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DESIGN AND CONSTRUCTION OF THE AXIAL INJECTION SYSTEM
FOR THE 88-INCH CYCLOTRON.^{*†}

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March 1969

SUMMARY

A new axial injection system for the 88-inch cyclotron has been constructed. It transports beams from external ion sources axially through the magnet yoke to the median plane of the cyclotron. The optical elements include a bending magnet, electric quadrupoles, and the magnetic field of the cyclotron. Beam monitoring is done with scanning wires, phosphor plates and Faraday cups.

^{*}Work performed under the auspices of the U.S. Atomic Energy Commission.

[†]Expanded version of paper presented at the 1969 Particle Accelerator Conference, Washington, D. C., March 5-7, 1969.

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1. INTRODUCTION

The old axial line¹ of 1966 used an ion source mounted directly on the line axis, and had electric quadrupole doublet lenses with a 3.0 cm aperture. The new line, Fig. 1, accepts beam from either a polarized ion source on axis, or a duoplasmatron source used with a 90° bending magnet. The aperture has been increased to 7.3 cm and quadrupole triplets are used for greater matching flexibility. This paper describes the system down to the median plane. The new inflector and center region electrodes will be the subject of a future paper.

2. DESIGN CONSIDERATIONS

Since the polarized source is a complex structure it was placed above the 7 ft thick concrete roof of the cyclotron vault, to allow construction and testing during cyclotron operation. The duoplasmatron source and future sources should also be at a convenient distance above the shielding to allow for expansion. The injection line is required to transport the beam about 15 feet from the sources to the median plane.

The requirements for the injection energy are determined by the center region orbits and geometry as follows:

1) The injected beam must clear the inflector electrode (Fig. 1) on the first turn in the cyclotron median plane, after being inflected into the dummy dee as at Birmingham.² This means having a large enough injection voltage, $V_{i,min}$, at the particular cyclotron magnetic field, B , being used, and $V_{i,min} \sim B^2$. For our geometry this requirement excludes the shaded area to the right in Fig. 2.

2) The beam must be nearly centered in the cyclotron after several turns of acceleration. This requires the injection voltage to be proportional to dee voltage, $V_i = KV_D$. In the present case of a single dee, on-axis injection and narrow accelerating gaps, $K \simeq .18$. Our normal maximum dee voltage is about 65 kV, so the maximum injection voltage is 12 kV. This limit is shown by the upper shading in Fig. 2. It should be noted that injection voltage can be increased to about 30 kV, for example, when the beam is injected .5 inches off center.

When one uses an injection voltage which increases with cyclotron field as $V_i \sim QB^2/M$ where Q and M are particle charge and mass, one has "scaled operation", as shown by the diagonal lines in Fig. 2, for example.

All beams on one line then have the same trajectories through the magnetic "hole lens" approaching the median plane, and in the first turn up to the first acceleration gap. The dee voltage must be kept proportional to injection voltage (requirement 2 above), so the orbit pattern in the cyclotron is also constant. The main advantage of this type of operation is that once the beam optics has been optimized in the injection line, hole lens, and cyclotron center region for one point on the line, all the other cyclotron energies and particles can be obtained easily by the proper variation of injection and dee voltage. Another way of stating the scaling law is $V_i \sim E_c/Q$ where E_c is final cyclotron energy.

At the highest energy beams, the dashed line must be used, because of the above requirements. At lower energies one can shift to the line giving the best transmission.

For low intensity polarized beam injection (several microamps) we can scale down to the low energy end using only 1 - 2 kV injection voltage without losing transmission efficiency. But with high intensity beams of several hundred microamps we would want to stay up in the 5 - 10 kV injection voltage region by shifting to other scaling lines at the lower magnetic fields.

3. ION SOURCES

The polarized ion source³ is of the usual atomic beam type, using a dissociator, sextupole, RF transitions and strong-field ionizer. We expect that it will produce polarized beam for experiments of 100-1000 times the intensity and much better quality than that available with the α -p scattered beam used during the past several years.

The duoplasmatron source⁴ produces intensities of over 500 μ A of protons, H_2^+ , H_3^+ and similar deuteron beams. It is being used to test the transport line performance for efficiency under low and high intensity conditions. Its output of doubly charged ions is small, a few micro-amps, so a PIG source is planned to give a higher α -particle output for pulsed beam work.

4. TRANSPORT SYSTEM

The 90° bending magnet brings the duoplasmatron beam into the axial line. It gives equal focusing in both planes with a flat field and edges cut at 36° to the beam normal. This large edge angle is used because of the large ratio of gap to beam path length in this magnet. Edge clamps are used to define the fringing field. Einzel lenses are used just before the magnet on both source lines to produce a waist about 40 cm before the first triplet.

Three quadrupole triplet lenses were chosen to transport the beam efficiently down the column to the median plane.⁵ They give versatile transformation of phase space ellipses to match the ion sources to the cyclotron, and transmit beam currents over 500 μ A at 10 kV injection voltage. Space between triplets is used for steering plates, scanning wires, phosphor plates, and Faraday cups. The scanning wires are motor-driven X-Y double scanners used for recording of beam shape on a storage oscilloscope. The Faraday cups and phosphor plates are remotely controlled by air cylinders. For phosphors we use either quartz or aluminum oxide. One of the sets of steering plates will be used for a future fast pulsing system by sweeping the beam into a downstream aperture. A future buncher will be placed in the space between the last two triplets to match the dc beam from the source to the RF time acceptance of the cyclotron. At present a sine-wave buncher is being planned, rather than the more ideal but more difficult sawtooth buncher suggested previously.⁶

The mechanical structure consists of 6-inch diameter tubes containing the lenses, inside a 12-inch square cross-section evacuated column, as shown in Fig. 1. As much shielding as possible is replaced around the injection line to reduce neutron leakage.

5. THE HOLE LENS

The beam entering the strong magnetic field of the cyclotron is focused to periodic waists by this half solenoid or "hole lens". Calculations were made on particle trajectories for various phase space shapes and waist positions.⁷ They showed that several discrete operating modes produce the desired beam size in the median plane of 2 - 3 mm diameter. The " λ mode"

is obtained by starting with a small waist about 14 cm before the median plane, which is then transferred to the median plane by the strong axial magnetic field. The " $3/2 \lambda$ mode" is produced with a lower injection voltage starting with a large waist 10 cm before the median plane. The median plane then sees the second small waist formed by the magnetic field. These two modes are shown on Fig. 2.

For high energy beams the dotted line in Fig. 2 must be used, as stated above, so we are between modes. A point on this line was checked on a test of the injection line. Figure 3 shows this case for 10 kV protons going into a 10 kg field with over 50% transmission through the line. The spot diameter is about 2 mm FWHM which is quite acceptable. This shows that one can operate efficiently some distance off the mode lines if necessary.

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FIGURE CAPTIONS

Fig. 1. Schematic drawing of axial injection line for 88-Inch Cyclotron.

An additional quadrupole triplet is located in the omitted section above the magnet.

Fig. 2. Chart of operating parameters for injection line. Forbidden regions are shaded: at the right because of the clearance requirement for inflected beam in the first turn, and at the top because of the orbit centering requirement.

Fig. 3. Photo of scanning wire sweep of beam at the median plane after passing from duoplasmatron source through injection line. Beam was 10 keV protons injected into a cyclotron field of 10 kG, corresponding to a 55 MeV proton cyclotron energy. Horizontal scale is 2 mm per large division.

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Fig. 1.

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Fig. 2.

XBB 692-1386

Fig. 3.

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