PROPOSAL FOR A BEAM SWINGER

John C Cornell
National Accelerator Centre, CSIR
P.O. Box 72, Faure, 7131, Republic of South Africa

Summary. A beam swinger is described which will permit the angle of incidence of particle beams onto a target to be varied from 0° to +30°. For symmetry checks the beam can also be swung to approximately -5°. Neutron detectors placed at 0°, 30°, 60° and 90° will then permit angular distributions to be measured using conventional time-of-flight methods, but without changing detector angle. The device requires two dipoles, bending the beam in opposite directions, together with a dump magnet. The design is intended to permit the largest of the dipoles to remain at a fixed field setting for a given particle energy, so that the angle of incidence is determined by the field of the first magnet alone.

Introduction

"Beam swinger" is the descriptive term used[1] to describe a device for bending a particle beam so that the angle of incidence on a fixed target can be varied. This is a means whereby angular distributions of reaction products can be measured without moving the detector. This is particularly useful for neutron spectroscopy using the time-of-flight method, where the detectors tend to be large (heavy), and where the collimators and shielding must of necessity be heavy. Although several kinds of beam swinger have been proposed and used elsewhere, it seems to be preferable to avoid (a) moving magnets, (b) moving targets inside a magnet, and especially (c) moving shielding. Unfortunately, as the energy of the primary beam rises, so do the mass and costs involved in both magnets and shielding for such facility.

We plan to use such a beam swinger at the north end of our experimental area. (Refer to Fig. 1 of reference[2]). The swinger and the target will be housed in a well-shielded vault, while the neutron energy will be measured with unshielded detectors, using the conventional time-of-flight technique. The neutron detectors and electronics will be housed in cabins on trailers which can be moved along roadways already constructed at 0°, 30° and 60°. A similar detector at 90° will be located inside the experimental hall itself. The flight-path at 0° is nearly 200 m long, while those at larger angles are shorter because of the marked decrease in neutron yield at such angles, so that increased solid angle is needed at the detector.

The Proposed Device

The proposed beam swinger consists of three dipoles, the first being a portion of a circular-pole dipole, which bends the beam through an angle α (Fig. 1). The second magnet then returns the beam to the target, bending it through an angle γ. We propose to offset the target by 5° from the incoming beam, to reduce the amount of radiation reaching the 0° detector from further upstream. A third magnet is required to deflect the primary beam into a shielded beam dump.

Thus for $\alpha = \gamma = 10°$, the beam will strike the target at $\theta = 0°$, i.e. parallel to the original beam direction.

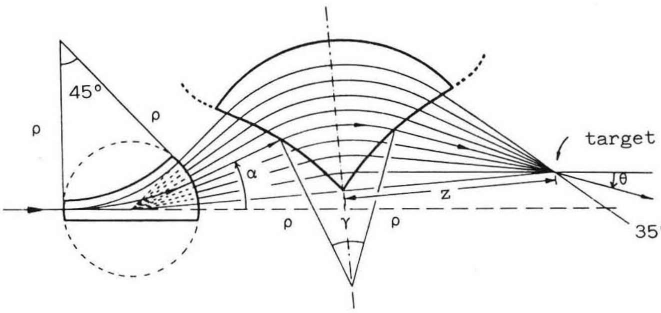

Fig. 1 Diagram of the proposed beam swinger.

In general we have:

$$\gamma = 2\alpha - 10°, \tag{1}$$

and $$\theta = \alpha - 10°. \tag{2}$$

As an initial condition, we require that the field in the second magnet should be constant for a given beam energy, independent of the angle of bend in the first dipole. This makes the operation of the swinger very easy, as there is only one parameter to adjust for different angles of incidence. However, in order to achieve this in practice, the second dipole must have a special profile.

Calculation of Magnet Edge Profile

If we draw the essential features of the second dipole, as in Fig. 2, we can calculate the x and y co-ordinates of any point on the curve $y = f(x)$ which defines the edge profile. From Fig. 2 we can see that the system has symmetry and a symmetrical dipole is required.

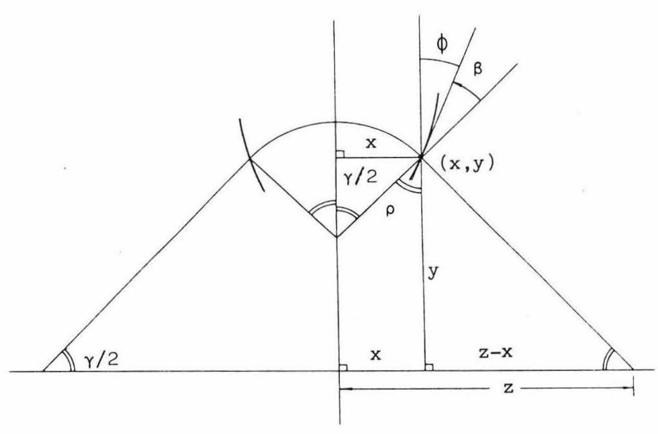

Fig. 2 Geometry of the second dipole in the beam swinger.

We have:

$$x = \rho \sin (\gamma/2) \quad (3)$$

and $$y = (z - x) \tan (\gamma/2) \quad (4)$$

where ρ is the constant radius of curvature for all values of γ, and z is the distance from the symmetry plane to the target, as shown.

For beam-optical calculations it is also necessary to know the entrance (and exit) edge angle β, shown as a positive angle in the figure. We have:

$$\beta = \gamma/2 - \phi \quad (5)$$

where $\phi = \arctan \frac{dx}{dy} = \pi/2 - \arctan \frac{dy}{dx}$.

Now from (3) and (4) we get

$$dx = \rho \cos (\gamma/2)\, d(\gamma/2)$$

and $$dy = (z - x) \sec^2 (\gamma/2)\, d(\gamma/2) - dx \tan (\gamma/2);$$

thus: $$\frac{dy}{dx} = \frac{z - x}{\rho \cos^3(\gamma/2)} - \tan (\gamma/2), \quad (6)$$

from which β can be evaluated for any value of the angle γ.

We have calculated this profile for a symmetrical dipole, for various distances z to the target. These curves are shown in Fig. 3. The choice of profile is dictated by the ratio of z to the bending radius ρ in the second dipole: the minimum practical value of z seems to be about 1.25 ρ, depending on target design and space required for the dipole magnet coils, etc. This ratio of z to ρ, i.e. 1.25 is the value used in Fig. 1. Smaller ratios imply the use of a more curved edge profile, while larger values lead to a larger (and hence more expensive) magnet, with correspondingly larger drift lengths. This dipole will probably be constructed with bolt-on pole edges, which can be re-machined after field mapping, if necessary.

A preliminary design of the magnets and vacuum chambers has shown that the values chosen are practical for a 200 MeV proton beam energy, with sufficient room for the coils.

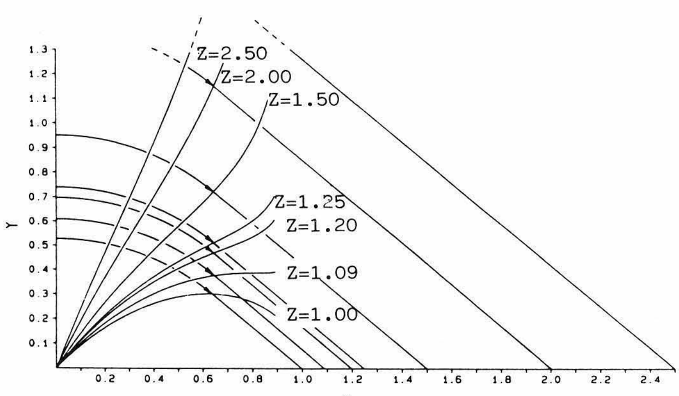

Fig. 3. Possible edge-profiles for the second dipole magnet, drawn for various values of the apex-to-target distance z. The radius of curvature of all the paths shown inside the dipole is unity.

Beam preparation

We propose to use a two-triplet configuration of quadrupoles, to transport the beam through the 90° dipole magnet serving the spectrometer beamline. The operation of these triplets is illustrated in Figs. 4 and 5 for $\theta = 0°$ and 35° respectively, i.e. the two extreme positions. (In practice it may be possible to go to small negative angles, up to −5°, depending on the nature of the fringe field near the apex of the second dipole).

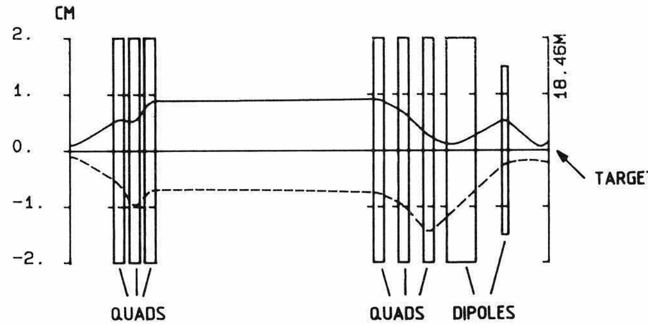

Fig. 4. The operation of a 2-triplet quadrupole telescope and the beam swinger, for $\theta = 0°$.

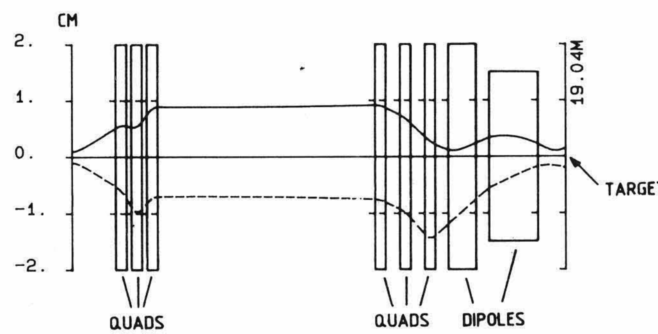

Fig. 5. The quadrupole telescope exactly as in Fig. 4, but with the beam swinger set for $\theta = 35°$, resulting in a longer path to the target.

Notice that the drift lengths on either side of the second dipole, as well as the path length inside this magnet are functions of θ, and are quite different for the two cases illustrated. The two quadrupole triplets focus the beam to a horizontal waist in the first (circular-pole) dipole, which is then transferred by the point-to-point optics to a small beam spot on target. The quadrupole settings were chosen to form a small spot size in both x and y at the target for $\theta = 0°$. The beam emittance was chosen to be 3π mm.mrad with x = y = 1 mm and x' = y' = 3 mrad at the slit at the start of the two-triplet system. With no change to the quadrupole settings the same beam was then transported for the θ=35° case, using the program TRANSPORT[3] to calculate the beam spot size, which in fact remains fairly constant, provided that the energy spread in the beam is fairly small.

θ :	0°	35°
x	0,1515	0,1514
y	0,2205	0,2302

No change is therefore needed in the quadrupole triplet settings for any value of θ, (provided of course that the beam energy remains constant).

Beam-dump magnet

The beam dump consists of a Faraday cup surrounded by iron shielding, embedded in a wall of shielding blocks. If we assume that this cup is at an angle of 35°, then the dump magnet, located immediately behind the target, must be capable of bending the beam from $\theta = 0°$ through an angle of 35°, to the beamp dump. Any small negative-angle beams up to $\theta = -5°$ will similarly have to be bent through an angle approaching 40°. The shape of this magnet is fairly arbitrary, and its precise setting can be adjusted to centre the primary beam (with target removed) at the back of the Faraday cup by comparing the currents measured on the four quadrants of the cup. Once determined, the relation between θ and the settings of the dump magnet is constant, and can be scaled for any beam energy.

Conclusion

It appears in principle to be possible to construct a beam swinger, operating from approximately 0° to 35°, for typical beams of protons up to 200 MeV. The proposed swinger would be relatively simple to operate, having a fixed field strength in the second dipole, and fixed quadrupole settings, for a given beam energy. The only variables would be the field strengths of the first and third dipole magnets, which would respectively determine and depend on the angle of incidence of the beam on target.

References

1. C.D. Goodman et al., A facility for studying neutron spectra at intermediate energies, IEEE Trans. on Nucl. Sci. NS-26 (1979) 2248 and refs. therein.

2. A.H. Botha et al., Commissioning of the NAC separated-sector cyclotron. This conference.

3. K.L. Brown et al., TRANSPORT: a computer program for designing charged particle beam transport systems, SLAC-91 revision 2 (Stanford 1977) and CERN 80-04 (Geneva, 1980).