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PRESENT STATUS AND FURTHER DEVELOPMENTS OF THE VICKSI HEAVY ION FACILITY

VICKSI-Group, presented by W. Busse
Hahn-Meitner-Institut Berlin, Glienicker Str. 100, D1000 Berlin 39, Germany

Summary

The VICKSI accelerator facility, a combination of a 6 MV Van de Graaff injector and a split pole cyclotron has been completed. Extensive beam tests and regular operation indicate that all specifications are obtained. Seven different ions have been accelerated to 23 different energies since the running in periods in 1977. In 1978 the beam was actually available about 60 % of the time scheduled for experiments. A second injector for the cyclotron is presently under study. It has been approved by the advisory committee to the scientific board and it is planned to be available in 1982.

Introduction

A detailed description of the VICKSI facility has been given earlier[1)2)3)4)]. Therefore we shall only give the main parameters here, before we report on the present status of the machine, on the beam development procedures and on our future plans.

Positive ions of mass $1 \leq A \leq 86$ and charge q_i (typically 1^+ to 4^+) are produced in an axial penning ion source of the van de Graaff terminal[5)]. After preacceleration in the van de Graaff the ions are stripped into charge state q_s and injected into the cyclotron where they are accelerated to about 17 times the injection energy. Thus the final energy is $E_f = q_i \times 6 \times 17\ \mathrm{MeV} \simeq q_i \times 100\ \mathrm{MeV}$. The energy limit given by the design of the cyclotron magnets is $E \leq 128 \cdot q_s^2/A$ MeV. This condition is fulfilled for energies $E \leq 200$ MeV and ions of mass $12 \leq A \leq 40$ using the most abundant charge state q_s (~30 %) from the stripper. For these energies and ions one can expect beam intensities of ~ 100 pnA at the exit of the cyclotron given the present ion source. Three bunchers compress about 50 % of the dc-intensity of the ion source into a 6° phase intervall of the cyclotron radio frequency. One of them, a prebuncher, is located in the van de Graaff terminal, the two others in the beam line between the van de Graaff and the cyclotron. Intensity losses should only be due to bunching and stripping, i.e. one can expect about 15 % of the dc-output of the ion source to be extracted from the cyclotron with an energy resolution of $\Delta E/E = 10^{-3}$.

Present Status

Details of the accelerator system layout have been described earlier. We can state now that the whole system is being completed. The beam lines to the target areas TA, TB, TC, TD have been installed and hooked to the control system. Experiments have been run in these areas since early 1978. The Q3D spectrograph and the vertical beam target area TV are now being finished. The first test run for the Q3D is scheduled for April this year.

With the recent installation of the 2nd buncher in the injection beam line, all the necessary accelerator components to accomplish the specifications of the original proposal have been set up. This buncher will refocus the beam from the stripper location to the center of the cyclotron to obtain a $\pm 3°$ phase width, necessary to get the required energy resolution of $\Delta E/E = 10^{-3}$. For ions with mass $A \leq 20$, a gas stripper can be used to obtain the necessary charge state for acceleration. The energy straggling in the gas stripper is small enough so that even without the use of the 2nd buncher separated runs and single turn extraction can be achieved. For heavier ions, however, a foil stripper is necessary and in this case the 2nd buncher must be operational to obtain beam within the specifications.

Fig. 1 illustrates this effect.

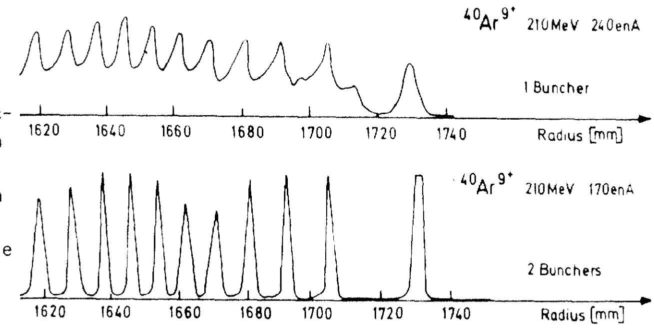

Fig. 1 Turn patterns in the extraction region taken with the radial differential probe in the injection valley. The turn at 1730 mm has passed through the electrostatic deflector. The upper pattern demonstrates the poor turn separation due to energy straggling of the foil stripper if only one buncher is in operation with its time focus in the center of the cyclotron. The lower pattern illustrates the effect of two bunchers, with one time focus at the stripper location and a second focus in the center of the cyclotron.

For the van de Graaff injector the performance of the terminal was improved by changes within the ion source extraction region and by improved cooling. Above all, the high voltage holding capability was considerably increased. During the first part of '78 it was difficult to run the van de Graaff above terminal voltages of 5.5 MV. We attribute this to several openings of the acceleration tube for repair work. Since then careful and intensive heating of the tube and the adjacent vacuum sections has cured the problem.

After the acceptance tests of the cyclotron in March '78, we tried to put further development work into some of its components or to improve their reliability. We had some difficulties with the stability of the main magnet power supply, with arcing of the RF-anode power supplies and with the voltage holding capability of the electrostatic inflector.

A microprocessor controlled current reading for the radial differential probes was implemented in the control system to improve the data acquisition of the turn patterns. Other new features offered by the control system in the course of 1978 are given in a separate contribution to this conference[6)].

Beam Development

For a given particle with given final energy, the pre- and post stripper charge states q_i and q_s are selected. Normally, one chooses the lowest possible charge state q_i out of the ion source compatible with the necessary injection energy for the cyclotron and a maximum terminal voltage of 6 MV.

The beam development from the van de Graaff ion source terminal to the first focus behind the analyzing magnet is done "manually" by the operator. Several computer routines are presently being developped to facilitate this operation. The whole setting up procedure generally takes about 3 to 4 hours mainly due to terminal hardware reaction times.

The setting of injection path elements between the van de Graaff analyzing magnet and the cyclotron was originally based on beam transport calculations. Subsequently, the settings were optimized "manually" with computer assistance. In the meantime, a corrected set of data has evolved from this experience. Presently, if the beam has been well aligned at the exit of the van de Graaff and if the injection path elements have been set to their predetermined values, a slight variation of the steerers behind the analyzing magnet is sufficient to guide the beam through the stripper to the cyclotron. If an optimization is needed to correct for unexpected beam losses about 1 hour is sufficient for this procedure. The same method is used for the beam transport between the cyclotron and the target areas.

The setting of the cyclotron is based on precalculated values by a program called PARSET which is run beforehand. They are extracted from the field mapping data that were taken before the cyclotron was delivered. The transfer of these values to the accelerator data base[7] and the subsequent setting of the cyclotron parameters is operator initiated. The optimization is then done in four steps. 1.) Optimization of the injection 2.) Setting up of the isochronous field 3.) Centering of the particle turns 4.) Optimization of the extraction. The first setting of the cyclotron is always precise enough to accelerate the beam to the extraction radius after a slight variation of the main magnet field (some ‰) and of the injection phase. The actual phase history of the beam with reference to the radius is then measured by 10 fixed phase probes[8]. The trim coil current correction for a constant phase is calculated from a correction matrix which was set up by PARSET. In general, 2 to 3 iterations are sufficient to find a constant phase value along the radius[9]. The turns of the accelerated particles are centered with the help of a radially localized field assymmetry in the 4 sectors (1st harmonic component of the magnetic field). This can be achieved by current adjustments of the harmonic coils 2 and 3 that are located at small radii. The method to center the turns is similar to that used for isochronisation. In this case the phase and amplitude of the local 1st harmonic are the variables, whilst the turn separations are the parameters to be measured. The latter are determined by automatic evaluation of the turn patterns that are acquired with the radial differential probes and that are stored by the computer. Contrary to isochronisation, the control matrix is determined experimentally[10]. For the extraction optimization, we vary the 1st harmonic of the magnetic field in the extraction area by current adjustment of the harmonic coil 11. This 1st harmonic largely influences the position of the last turn and the turn separation at the entrance of the electrostatic deflector. In general a 90-100% extraction efficiency can be achieved. Two to three hours are needed for an optimized cyclotron setting.

We have accelerated 7 different ions from ^{3}He to ^{84}Kr to a total of 23 energies. Another 6 ions have been extensively tested in the ion source test stand and the van de Graaff injector. They could be accelerated on request any time (cf. fig. 2). The particle transmission from the ion source to the faraday cup behind the cyclotron was 12.5% for a beam of ^{16}O-ions, in the best case. Routinely, transmission values between 5% and 10% are obtained. For the heavier ions, however, (^{40}Ar and ^{84}Kr) the transmission was only around 5%. We attribute this to the use of the foil stripper giving larger energy straggling than gas and consequently a larger phase width in the cyclotron. Therefore, the orbits are not quite as well separated which results in additional losses during extraction. Fig. 1 shows that this effect is eliminated with the 2nd buncher in operation and the proper time focus in the cyclotron center.

Experience with the System

At the beginning of 1978, even before the cyclotron had been accepted, a few preliminary experiments were started. Until the end of 1978, we had scheduled 182 days of operation, out of which 1373 hours of beam were delivered to experiments.

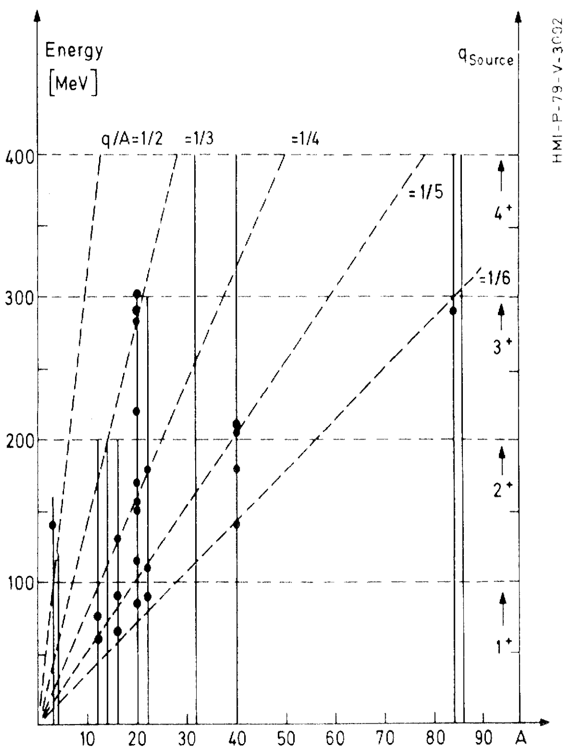

Fig. 2 Summary of the beams produced so far. The final energy is plotted versus nucleon number A. The vertical lines indicate ions which have been tested and can be produced. The dots are beams which have been accelerated in the cyclotron. On the right side, the limit due to the charge state of the ions out of the source is shown. The limit of the cyclotron magnets for charge to mass ratios 1/2 to 1/6 are also indicated.

This represents available beam at about 60% of the scheduled beam time, at about 31% of the scheduled operations time and about 15% of the calendar time.

44% of the unscheduled down time was due to problems with the injector including the terminal, 43% due to the cyclotron, 11% due to difficulties in the beam guiding system including stripper and bunchers, and 2% due to the computer control system. The down time caused by the injector is so high because any repair which requires an opening of the van de Graaff pressure tank, includes the time for opening and closing the tank. The down times of the cyclotron were mainly due to problems with the main magnet supply, which we think we have solved now.

It should be noted, however, that priority was given to careful fault analysis during this time and not necessarily to quick repairs and a short down time.

Furthermore, it should be mentioned that the ion source life time now extends beyond 300 hours of operation. As a consequence, there was no pressure tank opening in 1978 because of limited ion source life time.

Since the voltage holding of the van de Graaff had improved, we were able to run it up to 6.4 MV in conditioning periods. The machine is now stable when running at 6.2 MV. Its high voltage memory proved to be excellent. Pumping times after sparks also reduced considerably and the machine is back to its original voltage setting after 5-15 min. However, difficulties still show up if the machine is operated above 5.5 MV and with beam currents of more than 5 pμA.

The beam transport and observation system has turned out to be stable and fully capable. The settings reproduce the beam optics extremely well. The original philosophy[11)12)13)] on which the transport system is based, has proven to be correct.

Difficulties with the setting up, the running in and the operation of the machine has been greatly alleviated by making full use of the capabilities of the computer control system. It turned out to be easy to handle. It is versatile and flexible enough to allow future extensions.

Future Development

The setting up of the beam transport system to the target areas TE and TV, connecting it to control system and testing it will be one of the major tasks for the coming year. In spite of the interference due to running and servicing the machine, we hope to have the whole transport system ready in early 1980.

Much effort is presently being made to enhance the overall performance of the machine.

- The foilstripper is reconstructed to use a different way of wobbling with the aim to enlarge the medium lifetime of the foils.
- Radial fingerprobes replacing the existing radial differential probes in the cyclotron will allow a "non-destructive" way for turn pattern acquisition. This will allow us to check the centering and separation of the turnswhilst the beam is still delivered to the target areas.

The production of more ions to be extracted from the ion source and to be accelerated with sufficient beam current is constantly worked on. The ions $^{34}S^{1+,2+,3+}$ are the latest awaiting acceleration. Currents of 30 - 50μA, 1 - 3μA and 0.1 - 0.2μA respectively were drawn from the ion source.

Proposal of a Second Injector

The CN van de Graaff injector is and will be the part of the accelerator system which, in general, requires most of the service within the system. This is mainly because the ion source terminal is mounted in the pressure tank at the high voltage end.

Another limit is set by the present ion source because it can only produce ions from gaseous ion combinations.

Therefore, a second injector was proposed early in the project[14)] with the aim of increasing the availability of the whole system for experiments. Although a well founded study of various injector types was published, the project of a second injector had to be postponed because of our limited man power.

For the new proposal two alternatives were reviewed and discussed: a superconducting cyclotron matched to the present VICKSI cyclotron and a 6 to 8 MV tandem. Preference was given to the tandem for the following reasons:

- The tandem has external ion sources producing negative ions. Technically well developped ion sources are available today which can produce negative ions of high intensity for nearly any element (with the exception of rare gases).
- A tandem injector would complement the CN injector in the field of light ions up to mass A~100.
- For ions with mass A≤40 the tandem-cyclotron combination would deliver ions with maximum energies higher than those of the GSI UNILAC or the Heidelberg accelerator combination. For heavier ions, an injector cyclotron would be the better solution. However, this combination could still not compete with the UNILAC.
- A tandem injector may be bought off the shelf, i.e. only little manpower is needed for its installation compared to the superconducting cyclotron which would have to be developped on site and which requires much scientific manpower for years.

With these considerations in view, a proposal was submitted to the HMI scientific board and board of directors. The advisory committee to these boards has approved the proposal and planning money was put in this year's HMI budget. Presently different tandem versions are being studied for a detailed project description.

Acknowledgement

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