STATUS OF ELECTROSTATIC DEFLECTOR AT NSCL K1200 CYCLOTRON

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The NSCL K1200 cyclotron operates with partially overlapping turns at the extraction septum and beam loss of about 50% at extraction. We have improved the deflector's power dissipation and mechanical accuracy in pursuit of higher intensity for deflector-limited beams. The radial and vertical dimensions of the deflector are unusually compact to fit within the superconducting magnet. Improvements include adding water cooling to all segments (deflector is hinged), indirect cathode cooling via beryllium oxide support insulators, septum support and alignment and use of a leading edge notch to increase the radiating area. Experiments with a pyrolytic graphite septum show better power dissipation performance than with a tungsten septum, but with the maximum voltage somewhat reduced.

1 Introduction

At the NSCL we are attempting to increase the power handling ability of the deflectors, a necessity for the forthcoming Coupled Cyclotron mode of operation. Under the expected beam conditions, the septum will be required to dissipate at least 400 watts, a dissipation level, which was achieved recently. Here we present the important features of this deflector and a summary of its performance with respect to voltage and power.

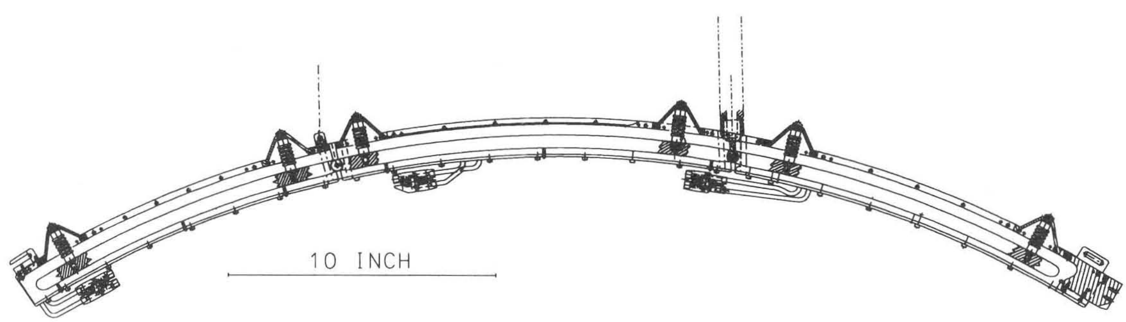

Figure 1: Plan View of E1 Deflector

2 Present System

There are two deflectors in the K1200 cyclotron, called E1 and E2 [1]. E1 is more strongly affected than E2 since the turns are not totally separated at extraction, whereas beam reaching E2 is already separated from the internal beam. Modifications and improvements efforts have been concentrated on E1, shown in Fig. 1.

E1 is approximately one meter long and is made in three segments to allow matching the shape to the different beam orbits. E2 is a single segment and is seventeen inches, or 43 centimeters, long. Since E2 dissipates negligible power in normal operation and is mechanically simpler than E1, we have had fewer problems with its operation. We have not been compelled by its performance to make improvements, and we shall not discuss E2 further in this report. We expect to eventually apply our developments to both deflectors.

The E1 deflector housings are now made of copper and are all water-cooled, a recent upgrade since until this year only the first segment was cooled. Both deflectors use anodized aluminum cathodes. The septum is clamped by aluminum strips to the top and bottom of the assembly. (See Fig. 2). The standard septum is made of sheet tungsten. The high voltage cathode is made of anodized aluminum. The three segments of E1 are held together by hinge pins in the ends of the cathode segments. The deflector is positioned by four motor driven push rods. One of them connects to the cathode and serves as the terminal to the cable for the power supply

2.1 Earlier Designs and Evolution Thereof

The original deflector design had no water cooling and the anode was made of stainless steel. Water was later added to cool the first segment, and the top and bottom plates of that segment were changed to copper. This design, called the Mark III, was in use for a number of years.

The cathode is cooled indirectly by means of heat conduction through beryllium oxide insulators. These insulators have tantalum buttons attached by brazing. (This is an upgrade from MACOR insulators in the original deflector, which had titanium buttons, bonded with glass

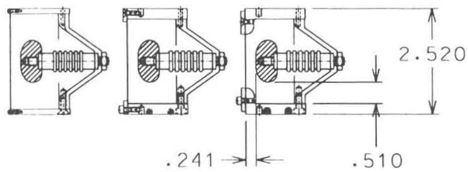

Figure 2: Left to right, cross sections of Mark III, IV and V deflectors. Sparking plates are Stainless Steel for Mark III and Copper for Mark IV and V. Note the water lines in the bases of Mark IV and Mark V. Dimensions are in inches.

powder.) We also have limited experience with aluminum nitride insulators, also with tantalum buttons, although we have run them only in the E2 deflector, which has no cooling. We have had some trouble with the aluminum nitride cracking.

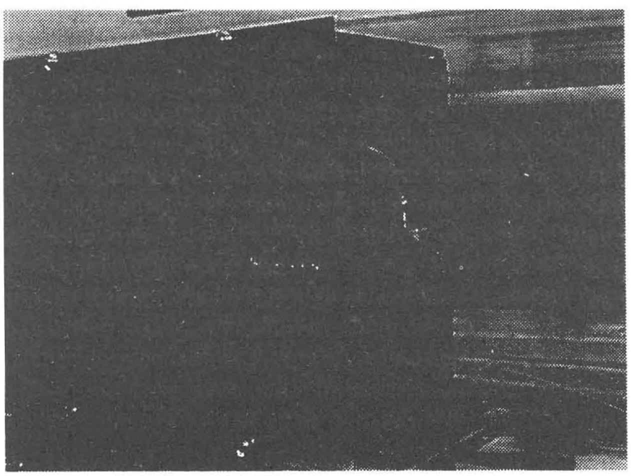

Figure 3: The Mark III design of the E1C segment, showing the septum clamped by screw heads. The slot in the middle was cut by beam.

We have given special attention to the smoothness of the joints between segments, to align the septa. Extraction efficiency has varied in the range 30% to 70%. We believe that misalignment of the septa in the past increased the effective septum thickness and reduced efficiency. Other factors that can reduce efficiency below the geometrical limit imposed by the seputm thickness are centering errors and finite emittance (including space charge effects) . Extraction efficiency improved when emittance was reduced at low intensity (approximately 50 enA), in general agreement with the results from a ray-tracing model of Blosser et. al. [2]. However, the benefit of reducing emittance of the injected beam was partly lost when the intensity was increased to about 300 enA. Efficiency of 70% has been obtained at high intensity when the beam was well centered.

In the original design (Mark III) the molybdenum septum was held in place by means of machine screws in keyhole shaped slots as shown in Fig. 3. This caused inaccuracy in the position of the septum over the length of the deflector. A version of the first segment was made, called the Mark IV, with aluminum strips clamping the septum in place. This gave a better shape to the septum than the slots, but there was still bowing of the septum at the ends. A further refinement was a version of the first segment with a vertically extended front face to provide more support for the septum, the Mark V. See Fig. 2. It provides vertical surfaces extending from the top and bottom so that the septum is narrower and has more support. The final step was to make the entire deflector in this shape. Now all three of the E1 segments use this system, and all three housings are water-cooled. A further refinement introduced clamping strips designed to leave the septum slightly loose. The idea is to allow the edges to move slightly when heated so as to minimize buckling.

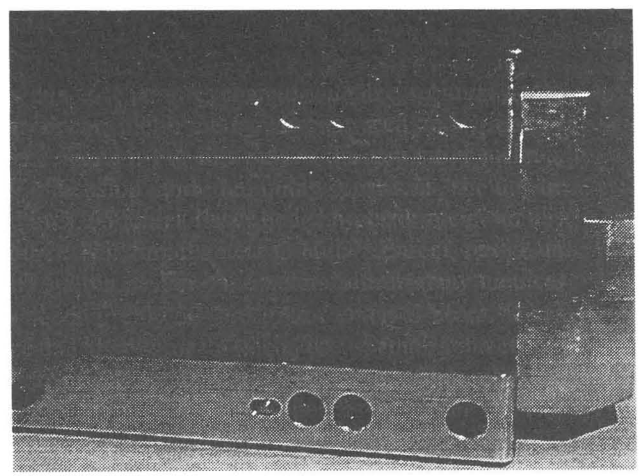

Figure 4: Photograph of the entrance to the present E1 deflector of Mark V design, shortly after removal from the cyclotron. The septum is 0.010 in. thick tungsten with a leading edge notch. This deflector was in use during the high power test in May 1998.

The key to successful operation at high power may well reside in the proper selection, preparation and usage of septum material. With the Mark V design we have been able to switch to tungsten for routine operation and we have tried pyrolytic graphite with limited success.

The power supply is a 100 kV, 1 mA supply made by Glassman High Voltage, Inc. The current limit is set to 0.1 mA. An external resistor is mounted in a pressurized tank. We recently changed its value from 50 megohm to 5 megohm to reduce voltage variations due to dark current.

There had been a problem with the high voltage cable insulation inside the high voltage feed-through melting when running intense beams. Presumably, heat transfer from the hot deflector cathode was sufficient to cause such melting, and occurred in spite of the water cooling of the housing. Two solutions were worked out and both are in use, one on each deflector. Air-cooling is used routinely on E2 with the air supplied from a pressurized resistor tank. Air bleeds along the center of the high voltage cable, from which the metal conductor has been removed, cooling the feed-through. Liquid cooling is in use on E1 where a supply of FC-77 Flourinert is pumped through the cable instead of air, and is cooled in an external cooling loop [3]. Both systems seem to work quite well.

3 Voltage Holding

Adequate voltage holding is critical for successful coupled cyclotron operation. We can presently operate at the maximum voltages needed at low beam intensities, and at low voltages we can raise the intensity considerably.

To suppress excessive or unstable dark current we find it beneficial to flow oxygen into the deflector at the rate of 0.1 to 1 sccm. When voltage holding is degraded due to intense beam, conditioning can often be quickly re-established by running the deflectors at the normal voltage for the beam and with the vacuum interlock bypassed. Approximately five to twenty sccm of oxygen is then allowed to flow into bad deflector for about fifteen minutes. This technique frequently effects a rapid cure.

Conditioning of deflectors is an ongoing proposition. Maintenance periods and beam change times are utilized to improve conditioning, a process facilitated by our deflector conditioning software. Voltage holding will degrade over time, especially during runs with intense beam. Conditioning is usually done with the power supply current limit set at 100 micro-amps, the same set point used during routine operation. One method of conditioning is to set the voltage at a level where the current is high and wait for the current to decrease. After the decrease, the voltage is raised a small amount, such as 1 kV, and the process continues. The other method is to let the computer ramp the voltage up until a software current limit is exceeded, at which point the voltage is lowered a given percentage and ramped again.

4 Power Dissipation Performance

The standard septum thickness was 0.010 inches. We tested 0.005 inch thick septa made of molybdenum and of tungsten in the cyclotron. The special problems with those deflectors were (1) extra bowing at the ends, and (2) permanent deformation in areas heated by the beam, e.g. the septum buckled. These problems were attributed to the reduced stiffness of the thinner material. We also did not observe any increase in extraction efficiency. One likely reason was that the extraction efficiency may have been limited by the radial and axial emittance. Another important factor was the alignment of the three sections of the deflector. We expect that further gains in performance may be possible using a thinner septum once higher extraction efficiency (>70%) is obtained consistently.

To a good approximation the only important cooling mechanism for the metal septum is radiation; conduction of heat through the thin sheet to the edge support is negligible. The area heated by the beam should be made as large as possible. For this purpose the notch in the leading edge of the septum is a great benefit for tungsten and molybdenum, where the range of particles such as Ne and Ar is a few mm. The effective area for radiation is increased by diffusion of heat beyond the region where the particles dissipate energy. Taking this into account, the notch increases the effective area for radiation by a factor of 5 in tungsten.

The power dissipation in a pyrolytic graphite septum should be very favorable because (1) its low density increases the area radiating, (2) its thermal conductivity is much greater than that of the metals. Therefore, both conduction and radiation can contribute to cooling. We have operated the cyclotron with pyrolytic graphite septa in 3 configurations: a "pre-septum" strip 1 inch wide followed by a normal tungsten septum in the rest of the deflector, a complete graphite septum in the first segment of the deflector, and graphite in all three segments. The first two configurations (pre-septum and first segment septum) in graphite were run for several weeks with normal physics program beams. The graphite was not damaged by heating with the beam in any of these tests, even though there was no notch used in the leading edge to enhance power dissipation. The septum dissipated more than 200 W in beam tests. The one drawback was that the presence of graphite seemed to increase the dark current of the deflector and degraded the maximum voltage capability. This effect was smallest with the small pre-septum and greatest with the full graphite septum (actually it was not usable in that case for the beams scheduled for nuclear science experiments). For this reason alone we must, at the present time, rely on the tungsten septum for routine operation.

We have tested the septum shown in Fig. 4 at 390 W beam power dissipated in steady state and briefly at 540 W, near the onset of thermo-mechanical instability. The beam conditions were $^{20}Ne^{6+}$ at 90 MeV/nucleon, internal beam current 2.8 μA, extracted beam 1.5 μA. The deflector voltage was 53 kV, and the gap was 6 mm.

5 Conclusions

The latest version of the deflector, fitted with a notched tungsten septum, can operate at 400 watt of dissipation power and 88 kV/cm.

The extraction efficiency is improved by precise centering of the orbits and by reducing the emittance.

Use of a pyrolytic graphite septum causes increased dark current and reduces the maximum voltage that can be used.

Acknowledgement

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References

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