THE MISALIGNMENT AND RF ERROR ANALYSESFOR THE RIA DRIVER LINAC *

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Abstract

The proposed Rare Isotope Accelerator (RIA) [1] driver linac being studied at the National Superconducting Cyclotron Laboratory (NSCL) consists of three parts separated by two charge-stripping chicanes. Superconducting quarter-wave, half-wave and 6-cell elliptical cavities with rf frequencies ranging from 80.5 MHz to 805 MHz are proposed to accelerate light and heavy ions to final beam energies of ≥400 MeV/nucleon. Superconducting solenoids and room temperature quadrupoles are proposed to provide transverse focusing and beam matching. Because of the high final beam power (100 to 400 kW) specified for RIA operation, beam loss must be limited to avoid radiation damage. Misalignment and rf error analysis for the superconducting cavities and focusing elements in the RIA driver linac were performed, and correction schemes developed using the computer codes DIMAD and LANA. The simulation results are presented, and the misalignment and rf error specifications are given for the RIA driver Linac.

1 INTRODUCTION

Figure 1 shows the Rare Isotope Accelerator (RIA) driver linac layout that is being evaluated at the NSCL. It consists of three segments of SRF linac separated by two charge-stripping sections that provide a cost-effective method of achieving the final beam energy of ≥400 MeV/nucleon with the required beam power of ≥100 kW. The first two segments of RIA use quarter-wave and half-wave resonators with frequencies ranging from 80.5 MHz to 322 MHz. Transverse focusing is provided by superconducting solenoid magnets inside the cryostats. The last segment uses 805 MHz, 6-cell elliptical cavities, and room temperature quadrupole doublets for transverse focusing.

The beam dynamics studies for the RIA driver linac [2] were performed using computer codes DIMAD [3] and LANA [5]. DIMAD was used to study the transverse focusing structure, beam matching, and transverse misalignment and correction schemes. LANA was used for the longitudinal beam dynamics studies, 6-D phase space particle tracking, and rf error analysis. Our simulations assumed a ^{238}U beam had an initial normalized beam emittance of 0.6 π mm-mrad. Charge states of 28+ and 29+, 73+ to 77+, and 87+ to 89+ will be accelerated in Part I, II and III of the driver linac, respectively.

2 TRANSVERSE MISALIGNMENT AND CORRECTIONS

The advantage of using DIMAD is its ability to simulate realistic transverse misalignment scenarios and evaluate alignment correction schemes based on a least square fitting subroutine that has been widely used for misalignment and correction studies for synchrotrons and beamline designs in SSC, SLAC and CEBAF projects. Modifications were made to better adapt DIMAD for RIA driver linac simulations. The misalignment analysis included all SRF cavities and focusing elements used in

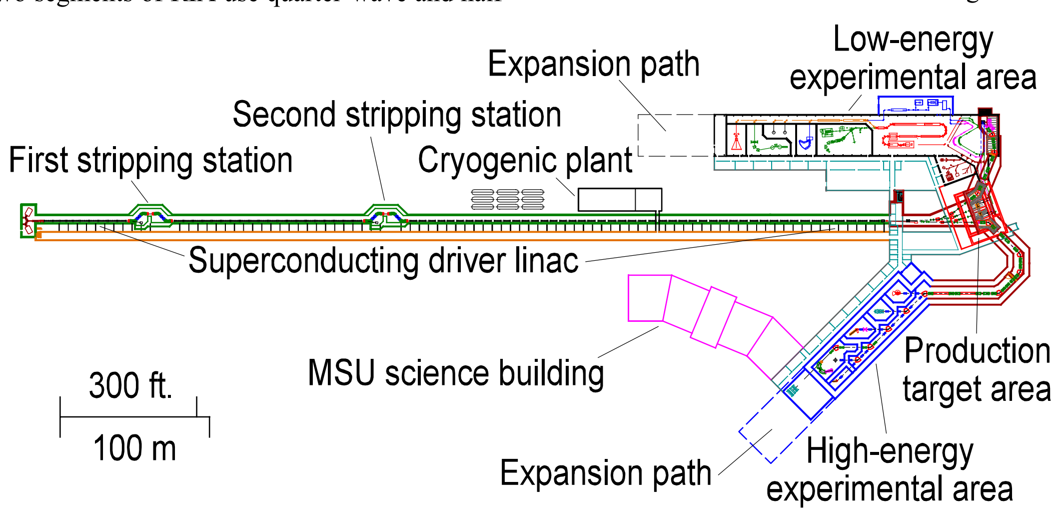

Figure 1: The layout of proposed the Rare Isotope Accelerator being studied at the NSCL.

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the three segments of the RIA driver linac assuming a Gaussian distribution (±2σ). The SRF cavities have a radial aperture of at least 15 mm and the initial beam size is about 5 mm in our lattice. Assuming a buffer zone of 5 mm between the beam envelope and cavity aperture, a maximum allowable central ray distortion of ±5 mm was taken as the criterion for the misalignment specification.

The superconducting cryomodules before the second stripping station have multiple SRF cavities and solenoid magnets. The correction scheme assumed no beam position monitors inside the cryomodules. Previous beam dynamics studies [2,5] showed that a strong focusing lattice was essential for multi-charge state beam acceleration. The strong magnetic field required for the superconducting solenoid magnets were found to be more sensitive to the misalignment errors than the SRF cavities in the lattice.

Part I of the RIA Driver linac has 18 cryomodules containing 153 cavities and 81 solenoid magnets. Eighteen beam position monitors located in the warm region between cryomodules and at the end of Part I were used in the alignment correction simulations. Two solenoid magnets near the front of each cryomodules were assumed to have dipole windings and used to provide horizontal and vertical central orbit corrections. From these simulations, the misalignment specifications are listed in Table 1 assuming the central orbit distortions limited to within ± 5mm after the correction. Figure 2 shows the central orbit distortions for a single random seed before and after the correction. The maximum orbit distortions before the correction were 6.8 mm and 10.7 mm in the transverse planes and were reduced to below 5 mm after the correction. Simulations were performed for multiple seeds with similar results.

Table 1: Misalignment specification for Part I

Misalignment Element	$\sigma_{x,y}$ (mm)	Maximum Error (mm)
SRF Cavities	1.0	±2.0
Solenoids	0.25	±0.5

Part II of the RIA driver linac consists of 32 cryomodules containing 257 cavities and 66 solenoids. Similar to Part I, thirty-two beam position monitors located in the warm region between cryomodules and at the end of Part II were used as elements of the orbit correction scheme. Two solenoid magnets with dipole windings in the front of each cryomodule were used as horizontal and vertical central orbit correctors. Due to the increased number of beam position monitors available and the decreased magnetic fields of the solenoids in the lattice, the misalignment specifications of the solenoid magnets as listed in Table 2 could be relaxed by a factor of two compared that required in Part I. The maximum orbit distortions of about 30 mm before the correction were reduced to below 5 mm after correction.

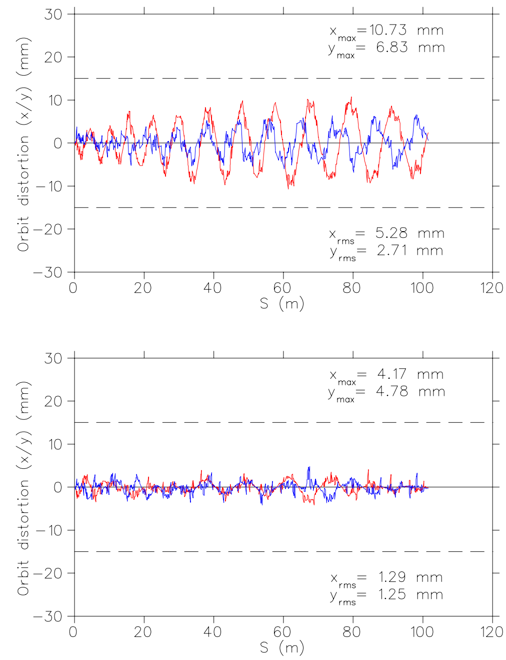

Figure 2: Central orbit distortions in the Part I of RIA driver linac for a single random seed before and after the correction.

Table 2: Misalignment specification for Part II

Misalignment Element	$\sigma_{x,y}$ (mm)	Maximum Error (mm)
SRF Cavities	1.0	±2.0
Solenoids	0.5	±1.0

The transverse focusing in Part III of the RIA driver linac was provided by room temperature quadrupoles positioned between cryomodules. Forty-nine beam position monitors located between the room temperature quadrupoles and at the end of Part III were used to in the orbit correction analyses. Horizontal and vertical dipole magnets were added to the lattice to provide required orbit corrections. Since the orbit correctors are paired with and close to the relatively weakly focusing quadrupoles, the orbit correction was much more effective than that for Parts I and II. With the misalignment specifications listed in Table 3, the maximum orbit distortions of about 80 mm before the correction can still be limited within ±4mm after the correction. Larger misalignment errors could be allowed. In addition, the 6-cell elliptical cavities used in Part III have a larger radial aperture of 40 mm. Hence, beam loss in this region is most probable in the quadrupole magnets that have a radial aperture of only 25 mm.

Table 3: Misalignment specification for Part III

Misalignment Element	$\sigma_{x,y}$ (mm)	Maximum Error (mm)
SRF Cavities	1.0	±2.0
Quadrupoles	1.0	±2.0

3 RF ERROR ANALYSIS

Longitudinal beam dynamics studies were performed using LANA [4]. Further studies were performed to evaluate the impact of rf phase and amplitude field errors on the beam transverse and longitudinal emittances and possible resulting beam loss. Due to the high beam power required for RIA, a beam loss criterion of 10^{-4} was chosen.

The transverse de-focusing of the SRF cavities are much weaker than the focusing provided by the solenoids and quadrupoles. Therefore, the impact on the transverse beam emittance by an rf field error is limited. However, the rf field errors have a significant effect on the longitudinal beam emittance. Figure 3 shows the transverse and longitudinal 99% beam emittance variations through the whole RIA driver linac due to the rf phase and amplitude field errors. Figure 4 shows a contour plot of the longitudinal rms emittance growth factor for the whole RIA driver linac vs. the rf phase and the amplitude field errors. The transverse rms emittances were not significantly affected with phase and amplitude errors up to 1° and 1% respectively.

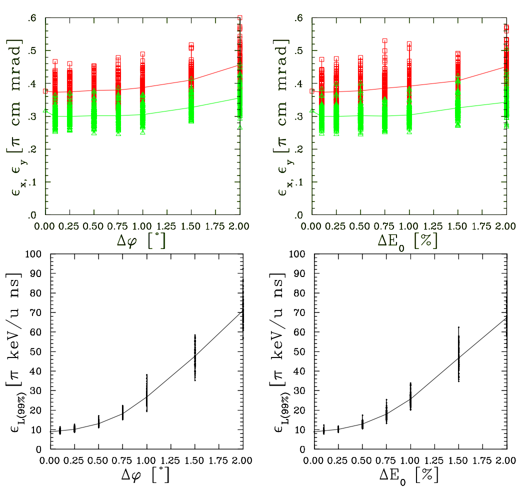

Figure 3: Transverse and longitudinal 99% beam emittances vs. rf field errors in phase and amplitude.

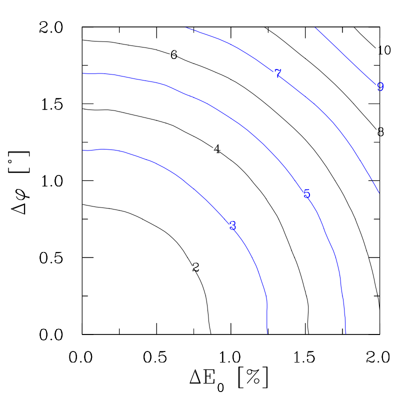

Figure 4: Longitudinal rms beam emittance growth factor contour plot.

A typical beam loss distribution for the RIA driver linac due to rf errors of $\Delta\phi = 1°$ in phase and $\Delta E_0 = 0.5\%$ in amplitude is shown in Figure 5. Beam loss $\leq 10^{-4}$ is achievable for combined rf field errors in the RIA driver linac of $\Delta\phi \leq 0.5°$ in phase and $\Delta E_0 \leq 0.5\%$ in amplitude.

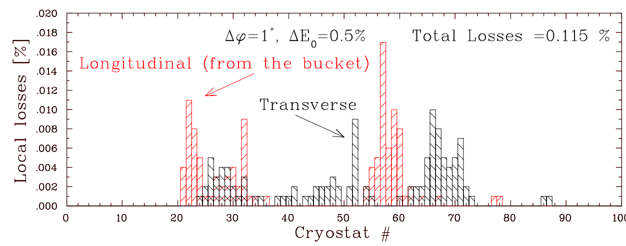

Figure 5: A typical beam loss distribution along the RIA driver linac.

4 SUMMARY AND CONCLUSIONS

Transverse misalignment specifications for different segments of the RIA driver linac were determined through simulations. The alignment specifications (±2 mm) for SRF cavities and quadrupoles are reasonable. The alignment of the superconducting solenoid magnets will be a challenge, especially for Part I of the linac. They are however, still significantly larger than that concluded from studies performed at ANL [6]. The rf field errors while having little impact on the transverse beam emittance were found to cause significant longitudinal beam emittance growth. A beam loss of $\leq 10^{-4}$ is achievable for combined rf field errors of $\Delta\phi \leq 0.5°$ in phase and $\Delta E_0 \leq 0.5\%$ in amplitude in RIA driver linac.

5 REFERENCES

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