THE ELECTROSTATIC EXTRACTOR CHANNEL FOR THE S.I.N. 590 MeV RING CYCLOTRON

M. Olivo,

S.I.N., Swiss Institute for Nuclear Research, 5234 Villigen, Switzerland

Abstract

The extraction system for the S.I.N. ring cyclotron consists of an electrostatic extractor channel (EEC), a combined quadrupole and dipole channel, and an extraction septum magnet. In this paper, the characteristics of the EEC are discussed and results after one year of operation in the ring accelerator are presented.

The EEC consists of a straight, 1 meter long, 13 mm gap, channel. The aluminium anti-septum is held at a nominal negative potential of 80 kV. The special feature of this channel is its very thin, radiation cooled, septum electrode made out of spring-loaded molybdenum strips 50 μm thick. Its past behaviour in the ring with a 590 MeV proton beam of up to 30 μA enables us to predict a trouble-free operation at the 100 μA level and an extraction efficiency of more than 96 %.

I. Introduction

An Electrostatic Extractor Channel (EEC) is used as the first element in the extraction system of the S.I.N. 590 MeV, 100 μA proton ring cyclotron[1]. The EEC is located in a free section of the ring accelerator between two sector magnets and can produce a separation of more than 7 mm between internal and extracted beams 45° downstream, enough to clear the wall of the Focusing Magnet (FM). This element, a quadrupole-dipole channel, compensates for the radial defocusing effect arising because the extracted beam path lies in a region where the main field begins to fall off. The beam is finally extracted from the machine vacuum chamber 45° further downstream by means of an Extraction "window-frame" Magnet (AHA). A separation of about 25 mm is achieved at this point by the combined effect of the EEC and FM, sufficient to clear the 20 mm thick septum coil. The extracted beam is bent past the return yoke of the main sector magnet and then guided to the experimental hall.

During the design stage of the EEC, the goal was to find a device which would simultaneously extract an internal 100 μA beam, have high extraction efficiency, be easy to service or replace and have high reliability. Of course, these characteristics are to some extent interconnected. A high extraction efficiency implies low heat absorption, leading to more reliable functioning, and low activation, leading to easier servicing of the device. It should be emphasized that a few per cent losses in the extraction system would, in most cases, be of no importance to the beam users, while that same amount could have a drastic effect in the life of the septum and on the activation of the machine and beam transport components.

II. Design Considerations

The beam losses in the extraction channel can, to a good approximation, be expressed by the following simple formula[2]:

$$\text{Beam loss} \lessdot \delta eff/(dR/dn), \quad \delta eff = \delta o+\delta s+\delta g$$

δo = physical thickness of septum wall entrance;

δs = shadow thickness (i.e., thickness which takes into account particles hitting the channel walls);

δg = thickness due to geometrical misalignment and fabrication errors.

For a given radial gain per turn, dR/dn, and radial beam amplitude, Xo, the losses in the extractor channel are determined by the effective thickness δeff.

It is worthwhile to discuss qualitatively the function of each term comprising δeff. The δo term accounts for the head-on collisions with septum leading edge. The shadow thickness δs arises from the fact that the beam has a finite radial emittance; therefore, no matter how carefully the septum shape is chosen, there will always be particles hitting the walls of the channel (we assume here Xo>dR/dn as is presently the case in the ring cyclotron). By using sophisticated shapes, one can reduce this thickness to a minimum; however, complicated septum shapes will tend to increase the fabrication errors, δg. It is clear that by reducing the length and increasing the gap of the extractor channel one can reduce further the losses due to shadow thickness. However, the above procedure requires higher voltages, for a given bending power, leading to a less reliable operation of the device.

The power per unit length dissipated by the beam in the septum electrode may also be predicted qualitatively. Dissipation is expected to be large at the entrance of the extractor channel due to the head-on collisions with the edge of the septum. It should then decrease rapidly along the septum since the particles scatter out of the thin septum material after travelling a short distance.

Proc. 7th Int. Conf. on Cyclotrons and their Applications (Birkhäuser, Basel, 1975), p. 292-296

It should be pointed out that below a certain septum thickness, the losses in the extractor channel can be mostly determined by the shadow and geometrical thicknesses. However, the use of very thin septums results in a lower temperature at the leading edge since cooling is predominatly due to radiation.

In order to study quantitatively the behaviour of the EEC for the S.I.N. ring cyclotron, a computer program using Monte Carlo techniques to simulate the internal beam and scattering events[3] can be used to follow individual particles throughout the extractor channel. One can then determine the extraction efficiency as well as the dissipated power distribution along the channel and fate of the scattered particles for different geometries and orientations of the extractor channel.

In our case, the extractor was to be located in a low magnetic field; moreover, the maximum deflection needed was in the mrad range. We were, therefore, able to consider a straight septum with the following advantages:

1) possibility of mounting very thin foils;

2) minimal fabrication errors;

3) simple construction and low cost.

The extractor has to produce a minimum beam deflection angle of 6 mrad at the extraction energy of 590 MeV. With the effective length of the channel fixed for practical reasons, to a maximum of 1000 mm, the electric field needed is 60 kV/cm.

Monte Carlo calculations on extraction efficiency and power distribution of the final EEC design[4] for a 100 μA internal beam and 50 μm thick molybdenum septum gave the following results:

- extraction efficiency ≃ 97 %
- temperature at the leading edge of septum ≃ 1200 °C

The 3 % loss is distributed as follows:

- internal beam colliding with septum wall = 1.3 %
- head-on collision with leading edge of septum = 0.9 %
- extracted beam colliding with septum wall = 0.8 %

With the chosen length and a gap of 13 mm, no beam was found to collide with the antiseptum electrode. This gap establishes an operating voltage of 78 kV giving a comfortably low $\varepsilon \cdot V$ value of 0.47×10^4 kV^2/cm.

Figure 1 shows the calculated power and temperature distribution in the first 35 mm along the septum foil. Figure 2 shows the calculated energy distribution of the extracted beam.

The Monte Carlo method also tells us the fate of the scattered particles. Our results show that it is possible to build, inside the accelerator, collimators to stop those particles and concentrate the activation in localized places[5,6].

III. Construction

What follows is the description of the improved version of an earlier design of the EEC[7]. This improved version has been in operation in the ring cyclotron since May 1975.

The supporting structure for the septum and antiseptum of the extractor channel is shown schematically in Fig. 3. The 1000 mm long, mirror finished, mechanically polished, aluminium (Al-MgSi1) cathode is supported by four solid BeO insulators.

The septum is made out of 129 molybdenum strips, 50 μm thick, 7 mm wide, spaced 1 mm apart. They are individually spring-loaded to ∿ 40 Kg/mm^2. To ease the power dissipation load at the entrance of the septum, two tungsten strips, 30 μm thick and 3 mm wide, were mounted in front of the Mo strips.

The EEC frame has a "C" structure similar to that previously put in operation in the CERN PS. The advantage of this type of structure is that very thin septa can be mounted with a flatness irregularity of less than ± 0.02 mm. Contrary to the CERN case, we were forced to place the high voltage electrode inside the "C" structure. This scheme proved to be very successful with the additional advantage of having a reasonably high electric field throughout the entire volume. Charged particles are rapidly swept to either electrode, thus decreasing the probability of collisions with the residual gas.

The high voltage arrangement, as it is presently used at S.I.N., is shown schematically in Fig. 4. The power supply can either be voltage or current regulated. The latter mode of operation is very convenient during the conditioning process.

The extractor is tested and conditioned in a laboratory vacuum chamber prior to its installation in the ring accelerator. Typical conditioning time for new electrodes to reach 100 kV is about 4 hours at a conditioning current of about 30 μA. If the ring is opened to air and pumped down again, it takes only a few minutes for a previously conditioned EEC to reach 100 kV again.

The EEC has already been in operation for several hundred hours, extracting proton beam currents of up to 30 μA from the ring cyclotron. Figure 5 shows a radiograph taken during machine service. The blackening at the entrance of the channel corresponds to an activation level of 1.2 krad/h.

Servicing of the EEC is easily done. The "C" structure can be demounted from the driving mechanism with the removal of 4 screws. Furthermore, the highly activated material is found only at the entrance of the septum. The removal of the small number of activated strips can be accomplished in a few seconds. Figures 6, 7 and 8 show different views of the EEC.

IV. Conclusions

A beam transmission through the ring cyclotron of more than 95 % has been measured. With the aid of a TV camera, the entrance of the extractor channel has been monitored during a run with a 25 µA beam. No visible light was observed coming from the entrance strips. The sparking rate of the EEC was very small (a fraction of a spark per hour) and unaffected by the presence of the beam.

Based on these results, it is possible to expect trouble-free operation of the EEC with beam currents of 100 µA.

Acknowledgements

It is a pleasure to acknowledge many fruitful discussions with W. Joho, U. Schryber and H. Willax. The author acknowledges the excellent work of E. Aebli, A. Boss, G. Irminger and E. Mariani. Finally, the author would like to thank J. Collins for the careful reading of the manuscript.

References

1. M. Olivo,
Proceedings of this conference.

2. W. Joho,
Proc. 5th Int. Cyclotron Conf. (Oxford, 1969), p. 159.

3. G.E. Tripard and W. Joho,
Nucl. Instr. and Meth. 79(1970)293.

4. M. Olivo,
S.I.N. - Annual Report 1971, p. 63.

5. E. Wagner,
S.I.N. - Internal Report TM-10-05.

6. J. Duvoisin,
S.I.N. - Internal Report TM-10-24.

7. M. Olivo,
S.I.N. - Annual Reports 1972, p. 43; 1973, p. 26 and 1974, p. 23.

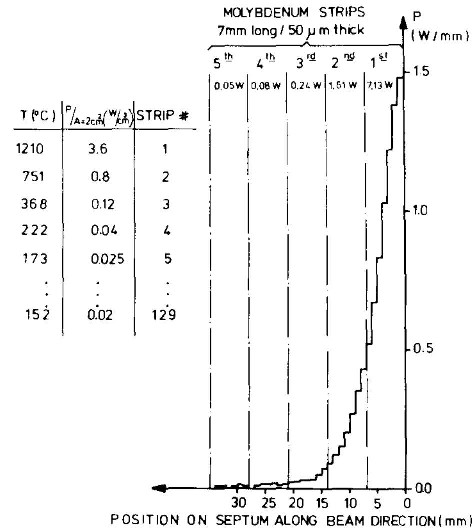

Fig. 1

Calculated power distribution in the first 35 mm of septum for a 100 µA internal beam. In the calculations, cells of 0.1 mm were considered and grouped afterwards in cells of 1 mm as shown in this figure. The septum electrode was finally built out of strips 7 mm wide. The table shows the expected temperature in each strip assuming a total radiating area of 2 cm^2. The power distribution throughout the rest of the septum is approximately constant. The Monte Carlo program followed the history of 50,000 particles.

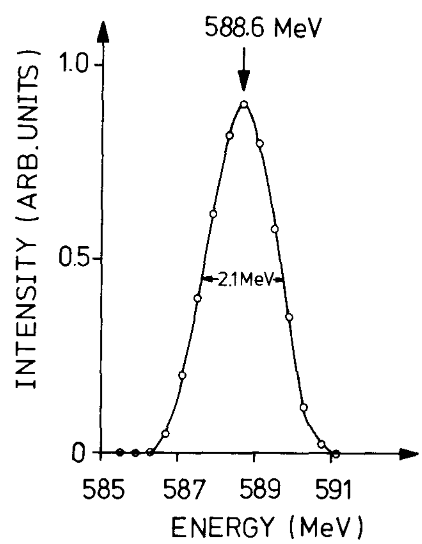

Fig. 2

Calculated energy distribution of the extracted beam for a continuous energy distribution of the internal beam at the extractor region. The septum entrance (θ = 342°) was positioned for this calculation at radius 4381 mm[1].

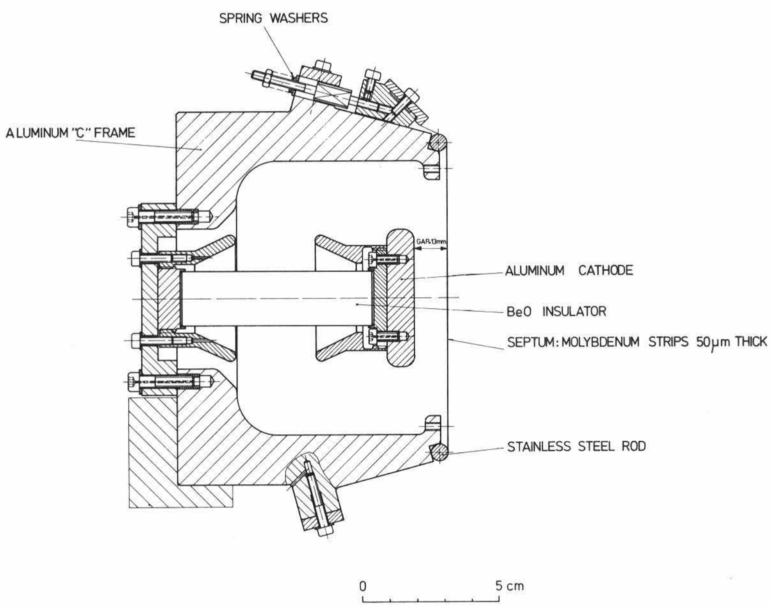

Fig. 3

Cross-sectional view of the EEC "C" frame. The stainless steel rods define a flatness for the septum strips of ± 0.02 mm. The Al "C" structure is supported by the angle shown at the lower left of the figure. This angle is attached to a positioning system and provides indirect cooling to the "C" structure.

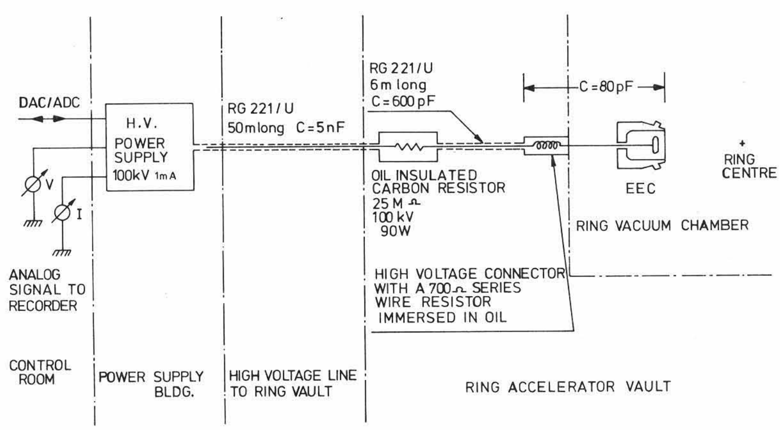

Fig. 4

High voltage supply schema presently used for the EEC. A 700 Ω wire resistor was placed inside the H.V. vacuum feed-through connector to partially decouple the EEC from the remaining capacitances. During tests without this resistor, a spark damaged both the cathode and some Mo strips. The addition of this resistor gave excellent results with voltages of up to 130 kV (the limit of a laboratory power supply).

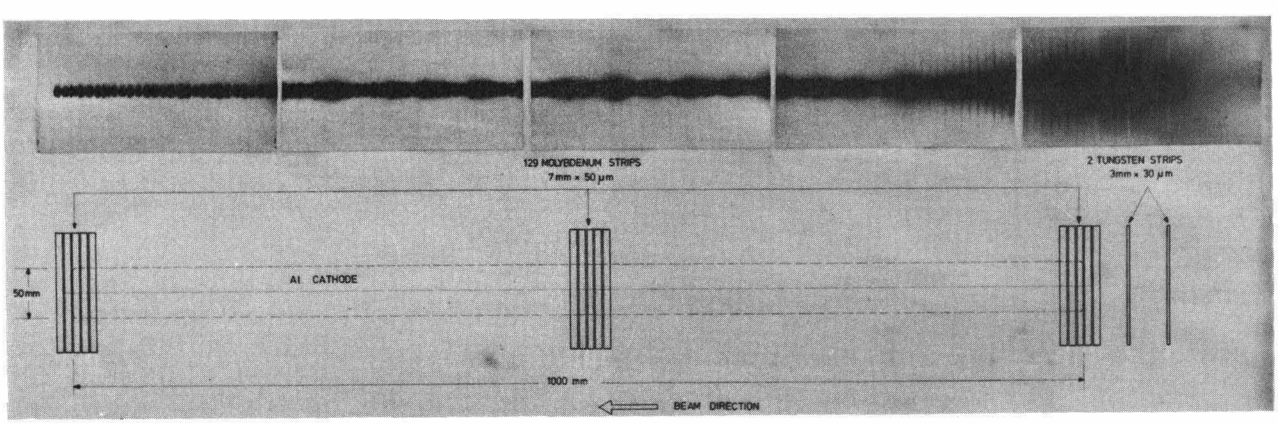

Fig. 5

Radiograph of the septum electrode. The blackening at the entrance and the exit of the channel corresponds to an activation level (β + γ) on the surface of the septum of 1.2 krad/h and 25 rad/h, respectively. The vertical size of the beam is shown here to be less than 10 mm (measured at the exit of the channel). The radiograph was taken two days after the beam was turned off. Time exposure was 180 sec.

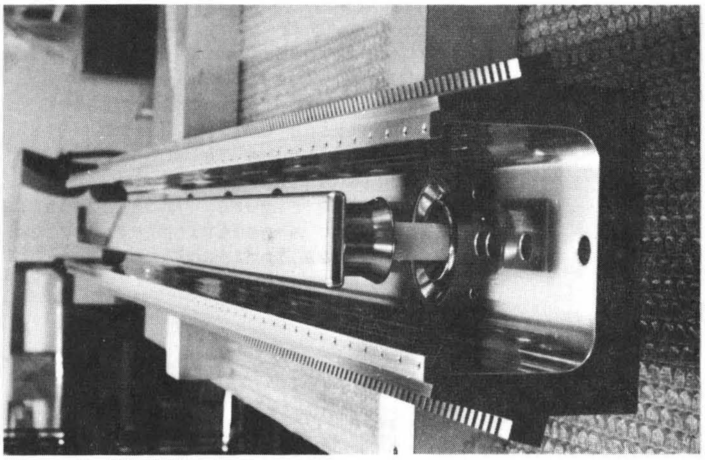

Fig. 6

The polished Al cathode mounted in the "C" structure. The cathode can be exchanged without removing the septum strips.

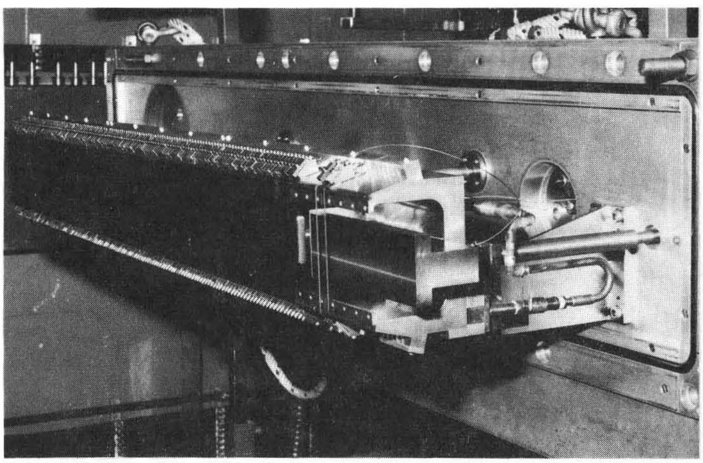

Fig. 7

The assembled "C" structure mounted onto the driving mechanism. A driving rod is seen at the right of the picture going through the vacuum flange to an outside motor. The extractor can be radially positioned to an accuracy of $\pm$ 0.05 mm by two independently driven motors located at the entrance and exit of the channel. An electrically insulated block of tungsten alloy has been mounted at the entrance of the channel as a protection against the beam hitting the cathode and insulators.

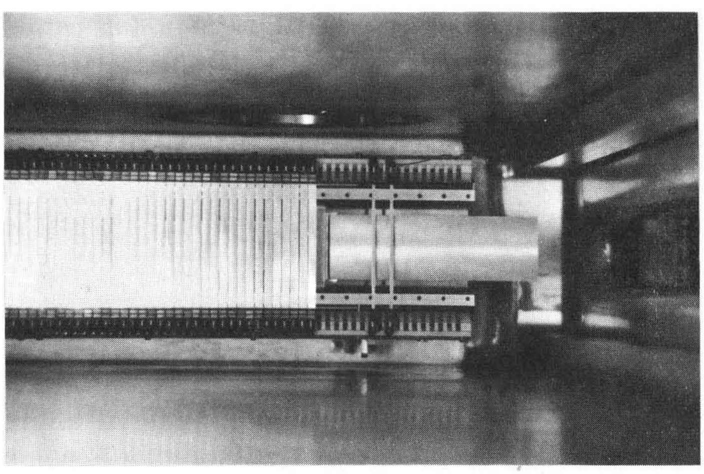

Fig. 8

Partial view of the EEC mounted in the ring accelerator. The beam travels from the right to the left of the picture. The two tungsten strips are seen at the entrance of the channel. This photograph was taken with a telephoto lens. A TV monitor sends the same view to the control-room during machine operation.