TRACKING STUDIES AND PERFORMANCE SIMULATIONS OF THE NSCL A1900 FRAGMENT SEPARATOR

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Abstract

At the National Superconducting Cyclotron Laboratory (NSCL), secondary beams of often short-lived radioactive nuclei are produced by the technique of projectile fragmentation where a primary beam impinges on a thin target to produce a broad spectrum of isotopes with near-beam velocity. As a major element of a recently funded upgrade of the NSCL facility, an increased capacity fragment separator used to select a particular isotope will be constructed. The key features of the new fragment separator include a high rigidity (6.3 T-m) and large acceptance with a solid angle of 8 msr, momentum acceptance of ±3%, and an energy resolution of 0.1%. Tracking studies and machine simulations have been done to verify the optical stability and performance of the lattice. The results of these studies, including simulations of magnet misalignment and magnetic field errors, are presented in this paper.

1 INTRODUCTION

World-wide there are significant physics programs which use ion beams of radioactive species as a unique tool to support research in nuclear structure and nuclear astrophysics research. Two complimentary processes are used to produce the radioactive beams. A technique called Isotope Production On-Line (ISOL) stops a primary, non-radioactive beam in a thick production target. The radioactive species produced are then transferred to an ion source where they are ionized and accelerated to final energy. A second technique called Projectile Fragmentation uses a primary, non-radioactive beam on a thin ($\Delta E/E$ • 10%) production target. In this case, the radioactive species produced have nearly the velocity of the primary beam and a downstream magnetic transport system (fragment separator) is used to select a particular radioactive species. The Projectile Fragmentation technique is used at the NSCL [1,2].

The projectile fragment separator is used to select the specific radioactive species by a two step process. Downstream of the production target, the mixture of primary and secondary ions is selected for $B\rho$ with an aperture system at a high-dispersion point. (See Figure 1.) Since energy loss is proportional to the square of the projectile atomic number, the isotopic selection is achieved by passing the $B\rho$−selected and dispersed ions through a wedge-shaped energy degrader. The remainder of the separator optics is then used to complete the isotopic separation. The nature and thickness of the production target and the energy degrader, as well as the sizes of the momentum apertures are parameters that are adjusted to control the secondary beam intensity and purity.

2 OPTICS

The fragment separator rigidity requirements are set by the primary beam energy and the fact that even fully stripped neutron-rich ions lighter than the primary beam will require a higher rigidity than that of the primary beam. At the NSCL, the K1200 cyclotron and the capacity of the following beam switch yard have set the design rigidity at 6.3 T-m or ~30% greater than that of the K1200 cyclotron.

In addition, the kinematics of the secondary beam production requires a large solid angle and momentum acceptance to achieve efficient capture of the radioactive species. A small magnification and large dispersion are desirable in the dispersive, horizontal plane (x) to achieve a high momentum resolution for the $B\rho$ selection. A small beam size and resulting larger angular spread are desirable in the vertical (y) plane to minimize the effect of multiple scattering in the energy-degrading wedge used for isotopic separation. The configuration of the planned, A1900 fragment separator is shown in Figure 1. Basic design specifications are given in Table1.

The initial secondary beam emittance at the production target position compatible with the A1900 admittance will be 25 π mm-mrad (0.5 mm x 50 mrad) and 20 π mm-mrad (0.5 mm x 40 mrad) for the horizontal (dispersive) and vertical planes respectively. These values provide the 8 msr solid angle specified in Table 1.

The first-order lattice functions are given in Figure 2. The lattice uses 24 quadrupoles configured in eight triplet packages, and four 45° dipoles in a reverse bend geometry so that the incoming and outgoing beams are coaxial.

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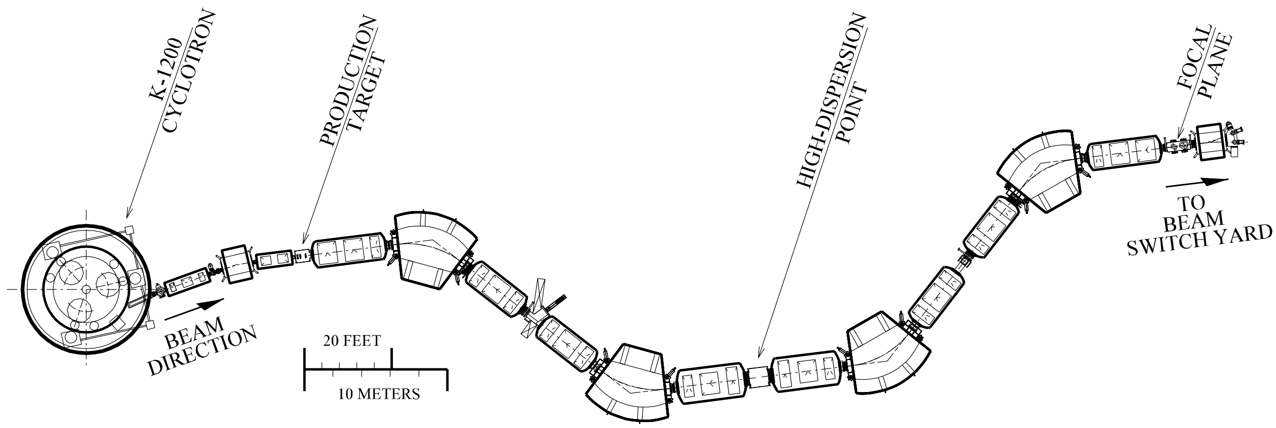

Figure 1. Layout of the proposed A1900 fragment separator.

The overall system (production target to focal plane) is a unit transfer.

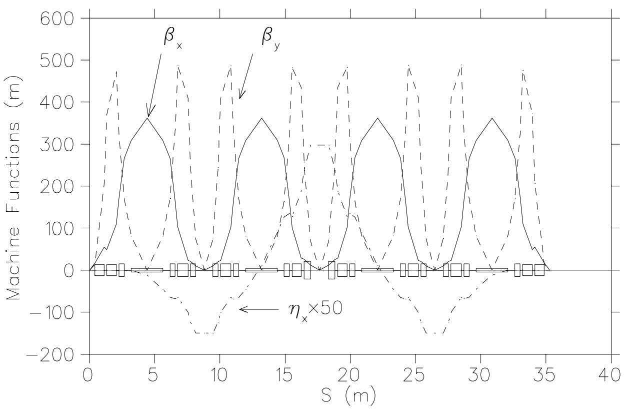

Figure 2. Lattice functions of the A1900.

Parameter	Specification
Solid Angle	8 msr
Rigidity	6.3 T-m
Momentum Acceptance	±3%
Intermediate Image (2)	
Magnification R11/R33	2.04/0.75
Resolving Power*	2915
Dispersion	5.95 m
Focal Plane	
Magnification (R11/R33)	1.0/1.0

Table 1. First-order, A1900 design parameters. *Resolving power = dispersion/(initial spot size x magnification).

3 SIMULATIONS

Since many of the quadrupoles will have a relatively poor aspect ratio (length:aperture = ~2.2:1) a 6th-order map generated by COSY INFINITY [3] was used to evaluate higher-order correction schemes and to track particles to determine transmission, resolving power, beam phase space, and error sensitivity.

The optical properties were evaluated by tracking 3,600 particles consisting of 400 particles uniformly populating the initial phase space for nine momenta values (±3%, ±2.5%, ±2%, ±1%, and 0%). Particle loss was considered at each magnet aperture and the phase space of the surviving particles was evaluated at the lattice mid-point and at the focal plane. Of the phase space delineated (8 msr and $\Delta p/p$ = ±3%), ~94% and ~92% survived to the lattice mid-point and the focal plane, respectively. The energy-degrader isotopic separation was not modeled in these simulations.

Due to the large momentum spread (±3%) and divergence (±50 mrad (x) and ±40mrad (y)) of the secondary beams, the higher-order aberrations are significant. The dominant 2nd-order aberrations are the chromatic terms $x|x'\delta$ and $y|y'\delta$. Six families of sextupoles were used to minimize all 2nd-order geometric and chromatic terms. The phase space generated by using the corrected 2nd-order map is given in Figure 3 for the lattice mid-point and Figure 4 for the focal plane. The maximum sextupole magnetic field required was 2 kG. Effort is now underway to provide a similar 3rd-order correction scheme.

Magnet alignment and mispowering errors were evaluated by applying the appropriate errors assuming a Gaussian distribution (±2σ) for each error and using particle tracking to determine the performance degradation as a function of the σ value. A degradation of 5% in the resolution was taken as the criteria for these specifications. As a result, the full-range, misalignment specifications have been set at ±0.5 mm for the transverse positions, ±0.5 mrad angular rotation about the beam axis, ± 5 mm longitudinal position, and ±10 mrad angular rotation about an axis perpendicular to the beam axis. Similarly, the full-scale ripple specifications have been set at $\pm 10^{-4}$ for the dipole and quadrupole and $\pm 10^{-3}$ for the multipole power supplies.

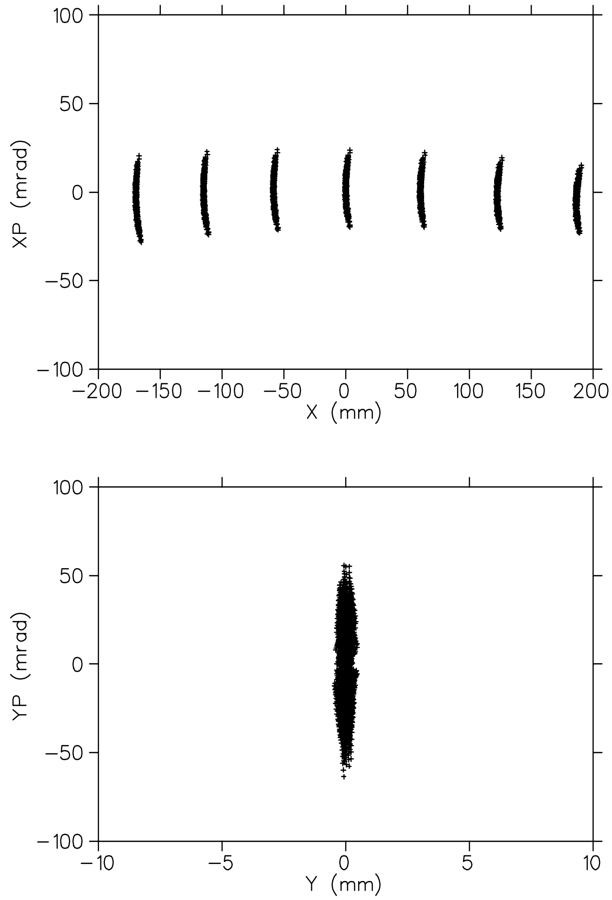

Figure 3. Transverse phase space for particles tracked through the corrected 2nd-order A1900 lattice from target to the high-dispersion mid-point.

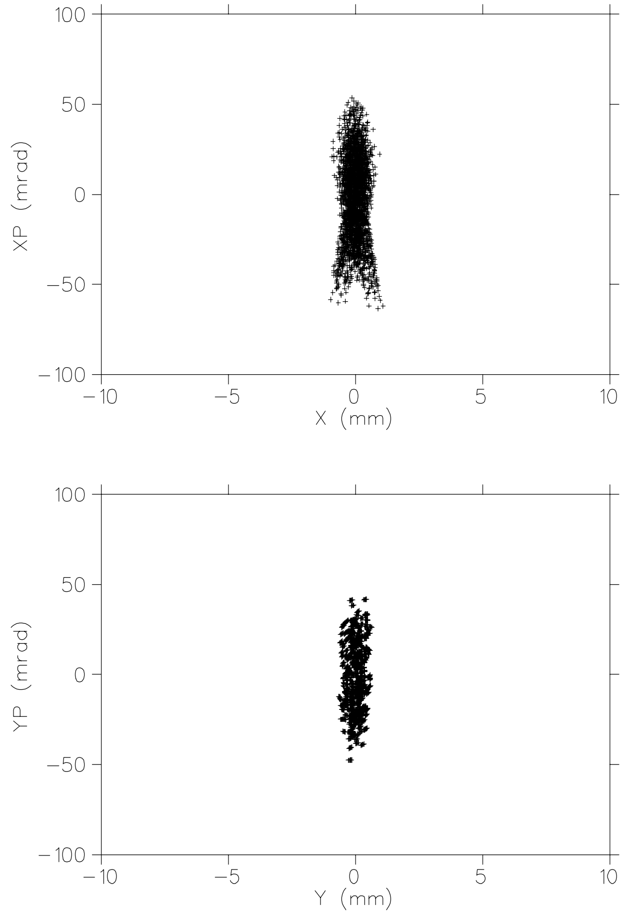

Figure 4. Transverse phase space for particles tracked through the corrected 2nd-order A1900 lattice from target to the focal plane.

4 HARDWARE

Of the 24 quadrupoles, 16 have multipole packages consisting of a sextupole and octupole pair. The half-lattice, symmetric about the mid-point is: (QA-QA-QB^{M}) - B - (QB^{M}-QC^{M}-QB^{M}) - (QB^{M}-QC^{M}-QB^{M}) - B - (QB^{M}-QE-QD) where QX represents a quadrupole type, ^{M} denotes those quadrupoles with multipole packages, ( ) delineates the triplet package, and B specifies a bend. Table 2 lists the primary magnetic specifications for the quadrupoles. For all magnets, the magnetic field shapes are determined by the iron configuration and the current coils are superconducting. The dipoles have a length of 2.5 m, a maximum pole-tip field of 2 T, and a good-field region of ±10 cm (x) and ±4.5 cm (y).

Type	**#**	**Effective Length (cm)**	**Pole Tip Radius (cm)**	**Warm Bore Radius (cm)**	**Max. Pole-Tip Field (kG)**
QA	4	72.3	13.3	10.0	22.1
QB	12	40.0	15.0	10.0	20.7
QC	4	79.0	15.0	10.0	22.1
QD	2	48.6	21.0	17.0	23.1
QE	2	70.0	15.0	11.6	24.1

Table 2. A1900 quadrupole paramaters.

5 REFERENCES

[1] “The K500⊗K1200 – A Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratory”, July 1994, Michigan State University, East Lansing, Michigan, MSUCL-939.

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[3] M. Berz, “User's Guide and Reference Manual for COSY INFINITY”, MSUCL-977, Michigan State University, 1995.