BEAM DISTRIBUTION SYSTEM FOR THE MSU-RIA DRIVER LINAC*

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Abstract

The proposed Rare Isotope Accelerator (RIA) facility [1] will deliver up to 400 kW of any stable isotope to multi-target areas to create radioactive ion beams using either Isotope Separation On Line or Particle Fragmentation methods. Operational and programmatic efficiency will be best served by a system that can simultaneously distribute the beam current over a large dynamic range to several targets. The proposed RIA beam switchyard (BSY) uses an rf kicker-magnetic septum system to distribute the beam to multi-target areas on a micro-bunch by micro-bunch basis. The micro-bunches can be differentially loaded in the RIA driver linac front end utilizing a scheme similar to that successfully used at Mainz and JLAB CEBAF facility. In these cases, consecutive electron micro-bunches are deflected by an rf kicker and their intensity separately adjusted through variable apertures with an identical second rf kicker returning the micro-bunches on-axis. The feasibility of using a similar system in RIA driver linac front end was explored.

FRONT-END BEAM DISTIBUTION SYSTEM

The microbunch intensity for two targets is adjusted in the front-end MEBT using two rf kickers and a transverse optical system with a π phase advance. Additional matching cells are used before and after the π phase advance cell for a total MEBT length of ~8 meters. The two matching cells are used to match the beam parameters into the π phase advance cell and into segment 1 of the RIA driver linac. The MEBT layout is shown in Figure 1.

The proposed MEBT will decompose the 300 keV/u, 80.5 MHz bunched beam from the RFQ into two 40.25 MHz beams with variable and independent intensities. The first rf kicker deflects consecutive bunches in opposite directions creating two 40.25 MHz beams with different transverse positions. A slit system can then adjust each beam intensity independently. Four quadrupoles provide a π phase advance in the transverse phase space, and a second rf kicker recombines the two 40.25 MHz beams into a single 80.5 MHz beam prior to acceleration in the first segment of the RIA driver linac. In the BSY, an additional rf kicker will be used to split the beam into its two 40.25 MHz sub-components of different intensities and distribute them onto separate targets.

As an illustration, the motion of two consecutive 80.5 MHz bunches in all six dimensions over the MEBT π phase advance cell is shown in Figure 2. Beam phase spaces are shown at five different locations along the cell. At the entrance of the first 40.25 MHz rf kicker, location 1, the two bunches are superimposed transversely and 360 degrees apart longitudinally (the RFQ 80.5 MHz is used as reference frequency). At the output of the first rf kicker, location 2, the two bunches are separated angularly in the vertical transverse phase space. At the collimating slits, location 3, consecutive bunches are separated spatially in the vertical dimension and their intensities can be adjusted independently. From the entrance of the first kicker to the entrance of the second kicker, location 4, bunches describe a π phase advance motion (the yy' phase space at location 4 is similar to the one at location 2 with positions of the bunches inverted). At the exit of the second rf kicker, location 5, the bunches are recombined and back onto beam axis.

For the rf kicker structure, a 40.25 MHz half-wave resonator with 5 cm aperture was designed and 3D field maps obtained from MAFIA were used in the beam dynamics simulations. The required voltage for the rf kickers to obtain reasonable beam separations at the collimator is ~30 kV.

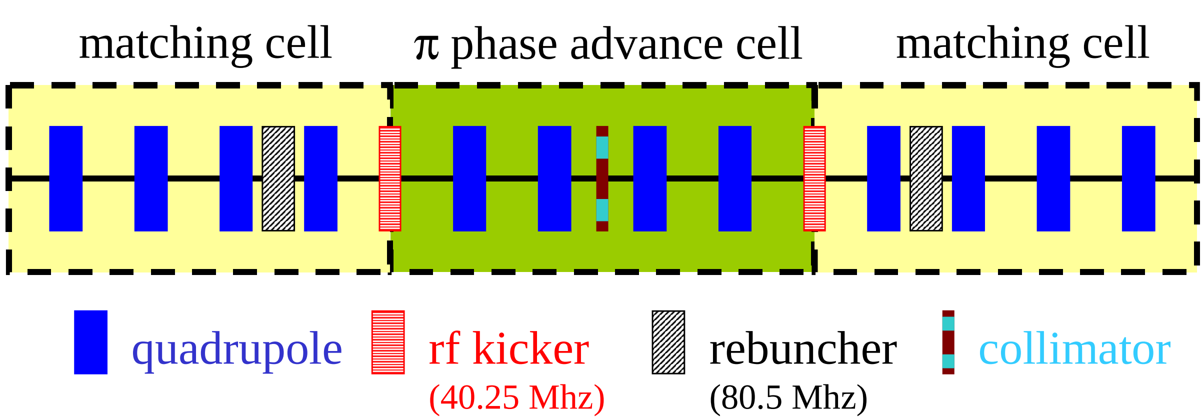

Figure 1: Layout of the front-end MEBT with the beam distribution system hardware for the RIA driver linac.

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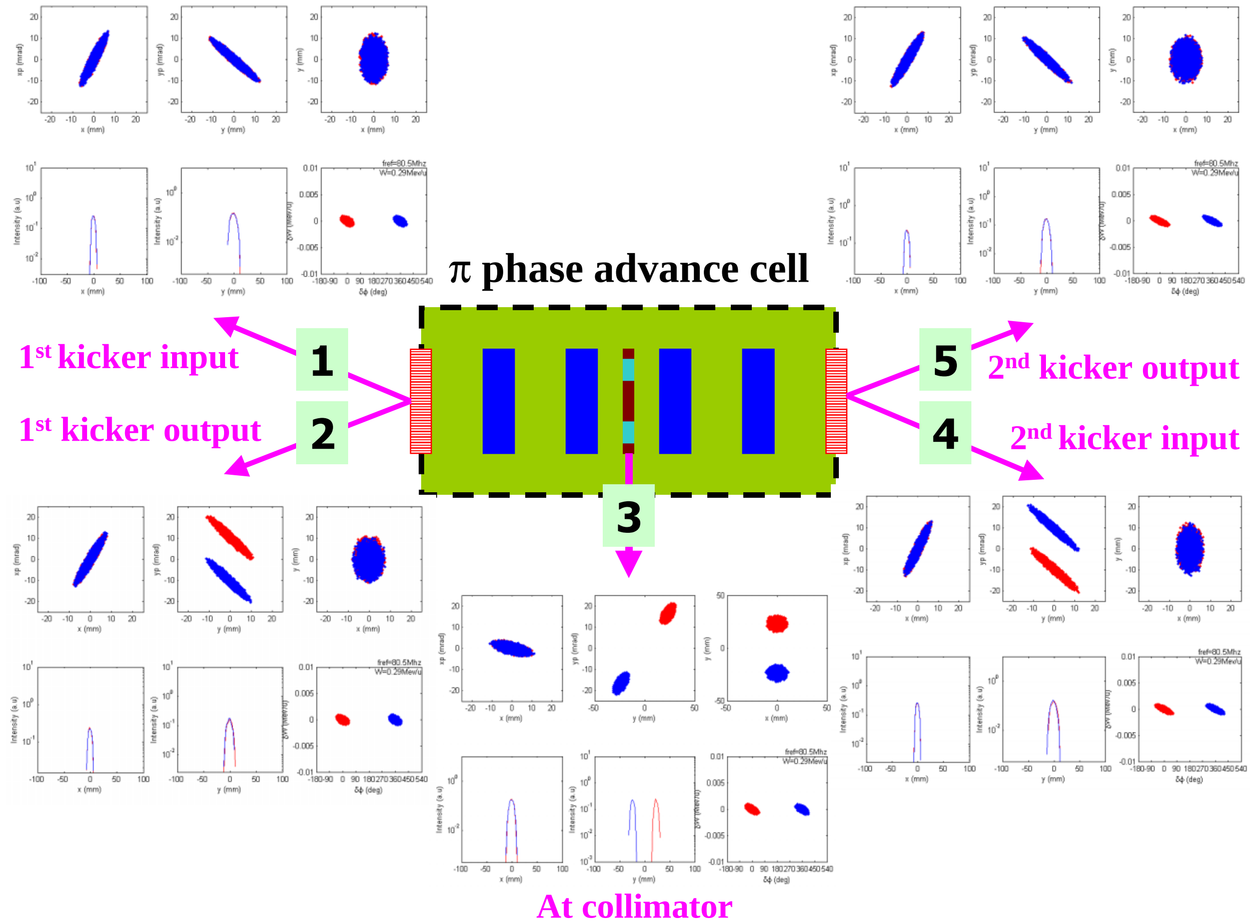

Figure 2: Motion of two consecutive 80.5 MHz bunches (red/light, blue/dark) along the π phase advance cell for ideal fields in the 40.25 MHz rf kickers. For each location, top row pictures are xx', yy' and xy spaces, bottom row pictures are horizontal profile, vertical profile and δϕδW phase space. At the third location, the scale of the x and y axes were changed for display.

Because of the stringent 1W/m beam loss requirement for the driver linac, the system may not introduce significant emittance growth. Thus, beam dynamics simulations were performed to estimate the beam transverse and longitudinal emittance increase in the MEBT.

Transverse emittance growth is primarily caused by mismatch between consecutive 80.5 MHz bunches. The mismatch itself is due to the fact that the transverse kicks in the 40.25 MHz kickers depend on the particle's entering position. Even if this dependence is linear, one bunch sees a focusing effect while the next sees a defocusing effect since consecutive bunches are separated by 180° in the 40.25 MHz rf kickers. When the bunches are recombined after the second rf kicker, this mismatch is equivalent to an effective transverse emittance growth for the beam as a whole.

Longitudinal emittance growth is driven by two different mechanisms. Firstly, it can be generated in the 40.25 MHz rf kickers through longitudinal mismatch between consecutive bunches. In the kickers, the vertical deflecting kick for a particle is proportional to cosϕ with ϕ the average phase of the particle through the deflecting gap To minimize the required amplitude of the deflecting voltage, the kickers are operated on-crest (i.e., ϕ=0 and π). The overall action of the longitudinal field on the other hand is proportional to sinϕ. If the amplitude of the longitudinal kick (i.e. integral of the longitudinal field through the kicker) is not negligible, one bunch experiences a longitudinal focusing effect while the next experiences a defocusing effect, thus creating a longitudinal mismatch and leading to an effective emittance growth.

Secondly, longitudinal emittance growth can occur because of non-linear effects in the 80.5 MHz rebunchers. Even though they are operated in the most linear region of the phase curve, the longitudinal emittance growth can be significant if the phase width of the beam is large as in the 2nd 80.5 MHz rebuncher (this effect is negligible in the 40.25 MHz kickers because of the lower frequency). To mitigate the longitudinal emittance growth in the 2nd 80.5 MHz rebuncher the beam is rotated longitudinally in the 1st rebuncher in order to reduce the energy spread of the beam in the MEBT.

The 40.25 MHz rf kickers were designed to mitigate transverse and longitudinal emittance growths. For the reasons described above, a half-wave structure was chosen over a quarter-wave structure. The variation of the integrated action of the transverse field is +/- 2.5% within the beam region and the integrated effect of the longitudinal field is less than 10% of the transverse field action. Using 3D field maps, only modest emittance growths in transverse (~ 5%) and longitudinal (~10%) rms emittances were observed in the beam dynamics simulations. The evolution of the beam emittances along the MEBT is illustrated in **Figure 3**.

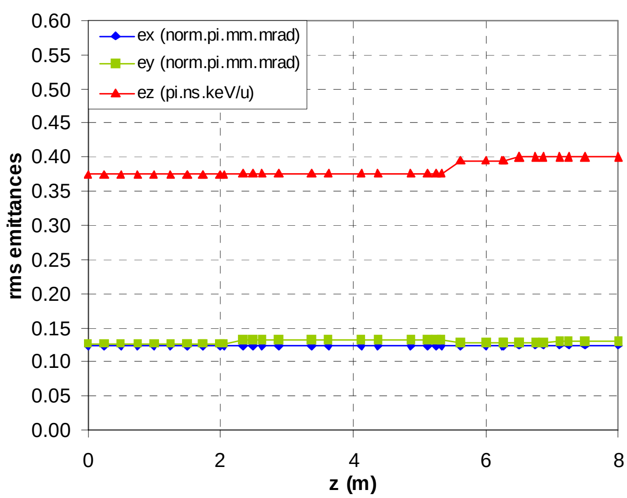

Figure 3: Beam rms emittances along MEBT.

As shown in **Figure 4**, the present design for the 40.25 MHz rf kickers of the MEBT is a typical coaxial loop. To facilitate the manufacture and assembly, dimensions of the coaxial tubes of the resonator are adjusted to match dimensions of standard rigid coaxial transmission lines. The proposed structures have a deflecting voltage of 30 kV, a quality factor of 8700 and an rf power loss of 385 W.

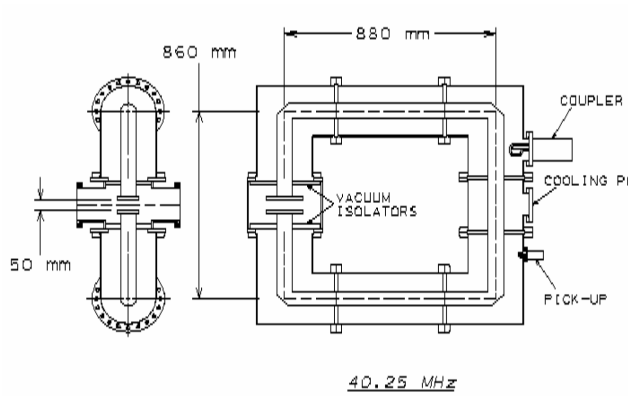

Figure 4: 40.25 MHz HW resonators for the kickers of the RIA MEBT beam distribution system.

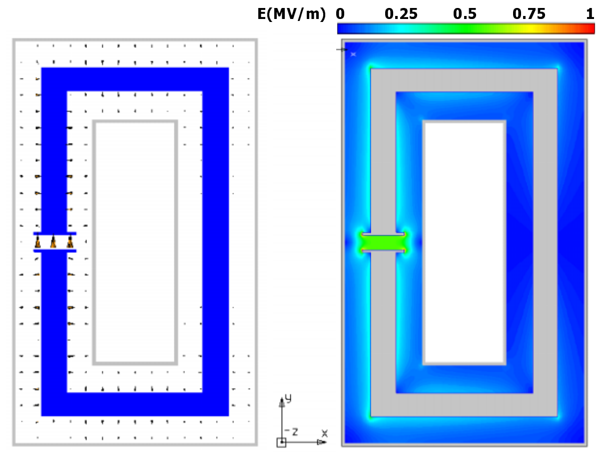

Figure 5: Deflecting field in the MEBT rf kickers.

BSY BEAM DISTIBUTION SYSTEM

The BSY Distribution system uses a rf kicker, a switch dipole and a septum magnet to either split RIA driver linac stable beams into two beamlines with 50% or less of beam power each, or supply a single target with 100% of beam power. **Figure 6** shows the layout of the RIA BSY beam distribution system. The rf kicker and switch dipole with same kick angle of about ±1.5 mrad are used to spilt or switch the incoming ion beam into the two downstream beamlines. A 10 m long drift after the beam split generates enough separation to accommodate a 10 mm septum in the septum magnet.

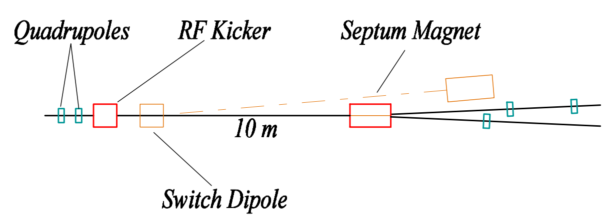

Figure 6: BSY beam distribution system layout.

SUMMARY

The RIA MEBT/BSY beam distribution system was presented and can simultaneously distribute the driver linac beam power over a large dynamic range to several targets. Results from particle tracking in the MEBT with realistic 3D fields showed modest transverse and longitudinal beam emittance increase and no performance degradation in the driver linac is anticipated.

REFERENCES

[1] X. Wu et al., "End-to-end Simulations for the MSU RIA Driver Linac" Proceedings of LINAC2004, Lubeck, Germany, 16^{th}-20^{th}, August 2004.