

STATUS OF THE TEXAS A&M COUPLED CYCLOTRON PROJECT

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Abstract. - Work is now beginning on the construction of a K500 superconducting cyclotron to be used in upgrading the Texas A&M cyclotron facility. The K500 machine will be of the Michigan State University design. It will provide stand-alone beams up to 80 MeV/nucleon for light ions and, using the present 224-cm cyclotron as a booster, beams of up to 37 MeV/nucleon for medium heavy ions.

1. **Introduction.** - A study of methods of extending light- and heavy-ion capability of the Cyclotron Institute, Texas A&M University, was undertaken by Texas A&M personnel with the advice and assistance of F. Resmini.¹⁾ This study concluded that the best choice would be to construct a superconducting cyclotron in the range K400-500 to be used both as an injector for the existing 224-cm (K147) cyclotron and as a stand-alone accelerator. As the Michigan State University (MSU) K500 SC cyclotron was near optimum to obtain scientific goals, construction of a copy of the MSU K500 SC cyclotron was chosen as preferable to design of a new cyclotron. Figure 1 shows the performance, which will be obtained by the coupled system and by the SC cyclotron used alone, compared with the existing machine and with other facilities. The SC cyclotron will be located in an extension of the existing building (Fig. 2), which will also house new experimental areas. The construction of this extension is scheduled to start in early 1982, and the first beam is expected in 1985-86. All experimental areas will be accessible to the coupled system while the beam from the SC cyclotron can be directed into half of the existing experimental areas containing important equipment such as the split-pole spectrograph.

2. **The K500 Superconducting Cyclotron.** - A detailed description of the K500 cyclotron can be obtained from Ref. 2. Main parameters are described in Table 1. While it is desirable to operate both cyclotrons at the same frequency, the frequency range of the existing machine is 5.5 - 16 MHz and MSU's K500 cyclotron is 9 - 32 MHz. As a consequence, for beams of orbital frequency between 5.5 and 9 MHz, the K500 cyclotron will operate at twice the frequency of the 224-cm cyclotron.

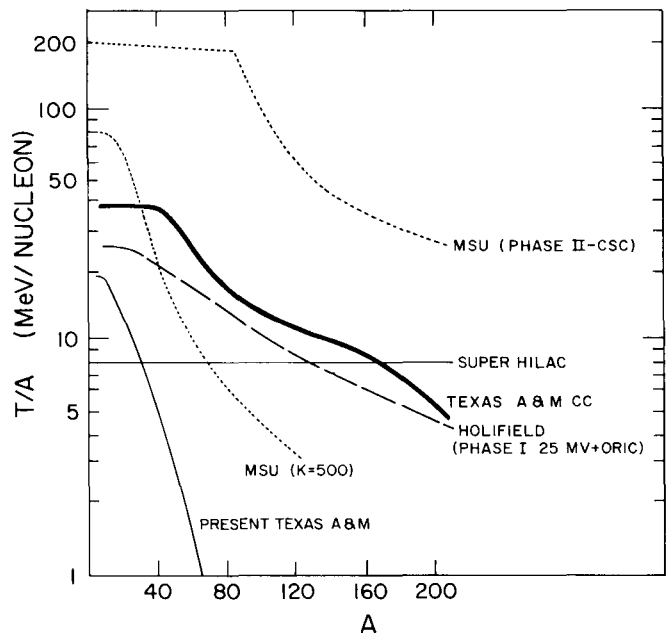


Fig. 1. The energy per nucleon which would be obtained from the proposed coupled-cyclotron (CC) system is compared with those from some existing and planned facilities. The curve for the present Texas A&M cyclotron assumes fluxes of at least 10^{11} particles/sec. The Texas A&M CC curve assumes a flux of 10^{11} particles/sec up to $A = 100$, and initial acceleration of charge state 12^+ for $A > 100$.

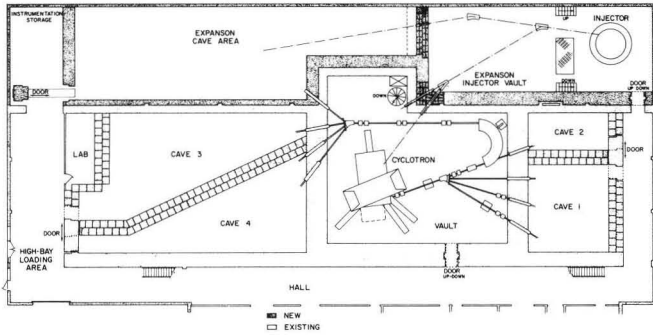


Fig. 2. Floor plan of the experimental area showing the location of the injector cyclotron and new experimental areas.

Table 1. Main parameters of the K500 SC cyclotron.

Bending limit	K = 500
Focusing limit	$K_f = 160$
Extraction radius	67 cm
Minimum operating field	30 kG
Maximum operating field	50 kG
Number of sectors	3
Minimum Hill Gap	6.35 cm
Maximum Valley Gap	55.9 cm
Iron Weight	100 tons
Number of Trim Coils	13/section
Maximum trim coils power	70 kW
RF frequency Range	9 - 32 MHz
Harmonic Mode	1, 2, 3, 4
Maximum Dee Voltage	100 kV
Coil: Maximum current density	3800 A/cm ²
Maximum Ampere-turns	small coil 1.8 x 10 ⁶ large coil 3.7 x 10 ⁶
Conductor	NbTi in Cu matrix

3. Coupling. - The performance of the coupled-cyclotron system is shown in Fig. 3. First harmonic operation of the 224-cm cyclotron occurs from the maximum final energy ($T_2/A = 37$ MeV/nucleon) continuously down to the low frequency cut-off (approximately 5.5 MHz where $T_2/A = 6$ MeV/nucleon). The practical coupling modes over this range are $h_1, h_2 = (1,1)$ and $(2,1)$ with non-relativistic energy multipliers N_E of 2.25 and 9.0 respectively. Below 6.0 MeV/nucleon, use of the third harmonic in the 224-cm cyclotron is required, and the $(4,3)$ mode becomes optimum ($N_E \approx 5.1$). In the $(2,1)$ coupling mode, a lower charge is used in the injector, and therefore more intense beams will be obtained from the injector. However, the lower energy from the injector results in an equilibrium charge distribution after stripping which is centered on a charge Q , which is substantially less than Q_2 required to obtain the maximum final energy. Thus as a practical matter, the $(2,1)$ coupling mode is limited to a region below the dashed line of Fig. 3. This

line corresponds to a stripping efficiency which yields 5% of the original beam intensity.

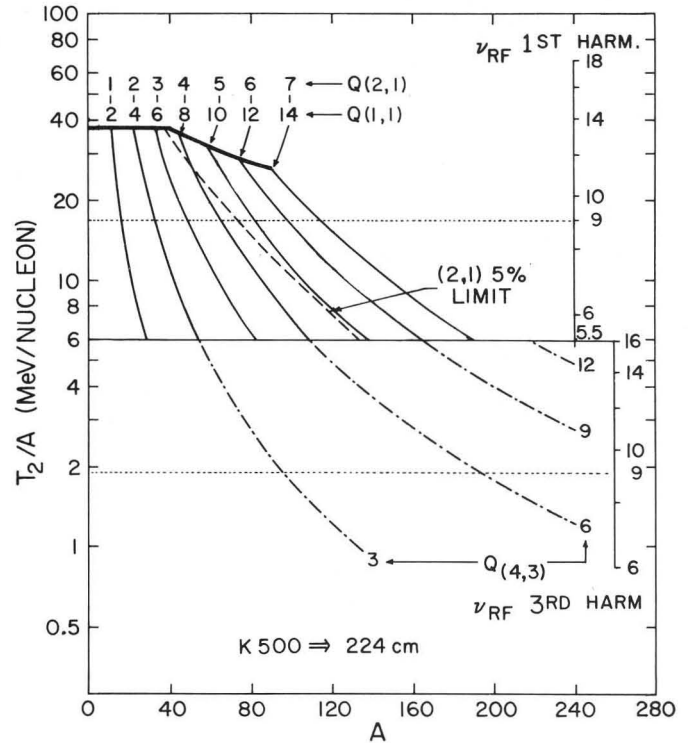


Fig. 3. Performance of a coupled-cyclotron system consisting of a K500 SC machine injecting the 224-cm cyclotron. The horizontal dotted lines represent the present 9 MHz lower frequency limit of the SC cyclotron. Below this line the SC cyclotron must be run at a multiple of the frequency of the 224-cm machine. The initial charge states required for each coupling mode are denoted by $Q(h_1/n_2, h_2/n_1)$. The $(2,1)$ coupling mode is limited to regions below the dashed line.

4. Injection. - The design philosophy and scheme are similar to those proposed for the MSU K500-K800 coupling³). The goal is to provide a narrow waist at the position of the stripping foil at the correct radius in the booster cyclotron with maximum transmission through the line. This has to be accomplished for all injection mode beams over the expected operating range of the K500 cyclotron. Because of the many passive magnetic elements in its extraction system, focusing and dispersion properties have a wide range of variation which the line must accommodate.

The design of the line is based on the following:
1. The momentum dispersion of the beam from the injector is brought to zero by using a combination of magnetic quadrupole focusing elements and a bending magnet.

2. Through the use of four quadrupoles the now achromatic beam is brought to a focus. Four quadrupoles are necessary so that the focus can be of uniform size and divergence for the entire range of injection mode beams. This uniform standard focus provides for standard diagnostic measurements of beam parameters and also decouples the two machines. Four parameters have to be adjusted to obtain this focus. Using TRANSPORT⁴) for that goal was found to be inconvenient. A program was written which, when given specific entry conditions, searches for a minimum in χ^2 by incrementing the quadrupole fields. For this

particular case, a solution can be found more easily and more quickly than with TRANSPORT.

3. The second part of the line is symmetric to the first with four quadrupoles being used for phase-space matching, followed by a bending magnet and quadrupoles for dispersion matching.

Using predictions from MSU⁵⁾ for emittance and dispersion of the K500 cyclotron, TRANSPORT calculations have been carried out up to the achromatic focus and thence into the 224-cm cyclotron using the hard-edge approximation. The proposed injection line and TRANSPORT calculation are shown in Fig. 4.

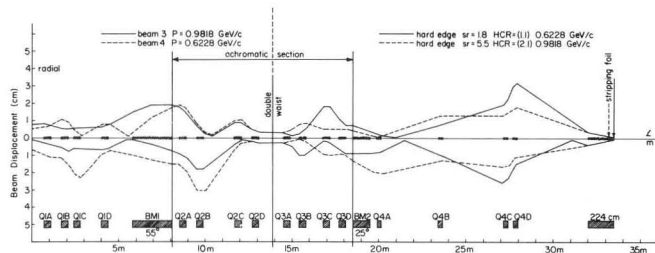


Fig. 4. TRANSPORT calculations for a proposed non-isochronous injection line. From the exit of the K500 cyclotron up to the achromatic double waist (± 3 mm), two beams of different radial dispersion are shown. From this double waist up to the stripping foil, hard-edge injection in the 224-cm cyclotron has been assumed; two different harmonic coupling ratios (HCR) and stripping ratios (sr) are shown.

Hard-edge injection studies indicated that no particular problem should arise with injection into the magnetic field of the 224-cm cyclotron. The only practical region for stripping is the half of the machine not occupied by the dee. The locations of the electrostatic deflector components and the dee stem structure limit the possible stripper foil locations and hence the injected beam trajectories to a small region of the cyclotron. This allows only a single "doorway" through the 224-cm RF resonator tank. All beam trajectories originate from a common point just outside the resonator tank, where a steering magnet is needed for final adjustments. (See Fig. 5.)

The calculations of trajectories in the magnetic field of the 224-cm cyclotron was accomplished for injection¹⁾ from a K400 cyclotron. Since the change to K500 requires a slightly different geometry, the calculations are being redone using the code GOC, written at Oak Ridge for the injection from a tandem into ORIC⁶⁾. However, no significant changes in the conclusions are expected.

As shown in Fig. 5, injection with a large stripping ratio requires stripping at points very near the end of the present dee. This difficulty can be removed by slanting the dee at an angle of about 20°. A dummy dee will probably be necessary to shield the stripper foil from the RF fields present inside the machine.

Another source of concern is isochronism. The increase of bunch length comes from two different effects:

- a) geometrical non-isochronism
Using TRANSPORT notation

$$l = R_{51}x_0 + R_{52}x_0'$$

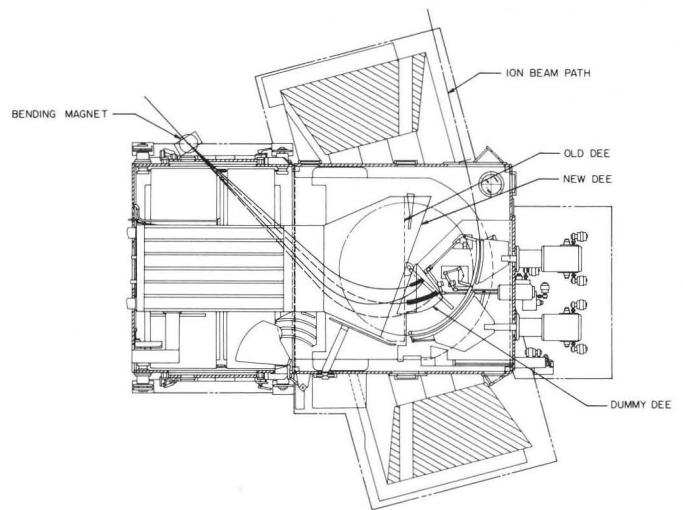


Fig. 5. Injection trajectories are shown for the 224-cm cyclotron (for a K400 injector). The black areas at the end of the trajectories show the range of locations of the stripping foil for the (1,1) (solid lines) and (2,1) (dashed lines) harmonic coupling modes.

There is a relation between R_{51} , R_{52} , and R_{16} , R_{26} so that cancelling the last two will cancel the first two. As we have an achromatic solution, we necessarily have isochronism for monochromatic particles.

- b) chromatic non-isochronism (R_{56})

This effect was evaluated for the injection line illustrated in Fig. 4. The bunch length increase is about the same as for a drift of equal length; starting with a $\pm 2.5^\circ$ bunch, it becomes $\pm 4^\circ$ at the stripping foil, well within the expected phase acceptance of the 224-cm cyclotron. Conversion to an isochronous line is under study as bunch length is important for experimental programs utilizing time-of-flight. To obtain minimum bunch length the stability of the 224-cm cyclotron and isochronism of its beam lines must also be improved.

5. References.

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