OPERATIONAL EXPERIENCE WITH THE SIN 870 KEV COCKCROFT-WALTON PRE-INJECTOR

M. Olivo
SIN, Swiss Institute for Nuclear Research
CH-5234 Villigen, Switzerland

Summary

As part of the program to increase the beam current from the SIN 590MeV proton ring accelerator, a new injector system based on a 72MeV isochronous ring cyclotron has been built. Commissioning of the 870keV pre-injector for the 72MeV machine was started in December 1983. This is of the Cockcroft-Walton (CW) type, consisting of a 900kV, 30mA d.c. generator, a high voltage dome housing an ion source with a 60keV beam line, and a SF_6 insulated acceleration tube. A general description of the operational experience of the pre-injector since that time is given.

Introduction

The concept of the new injector (Injector II) and its commissioning has been previously reported [1,2,3] and its performance summarized in another paper presented at this conference [4]. Initial operational experience of the 870keV pre-injector has also been described in a previous publication [5].

The SIN accelerator complex (the 72MeV Injector II and 590MeV Ring isochronous-cyclotrons) should in the future deliver a 1.5mA beam to target. To achieve this, a d.c. beam of about 25mA is required from the 870keV CW pre-injector, but this might be reduced to about 20mA if the expected buncher performance can be achieved. The pre-injector delivers today a d.c. current of 8mA for routine 72MeV and 590MeV proton beam production. During high intensity tests a maximum d.c. current of 16mA has been injected into the Injector II.

Ion source

Plasma Chambers

The ion source is shown schematically in Fig. 1. Two different plasma chambers were built (Figs. 2 and 3) that fit the same extraction system. The cubic chamber, based on a design by Holmes et al. [6], is used for routine operation. It has four filaments which allow for a full week of uninterrupted operation. Typical operating values are 50mA total extraction current at 60kV (optimized for the present extraction geometry) with an arc current of about 30A. The proton fraction in the beam is rather low, typically 25%. The cylindrical chamber is used during high intensity beam tests of the entire accelerator complex. Because of its bigger volume it is operated at a higher arc current (~50 A) to obtain the same total extraction current, leading to a higher proton fraction of up to 40%. Typical filament lifetime for both sources is $I_{arc} \cdot Z \cdot t$ = 160kWh. The sources are normally operated at a constant plasma impedance, Z, of about 2.5 Ohm.

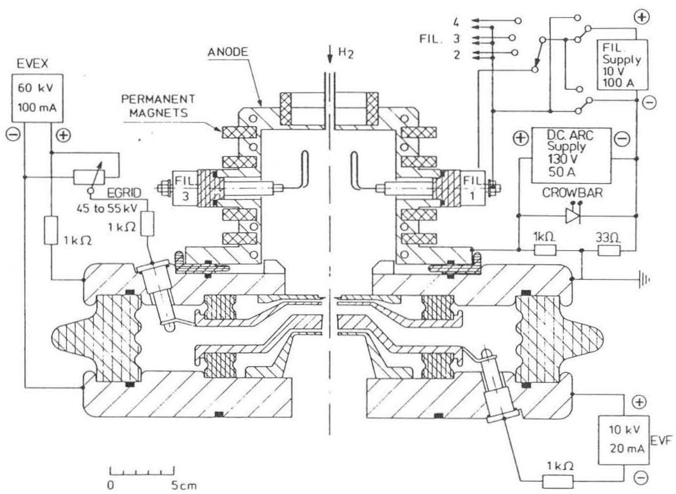

Fig. 1: Schematic view of the ion source fitted with a rectangular plasma chamber. The filament supply is voltage regulated. The source operates with one filament at the time. A polarity switch is provided in order to extent their life time. The arc supply is current regulated. The plasma impedance is kept constant by varying the filament emission. A soft-ware loop can be turned on for this purpose. A crowbar on the arc supply allows for fast beam switch-off for those cases where an interlock condition arises between the source and the kicker magnet (see text).

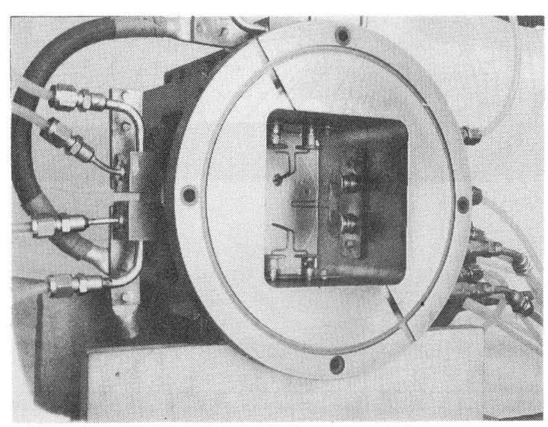

Fig. 2: Rectangular plasma chamber. The body has a water cooled OFHC copper case (cuboid of side 11cm). The arrangement of the 3.5kG Sm-Co magnets is shown in Fig. 1. Four hair-pin shaped filaments of thoriated tungsten wire (1.5mm diam.) are mounted on the sides of the plasma chamber.

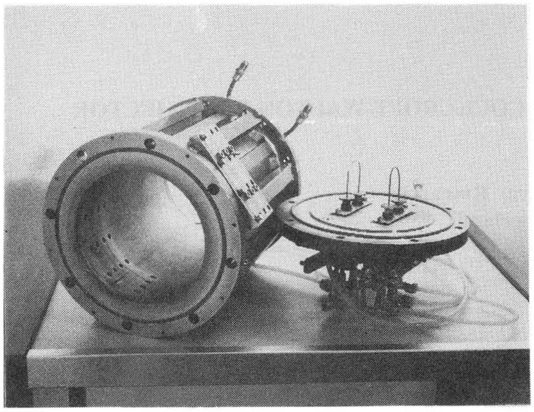

Fig. 3: Cylindrical plasma chamber. The body is a water-cooled OFHC copper cylinder, 15cm in diameter and 25cm deep. It has 8 columns of 3.5kG Sm-Co magnets axially deployed and embeded into the outside of the wall chamber. The back face contains 3 extra rows of magnets and two filaments of thoriated tungsten wire (2mm diam.) located between them. The wall chamber has four sets of four holes to allow the instalation of a magnetic filter. The position of the filter can be varied axially in 15mm steps, the closest to the extraction aperture being 30mm away.

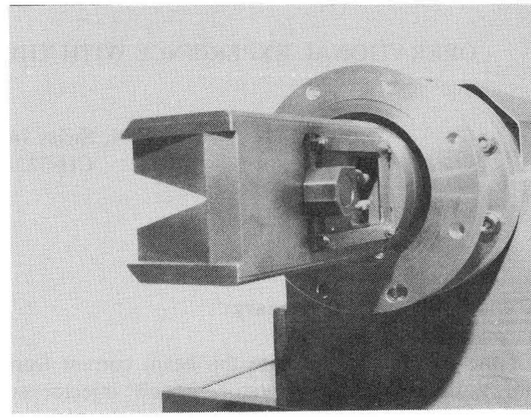

Fig. 5: Calorimeter beam profile monitor (MVP1). It consists of a double wedged water cooled 6cm high copper block with a 0.1mm wide vertical slit (not seen). Behind the slit there is an smaller independently water cooled beam stopper. Two thermocouples, mounted inside the entrance and exit of its cooling pipes, measure the water temperature difference. The generated voltage signal is plotted against slit position. The time constant is about 1 sec.

Extraction Configuration

The AXCEL-GSI code [7] was used to optimize the geometry of the four-electrode extraction system. Ion trajectories are shown in Fig. 4. The divergence of the beam as a function of the total extracted current was measured at .335m from the 7mm diam. extraction aperture and for three different energies, using the beam profile monitor shown in Fig. 5. The results are presented in Fig. 6. The total beam current as a function of the extraction voltage shows the expected $E^{3/2}$ dependence. Figure 7 shows a typical beam profile.

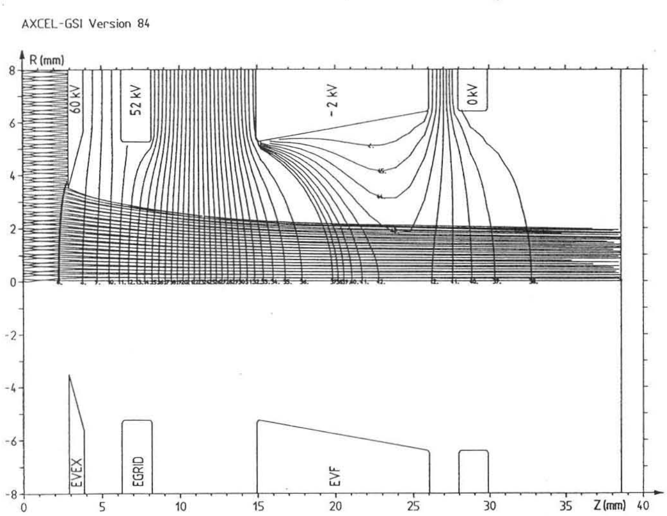

Fig. 4: Computed ion trajectories for the geometry presently used in the ion source. For the calculation the following values were used: j = 137mA/cm², Te = 5eV, Ti = 0.6eV and an average mass to charge ratio of 1.78 (30% H_1^+, 35% H_2^+, 35% H_3^+).

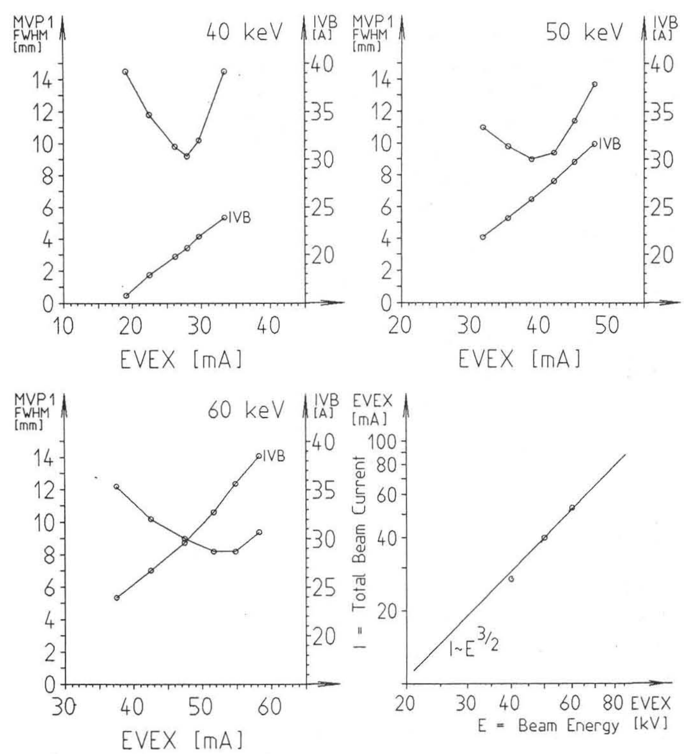

Fig. 6: Beam widths at 335mm from the extraction aperture of the ion source as a function of the total extracted beam current, measured at three different energies. For these measurements the arc current was varied and the filament emission correspondingly adjusted to maintain a constant plasma impedance of 2.5 Ohm. In the lower right figure the extracted current values for minimum beam widths are plotted against beam energy. The full line shows the $E^{3/2}$ dependence.

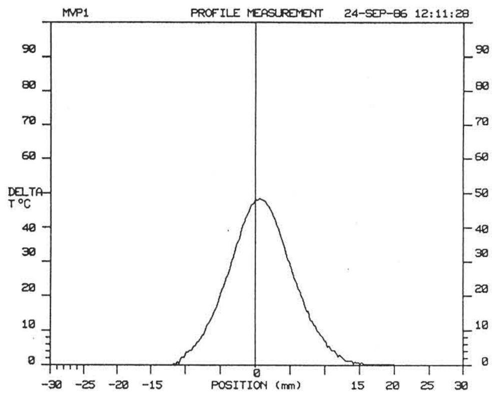

Fig. 7: Profile of a 54mA, 60keV beam measured at 335mm from the extraction aperture of the ion source using the profile monitor shown in Fig. 5.

60keV Beam Transfer Line and Acceleration

The 60keV b.t.l. which guides the beam towards the acceleration tube is shown in Fig. 8. Beam profiles have been measured just after the source using MVP1, at the exit of the acceleration tube with MWPL, a novel light-profile monitor [8] and further down stream with two pairs of conventional scanning monitors (MWP1,2; 3,4). The measurements were made using a 16mA proton beam (out of the 54mA extracted from the ion source) accelerated to 870keV and stopped at the vertical collimator (FWOU). Figure 9 shows the beam envelopes from the source to the exit of the acceleration tube, including the first 3m of the 18m long 870keV beam transfer line [9], obtained by using the "Transport"-SIN code [10,11,12]. A good fit to measured beam widths is achieved when at least 99% beam neutralisation in the 60keV line (the operating pressure is $1.5 \cdot 10^{-5}$mbar) and a non-neutralised proton beam of 16mA inside the tube are assumed. There is not enough data to indicate the degree of neutralisation in the 870keV region. The best overall fit was obtained when the waist of the beam exiting the ion source was assumed to be 3cm beyond the last extraction electrode. The beam radius at this point was fixed at the value predicted by AXCEL (1.9mm, see Fig. 4). The field of the solenoids as well as the divergence of the beam exiting the source were determined by the fit; this gave solenoid field values which differed by 2% with respect to those set and a beam divergence of 24.6 mrad. This results in a computed normalized beam emittance of $0.53 \cdot$pi mm mrad. This value is compatible with measurements done by other methods in the beam transfer lines.

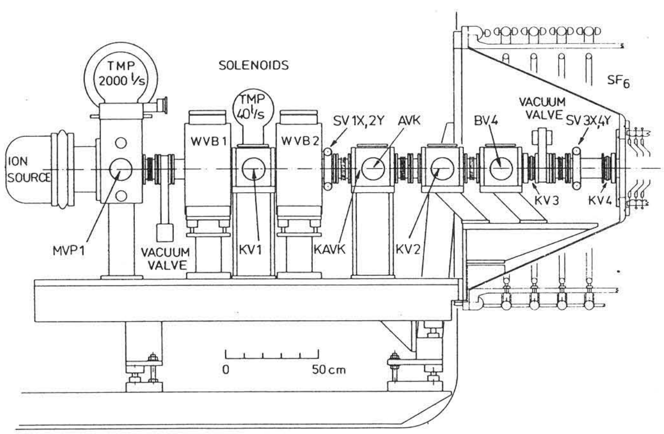

Fig. 8: The 60keV beam transfer line. Shown are the location of the kicker magnet (AVK) and the 6mm aperture iris (KV2). The collimators KV3 and KV4 protect the acceleration tube electrodes from the direct beam. A collimator having different apertures and placed between the two solenoids (KV1) limits the beam current without varying the source parameters. It also cuts away unwanted beam tails. BV4 is a 6 kW beam stopper and the S's indicate steering magnets.

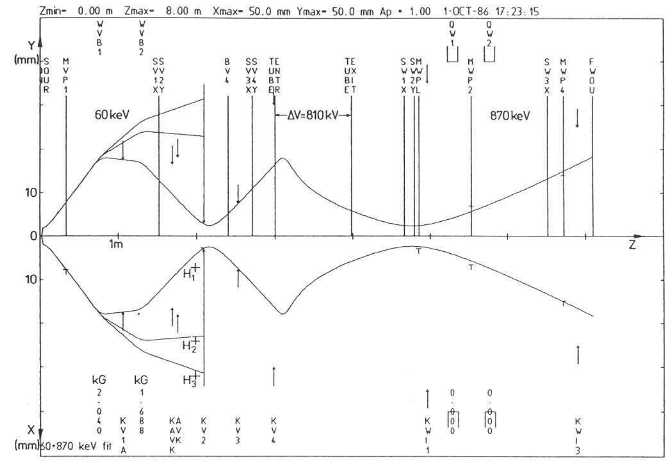

Fig. 9: Fitted beam envelope, from the exit of the ion source to the exit of the acceleration tube including the first 3m of the 18m long 870keV beam transfer line, to the measured beam widths (2- sigma amplitude) at the MVP1, MWPL, MWP1,2; 3,4 locations. Also shown are the beam envelopes for the unwanted molecular species to the 6mm diam. iris (KV2) where most of their removal takes place.

To tune the 870keV transport system the beam has to be pulsed to avoid thermal damage to the components, mainly the beam scanners. For this purpose a kicker magnet (AVK) was built [13] and installed in the 60keV beam line (Fig. 8). Pulsing is accomplished by deflecting the beam away from the iris (KV2). It is also used to switch-off the beam when a machine interlock condition arises. The signal from a current transformer [14] of an 8.5mA pulsed beam is shown in Fig. 10. The fast rise and fall times would indicate that the 870keV beam is fully non-neutralised at this energy. A beam profile measured with the light-sensitive monitor of a d.c. beam and 50% chopped is shown in Fig. 11. Pulsing of the beam results in load changes to the 900kV cascade generator, leading to a modulation in the beam energy. Figure 12 shows the smoothing effect of the "bouncer" when it is included in the voltage regulation loop of the high-voltage power supply.

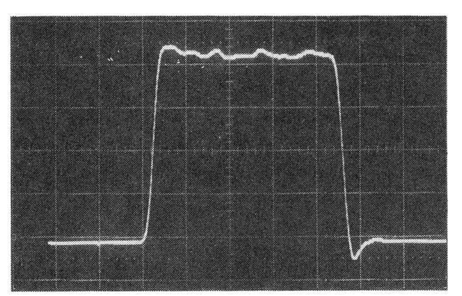

Fig. 10: Beam current trace measured with a current transformer located in the 870keV b.t.l. 13m from the exit of the acceleration tube. The beam was pulsed at a repetition rate of 500Hz with a duty cycle of 3%. Ver. scale: 2mA/div; Hor. scale: 10μs/div.

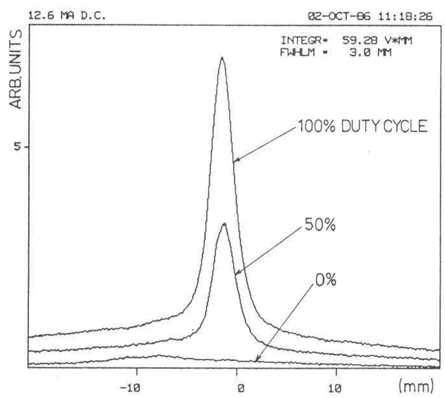

Fig. 11: *Profile of a 13mA d.c., 870keV proton beam measured at the exit of the acceleration tube using a non-intercepting ligth sensitive profile monitor (MWPL). Also shown is the profile of the same beam pulsed at a repetition rate of 500Hz and a duty cycle of 50%. The lowest trace corresponds to the beam-off state (kicker magnet ON) and it shows H_2^+ and H_3^+ remanents. The vertical shift in the traces is most likely due to light reflections in the beam pipe.*

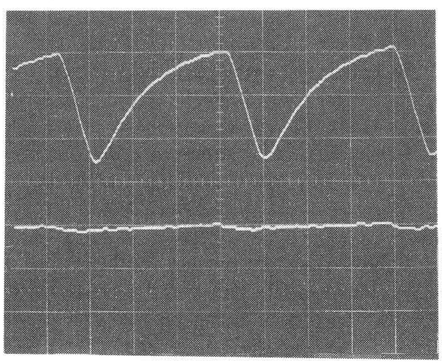

Fig. 12: *Signals obtained from the 900kV ohmic-capacitive voltage divider which is attached to the dome and used in the voltage regulation loop of the Cockcroft-Walton power supply. The upper trace shows the voltage variation in the dome when a 13mA proton beam was pulsed at a repetition rate of 500Hz and a duty cycle of 20%. The lower trace shows the result when the "bouncer" was included in the regulation loop. The bouncer raises or lowers the potential to ground of the cascade generator. Ver. scale: 450V/div; Hor. scale: 0.5ms/div.*

Conclusions

The Cockcroft-Walton pre-injector (Fig. 13) delivers a d.c. current of 8mA for routine 72MeV and 590MeV proton beam production. A maximum current of 16mA has been injected into the Injector II cyclotron during high intensity tests using the cylindrical plasma chamber but further development is required for the ion source. A new ion source test stand has been built which resembles the installed 60keV beam line and will be used for the following:

(i) To reach 25mA - The most attractive way would be to increase the proton fraction to at least 50%. A possibility is the use of a magnetic filter [15].

(ii) To increase the filament lifetime - e.g. use of Lanthanum Hexaboride [16]

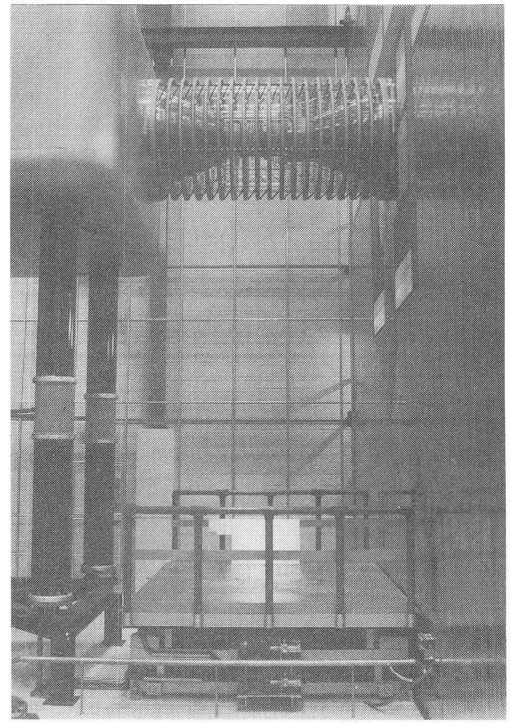

Fig. 13: *Photograph showing the acceleration structure of the 870keV Cockcroft-Walton pre-injector. The SF_6 insulated, 80cm long acceleration tube is enclosed in a 3m long acrylic jacket. A scissors-type lifting platform provides access to the dome.*

Acknowledgements

The author acknowledges, with grateful thanks, the dedicated engineering and technical assistance of the SIN staff, especially E. Mariani, D. Lucy and the Electrical and Control System groups. Fruitful discussions with W. Joho and U. Schryber are also gratefully acknowledged.

References

[1] U. Schryber et al., Proc. 9th Int. Conf. on Cyclotrons and their Applications, Caen (France) 1981, p. 43

[2] U. Schryber, Proc. 10th Int. Conf. on Cyclotrons and their Appl., East Lansing, Michigan (USA) 1984, p. 195

[3] W. Joho et al., IEEE NS-32, No.5 (1985) 2666

[4] W. Joho, High Intensity Beam Acceleration with the SIN Cyclotron Facility, these proceedings

[5] M. Olivo, Proc. of the 1984 Linear Acc. Conference, Darmstadt (Fed. Rep. of Germany) 1984, p. 380

[6] A.J.T. Holmes et al., J. Phys. E.: Sci. Instrum. 14 (1981) p. 856

[7] P. Spaedtke, AXCEL-GSI Code, GSI-38-9 Report, (1983)

[8] L. Rezzonico, Beam Diagnostic at SIN, these proceedings

[9] C. Markovits, Proc. 9th Int. Conf. on Cyclotrons and their Applications, Caen (France) 1981, p. 525

[10] K.L. Brown et al., CERN 80-04 (1980)

[11] F. Sacherer and T.R. Sherwood, CERN MPS-SI/note-Lin/71-7 (1971)

[12] U. Rohrer, "Transport"-SIN Code, May 1982, SIN, unpublished report

[13] D. George and O. Szavits, SIN, unpublished report

[14] J. Cherix, SIN Internal Report, TM-56-01 (1984)

[15] K.W. Ehlers and K.N. Leung, Rev. Sci. Instrum. 52 (1981) p. 1452

[16] K.N. Leung et al., Rev. Sci. Instrum. 57 (1986) p. 1274