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K-500 SUPERCONDUCTING CYCLOTRON DEFLECTOR HIGH VOLTAGE TESTS

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Summary

We report measurements of electrical properties of a compact electrostatic deflector and high voltage transmission line for the K-500 cyclotron. The voltage limits, sparking rates, dark current levels and the effects of conditioning are observed. The system supports the maximum required voltage and fits within the space available at the mid-plane of the superconducting magnet. Both stainless steel and titanium are suitable anode materials. A surge-limiting resistance between power supply and deflector greatly reduces spark damage to the anode surface.

Introduction

The extraction system of the K-500 superconducting cyclotron consists of two electrostatic deflectors, eight inert iron focusing bars, and two harmonic compensation bars. The final design features are the result of extensive calculations of the extraction beam dynamics.[1] The deflectors must support voltages as high as 94 kV. The connection to the power supply penetrates the cryostat at the median plane. We must therefore compromise between thermal insulation and electrical insulation when allocating space. These requirements lead to the present coaxial design of the transmission line ("feed thru") whose essential features are indicated in Fig. 1.

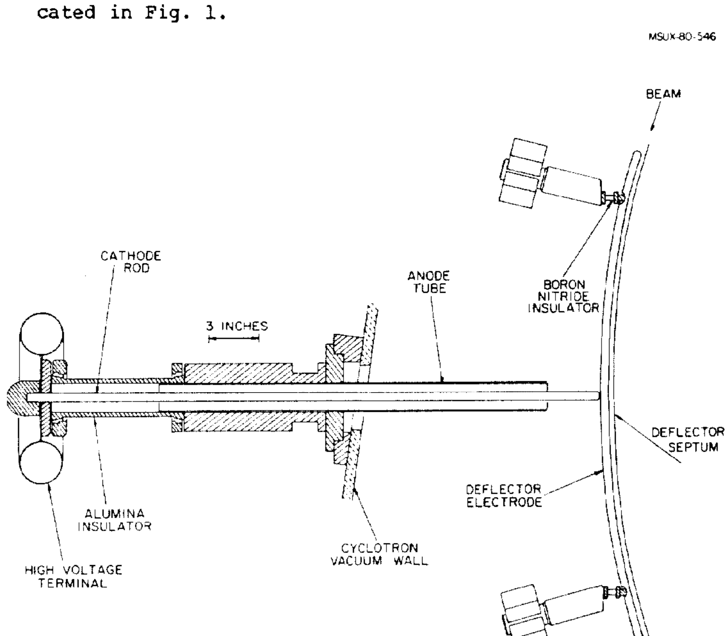

FIG. 1. The K-500 type high voltage feedthru supplies the existing 50 MeV cyclotron electrostatic deflector for feedthru high voltage testing. The center conductor length is 32 inches and will increase to 44 inches in the K-500 cyclotron. The deflector electrode is 29 inches long.

The feedthru is shown attached to the 50 MeV cyclotron deflector for tests. The center conductor and the attached deflector electrode are supported by the terminal nut at one end and the deflector insulators at the other. The anode is actually two concentric tubes, the inner a removeable spark liner.

The mechanical design of the K-500 deflector is in part fixed by the requirement that it be moveable. The deflector electrode and septum reside in a self-contained housing. The cross-section of a mock-up deflector, as assembled for tests in the 50 MeV cyclotron, is seen in Fig. 2. The electrode cross-section and clearances are identical to those planned for the K-500 cyclotron.

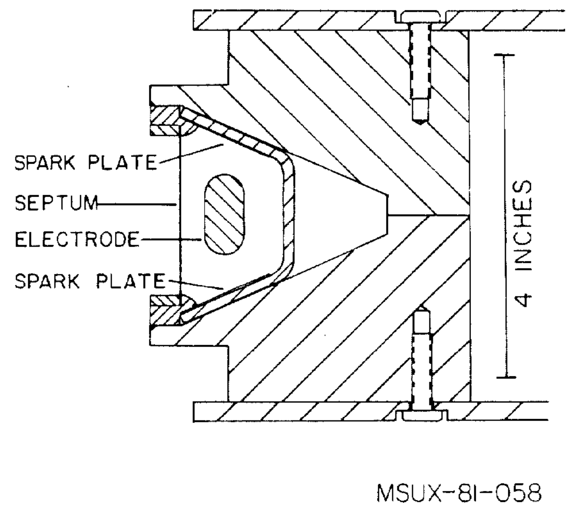

FIG. 2. Cross-section of the K-500 style electrostatic deflector model showing the electrode geometry. The deflector electrode and septum are 7 mm apart.

Apart from the smaller axial gaps, the K-500 deflector design is a straight-forward extension of the deflector that operated for many years in the 50 MeV cyclotron (same insulators, radial gap and electrode shape). Note that water-cooling of the deflector is not provided (to save space) and it is unnecessary according to this experience. The high voltage transmission line is improved by eliminating plastic and shielding the insulator from sparks. It must also be smaller in diameter to fit through the midplane of the coil, so the electric field becomes larger than in the deflector gap. At 94 kV, the maximum electric field in the deflector is 134 kV/cm, but in the feedthru it is 172.9 kV/cm, 22% higher. The 1.25 inch outside diameter of the anode liner represents the largest tube that leaves adequate clearance. After some experimentation with larger diameter anode tubes, the objectives were accomplished for two different anode materials in the required size: (1) 304 stainless steel and (2) titanium. In both cases, the cathode material was stainless steel.

Description of the High Voltage Experiments

The experiments described here were performed in the 50 MeV cyclotron without beam present. Air pressure in the vacuum chamber was maintained at 2×10^{-5} torr by a single oil diffusion pump. Since a magnetic field influences the behavior of the deflector during sparking, we did testing with and without the magnet on. The position of the deflector relative to the average magnetic field profile is shown in Fig. 3.

Prototype Deflector Tests

The 50 MeV cyclotron deflector was replaced by a mock-up K-500 deflector assembly. The external deflector terminal, power supply connections and controls were

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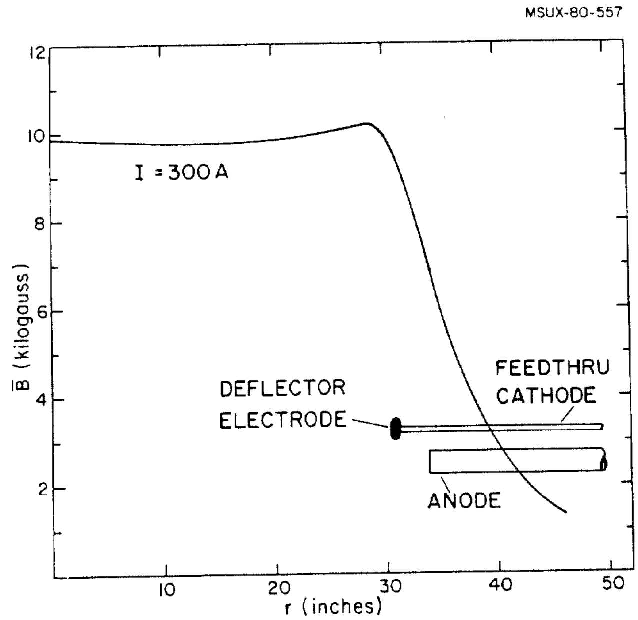

FIG. 3. Azimuthal average value of the axial magnetic field component for a 300A excitation of the 50 MeV cyclotron main coils. The deflector electrode and feedthru elements are shown relative to the fringe field.

not altered. The 100 kV voltage supply used the rf high-voltage technique. The stainless steel deflector electrode was set 7 mm from a 0.035 inch thick grounded tungsten septum. The removeable tungsten sparking plates were 0.035 inch thick.

High Voltage Feedthru Tests

The test circuit is shown in Fig. 4. A new 150 kV DC power supply was acquired for the tests and will be used to power one of the K-500 deflectors. The deflector capacitance was measured from the high voltage terminal to ground with the K-500 feedthru in place. The voltage divider leg permits an independent measurement of the voltage, and also allows deflector sparks to be viewed on a differential oscilloscope. The 1K resistor connected to the power supply ground return allows the

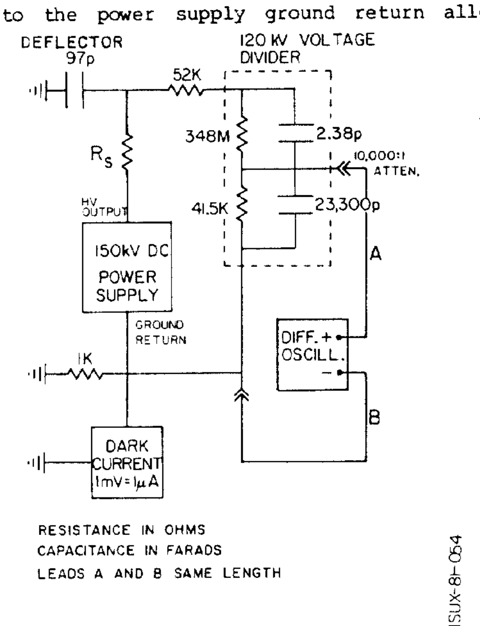

FIG. 4. Schematic diagram for the high voltage supply and monitor circuits employed in the feedthru tests.

deflector current to be measured directly. A large resistance R_S is placed in series between the power supply and the deflector. When a spark occurs this resistance reduces the energy initially dissipated in the deflector to that stored in the deflector capacitance by limiting the short circuit current. A large surge resistance was also reported by Paulin and Zoric to be beneficial in their work on the electrostatic elements for SIN.[2]

The feedthru cathode was fabricated from 0.5 inch diameter stainless steel rod and polished to a highly reflective finish. Titanium and stainless steel anode liners having an outside diameter of 1.25 inches were tested. The inside diameters were 1.177 and 1.180 inches respectively. The only treatment the liners received initially was cleaning with acetone and rinsing in distilled water. After some tests with the titanium anode we experimented with polishing the liner interior using a succession of finer aluminum oxide grits.

Hydrogen glow discharge conditioning of the deflector was also done routinely. The arc current was 0.15 A (rms) at 60 Hz, and the deflector potential was 300 V. The pressure of 0.3 torr was maintained by the mechanical roughing pump while hydrogen gas was continuously admitted through a needle valve.

High Voltage Characteristics

Prototype Deflector

The prototype deflector easily held voltages to 100 kV in an 18 kG magnetic field. The only significant sparking damage (spark pits) occurred in the anode part of the coaxial high voltage feedthru attached to the deflector enclosure.

High Voltage Feedthru

Some preliminary experiments were performed with feedthru anode diameters greater than 1.25 inches. There were two main results of this work. First, a working value for the surge resistance R_S was determined. Observations of spark duration on the differential oscilloscope showed that continuous arcing was suppressed when the surge resistance was increased from 487 kΩ to 1.1 MΩ. Second, the voltage holding ability of the deflector and deflector insulators was determined to be in excess of 114 kV. After confirming that several larger anode tubes could hold more than 100 kV we used only the 1.25 inch O.D. tubes mentioned above in subsequent tests.

The titanium liner was installed in the feedthru. Initially, the deflector was operated with the cyclotron magnet off. The sparking rate and dark current were unacceptably high at voltages up to 100 kV. The dark current grew to over 40 µA as the result of sparking. After several days at voltages above 90 kV, the dark current dropped to less than 1 µA and the sparking rate to a few per hour. In Fig. 5, the dark current voltage dependence is shown for this deflector arrangement during a sequence of tests. Curve (1) reflects the situation after the above-mentioned electrostatic conditioning. Such low dark current resulted in stable operation (steady voltage, few sparks). The sparks extinguished in less than 4 µsec and continuous arcing was never observed. The highest voltage attained at that time was 114.3 kV. This corresponded to a 163.3 kV/cm extraction field. After a period of operation above 100 kV, we found that the sparking rate at lower voltages was negligible. Once conditioned, low sparking rates were easily achieved after a short warm up period.

When the cyclotron magnet was turned on, the situation became suddenly worse. In curve (2) the dark current is plotted after the conditioned system was raised to high voltage in a 10 kG magnetic field. The

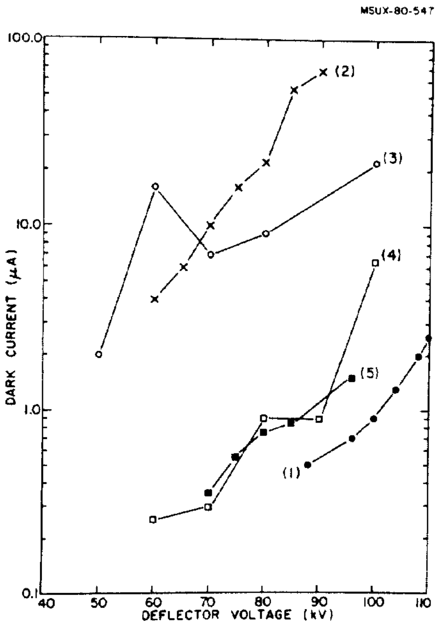

FIG. 5. The dark current for a 1.25 O.D. titanium anode installed in the K-500 feedthru (see text).

dark current at 90 kV was over 100 times larger than in curve (1). The sparking rate was typically a few sparks per minute for dark currents over 10 μA and increased as the dark current increased. Continuous arcing from the feedthru cathode to the inside surface of the anode at the end in the high magnetic field occurred when the voltage reached 100 kV. Disassembly revealed substantial pitting of the inside surface of the anode, along the top and bottom at the deflector end. Vaporized metal had condensed on the cathode at corresponding locations. There was no evidence of deleterious sparking on any other surface. So the high dark current in curve (2) must be attributed to the damaged anode. It was polished using a succession of aluminum oxide grits to remove the spark pits. The stainless steel cathode was buffed to remove the deposited metal. Curve (3) shows the dark current with the polished titanium liner in place. Substantial lowering of the dark current has occurred. After about 20 hours above 90 kV, the deflector conditioned down to curve (4). The deflector voltage was again raised in the 10 kG field but at 97 kV the continuous arcing returned. Sparks had sufficient energy to melt the titanium liner.

We then increased the surge resistance from 1.1 MΩ to 5.2 MΩ, which reduced the maximum short circuit current five-fold. Observations of deflector sparks then showed that once again their duration was 4 sec or less, and self-extinguishing. Since the dark current is subject to short term fluctuations of ±30% the highest dark current consistent with the desired voltage stability of ±15 V under these conditions is 10μA. Slow voltage adjustment to avoid sparks and increased circuit resistance were used to successfully condition the deflector to high voltage in the strong magnetic field. Curve (5) shows the dark current after 18 hours at voltages between 90 and 94 kV in the 10 kG magnetic field. Additional testing showed that the system could go as high as 100 kV without difficulty.

Tests of an all stainless steel feedthru were then performed. The new anode was cleaned as described above but received no special polishing treatment. The voltage was raised slowly to 85 kV and held there for 16 hours. The dark current conditioned to 1 μA with less than one spark per 10 minute interval. Eventually, the voltage was raised to 102.1 kV (see curve (1) of Fig. 6). After 40 hours of electrostatic conditioning, the deflector was raised from zero to 90.1 kV in 1.5 minutes in a 6 kG magnetic field, and held continuously above 90 kV for the next 4 days. Afterward, inspection showed no evidence of spark pitting in the feedthru. The final measured dark current for this system is shown in curve (2) of Fig. 6.

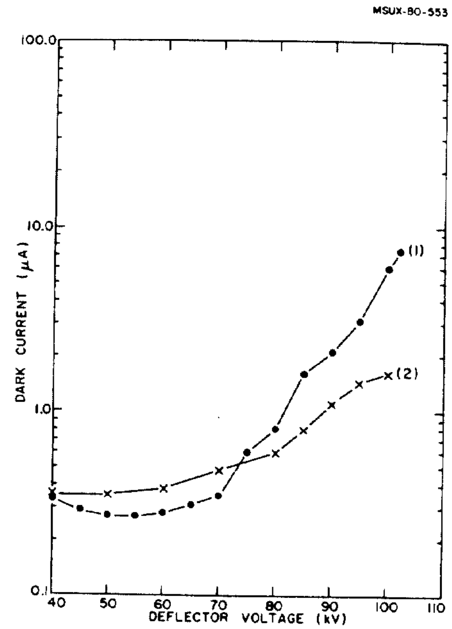

FIG. 6. The dark current for a 1.25 O.D. stainless steel anode installed in the K-500 feedthru (see text).

Conclusions

We conclude that the transmission line and the deflector will operate at the required maximum voltages. The 1.25 inch coaxial line provides a compact high voltage path through the cryostat without impressing an excessive heat load on the helium refrigerator. The transmission line and the deflector both possess good conditioning properties. (This was not true of the old feedthru system in the 50 MeV cyclotron). A 5 megohm surge resistance between the power supply and deflector protected the deflector from damage by continuous arcing; the system must be conditioned to have a dark current less than 10 μA to prevent unacceptable fluctuations in the deflector voltage. High dark current is correlated with a higher sparking rate as well. We conclude that a current monitor is an important element of the control system for the cyclotron. Low voltage, glow-discharge conditioning of the electrodes also improves the rate of subsequent conditioning with sparks at high voltage.

References

1. E. Fabrici, D. Johnson, F.G. Resmini, The Extraction System for the K-500 Cyclotron at MSU, MSUCP-33, June 1980.
2. A. Paulin and T. Zoric, Nucl. Instr. Methods 150 (1978) 369-376.