ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-THPF136

BEAM DYNAMICS OPTIMIZATION OF FRIB FOLDING SEGMENT 1 WITH A SINGLE TYPE OF REBUNCHER CRYOMODULE

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Abstract

The Facility for Rare Isotope Beams (FRIB) uses a charge stripper in folding segment 1 to increase the number of charge states of particles to enhance the acceleration efficiency. To control possible emittance growth after the charge stripper, the 3-dimensional on-stripper beam size should be as small as possible. The original 2-cavity-HWR (HWR stands for half wave resonator) rebuncher cryomodule is responsible for the longitudinal focusing before stripper. In order to accept and transport the beam downstream to linac segment 2, another kind of 3-cavity-QWR (QWR stands for quarter wave resonator) rebuncher cryomodule is baselined after the stripper. However, two kinds of cryomodules would increase the cost in design, therefore would be quite inefficient. In this paper, the FRIB lattice with only single-type 4-cavity-QWR rebuncher cryomodule in folding segment 1 is discussed. Positions of lattice elements are adjusted to accommodate the new type of cryomodule. Beam dynamics is optimized to meet the on-stripper beam requirement. The lattice is then adjusted and rematched.

INTRODUCTION

In the FRIB [1] baseline design of linac segment 1 (LS1) and folding segment 1 (FS1), there are two types of rebuncher cryomodules, one type is the 2-cavity-HWR rebuncher, and another is the 3-cavity-QWR rebuncher.And There are two rebuncher cryomodules for each type, two 2-cavity-HWR rebunchers and two 3-cavity-QWR rebunchers. The baseline design aims at decreasing the total number of RF cavities, however, further cost optimization favored the choice of decreasing the type of rebuncher cryomodules to a single type 4-cavity-QWR rebuncher, which can save design and manufacturing cost. A proposal was made to reduce the type of rebunchers from 2 to 1. And the feasibility of the new lattice with new type of rebuncher from beam dynamics point of view is studied and described in this paper.

NEW LATTICE DESIGN CONFIGURATION

This section mainly provides information on the new type of 4-cavity-QWR rebuncher and the two criteria of lattice design:

New Type of 4-cavity-QWR Rebuncher

Some pre-study shows that a single type of 4-cavity-QWR rebuncher is capable of replacing the two types of rebunchers. The drawing of the new 4-cavity-QWR rebuncher can

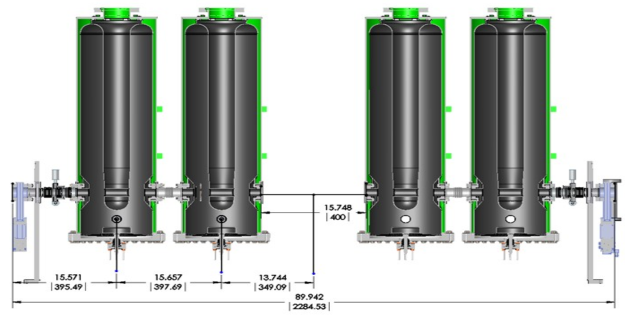

Figure 1: Mechanical drawing of the new 4-cavity-QWR rebuncher.

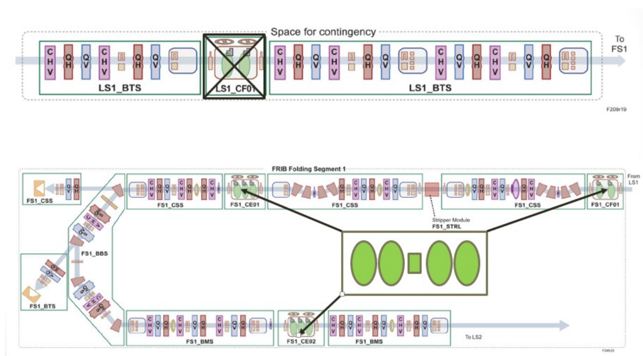

Figure 2: New lattice design with a single type of 4-cavity-QWR rebuncher (Criterion 1) [2].

be seen in Fig. 1. There are 4 $\beta = 0.085$ QWRs in one rebuncher cryomodule, and a 0.4 m reserved space at the center of the cryomodule for heat exchanger. The total length of the new rebuncher cryomodule is 2.285 m.

New Lattice Design Criterion 1

The first criterion of a new lattice design with a single type 4-cavity-QWR rebuncher can be seen in Fig. 2. The 2-cavity-HWR rebuncher LS1-CF01 is deleted, and the remaining rebunchers FS1-CF01, FS1-CE01, FS1-CE02 are changed into the 4-cavity-QWR rebuncher. In order to preserve cryogenic port position, center position of each rebuncher cryomodule is fixed.

The original 2-cavity-HWR rebuncher is 1.243 m long and the 3-cavity-QWR rebuncher is 1.589 m long, both kinds of old rebunchers are smaller in size. In order to accommodate the new rebuncher, lattice elements should be shifted around and drift spaces must be compressed to make room for the new rebuncher.

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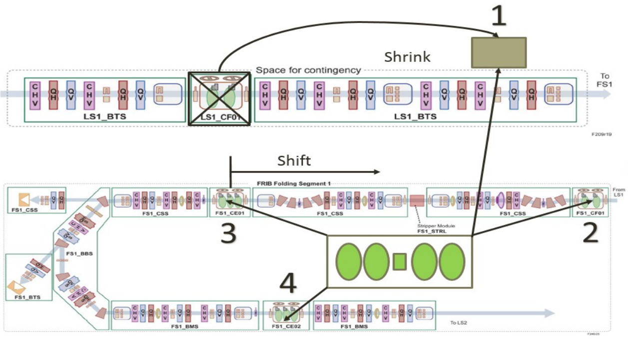

Figure 3: New lattice design with a single type of 4-cavity-QWR rebuncher (Criterion 2).

New Lattice Design Criterion 2

Another criterion is also proposed as in Fig. 3. In this criterion, we replace all rebunchers with the new 4-cavity-QWR rebunchers, relax the requirement of fixing position of all cryomodules. To be specific, we fix the center location of rebuncher 3 and 4, and allow rebuncher 1 and 2 to move. Because the new rebuncher is longer, for rebuncher 3, it'll expand in both direction. Downstream expansion can be compensated by taking away the original contingency space for an extra 161 MHz cavity. Upstream expansion will be accommodated by element shift, so the segment between rebuncher 3 to stripper, which is already quite crowded, will not shrink. We reserved a drift space for rebuncher 1 for future update, in case that the voltage of rebuncher 2 is not enough.

BEAM TUNING AND OPTIMIZATION WITH CRITERION 1

The geometry settings of lattice geometry criterion 1 are firstly generated. Then, a segment-by-segment beam tuning is performed by optimizer-based method. IMPACT [3] and TLM [4] model is used for simulation. A professional general-purpose optimizer Dakota [5] is used.

First, the longitudinal direction of LS1 is tuned. The goal is to minimize on-stripper longitudinal beam size while keeping similar on-stripper beam energy. The baseline on-stripper beam energy is 16.74 MeV/u and longitudinal on-stripper RMS beam size is 0.312°. We set the synchrotron phase of new rebunchers as -90°, and acceleration voltage scaling factor as 0.95. We assume synchrotron phases of LS1 acceleration cavities as tuning parameters. Figure 4 shows the longitudinal RMS size. Blue line is for baseline and red line is for new lattice (similar notation will be used for longitudinal direction). The on-stripper beam energy for new lattice is 17.11 MeV/u and longitudinal on-stripper RMS beam size is 0.392°, which is similar to baseline design.

Then, the transverse direction of LS1 is tuned. The goal is to minimize on-stripper transverse beam size while keeping similar beam size along LS1. The baseline on-stripper transverse beam size is 0.426 mm for horizontal and 0.461 mm

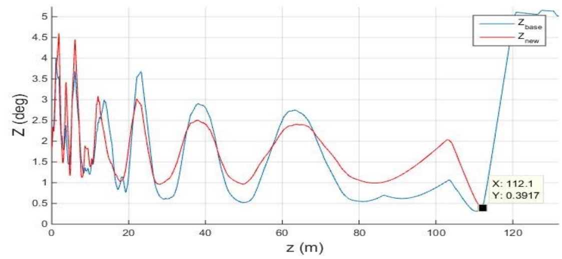

Figure 4: Longitudinal and RMS of baseline and new lattice design (Criterion 1).

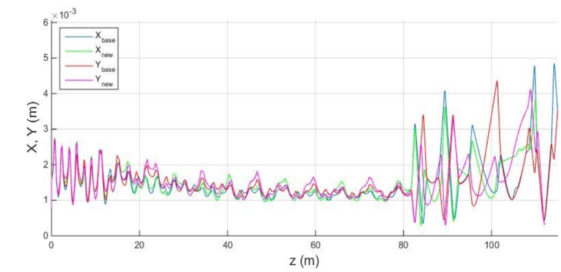

Figure 5: Transverse beam RMS size along LS1 in baseline and new rebuncher design (Criterion 1).

for vertical. Strength of solenoids keeps the same. Because quadrupoles are shifted, all quadrupoles' strength is adjusted. Figure 5 shows the transverse beam RMS size along LS1. Blue line is for baseline horizontal and red line is for baseline vertical. Green line is for new lattice horizontal and magenta line is for baseline vertical (similar notation would be used for transverse direction). The on-stripper transverse beam size for the new lattice is 0.455 mm for horizontal direction and 0.345 mm for vertical direction, which is similar to baseline design.

After optimization of lattice settings from LS1 to stripper, the next task is to tune the rebunchers and quadrupoles to transport the beam to LS2. The RMS emittance is firstly checked to insure no severe emittance growth is induced by the stripper. Simulation witnesses 20% emittance growth in longitudinal direction and no emittance growth in transverse direction. Next, both rebunchers and quadrupoles are adjusted to match beam into the 180° bender. Results show that after careful matching, longitudinal and transverse beam profiles are similar to the baseline.

BEAM TUNING AND OPTIMIZATION WITH CRITERION 2

We also created the geometry settings with new lattice design criterion 2. Then, a segment-by-segment beam tuning is performed to obtain a proper settings for the new lattice.

First, the longitudinal direction of LS1 is tuned. This time, we no longer assume optimization of synchronous phases for LS1. Two cases of rebuncher settings, one with contingency rebuncher, the other without, are studied. For the case with contingency rebuncher, we set the synchrotron phase of new rebunchers as -90°, and acceleration voltage scaling factor

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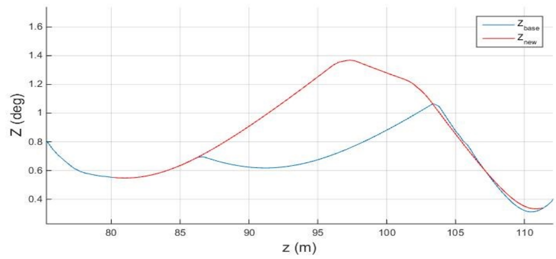
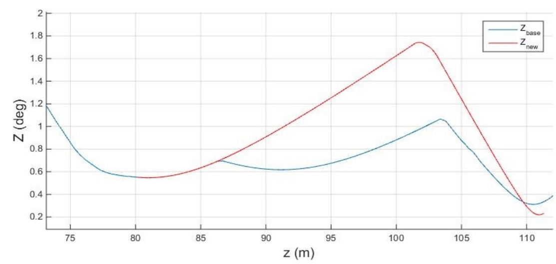


(a)



(b)

Figure 6: Longitudinal RMS size of baseline and new lattice design (Criterion 2). (a) with rebuncher 1 and (b) without rebuncher 1 for new lattice design.

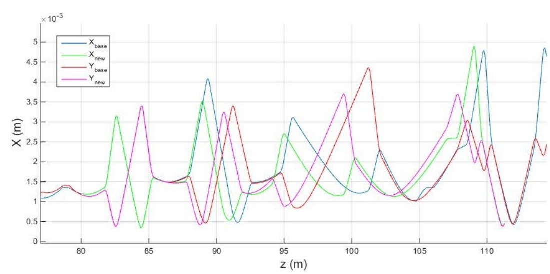


Figure 7: Transverse beam RMS size along LS1 in baseline and new rebuncher design (Criterion 2)

as 0.47. The longitudinal RMS size evolution can be seen in Fig. 6(a). The longitudinal on-stripper RMS beam size is 0.3385°, which is similar to baseline design. For the case without contingency rebuncher, we set the synchrotron phase as -90°, and acceleration voltage scaling factor as 0.94. The longitudinal RMS size evolution can be seen in Fig. 6(b). The longitudinal on-stripper RMS beam size is 0.2314°, which is even smaller than baseline design.

Then, the transverse direction of LS1 is tuned. The goal for LS1 transverse direction is also to minimize on-stripper beam size while keeping reasonably small beam size along whole LS1. We didn't change the strength of any solenoid in LS1. Because quadrupoles are shifted, the strength of all quadrupoles may be subjected to change. Figure 7 shows the transverse beam RMS size along LS1. The on-stripper transverse beam size for the new lattice is 0.432 mm for horizontal direction and 0.446 mm for vertical direction, which is similar to baseline design.

Next, we tune the rebunchers and quadrupoles to accept the beam from the stripper and match it into the folding segment. We choose the output beam of the case with contingency rebuncher. The RMS emittance is firstly checked and it has been confirmed that transverse RMS emittance of new design is similar to the baseline, while longitudinal RMS emittance of new design is even smaller than the baseline. Finally, both rebunchers and quadrupoles are adjusted to match the beam into the 180° bender. Matching results show that after careful matching, longitudinal and transverse beam profiles are nearly the same as the baseline.

CONCLUSION

Beam dynamics study was conducted to confirm the feasibility of new rebuncher design where only one type of rebuncher cryomodule with four $\beta = 0.085$ QWR cavities. Two different criteria is considered. In Criterion 1, the longitudinal centers of rebuncher cryomodule are fixed. Meanwhile, this constraint is eased in Criterion 2. The longitudinal emittance obtained for Criterion 1 is 20% larger than the baseline. On the other hand, the longitudinal emittance obtained for Criterion 2 is smaller than the baseline. This result indicates that Criterion 2 has a clear advantage in realizing a low emittance beam. Furthermore, we can increase the amplitude margin for rebuncher 2 by adding rebuncher 1 in Criterion 2. Considering that the vacuum environment around rebuncher cryomodule could be worse and rebuncher cryomodules could be the causes of single point failures, it is preferable to have an upgrade path to increase the amplitude margin. These observations lead us to conclude that Criterion 2 is a more preferable option from beam dynamics point of view.

ACKNOWLEDGMENT

The authors would like to thank Bradley Yonkers, Matt Johnson, Richard Swanson, Sergio Rodriguez for helpful discussions. The work is supported by the U.S. National Science Foundation under Grant No. PHY-11-02511, and the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661.

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