A CENTRE-REGION MODEL OF A THREE-SECTOR CYCLOTRON

D. J. Clark
Rutherford High Energy Laboratory, Chilton

The former 4-sector centre-region model cyclotron has been modified to study central acceleration problems for the Variable Energy Cyclotron now under construction. It is shown in Fig. 1. When it operated as a 4-sector cyclotron it accelerated protons to 4 MeV at a radius of 9 inches. The last previous report on this machine was given in February 1959[1] by Snowden during magnetic field measurements. This was a model to give the same field in the center region as in the proposed conversion of the Harwell 110 inch cyclotron. The operation was with a hooded source, no puller, and 25 kV on the dee. The machine was pulsed at 1% duty cycle. The beam current during the pulse was 300 μA. Neutron production was observed above 2 MeV from the (p, n) reaction on copper. A number of beam probes which were developed during this operation are proving useful during the present operation.

Scaling Considerations

When the model cyclotron was to be converted to a 3-sector model of the center of the V.E.C. the question of scaling the ridge system had to be settled. The law which had to be followed in simulating full-scale particle orbits with protons in the model is:

$$\frac{V_m}{V_f} = \left(\frac{B_m}{B_f}\right)^2 \left(\frac{R_m}{R_f}\right)^2 \frac{A}{N} ,$$

where subscripts m and f refer to the model and full-scale machines; V is dee voltage; B is magnetic field; R is radius; A is mass number and N is charge state for particles in the full-scale machine. If this relation is satisfied then there will be the same number of proton revolutions out to radius R_m in the model as there are revolutions of particle (A, N) out to radius R_f in the full-scale machine. The phase and the axial and radial stability properties in the two machines will be the same at corresponding radii. For scaling the magnetic field it is convenient to make $B_m = B_f$ since the iron saturation will then have a similar effect at corresponding radii in two machines, for any scaling ratio R_m/R_f. This is especially useful when simulating a hole through the center of the yoke, where saturation is a dominant feature of the resulting field. The most important particles to be simulated are protons, because they have the most revolutions and so their phase and focusing problems are the most critical. Orbits of heavier ions can be simulated to some extent by raising V_m or lowering B_m, to the upper limit of V_m and the lower end of the RF frequency range on the model. So on the model $B_m/B_f = 0.96$ for simulating full energy protons. $R_m/R_f = 0.63$, the smallest value permitted by the existing dee, with a 7/8 in. dee-liner spacing. This gives a 4 in. minimum gap, and 3 in. thick ridges. The operating dee voltage $V_m = 30$ kV. From the scaling relation, $V_f = 80$ kV, reasonably below the desigm value of 100 kV.

Machine Description

The cyclotron magnet is operated at 13 kG with a power of 90 kW for excitation. The RF system is a single dee and coaxial line with a movable capacitive short capable of tuning from 15-20 Mc/s. The coupling loop is driven by a crystal controlled power amplifier. A dee bias of about 500 V is usually used. A plan view of the vacuum box is shown in Fig. 2. The single dee has a beam space of about 2 in. with a dummy dee opposite it. The three Thomas ridges are shown in the figure. The ion source is of the Oak Ridge hooded type with a reflector, a 3/8 in. dia chimney, and a 0.06 x 0.23 in. beam slot. It will translate in three dimensions and rotate about both horizontal axes. There is a puller electrode on the dee which is movable in-out and side-side during cyclotron operation, by means of wires down the dee line. There are three probes around the machine, two for beam collection on the front side and one in the dee for cut-off purposes, operated by a wire down the dee line. In addition there are two control rods near the source which are now used to position a phosphor screen and a defining post to clip off unwanted beam near the source.

Magnetic Field

Thomas ridges were used for simplicity, rather than spiral ridges. The magnetic field measurements for the new ridge system were made principally with a "yo-yo" device, which is a system of two moving coils in series, one in a hill and one in a valley. They rotate in a circle on the same radius and then are moved to the centre of the machine. The change in fluxmeter reading gives the difference in average field between the centre and the original radius. The accuracy is about 5 gauss for this method. Shimming to achieve a reasonable average field consisted of increasing the ridge width at larger radii and adding Rose shims at the edge. Widening the ridges was more satisfactory for maintaining adequate flutter to large radii. The resulting average fields at various magnet levels are shown in Fig. 3. The model has a 2 in. dia hole down the yoke to simulate a 3.2 in. dia hole in the full-scale machine. This hole was largely shimmed out by iron around the hole, but its effect is visible in the 13 kG curve in Fig. 3. Also shown in this curve is the 100 gauss central bump for focusing. Twelve circular trimming coils are ready to be installed, and should increase the usable radius up to about 7.5 in. at 13 kG, or 50 turns at 30 kV on the dee.

Preliminary Operation

Beam in the modified model was obtained at the end of February, 1963. The RF was operated pulsed at 50 cycles/s, 200 μs pulse width, as before. The operating dee

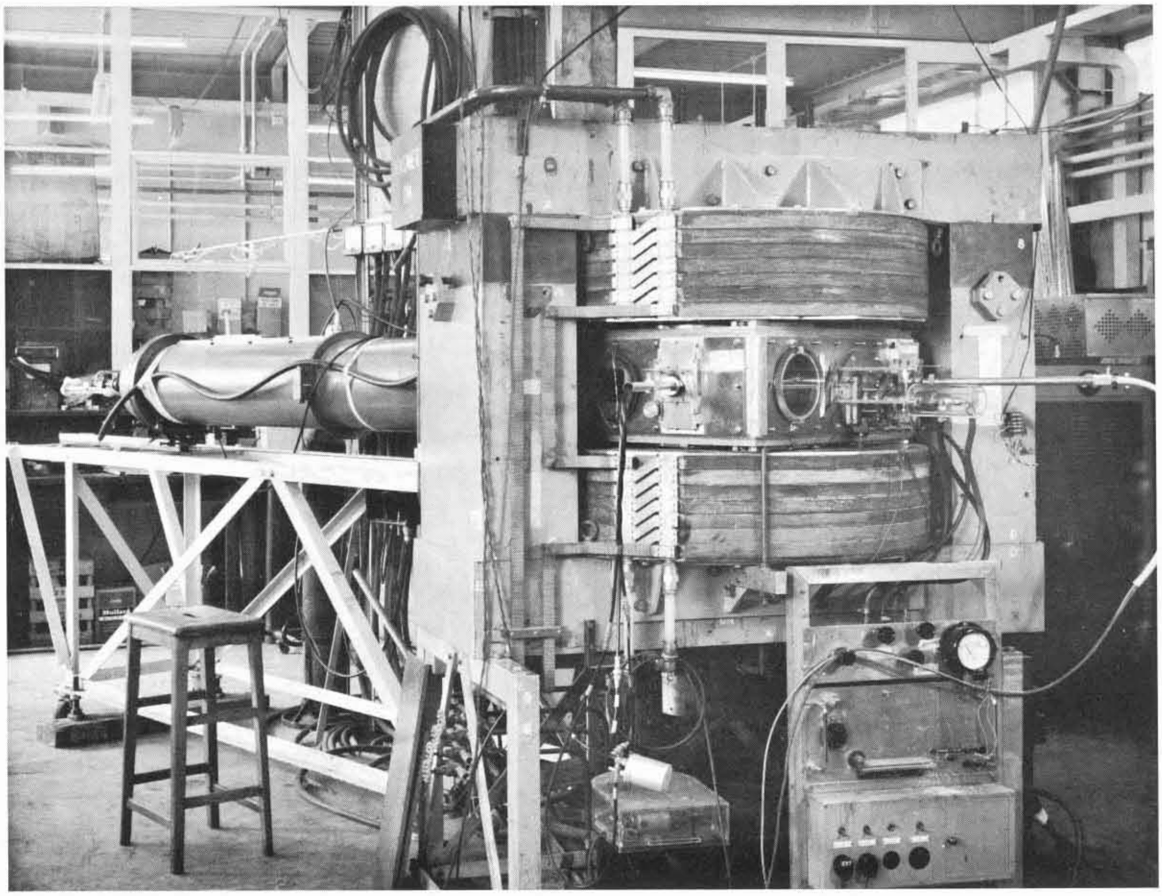

Fig. 1 Model proton cyclotron showing dee stem, magnet and vacuum tank

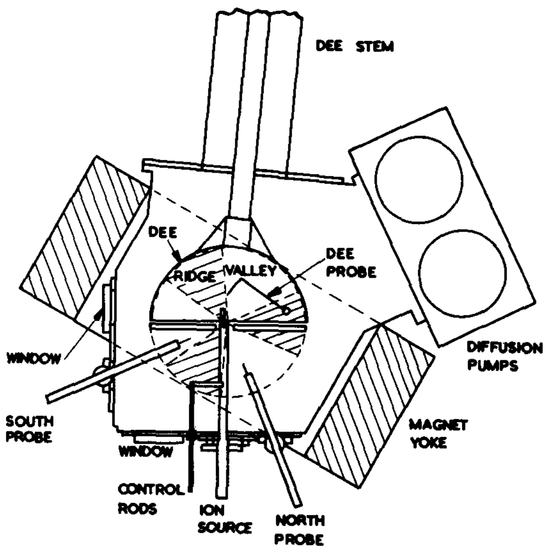

Fig. 2 Plan view of cyclotron at median plane level.

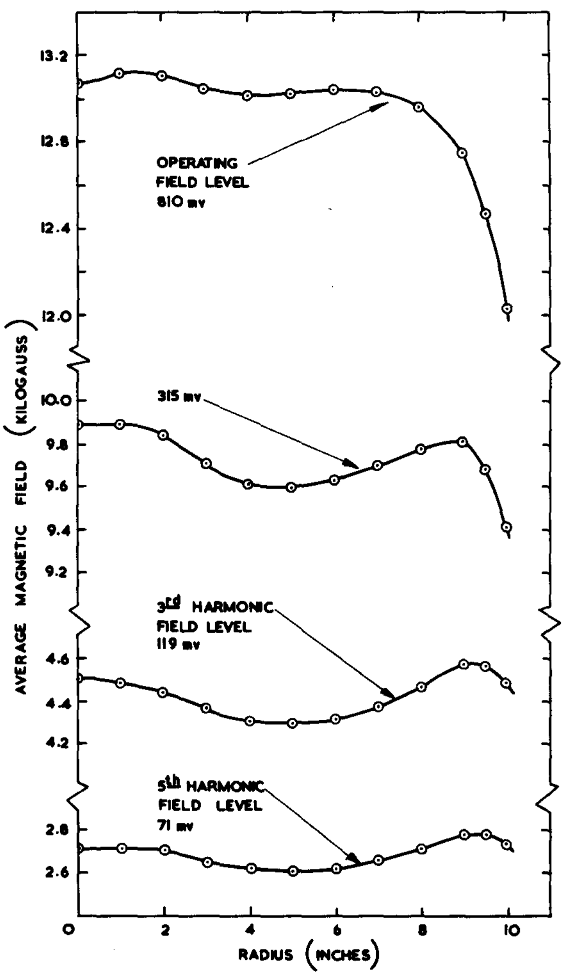

Fig. 3 Average magnetic field versus radius at four field levels.

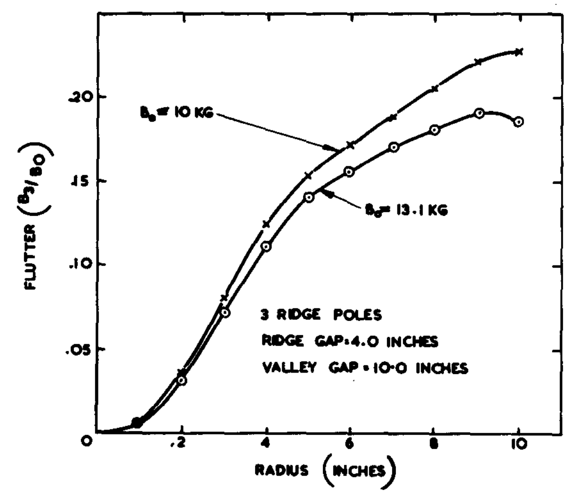

Fig. 4 Flutter versus radius for two magnetic field levels. B_3 is amplitude of third harmonic of field. B_0 is center field.

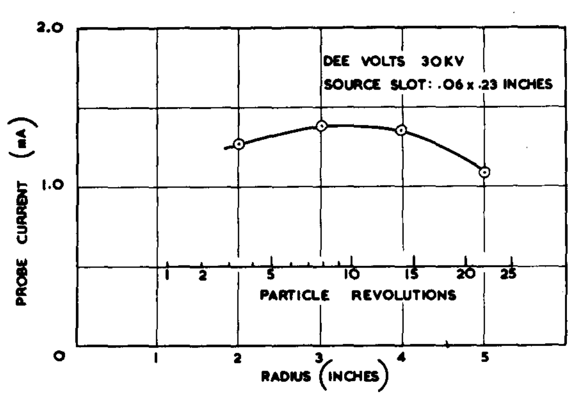

Fig. 5 Average beam current on probe during pulse versus radius and number of particle revolution. Source and puller of Fig. 7 are used here with 13/32 in. separation.

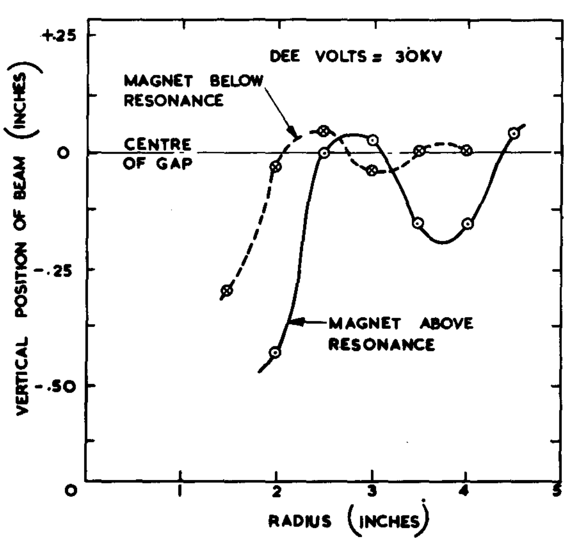

Fig. 6 Axial center of intensity of beam versus radius for two field levels, showing variation of vertical oscillation frequency due to electric focusing. Conditions as in Fig. 5.

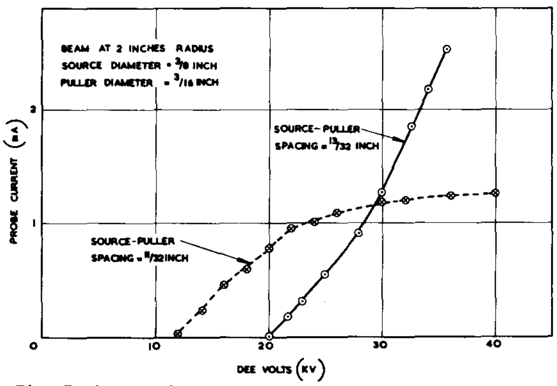

Fig. 7 Average beam current during pulse versus dee voltage for two source-puller separations, showing puller interception of beam.

voltage was 30 kV. The puller electrode was a 3/16 in. dia post placed 13/32 in. away from the source. After the beam was centered within 0.1 in., about 1 mA was obtained during the pulse. A typical current versus radius curve is shown in Fig. 5. The decrease in current at 2 in. is probably due to distortion of the beam by the probe, and the decrease at 5 in. is due to a defocusing magnetic field there, which will be corrected with trim coils. The attenuation is small for the first 20 revolutions. The centre spread is about 0.36 in. along the dee edge and 0.32 in. perpendicular to the dee edge at 3 in. radius. It is hoped that this can be reduced with a beam clipper at the first or second turn.

The vertical profile is being studied with a phosphor probe and with a probe divided into several collecting electrodes. The current collected on the 0.1 in. high middle finger of this probe is shown in Fig. 6 for two magnet levels. Coherent vertical oscillations of the beam are apparent. The more rapid oscillation when the magnet is below resonance is due to the greater electric focusing because of the more lagging phase for this case. The frequencies of about 0.1-0.2 for Q_z are in agreement with calculations.

Another measurement of interest is that of beam current versus dee voltage as near the centre as possible. Two curves of this type are shown in Fig. 7 for two source-puller separations. For the smaller separation of 11/32 in., the beam current increases with dee voltage to about 22 kV where it starts hitting the puller. For the larger separation of 13/32 in. the beam is still increasing at 35 kV. This sharp dependence of puller interception voltage on separation distance is expected from the orbit trajectory, being $V_i \sim d^4$ for small transit times. Better beam quality should be obtained when no beam hits the puller on the initial acceleration, so the 13/32 in. separation was chosen for further operation.

Some phase measurements have been made with a sampling oscilloscope showing a phase spread of about 50°; the best beam lagging the RF voltage by about 20°.

Operation is preliminary thus far. Many experiments are planned on comparing puller types, minimizing centre spread, optimizing the centre magnetic bump shape with trimming coils, and operating on the 3rd and 5th harmonic modes. The present transit time from source to puller is rather long - about 80°. A reduction of transit time by use of a smaller diameter puller, or a slit instead of a post, should give less centre spread and better acceleration on 3rd and 5th harmonic modes.

Acknowledgments

This cyclotron was constructed under the guidance of M. Snowdon by K.J. Howard, H.E. Payne, H.E. Walford, and H.H.H. Watson. It was operated as a 4-sector model by E.J. Jones and T.C. Randle. The author wishes to thank J.D. Lawson for guidance in this project and P.S. Rogers, H.E. Walford, and T.P. Parry for help during the present operation.

Reference

1) National Academy of Sciences - National Research Council Pub. 659 (1959), M. Snowdon, p 47.