ELECTROSTATIC SEPTUM FOR KILOWATT HEAVY ION BEAMS

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Abstract

A septum of improved design has replaced the standard tungsten septum with uniform thickness used in the deflector for the K1200 cyclotron at Michigan State University.[1] A V-notch in the leading edge enhanced radiation cooling, and an increased septum thickness away from the median plane enhanced conduction of heat to the water cooled housing. Previously observed degradation of beam transmission attributed to thermally induced deformation of the septum was greatly improved with the new septum. The demonstrated power dissipation with an Ar beam was 900 W.

1 INTRODUCTION

The improvements in design of the electrostatic deflector E1 in the K1200 cyclotron and its performance are reported here. The superconducting cyclotrons at Michigan State University have been coupled together in tandem as part of a five year upgrade project ending in 2001. The K500 cyclotron injects the beam into the K1200, which boosts the energy approximately a factor of 10. The system is capable of accelerating elements with atomic number Z>7 to final energies in the range 50 to 200 MeV/u. The maximum beam power will be >4 kW for some Ar beams. The capability of the septum to dissipate approximately 1 kW has been demonstrated with a beam, specifically 100 MeV/u Ar particles, and with electric field of 100 kV/cm.

2 DESIGN OF THE DEFLECTOR

2.1 Mechanical

A photograph of the assembled deflector on the bench is seen in Fig. 1. Its length is 1 meter.

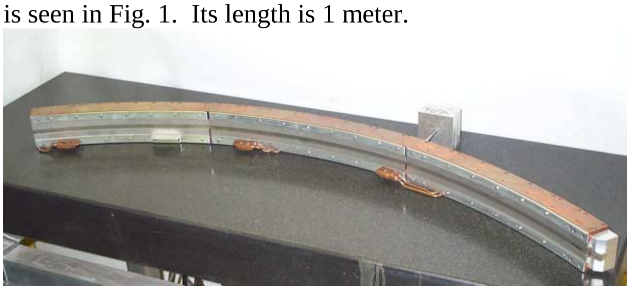

Figure 1: A photograph showing the entire K1200 E1 deflector.

The device is divided into three parts, hinged together at the joints in the cathode. This gives the necessary flexibility to approximate the varying shape of the orbit of particles with different rigidities. A cross sectional view, showing the cathode and the tungsten septum, is in Fig. 2. The required electric field in the 6 mm working gap varies, up to a maximum of 130 kV/cm. The relatively small cross sectional area of the deflector is determined by the location of the cryostat wall for the superconducting magnet.

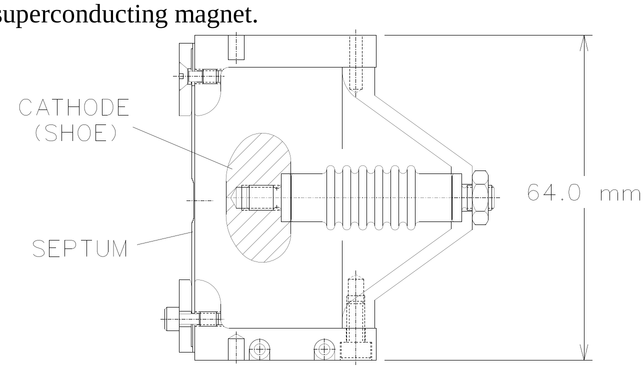

Figure 2: A cross section of the K1200 E1 deflector. Note the narrow section in the center of the septum.

Water-cooling lines can be seen at the bottom. The insulators are made of beryllium oxide with tantalum ends.

The cathode is machined from aluminum bar. It is hard anodized to a thickness of 0.05 mm. Due to the necessity for hinges it is not possible to cool the cathode directly. A water cooling loop is installed in the lower plate of the copper deflector housing. The cathode is cooled by conduction of heat through the BeO support insulators (2 per section) to the housing. The cathode is protected by a aluminum beam stop (part of the housing) just upstream to prevent a mis-tuned beam from impacting the end of the cathode. Heating of the cathode by stray beam is expected to be minimal. There is considerable beam power dissipated in the leading edge of the septum, some of which is radiated to the cathode. The above-mentioned beam stop also intercepts some of the thermal radiation from the septum, preventing it from reaching the cathode. The temperature of the cathode for a given assumed input power can be estimated from the following data.

Thermal power (one insulator)	25 W	(assumed)
Insulator assembly		
conduction coefficient	0.18 W/K	(measured)
delta T	139 C	
Copper housing		
conduction coefficient	1.44 W/K	(calculated)
delta T	17 C	
Temperature of housing back wall	190 C	(estimated)
Temperature of cathode	346 C	

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference*, edited by F. Marti

Since there are two insulators cooling each section of the cathode the input power is 50 W for the given cathode temperature.

2.2 Septum cooling considerations

The septum should be as thin as possible to minimize the beam flux intercepted. The extracted turn is not completely separated from the turn before it, so some beam loss on the septum is inevitable. The intercepted particles are lost from the beam after passing through even 0.1 mm of tungsten because of the high dE/dx, corresponding to a short range, typically 2.35 mm in tantalum for 150 MeV/u ^{40}Ar [2]. We have had the best performance so far using a septum thickness of 0.25 mm. Such a thin septum does not conduct heat very far. The beam makes a small hot spot on the leading edge of the septum. The high temperature produces stress in the septum which, above some limit, could cause a runaway mechanical deformation. (The septum becomes wavy, intercepts more beam, deforms further, etc.) This instability is opposed by making the temperature lower and by supporting the septum more rigidly.

To lower the operating temperature at a given input power the leading edge of the septum is cut out in a narrow V-shape notch where the beam will hit it. This increases the radiating area in proportion to the length of the notch. We have used a notch 1.6 inches (41 mm) long, which remains mostly out of the region containing the electric field. The gain in radiating area is approximately 11 as compared to no notch. We have tested a deflector with the notch positioned directly opposite the cathode and found no degradation of voltage holding ability, compared to a continuous septum without a notch.

The present design has a greater septum thickness (0.63 mm) except for a small band, approximately 10 mm wide, centered around the median plane, where the thickness is 0.25 mm. This profile results in a more stable septum position under varying power levels and has the added benefit of significant conduction cooling of the hot spot through the thicker portions

2.3 Septum materials

The short range of the particles means that the heat from the beam lost in the septum is generated in an area on the order of 1 cm^2. This heat must be dissipated by radiation and conduction. The best performing septum material we found was tungsten. We tried septums made of pyrolytic graphite in various configurations to try to exploit the theoretical advantages of that material: (1) low density, which implies longer particle range and lower power density; (2) excellent thermal conductivity; and (3) low residual radioactivation. The maximum working temperature of graphite is lower than for tungsten, but, in principle, that could be offset by its higher thermal conductivity. The problem that forced us to abandon graphite was inability to hold enough voltage on the cathode. We coated some graphite septums with a thin metal layer deposited by vacuum evaporation on each side to see if that would improve the maximum voltage. The results were still unacceptable. We also tried molybdenum septums, which performed somewhat less well than tungsten.

2.4 Power supply connection

The electrical circuit is shown schematically in Fig. 3. The power supply is a voltage regulated 0 to 100 kV power supply (Glassman High Voltage Inc. PS/WR100N2.5Y36) with automatic crossover current limiting, normally set at 100 μA. The 5 MΩ surge limiting resistor is housed in a tank pressurized with air at 2 bar gauge pressure and able to support 100 kV. The resistor is mounted at the cyclotron and connects to the deflector with a 2 m long coaxial cable rated for 100 kV (Dielectric Sciences 2125). The cable enters the deflector through a stainless steel tube terminated with a specially designed feed-through insulator having a terminal to take the voltage into the cyclotron vacuum at its end. A pin in this terminal serves as the hinge pin for joining two sections of the cathode. The feed-through tube and insulator assembly serves also as a pushrod for positioning the deflector. See Fig. 4.

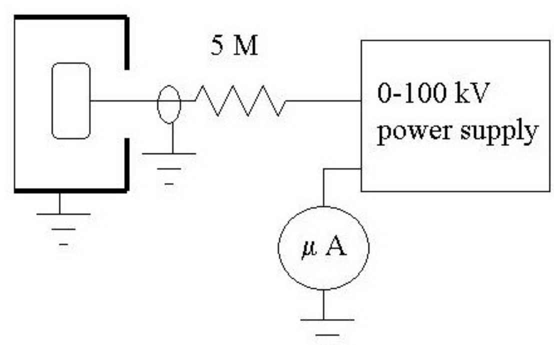

Figure 3: Electrical schematic diagram

3 PERFORMANCE IN THE K1200 CYCLOTRON

The E1 deflector was fitted with the stepped-thickness septum in just the first section (one third of the length) and installed in the cyclotron. The remaining sections were fitted with a septum of uniform thickness= 0.25 mm. At an internal beam power of 560 W and extraction efficiency of 60% the power of the beam lost was about 200 W. The septum began to glow at the beginning of the second section, i.e. on the thin, uniform thickness material. There was no thermal radiation visible on the television from the leading edge of the stepped thickness septum. This test caused the thin septum to become warped permanently, but there was no damage to the stepped one.

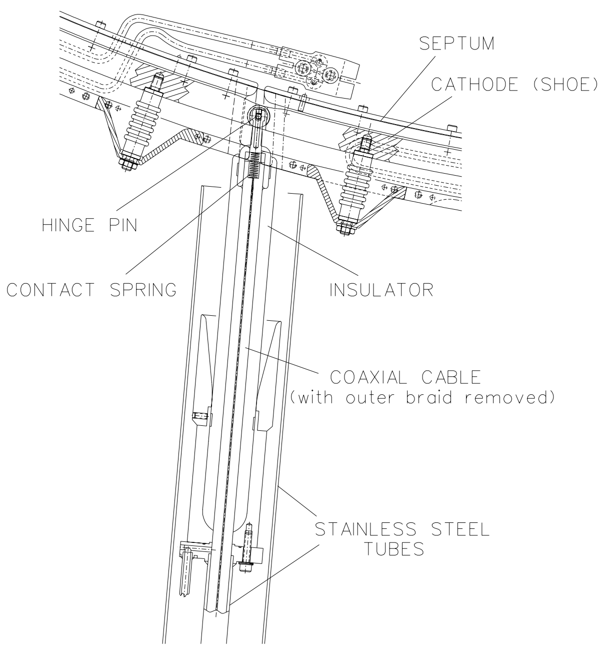

Figure 4: A top view of part of the K1200 E1 deflector showing the high voltage feedthrough and the joint of the first two segments. The tip of the feedthrough provides a pivot to which the two high voltage electrodes attach. The high voltage cable extends into the metal termination and is air-cooled through the central channel from which the copper has been removed.

In the next test, all three sections of the septum were the new style. A 1000 W internal beam of ^{40}Ar was accelerated to 100 MeV/u and approximately 70% was extracted, as recorded by the trace of beam current measured by a probe vs. the radius, seen in Fig. 5. At these conditions the beam was stable and there was no glow from the septum. To increase the power dissipated the deflector was tilted by repositioning a radial drive motor to make more beam hit the septum. A light glow was observed when the dissipated power was 900 W. After this test the deflector was not damaged and continued to function efficiently. The deflector temperature (back of the housing) reached a maximum value of 190 degrees C.

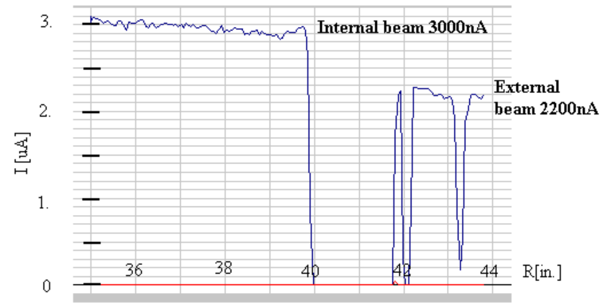

Figure 5: Probe trace for showing internal and extracted $^{40}Ar^{12+}$ beam intensity.

The stepped thickness tungsten septum gives the deflector a substantially (4 x) higher beam power capability than the previous version. This capability will allow the cyclotrons to produce multi-kilowatt beams as these are developed and the necessary beam diagnostics to support high power operation are commissioned.

4 ACKNOWLEDGEMENT

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