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THE NEW VAN DE GRAAFF TERMINAL FOR VICKSI

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Summary

A heavy-ion terminal for the CN-Van de Graaff as the injector of the VICKSI accelerator combination has been developed and tested. Beams of all kinds of ion species with the mass numbers of up to about 40 and charge states of 1^+, 2^+, and 3^+ will be produced and transported, properly matched, to the acceleration tube of the Van de Graaff; average beam currents out of the Van de Graaff are anticipated to rate up to 20 µA.

Introduction

Within the accelerator project VICKSI[1] at the Hahn-Meitner-Institut in Berlin the single ended 6-MV Van de Graaff has been converted into a heavy-ion accelerator to serve as the injector machine into the four sector cyclotron. As part of the conversion a completely new terminal has been built.

Besides the ion production four essentials are realized within the terminal: (i) charge state selection in order to avoid unnecessary beam blow-up and beam loading of the acceleration tube and other terminal components, (ii) prebunching to minimize intensity losses,when transforming the dc-beam out of the source into a pulsed beam accepted by the cyclotron, (iii) beam matching to the optics of the acceleration tube, and (iv) sufficient pumping capacity to ensure a vacuum of 10^{-7} to 10^{-8} torr within the tube. In addition the terminal has to fulfill the specific conditions dictated by a single stage machine with respect to space and power limitations and the surrounding tank gas pressure of 16 kgf/cm^2.

Full beam and power tests have been undertaken on the terminal by installation in a separate pressure vessel prior to the final installation on top of the Van de Graaff. In the following sections a more detailed description of the main components and of the terminal system is presented.

Description of the Main Components

Ion Source

An improved version of the axial extraction Penning ion source (originally designed by Baumann,Bethge and Heinicke[2]) was chosen because of its small size and power consumption (less than 300 W). Up to now we have only used it for the production of ions out of gaseous elements or compounds. The characteristic operating data are: gas flow F = 3...15 st.cm^3/h, magnetic field B = 0.5...1.1 kG, arc voltage U_a = 1...4 kV, arc current I_a = 1...20 mA. Total beam currents out of the source are in the order of 1 mA. Reliable operation could be demonstrated with lifetimes of about a week. Current and emittance measurements[3] on which the design of the new terminal was based showed that for typical beams like N, Ne or Ar an intensity of at least 1 µA for doubly charged ions can be expected yielding a beam intensity on target of more than 100 pnA if the theoretical transmission for the whole system of 10 % can be realized.

Charge State Selector

As the charge state selector a crossed-field analyzer (Wien-filter) with permanent magnets is used. The following dimensions were chosen:

length (mid entrance-mid exit gap)	=	136 mm
electric field gap	=	26 mm
magnetic field gap	=	35 mm
magnetic field	=	2.1 kG

The voltage for the electric field applied to each plate can independently be varied up to 5 kV.With these dimensions the balance condition for passing the filter can be fulfilled for all ions with beam voltages between 20 and 30 kV. For all particles in this energy range except the very light ones the filter has negligible focusing or defocusing effects so that the filter can be considered as a drift length for the passing component. The unwanted component is deflected with an angle at the exit large enough to be separated at an aperture 55 mm downstream. As an example, the separation between an Ar^{2+}-beam and the deflected Ar^{1+}-beam at 30-kV beam voltage is 9 mm at the separation aperture.

Prebuncher

Following the klystron bunching technique with a sinusoidal rf-voltage applied to a buncher tube about 50 % of the dc-beam can be focused into a 60° phase interval at the exit of the Van de Graaff with a negligible energy spread. The main bunching system within the beam line from the Van de Graaff to the cyclotron then compresses the intensity within the 60°-interval down to the acceptance of the cyclotron which is of the order of 6° depending on the desired energy resolution.

The frequency with which the prebuncher is driven is given by the frequency of the cyclotron rf-system, namely 8 to 20 MHz. The most effective utilization of the buncher voltage is obtained,when the phase length $\alpha = 2\pi\cdot\nu\cdot\ell/v$ (ν frequency, ℓ distance between entrance and exit gap, v particle velocity at the buncher)of the buncher tube corresponds to 180°. With the many different velocities and frequencies for all possible ions the range in the phase length variation would have been too large to be covered with one buncher tube length. However, due to the correlation of the frequency and the particle velocity given by the cyclotron and with the help of an extra acceleration gap (0-20 kV) preceding the buncher to adjust the velocity the phase length can be kept within the limits of $\pi/2$ to $3\pi/2$ with a gap distance of ℓ = 25 mm.

In the beam transport section following the buncher the beam energy is adapted to the acceleration tube so that the drift length,i.e. the focal length of the buncher is not constant but strongly dependent on the beam voltage V_o at the buncher. This leads to a nearly constant bunching amplitude V_m for all sorts of ions except for the very light ones; at 6-MV Van de Graaff voltage an amplitude of V_m = 0.5..0.6 kV is needed; for p and ^{3}He the necessary amplitude is 1.1 kV. The buncher voltage is provided by a final 200-W amplifier-signal generator with automatic frequency regulation[4]. The reference frequency is transmitted to the terminal via an infrared data link; the amplitude can be set between 0.2 and 1.5 kV.

Einzel Lenses

In comparison with other lens types the einzel lens has the advantage that only one power supply is needed and that the focal properties are independent on charge and mass of the ion. The disadvantages one has to deal with, however, are the aberrations, especially when several lenses are used in series. Therefore computer calculations with ray tracing were performed for different lens geometries and potentials[5]. With a fixed diameter D and gap width d the smallest focal length deviations resulted for lenses with an inner electrode length ℓ_i larger than the diameter (cf. Liebmann's investigation[6]), and the relative focal length deviation as a function of axial distance turned out to be nearly independent on the relative lens potential Q ($Q = 1-V_c/V_o$, V_c center electrode potential) which determines the paraxial focal length. As a measure of the chromatic aberration it was found that the relative change in focal length is about three times the relative beam energy change.

For the lenses needed within the system the following dimensions (in mm) were chosen as a compromise with the size of the vacuum chambers:

	d	D	ℓ_i	Q	$V_{c\ max}$
lens EL1	10	64	50	~0.1	30 kV
lens EL2	10	60	70	~0.2	30 kV
lens EL3	10	60	80	~0.3	60 kV

Insulation and alignment of the lens electrodes is made by ceramic balls; each ball is shielded with a metallic cylinder. For the lens 3 the shielding cylinders had to be replaced by a common shielding ring to get safe lens operation of up to 70-kV potential difference. The lens power supplies are grounded at extraction potential to keep the necessary voltages as low as possible.

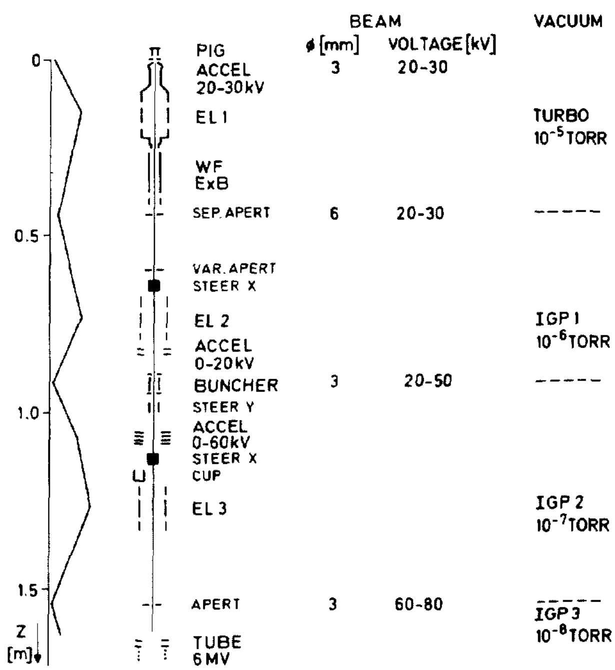

Fig. 1 Basic scheme of the Van de Graaff terminal

Beam Transport through the System

Charge state selection, prebunching, and beam matching are realized within three optical sections with an einzel lens as the focal element in each section. The basic scheme is illustrated in Fig. 1. With the lens 1 following the ion extraction with 20 to 30 kV across a 6-mm extraction gap the beam is focused through the Wien-filter with a beam spot size of about 6 mm at the separation aperture. The lens 2 focuses the beam through the 20-kV acceleration gap into the buncher tube with a beam diameter of about 3 mm. In the third section 1:1-imaging is done to the entrance aperture of the acceleration tube. With the preacceleration tube the energy ratio Q (acceleration tube voltage to terminal beam voltage) is adjusted to Q=75.100 to provide constant optical properties of the acceleration tube; the short tube precedes the lens 3. Steering plates and beam diagnostic elements (Faraday cup, aperture plates) are integrated within the sections.

The transport of the beam from the Wien-filter exit to the tube entrance as calculated by ray-tracing is demonstrated in Fig. 2. At the buncher a beam voltage

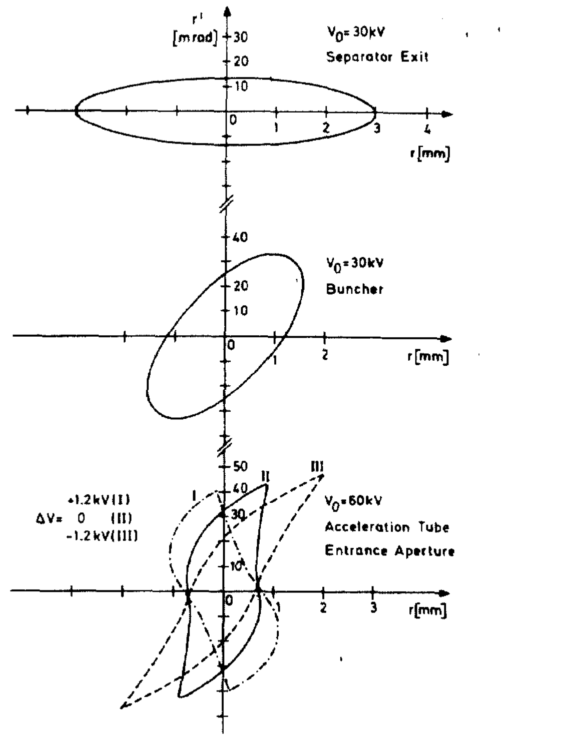

Fig. 2 Phase contours for the beam transport through the terminal.

variation ΔV is added resulting in a 2 % energy variation at the tube entrance. The effect of the chromatic aberration of the einzel lens is indicated by the different phase contours at the tube entrance. In nearly all cases more than 90 % of the beam will pass the 3-mm entrance aperture and will be accelerated through the tube.

Vacuum System

In accordance with the three optical sections, three vacuum sections are formed by using the image points as vacuum apertures with low conductance in order to achieve differential pumping and reduce the neutral gas loading of the acceleration tube. In the first section including the ion source and ending at the separation aperture of the Wien-filter the gas load from the feeding to the source is taken away by a turbo molecular pumping system with nominal 450-l/sec pumping speed[7]. The first section can be shut off from the following ones by an automatic valve in case of a vacuum failure. The following sections are pumped with ion getter pumps. Two getter pumps are arranged around the respective einzel lenses (cf. Fig. 1). With μ-metal shields around the lens electrodes the magnetic field on the beam axis is reduced to less than 0.5 G. The nominal pumping speed of pump 1 and 2 is of the order of 90 l/sec. The conductance between the pumping sections is approximately 1 l/sec. A third getter pump separated from the rest of the terminal by the tube-entrance aperture with a conductance of only 1/10 l/sec only pumps the tube with a nominal speed of 150 l/sec. The pressure range in the different sections is indicated in Fig. 1.

Power Supplies and Control

Due to the limited space and power on top of the Van de Graaff nearly all power supplies consist of conventional unregulated high voltage modules. The voltage setting is done by motor-driven variable transformers. For control purposes all output voltages and/or currents are metered by normalized analogue signals. All input/output signals are carefully shielded with filters, spark gaps, and in some cases varistors for spark protection.

The power for all the terminal components is provided by the charging belt, which drives a single phase 115-V, 400-Hz generator directly and an extra three phase 115-V, 400-Hz generator needed for the turbo molecular pumping system via an insulated fan belt. The total power under running conditions sums up to about 3 kW.

The control and read-out signals are collected on each terminal potential deck, digitalized and transfered via fiber glass cables to a main storage at terminal potential, from where the communication to ground potential is done via three infrared light links[8]. The register at ground potential is connected to the CAMAC-branch of the VICKSI computer control[9].

Tests and Final Installation

Before the terminal was mounted on top of the Van de Graaff the whole system was thoroughly tested under full operation in a separate pressure vessel. To get a better beam analysis the beam was additionally accelerated in a 150-kV tube and analyzed with a 90°-magnet outside the tank. Beams of He, N_2, Ne and Ar were run at open air with total beam voltages up to 40 kV and under full pressure with the full terminal voltage of 60 to 80 kV with analyzed beam currents behind the magnet of e.g. more than 10 pμA for Ar^{2+}. In long term runs the system proved to function reliably.

In the final installation on top of the Van de Graaff all components had to be carefully adapted to fit into the given space of 1 m in diameter and 2.7 m in overall height. The view of the new terminal given in Fig. 3 illustrates the very compact arrangement. The total weight of the terminal including the electrostatic cover (spinning) amounts to about 2000 kg, carried by the column structure of the Van de Graaff.

Conclusion

With the installation of the terminal being completed experience has to be gained about long term stability and reliability in the Van de Graaff operation. The first run over about two days with a 1 μA-Ar^{3+}-beam of 12 MeV was very encouraging.

Acknowledgement

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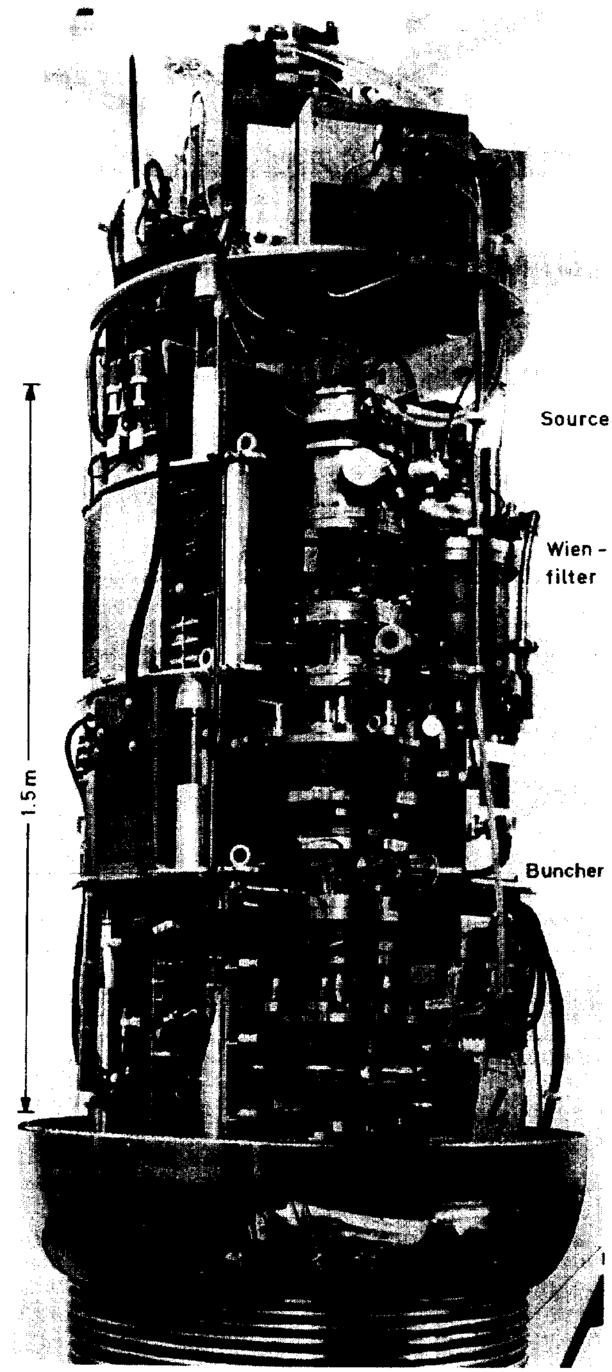

Fig. 3 The installed terminal on the Van de Graaff.

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