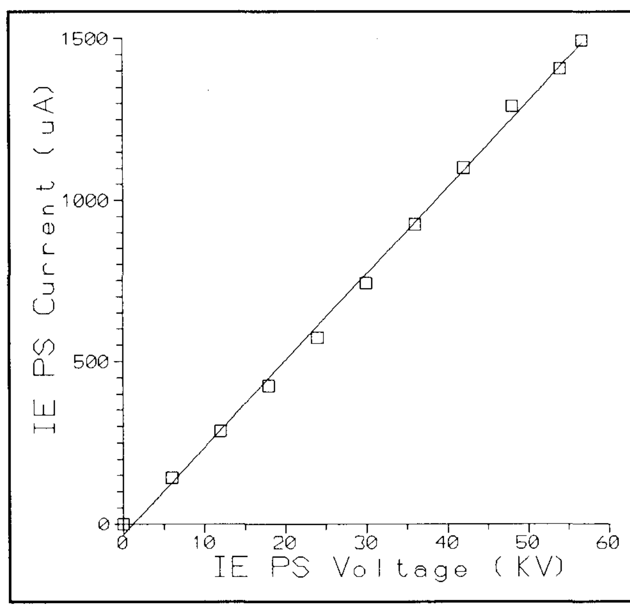

Fig. 6 Feed insulator characteristic for the intermediate electrodes.

Several variations of the configuration shown in Fig. 2 were studied. They include the electrodes with the support insulators (B), the electrodes with insulator (F), and the full configuration displayed in Fig. 2. Holes in the electrodes were filled as required with stainless steel inserts. Conditioning of these configurations to voltages of -100 kV on the main electrode and -50 kV on the intermediate electrode was straightforward, and was performed with the magnet off. With one exception discussed below, leakage currents to septum and sparking plates usually did not exceed a few microamperes during conditioning microdischarges, which were accompanied by X-ray emission. When the magnet was turned on, the septum leakage current was extinguished and X-ray emission ceased. Leakage current to the sparking plates increased, but subsequently decayed away to about 50 nA or less, which is consistent with the surface resistivity of the coatings on the insulator posts. The surface resistance on the insulator posts depends on the thickness of the Cr_2O_3 coating (which was not controlled), but is usually the order of 10^{11} Ω per square.

Attempts were made to measure the intermediate electrode voltage directly with a high-voltage resistive divider (total resistance of 2 GΩ). The presence of the divider invariably led to enhanced sparking that did not condition away. The divider could be connected to either the intermediate or deflector electrode through a port in the vacuum chamber, via a 4.5 metre length of high-voltage cable and appropriate fittings, with no isolation resistor at the electrode end. Sparks occurred inside the vacuum chamber and discharges in air occurred in a bushing near the top of the divider. This divider had been used previously in another system with a similar connection method without such breakdown, but with a connecting cable about 0.5 m long. The energy storage in the full-length divider cable is the order of 1 joule. It appears possible that the availability of this stored energy might influence the sparking behaviour.

The model deflector with an intermediate electrode operated satisfactorily in a 0.5 T magnetic field. Successful operation of the intermediate electrode feed insulator demonstrated a plausible system to provide another high-voltage source in the cyclotron dee with excellent isolation resistance essentially next to the electrodes. Such water isolation resistors of small physical dimensions have been used for about 7 years in the Chalk River superconducting cyclotron, and have been reliable.

The next step in this development is to test an intermediate electrode assembly in the cyclotron. The preferred configuration is the one with only the post insulators (F) in Fig. 2. It is believed that a rigid electrode assembly can be designed that can be supported in the same fashion as the existing deflector electrode in the cyclotron. The feed insulator would occupy the space of the existing support insulator. However, a second high-voltage input system to the deflector dee is required in a region where space constrains are severe.

4. ACKNOWLEDGEMENTS

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