PREACCELERATOR DESIGN AND COMPONENT DEVELOPMENT FOR THE SNQ LINEAR ACCELERATOR

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Summary

As a part of a study for a spallation neutron source SNQ[1] an electrostatic preaccelerator for a proton linear accelerator has been designed. Considerations and requirements concerning the layout are presented. In addition some experimental work on a magnetic multipole ion source as well as on extraction and ion beam transport has been done for that purpose. Results and remaining problems are pointed out.

Introduction

The SNQ consists of a linear accelerator accelerating 100 mA protons with 5 % duty factor up to 1.1 GeV and of a rotating heavy metal target.

For the design of the SNQ-linac a conventional electrostatic preaccelerator was proposed as injector into the rf-linac. Before a final decision will be taken, the rf-quadrupole structure will be examined extensively as a possible alternative way of injection. In the following the main design criteria, as suggested in the SNQ-study, will be presented and discussed. In addition, some results of experimental work on ion sources, beam extraction and beam transport of a neutralized ion beam will be given.

Design of the Electrostatic Preaccelerator

Requirements

The design current for the SNQ-Linac is 100 mA protons with a pulse length of 500 μsec and a repetition rate of 100 Hz. In order to achieve a sufficiently low level of activation along the linac, only small beam losses are allowed. It is felt that stable beam conditions are of particular importance to obtain a clean machine. A stability of the beam current in the order of one percent both during a pulse and over long time were therefore specified. All components have to work very reliably and, after shutdown have to deliver reproducible beam conditions in order to guarantee the desired availability of the SNQ.

Choice of the Injection Energy

A high injection energy is desirable in order to reduce the problems of beam dynamics at the front end of the accelerator. On the other side, the availability of an electrostatic preaccelerator decreases with increasing accelerating voltage because of high voltage breakdowns. Taking into account the stringent requirements on reliability for the SNQ and considering expecially the experiences in accelerating continous ion beams at CRNL[2] and at LLL[3] an injection energy of 450 keV was chosen. An increase up to 600 or even 800 keV seems to be possible after an adequate development time. Valuable experiences for operation at higher voltages will be obtained from other projects under construction[4,5].

Principle Arrangement of the Preaccelerator

The electrostatic acceleration takes place in two stages. First the ion beam is extracted out of the ion source at a low voltage ($\lesssim$ 50 kV), transported to a high voltage column and then accelerated there to the desired energy (Fig. 1). The two-stage arrangement chosen offers considerable advantages over the more

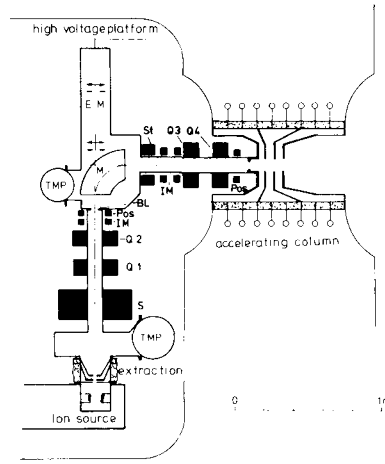

Fig. 1: Schematic arrangement of the two-stage preaccelerator. TMP = turbomolecular pump, S = solenoid, Q_1 - Q_4 = quadrupoles, M = 90°-bending magnet, St = steering magnet, IM, Pos, EM = diagnostic elements

conventional one-stage system where the ion source is directly attached to the high voltage column[6,7].

- The extraction voltage can be chosen independently from the total preacceleration voltage. The extracted ion beam current can be appropriately controlled ($I \propto U^{3/2}$), therefore.
- The beam transport system, which follows the extraction from the ion source can be used to match the beam to the optics of the accelerating column. By removing the beam halo at the entrance of the column, beam spill inside the column can be reduced.
- The pressure in the high voltage colums can be kept low by differential pumping.

However, the extracted low energy ($\leq$ 50 keV) ion beam must be transported with a high degree of neutralization. The transport of a neutralized ion beam, especially through magnetic transport elements, may result in an emittance growth by beam plasma oscillations[8].

To keep the beam parameters sufficiently constant over the pulse length and to provide short (< 1 μsec) rise and fall times, the required pulse of 500 μsec will be formed on the 450 keV level by an ultra fast beam deflector. A rough pulse will be preformed by pulsing the ion source. Chopping the beam at 50 keV was excluded, because of the high space charge forces at that energy.

Description of the Components and Experimental Results

Ion Source

A magnetic multipole ("bucket") source [9,10] has been chosen, although several other kinds of ion sources are able to generate the required proton currents. The main advantages of the multipole source for accelerator operation are:

- The arc discharge is quiet. The noise level (1 MHz bandwidth) of the extracted ion current was measured to be less than 1 % at continous operation.
- The ion current density is constant over the extraction aperture. Therefore, the beam can be ex-

tracted nearly free from aberrations with reproducible beam properties.
- The operation of the source is simple and reproducible.

The disadvantage of the multipole source is its relatively low proton percentage.

To evaluate the properties of the source, especially for an accelerator application an experimental program was started. Extensive measurements have been done mainly on the ion source shown in Fig. 2 and 3. The source consists of a cylindrical anode body (diameter = 11 cm, length = 15,8 cm). Twelve rows of cobalt-samarium magnets produce a magnetic multipole field. On the backplate the magnets were arranged either radially or parallel without any significant difference seen in operation of the source. Tungsten filaments were used as cathode. The heating current of the filaments was used to control the discharge current at constant discharge voltage (emission limited mode). The extraction plate was normally kept on cathode potential. The source was operated at pressures between 2 and 20 µbar, mainly, however, around 6 µbar. The maximum discharge power limited by the power supply and by the cooling capability of the source was 10 kW (80 A, 125 V) for continous operation. The corresponding ion current density j_+ at the extraction aperture was measured to be $\sim$ 500 mA/cm^2. At constant gas pressure j_+ is proportional to the discharge current with only a weak dependance on the discharge voltage.

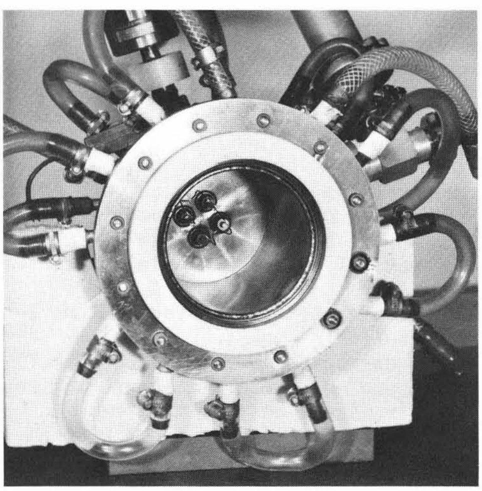

Fig. 2: The tested magnetic multipole source with removed extraction plate

With a movable probe j_+ near the extraction plate was measured as a function of the radius and was found to be sufficiently homogenous. Over the extraction aperture with a radius of 6.5 mm j_+ is constant to better than 1 % (Fig. 4).
The lifetime of the tungsten filament consisting of two parallel 16 cm long tungsten wires helically wound was tested at continuous discharge operation. The filament current was controlled to keep the discharge current constant at 40 A at a constant voltage of 90 V. The required filament current decreased from 98 A at the beginning of the test to 85 A after 155 h of operation when the cathode failed. During this operation time the diameter of the tungsten filaments decreased from 1.0 mm to about 0.9 mm. Not only thermal evaporation, but also sputtering through the plasma ions causes a significant reduction of the filament diameter as observed on an additional cold filament, which

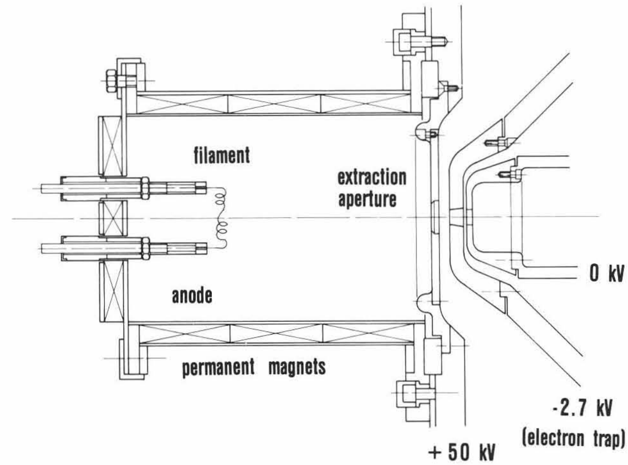

Fig. 3: A schematic view of the tested ion source with a 3-electrode extraction

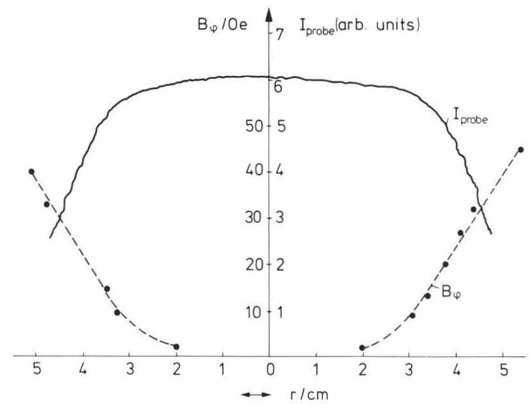

Fig. 4: A typical plot of the ion current density j_+ and the azimuthal magnetic field B_ϕ near the extraction plate as a function of the radius

diameter decreased to about 0.95mm over the operation time. For a pulsed operation with a low duty factor the effect of the plasma is strongly reduced, therefore a longer lifetime is expected even if the filament is heated continuously.
The proton yield of the extracted beam was found unconfortably low. The highest proton percentage achieved was 55 % at the highest obtainable discharge current of 80 A (Fig. 5). Experiments on modified source geometries as suppested from experiences at UKEA Culham[9] and LBL[10] are underway.

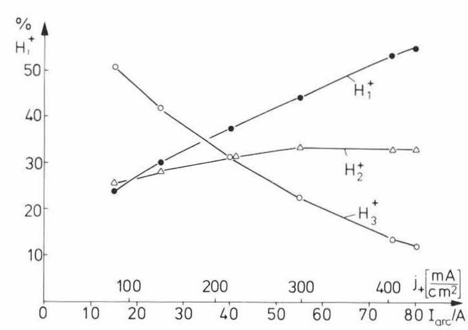

Fig. 5: Ion species as a function of discharge current I_{arc} resp. ion current density j_+ at U_{arc} = 125 V and p_{arc} = 10 µbar

The pulsing behaviour of the ion source was tested by pulsing the arc voltage. The rise time was observed to be about 30 μsec. During a pulse the discharge current respectively the ion current are decreasing by typically 2 or more percent over 100 μsec for pulses of a total length up to 2 msec. An improvement in the stability of the ion current is expected by pulsing with a constant current generator and allowing the discharge voltage to change during a pulse.

Extraction and Ion Source Beam Transport

In order to obtain 100 mA of protons at the entrance of the rf-accelerator, a total ion beam of about 250 mA has to be extracted assuming a proton yield of 60 %, a bunching efficiency of 80 % and beam losses on scrapers and due to charge exchange of 20 %. A 250 mA ion beam can be extracted out of a single aperture with diameter of 13 mm at ∿ 50 kV. The results of a computer optimization are shown in Fig. 6. The calculations have resulted in a divergence of less than 20 mrad and a normalized rms-emittance of about 0.05 π mm mrad for an ion temperature of 0.7 eV. The suggested beam transport system between the ion source and the accelerating system is shown schematically in Fig. 1. The extracted divergent beam is matched to the following part of the system by a solenoid. Four quadrupoles and a 90°-bending magnet transfer the beam in a 1:1 scale to the entrance of the acceleration column, where the beam halo will be scraped off. A comparable system was optimized with the TRACE program and it was found that the extracted ion beam can easily be transportet if the space charge is neutralized to at least 90 %.

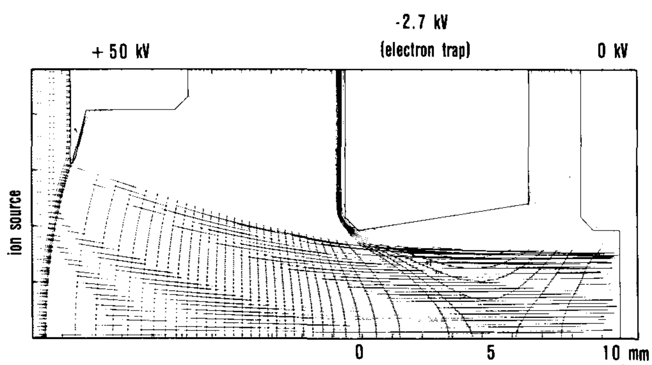

Fig. 6: Beam forming in an optimized 3-electrode extraction system. $j_+ = 200\ mA/cm^2$, $\Phi_{aperture} = 13$ mm

In order to study the behaviour as well of the extraction as of the transport of a neutralized ion beam, some experimental work has been done on a high voltage test stand. An ion beam was extracted with a 3-electrode extraction system (Figs. 3, 6). The perveance and divergende were found in good agreement with the calculated values. At 50 kV a total ion current of 240 mA has been extracted at continuous operation resulting in a perveance of $2 \cdot 10^{-8}\ A/V^{3/2}$.

In addition to a visual observation of the beam width the beam profile was measured with a movable multi wire scanner consisting of a cooled 0.5 mm slit with an arrangement of tungsten wires behind it. From the thus measured divergence of the drifting beam a neutralization degree fo at least 97 % was estimated for a 35 mA beam at 45 keV at a pressure of $2 \cdot 10^{-8}$ bar.
The focusing effect of a solenoid on the transport of a neutralized ion beam was examined. Within the estimation error of about 5 % the experimental focal length of the solenoid agrees with the calculated value for the space charge free case. When focusing the ion beam (one species) to a spot of a few mm diameter an increase of the amplitude of oscillations by more than a factor of 10 was observed with the multi wire scanner coming presumably from oscillations in the beam plasma. The main frequency of the oscillations is around 30 to 50 kHz. It will be proven, how far these oscillations are causing a modulation of the ion beam current density. The experiences gained with the solenoid demonstrate that a low energy (≤ 50 keV) neutralized ion beam can easily be matched with reproducible properties to a high voltage column only with a solenoid, giving thus on alternative to the suggested transport system (Fig. 1).

The Accelerating Column

The ion beam will be postaccelerated in a high voltage column up to the desired injection energy. Experiences at LLL[2] were taken into account for designing the column. The total voltage is distributed over 3 accelerating gaps producing a nearly constant field of 30 kV/cm. The beam transport inside the column was verified with a computer code. The large aperture of the electrodes of 10 cm diameter gives a high pumping speed and reduces beam losses inside the column.

Conclusions

Within the present state of the art the preaccelerator for the SNQ-linac can be built reliably. To guarantee the strong requirements on beam properties some development work on the ion source concerning the pulsing behaviour and also the proton yield are necessary. In order to know the beam properties extensive measurements especially of the beam emittance have to be done.

Acknowledgements

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