A BEAM SPLITTER FOR THE PARASITIC USE OF THE 72 MEV PROTON BEAM LINE TO PRODUCE ISOTOPES

M. Olivo and H.W. Reist
PSI, PAUL SCHERRER INSTITUTE (formerly SIN)
CH-5234 Villigen, Switzerland

Summary

An electrostatic beam splitter has been built and installed in the transfer line from the 72 MeV Injector II to the 590 MeV Ring machine, to provide protons for a new isotope production facility. In normal operation, 75 μA are peeled from the main beam of 300 μA with an overall loss of 0.2 μA. So far the beam splitter has provided 40'000 μAh to the production targets without failure. Constructional details and operating experience of the beam splitter and of the new beam line are presented.

Introduction

Physiologically specific pharmaceuticals like proteins, antibiotics, fatty acids, hormones, antibodies and receptors, labelled with a radioactive isotope, have become an important tool in nuclear-medicine applications and clinical research.

Due to the increasing demand for high purity I-123 and for short lived isotopes like C-11, N-13, O-15, F-18 and Sr-82/Rb-82 with their good labelling and decay characteristics for detection in medical imaging systems, a new isotope production facility has been built, supplied with protons by peeling-off a fraction of the beam from the new 72 MeV high intensity injector cyclotron for the 590 MeV Ring machine [1]. The first target station became operational in 1986, since when isotopes has been produced on a routine basis.

The choice and design of the splitter is restricted by the following conditions:

- The 50 MHz, 0.4 ns (FWHM) time structure of the proton beam has to be maintained. This condition excludes RF splitting devices.
- The operation of providing beam for the isotope production facility should not disturb the alignment of the main beam.
- The intensity of the peeled-off beam has to be variable between 0 and 100 μA.
- Activation of the splitter itself and other beam transport components should be kept as small as possible.

These conditions are satisfied by an electrostatic beam splitter with a thin septum.

Design description

The adopted design is based on the splitter in the 590 MeV beam line, built at SIN, to provide protons for the medical pion therapy irradiation facility [2]. A schematic view is shown in Fig. 1. The part of the beam on the left of the septum (the main beam) is in a field-free region, while that to the right sees the deflecting electric field between cathode and septum. The transverse position of the septum is varied until the desired beam intensity is reached.

The septum is made of 117 Tungsten strips 2 mm wide, 0.05 mm thick, spaced 4 mm apart. The strips are held by a C-shaped structure and separately tensioned to about 5 kg/mm² by a pair of steel springs. The tension is large enough to ensure an overall flatness of approx. ±10 μm, but small enough to ensure a long-life at working temperatures up to about 1100 °C.

Fringe field leakage into the aperture for the main beam has to be reduced sufficiently, so that operation of the splitter does not affect injection into the 590 MeV Ring cyclotron. This has been achieved by making the septum overhang the end of the cathode by 40 mm and adding an L-shaped grounded end plate, at both entrance and exit (Fig. 2 a,b,c).

A high precision gear system coupled to a fast d.c. motor allows transverse positioning of the septum to better than 0.1 mm, and takes 550 ms to cover the full 55 mm adjustment range. A second motor-gear system fixed to the moving structure allows alignment of the septum with respect to the incoming beam in order to minimize beam losses due to septum shadow effects.

The high voltage is provided by a 150 kV, 0.1 mA d.c. power supply with ±1%regulation. Surge resistors (5 MΩ) are connected at both ends of the 40 m long H.V. coaxial cable linking the power supply with the splitter. A 160 Ω low inductance wire resistor, installed between the H.V. feed-through and cathode reduces the energy available (the energy which is stored in the 4 m cable joining the 5 MΩ surge resistor with the H.V. feed-through) to a spark. The splitter is normally operated at 120 kV, draining between 5 to 10 μA dark current. The voltage is always left on, including when the splitter is not in operation.

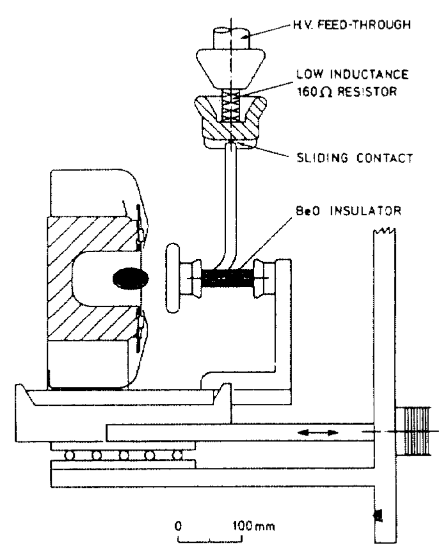

Fig. 1: Schematic view of the splitter mounted onto the positioning table. The mirror, polished aluminium (Al-MgSi1) cathode (620 mm long, 110 mm high and 20 mm thick) is supported by two BeO insulators. The 704 mm long grounded septum electrode consists of 117 Tungsten strips, 2 mm wide, 50 μm thick, spaced 4 mm apart. Each strip is separately tensioned to about 5 kg/mm². If a strip breaks, the tensioning springs pull the fragments into the upper and lower storage containers. The gap between cathode and septum is fixed and amounts to 40 mm.

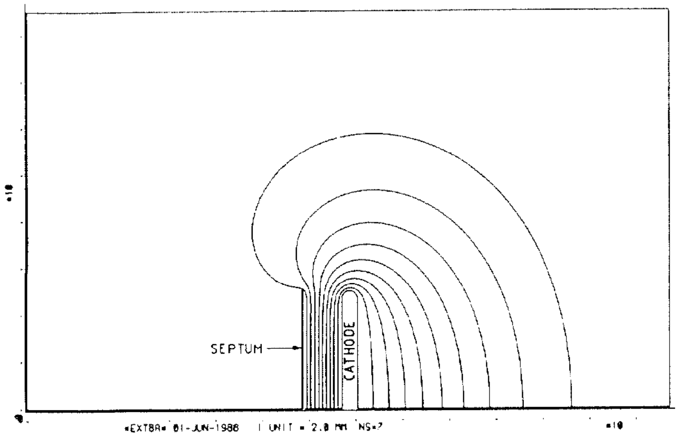

Fig. 2 a: The equipotential distribution at the exit of the splitter channel. Shown is the case in which both septum and cathode have the same length.

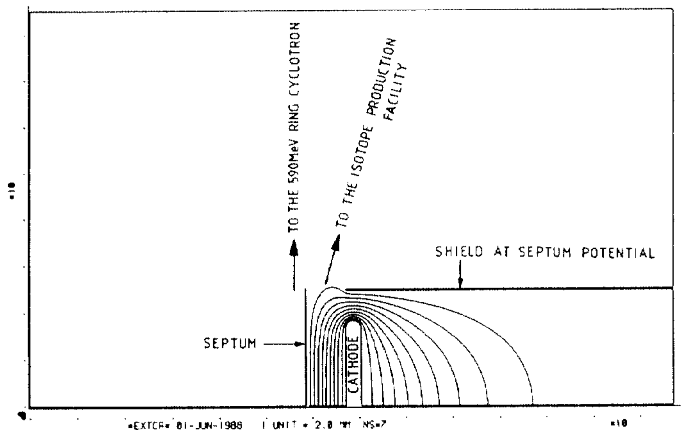

Fig. 2 b: Equipotential distribution of the splitter as it was built.

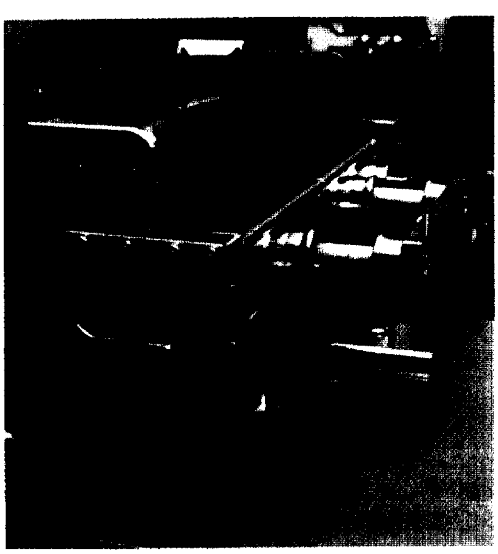

Fig. 2 c: Photograph of the beam splitter prior to its assembly onto the positioning table. Three electrically insulated copper blocks (10 mm thick) define the useful entrance of the splitter. Under normal operating conditions no losses are detected on these (indirectly cooled) protection beam stoppers. Two L-shaped aluminium grounded electrodes installed at both ends of the cathode reduce the leakage of the field into the path of the main beam. To repair an active splitter, a remotely controlled hook can be attached to its top to lift it into a radiation shielding removal box.

Figure 3 shows the splitter partly inserted into its vacuum chamber. The splitter has its own vacuum pumping system (normal operating pressure $5 \cdot 10^{-6}$ mbar). The vacuum chamber (housing the splitter) is surrounded by a radiation shield consisting of Antimony-free Lead and a final layer of Marble. The radiation level in the neighbourhood of the splitter after long operation periods is sufficiently low to allow immediate access after beam switch-off.

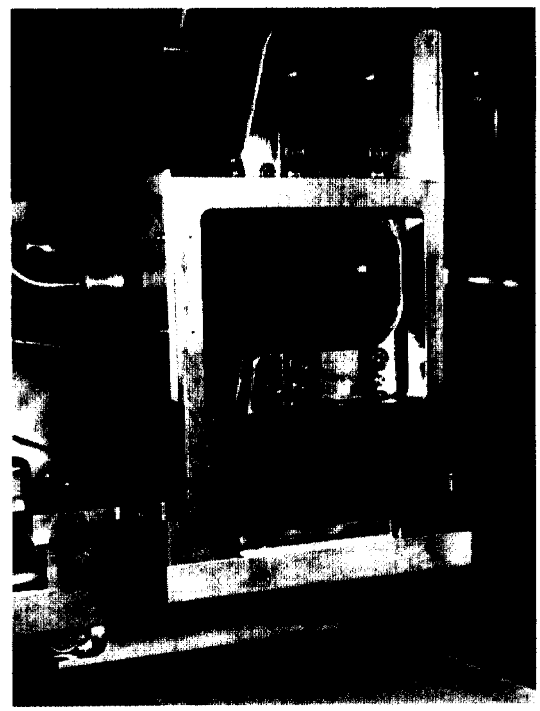

Fig. 3: Photograph of the splitter mounted on the positioning table and viewed on the downstream side. The arms of two beam profile monitors (for horizontal and vertical scanns) can be seen to the right of the picture. These monitors are mounted onto the vacuum chamber that houses the splitter. There is also a pair of profile monitors at the exit-end of the splitter (not visible).

Layout and beam optics

Figure 4 shows the beginning of the beam line to the isotope production facility branching away from the transfer beam line from the injector II cyclotron to the 590 MeV ring machine. The separation angle of the peeled-off beam leaving the splitter (EXT) is 13 mrad for 120 kV. The separated beam is further deflected to 14.5 mrad by the beam optics, resulting in a separation of 44 mm at the entrance of the septum magnet AYA 4 m downstream. The 25 mm thick septum coil is placed between the two beams and protected by a collimator. Figure 5 shows measured profiles of the incident and splitted beams. Again the stray field of the septum magnet has to be carefully shielded in order not to interfere with the main beam.

To keep the thermal load on the septum to an acceptable level and to minimize the beam losses, the beam is widened to typically 16 mm FWHM in X and to 12 mm FWHM in Y at the beam splitter. Further, to minimize shadow effects, the beam is made slightly divergent in the horizontal plane. The beam is focused to a waist in the horizontal plane at the entrance of the septum magnet AYA to provide the maximum physical separation between the two beams and to keep it independent of the position of the septum foils, that is, independent of the intensity of the peeled-off beam. The entrance angle into the septum magnet changes by 0.29 mrad for each millimetre change of position of the septum foils, which is compensated by adjusting the strength of the magnets AYA and AYB.

Beam losses and thermal load

Monitoring of beam losses is used as a diagnostic to indicate any deformation or misalignments of the septum strips. So far no increase of beam loss has been observed. Beam losses were calculated using the PSI version of the program TURTLE. Based on the results of these calculations, the dimensions and the positions of the collimators in the beam line between the splitter and the septum magnet were determined. For the case of splitting 75 μA from a 300 μA incident beam, the calculated beam loss due to the splitter is 0.15 μA. This compares well with the measured loss of 0.17 ± 0.04 μA.

The present splitter septum is fabricated from pure Tungsten. To guarantee a reliable operation, and to minimize the creep rate, care is taken to keep the maximum temperature of the septum below 1100 °C [3]. A higher temperature limit of about 1400 °C will be allowable if strips fabricated from the Tungsten alloys W-VM or W1.5ThO_2-VM are used [4]. The maximum current which may be peeled-off without exceeding the temperature limit can be calculated from the current and the horizontal and vertical widths of the incident beam. These may be measured before the splitter moves into the beam and used as a protective control step.

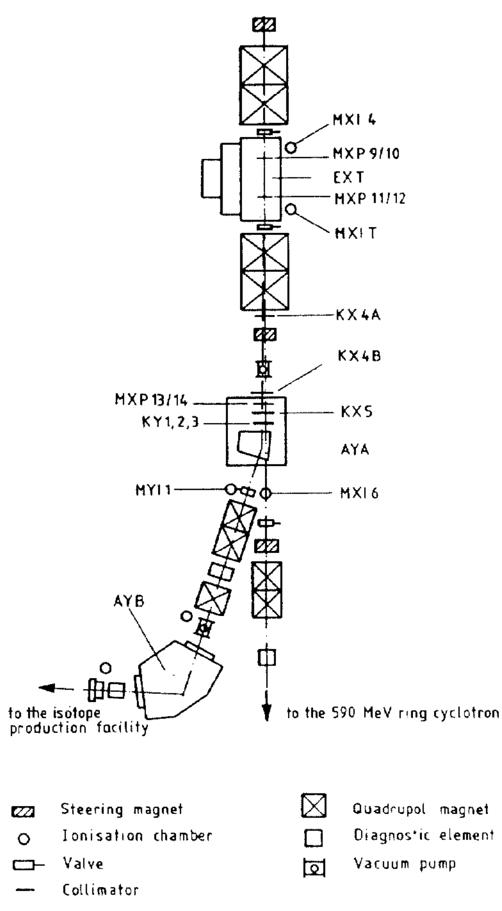

Fig. 4: Beginning of the beam line to the isotope production facility branching away from the transfer beam line from the injector II cyclotron to the 590 MeV ring machine.

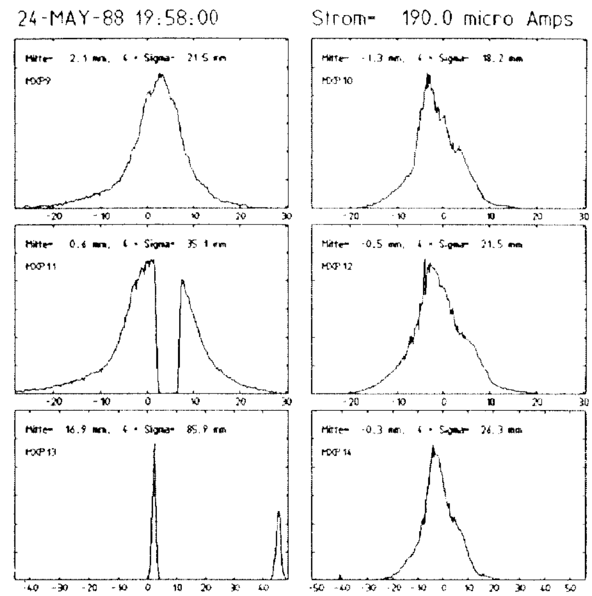

Fig. 5: Measured horizontal and vertical beam profiles in front of and behind the beam splitter and in front of the magnetic septum where the two beams are separated by 44 mm.

Operation

The isotope production facility is one aspect of a multi-user accelerator complex. A major operational requirement is that the beam current to the ring cyclotron is constant and independent of the intensity peeled-off for isotope production. This is achieved by two regulation loops. The first loop keeps the 590 MeV accelerated beam intensity constant by adjusting the total beam current from the Injector II, the second loop regulates the beam intensity for the isotope production by adjusting the position of the splitter septum. The characteristic curve which gives the variation in the beam current for each millimetre change of position of the septum, used for the regulation of the beam intensity to the isotope facility, is calculated from the measured beam profile at the splitter. The speed of the septum movement had to be limited to allow time for all corresponding adjustments of the main beam intensity by the first loop, including e.g. any necessary repositioning of the beams to keep the overall beam losses small. The tilt angle of the septum is adjusted to minimize beam losses. These are measured with the ionization chambers placed close to the splitter and at other positions further downstream.

Acknowledgement

The authors acknowledge, with grateful thanks, the dedicated engineering and technical assistance of D. Lucy, E. Mariani and D. Rossetti. The contributions of T. Blumer et al. (Control System), L. Rezzonico et al. (Diagnostics) and I. Röthlisberger are also gratefully acknowledged.

References

[1] U. Schryber et al., "Status report on the New Injector at SIN", in proceedings of the 9th Int. Conf. on Cyclotrons and their Applications, Caen (France), 1981, pp. 43-53.

[2] M. Olivo et al., "An electrostatic beam splitter for the SIN 590 MeV proton beam line", IEEE, Vol. NS-28, No. 3, June 1981, pp. 3094-3096.

[3] I. Röthlisberger, PSI, Villigen, Private communication.

[4] H. Bildstein et al., Metallwerk Plansee GmbH, A-6600 Reutte/Tirol, Private communication.