STATUS OF THE NSCL COUPLING LINE

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Abstract

We report the results of a re-examination of the coupling line between the K500 and K800 cyclotrons at NSCL. The basic optical mode has been retained from the earlier study, but the details of the system have changed somewhat. The details of the magnet design to switch the beam into the K500-K800 transfer line are presented. Beam diagnostics are also discussed, along with plans for controlling the system.

Introduction

The NSCL facility in its final form will have the beam from the K500 cyclotron injected into the K800 cyclotron for re-acceleration to higher energies; the K800 cyclotron will effectively act as an energy multiplier with the multiplication factor being about twenty. In order to achieve this mode of operation, the beam from the K500 must be transported to K800 while having its six-dimensional emittance ellipsoid modified to match the acceptance of the K800 injection. A transport system has been designed to do this. After a short description of the optics of the coupling line, the most recent advancements will be described.

Coupling line optics

As this system has been reported previously (see Refs. 1 and 2), the philosophical details of the design will be presented in a very schematic form: 1)in order to decouple the tuning of the two machines and simplify the tuning of the transfer line, an achromatic double-waist (3 mm half-width in each plane) is formed about midway through the system and 2)to prevent beam-loss to longitudinal spreading, the transfer line is isochronous (including the dispersion induced by the extraction channel). These goals are accomplished by using: 1)four quadrupoles to match the emittance of the K500 to the acceptance of the transfer line, 2)two quadrupoles and a large dipole to isochronize the beam, 3)two quadrupoles and a dipole to make the beam achromatic, 4) five quadrupoles to form the double-waist of known (3 mm) size, 5)four quadrupoles to match the double-waist to the acceptance of the "injection" section, and 6) five quadrupoles to match the beam emittance and dispersion to those required for injection. A plan view of the system is shown in fig. 1. Many elements serve multiple functions. For example, the large (135°) bending magnet does most of the job of turning the beam toward the K800 and also provides a place to do

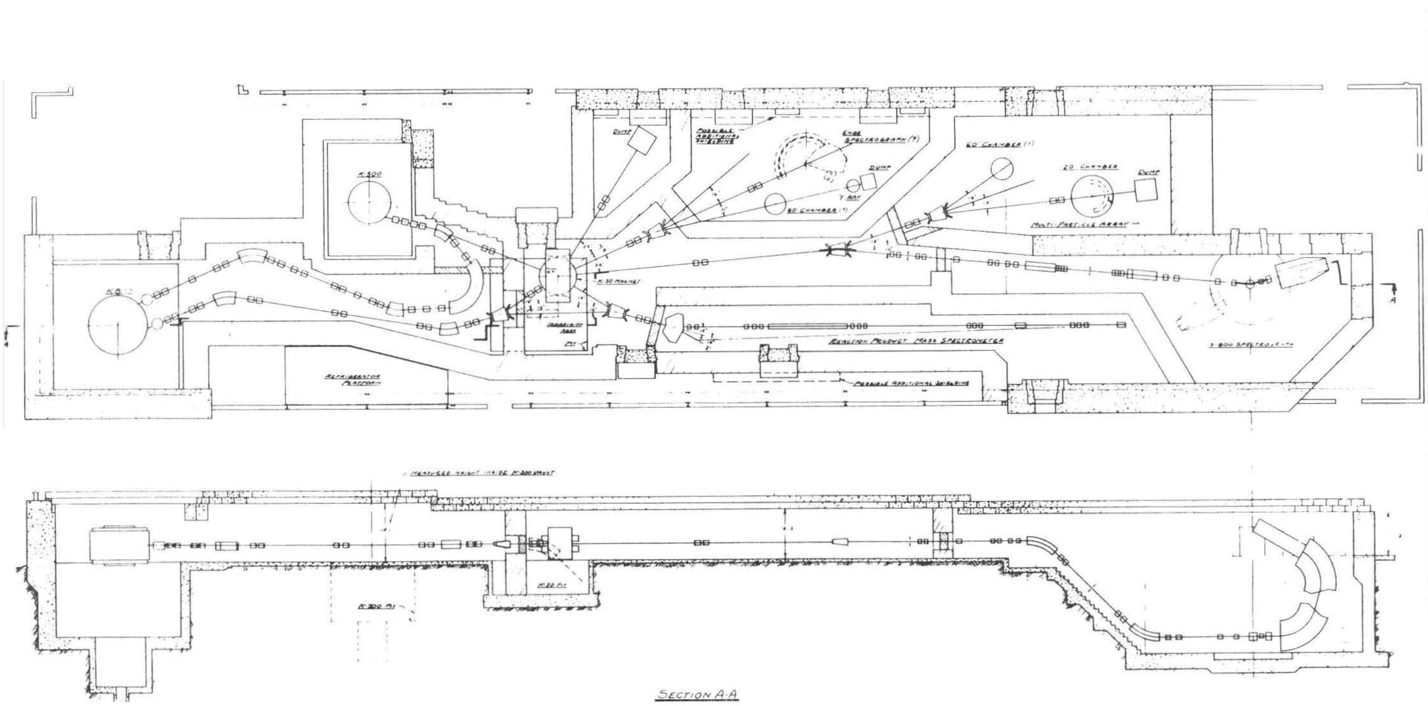

Fig. 1. Plan view of NSCL high-bay.

the large amount of isochronizing necessary. Likewise, the second dipole not only helps turn the beam toward the K800 but also reverses its bend in order to send the beam to the main switching magnet for K500 "stand-alone" operation.

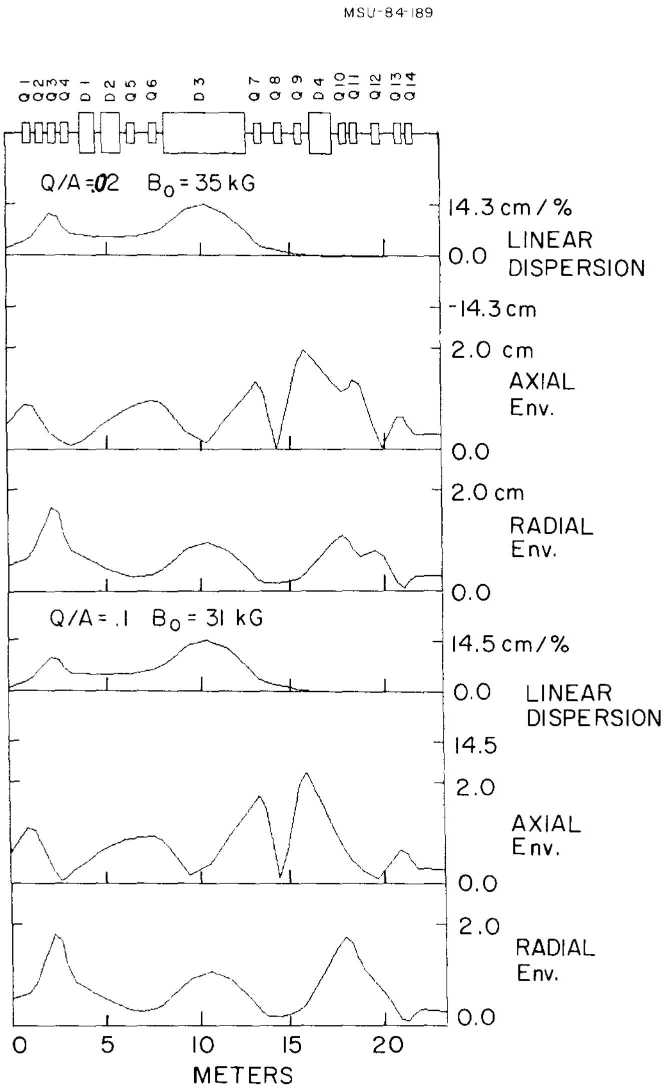

Fig. 2. Plots of linear dispersion, axial envelop, and radial envelop for Q/A = .02, B_0 = 35 kG and Q/A = .1, B_0 = 31 kG beams from the K500 up to the achromatic double-waist.

Example beams were calculated using the code "TRANSGRAF" (ref. 3), with the resulting beam envelops and dispersions being displayed in figs. 2-4. The magnet setting for these beams are given in tables I and II. The criteria for matching to K800 injection were very similar for most beams, therefore only one set of plots and magnet settings is presented for the "injection" part of the coupling line. For the "extraction" section, four quite different beams are presented; for example, the linear dispersion at extraction from the K500 ranges from 2.0 cm/% to -15 cm/%. The details of the emittances of all beams and matching conditions can be found in Table III.

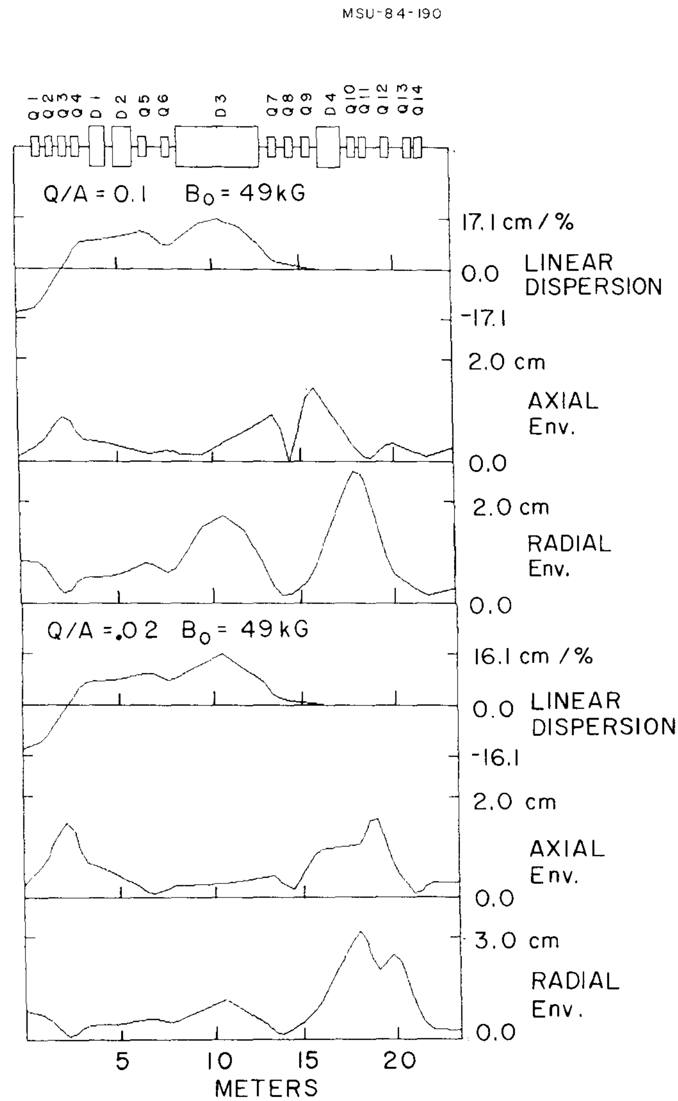

Fig. 3. Plots of linear dispersion, axial envelop, and radial envelop for Q/A = .1, B_0= 49 kG and Q/A = .02, B_0 = 49 kG beams from the K500 up to the achromatic double-waist.

Magnet design

All magnets in the coupling line will be superconducting and will be constructed locally. Many are identical or very similar to magnets used elsewhere in the beam transfer system. The large 135° bending magnet will operate up to 17.5 kG and, as currently envisioned, will have a cross-section (shown in fig. 5) which is nearly identical to the ± 16° switching magnets designed for the K800 beamlines; the two dipoles which follow it will also have similar cross-sections. The quadrupoles will all be standard NSCL (see paper B16 at this conference) beamline elements with 5 cm. radius apertures and 40 cm effective lengths.

The first two dipoles in the system represent a solution to a problem existing in earlier designs: how to switch the beam from "stand-alone" to "injection" mode (and vice-versa) with a minimum of inconvenience. Earlier designs provided no good solution as they either required a magnet with a hole in its side to let the beam exit with the magnet turned off or,

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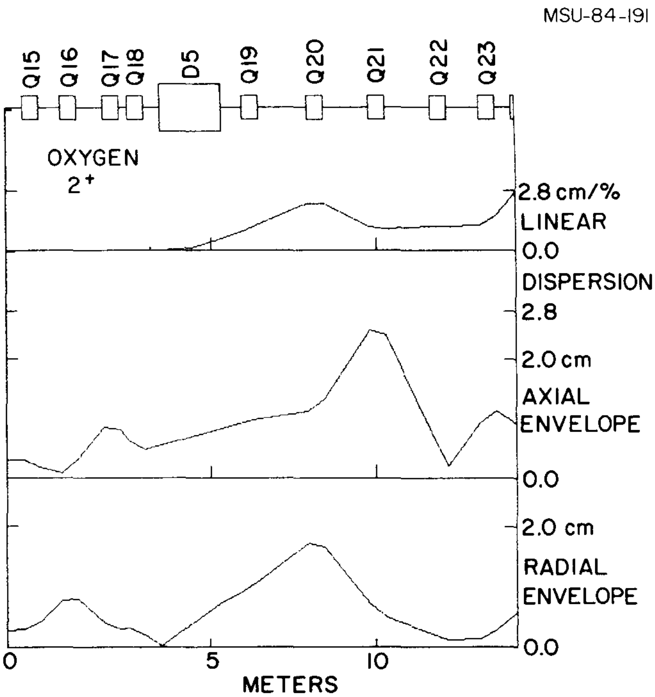

Fig. 4. Plots of linear dispersion, axial envelop, and radial envelop for oxygen 2+ beam to be injected into the K800.

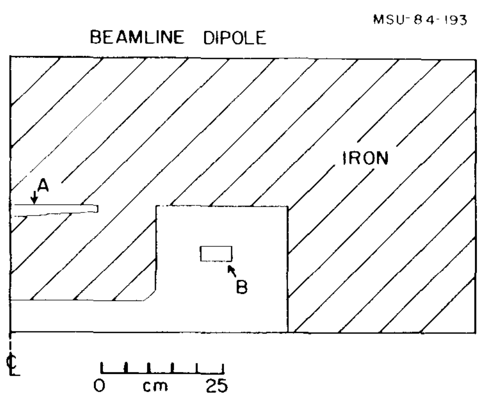

Fig. 5. Upper right quadrant of a cross-section of the 135° dipole. "A" is the tapered "flux guide" (tapered Purcell filter) and "B" is the coil.

alternatively, required removal of all or some part of the magnet. The present arrangement requires neither. As shown in fig. 6 (Note: The present arrangement is different than that shown in fig. 1.), the first magnet always bends the beam by 21° . The second magnet is a ± 16° switching magnet that either sends the beam into the coupling line or on to the main switchyard magnet. This arrangement provides for bending the necessary 37° into the coupling line and also for bending the beam the necessary 10° (in the same direction) by reversing the polarity of the 16° magnet and cancelling some of the deflection that the first magnet generates. Neither of the two magnets had to be specially designed for this location; the switching magnet is one of the standard NSCL switching magnets and the 21° magnet is essentially the same as one of the 22.5° magnets planned for the beam analysis system for the S800 spectrometer.

Two dipole magnets are not shown in the designs that will be needed. Each is a small dipole located

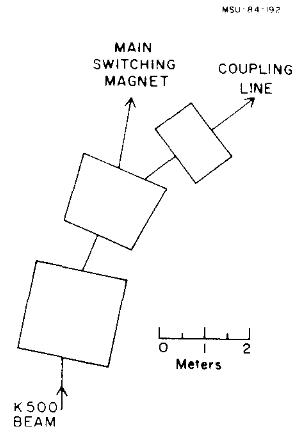

Fig. 6. Scaled plan view of initial beam switching area. Beam comes from the K500 cyclotron, bends 21° in the first dipole, and is switched into the injection line (additional 16° bend) or toward the main switchyard magnet by the second dipole (dipole is reversed and bends the beam -10°).

TABLE I

QUADRUPOLE STRENGTHS BEFORE DOUBLE-WAIST [1]

Quad. Number	.1/31[2]	.1/49	.02/35	.02/49
1	-3.80	2.47	3.40	2.20
2	0.20	-0.70	0.00	-1.00
3	4.45	-4.00	4.50	-3.75
4	-4.45	4.10	-4.55	4.25
5	-0.33	1.70	-0.31	1.25
6	-1.31	-3.70	-1.26	-2.65
7	-4.80	-6.49	-5.24	-6.21
8	0.0	0.50	0.00	-1.00
9	-4.10	-4.35	-3.48	-2.02
10	3.01	2.03	3.50	3.32
11	-1.81	0.25	-4.49	-4.51
12	0.76	-2.13	3.50	2.88
13	-6.11	-1.83	-8.09	-3.92
14	6.77	-1.26	7.31	-5.65

[1] Field strengths, in kG, at a 4 cm. radius pole are given. Positive values correspond to focussing in the median plane. While the dispersions and emittances are correct for each beam, the momentum used for all calculations is 1 GeV/c.

[2] Beams are labelled with "X/Y" denoting: X = Q/A for the beam and Y = K500 cyclotron central field, eg. ".1/31" means Q/A = 0.1 and the cyclotron field is 31 kG.

near each cyclotron; these dipoles will be needed to counteract the strong fringing field effects of the cyclotron magnets. Significant problems in tuning the beam from the K500 have been experienced with the present beamline; we anticipate that most of these problems can be eliminated by a repositioning of the beamline to more nearly coincide with the particles' trajectories and the rest can be controlled with the small dipoles. The small (1°-2°) bend angles of these dipoles will be sufficiently small that their effects on the optics will be negligible.

TABLE II

QUADRUPOLE STRENGTHS AFTER DOUBLE-WAIST [1]

Quad. Number	Quad. strength (kG) at 4 cm. radius
15	-0.33
16	-1.31
17	-4.80
18	0.0
19	-4.10
20	3.01
21	-1.81
22	0.76

[1] The fields shown are appropriate for matching a 0(+2) beam into injection of the K800; as in Table I, the momentum used for the calculations was 1 GeV/c.

Table III

Emittance Parameters for Example K500 Beams and K800 Injection-matching

$(\frac{Z}{A})/B_0$	$\frac{T}{A}$ $\frac{MeV}{u}$	σ_x (cm)	σ_θ (mrad)	$r^{(1)}_{1,2}$	σ_y (cm)	σ_ϕ (mrad)	$r^{(1)}_{3,4}$	$R^{(1)}_{1,6}$ (cm/%)	$R^{(1)}_{2,6}$ (mrad/%)
.1/49	5.16	.24	.80	0.	.505	2.5	.988	-10.	20.
.1/31	2.08	.43	1.20	.93	.551	0.5	.997	1.0	20.
.02/49	.206	.40	.80	-.75	.25	3.6	.971	-14.8	2.0
.02/35	.106	.40	.90	.85	.422	4.0	.994	2.0	20.
.125(2)	7.2	.61	6.13	.9987	.917	4.65	-.999	-2.8	-21.4

1) The orientations are denoted in TRANSPORT notation; these are the "r" columns. The linear and angular dispersions are listed as "$R_{1,6}$" and "$R_{2,6}$", resp.

2) The conditions given for this beam are the conditions that must be matched at the end of the "injection" line.

Control and Diagnostics

The optical constraints on the beam in the coupling line are many. Diagnostics to check whether the conditions are fulfilled will be difficult, at best. The first decision regarding diagnostics was to include a "viewer" of some sort at the entrance and exit of each major dipole; this will prevent some of the tuning problems encountered in the present beamline where tunes have been used which had the dipoles adjusted such that the beam was not in the center of the beam-tube. These viewers will be a mix of at least two devices. One is a standard beam viewer box which would contain interchangeable apertures and scintillators. The other is an ion-chamber with two-dimensional read-out; this counter has been designed at LAMPF (ref. 4) for beam monitoring purposes. With this counter a complete two-dimensional profile of the beam intensity can be displayed every half-second. Resolution of 1 mm/pixel with a 48x48 grid is possible with the present electronics. The counter is at the "production-model prototype" stage. Local modifications will be necessary to accomodate the much larger energy losses and much shorter ranges of the heavy-ions relative to the high-energy protons and pions at LAMPF.

One of the most difficult conditions to test will be the achromaticity of the beam at the intermediate double-waist. The present scheme is to measure the emittance of the beam near the dipole that precedes the double-waist, measure it again near the entrance to the next dipole, and compare the results. If the beam is achromatic, or nearly so, the two "effective" emittances will be the same; if they are different, then the beam has dispersion that must be tuned away. An additional emittance measurement will probably be made before entry into the first dipole; this measurement will confirm whether the cyclotron emittance is consistent with that for which the beamline is tuned.

All beamline elements will be under computer control. This should greatly facilitate tuning of the beamline. Tunes that have been developed previously can be easily regained. New tunes can be explored rapidly by having the computer run quadrupoles singly or in groups; for example, the entire beamline could be ramped up and down proportionally by using a single "knob" on the console. Tunes developed with the optics code can be loaded directly into the beamline by utilizing the hardware links between the various cpu. Likewise, the mathematical optics of an empirical tune can be examined by transmitting the magnet settings to the optics program.

Summary

The present optical design for the coupling line is based on the calculated characteristics of beams extracted from the K500 cyclotron and on beams to be injected into the K800 cyclotron; as measured emittances of the beams become available, the beamline will be tested. The injection parameters will also be retested when the final injection trajectories have been calculated. Other than this we consider the optical design firm. Beamline components are presently being designed or are being prototyped. Prototypes of the quadrupoles and the small dipoles will operate this summer. Presently under review are the details of the beam viewer box and the winding scheme for the 135° bending magnet. We anticipate no problem having the coupling line ready consistent with the rest of the system needed for coupled cyclotron operation.

References

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