ELECTROMAGNETIC DESIGN OF A MULTI-HARMONIC BUNCHER FOR THE FRIB DRIVER LINAC*

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Abstract

The driver linac for the Facility for Rare Isotope Beams [1] (FRIB) at MSU will produce primary beams of ions at 200 MeV/u for nuclear physics research. A dc ion beam from an ECR ion source will be pre-bunched upstream of the radio frequency quadrupole linac. A multi-harmonic buncher (MHB) was designed for this purpose, using experience gained with a similar buncher for the ReA3 [2] re-accelerator linac, which is presently being commissioned at MSU. The FRIB MHB resonator operates with three frequencies (40.25 MHz, 80.5 MHz, and 120.75 MHz) to produce an approximately linear sawtooth in the voltage as a function of time. The three resonant frequencies are produced via two quarter-wave resonators with a common gridless gap: one resonator is driven at its fundamental mode at 40.25 MHz and its first higher-order mode (120.75 MHz), while the other is driven only at its fundamental mode of 80.5 MHz. The electromagnetic design of the MHB resonator will be presented, including the electrode design and tuning mechanisms.

INTRODUCTION

The scheme of using an external buncher upstream of the Radio Frequency Quadrupole (RFQ) linac [3, 4] was chosen for the FRIB linac to produce a small longitudinal emittance beam required for injection into the superconducting linac. The buncher will operate at fundamental frequency of 40.25 MHz with two higher harmonics (80.5 MHz and 120.75 MHz). The multi-harmonic buncher consists of two coaxial resonators, as shown in Figure 1, which is similar to the ReA3 buncher that was developed and tested at NSCL [5]. One resonator provides both the fundamental and the third harmonic. The other resonator provides the second harmonic with a $\lambda/4$ mode. The dual frequency resonator will operate simultaneously at the $\lambda/4$ and $3\lambda/4$ modes, similar to the one at [6]. A pair of drift tubes without grids will be used as the electrodes. Each electrode will be directly connected to the inner conductors of the two coaxial resonators and housed in a grounded vacuum chamber. Beam dynamics requires the electrodes separated by 4 mm with aperture diameters of 10 mm. Both drift tubes will have a conic shape [7] so that the fields will be confined to the gap region and the fringing fields do not negatively affect the beam dynamics.

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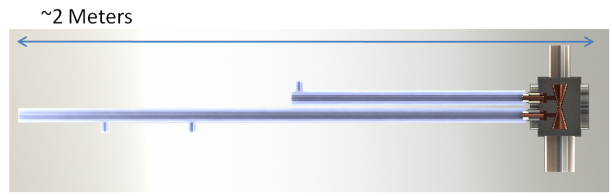

Figure 1: The current FRIB MHB design

ELECTROMAGNETIC DESIGN

Design Features

The MHB design has been optimized for use in a heavy ion accelerator operating at 40.25 MHz, 80.5 MHz, and 120.75 MHz. These frequencies result in resonator lengths of approximately 1 and 2 meters (see Fig. 1). The MHB is going to be used in the driver linac with beam currents of 400 μA. This beam current precludes the use of gridded electrodes, and open, conical electrodes have been chosen instead. Figure 3 shows a comparison between these two styles of electrodes in detail. The gridded electrodes, used for the ReA3 MHB, confine the fields to a small region, ensuring a high transit-time factor and low required power for all three modes with a large aperture. In order to maintain this high-transit time factor for all three modes, a small gap length and aperture are required at the central gap, with the third mode being the most challenging. The current electrode design has a center aperture of 10 mm which opens to a diameter of 50 mm at the opposite end.

Accelerating Field Profile

Each mode is effectively raising and lowering the voltage of one electrode. This generates electric fields in the gaps on either side of that electrode. The conical shape of the electrodes focuses the fields in the center gap on the beam axis while spreading out the fields in the outer gap. The outer gap field is spread out enough that the integrated force the beam sees is close to zero, effectively making the structure a one gap structure. In the ReA3 MHB, the electrodes are strongly coupled enough that it generates significant parasitic fields in the opposite outside gap, decreasing the field in the center gap, increasing the required power. This coupling is much weaker because of the conical electrode design, eliminating this problem almost entirely. All three of these features (strong center gap fields, broad outer gap fields, and minimal paracitic fields) are evident in Figure 2.

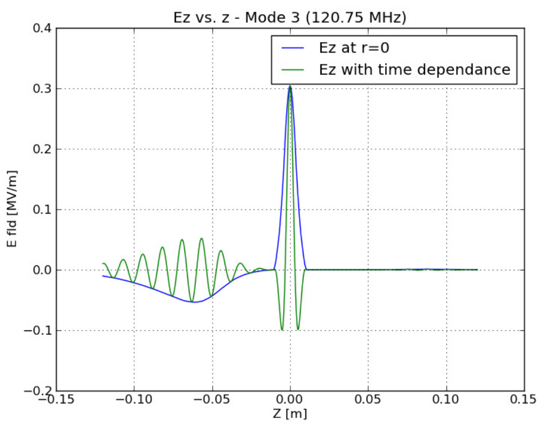

Figure 2: The accelerating electric field of the FRIB MHB third mode (120.75 MHz) with and without time variation.

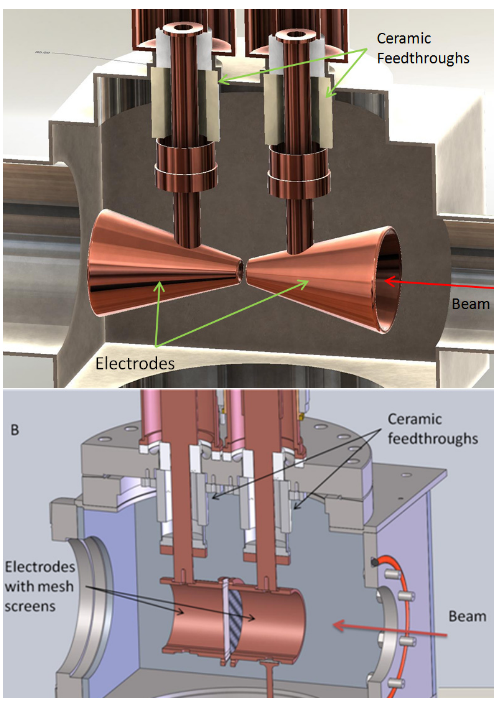

Figure 3: FRIB MHB vacuum box (top) and ReA3 MHB vacuum box (bottom)

Mode Tuning

Course tuning is done by adjusting the length of the resonators. The length of the resonators are around 1 and 2 meters, respectively. The predicted accuracy of adjusting these lengths is 1 mm, giving a predicted coarse frequency tuning resolution of 20 kHz, 80 kHz, and 60 kHz for the three modes. This puts the coarse tuning to within, at most, two bandwidths of each mode, assuming the most conservative (ideal) bandwidth. The mesh screen electrodes used in the ReA3 MHB design have the significant downside that they strongly capacitively couple the two resonators. This causes all three operational modes to be coupled strongly. This significantly complicates tuning and commissioning of the structure, resulting in much higher required power than simulated. The conical electrodes used in the FRIB MHB have a much smaller capacitance, resulting in very little coupling between the two resonators. This means that the fine tuning mechanism for the FRIB MHB can be much more simple and effective, reducing the complexity of commissioning. Using stub tuners, the initial fine tuning design shows good mode seperation (see Table 1).

Table 1: Tuning range in kHz of all three harmonics over full tuner movement (from +9 mm to -15 mm)

	Mode 1	Mode 2	Mode 3
Tuner #1	-53	0	128
Tuner #2	0	-263	-1
Tuner #3	-4	1	549

Figures of Merit

RF parameters of the buncher were simulated and optimized using the 3D field solver ANSYS-APDL [8]. The cavity figures of merit can be seen in Table 2.

Table 2: Electromagnetic Figures of Merit

	Mode 1	Mode 2	Mode 3
Frequency [MHz]	40.25	80.5	120.45
Geometry Factor [Ω]	1.87	3.74	5.63
Quality Factor	1131	1596	1963
R/Q [Ω]	292	102	7.67
Stored Energy [μJ]	13.6	10.8	4.85
Particle β	0.0057	0.0057	0.0057
Effective V_{acc} [V]	1000	500	250
Effective R_{sh} [Ω]	329924	162825	15042

CONCLUSIONS

Inital electromagnetic design of the Multi-Harmonic Buncher for the FRIB driver linac has been completed. More detailed study of tuning systems and coupling systems of the device are ongoing in preparation for production in the next few months.

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