INITIAL OPERATION OF THE SIN 860 KEV COCKCROFT-WALTON PRE-INJECTOR

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Summary

As part of the program to increase the beam current from the SIN 590 MeV proton ring machine, a new injector system based on a 72 MeV isochronous ring cyclotron is being built.

Commissioning of the 860 keV pre-injector for the 72 MeV machine has started. This pre-accelerator is of the Cockcroft-Walton type consisting of a 900 kV, 30 mA d.c. generator, a high voltage dome housing an ion source with a 60 keV beam line, and a SF_6 insulated acceleration tube. Details of the design and initial operating experience will be presented.

Introduction

The new injector[1,2] for the SIN 590 MeV proton ring cyclotron consists of a 860 keV Cockcroft-Walton pre-injector and a 72 MeV isochronous ring cyclotron. This paper describes the pre-injector as built, and is a modified version of an earlier design[3]. The pre-injector consists of a 60 keV ion source, a 3 m long beam transfer line and an acceleration tube. It has been designed to deliver an 860 keV, 20 mA d.c. proton beam with a $\Delta E/E \leq 10**-4$ and a normalized emittance of less than πx0.5 mm mrad. A 15 mA d.c. proton beam is required from the pre- injector to produce a 1.5 mA beam at 72 MeV. A general view of the pre-injector is shown in fig. 1.

Ion Source and Beam Transfer Line

The ion source is of the multi-cusp type with a four-electrode extraction system (fig. 2). It is based on a design by A.J.T. Holmes et al.[4]. Figure 3 shows the beam envelopes from the exit of the ion source to the exit of the acceleration tube including the first 4 m of the ≃20 m long 860 keV transfer line to the 72 MeV ring machine. For this calculation the beam was assumed to be fully space charge neutralized except in the acceleration tube, where a current of 10 mA was considered. The beam envelopes were calculated using a modified version of the TRANSPORT code which treats transverse space charge effects and the acceleration[5,6,7]. A pair of 12 cm diameter solenoids (WVB1,2) allow the cleaning of the parasitics from the beam by focussing the protons through a small iris diaphragm (KV2) which then stops most of the H_2^+ and H_3^+. The beam current may be changed either by varying the diameter of a second diaphragm installed between the two solenoids (KV1), thus leaving the ion source parameters unchanged, or by varying the extraction voltage of the ion source. The beam transfer line between ion source and acceleration tube is illustrated in fig. 4.

Acceleration Structure

The acceleration structure is shown schematically in fig. 5. The design has been based on that for similar structures already in operation at LAMPF[8]. It consists of a 72 cm long constant gradient tube (E≃13 kV/cm) enclosed in a 3 m long acrylic jacket filled with SF_6 at atmospheric pressure. The tube is made up from Titanium rings brazed to 94% Alumina ceramic spacers (fig. 6). The shape of the ceramic rings was chosen following the work of Joy[9]. A measure of protection for the ceramic rings from being struck by charge particles and X-rays is obtained by using massive, saucer-shaped stainless steel acceleration electrodes[10]. The SLAC code[11] was used to calculate the potential distribution for the relevant regions of the acceleration structure (figs. 7,8,9). Fig. 10 shows a picture of the complete structure.

One 2000 l/s turbo molecular pump is used to pump the acceleration tube. The pressure at the entrance and exit of the tube is less than 10**-7 Torr and with a typical H_2 gas load of 5 cc/min (S.T.P.) at the ion source, 1.5x10**-5 and 1x10**-6 Torr (H_2 corrected) respectively. The acceleration tube was brought to 850 kV using the following procedure. The acceleration gaps were first brought one by one to the voltage breakdown of the spark gaps (about 62 kV), this took less than 10 min per gap, after which it took less than 30 min to bring the whole tube to the full voltage. The voltage breakdown rate after intermittent operation for a few weeks, is less than 1 per 8 hours. No X-rays have been detected with a counter located outside the Faraday cage near the end of the acceleration structure.

Initial Operating Results

The ion source parameters have been optimized for low beam current operation which is required for the commissioning of the 72 MeV ring machine. In particular, operation of the source has been restricted to voltages below 40 kV. At 31 kV a total beam current of 17 mA has been extracted from a 7 mm diameter aperture with a proton content of about 30%. The arc current was 20 A. The arc voltage was kept at ≃80 V by varying the heating current of the filament (starting at ≃75 A for a 1.5 mm dia., 10 cm long Tantalum wire). The H_2 flow was 5 cc/min (S.T.P.) and the pressure in the arc chamber of ≃12 mTorr.

Figure 11 shows particle trajectories from the ion source, calculated using the AXCEL code[12]. Good agreement is found between the results of this calculation and the measured beam properties if an ion current density of 45 mA/cm² and an ion temperature of 0.6 eV are used. The beam emittance has been computed from measured beam profile widths at 31 keV with the program TRANSPORT-SIN and by using a tomographic method[13,14] at 380 keV (figs. 12a,b). Both methods agreed within 20%. The normalized emittance was found to be πx0.35 mm mrad for approximately 90% of the beam.

A 1 mA d.c. proton beam was accelerated to 860 keV for the first time in December 1983. Since then the beam has been used for commissioning work on the 860 keV beam line and the 72 MeV cyclotron. The voltage breakdown rate is less than 2 per shift at the present operating intensities of a few milliamperes. The X-ray level is ≃3.5 mR/h/mA measured at the exit of the acceleration structure. The set-up takes typically 1 hour.

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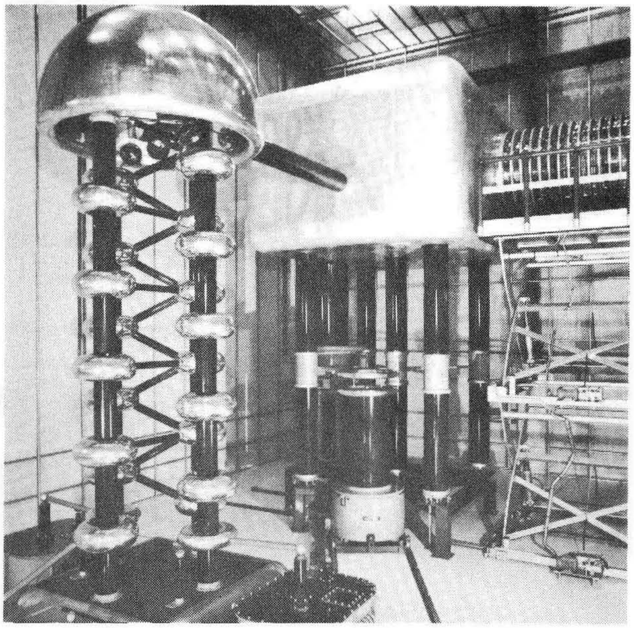


Fig. 1: 860 keV pre-injector. The high voltage power supply is a 900 kV, 30 mA symmetric cascade generator. A 0.05% precision ohmic-capacitive high voltage divider, ensures a long term voltage stability of better than 1 part in 10**-4. Power for the dome is supplied via two 450 kV insulated 50 kVA transformers connected in series. The total capacitance between dome and ground is 2.4 nF. A CAMAC based system utilizing a 1 MHz driven fibre-optic link between ion source potential and dome, and a laser link between dome potential and ground is used for data acquisition and the transmission of control information. Heat generated in the dome is carried to "ground potential" via a closed liquid "FREON TF" circuit. A scissors-type lifting platform provides access to the dome. Only temperature control (of ±1 °C) is maintained in the Cockcroft-Walton room.

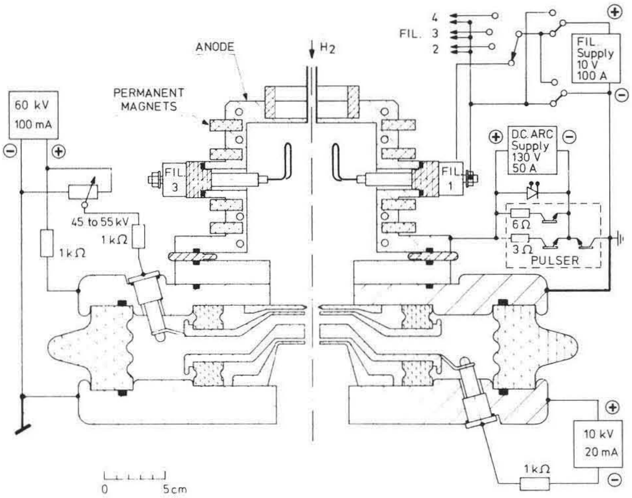


Fig. 2: Schematic view of the ion source. The filament power supply is voltage regulated. The source operates with one filament at the time. A polarity switch has been provided in order to extend their life time. The arc p.s. is current regulated. It is connected to the ion source via a fast electronic switch. This device allows the pulsing of the arc between 1 Hz and a few kHz with duty factors between 1% and 100%. It will be used to vary the average current during beam set-up. It can also be used to switch off the beam when a machine interlock condition arises since the quenching time of the arc is less than 10 µs.

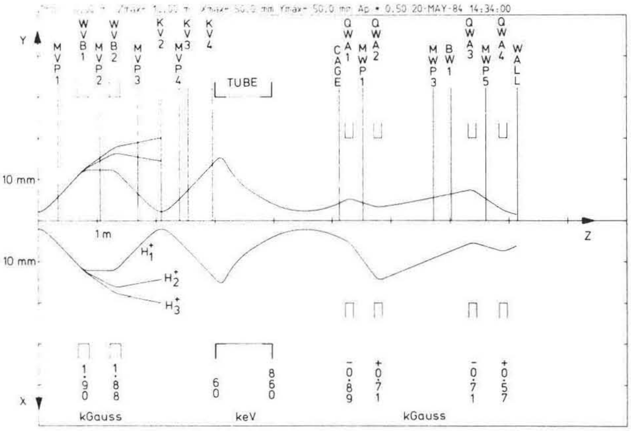


Fig. 3: Calculated beam envelopes from the exit of the ion source to the exit of the acceleration tube including the first 4 m of the ≈20 m long 860 keV transfer line. The initial beam conditions assumed here are: Xo=Yo=2.1 mm and Xo'=Yo'=15.8 mrad. The effective length of the solenoids is 18.5 cm. MVP's are calorimetric beam profile monitors. MWP's are current b.p.m.. BW1 is a 15 kW beam stopper.

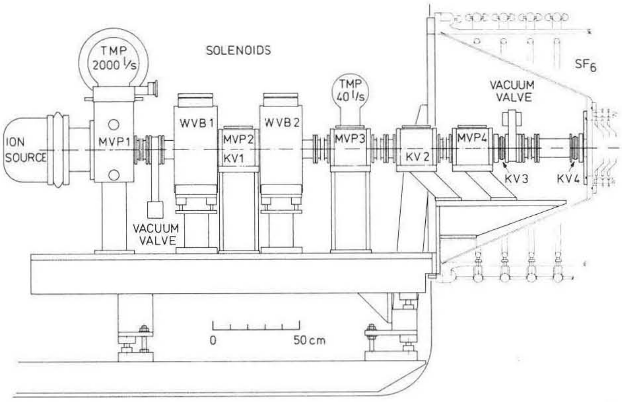


Fig. 4: The 60 keV beam transfer line. With a typical H_2 flow of 5 cc/min (S.T.P.) at the ion source the average pressure in the beam line is 2x10**-5 Torr. The collimators KV3 and KV4 protect the acceleration tube electrodes from direct beam impact.

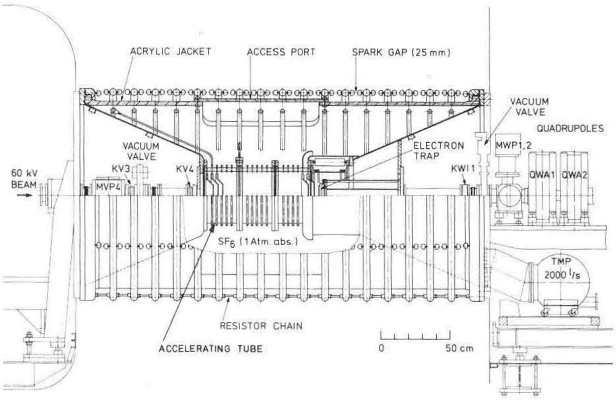


Fig. 5: Schematic view of the acceleration structure. The 900 Mohm potential divider is constructed from three parallel resistor chains. Each acceleration electrode is connected to the resistor chains via 2 spokes which follow closely the calculated equipotential lines (Fig. 9). Three spark gap chains (hemispheres of 20 mm radius) are set for a voltage breakdown of 62±1 kV at the operating atmospheric pressure of 730±20 mmHg. The acceleration tube can be removed through the access port.

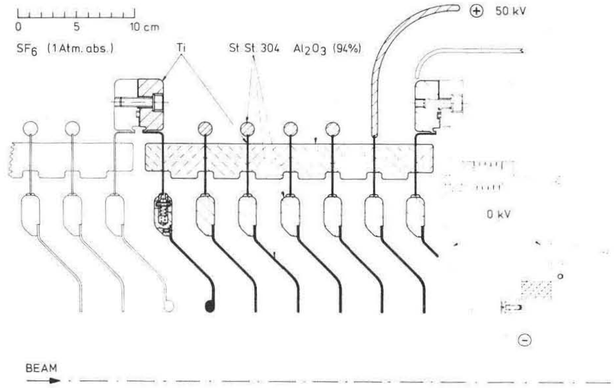


Fig. 6: Schematic view of the end portion of the acceleration tube. Based on practical considerations, the tube is made up from three identical sections joined together with metal "O" ring seals. The 12 cm inner diameter stainless steel acceleration electrodes are spring clamped to the Titanium rings for easy removal. The electron trap assembly can be removed without dismounting the acceleration structure.

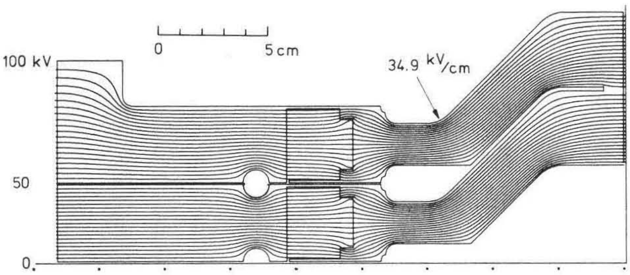


Fig. 7: Potential distribution between adjacent acceleration electrodes. The maximum electric field in this configuration is 34.9 kV/cm.

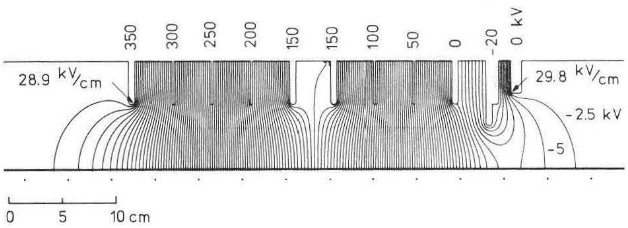


Fig. 8: Potential distribution for the acceleration tube. The structure calculated includes all relevant regions (i.e. entrance, adjacent sections and exit with the electron trap electrode). The potential distribution along the axis for the entire tube was used in the calculation of the beam envelopes shown in fig. 3.

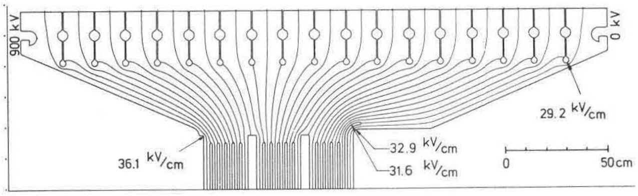


Fig. 9: Potential distribution in the SF_6 filled volume of the acceleration structure.

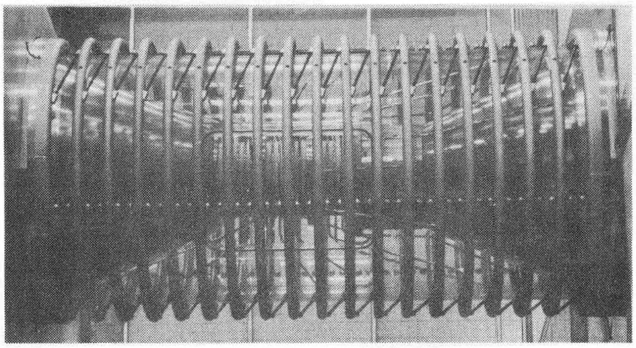


Fig. 10: Photograph of the acceleration structure.

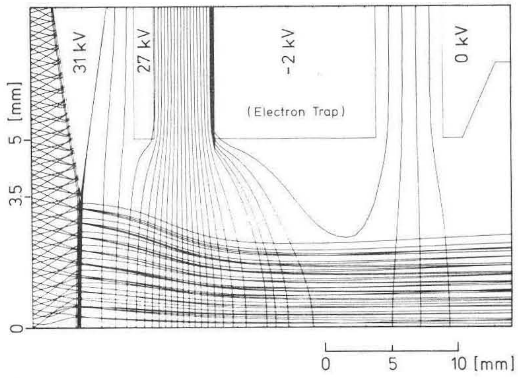


Fig. 11: Computed ion trajectories and equipotentials for the extraction geometry used in the ion source.

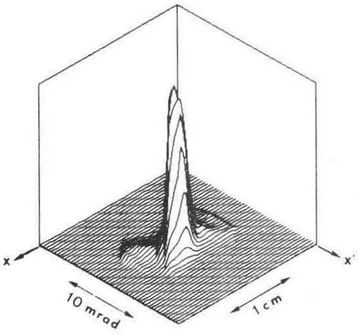
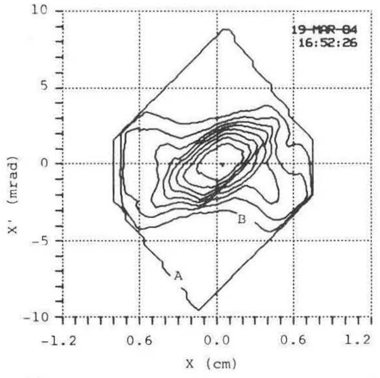


Fig. 12a: Current distribution in the (x,x') phase space of a 380 keV proton beam. The distribution is reconstructed from beam profiles measured at three different locations (MWP1,3,5 in Fig. 3). The residuals H_2^+ and H_3^+ ions may contribute to the formation of the "halo".



Cont	π·mm·mrad	%
A:	172.1	100.0
B:	93.1	99.6
C:	67.9	97.8
D:	38.5	92.2
E:	26.3	87.4
F:	20.3	82.9
G:	14.7	75.2
H:	10.5	64.8
I:	5.7	44.0
J:	0.1	0.8

Fig. 12b: Contour-diagram of the (x,x') distribution of fig. 12a showing emittance values for given beam percentages.