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AN ELECTROSTATIC BEAM SPLITTER FOR THE SIN 590 MEV PROTON BEAM LINE

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Summary

An electrostatic beam splitter was built at S.I.N. to provide simultaneously proton beams to the experimental physics area as well as to the medical pion therapy irradiation facility. Splitted beams of 100 and 16 µA respectively are typically produced with an overall beam loss of 0.5 ± 0.1%. Constructional details and operating experience are presented.

Introduction

The construction of a new biomedical facility at S.I.N.[1] with its own pion production target made it necessary to peel off a beam of up to 20 µA from the existing 590 MeV proton beam. The boundary conditions for a beam splitter were the following:

- The present 50 MHz, 0.4 ns (FWHM) time structure of the main beam had to be maintained.
- The beam for the biomedical facility should be turned ON and OFF, and its intensity be variable between 0 and 20 µA, without disturbing the main beam.

These conditions excluded all RF splitting devices and left systems with magnetic or electrostatic septa. An electrostatic septum was chosen because of the lower beam losses expected with its thinner septum. In addition to the requirements listed above there was the serious restriction of free space to introduce the splitter in the existing beam line. This limitation in space would require, for a conventional single sided septum a prohibitively high voltage in order to producethe needed beam deflection. By applying a field on both sides of the septum the specifications could be met without using very high voltages. Since the main proton beam should remain essentially undeflected, an additional steering magnet was required to compensate the effects of the electric field on that portion of the beam.

Design description

The splitter channel consists of two fixed cathodes and a movable thin septum. A cross-section of the splitter is shown in Fig. 1. For the given geometry and with the septum in the middle of the channel a voltage of approx. 180 kV (applied to both cathodes) is needed to achieve the required angle of 6 mrad between the emerging 590 MeV splitted beams. The position of the beam at the entrance of the splitter is kept centered between the two fixed cathodes. The position of the septum is varied until the desired beam intensity for the medical area is reached.

The movable septum consists of 47 Molybdenum strips (50 µm thick, 3 mm wide) separately tensioned over a supporting structure. The structure is basically similar to the Electrostatic Extractor Channel of the S.I.N. 590 MeV ring cyclotron.[2] The assembling of the Mo strips was done with the "C" structure mounted on a high precision milling machine. With the help of a microscope of very small depth of field, the position and flatness of the strips were carefully controlled during their tensioning. An overall flatness, including the irregularities of the "C" structure, of ± 10 µm was achieved resulting in an effective septum thickness of 70 µm. To reduce the beam load on the leading strips, a Mo wire 75 µm thick was mounted 37 mm in front of the first strip.

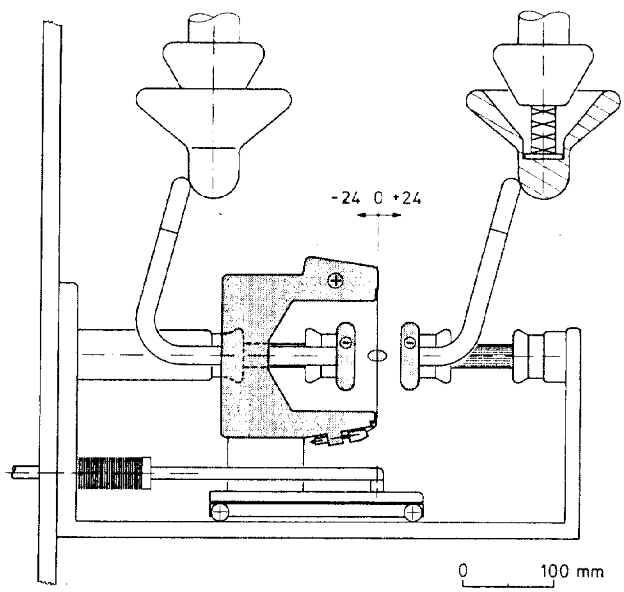

Fig. 1 Cross-section of the splitter. The high voltage, mirror polished, Aluminium (Al-MgSi1) electrodes (390 mm long, 75 mm high, 20 mm thick) are supported by BeO insulators. The grounded Molybdenum strips (3 mm wide, 50 µm thick, spaced 5 mm apart), forming the septum, are mounted on a "C" shaped St.St. structure. To reduce the power load on the first strips a Mo wire 75 µm thick, acting as a scatterer, was mounted 37 mm upstream from the first strip. The wire and the strips are separately tensioned to about 20 kg/mm^2. Each cathode is connected to the H.V. feed-throughs via low inductance 160 Ω wire resistors. The gap between the fixed cathodes is 50 mm. The movement of the septum is restricted to ± 24 mm.

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Movement of the septum is provided via a high precision gear system coupled to a fast d.c. motor. The septum can be positioned to better than 0.1 mm. It takes 500 msec to cover the 50 mm gap or 25 sec if it is done in steps of 0.1 mm (50 msec per 0.1 mm step). A second motor, fixed to the moving structure, was provided to adjust the septum orientation to the incoming beam.

The voltage from a common 240 kV, 1 mA d.c. power supply is brought separately to a pair of 30 MΩ surge resistors and 2000 MΩ voltage dividers via two 20 m long H.V. cables. Two 6 m long cables connect the H.V. vacuum feed-throughs to the surge resistors. Each cathode is connected to the feed-throughs via low inductance 160 Ω wire resistors. These wire resistors were added after noticing that sparks tended to deforme considerably the septum strips. The addition brought excellent results. Under normal operating conditions the current from the power supply is electronically limited to 250 μA. The assembled splitter is shown in Fig. 2.

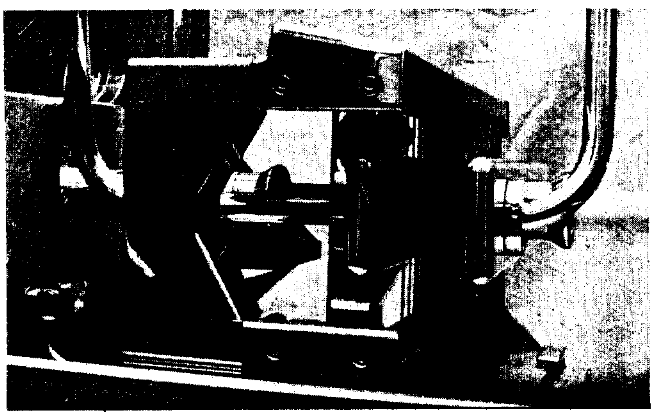

Fig. 2 Photograph of the assembled splitter outside the vacuum chamber.

Operation

As it was already mentioned, the beam for the biomedical target has to be turned on and off without affecting the main proton beam. This calls for the simultaneous setting of 4 parameters of the splitting system (septum position, high voltage, steering magnet current, ion source intensity) by the control computer, as shown in Fig. 3. Five control parameters have to be checked (septum position, high voltage, steering magnet current and two beam currents) to control the action of the system. The steering magnet, located at the exit of the splitter, compensates for the effect of the electrostatic field on the main portion of the beam. It produces a deflection angle of 6 mrad at 140 A. In order to maintain a separation of $\alpha_1+\alpha_2$ = 6 mrad (see Fig. 4) independent of the septum position d_1, the high voltage EHTV has to fulfill the following equation:

$$\mathrm{EHTV\ (kV)} = 0.292 \cdot d_1(\mathrm{mm}) \cdot d_2(\mathrm{mm})$$

The compensating effect of the steering magnet depends also on the septum position:

$$\mathrm{SHCI\ (A)} = 2.70 \cdot d_1(\mathrm{mm})$$

These two relations are presented graphically in Fig. 5. Near the park position the separation is gradually lowered to 3 mrads in order to bring the high voltage down to 30 kV. Larger values would cause arcing due to the insufficient quality of the vacuum in the proton channel.

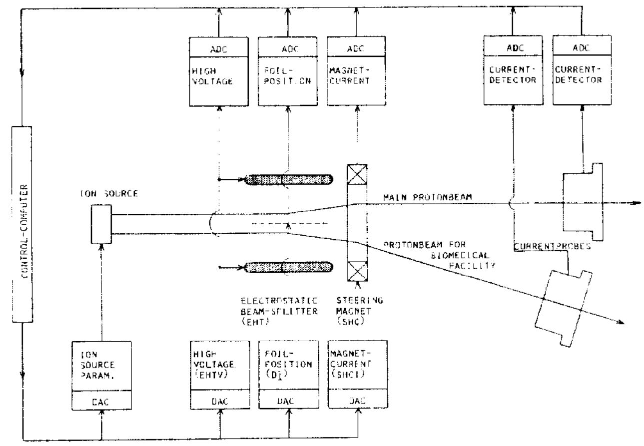

Fig. 3 Control diagram of the electrostatic splitter. Shown are the interconnections between the Control Computer and the parameters for setting (four) and checking (five) the splitter.

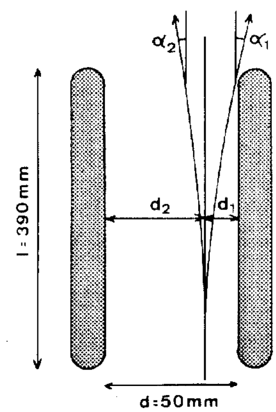

Fig. 4 Geometric parameters of the beam splitter. The distance between the two cathodes (dotted area) is constant. The sum of the two deflection angles α_1 and α_2 is constant and must not depend on the septum position.

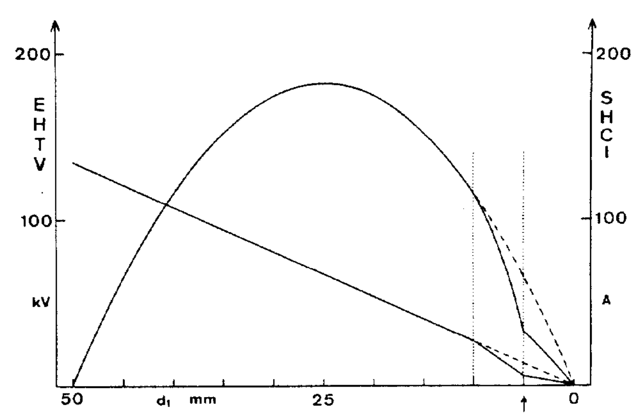

Fig. 5 Graphical representation of the parabolic relation between d_1 and EHTV (common high voltage on the cathodes) and the linear relation between d_1 and SHCI (current through the steering magnet SHC).

Beam loss: Calculation and Experimental Results

In order to minimize the losses at the septum the optics of the 590 MeV proton beam line was arranged such as to provide a wide (typically 12 mm FWHM) and slightly divergent beam at the location of the splitter. Measured beam profiles were fitted with the program TRANSPORT to obtain the actual phase space beam ellipse at the entrance of the splitter. Beam losses were estimated using a code (SPLIT) based on a Monte Carlo method with the particles described by a binomial distribution.[3] The program follows the fate of the randomly picked particles throughout the splitter channel. It determines the number of particles colliding with the septum electrode and it calculates the power deposited in the strips as well as the energy and angular distribution of the scattered particles. Calculations based on the septum geometry described earlier were carried out for typical splitter operating conditions. For a peeled-off beam of 15 µA from a 120 µA incoming beam, 0.5 µA (0.42%) were found to collide with the septum electrode. The calculated maximum temperature is 340°C for the Mo wire and 550°C for the first Mo strip. Without the wire the temperature of the first Mo strip would reach 640°C.

The beam losses were measured by comparing the intensity of the incoming and splitted beams. Each beam was monitored separately using 3 calibrated beam current probes.
A beam loss of 0.5 ± 0.1% was measured for a splitting ratio and an incoming beam of intensity and shape equivalent to the values used in the calculation. Measurements were also done with intensities of up to 150 and 20 µA for the incoming and peeled-off beams, respectively. The losses scaled as predicted and no deterioration with time was observed.

Profiles of the splitted 590 MeV beam 0.5 m after the splitter and at the entrance of a septum bending magnet, 4.5 m further downstream, are shown in Fig. 6.

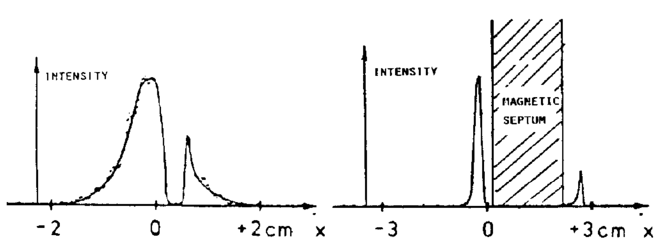

Fig. 6 Profiles of the splitted beam measured 0.5 m (left) and 5 m (right) after the splitter. The shaded area indicates the 20 mm thick septum coil of the bending magnet which separates completely the beam for the biomedical irradiation facility (small profile) from the main beam. At this point the beams are brought to two separate foci. The horizontal emittance of the unsplitted 590 MeV beam is $\pi \cdot 2.4$ mm mrad for 87% of the beam.

Figure 7 shows a radiograph taken from one of the several septum configurations used for tests. The blackening at the left of the picture corresponds to the power distribution predicted by the code. Lack of sufficient flatness in some of the strips is probably the reason for the dark spots seen along the septum.

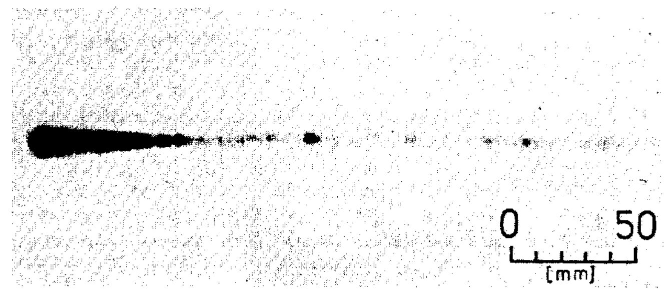

Fig. 7 Radiograph (Kodirex) taken from a septum electrode. This septum (49 molybdenum strips, 7 mm wide, 0.1 mm thick, spaced 1 mm apart) was used to split in half a 590 MeV, 12 µA proton beam for a total of 20 µAh. The radiograph was taken 2 days after the septum was removed from the beam line. Dose rate at the entrance of the septum was 3R/hr. Time of exposure was 5 sec. Shown are the first 32 strips.

Acknowledgments

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