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STATUS OF THE VICKSI HEAVY ION ACCELERATOR

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Summary

The heavy ion accelerator combination VICKSI being built at the Hahn-Meitner-Institute in Berlin consists of a 6-MV Van de Graaff accelerator as injector into a 4 sector cyclotron with a mass energy product of 100. The primary design aim of this accelerator combination is 200 MeV for Carbon to Argon ions. The Van de Graaff including ion source and high voltage terminal is undergoing major reconstruction. The beam matching and transport system between the two accelerators comprising a stripper and two bunchers has been designed. The components for this system have been or will be ordered until March 1975. The cyclotron is being built by Scanditronix/Sweden. The four sector magnets will be assembled at Scanditronix for final shimming and field mapping. The RF-system is under test with low power. The new building for the cyclotron is completed except for interior work. The anticipated date for first beam injection into the cyclotron is November 1976.

Introduction

In April 1973 the nuclear physics division at the Hahn-Meitner-Institute in Berlin got the final approval for the construction of a heavy ion accelerator. This new accelerator is a combination[1,2] of the existing 6-MV single stage Van de Graaff accelerator and a four sector cyclotron.

The parameters of this new accelerator were specified by the needs of the research program of the physics division being equally split between nuclear physics, nuclear solid state physics and atomic physics. The accelerator combination VICKSI (Van de Graaff Isochron Cyclotron Kombination für Schwere Ionen) will be able to accelerate all ions between Hydrogen and Argon to energies above the Coulomb barrier of any target nucleus. The energy will be variable with a resolution of $5\cdot10^{-3}$ to $2\cdot10^{-4}$. The beam currents available for experiments will be 10-200 pnA depending on the ion species, energy resolution and time resolution.

Multiply charged ions (q_1 = 1, 2, 3) will be produced in a PIG-ion source with axial extraction or in a duoplasmatron. These ions are accelerated in the 6-MV single stage Van de Graaff accelerator to maximum energies of $q_1 \cdot 6$ MeV. The momentum analysed beam is bunched to 6^o of the RF-frequency of the cyclotron. The charge state q_1 is increased to q_2 in a gas or foil stripper. This beam is injected into the cyclotron along one of the four nearly field free magnet valleys.

The maximum energy of the extracted beam will be $q_1 \cdot 100$ MeV with the condition $q_1 \cdot 100 \leq K \cdot q_2^2/A$. The cyclotron constant K is guaranteed to be 100 but probably the design aim K = 120 will be feasible. The maximum energy for protons will be 50 MeV in order to reduce the upper frequency of the cyclotron.

In our original proposal we intended to use in addition to the Van de Graaff an open air insulated 1-MV preaccelerator or a 4-MV tandem. These plans have been postponed to a future improvement of the VICKSI heavy ion accelerator.

Van de Graaff Injector

In order to accelerate large currents of heavy ions (10-20 pμA) it is an absolute necessity to reduce the production of secondary electrons produced by ionising the residual gas. In order to improve the vacuum the stainless steel high gradient accelerating tube of the Van de Graaff accelerator (CN) has been replaced by an all metal bonded tube from NEC consisting of 20 tube sections. The length of the column has been increased by 10 cm in order to adjust it to the tube. The tube has its own corona point potential distribution and is mechanically and electrically fixed to the column every 5th tube section.

The tube is being pumped with ion getter pumps at both ends and the vacuum achieved is $1-5\cdot10^{-9}$ Torr close to the pumps. The target thickness of the tube is lower than $4\cdot10^{-6}$ Torr·cm which is about 100 times smaller than with the old tubes. The tube has been voltage tested up to 5 MV, however, no beam has been accelerated.

A detailed investigation[3] has been performed to calculate exactly the beam optics of the NEC tube. Especially it is interesting to know the maximum energy to which electrons can be accelerated which have been produced at the one inch apertures at the end of each tube section. The result of this calculation is shown in fig.1. All electrons which are produced at radii smaller than the curve indicated with n = 1, 2, 5, 10 or 20 are accelerated at least through n+1 tube sections whereas all electrons produced at larger radii are hitting any aperture of the next n tube sections.

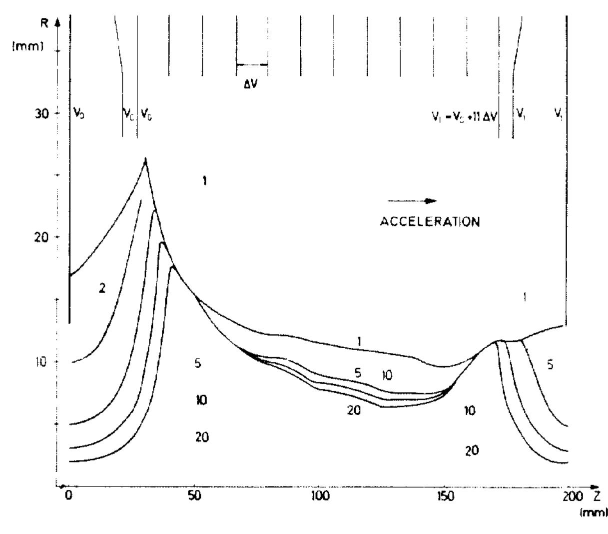

Fig. 1 Areas of a NEC tube section from which secondary electrons are being accelerated through at least n = 1, 2, 5, 10 or 20 tube sections.

To provide the additional space for the heavy ion source and associated electronics, beam optics, pumps, power generators, and cooling capacity, the length of the high voltage terminal has been increased from 150 to 300 cm. The shape of the new spinning has been changed in such a way that the maximum electrical field on the surface of the spinning and the adjoining hoops has been decreased by approximately 20 %. In fig. 2 the electrical fields are shown for the old and new spinning shape. The new spinning and tank ring have been delivered and will be installed in May or June 1975.

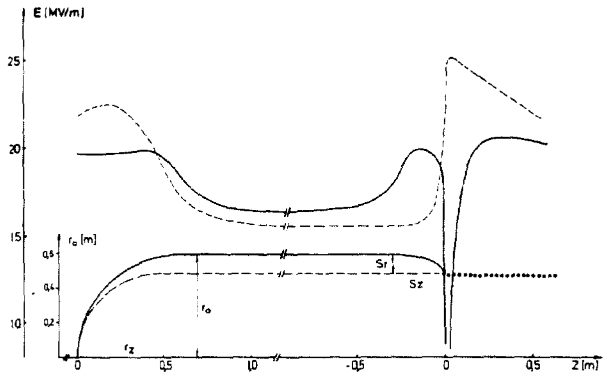

Fig. 2 Electrical fields on the surface of the new (solid line) and old (dashed line) spinning at 7 MV terminal voltage. The radius of the new spinning is 60 cm, the ratios r_z/r_o = 1.15 and s_z/s_r = 2.5.

Because of the short lifetime of the ion source (~180 h) and possible malfunctioning of the complicated electronics it was necessary to provide a short access time to the high voltage terminal for repair, service, and maintenance work. For this purpose a fast gas handling system has been built with a turn-around time of 3 h.

For differential pumping in the terminal a pressure tight turbo molecular pump from Leybold and Balzers is being used. A special pressure tight forepump with a 50 Hz and 400 Hz motor has been developed to be used in the terminal. The exhaust of the pump is being pumped into a 2 l gas bottle.

Terminal and Ion Source

For the production of doubly charged ions a Penning-type ion source with axial extraction[4] is being used on the Van de Graaff terminal. The PIG-source was already run in the Van de Graaff over a 4-months period successfully. A more detailed description on the performance and on the beam quality of the axial PIG-source is given in reference 5. Based on the results of the beam parameter studies and on ray trace calculations, a terminal beam handling system is being built the principle of which is presented in fig. 3. The extracted beam is charge state separated in a Wien-filter, a gross time-structure is imprinted to the beam in a prebuncher running with the cyclotron frequency, and a variable preacceleration of up to 80 KV will provide matching to the 6-MV tube optics. The parameter setting and reading will be done via an infrared data transmission light beam.

Stripper

The energy straggling, angular straggling, charge state distributions, and equilibrium target thicknesses have been extensively investigated for N, Ne and Ar ions in gas and foil targets[6]. Using alternatively a gas or a foil stripper it will be possible to reach the maximum energies at the cyclotron exit for Ne and Ar ions as given in table 1.

Table 1: Maximum particle energies. Numbers without or with parenthesis are the energies for K=100 or 120, respectively.

Yield	Stripper	E_{max} (cyclotron) in MeV Ne		Ar	
≥ 10 %	foil	400	(490)	300	(360)
	gas	320	(380)	60	(75)
≥ 1 %	foil	500	(600)	500	(590)
	gas	405	(490)	200	(240)

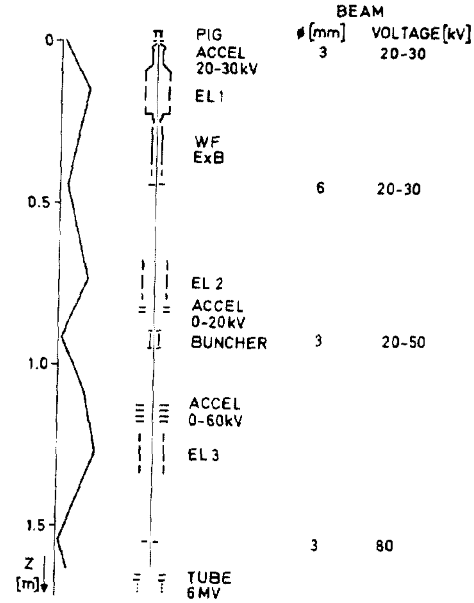

Fig. 3 Beam transport from the ion source to the acceleration tube.

However, the maximum energies will also be limited by the maximum charge state q_1 achieved in the ion source: $E_{max} \leq q_1 \cdot 100$ MeV. If q_1 is larger than 2, the beam currents given above will however not be reached. The current decreases approximately a factor of ten for each charge state.

The stripper will be situated between the Van de Graaff and the cyclotron at the telescopic image of the analysing slits. The center of the gas stripper will be at the same position as the foil. The differential pumping will be done with two cryogenic pumps.

Beam Transport System

The beam transport system of the injection path[7] and from the cyclotron to the experimental area[8] is completely calculated and designed. The optical elements, dipoles and quadrupoles, were specified and quotations were given by various manufacturers. The components will be ordered during March 1975. The design of the vacuumsystem for a vacuum of $<10^{-7}$ torr is completed. It consists of a combination of turbomolecular pumps and ion getter pumps, which have been delivered and tested. Tests are performed for the monitoring and controlling devices in a 10 m prototype section. Prototypes for all beam diagnostic elements (Faraday cups, beam scanners, slits, and a device for the measurement of the beam emittance) are built and under test using the Van de Graaff beam.

Cyclotron

The cyclotron is a four sector split pole machine which is being designed and built by Scanditronix (Sweden). The basic design parameters are given in table 2. A plan view of the cyclotron is depicted in fig. 4. It is planned to have the subsystems, in particular the magnet- and RF-system assembled and tested at the site of Scanditronix before shipment to Berlin. The present status of the work is as follows:

Magnets: A half scale model (fig.5) consisting of two full magnets and two central region magnets, representing the center parts of two sector magnets, has been built. It was used extensively to determine sector- and valley fields and the magnetic field in the central region, which is particularly important for injection. Based on the results from the model the pieces of the full size magnets have been ordered and are presently being delivered and assembled in Sweden. The pole pieces have removable edge shims to enable final touch up and shimming of the magnetic field. The base field will be shimmed to be isochrounous for deuterons. In the coming

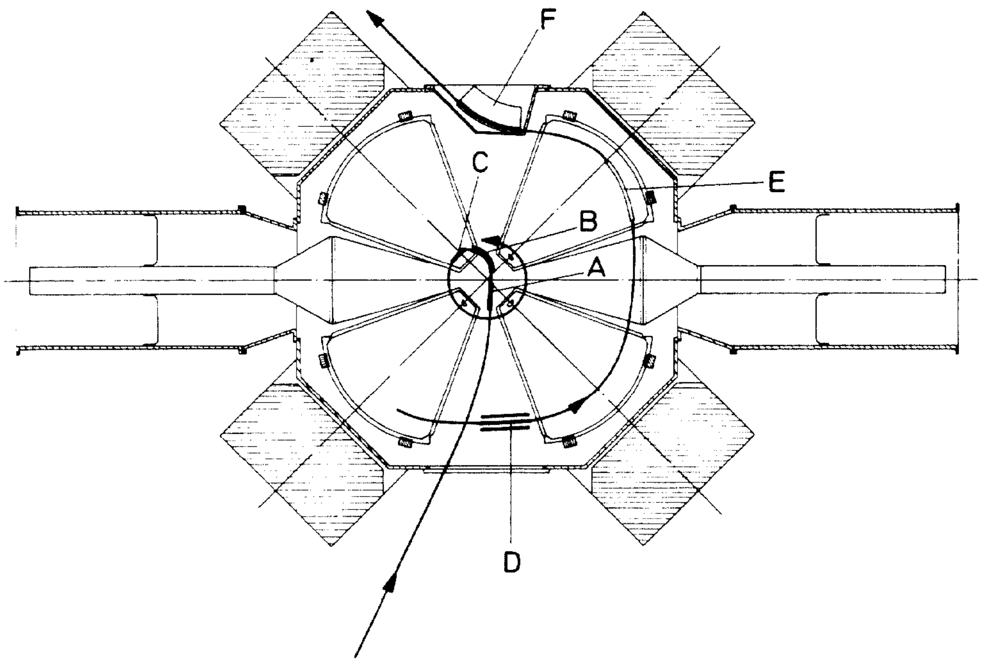

Fig. 4 Planview of the cyclotron

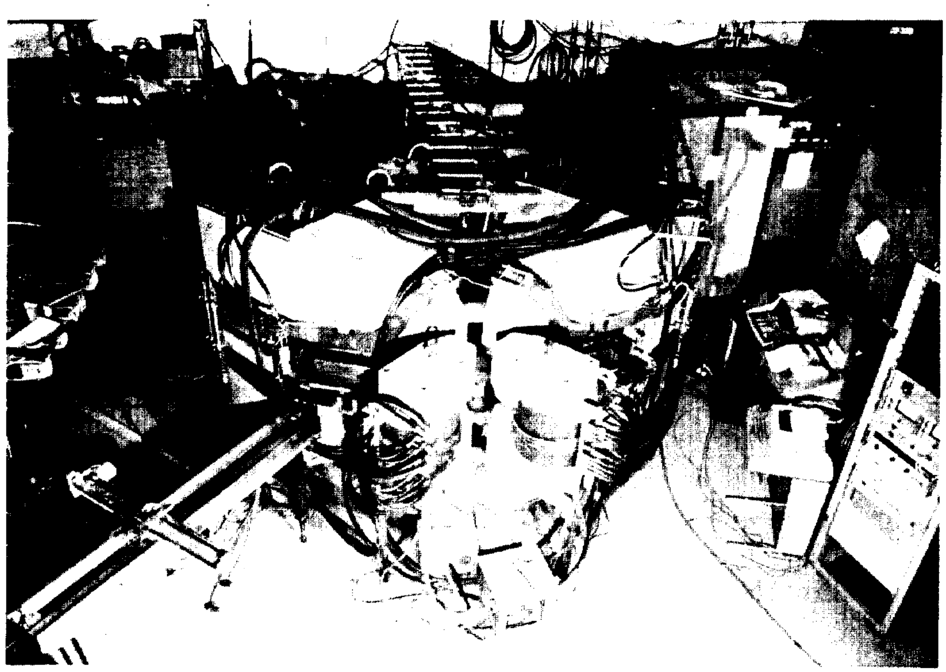

Fig. 5 Half scale model of the cyclotron magnets

months an extensive field measuring and mapping program will be performed giving the base field and the contributions of the trim coils at different field levels.

Table 2

Magnets	
Number of sectors	4
Sector angle	$\approx 50^\circ$
Pole gap	0.06 m
Pole radii	0.306-2.054 m
Beam radii (mid sector)	0.45-1.89 m
Sector field	0.5-1.55 T
Field flutter	0.63-0.82
Radial betatron frequency	1.06-1.14
Vertical betatron frequency	0.65-0.82
Weight of one sector	$\approx$100 ton
Height	3.21 m
Power consumption	300 kW
Preliminary number of trim coils	14
Trim coil power	$\approx$25 kW
Current stability	$5 \cdot 10^{-6}$
RF-system	
Nr of dees	2
Dee angle	$\approx 36^\circ$
Gap voltage	100 kV
Frequency range	8-20 MHz
Frequency stability	10^{-6}
Harmonic number	2-6
Rough tuning	moving shorts
Fine tuning	capacitive
Length of resonator from cyclotron centre	~5 m
Resonator Diameter	~1.5 m
Voltage stability	$<10^{-3}$
Inter-dee phase stability	$<1^\circ$
Total RF-power	<180 kW

RF-System: The two cavities have been delivered and vacuum tested. A first version of the dee has also been built. It will be used for outgasing and low- and medium power RF-tests. However, for the cyclotron a second version will be built. All the final hardware like stem, dee- and stem cantilever support, shorting piston, and coupling loop are scheduled to be finished by the end of this summer, so that full power tests will begin some time early this fall.

Vacuum: The final design of the vacuum chamber is presently being done. The pumping system consists of two 400 l/sec turbomolecular pumps with two 30 m^3/h fore pumps and two 10,000 l/sec cryopumps. The system is designed to provide a vacuum of 1-5 x 10^{-7} torr.

Injection: The injection system consists of two inflector magnets (A,B) situated in the central region between the four sector magnets and an electrostatic channel (C) located in the gap of one of the sector magnets (see fig. 4). The inflector magnets have been designed with the help of the half scale model and tests with an electrostatic inflector in the magnet gap have proven, that it is possible to hold the necessary voltage to obtain the desired field strength across the gap of the inflector.

Extraction: The extraction system consists of an electrostatic deflector (D), located in the injection valley (see fig. 4), a current septum (E), and a window frame deflection magnet (F). The necessary turn-separation will be obtained for heavy ions by acceleration and for light ions and protons via resonance extraction at $\nu_r = 1$.

Diagnostics: In the design of the diagnostics system the idea to be able to trace the beam as far as possible from the beginning of injection until after extraction was used as a guide line. An emittance measuring device (EMD) will be installed at the end of the beam transport system of the injection path. This EMD is designed in such a way, that we will be able to measure the horizontal and vertical emittance and, in connection with the last dipole magnets, the energy-time correlation of the beam pulses. Furthermore there will be a Faraday-cup and a beam profile monitor just before the entrance of the cyclotron vacuum chamber. Inside the cyclotron a probe will be installed in front of the first inflector magnet. This probe allows to measure total intensity, size, shape, and location of the beam horizontally as well as vertically. A horizontal position probe in front of the electrostatic inflector, will give information to center the beam into the electrostatic channel. Two radial differential probes and a total of ten phase probes will be provided, to observe the beam during acceleration. In the extraction path we will have a horizontal position probe in front of the first deflector and another one in front of the current septum plus the differential probes already mentioned. At the cyclotron exit, after the extraction magnet, a beam profile monitor and a Faraday-cup will be installed. In addition a prompt γ-ray detector, which will work in connection with one of the radial differential probes, is planned.

Computer Control

The computer control system[9] for the whole accelerator system including beam lines will be based on a PDP-11/40 computer and a single loop CAMAC Serial Highway system as an interface to the accelerator and beam-line components. Operator interaction with these components will be done via a general purpose-control console including displays, touch pannels, knobs etc. for standard operations or an interpreter for more sophisticated investigations.

The serial highway of about 300 m total length will include 35 CAMAC crates with about 600 modules. Special attention was given to the design of these modules in order to reduce the number of different types (5 actually) to standardize the connector ports to the external equipment and to simplify the software.

The hardware components have been delivered to about 90 %, the operator's console is under construction, and the first approach to the final software system is running. The basic control system is planned to be available for practice at fall this year.

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+) Half time leave from the MSC-Division, CERN, Geneva

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