Proceedings of the International Conference on
Sector-Focused Cyclotrons and Meson Factories

THE PHILIPS AVF PROTOTYPE CYCLOTRON

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(Presented by N.F. Verster)

The Philips AVF Cyclotron is a variable energy all-particle accelerator. The maximum energy for protons is about 25 MeV (alpha particles 25 MeV and deuterons 13 MeV). The features of the cyclotron have already been described in several papers[1,2,3,4]. We shall report here the progress made since these publications. New calculations on the particle motion in the cyclotron centre have been made[5] which give the position of the ion source accurately; calculations on the extraction of the beam are described elsewhere[6].

An internal beam has been obtained and the properties agree very well with the theoretical predictions. The beam has been extracted with an efficiency of about 30%.

Vacuum and Ion Source

The construction of the vacuum chamber, see Fig. 1, has already been described[1]. We did not meet troubles of any importance with this chamber. The pressure without

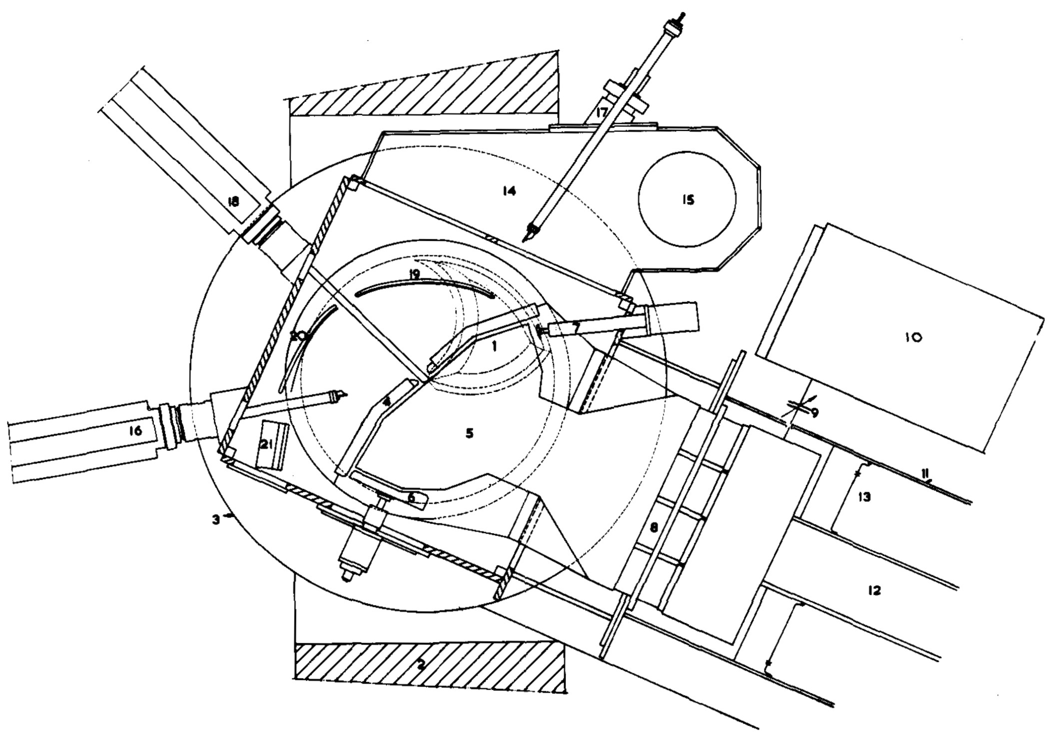

Fig. 1 The layout of the cyclotron : 1) pole segment; 2) yoke; 3) main coil; 4) dummy dee; 5) dee; 6) trimming unit; 7) dee voltage meter; 8) feedthrough insulator; 9) coupling condenser; 10) oscillator; 11) outer resonance tube; 12) inner resonance tube; 13) shorting plate; 14) pumping house; 15) vacuum pump; 16) and 17) targets; 18) ion source; 19) and 20) electrostatic deflection system; 21) magnetic channel.

hydrogen inlet was about 1.10^{-5} torr, and with a working ion source about 2.10^{-5} torr. We use a 8000 l/s oil diffusion pump.

The ion source is of the Livingston type. The plasma is in a graphite chimney with an inner diameter of 10 mm. The arc is fed by a constant current supply (maximum current 1 A, maximum voltage 500 V). The heating current of the tungsten cathode is 200 A. During an experiment with a d.c. voltage extraction electrode we measured an extracted current of several milliamps. The shape of the beam will be shown in another paper[6]. The extraction aperture in the chimney has a diameter of 5 mm. We can pulse the ion source with pulses of 1 ms, and longer.

Targets

The position of the internal orbits is measured by two motor-driven main targets and a simple third target moved hydraulically. All the targets can be adjusted from the control room. To minimize the radioactivity the targets are tantalum-clad.

Extraction System

The extraction system consists of two electrostatic channels, separated by the tubes of the ion source, and a magnetic channel. The first 10 cm of the septum is 0.5 mm carbon, and the remainder is highly polished aluminium. The negative electrode is 30 mm high and also of aluminium. The electrostatic system can be operated from the control room. There are eight independent variables. The maximum field strength needed for extraction of 26 MeV protons is 52.5 kV over 5 mm. A theoretical discussion of the extraction will be given in another paper[5].

The High Frequency System

The resonant circuit (a quarter-wave system) consists of a concentric resonant line with a movable shorting plate, a coupling tank, and a set of four feedthrough insulators supporting the dee stem.

The feedthrough insulators, located near the outer edge of the main coil, form the separation between the vacuum chamber and the line. The coupling tank adapts the feedthrough insulators to the line and houses the adjustable coupling condenser between the resonant circuit and the oscillator.

The oscillator circuit is similar to the circuit used in the Moscow 6-meter synchro-cyclotron[1].

The concentric resonant line consists of two tubes, made by electrolytic deposition. The shorting plate (Fig. 2 and 3) inside the resonant line rides on two guide rails, fixed to the wall of the outer tube. The position of the shorting plate (hence the frequency) may be changed by remote control during operation).

A large number of small silver-graphite contacts mounted along the inner and outer circumference of the shorting plate provide for the contact to the inner and outer tubes of the line. The contact pressure of each of the contacts is about 300 grams. The maximum current through each of the 120 contacts on the inner tube is

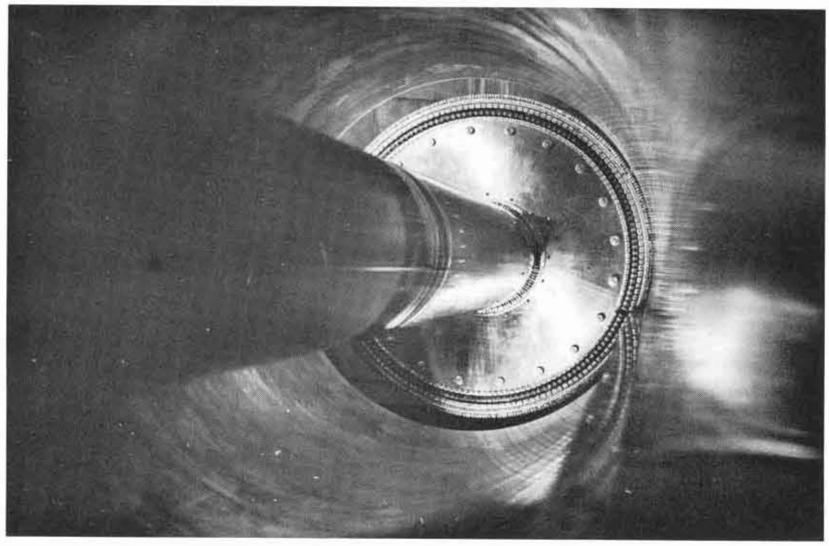

Fig. 2 View through the concentric resonant line.

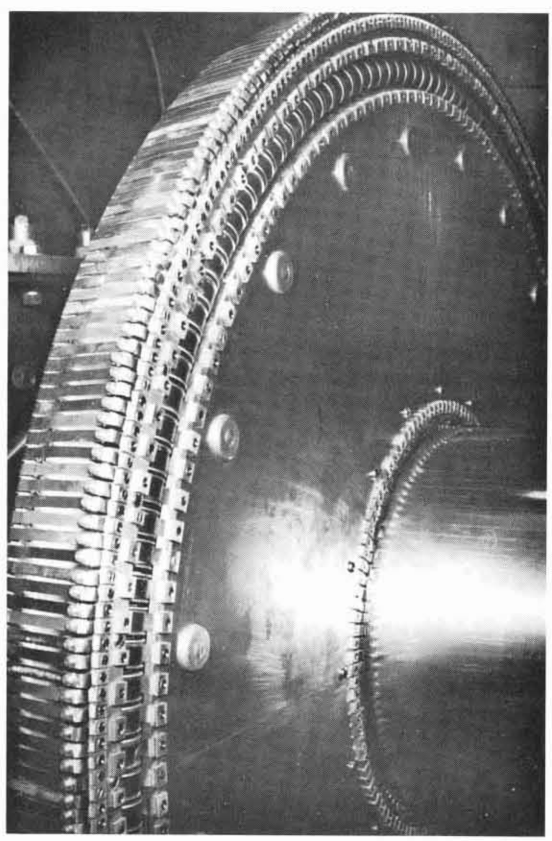

Fig. 3 View of the shorting plate.

30 to 40 A. On the outer tube are 360 shorting contacts. The inner tube is at dee-bias voltage, insulated from the outer tube. High frequency bypass is provided by 250 mica condensers, located near the outer circumference of the shorting plate.

The dee voltage is stabilized (to better than 1 : 10^3) by controlling the anode d.c. voltage of the oscillator with a series tube regulator. Frequency stability (better than 1 : 2.10^4) is obtained by means of a digital control system (Fig. 4) actuating a trimming condenser.

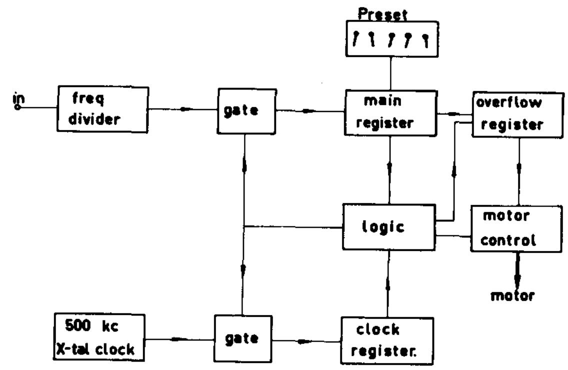

Fig. 4 Block diagram of the frequency control system. The frequency is checked against a 500 kc crystal clock. The clock and the main register each give a pulse after a preset number of cycles. The overflow register is started at the first incoming pulse and stopped at the second. Pulse sequence determines the sign of the frequency deviation, while the overflow determines the magnitude of the error.

The Isochronism of the Magnetic Field

The isochronous field is trimmed by ten circular coils, the currents through which are determined by means of a least squares analysis computer program, described by Verster[2]. The magnetic field, after adjustment with these current settings, was measured again to check the results. The isochronism of the field is sufficient and the field shape is close to the prediction of the computer results. This is shown in Fig. 5 for a mean field of 10,415 gauss, where the difference between the actual field and the isochronous field is shown. The dotted curve is the calculated field, and the full line is the measured field. The phase excursion is very small over the whole region (± 6°).

In our beam experiments we have only trimmed the main magnetic field or the frequency of the RF system. All settings of the correction coils are kept as they were given by the computer results. In our phase calculations we have assumed that the beam will make about 250 revolution. In the experiments we had, due to a somewhat low dee voltage, about 400 revolutions; however, this did not harm the beam. The beam was accelerated well beyond the resonances without losing intensity. To accelerate to as great a radius as possible, the main magnetic field was made slightly greater than the resonance field.

The experiments were performed in a mean magnetic induction of 10,415 gauss. Protons were accelerated to an energy of approximately 14 MeV.

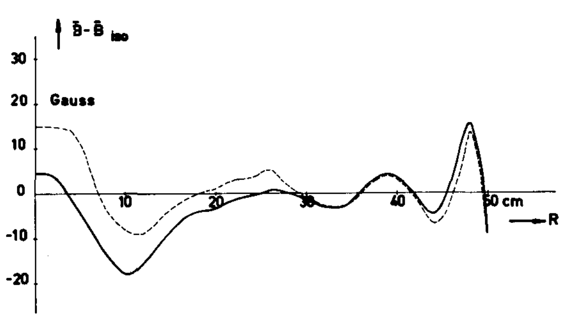

Fig. 5 The deviation of the mean magnetic induction ($\bar{B}$) from the isochronous value ($\bar{B}_{iso}$) as a function of radius. The full line represents the measured field. The dotted line represents the calculated field. The magnetic induction in the centre is 10,415 gauss.

Beam Behaviour

The behaviour of the internal beam of

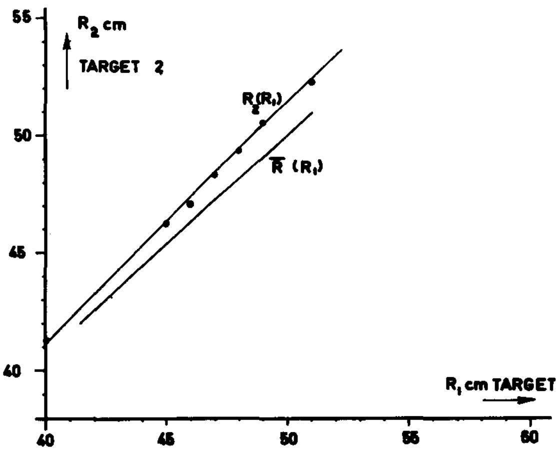

Fig. 6 The radial position of the equilibrium orbit at the second target as a function of the radial position at the first target. The theoretical function is given by the line $r_2(r_1)$. The marked points are measured values of the beam position. The curve $\bar{r}(r_1)$ gives the mean radius as a function of the position of the first target.

the cyclotron agrees well with the prediction of the theory. All the currents for the correction coils (circular and harmonic) are adjusted to the values computed. Thus far we have accelerated protons for energies to 8, 14 and 20 MeV; switching the energy takes only a few minutes. The position of the beam is measured with two targets situated at angles separated in azimuth by about 140^0 (see Fig. 1).

In Fig. 6 the radial position of the equilibrium orbit at the second target is given as a function of the position of the first target. The marked points give the measured values of the beam position. This figure thus indicates that the beam is very well centered in the cyclotron.

Due to the small eccentricity of the beam it was possible to accelerate through all dangerous resonances. This is shown in Fig. 7.

For acceleration to as great a radius as possible the main magnetic induction was adjusted so that at the resonance region the particles had a positive phase slip. In Fig. 8 this case is represented by 0. For a slightly higher magnetic induction the positive phase lag at 50 cm becomes greater so that the number of revolutions at this dangerous region increases. This causes a loss of beam intensity due to the resonances. (In Fig. 8 this is shown by the three curves for which the mean magnetic induction is 1.25×10^{-4}; 2.5×10^{-4} and 5×10^{-4} too high). A slightly lower magnetic induction gives a smaller decrease of beam intensity. In this case the beam makes fewer revolutions in the dangerous resonance region. (In Fig. 8 two curves are shown for which the magnetic induction is 2.5×10^{-4} and 5×10^{-4} too low). A disadvantage of

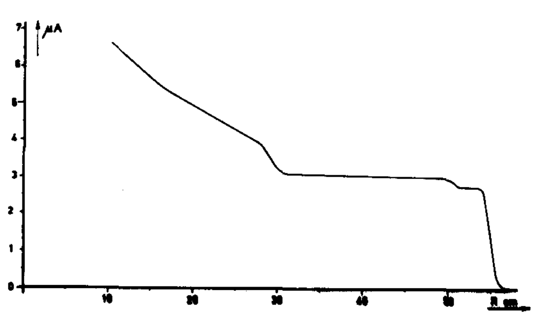

Fig. 7 The intensity of the internal beam as a function of the radius. The very small decrease of the intensity at a radius of about 50 cm is due to the $\nu_R = 1$ and $\nu_R = 2\ \nu_z$ resonances.

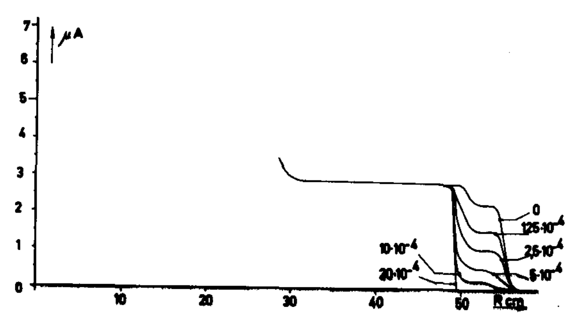

Fig. 8 Beam intensity as a function of radius for different values of the angular frequencies of the particles. The nominal frequency is 15.90 Mc/s. In the figure the relative deviations with respect to this value are given.

too low a magnetic field is that the beam cannot be accelerated to as great a radius. This is also shown in Fig. 8.

The influence of a small first harmonic in the magnetic field is given in Fig. 9. Even a first harmonic as large as 1.25 gauss gives a remarkable intensity decrease.

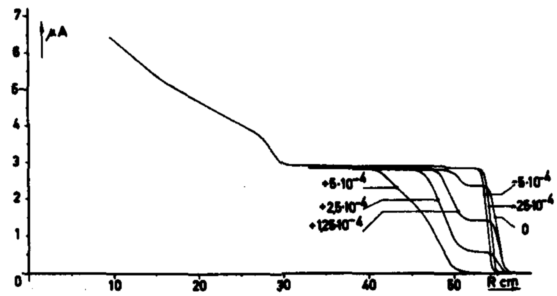

Fig. 9 The beam intensity as a function of radius for different values of the first harmonic for which the values are given in gauss.

References

1) N.F. Verster et al., Nucl. Instr. and Meth. 18, 19, 88 (1962).
2) H.L. Hagedoorn and N.F. Verster, Nucl. Instr. and Meth. 18, 19, 201 (1962).
3) N.F. Verster and H.L. Hagedoorn, Nucl. Instr. and Meth. 18, 19, 327 (1962).
4) H.L. Hagedoorn and N.F. Verster, Nucl. Instr. and Meth. 18, 19, 336 (1962).
5) H.L. Hagedoorn, See paper V-9, CERN Report, 1963, Conference on Sector-Focused Cyclotrons.
6) P. Kramer et al., See paper V-7.

DISCUSSION

MARTIN : What kind of a deflection system are you using?

VERSTER : We use an electrostatic deflection system of exactly the same principle as the one at Berkeley. The deflection is at the highest possible radius which can be obtained.