BEAM BUNCHERS FOR LANSCE MODIFICATION PROJECT*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) accelerator complex delivers both protons and negative hydrogen ions with various beam time patterns simultaneously to multiple users. The LANSCE linac front end is still based on Cockcroft-Walton voltage generators. An upgrade of the front end to a modern, RFQ-based version – a part of the LANSCE Modernization Project (LAMP) – is now in the conceptual design stage. The LAMP will need beam bunchers both in the low-energy transport (LEBT, 100 keV) before RFQ, and in the medium-energy transport (MEBT, 3 MeV) after RFQ. We use CST modeling to develop buncher cavities for LAMP. A few RF cavity types for MEBT: re-entrant, quarter-wave, and half-wave – are considered and compared. The LEBT low frequency buncher is different: it is a two-gap structure driven by an LC-circuit and used for beam velocity bunching.

INTRODUCTION

We consider design options for beam bunchers in the LAMP LEBT and MEBT. The low frequency buncher (LFB) is used in LEBT to form special high-charge bunches for time-of-flight experiments. The LFB imposes an energy tilt on a continuous 100-keV H$^-$ beam chopped to about 25 ns, which is equivalent to 5 RF periods of the LAMP drift-tube linac (DTL) operating at RF frequency of 201.25 MHz, for beam velocity bunching at the RFQ entrance [1]. Such high-charge bunches are separated by 1.8 µs. A similar scheme with LFB is used in the LANSCE linac front end at 750 keV [2]. The LANSCE LFB is an RF device driven by an external LC circuit at 16.77 MHz (1/12 sub-harmonic of 201.25 MHz).

The MEBT transfers the beams from the RFQ, where they are bunched and accelerated to the energy of 3 MeV, to the DTL. The preliminary LAMP MEBT design [1] anticipates four bunchers at RF frequency of 201.25 MHz with the beam aperture radius $a = 1.8$ cm and effective voltage $V_{eff} = 90$ kV [1]. Clearly, minimizing the buncher cavity footprint along the beamline is highly desirable. We use these parameters to evaluate and compare three different buncher designs: re-entrant TM$_{010}$-mode resonator, quarter-wave and half-wave RF cavities – using EM modeling in CST Studio [3].

LEBT BUNCHERS

The low frequency buncher (LFB) looks like a coaxial structure, see a simplified model in Fig. 1. Its inner beam pipe has two narrow transverse gaps, with the central piece supported by an isolated radial rod (not shown). The LC circuit voltage is fed via rod to this central piece, while the end pieces and cylindrical enclosure are grounded. The

LFB enclosure length is 22 cm, the beampipe inner radius is 1.5875 cm, and the gap widths are 0.4 cm. The gap edges are rounded. The gap centers are separated by the distance $\beta\lambda/2 = 13$ cm, where $\beta = 0.0146$ for 100-keV protons or H$^-$ ions, and $\lambda = 17.877$ m is the wavelength at 16.77 MHz. The LFB electric field is calculated either in electrostatics or by an eigensolver as a quasi-static mode. The calculated field is the same; the on-axis field is plotted for the applied potential of 5 kV/gap in the inset of Fig. 1.
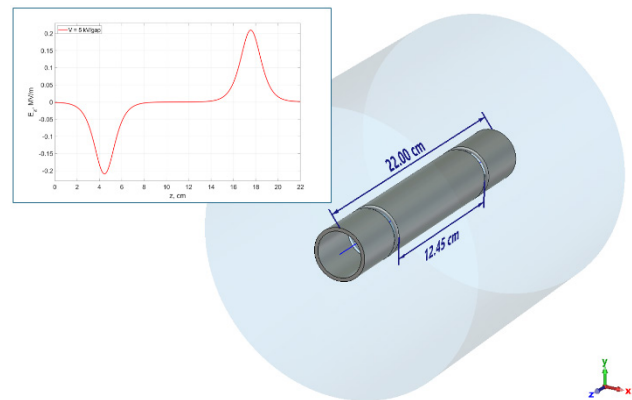

Figure 1: Vacuum volume in CST model of LFB (outer enclosure walls not shown).

More details and PIC simulations of longitudinal beam dynamics with LFB can be found in [2, 4].

MEBT BUNCHERS

We consider three design options for the 201.25-MHz beam bunchers at 3 MeV ($\beta = 0.08$) in the LAMP MEBT – reentrant single-gap, quarter-wave (QW), and half-wave (HW) resonators The cavity CST models are shown in Fig. 2, keeping their relative sizes in approximately correct ratios.
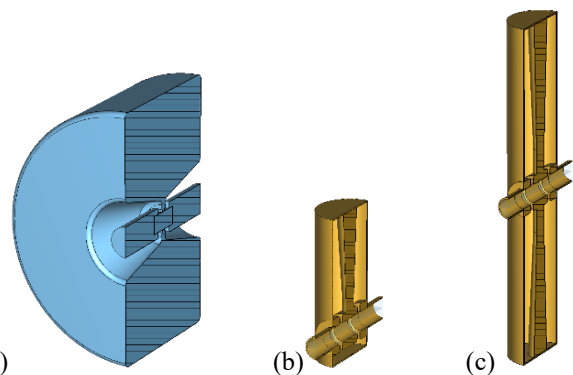

Figure 2: MEBT buncher cavities, cut view: (a) re-entrant (vacuum volume only), (b) QW, and (c) HW resonators.

For all these RF cavities we assume the beam aperture radius 1.8 cm and total effective voltage $V_{eff} = 90$ kV. For QW and HW resonators it means 45 kV/gap. The re-entrant

buncher is an axisymmetric TM_{010}-mode single-gap cavity, like that used in the LANSCE front end. For 2-gap cavities, the spacing between gaps is $\beta\lambda/2 = 5.92$ cm and the outer radius of drift tube is 3 cm. Some bunchers cavity dimensions are compared in Table 1. In tables, we color worse values by red, best by green.

Table 1: Buncher Dimensions

Dimension (cm)	Re-entr.	QW*	HW*
Along beamline	28	11.92	11.92
Transverse max.	55.2	26.5	64.0
Gap	1.2	0.8 (x2)	0.8 (x2)

* Including two cavity walls of 0.25-cm thickness.

Buncher Cavity Fields

The cavity fields were calculated with CST eigensolver. The distributions of the surface electric field on the cavity walls are shown in Fig. 3. Red color indicates high values, blue – low ones. As expected, the higher electric field values are near the gaps. The field scales are different for different cavities.

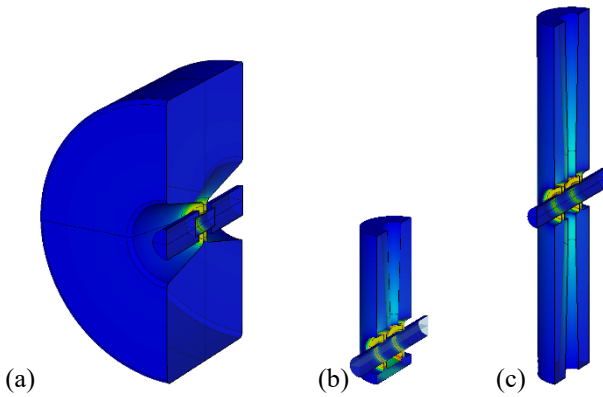(a)   (b)   (c)

Figure 3: Magnitude of surface electric field in buncher cavities: (a) re-entrant, (b) QW, and (c) HW.

The distributions of surface current magnitude on the cavity inner walls are shown in Fig. 4.

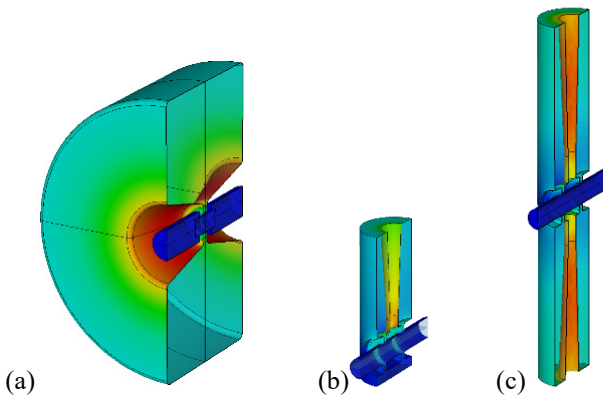(a)   (b)   (c)

Figure 4: Magnitude of surface current in buncher cavities: (a) re-entrant, (b) QW, and (c) HW.

Buncher Electromagnetic (EM) Parameters

The cavity electromagnetic parameters are summarized in Table 2 for total buncher voltage $V_{eff} = V_0 T = 90$ kV. The maximum electric field E_{max} should be compared to the Kilpatrick field $E_K = 14.7$ MV/m at 201.25 MHz.

Table 2: Electromagnetic Parameters of MEBT Bunchers

Parameter	Re-entr.	QW	HW
Quality factor Q*	24300	5800	6350
Transit-time factor T	0.78	0.84	0.84
E-field E_{max}, MV/m*	14	9.8	9.5
Wall power P, kW*	2.5	4.7	5.7
Max dP/dS, W/cm²*	1.3	33	8.8

*100% duty with wall conductivity $\sigma = 5.6 \cdot 10^7$ Sm/m.

From Tables 1-2 one can see that the re-entrant cavity has good electromagnetic parameters, but its footprint on the beamline is too long. Another limitation is its high maximum electric field E_{max}, $0.95E_K$, which means that there is no margin for increasing the buncher voltage if needed.

The quarter-wave cavity has the smallest transverse size, but the maximal surface-loss power density dP/dS is very high – there is a hot spot on its stem near drift tube. Overall, the half-wave buncher cavity has the best EM properties. The surface current is relatively evenly distributed along its stems, which should simplify stem cooling with water channels inside stems. For HW buncher, the buncher voltage can be safely increased. The HW cavity large vertical size can be handled with proper MEBT mechanical design.

One additional consideration from the beam dynamics viewpoint is related to the buncher field asymmetry near the gap, which may affect the beam quality. For the re-entrant cavity the field is axisymmetric, which is the best case. In the QW buncher there are transverse electric fields in the gaps [5] due to the cavity asymmetry, though they are small in this design with relatively large drift tube size. They can produce a dipole kick for passing particles, which can be mitigated by making an asymmetric drift tube. In HW buncher, the lowest transverse field component is a quadrupole, which is less harmful for beam quality and can be further reduced by cavity EM design optimization.

There are also important mechanical considerations for practical choice of buncher design. For example, the QW buncher is more sensitive to vibrations since its drift tube is suspended, though that effect should be studied with engineering analysis. The HW buncher is more rigid mechanically, obviously, and its cooling will be easier to implement since the heat load is more evenly distributed along the stems.

MEBT Bunchers – Conclusion

We looked at three design options – reentrant single-gap, quarter-wave (QW) and half-wave (HW) two-gap resonators – for the 201.25-MHz beam bunchers at 3 MeV ($\beta = 0.08$) in the LAMP MEBT. Main parameters are compared in Tables 1-2, assuming for all bunchers the beam aperture radius 1.8 cm and total effective voltage $V_{eff} = 90$ kV. The values in green are better, in red worse.

Both QW and HW bunchers minimize the beamline footprint; the QW buncher also has the smallest transverse size.

The effective voltage can be easily increased, if needed, in both QW and HW bunchers, while the re-entrant buncher is more efficient (higher Q and lower RF power). The higher value of the maximum surface power density in QW resonator is acceptable, since the bunchers will operate at duty of about 10%. In both QW and HW bunchers, the wall loss power is mostly deposited on the stem, so water cooling channels inside stems are needed.

While the buncher cavities can be further optimized, our results provide a good base for design comparison and selection. Based on EM parameters, mechanical considerations, and practical reasons, the half-wave cavity appears to be the best choice for the MEBT beam bunchers.

CONCLUSION

CST modeling was used to evaluate buncher cavities for LAMP. The LEBT low frequency buncher, used for velocity bunching of 100-keV beam, was scaled from a similar device operating at LANSCE at 750 keV. It is a two-gap structure driven by an LC-circuit at 16.77 MHz, which is 1/12 sub-harmonic of the DTL RF frequency 201.25 MHz.

Three types of 201.25-MHz RF buncher cavities for MEBT: re-entrant, quarter-wave, and half-wave – were modeled and compared. Based on comparison of EM and mechanical parameters, the half-wave buncher cavity looks like the best choice for the MEBT beam bunchers.

The subsequent work should include modeling beam dynamics in the LAMP bunchers using realistic 3D beam distributions. This will help accurately predict the overall beam quality in the LAMP linac.

REFERENCES

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