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STATUS OF THE CHALK RIVER SUPERCONDUCTING HEAVY-ION CYCLOTRON

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Summary

A K = 520 superconducting cyclotron using the Chalk River 13 MV tandem accelerator as an injector is being designed to accelerate all ions from Li (to 50 MeV/u) to U (to 10 MeV/u). The cyclotron will considerably upgrade the Chalk River accelerator facility. The basic design of the cyclotron remains unchanged but details of trim rods, injection and extraction arrangements have changed and other features have become firm. Full scale modelling of the magnet and radiofrequency accelerating system is proceeding concurrently with the cyclotron design; the status of both is reported.

Introduction

Figure 1 shows the principal features of the cyclotron. The reader is referred to reference 1 for a more detailed description of the basic design; this paper summarizes developments since that report, expands on some items not previously discussed in detail and reviews present status. Other papers in this conference proceedings discuss details of the radiofrequency structure[2], trim rods[3] and extraction system[4].

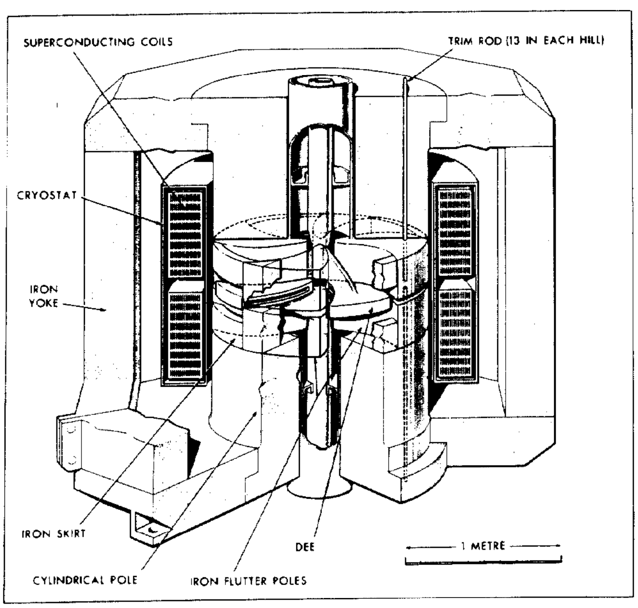

Fig. 1 Superconducting cyclotron

In brief, ions from the tandem are injected along the midplane of the cyclotron and are intercepted by a thin carbon foil near the centre where they are stripped to a higher charge state and accelerated out to a radius of 0.65 m by a four-dee radiofrequency system. The beam is extracted by an electrostatic deflector and magnetic channel. High energy is made possible with this small radius by the 5 T average midplane field produced by the 6 MA-turn superconducting coils. High energy gain per turn (∿ 25 MeV per turn for uranium) eases extraction and limits the maximum number of turns to less than 200.

Figure 2 shows the revised layout of the tandem, cyclotron and experimental areas which differs considerably from the original proposal[5]. Now the tandem will have its accelerating structures reversed to accelerate beam in the opposite direction. (The tank and charging system need no major changes.) This layout makes more economical use of existing space for the changed extraction direction which is now approximately normal to injection. (Originally it was intended to extract at ∿ 180° to injection.) The option of using the tandem beam directly is preserved by operating the analyzing magnet at 115° deflection into the bypass beam line.

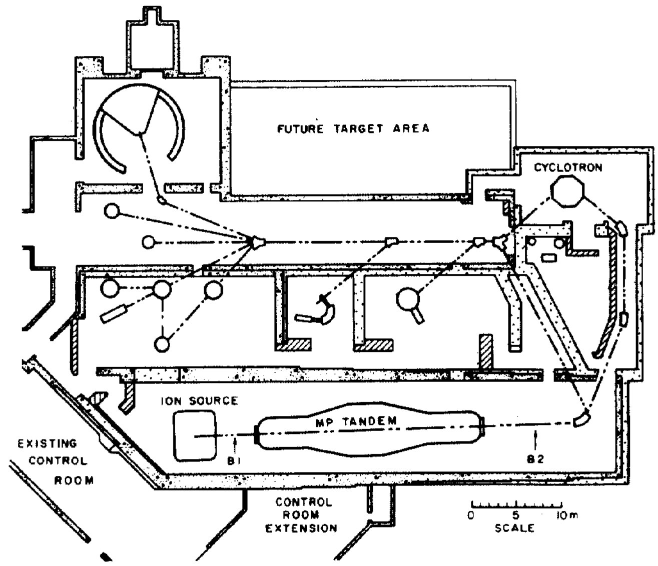

Fig. 2 Plan view of the heavy-ion accelerator facility.

Buncher

The beam is bunched by a double-drift second-harmonic buncher located as shown in Fig. 2 at B1 between the 250 kV ion source and the tandem. Another second harmonic buncher is located at B2 upstream of the analyzing magnet. Together, these can compress 50-70% of the beam into the desired 3 degrees of phase with modest buncher voltages of ∿ 1 kV at B1 and ∿ 10 kV at B2 while introducing momentum spread of only a few parts in 10^4. This bunching efficiency is approximately twice that previously reported[1] because recent measurements[6] on sputter ion sources show less energy spread than assumed earlier. Use of a conventional chopper has been ruled out because of the large energy spread it would introduce, but scraping within the cyclotron can eliminate ∿ 80% of the unwanted beam. The energy modulation from the bunchers has been included in second order transport calculations over the ∿ 40 meters of beam line.

Injection

Figure 3 shows the cyclotron midplane in plan. All ions follow a common trajectory to an injection steering magnet that deflects them through a maximum angle of ± 1°. The trajectories are mainly in a valley and cross a hill to the stripping foil in the adjacent valley. Note that except for this near-normal crossing, the trajectories avoid the large field gradients that occur at hill-valley interfaces. No azimuthal motion of the stripping foil is required. The single fixed injection channel with only radial stripping foil motion may be peculiar to 4-sector geometry with modest spiral; midplane injection to 3-sector machines appears to require azimuthal motion of the stripping foil[7,8].

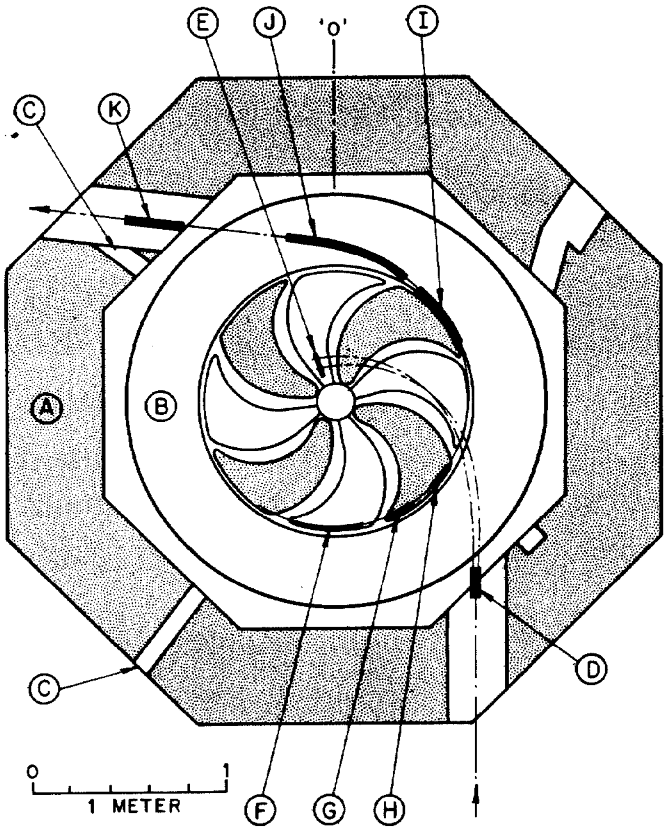

Fig. 3 Midplane plan of cyclotron; A - yoke, B - cryostat, C - probe hole, D - injection steering magnet, E - stripping foil, F - electrostatic deflector, G,H - focusing lenses, I,J - magnetic extraction channel, K - extraction steering magnet.

The injection magnet is located as close to the cryostat as practicable and centered radially in a 300 mm diameter hole in the cyclotron yoke. The injection magnet's yoke is a 240 mm diameter cylindrical shell with a 30 mm wall leaving a 30 mm gap between it and the cyclotron yoke. The induction in the cyclotron yoke can exceed 2 T and significant flux leaks into the smaller yoke. Calculations with the relaxation code TRIM[9] have confirmed that the 150 mm length is sufficient to provide the required ± 1° deflection with this leakage flux.

Foils are mounted at fixed intervals on a continuous "bicycle" chain that passes down the dee support stem of the upper coaxial line into a dee but above the midplane gap. Predicted foil lifetimes vary from one half to several hours; when a foil fails the chain is advanced to the next foil. Damaged foils are carried by the chain to the top of the yoke and replaced from a magazine that can be itself replaced through a vacuum lock. The foils are positioned in the required radial range of r = 146 to 220 mm by advancing or reversing the chain.

Orbit Dynamics

The lowest magnetic field has been increased to 2 T. Operation below 2 T is marginal largely because of excessive orbit scalloping. (Scalloping increases with decreasing magnetic field because the hill-valley magnetic field difference is independent of the average field as long as the hills are saturated.)

The main coils are connected electrically as an inner and outer pair relative to the midplane. The required variation in the magnetic field radial profile is achieved by changing their relative excitation followed by adjustment of the trim rods[10]. The number of trim rods per hill has been increased to 13 (104 rods in all). The innermost rods are located at a radius of 172.5 mm. The innermost four radial positions have 40 mm diameter rods, the next four 60 mm, the next four 40 mm and finally a 60 mm diameter rod at a radius of 643.2 mm. The rods in each hill are staggered azimuthally. They are raised and lowered by electric motors mounted on the top and bottom of the pole pieces. Even when placed at their optimum radial spacing the rods introduce a significant but acceptable ripple in the radial profile. The effect of this ripple on the axial betatron frequency can be seen in Fig. 4. A more detailed description of the orbit dynamics is given elsewhere in these proceedings[3].

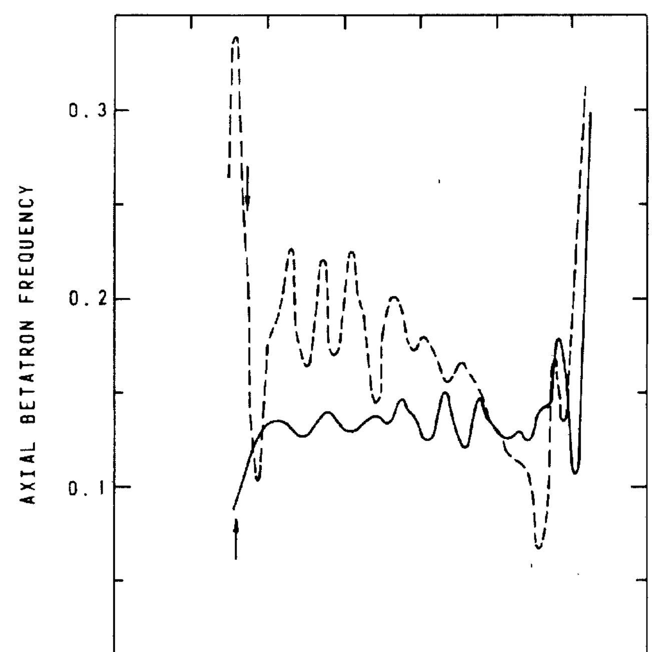

Fig. 4 Axial betatron frequencies for 10 MeV/u uranium (solid line) and 50 MeV/u carbon (dashed line). The arrows indicate the minimum radius.

Two radial beam probes, separated azimuthally by 90°, penetrate the yoke in the positions shown in Fig. 3. The direction of the probe motion is offset 40 mm from the axis of the cyclotron to maximize the distance between the probe and the accelerating gaps. Interchangeable heads will measure radial or axial position or phase of the circulating beam.

Extraction

The layout of the facility has been changed to that shown in Fig. 2 because detailed calculations showed it would be very difficult to extract the beam at 180° to the injection path as previously intended. As seen in Fig. 3, the beam now leaves the cyclotron 83° from its direction at entry.

In extraction[4], the beam is first perturbed at the radial integral resonance using the outermost set of trim rods to generate a first harmonic field bump. A single electrostatic deflector located in a dee, subtending 31° azimuthally, has a radial electric field of 120 kV/cm across its 7 mm gap. Two short mild steel lenses are located in the hill immediately after the electrostatic deflector to reduce the radial defocusing and augment beam deflection. The beam enters the main magnetic channel at a radius of 696 mm after the next dee. The channel is divided azimuthally into two parts: the first subtends 29° with a fixed gradient of 30 T/m and a variable bias field up to 0.4 T; the second subtends 45° with a variable gradient up to 20 T/m and a variable bias up to 0.2 T. A steering magnet in the extraction hole of the yoke wall directs the beam into a conventional beam transport system.

Radiofrequency and Vacuum System

The accelerating system[2] consists of four dees supported by the centre conductors of two shorted coaxial lines concentric with the magnet as shown in Fig. 1 and Fig. 3. Operation is in either 0- or π-mode with harmonic numbers 2, 4 or 6. The frequency range is 31-62 MHz and the peak dee to ground voltage 100 kV. A thin copper skin covers the hills forming both the outer shell of the resonators and the high vacuum enclosure. Two 1500 ℓ/s cryopanels at 4.6 K provide the main pumping. Each is nested at the top of a valley and charged with helium from the main cryostat. In addition, two 100 ℓ/s diffusion pumps are hung from the lower pole piece and connected to the midplane vacuum.

The predominant load is outgassing of the radiofrequency structure, and the pumping capacity is designed to maintain a midplane vacuum of $\sim 10^{-5}$ Pa to keep beam losses from charge exchange to less than 5%.

The full scale radiofrequency accelerating system is being fabricated and initial tests outside the magnet using an existing 20 kW rf supply are scheduled for this summer.

Magnet

The outer diameter of the pair of 3 MA-turn superconducting coils has been reduced from 1900 mm to 1877 mm, but all other features are as previous reported[1]. All of the superconductor has been received and nine of the thirty-two double pancakes have been wound. Figure 5 shows a double pancake being removed from the winding table. The critical current has been measured in short samples from each of the thirty-four lengths of superconductor - all have exceeded the specified 3400 A at 4.2 K in a 4 T transverse magnetic field.

The helium liquefier has been operating on a routine basis for more than a year and supplies liquid helium for the short sample test apparatus and experiments on the cryopanels and current leads.

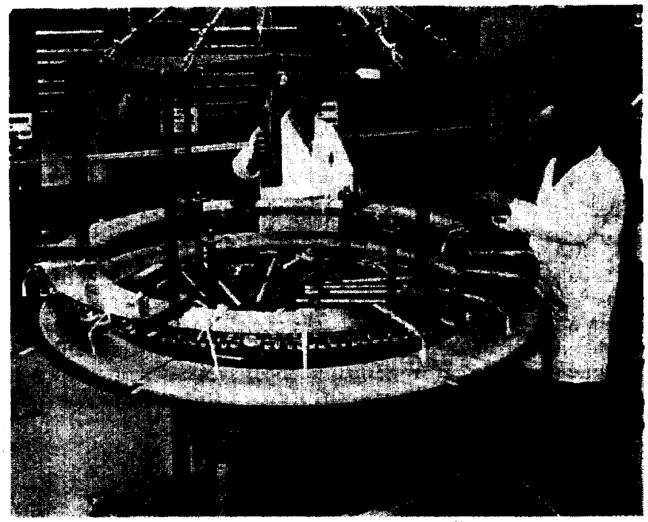

Fig. 5 A double pancake of the superconducting coil being removed from the winding table.

The location of the injection, extraction and two probe holes in the yoke wall are as shown in Fig. 3. Two other holes have been introduced to reduce the first harmonic magnetic field to less than 0.03 mT from the uncompensated value of 2 mT.

Detailed calculations on tolerances required for both the coils and the steel have not revealed any unreasonable requirements.

The building to house the full scale model during tests is ready. The yoke itself is nearly complete, delivery is scheduled for March. Detailed field mapping is scheduled to start late this year.

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