A COMBINATION OF A VAN DE GRAAFF ACCELERATOR AND A SPLIT-POLE CYCLOTRON FOR HEAVY IONS

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ABSTRACT

The proposed accelerator system consists of a HVEC model CN Van de Graaff as injector and a split-pole-cyclotron. This combination is able to accelerate ions of mass $A \leqslant 40$ up to an energy of 200 MeV. Beam currents of 10^{12} particles/sec at an energy resolution of $\Delta E/E = 10^{-3}$ are anticipated.

The Van de Graaff accelerates doubly charged ions to $E_i \leqslant 12$ MeV. The ions are stripped and further accelerated in the cyclotron to $16.8 \cdot E_i$. The cyclotron consists of 4 separated 50° magnets and two 36° Dees. The energy capability of the magnet is $A \cdot E/q^2 = 100$ MeV.

INTRODUCTION

The research program of the nuclear physics division of the HMI, Berlin, is about equally split between nuclear physics and nuclear solid state physics. The needs of these two fields determined the parameters of the proposed accelerator system VICKSI 1). Variable energy, good energy resolution, and sharp time structure of the beam are required for ions lighter than 40 Ar with a maximum energy that exceeds the Coulomb barrier for all target nuclei. With these requirements we consider the combination of a cyclotron with the existing 6 MV Van de Graaff as injector the best choice.

LAYOUT AND GENERAL SPECIFICATIONS

A layout of the system is shown in fig. 1. Doubly charged ions are produced in a source in the high voltage terminal of the Van de Graaff. This beam is mass analyzed, chopped and/or bunched with the cyclotron frequency before acceleration. After acceleration to 12 MeV the beam is momentum analyzed in a 90° magnet. The beamline to the cyclotron incorporates a chopper,

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buncher and a gas or foil stripper to adapt the charge state and time structure of the beam to the cyclotron. Medianplane injection into the cyclotron is accomplished through a nearly field free valley region and two magnetic and one electrostatic inflectors in the central region. After acceleration and extraction a beam handling system composed of double monochromator systems delivers the beam to the target positions.

The final energy is limited by the cyclotron magnet to $E = 100 \cdot q^2/A$ MeV. For 200 MeV ^{40}Ar $q = 9^+$ is necessary which is the most abundant charge state after a foil stripper at the corresponding injection energy of $E_i = 12$ MeV. The other limit is due to the relation $E = (R_{ex}/R_{in})^2 \cdot E_i = 16.8 \cdot E_i$ for non relativistic particles which gives with the limit of $2 \cdot 6$ MeV from the Van de Graaff $E \leqslant 200$ MeV.

The estimate of the current is based on a DC output of 10^{14} doubly charged particles/s from the ion source. The phase acceptance of the cyclotron of about 0.01 reduces this to 10^{12} p/s. Losses in the stripper mainly and e.g. at extraction should amount to less than a factor 5 and will be compensated by bunching the beam before injection.

Besides the Van de Graaff an air insulated 1 MV injector is planned. It will be used during down times of the Van de Graaff and for modest energy beams of metal ions.

VAN DE GRAAFF

The model CN Van de Graaff$^+$ of the HMI that will be used as injector has been routinely operated with hydrogen and helium at 7 MV terminal voltage and beam currents of 80 μA. The requirements for the use as an injector are 6 MV and 10 p μA for heavy ions. A new terminal is being developped. A Penning ion source with either radial or axial extraction will deliver about 10^{14} p/s of doubly charged ions. To reduce the current that is to be accelerated a chopper or buncher will modulate the beam cutting down those parts that would arrive out of phase at the cyclotron. We anticipate that the pressure tank has to be opened for maintenance of the ion source every 100 hours. A fast gas handling system similar to that at the Brookhaven tandems[2)] will reduce the down time to about 1o hours.

$^+$ made by HVEC, Burlington, Mass., USA

BEAM MATCHING TO THE CYCLOTRON

Up to about Silicon the most abundant charge state after a gas stripper can be accelerated in the cyclotron while for ions up to mass 40 the same holds only for a foil stripper. A chopper and buncher will produce clean beam pulses of 6° or slightly wider in RF-phase. The time width of the beam pulses is mainly determined by the energy straggling introduced in the stripper and experiments to measure this have been started. Preliminary calculations indicate that the matching of the beam emittance to the acceptance of the cyclotron injection channel does not present any major difficulties.

CYCLOTRON

The cyclotron is of the split-pole type (separate magnets) to facilitate injection of the beam. The design presented below was made by Scanditronix/Sweden. The main characteristics are given in the table. The injection system is shown in fig. 2. The optical properties of the path to the central region in the fringe field of the magnets have been calculated with a measured field from a similar magnet. This showed that inspite of the energy gain of a factor 16.8 no severe problems occur. The inflector magnet, a magnetic channel and a mechanically adjustable electrostatic inflector center the beam on the first orbit.

Beam dynamics during acceleration have been calculated mainly with hard edge fields. The resonance diagram in fig. 3 however is based on an approximated soft edge field. It shows that no major resonance has to be passed. The calculations reveal a coupling between the radial and longitudinal phase space during the first ($\sim$ 15) turns. Because of this the width of the injected beam is limited to about 4° of the RF for an energy resolution of 10^{-3}. Since this might not be possible to achieve with the chopper the use of radial slits to determine the phase width has been investigated. The result is that at about the 15^{th} turn such slits can be effectively used.

Due to the low average field and high energy gain per turn the extraction presents no major difficulties. Already the turn separation due to acceleration in an isochronous field leads to just slightly separated orbits for the worst case of 50 MeV protons. Calculations show that a decrease of the field with radius can be realized that nearly doubles the turn separation by going to $\nu_r = 0.8$ without introducing nonlinear distortions of the beam. Precessional extraction has been investigated for an earlier design aim of 100 MeV protons and found to give adequate turn separation even in this case. For heavy ions ($A > 12$) the turn separation is at least

3 times as large as for 50 MeV protons. Two electrostatic deflectors give enough orbit spacing that finally a window frame magnet can clear the beam from the yoke of the next main magnet.

PARAMTERS OF THE CYCLOTRON

Magnets

4 C-shaped sector magnets of 50° width with flat pole faces.

Magnet gap		6 cm
Maximum field		14.5 kG
injection radius (middle valley)		39 cm
extraction radius (middle valley)		160 cm
$B \cdot \rho$ at extraction		14.5 kGm
Energy capability	$A \cdot E/q^2 =$	100 MeV
Weight (4 magnets)		400 t
Power consumption		400 kW
current stability		$2 \cdot 10^{-5}$

About 15 pole face windings/per magnet

RF system

Two dees of 36° width located between the magnets. Each dee is part of a $\lambda/2$ resonating line similar to the Indiana system[3] and driven by its own amplifier.

Range of orbit frequencies	1.9 - 8.5 MHz
RF frequency range (harmonics 2-6, capacitive tuning)	11.3 - 17 MHz
RF amplitude	100 kV
Amplitude stability	$< 10^{-3}$
RF power (2 dees)	200 kW

Vacuum system

pressure (mainly cryopumps)	5×10^{-7} torr

Energies

Protons (limited by frequency range)	$E < 50$ MeV
ions with $2 < A < 7$	$E \leqslant 100\ q^2/A$ MeV
ions with $10 < A < 40$ (limited by $E = 16.8 \cdot 12$ MeV)	$E \leqslant 200$ MeV

BEAM HANDLING SYSTEM

The beam handling system (fig. 1) consist of four identical 90° magnets and appropriate quadrupole lenses. The first bending magnet with each of the three other magnets forms a symmetric double monochromator system. Depending on the quadrupole settings a continuous range between achromatic and highly dispersive operating conditions will be feasable. In the latter case an energy resolution of $5 \cdot 10^{-4}$ or better (depending on second order corrections) can be obtained. Most interesting probably is the mode in which the total system is achromatic and hereby approximately isochronous while both halfs of the system are highly dispersive. Thus nanosecond time resolution can be obtained simultaneously with energy selection at the median plane of the system.

It is a pleasure to thank the many colleagues who have assisted us with very valuable advice, especially Dr. R. W. Müller, Prof. M. E. Rickey, Dr. G. Schatz and Prof. Ch. Schmelzer. The studies of the RF system have been undertaken by Dr. A. Susini. A decisive incentive for the start of this project and a major part of the cyclotron design are due to the late Dr. A. Svanheden.

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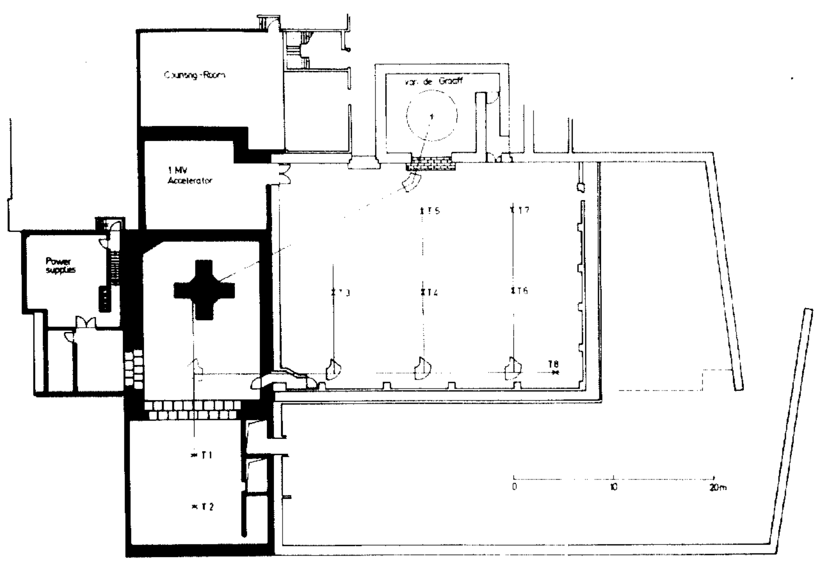

Fig.1: General layout of the system. Target locations are indicated by T_1 to T_8. The walls of building to be constructed are shown in block.

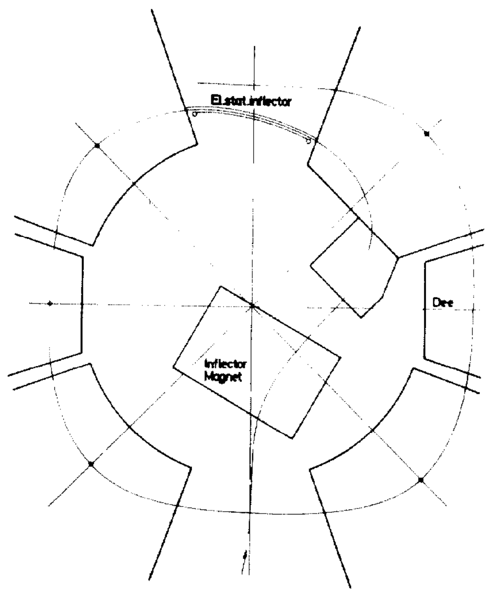

Fig. 2: Injection Channel

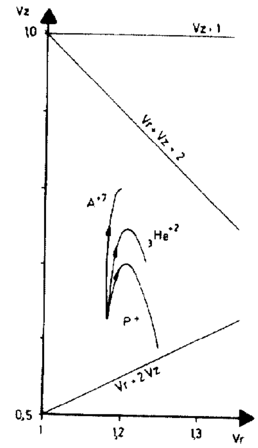

Fig. 3: Resonance diagram