STATUS REPORT ON THE K.V.I.CYCLOTRON

O.C.Dermois, A.G.Drentje, H.W.Schreuder*)

Abstract

The K.V.I. cyclotron, which has a maximum energy of 160 Q^2/A MeV and which has been constructed by Philips, has been in regular operation since 1972. The machine is used mainly for nuclear physics with light ion beams. However, beams of heavier ions are in increasing demand. The Livingston type ion source now used only gives modest currents of C and O beams; a Dubna type source is being developed with the aim of increasing heavy ion beam currents. Also, a 7500 ℓ/s cryopump is being built. An rf beam pulser to be used for increasing the time interval between successive beam pulses on target has been installed and is being used regularly. A new beam line has recently been completed, two more beam lines will follow next year. The magnetic spectrograph is used for more than 50% of the nuclear physics beam time. Its data acquisition system allows an on-line check of the image on the focal plane detector. For use in beam lines and inside the cyclotron, pick-up probes have been built, allowing real-time observation of beam pulse shape and timing. A beginning has been made with computer controlled beam diagnostics. Design work on an axial injection system has been started; the main reassons for wanting such a system are improved heavy ion capabilities.

Introduction

This status report has been written with the purpose of giving an overview of the cyclotron installation at the K.V.I. since such a description is not yet generally available. Attention will also be paid to operational data and to ongoing development and improvement projects and to extension plans.

Cyclotron and beam lines

The K.V.I. isochronous cyclotron, illustrated in fig.1, is a multiparticle, variable energy accelerator with a maximum energy of 160 Q^2/A MeV 1). The energy range for different ions is given in fig.2, in which also the limits imposed by frequency range and maximum magnetic field strength are indicated.

In the schematic view of the beam line lay-out (fig. 3) the dashed walls and beams lines are being built and are planned for completion in 1979. Beam line A is at present being commissioned. The beam lines A,B,C and D can be reached with analyzed beams from beam line S. The energy analysing system, the main component of which is a 105° magnet, gives an energy resolution of 1:5000 with a transmission of 3%. Unanalyzed beams from beam line M can be switched to the lines C, D and E. Beam line I is used for irradiations and for medical isotope production, beam line G will take over most of this task after its completion. The C-line has a 60 cm scattering chamber, while a 120 cm chamber is being constructed. It will be placed in the B-line which now is in the build-up stage. The E-line is mainly used for in-beam γ-ray measurements, for which a turning table and a multiplicity set-up are available and for in-beam measurements on conversion electrons with a mini-orange spectrometer. Beam line D serves the Q3D magnetic spectrograph.

An rf beam deflector 2) in beam line M is used for suppressing n out of n+1 consecutive beam bursts; it is similar to the one described by Abrahamsson et al.3). The deflector electrodes have a length of 0.90 m and have a gap , when operating of 15 mm. The peak voltage between the electrodes needed for suppression is given by

$$V_p \approx 16nE/Q \text{ volt}$$

in which n is the number of consecutive bursts to be

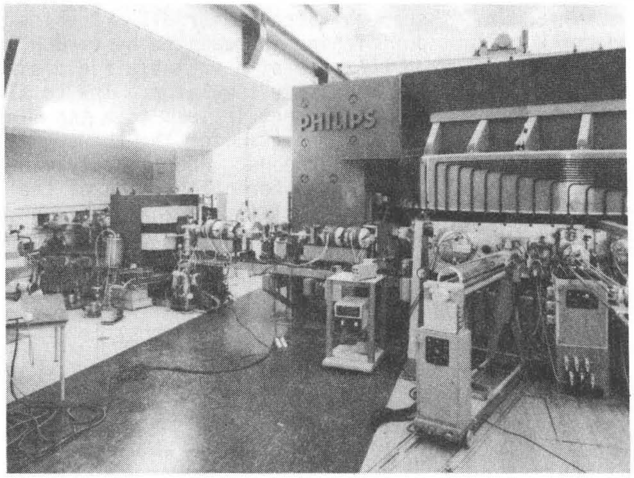

Fig.1. The K.V.I. isochronous cyclotron

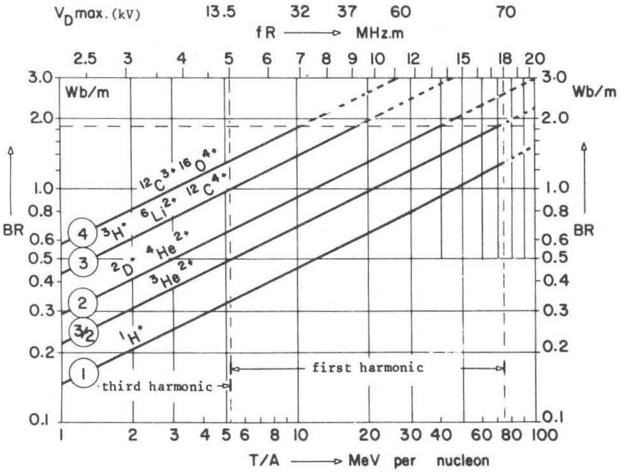

Fig.2. Energy range for ions with different Q/A

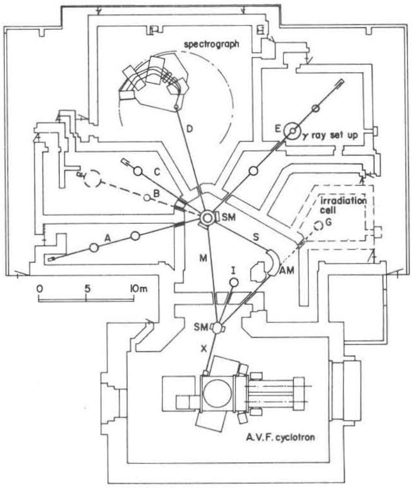

Fig.3. Beam line lay-out

---

*) Kernfysisch Versneller Instituut, Zernikelaan 25, 9747 AA GRONINGEN, The Netherlands.

0018-9499/79/0400-1992$00.75 ©1979 IEEE

suppressed, E the beam energy in MeV and Q the charge state of the beam particles. The rf field sweeps the beam vertically over a slit with an aperture of 4 mm. The rf system has a frequency range of 0,5-1 MHz and is capable of giving a maximum voltage of 20 kV peak between the deflector plates. The rf power of 200 W maximum is supplied by a broadband power amplifier; the drive signal is obtained from the cyclotron rf by suitable frequency division and phase locking. This deflector, the design and construction of which has been a joint effort of the General Physics Lab. of Groningen University and the K.V.I., works according to expectations.

Magnetic spectrograph

The magnetic spectrograph QMG/2 has a large solid angle, 10 msr, and a high intrinsic energy resolution: $\Delta E/E = 1:5000$, equal to that of the beam analyzing system. The dispersion along the straight focal plane is 11 cm/% momentum. The configuration of this spectrograph4) is quadrupole-multipole-dipole-multipole-dipole-dipole; moreover, the 2nd and 3rd dipole magnets are equipped with flexible devices - called "snakes" - which can be used to adjust the shape of the respective field boundaries to correct possible deviations from a straight focal plane5).

The instrument - built by Scanditronix, Sweden - became operational at the end of 1977. Two position sensitive detector systems cover together about 75% of the focal plane; the set-up allows detection of all light particles from p to ^{7}Li. At present the spectrograph is used for more than 50% of the nuclear physics beam time.

To illustrate in some more detail the ease of operation for the user we show in fig. 4a a computer display of "trajectories" of particles incident on the focal plane detector system6). These trajectories have been obtained by measuring the position in two position sensitive detectors (indicated by the horizontal lines), one located in the focal plane, the other placed 10 cm downstream. The reaction is ^{24}Mg(d,^{6}Li); two groups of ^{6}Li-ions from excitation of the ground state and an excited state are incorrectly focussed near the second detector; ^{6}Li-ions from a contaminant reaction ^{12}C(d,^{6}Li) have a different kinematic factor and are focussed in front of the first detector. Fig.4b displays the spectrum, as measured with the first detector, and also a "twinkle" plot of the horizontal phase space of the trajectories (horizontal: position; vertical: angle of incidence). In order to improve the experimental resolution the user can adjust the second multipole magnet excitation such that the particles of interest are focussed in the first detector; the result is shown in fig.4c. This displayed phase space plot is very powerful for identification of reaction products from target contaminants.

In a few cases the ion optical elements in the spectrograph beam line have been set such that the analyzing magnet dispersion on target matched the spectrograph dispersion. After opening the exit slits the transmission of the analyzing system increased by a factor of three.

Operation

The weekly cyclotron operation schedule extends from Monday 8 a.m. to Saturday 3 p.m..Due to a lack of operators the schedule cannot be extended. However, during many weekends the cyclotron is operated by the research staff. There is no planned long shutdown period once a year; instead, four maintenance periods of one week each are scheduled at approximately 3 month intervals.

The operating record of the first half of 1978 is given in table I; the distribution of beam time among different categories of users is given in table II. Table III gives beam time statistics according to the particle accelerated.

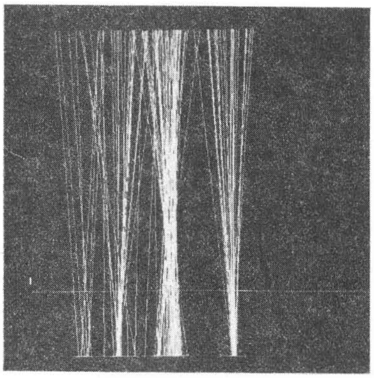

Fig.4a. Particle trajectories near spectrograph focal plane.

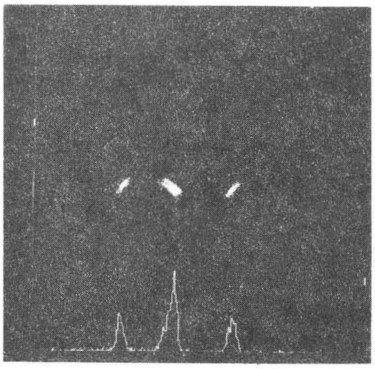

Fig.4b. Position spectrum and phase space plots.

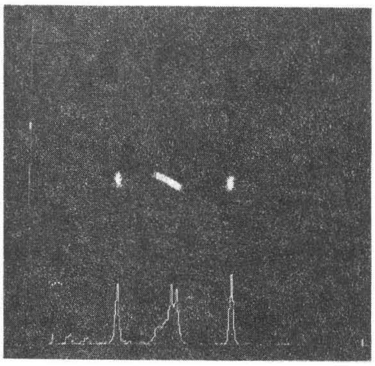

Fig.4c. As fig.4b, now with correct focussing.

Table I

Cyclotron operating record January - June 1978

beam available	: 84%
planned maintenance	: 7%
unplanned stops,failures	: 9%
total of scheduled time	:100% or 3187 hours

0018-9499/79/0400-1993$00.75 ©1979 IEEE

Table II

Distribution of beam time among users
January - June 1978

K.V.I. nuclear physics	60%
Physics Lab. Univ.Groningen	15%
other nuclear physicists	5%
Nuclear Medicine	7%
Energy Centre Netherlands	4%
Cyclotron and heavy ion beam development	5%
Development of spectrograph and detector tests	4%

Table III

Distribution of beam time according to projectiles

January - June 1978

protons	14%
deuterons	19%
^{3}He	7%
α	33%
^{12}C, ^{16}O	27%

Heavy ions

Heavy ions are in increasing demand at the K.V.I. and in the first half of 1978 27% of the beam time has been scheduled for these beams. A great number of different beams of C^{3+} and C^{4+} ions have been produced in the energy range of 55-200 MeV, the lower energy beam being accelerated in third harmonic mode. Also some O^{4+} beams have been used in experiments. The ions are produced by a Livingston type ion source. This source has been designed and constructed with the purpose of producing α's and the lighter heavy ions; α-beams of 100 μA have been made. For heavy ions the source is generally operated at 1,8 A arc current, 400 V arc voltage and a gasflow of 0,6 std.cc/minute. Up to a few 100 nA of C^{4+} can be produced. Under these conditions the lifetime of the filament is 4 hours. Using the experience obtained with this source, a PIG-type ion source is being built. A drawing of part of this source is given in fig.5; a prototype is now being assembled. The arc power will be supplied by a power supply[7]), which can be used both in d.c. and pulsed modes.

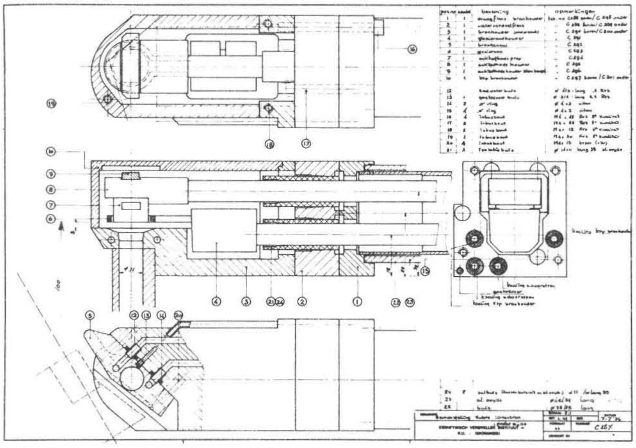

Fig.5. Upper head of PIG heavy ion source.

An important tool for the development and testing of these heavy ion sources is the ion source test stand (Fig.6). The magnet has a gap of 13 cm, the maximum field is 1T. An optical monochromator is used for gaining information on ionization and excitation processes and about the electron energy distribution.

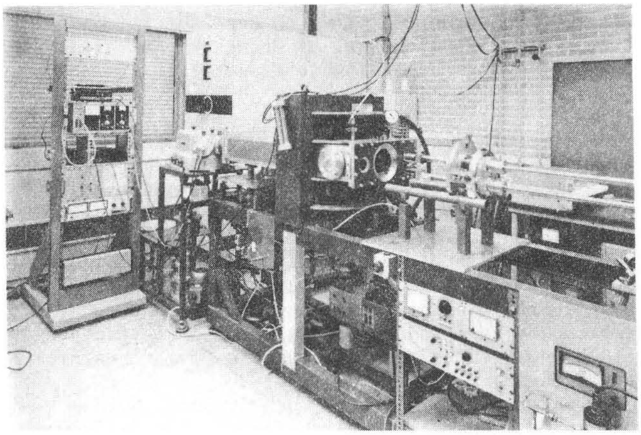

Fig.6. Ion source test stand.

The vacuum that can be obtained inside the cyclotron, at the present time 2.10^{-6}Torr at the pumping ports, limits efficient acceleration of heavier ions. In order to improve the situation, particularly in the cyclotron centre, we plan to install a cryopump which has specifically been designed to optimize the pumping speed in the median plane in the direction of the central region. The pump will have a net capacity of 7500 ℓ/s and will be mounted on the front side of the cyclotron, diametrically opposite the two diffusion pumps. The pump will be driven by a cryomachine, capable of delivering 3 watts at 20K and simultaneously 80 watts at 100K.

Axial injection

Recently the K.V.I. submitted a proposal for building an axial injection system for the cyclotron[8]). The main reasons for the proposal are: (i) an expected increase in heavy ion beam current of an order of magnitude, (ii) more degrees of freedom for improving PIG-type ion sources, (iii) the possibility of installing polarized ion sources and heavy ion sources of ECRIS or EBIS type.

The expected increase in beam current is due mainly to improved vacuum conditions in the cyclotron centre and to the buncher. The available space for an externally mounted ion source will be much greater than for an internal source. This means that a larger ion source can be designed, in which more power can be dissipated, where a sputtering electrode can be incorporated, and where magnetic mirror fields might be added.

The proposed axial injection system is schematically illustrated in fig.7. The main component of the ion source set-up is a magnet for the PIG-type ion source. The gap will be 20 cm and a pole diameter of 44 cm is sufficient for a field homogeneity of 1% in the volume occupied by the arc, provided the magnet is shimmed carefully. The set-up will accept ion sources that can all be used internally in the cyclotron as well as more advanced PIG-sources, specifically designed for external operation. The horizontal part of the beam line will have space for the possible later addition of a horizontal bending magnet to accomodate more ion source set-ups.

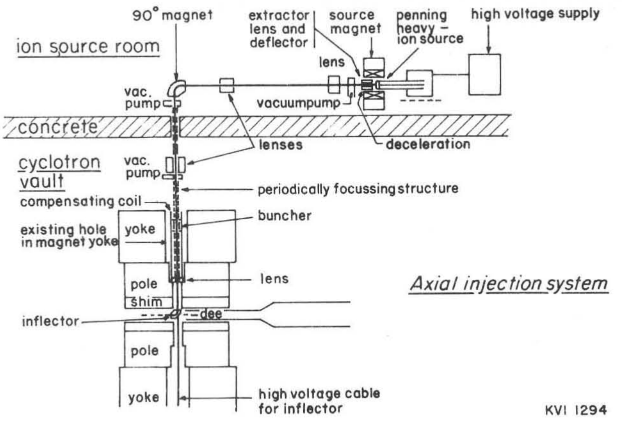

Fig.7. Lay-out of proposed axial injection system.

In the vertical beam line a periodically focussing structure9) is planned since it has a large acceptance and is expected to be easy to operate. Near the end of the axial hole, which was already provided when the cyclotron was built, a cylindric magnetic lens will be used for focussing the beam. It is not possible to use a single constant orbit mode of operation for the entire energy range of the cyclotron: the inherent energy spread in the injected beam and space charge problems indicate a minimum injection energy of approximately 10 keV, while voltage holding will give problems at energies above 25 keV. Therefore the energy range will be divided into a high and a low energy part, each with its own central orbit geometry. For the high energy part it is feasable to use a hyperboloidal inflector10) followed by a horizontal deflector, while for the low energy region a channel inflector of the Grenoble type11) is the most likely candidate. The inflectors will be mounted on the radial support now used for internal ion sources.

With regard to timing of the project, we hope to obtain funds for initiating the project in 1979 and, if all goes well, the system can be operational in 1982.

Diagnostics and computer control

Standard beam diagnostic equipment consists of beam probes with differential and three finger heads for measurements on the internal beam, while fluorescent targets, current measuring beam stops, slits and vibrating blade beam scanners are used in the beam lines.

A stepping-motor driven beam scanner determining the position of the centre of gravity of the beam charge distribution has been designed and tested12). A CAMAC based version of this scanner is being built, in which a K.V.I. designed CAMAC crate controller with a microprocessor is used, replacing much analog electronics. A single control unit will initially be multiplexed for driving 16 scanners.

Beam phase probes are available for observing the timing and the time structure of the extracted beam in real time. The latest version of a beam line mounted probe is illustrated in fig.8. The essential feature of the probe is a broad band amplifier mounted very close to the pick-up electrode inside the beam line13). The overall risetime when observing beam pulses with a sampling scope is 2 ns. Experience indicates that radiation damage is no great problem since one amplifier has operated inside the cyclotron for one year without noticeable degradation. Beam phase measurement equipment based on the use of these probes is being tested13).

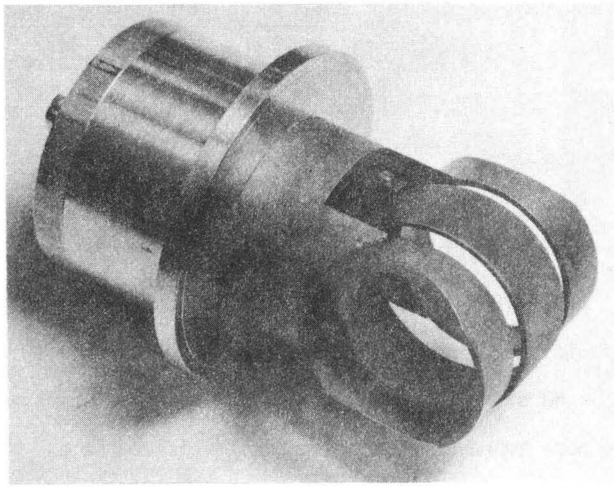

Fig.8. Pick-up probe with integral amplifier.

Computer control is in a stage of preparation; a proposal for buying a computer system awaits technical approval. The main tasks for this system will be beam diagnostics, accelerator data acquisition and control of major extensions to the installation. The system will have a CAMAC Serial Highway with a total length of 400 m which will serve up to 5 clusters, each consisting of 1-3 CAMAC crates.

The first beam diagnostics to be implemented on the new computer are emittance measurements, which already run on the on-line PDP-15 (unfortunately seldom available for this purpose), differential probe measurements, which have been partially tested, and beam position measurements using the beam scanners described above. Data acquisition is an urgent need from an operational point of view, since existing equipment is not very reliable and cannot be extended.

References

1. F.T.Howard, editor, Compilation of cyclotron data, S.I.N.,1975.
2. A.R.Arends,H.de Waard,H.Messchendorp,L.Foreman, H.W.Schreuder, KVI-Annual Report 1977,p.107.
3. K.Abrahamsson, A.Filevich, K.G.Rensvelt, J. Sztarkier, Nucl.Instr.& Meth.111(1973)125.
4. A.G.Drentje,H.A.Enge,S.B.Kowalski,Nucl.Instr.& Meth.122(1974)485.
5. A.G.Drentje,R.J.de Meijer,H.A.Enge, S.B.Kowalski, Nucl.Instr.& Meth.133(1976)209.
6. J.C.Vermeulen,A.G.Drentje,L.W.Put,A.van der Woude, KVI-Annual Report 1977, p.26.
7. O.C.Dermois,H.Fraiquin, KVI-Annual Report 1973, p.76.
8. KVI staff. Internal Report KVI-62.
9. O.C.Dermois,Proceedings of the Fifth International Cyclotron Conference, Butterworths, London, 1969, p.620.
10. R.W.Müller, Nucl.Instr.& Meth.54(1967)29.
11. J.L.Belmont,J.L.Pabot, IEEE Trans.on Nuclear Science vol.NS-13 no.4(1966)191.
12. R.J.Vader,O.C.Dermois, Nucl.Instr.& Meth.144(1977) 423.
13. R.J.Vader,H.W.Schreuder, this conference, contribution D22.

0018-9499/79/0400-1995$00.75 ©1979 IEEE