2003-237-N0 -- STUDY OF BEAM HALO FORMATION IN LONGITUDINAL PHASE SPACE IN THE RIA DRIVER LINAC

Principal Investigators: P. N. Ostroumov, Physics
V. N. Aseev, Physics
E. Lessner, Physics
J. Nolen, Physics

Funding Profile: FY 2001 $0K
FY 2002 $0K
FY 2003 $389.7K
FY 2004 $220K
FY 2005 $0K

Purpose: The Rare Isotope Accelerator (RIA) includes a high-intensity 1.4 GeV driver linac. To avoid problems from beam-induced radioactivation, beam losses must be limited, particularly in the high-energy part of the accelerator where fractional beam losses must be less than 10^{-4}. Beam dynamics studies are necessary with the goal of identifying sources of halo formation in the longitudinal phase space specifically. Knowing the sources and properties of the longitudinal halo, methods for halo collimation can be developed.

Approach: Understanding the sources of halo formation mechanisms is an important issue for the design of high-intensity medium energy heavy-ion accelerators. The formation of beam halo in the longitudinal phase space is expected for several reasons: 1) strongly non-linear motion in the longitudinal phase space during acceleration in the radio-frequency quadrupole (RFQ), 2) effect of the stripping foils or films, 3) effect of the random errors of rf field phase and amplitude. We have studied the formation of beam halo in order to estimate the level of beam losses in the high-energy section of the driver linac. Several options of the driver linac have been studied. The methods of beam collimation in the post-stripper beam transport area have been developed. The beam dynamics simulation code TRACK has been significantly updated toward the studies of beam halo formation in heavy-ion superconducting linacs and transport systems.

Technical Progress and Results: Beam dynamics in the proposed RIA driver linac have been numerically simulated using the TRACK code. The simulation starts from the exit of electron cyclotron resonance (ECR) source high-voltage (HV) platform. A multi-component heavy-ion beam is transported through the achromatic charge-selection system and accelerated by the RFQ. Space charge effects are significant in the low energy beam transport (LEBT) and have been included in simulations up to the end of the RFQ. In these simulations particles represent a two-charge state uranium beam in the low-β section, five charge states in the medium-β and four charge states in the high-β section. Due to the non-linear formation of the longitudinal emittance there is a significant beam halo formation in the RFQ. Figure 1 shows a relative number of particles outside of given longitudinal emittance as a function of the emittance. A low populated longitudinal halo can be seen as a number of simulated particles is increased up to 10^6. This observation suggests that for the realistic beam loss calculations a large number of particles should be tracked through the driver linac.

The most significant emittance growth and halo formation in the driver linac is associated with the second stripper. There are no experimental data of detailed particle energy and angle distributions after the passage of ~85 MeV/u uranium beam through a stripping foil. We have used the code SRIM for the Monte Carlo simulation of the transport of incident monochromatic beam containing 10^6 uranium ions through a stripping foil. About 0.2% of ions will experience nuclear reactions. Currently our studies do not include the dynamics of nuclear reaction products. According to preliminary estimations these products can result to ~10^{-6} relative beam losses in high energy section of the driver linac. Figure 2 shows the distribution of 99.8% of particles that experienced elastic scattering in the (α, W) plane, where $\alpha = \sqrt{x'^2 + y'^2}$, and W is the ion energy per nucleon. A strong correlation between the large scattered angles and ion energy is clearly seen from the figure. This correlation suggests a simple way to remove the low-energy halo by the system of collimators along the post-stripper magnetic transport system (MTS). The main collimator is located in a highly dispersive area of the MTS and dumps all unwanted charge states. An additional five collimators along the MTS are designed to clean the beam halo in the transverse phase planes.

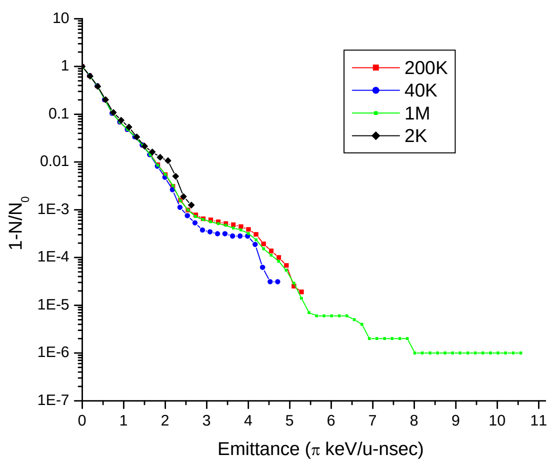

Fig. 1. Relative number of particles outside of given longitudinal emittance as a function of the emittance.

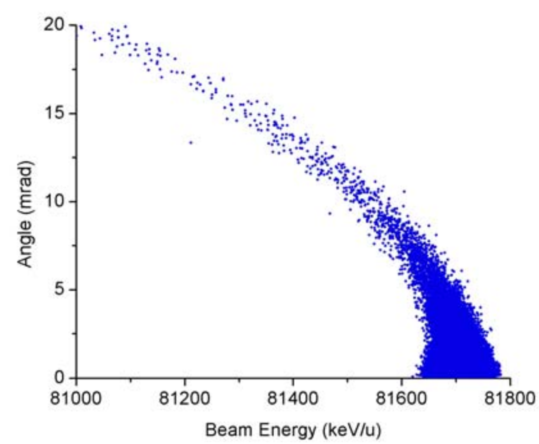

Fig. 2. Distribution of uranium ions in the angle-energy plane.

To minimize beam losses, the longitudinal acceptance of the high-β section must accept the full beam emittance, including halo particles. The longitudinal acceptance can be increased by the factor of four if the triple-spoke resonators operating at 345 MHz are used in the high-β section of the linac. Basic results of the simulations are summarized in Table I. We have assumed ±5% stripping foil thickness fluctuation. All errors are randomly generated as a uniform distribution for given rms values. The sensitivity of multi-q beam parameters to various types of random errors and misalignments were studied by the TRACK code. Phase and amplitude errors of the rf field are fast fluctuations and produce effective longitudinal emittance growth of multi-q beams. Monte Carlo simulations of the dynamics of multi-q beams in the presence of both accelerating field and alignment errors have been performed. Two designs of the high-β section have been studied: 1) elliptical cavity linac (ECL) which is the baseline design for the RIA driver linac and 2) triple-spoke linac (TSL).

Table 1.

δW (keV/u)	Beam loss in ECL	Beam loss in TSL
17.6 (SRIM)	No	No
53	$6 \cdot 10^{-5}$	No
88	$2 \cdot 10^{-4}$	No

If the energy distribution after the stripper is taken from the SRIM code there are no losses in the high-β section for the both linac designs. The TSL is much less sensitive to the energy distribution after the stripper as well as to the stripper thickness fluctuations. As we mentioned earlier these simulations do not include radioactive products generated after the passage of the stripping foils.

Future objectives include the extension of the TRACK code for parallel computing in the ANL JAZZ computer cluster. The parallel computing will allow us to study beam halo in the driver linac by tracking 10^6 particles in the presence of errors and misalignments of the accelerating and focusing fields. All simulations will be done for multi-component ion beams in the presence of internal (due to the beam space charge) and external three-dimensional electromagnetic fields.

Specific Accomplishments:

K.W. Shepard, P.N. Ostroumov, J.R. Delayen, "High-Energy Ion Linacs Based on Superconducting Spoke Cavities," *Phys. Rev. ST. Accel. Beams*, **6**:080101 (2003).

P.N. Ostroumov, "Heavy-Ion Beam Dynamics in the RIA Accelerators," 2002 Charged Particle Optics Conference (CPO-6), Greenbelt, Maryland (October 22-25, 2002).

P.N. Ostroumov, "Heavy-Ion Beam Dynamics in the Rare Isotope Accelerator Facility," PAC2003 Particle Accelerator Conference, Portland, Oregon (May 12-16, 2003) Abstract book, p. 111.

P.N. Ostroumov, "Source of Beam Halo Formation in Heavy-Ion Superconducting Linac and Development of Halo Cleaning Methods," ICFA Advanced Beam Dynamic Workshop (Halo'03), Montauk, New York (May 19-23, 2003).

P.N. Ostroumov, V.N. Aseev, J.A. Nolen, "Design Study of Acceleration and Utilization of High Power Beams in the RIA Facility. Accelerator Applications in a Nuclear Renaissance," (AccApp'03) San Diego, California (June 1-5, 2003).

E.S. Lessner and P.N. Ostroumov, “Beam Dynamics Optimization in the Rare Isotope Accelerator Driver Linac,” PAC2003 Particle Accelerator Conference, Portland, Oregon (May 12-16, 2003), Abstract book, p. 239.

P.N. Ostroumov, “Driver Linac Beam Dynamics,” RIA R&D Workshop, Bethesda, Maryland (August 26-28, 2003).

B. Mustapha, J.A. Nolen and P.N. Ostroumov, “Large Scale Computing for Beam Dynamics Simulations and Target Modeling, RIA R&D Workshop, Bethesda, Maryland (August 26-28, 2003).

E.S. Lessner and P.N. Ostroumov, “Multiple-Charge-State-Beam Steering in the RIA Driver Linac,” RIA R&D Workshop, Bethesda, Maryland (August 26-28, 2003).