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MODULATED PROTON BEAM FOR AN RF-SEPARATED BEAM

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It has been suggested that some economy may be had in the construction of an rf-separated beam by modulating the primary proton beam.[1] The extent of the economy depends upon how the modulation is performed. If the frequency of the modulated beam is the same as the cavity frequency, a typical 100 GeV, 1.2 km, rf beam[2] can be made shorter by 265 m. This is the distance between the target and the first deflector. It is also possible to make the frequency of the modulated beam twice the cavity frequency in which case the rf beam can be made shorter--by 610 meters, a reduction of the beam length by half.

Of the several problems associated with the modulation of the proton beam we shall discuss two: isochronism and a scheme for modulating the primary proton beam.

Isochronism

Only a small difference in path lengths between the central trajectory and an extreme trajectory can destroy the synchronism of a beam. For example, the wave length of an X band (10 GHz) cavity is 3 cm--a 1° phase shift corresponds to 0.083 mm.

Phase Dispersion by Quadrupole Focusing. As may be deduced from Fig. 1(a) the path length dispersion from the focusing action of the beam is

$$\delta = \frac{1}{2} \int_0^{s'} \left(\frac{dy}{ds}\right)^2 ds,$$

where $\frac{dy}{ds}$ is the slope between the trajectory and the beam axis (a straight line), δ is the distance a particle traversing an off-axis trajectory will lag a particle on the axis at a distance s' from the starting point. Both particles left the starting point together and have the same velocity.

The part of the beam which may be troublesome when the proton beam is modulated is from the target to the first cavity. It is here that the angles the trajectories make with the beam axis are large. We have computed the phase dispersion in the interval between the target and the first cavity for Joe Lach's beam and find

$$\delta = 0.25 \text{ mm}.$$

The phase dispersion is 3° and is small enough to cause no difficulty.

Phase Dispersion by Dipole Deflections. A parallel beam of width a and which is deflected by an angle θ has a path difference between the two extreme rays

$$\delta = 2a \tan \theta / 2,$$

as may be seen in Fig. 1(b). The entrance and exit angles are chosen to be equal. In order to achieve good momentum resolution we may have at typical deflecting magnets $a = 60$ mm, $\theta = 30$ mrad, then

$$\delta = 1.8 \text{ mm}.$$

The phase dispersion is now 22° which is too large to be ignored.

It is possible to make a beam which remains synchronized and is momentum analyzed. Such an isochronous system requires at least two deflections as shown in Fig. 1(c). We now give the condition for isochronism in terms of the transport matrix B between the first deflection magnet and the second deflection magnet.

$$B = \begin{vmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{vmatrix}.$$

The condition for isochronism is

$$b_{12} = 0,$$

and

$$b_{11} = -\frac{\tan \theta_1}{\tan \theta_2};$$

$$b_{11} \times b_{22} = 1.$$

θ_1 and θ_2 are the deflections in the first and second magnets. We note that this is also the same condition required for the spatial recombination a beam with a spread in momentum, i.e., all particles which enter the first magnet at a given position and angle will exit the second magnet at the same position and with the same angle independent of momentum.

We find it remarkable that the condition for isochronism is identical to the condition for recombination of particles with different momenta in configuration space. In this connection we also note that if a quadrupole focusing system, as in Fig. 1(a), images a ray of momentum p from a point on the axis at 3 = 0 to another point on the axis at z = s, a ray with momentum p + Δp will not be imaged on to the axis but will deviate from the axis by an amount

$$u = \left(\frac{\Delta p}{p}\right)\left(\frac{dy(s)}{dz}\right)^{-1} \cdot \int_0^s 1\left(\frac{dy}{dz}\right)^2 \cdot dz .$$

This formula resembles the formula for the phase dispersion by quadrupole focusing. The similarity between the formulae for isochronism and spatial identity, suggests some principle like the action principle in optics. Such a principle would be very useful for the design of rf beams and would save many hours of computer time.

Modulated Proton Beam

Two possible schemes are suggested; the first involves sweeping the proton beam across the target. The secondary beam is then modulated at the cavity frequency or at twice the cavity frequency depending upon the target location. This is schematically illustrated in Fig. 2(a).

The deflection in a 5 m X-band rf deflector is certainly adequate. The phase volume occupied by the beam is (0.04 × 0.04 cm-mrad). The proton beam is first shaped to have a horizontal extent of 8 mm and an angular divergence of 0.05 mrad.

If the separator can impart 6 MeV/c transverse momentum to the beam per meter the 200-GeV proton beam will be deflected with amplitude three times its angular spread. The focal length of the optical system needed to focus the beam from the detector to a 1-mm target is only 20 m and easily constructed.

The second scheme we propose is less wasteful of proton beam intensity and is sketched in Fig. 2(b). The incident proton beam is deflected twice, first by an rf deflector and then again by a dc deflector made of two rectangular boxes separated by 1 cm (in this example). The protons which pass through the gap between the boxes are deflected into the channel for the separated beam. The others can pass on to a second target. The proposal is an rf modulated micro-split in the beam to be performed upstream of the hot box.

The shape of the proton beam as it enters the rf cavity is the same as described in the first example. Between the rf deflector and the dc reflector is an optical system which transforms all rays emanating from a point into a parallel beam (in the plane of the deflections). We find it is satisfactory to have a 5-m deflector which has an electric field of 50 kV/cm. The lens system between deflectors should have a focal length of 330 meters for 10% of the proton intensity to the rf separated beam. No detail design exists for this lens system but the requirement is modest and easily achievable with less than 100 m between deflectors.

REFERENCES

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[2]J. Lach, 200-BeV Accelerator: Studies on Experimental Use 1964-5, University of California Lawrence Radiation Laboratory UCRL-16830, Vol. I, p. 190.

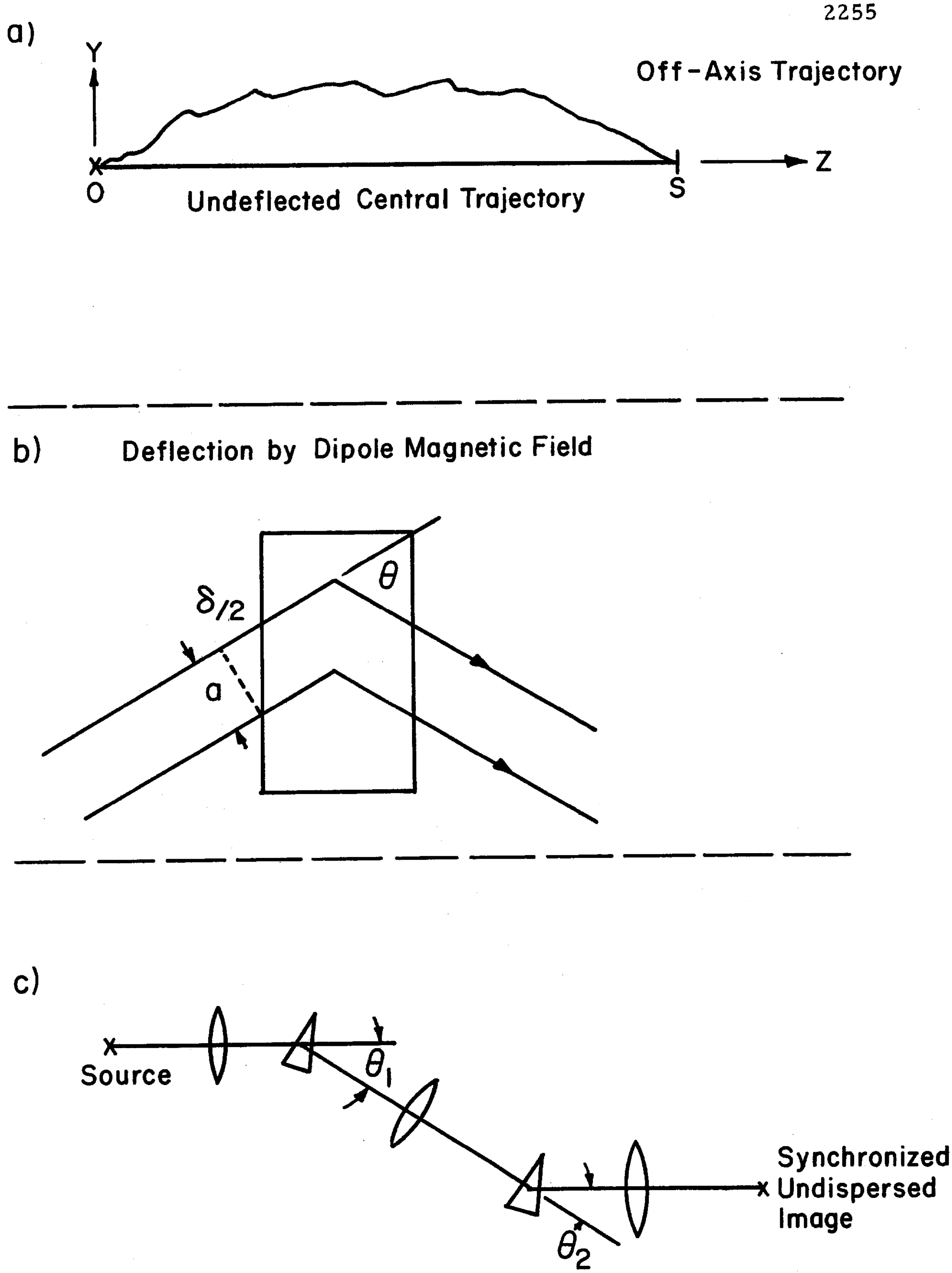

Fig. 1(a). Illustration for path length dispersion (see text); (b) path difference introduced by dipole deflection; (c) isochronous system using two equal and opposite deflections.

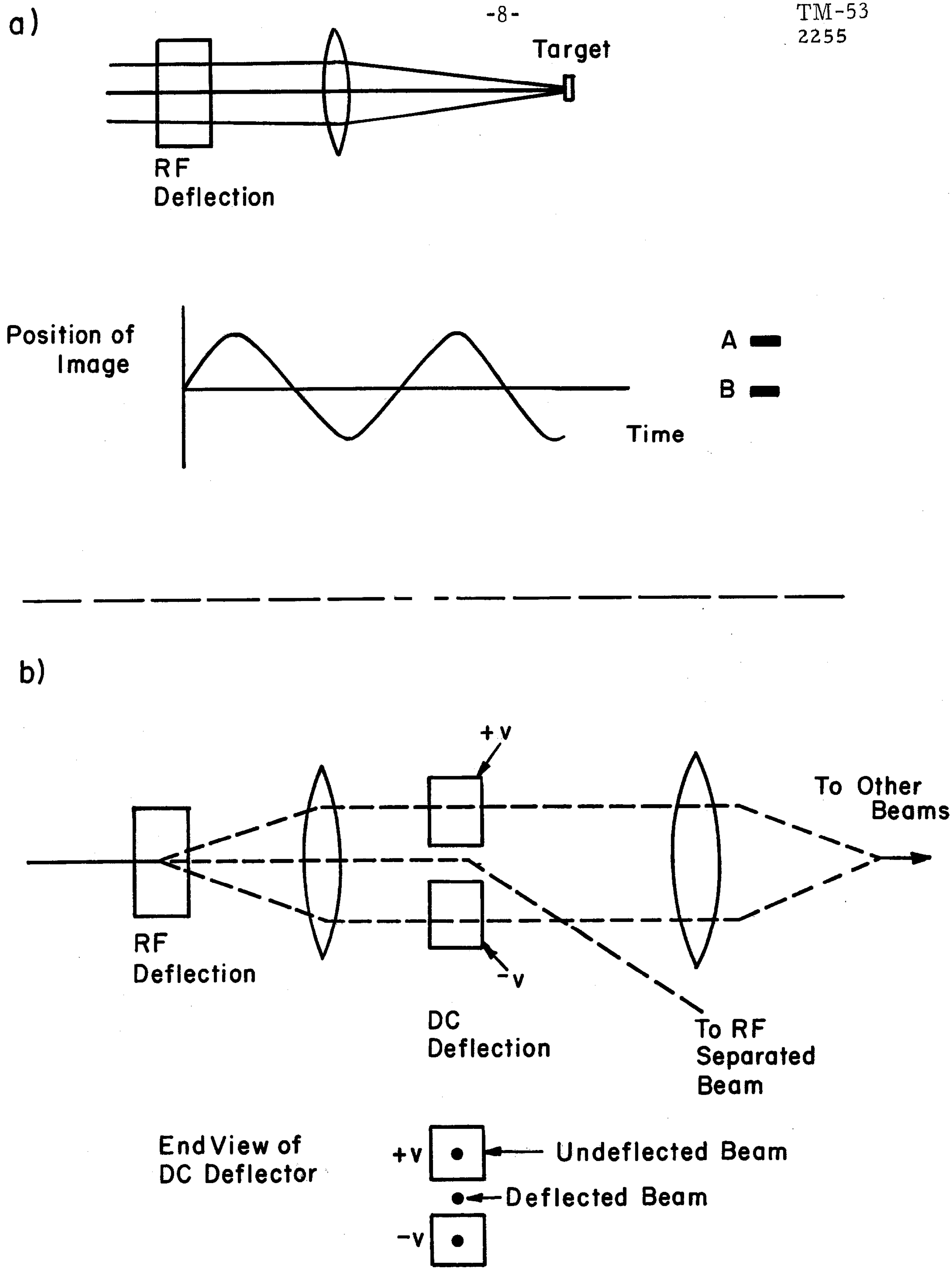

Fig. 2(a). Lateral sweep produced by rf deflection; (b) deflection scheme utilizing only part of the total available beam.