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# INJECTION FROM THE K500 SUPERCONDUCTING CYCLOTRON INTO THE 88" CYCLOTRON AT TEXAS A&M

B. Launé, D. P. May, R. C. Rogers, W. C. Chapman, W. J. Walterscheid, G. Derrig, Y. L. Tsien, P. Smelser, and D. H. Youngblood
Cyclotron Institute, Texas A&M University
College Station, Texas

## Abstract

The construction of a superconducting cyclotron of the MSU design (K=500, $K_f$=160) is under way at Texas A&M. It will be used both alone and as an injector for the existing 88" (K147) cyclotron. A beam optics study has been carried out for injection of K500 cyclotron heavy-ion beams into the K147 cyclotron. This study traces a variety of beams from extraction at the K500 cyclotron until focused and dispersion matched into the proper orbit of the K147 cyclotron. The line is configured to decouple the parameters of each cyclotron by first bringing the momentum dispersion to zero and then producing a double waist which serves as the apparent source for the second cyclotron. Beam line optics for stand-alone operation of the K500 cyclotron, which provides for use of the present experimental facilities, have also been studied. Construction of the K500 cyclotron is proceeding approximately on schedule with operation expected in 1985.

## Introduction

The performance of the coupled and stand-alone modes has already been described[1,2]. The layout of the facility is shown in Figure 1. Beams from the K500 cyclotron can be directed to the K147 cyclotron for coupled operation, to the new experimental area (through a transport line which can provide some analysis) or to the existing lines in areas 3 and 4. Beams from the K147 cyclotron can also be directed into the new cave.

## Transfer line: Philosophy

The purpose of the line is to transport the beam from the exit port of the K500 cyclotron into the K147 cyclotron with maximum transmission and with the necessary properties for efficient acceleration. These properties are achromaticity (2 parameters) and a double waist of determined size (4 parameters) at the stripping foil inside the K147 cyclotron. The parameters of the beams from the K500 cyclotron vary widely and are interdependent. To decouple these parameters and simplify calculation and tuning, the line is configured with three sections. In the first section the momentum dispersion of the beam is brought to zero (dispersion matching) and in the following section the emittance matching requirements are fulfilled on the now achromatic beam. The dispersion parameters for injection into the K147 cyclotron are then established in a last section. By providing a double waist in the middle of the achromatic section, the transport from the K500 cyclotron can be decoupled from the transport to the K147 cyclotron. This scheme is similar to the one used for the K500-K800 coupling at MSU[3].

## Injection into the K147 cyclotron

Realistic field maps of the existing K147 cyclotron are needed to predict the stripping foil position and the phase space behavior. The program CYDE[4] has been used to produce maps from field measurements made at the time of the construction of the machine. These measurements extend only to a radius of 67", where the magnetic field is not yet negligible, and in addition the data taken at high fields do not have adequate accuracy. The magnetic field of the K147 cyclotron will be remeasured when the dee is removed for modification. However we do not anticipate any significant change in the conclusions.

The two cyclotrons will run at the same RF frequency when coupled. From the maximum energy (37 MeV/nucleon) down to the low frequency cut-off (6.2 MeV/nucleon), the K147 cyclotron runs on first harmonic, while in the K500 cyclotron first or second harmonic may be used. The coupling modes are then (1,1) or (2,1). Below 6.2 MeV/nucleon the third har-

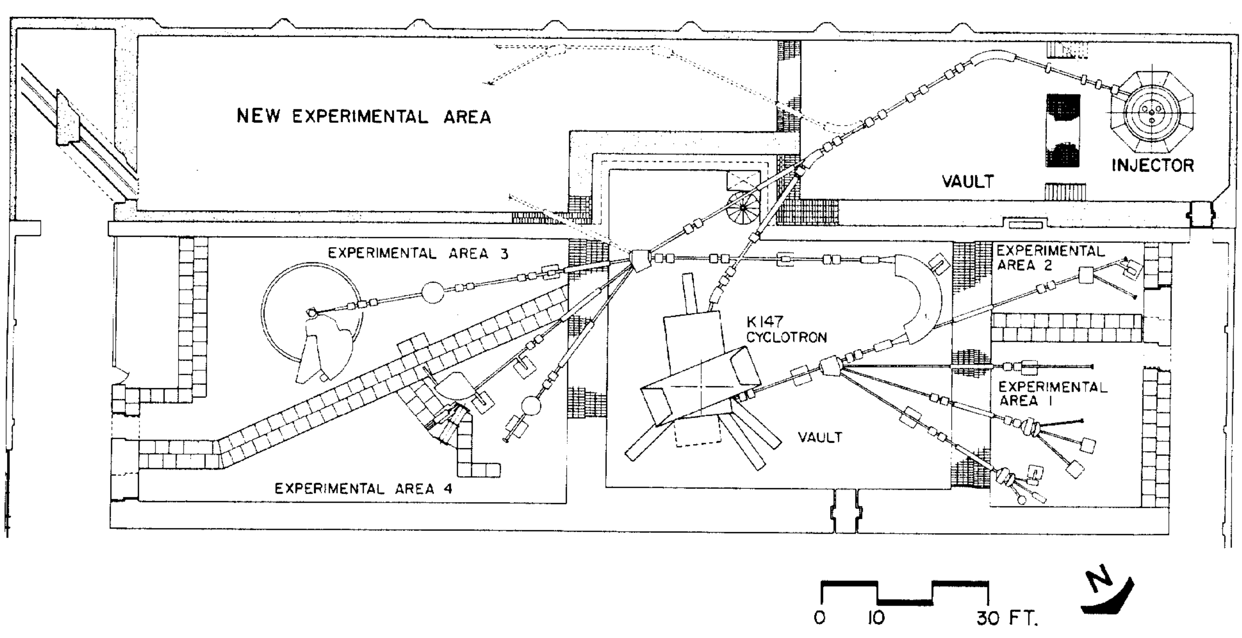


Figure 1. Floor plan showing injector (K500), booster (K147), transfer line and new experimental area.

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monic is used in the booster and the coupling modes modes may be (4,3) or (3,3).

The ray-tracing calculations were made with the program GOC, used for calculation of injection into ORIC[5]. Injection trajectories are shown in Figure 2 for the following representative cases:

- $^{16}O^{8+}$ 513 MeV (32.05 MeV/nucleon)
  B=16.4 kG (1,1) Coupling and Stripping Ratio (SR) =2.
  (2,1) SR=4.
- $^{16}O^{8+}$ 112 MeV (7.0 MeV/nucleon)
  B=7.6 kG (1,1) SR=4.
  (2,1) SR=8.

All the trajectories originate from a single point in the transfer line where a steering magnet is located. A first trial was made with the magnet located at the side of the K147 cyclotron resonator tank (position A in Figure 2) as was assumed in the original calculations[1]. These calculations assumed a K400 injector; since the injection radius is now larger it was found that the dee lip would have to be canted substantially more to provide room for the stripping foil mechanism. Calculations were then performed for a steering magnet located at the back of the resonator tank (position B in Figure 2). For this case the entire range of stripping ratios (SR) may be available without canting the dee lip. New magnetic measurements will be required to determine whether the dee will have to be altered. Entering through the back requires more modification to the dee stem since the beam path crosses a region containing considerable structure.

The emittance we assume from the K500 cyclotron is about 7 mm mrad and we first try to match a double waist of ±0.75x3 mm mrad. Transporting this image from the stripping foil back to the steering magnet leads to a horizontally wide beam because of the entry angle into the K147 cyclotron magnetic field. This spreading is even worse in a case like (2,1)

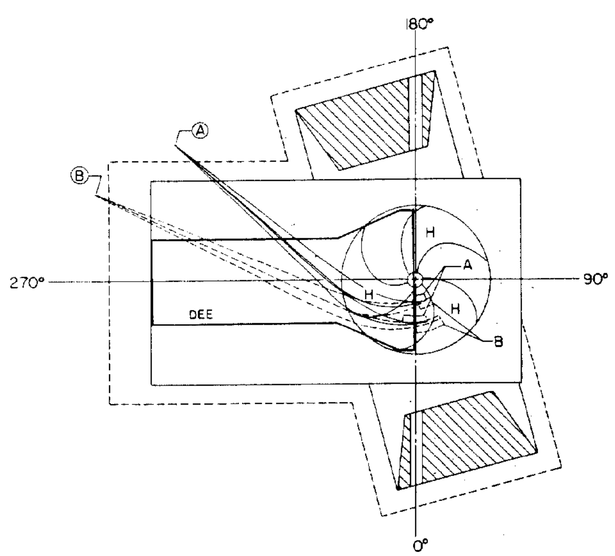


Figure 2. Injection trajectories are shown for two steering magnet locations (A and B) and two coupling modes (1,1) and (2,1), the latter mode at the smaller radius. The azimuthal extension of the stripping foil is indicated by boxes for each mode and magnet location. It can be seen that for the location B the dee does not need to be canted as much as for the location A; but the beam crosses a larger section of the dee. Also indicated are the hills (H) and valleys.

SR=4 where the beam path is almost tangent to the hill-valley boundary. In such a case the spot size was increased in order to reduce the divergence angle and hence the beam width at the steering magnet location. Such an increase in spot size still leaves a beam small enough to clear the stripping foil on the next turn for all beams of interest. The spot size in the vertical plane has been increased to (±2.25 mm), to reduce the height of the accelerated beam and make the transport through the transfer line easier. The values of the dispersion parameters $R_{16}$ and $R_{26}$ (TRANSPORT notation) required at the steering magnet position are listed in Table 1.

Table 1. Dispersion parameters for several beams.

| Beam | $R_{16}$ (cm/%) | $R_{26}$ (mrad/%) |
|---|---|---|
| (1,1) SR=2 | 7.6 | 15.5 |
| (2,1) SR=4 | 3.1 | 6.3 |
| (1,1) SR=4 | 9.2 | 20.1 |
| (2,1) SR=8 | 3.0 | 6.4 |

## Transfer line

Calculations for the transfer line were carried out using the code TRANSPORT[6] for using parameters predicted for beams from the K500 cyclotron[7]. These parameters are listed in Table 2 and represent extremes of the operating conditions. The first section, which brings the beam to achromaticity, is composed of four standard quadrupoles (25 cm long, pole radius of 5 cm and maximum field of 8400 G) followed by a 48° bending magnet. The most difficult cases to handle are those like #2 and #4 (see Table 2) in which the sign of the dispersion parameter $R_{16}$ has to be changed. The second and third sections are symmetric and also composed of 4 quadrupoles, which are standard except for those adjacent to the double waist, their diameter has been reduced to 6 cm (25 cm long, 8400 G). The fourth section has a 25° bending magnet and four standard quadrupoles. The steering magnet has a bending angle adjustable between 16° and 21°. The maximum field of the bending magnet was taken as 14 kG, which corresponds to a bending radius of 2.38 m, so room temperature coils may be used. The line is not isochronous, but since the phase acceptance of the K147 cyclotron is very large compared to the expected phase width of the beam from the K500 cyclotron isochronism may not be required.

Table 2. Parameters for the beams out of the K500, (from Ref. 7).

| Beam | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $Z/A/B_0$ (kG) | 0.02/49 | 0.02/35 | 0.1/49 | 0.1/31 |
| T/A (MeV/u) | 0.206 | 0.106 | 5.16 | 2.08 |
| P (GeV/c) | 0.9796 | 0.7026 | 0.9818 | 0.6227 |
| $E_x$(cm mrad) | 1.57 | 1.26 | 0.7 | 0.7 |
| $\sqrt{\sigma_{11}}$(cm) | 0.5 | 0.5 | 0.43 | 0.52 |
| $\sqrt{\sigma_{22}}$(mrad) | 1.0 | 0.8 | 0.8 | 1.4 |
| $r_{12}$ | 0.0 | 0.0 | 0.7619 | 0.9519 |
| $E_y$(cm rad) | 0.7 | 0.7 | 0.7 | 0.7 |
| $\sqrt{\sigma_{33}}$(cm) | 0.25 | 0.5 | 0.1 | 0.63 |
| $\sqrt{\sigma_{44}}$(mrad) | 3.5 | 4.0 | 2.5 | 5.4 |
| $r_{34}$ | 0.9670 | 0.9938 | 0.4535 | 0.9978 |
| $R_{16}$ (cm/%) | -14.0 | 2.5 | -14.5 | 1.0 |
| $R_{26}$(mrad/%) | 24.0 | 19.0 | 16.0 | 23.5 |

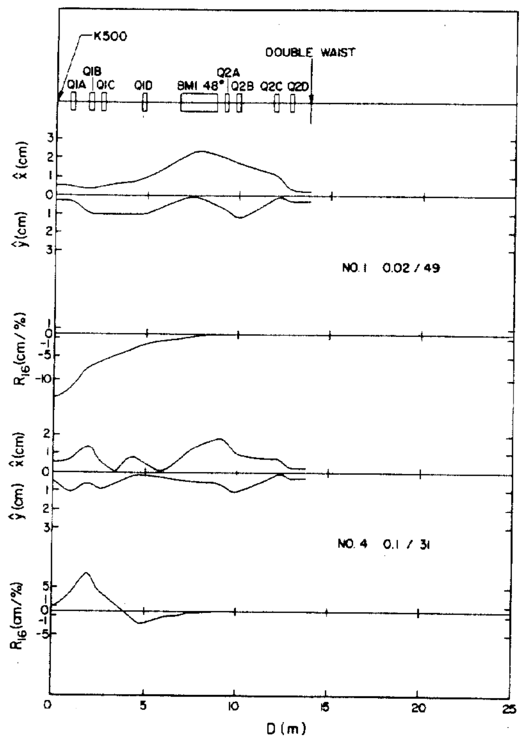


Figure 3. Beam envelope and $R_{16}$ value for beams #1 and #4 from the exit port of the K500 cyclotron up to the achromatic double waist.

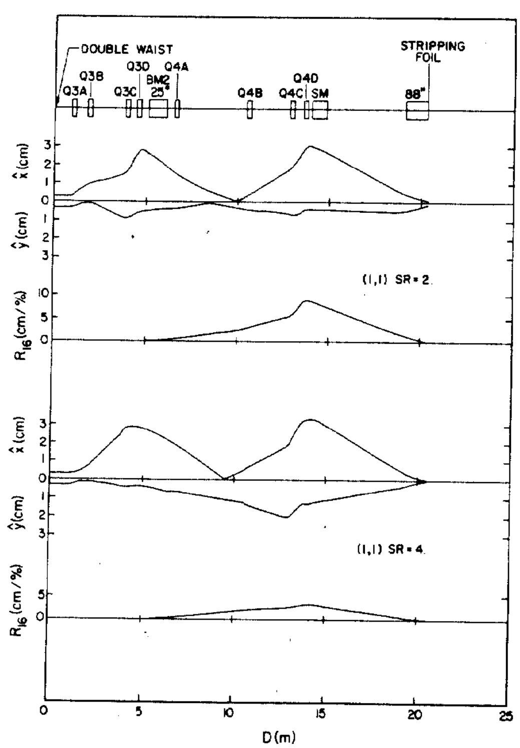


Figure 4. Beam envelope and $R_{16}$ for two injected beams from the achromatic double waist up to the stripper.

However space is provided for a buncher at the double waist location. Figure 3 shows the result of the calculation for two beams up to an achromatic double waist of $\pm 0.3$ cm. Figure 4 shows the rest of the line for two injected beams.

Using the programs TRANSPORT[6] and TURTLE[8], calculations have been performed to study higher order effects. No significant aberrations arise except for beams like #2 and #4 (see above); here a strong vertical aberration appears when a second order component is assumed in the bending magnets. Because the waist size is affected by this aberrationtwo sextupole magnets will be necessary, both are located in the achromatic section (one before the waist, the other after it) to avoid affecting the dispersion terms. Careful design of the magnets is required in order to avoid this problem.

## Stand Alone Transport

This transfer line configuration has been checked for its ability to provide good beams to existing experimental areas 3 and 4. As a test we performed a calculation up to the Enge split-pole spectrograph in the energy loss mode. We found that the beam can be successfully transported in this mode without modification to either the transfer line or the existing beam line.

## Diagnostics

Considering the complexity of the line, a good knowledge of the properties of the beam will be needed. We felt that a secondary emission multi-wire detector would be a very useful device since it allows not only the determination of the beam profile and position but also provides a quick measurement of the emittance using the three-gradients method. A prototype has been constructed and successfully tested on the existing beam lines. A program has been written to calculate the emittance. We anticipate improving the electronics of the device and connecting it directly to our existing VAX computer for on-line measurement of the emittance. Extensive testing in the existing beam lines is planned.

## Status of the project

The project schedule calls for completion of the building in May, 1983 with first cooldown of the superconducting main coil in January, 1984. First operation is expected in 1985, with coupled operation occurring in 1986.

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