DNPL EL/TM021

TEST ARRANGEMENTS FOR THE INJECTOR

National Institute for Research in Nuclear Science
Daresbury Nuclear Physics Laboratory,
Keckwick Lane,
Daresbury,
Nr. Warrington,
Lancs.

21st May, 196

TEST ARRANGEMENTS FOR THE INJECTOR

The specification for the injector calls for two sets of measurements to be carried out to determine the quality of the electron beam - measurement of the energy spectrum and of the emittance of the beam. These measurements can be carried out separately, but this may lead to a pessimistic figure for the beam current coming within the specification, and so provision has to be made for the simultaneous measurement of these qualities. In addition, it would be convenient if some or all of the measurements could be repeated after the injector had been connected into the synchrotron.

Shielding

It is essential for the initial tests to be carried out while the ring tunnel is occupied, and desirable that subsequent tests can be made under the same condition. It has been estimated that over 3.5 m of ordinary concrete would be required to ensure a dose level below tolerance on the ring side of the shield wall if the beam is allowed to hit a target close to the wall. Therefore a side arm has been provided in the injector tunnel,and if the beam is directed down this arm, about 2.5 m of concrete between the injector tunnel and the ring will be sufficient. With this thinner shielding, it will be necessary to interlock the operation of the injector with the excitation of the bending magnets.

Emittance Measurement

For this measurement the electron beam is passed through a narrow collimator slit, the position of which is adjustable across the beam in one plane, say the horizontal. A quadrupole triplet is placed at a distance equal to its focal length behind the collimator, and a similar collimator, adjustable in the same plane, is placed an equal distance behind the quadrupole triplet.

If F is the focal length of the triplet, the transfer matrix for the system from one collimator to the other is

$$\begin{bmatrix} 0 & F \\ -\frac{1}{F} & 0 \end{bmatrix}$$

so that the position of an electron at the second collimator is dependant only on its divergence at the first collimator, and not on its position there. It is thus possible to measure the range of divergence for electrons coming from a given horizontal position in the beam, and thus plot the emittance diagram for this plane. By rotating the collimators through 90°, the emittance in the vertical plane can be measured.

The sensitivity of the method depends on the focal length of the quadrupole triplet, which should be as great as possible. The maximum focal length that can be used conveniently is 4 m, giving a deflection of 4 mm at the second collimator, per milliradian divergence. With the expected divergence of less than a milliradian, the collimator slit will have to be of the order of 0.1 mm wide, and its position accurately adjustable.

During these emittance measurements, the majority of the beam current is stopped by the first collimator. This will be about 12 m. from the shielding wall, and a total wall thickness of 3 m will be required. It may be sufficient to thicken up the wall locally, for a short distance either side of the direct beam line.

Energy Spectrum Measurement

For the purpose of the acceptance tests, it is only necessary to measure the proportion of the total current coming within a 1% energy band, but it will obviously be of interest to make a more detailed examination of the energy spectrum as well.

Both requirements can be met with a bending magnet system that has an adjustable collimator slit at the focal point in the bending plane.

In order to take advantage of the side arm in the injector tunnel, it will be necessary to have a magnet system that bends the beam in the horizontal plane through approximately 90°, and which has a focal length in this plane of at least 4 m. A single, 90°, uniform field, bending magnet has its focal point at the exit edge, and even with slant faces or non-linear fields, it is difficult to devise a single 90° magnet with a focal point at a greater distance than that equal to the radius of curvature of the particles in the magnet. However, this can be done with a two-magnet system.

By the use of slant faces with uniform field magnets, the horizontal focal length can be increased, but this introduces focusing in the vertical plane. If two magnets, one the mirror image of the other, are placed a distance apart equal to twice the focal length in the vertical plane, the beam will be inverted in that plane, but the beam height and divergence will be unchanged.

For such a magnet with one slant face, the vertical transfer matrix is

$$\begin{bmatrix} 1 - \alpha \operatorname{Tan} \beta & \alpha R \\ -\frac{1}{R} \operatorname{Tan} \beta & 1 \end{bmatrix} \begin{bmatrix} y \\ \phi \end{bmatrix}$$

where α is the angle of deflection on a radius R,

and β the angle between the slant face and the normal to the central beam line.

If the beam radius and divergence are to be unaltered in the vertical plane,

$$1 - \alpha \operatorname{Tan} \beta - \frac{L}{R} \operatorname{Tan} \beta = 0$$

$$\text{or } \frac{L}{R} = \operatorname{Cot} \beta - \alpha$$

where 2L is the spacing between the magnets.

The horizontal matrix for such a magnet is

$$\begin{bmatrix} \frac{\cos(\alpha - \beta)}{\cos\beta} & R\sin\alpha & R(1-\cos\alpha) \\ -\frac{\sin(\alpha-\beta)}{R\cos\beta} & \cos\alpha & \sin\alpha \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ \theta \\ \Delta p/p \end{bmatrix}$$

If such a magnet and its inverse are placed apart a distance 2L, determined as above, the focal length in the horizontal plane is given by

$$\frac{F}{R} = \cos\beta \left[\frac{\cos\alpha\ \cos(\alpha-\beta) - \sin\alpha\ \sin(\alpha-\beta) - 2(\cot\beta - \alpha)\ \cos\ \alpha\sin(\alpha-\beta)}{2\ \sin(\alpha-\beta)\ \cos(\alpha-\beta) - 2(\cot\ \beta - \alpha)\ \sin^2(\alpha-\beta)} \right]$$

For the layout desired, if $\alpha = 45^\circ$, the focal point should be between 4 and 5 m from the magnet, and if we assume a radius of curvature of 1 m, this gives $4 < \frac{F'}{R} < 5$. Inserting trial values of β in the above expression, it is found that, for $\beta = 42^\circ$, F = 4.67 m, which is acceptable.

With these values, the transfer matrix for the whole system to the focal point becomes

$$\begin{bmatrix} 0 & 5.38 & 11.67 \\ -.186 & 0.10 & 1.87 \\ 0 & 0 & 1 \end{bmatrix}$$

From this it can be seen that 1% $\Delta p/p$ will result in a displacement of the focal point by 11.7 cm. As far as the electron optics are concerned the energy resolution of the system will be limited by the initial divergence of the electron beam, 1 milliradian divergence resulting in a displacement of .54 cm. Since the initial divergence should not exceed $\frac{1}{2}$ milliradian, a resolution of 0.025% should be attainable.

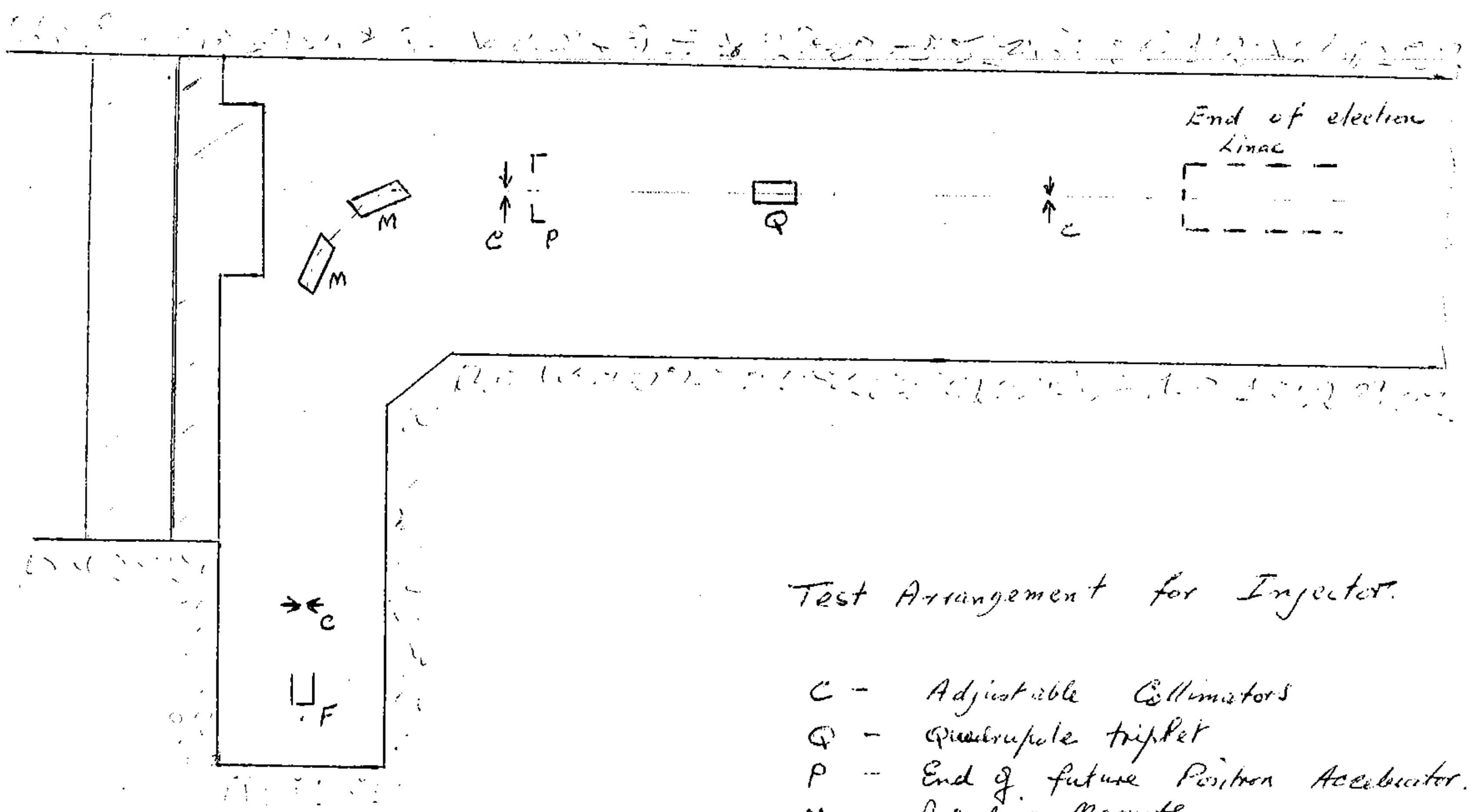
Combined Measurements

With the arrangement shown in the figure, it will be possible to carry out both the separate measurements of energy spectrum and emittance, and, if necessary, to measure the energy spectrum at any point in the emittance phase-space diagram. Thus, an accurate figure for the fraction of the total current coming within the specification limits can be obtained.

It seems almost certain that the energy analysing system can be left in place permanently, subject to effective de-gaussing of the first magnet, so that any necessary checks on the performance of the injector can be made after the injection path has been completed. The quadrupoles and collimators for the emittance measurements will have to be moved further downstream when the positron accelerator is installed.

M. C. Crowley-Milling

EL/TN/21
21st May, 1964.



Test Arrangement for Injector.

C – Adjustable Collimators
Q – Quadrupole triplet
P – End of future Positron Accelerator.
M – Bending Magnets.
F – Beam collector.