The external beam handling system for the A.V.F. cyclotron of the University of Groningen

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ABSTRACT

The layout of the beam handling system for the isochronous cyclotron is described. This system differs in some respects from more or less conventional systems. These differences will be motivated.

One of the major parts of the system is the analysing system, consisting of a 105° magnet with homogeneous field and edge focusing and a quadrupole doublet. It will be shown that by including a quadrupole in the system the attainable momentum resolution can be improved considerably. The expected momentum resolution is 1×10^{-4}. The transmission of the analysing system is 100% for a mono-energetic beam with phase space areas of 10 mm mrad and 70 mm mrad in the horizontal and vertical plane respectively.

The design and positioning of the switching magnet is such that both the non-analysed beam and the analysed beam can be switched into the experimental area, while at least three experimental stations can be reached by both types of beams.

1. INTRODUCTION

This paper describes briefly the beam transport system for the A.V.F. cyclotron of the University of Groningen.[1] This cyclotron will be in operation in 1970 and will deliver high intensity external beams of protons (5–70 MeV), deuterons (10–65 MeV), and heavier particles of corresponding magnetic rigidity. The emittance in the horizontal (radial) as well as in the vertical (axial) plane is expected to be 25 mm mrad. The momentum resolution will be 0·1%.

The general layout of the beam handling system is described in Section 2. One of the major components is the analysing system, described in Section 3.

2. GENERAL LAYOUT

A plan view of the experimental area with the beam transport system is given in Fig. 1.

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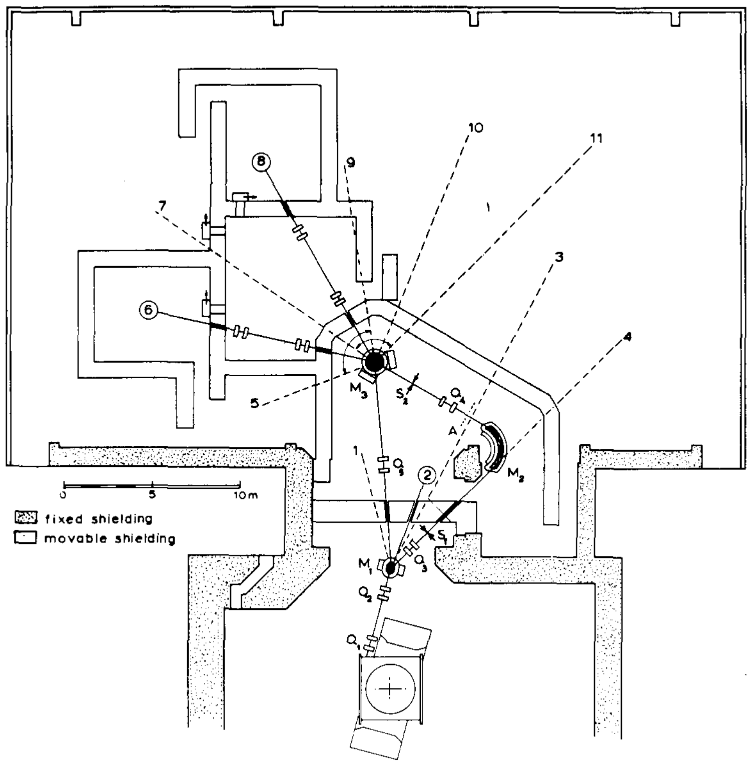

Fig. 1. Layout of external beam transport system

We aimed at a layout in which the target stations are evenly distributed over the experimental area. Each target station should have its own shielding so that an experiment can be set up in one room while the beam is going to another room. Using movable shielding gives complete freedom in location and size of the experimental rooms.

Making use of an existing small switching magnet M_1 with bending angles between $-30°$ and $+30°$ a satisfactory layout with one large switching magnet for the non-analysed beam and one analysing magnet with an additional switching magnet could not be found. Apart from the high cost of such a system none of the studied layouts resulted in an effective use of the experimental area.

A more satisfactory layout, with the advantage that a number of adjacent target stations can be reached by the non-analysed beam as well as the analysed beam, is given in Fig. 1. A switching magnet, M_3, is positioned at the intersection of the directions of the analysed beam from the analysing magnet M_2 (see Section 3) and the non-analysed beam from M_1. The particular shape of the yoke of M_3 with its circular pole face should enable both types of beams to be switched over a large angular range. The angles $\pm 50°$ for M_3 and $105°$ for M_2 turned out to be the most favourable combination of bending angles for these magnets. The pole diam. of M_3 is 1·05 m, its maximum field 14·7 kG. A smaller value of α_{M_2}, for instance, would result in larger object and image distances for M_2 and a position of M_3 farther away from the cyclotron.

For this combination of angles the analysed beam can reach the target stations

5-9. The non-analysed beam can be switched to positions 7-11. Positions 1 or 2 will be suitable for isotope production.

Ion optical calculations[2] showed that using beam pipes with i.d. of 45 mm a beam with emittance of 25 mm mrad can easily be transmitted by the system of Fig. 1. The aperture of quadrupole magnets could thus be chosen as 50 mm.

To keep the pole gap of M_2 and M_3 small the height of the beam in the magnets will be made as small as possible. M_2 and M_3 will have gaps of 4·5 cm and 4·0 cm respectively.

The components of the system are presently under construction with an industrial company. To start with, beam pipes and shielding for the stations 2, 6, and 8 (Fig. 1) are being installed.

3. ANALYSING SYSTEM

An analysing system can have either a uniform field or a gradient field. Usually a gradient field is preferred because of its vertical focusing properties, in particular double focusing for a field index $n = ½$. For a uniform field, however, about the same vertical focusing properties are obtained when the angle β (Fig. 2) has a proper positive value double focusing occurs if $\mathrm{tg}\,\beta = ½\ \mathrm{tg}\ \alpha/2$ and $l_1 = l_2$.

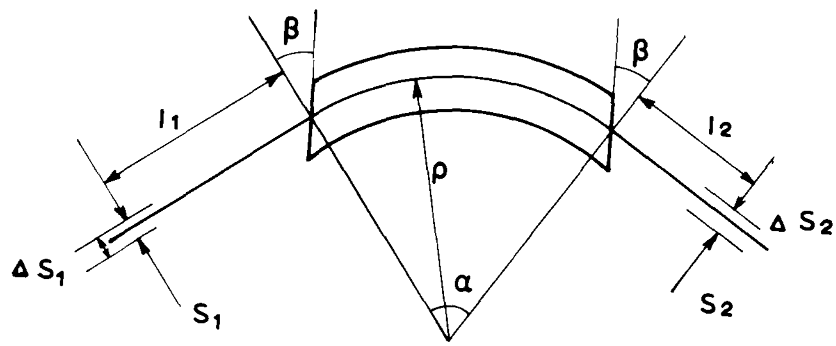

Fig. 2. Plan view of analysing magnet

As it is easier to machine a magnet with uniform field with the required accuracy, it was decided to use this type of magnet. The momentum resolution attainable with such a magnet is in first order of approximation given by

$$\frac{\Delta p}{p} = \frac{\Delta S_i}{\rho(1-\cos\alpha) + l_i\left[\sin\alpha + (1-\cos\alpha)\tan\beta\right]} \qquad i = 1, 2 \qquad (1)$$

From this expression it is evident that choosing a value $\beta > 0$ also improves the resolution.

Our design goal was to get a resolution of 1×10^{-4}. To avoid serious slit scattering effects the width of slits should not be less than 1 mm. To achieve $\Delta p/p = 1 \times 10^{-4}$ with a magnet with $\alpha = 105°$ (cf. Section 2) and $\beta = 33°$ (double focusing condition) in an arrangement with equal object and image distance would require $\rho = 2{\cdot}50$ m. From (1) it is evident that in order to reduce the size of the magnet the object (or image) distance has to be increased. Choosing $\rho = 1{\cdot}5$ m, $l_1 = 5{\cdot}0$ m, and $\beta = 33°$ results in a first order resolution of $0{\cdot}9 \times 10^{-4}\,\mathrm{mm}^{-1}$ and a radial magnification of 0·4. In Fig. 1 the position of the radial image is indicated by A. As a narrow slit will give serious slit scattering a quadrupole doublet Q_4 will be used to produce an enlarged radial image at S_2. A total radial magnification between S_1 and S_2 of 2 will enable us to use a 2 mm wide exit slit.

Ion optical calculations[2] showed that the transmission of the analysing system is 100% for a monoenergetic beam with phase space areas of at least 10 mm mrad and 70 mm mrad in the radial and vertical plane respectively.

To use a quadrupole (Q_4) in an analysing system requires an accurately constructed quadrupole with very well known properties. A radial variation of the effective length of 0·5% over the beam diameter, for instance, would make the resolution appreciably worse. The chromatic aberration, inherent in the use of a quadrupole, has only a negligible effect.

The most important aberration of the magnet, the $x_0'^2$-aberration, can be eliminated in a uniform field magnet by curving the entrance and exit edges. Instead of machining the pole edges with the calculated radius of curvature, curved shim pieces will be attached to the edges. After the field of the magnet without shims has been measured the optimal shape of the shims will be determined experimentally. This procedure has the advantage that not only the correction for the $x_0'^2$-aberration can be made but also for aberrations due to deviations from the ideal uniform field. The final momentum resolution is expected to be $1{\cdot}0 \times 10^{-4}\,\mathrm{mm}^{-1}$.

REFERENCES

1. van Kranenburg., A. A., Wierts, D., and Hagedoorn, H. L., *I.E.E.E. Trans. Nucl. Sci.* **NS-13**, 447, (1966).
2. Put, L. W. Report KVI-2, Groningen (1967).