BEAM THROUGH THE VIVITRON

R. Rebmeister, F. Haas, G. Heng, A. Nadji, C. Muller and J.D. Larson
Centre de Recherches Nucléaires, IN2P3-CNRS/Université Louis Pasteur
BP 20, F-67037 Strasbourg Cedex, France

Abstract : Methods and techniques of beam transport through the new 35 MV accelerator are reviewed. Emphasis is placed on recent changes and improvements.

Introduction

The Strasbourg 35 MV Vivitron tandem electrostatic accelerator now under construction inaugurates new technology in high voltage generators. Beam transport through the Vivitron is deliberately less innovative, relying more on conventional methods that have proved successful in MP-class tandem accelerators. Recent measurements and calculations are being analysed in an effort to identify the causes of beam loss so that beam transmission can be maximized.

The general operation of the accelerator has been outlined previously [1]. At that time, the injection energy was assumed to be ~ 150 keV and the terminal lens system that both matches beam into the high energy (HE) section and also provides charge state selection was assumed to require a conventional point-to-point focus. A more detailed description [2] was based on a quantitative approach to beam transmission but assumed a comparatively large value for the ion source emittance that now seems unnecessarely pessimistic. Recent measurements [3] show that for beams of a few μA intensity, 90 % of particles from the negative ion sources of interest to this project have a normalized emittance less than 5 π.mm.mrad.MeV$^{1/2}$. Extensive transmission measurements performed on the Strasbourg MP accelerator [4] have distinguished between beam losses due to insufficient vacuum and losses caused by emittance growth in stripper foils.

Low Energy Acceleration Stage

Injector

The negative ion injector platform [5] will be powered by a 300 kV dc high-stability Haefely power supply and a separate 50 kVA, 3-phase isolation transformer. Mounted on this platform will be a 75°, 0.67 m radius mass analysing magnet preceded by an additional 60 kV stage of pre-acceleration. With ~ 20kV provided directly by the ion source, ~ 380 keV injection energy will be available at the Vivitron low energy (LE) entrance. Since publication of the injector details [5], refinements have been made to matrices used in the TRANSPORT code [6] for electrostatic lens calculations, the downstream quadrupole triplet lens has been relocated and adjusted to better match the new Vivitron LE object point (which, for practical reasons, has been pushed 0.5 m further upstream), and a new standard emittance of 5 π.mm.mrad.MeV$^{1/2}$ has been adopted for calculations.

Low Energy Section and Tube 1

All Vivitron accelerator tubes are of the conventional inclined-field type manufactured by Vivirad-High Voltage. The LE section [1] comprises tubes 2 through 8, all of 2.54 m insulated length, preceded by 1.68 m long tube 1 and terminated by 1.32 m long tube 9 (see Fig. 1).

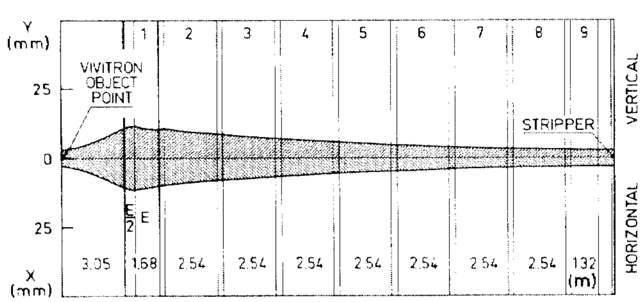

Fig. 1. Half beam envelopes of $^{60}Ni^-$ in the LE section of the Vivitron for an injection energy E_I = 250 keV and a terminal voltage V_T = 28 MV.

Tube 1 requires a special design to accomodate low energy injected beams. A prototype fully-inclined tube 1 using 7° entrance electrodes and capable of operating with injection energies below 100 keV has been successfully tested in the Strasbourg MP accelerator. Subsequently, it has been decided to provide the Vivitron with injection energies of 250 keV, or more, and it was thus proposed to change the initial electrodes in tube 1 from 7° to 14° ; consequently, the Vivitron accelerator tubes will be equipped with only 14° inclined electrodes except for standard 7° and 0° transition electrodes where a change in field direction takes place. The first two 14° inclined sections will be operated at half gradient in order to reduce the initial strong steering effect. Off-axis beam injection will be required, as has been the case for the 7° prototype tube.

The strong natural aperture lens caused by fringing fields at the entrance to tube 1 is cancelled by a grid mesh stretched across the opening. An adjustable, gridded gap lens is then created by placing a grounded cylinder in front of the grid and applying voltage to the grid. A useful approximation for calculating the optics of the gridded lens has been deduced from the work of Verster [7] in the form [8] :

$$T = \begin{pmatrix} \gamma & 0 \\ (k\gamma\ln\gamma)/D & \gamma \end{pmatrix} \qquad (1)$$

$$P = -(k\ln\gamma)/D \qquad (2)$$

where T is the first order beam transport matrix, P is the lens power, k = 2.652, $\gamma = (U_1/U_2)^{1/4}$, U_1 and U_2 are the potential drops from the source to each side of the lens, and D is the diameter of the cylinder facing the grid. This adjustable lens controls the focus between the fixed external object point and a stripper in the high voltage terminal.

At the location where the transition from the half to full gradient takes place within tube 1, a second aperture lens arises with focal length :

$$f = 8L\left(\frac{V_I}{V_T} + \frac{l}{2L}\right) \qquad (3)$$

where V_I is the injector voltage (total magnitude), V_T is the terminal voltage, l = 0.48 m is the length of the half-gradient acceleration and L = 20.48 m is the electrically active (effective) length of the LE section. The focal length of this second lens ranges from about L/3.5 to L/7 and it provides most of the required focusing. With the new object point located 3 m in front of tube 1, the adjustable gridded lens will provide from 0 to about 1/3 of the total focal strength, depending on injection and terminal voltages.

This concentration of lenses at the LE entrance is usual but has drawbacks. The grid intercepts about 13 % of the beam and produces secondary electrons and negative ions that accelerate into tube 1. The beam arrives at the terminal stripper with comparatively large size and low divergence (0.2 to 0.3 mrad) ; consequently, stripping causes a large growth in beam emittance [9]. An alternative is to locate one or more intermediate lenses within the LE section but such possibility has been rejected because it would diminish the space available for accelerator tubes.

Contrary to a previous assertion [2], the low energy acceptance is now expected to be at least as large as the beam emittance provided the terminal voltage exceeds 20 MV ; therefore, the choice of the LE optics described above is not expected to limit beam transmission (except for a 13 % loss at the grid) as illustrated in

Fig.1. A vacuum pump installed in the dead section between tube 4 and tube 5 will produce in the LE section a pressure ranging from 10^{-6} to 10^{-7} torr [10]. Beam transmission measurements done with the Strasbourg MP accelerator and extrapolated to the Vivitron predict overall LE transmission of about 0.58 with gas stripping and 0.70 with foil stripping [4].

High Energy Acceleration Stage

Terminal Region

Most of the space in the 3 m long terminal is occupied by gas and foil stripper assemblies (37 %) and the charge selector (53 %). A Faraday cup located in front of the strippers and vertical steerers following the selector occupy the remaining space. The gas stripper canal has a length of 834 mm and a inner diameter of 10 mm. The main quadrupole lenses of the charge selector assembly are displaced 20 mm off axis horizontally. Other details of these systems have been given previously [11].

Recent studies have revealed improved modes for operating the charge selector. Because the lenses are close to the strippers and far from the selection aperture, the point-to-point magnification is incomfortably large (typically ~ 3-fold) even after including compressive effects due to acceleration. The relatively large radius r of the beam (up to 5 mm) at the stripper and moderate divergence r' after stripping (typically less than 3 mrad) are in favor of parallel-to-point focusing. Simulations with the codes TRANSPORT and OPTICII [12] show that for r' < 1.5 mrad, the parallel-to-point mode in both horizontal and vertical planes is best while for r' > 1.5 mrad a mixed mode of point-to-point in the horizontal plane and parallel-to-point in the vertical may be preferable. For V_T = 20 MV and a 5 μg/cm² carbon foil stripper the transition region where r' = 1.5 mrad occurs at mass A ~ 100. A fourth quadrupole lens element already incorporated into the charge selector system makes this variety of operational modes possible by allowing some limited independence between adjustments for charge selection and for focusing.

High Energy Section

Like the LE section, the HE section contains 7 long (2.54 m) accelerator tubes (11 through 17) bounded by "half-length" (1.32 m) tubes 10 and 18. The natural aperture lens at the entrance of tube 10 is convergent in the vertical plane with approximate focal length

$$f = 2\,L/Q, \qquad (4)$$

where Q is the ion charge state and L is the electrically active length of the HE section. This tube entrance lens provides no focusing in the horizontal plane (because of slot aperture geometry) but the resulting astigmatism is overcome by quadrupole lenses in the terminal so that a beam of minimal size and nearly circular shape can be obtained at the second stripper located after tube 12. The charge selection aperture and a Faraday cup have been shifted upstream to the dead section between tube 11 and tube 12. An example of calculated beam trajectories is shown in Fig. 2

As in the LE section, the pressure in the HE tubes is forseen to fall in the range 10^{-6} to 10^{-7} torr ; therefore, no significant loss of this more energetic beam due to collisions with the residual gas will occur. However, a possible loss due to emittance growth in the terminal stripper has to be taken into account. Emittance growth in the second stripper will be small by comparison. Using only a foil stripper in the terminal, HE beam transmission is predicted to range from 0.6 to 1.0 (before adjustment for charge state distribution). Because of the present short lifetimes of foil strippers in the terminal, the likely operating mode for heavy beams (A > 40) will be gas stripping in the terminal followed by foil stripping at the second stripper.

Beam Transport After Acceleration

A magnetic quadrupole doublet lens will focus the beam to the object point of a conventional 90°, 1.83 m radius, K = 400 MeV.amu, double focusing analysing magnet. Signals obtained from slits at the magnet image focus will provide feedback to control terminal voltage using conventional methods. Downstream of the analysing magnet a magnetic quadrupole triplet lens, split and separated into a pair of doublets with an intermediate horizontal image, will match the beam into the existing beam lines while maintaining a magnification/dispersion ratio whose sign is the same as in the actual MP accelerator configuration.

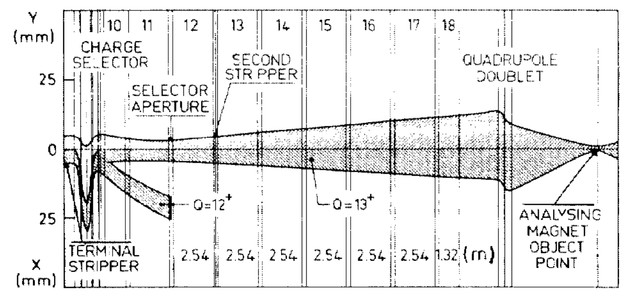

Fig. 2. Half beam enveloppes of $^{60}Ni^{13+}$ and $^{60}Ni^{12+}$ in the HE section of the Vivitron at a terminal voltage V_T = 28 MV. The charge selector is tuned for charge state 13^+. Ions of charge state 12^+ are stopped at the selection aperture.

Conclusion

Although the Vivitron, equipped with tubes of the same geometry as our actual MP accelerator, is twice as long as the MP, one expects a beam transmission of the same order of magnitude or even better. Moreover, high mass resolution at the injector and charge selection inside the terminal electrode should provide the users with a unambiguous particle species and a beam of excellent stability.

References

[1] J.D. Larson, Nucl. Instr. and Meth. A244 (1986) 192

[2] A. Nadji, F. Haas, G. Heng, J. Hoffmann, Ch. Muller and R. Rebmeister, Revue Phys. Appl. 23 (1988) 1445

[3] A. Nadji, F. Haas, G. Heng, Ch. Muller and R. Rebmeister, Nucl. Instr. and Meth. A287 (1990) 173

[4] R. Rebmeister, F. Haas, Ch. Muller and A. Nadji, Nucl. Instr. and Meth. A287 (1990) 150

[5] F. Haas, G. Heng, J. Hoffmann, Ch. Muller and R. Rebmeister, Nucl. Instr. and Meth. A268 (1988) 465

[6] K.L. Brown, D.C. Carey, Ch. Iselin and F. Rothacker, TRANSPORT : A computer program for designing charged particle beam transport systems, Internal Report, CERN 80-84. An electrostatic accelerating element and a drawing package were added at Strasbourg to the original CERN version.

[7] J.L. Verster, Philips Research Report 18 (1963) 467

[8] R. Rebmeister, "Matrice de la lentille-grille équipant les accélérateurs Tandem", in Vivitron Annual Report (1989)

[9] F. Hinterberger and D. Prasuhn, Nucl. Instr. and Meth. A279 (1989) 413

[10] J. Heugel et al. Nucl. Instr. and Meth. A287 (1990) 109

[11] R. Rebmeister, "L'injecteur, le terminal et le transfert du faisceau vers les lignes actuelles", Internal Report CRN-VIV-57 (1988)

[12] J.D. Larson, OPTICII, A computer code for the same purpose as ref. [6] that includes an electrostatic accelerating element (unpublished).