A SPECIALIZED MEBT DESIGN FOR THE LANSCE H^+ RFQ UPGRADE PROJECT*

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Abstract

The LANSCE accelerator operates with both H^+ and H^- ions. Presently, each species has its own 750-keV Cockcroft-Walton (CW) and an initial transport line. The two transport lines merge into a common transport after which both species are injected into the 201.25-MHz DTL. The H^+ CW will be replaced with a 4-rod RFQ that is now in final design. Because of the complication of accommodating two beam species, the MEBT for the RFQ beam is much longer than usual. The length of the MEBT for the H+ beam, and a requirement to merge it with the existing common transport, present new and unique challenges for the MEBT design. In particular, multiple ¼-wave bunchers in addition to the existing final buncher upstream of the DTL are necessary to minimize phase spread of the RFQ output beam for DTL injection. Estimates of emittance growth, matching into the DTL over a range of H^+ beam currents, and simulations through the first two DTL tanks are presented.

INTRODUCTION

The LANSCE accelerator presently has 2 CWs for H^+ and H^- operation. The plan is to replace the H^+ CW with a 750-keV 4-rod RFQ being designed by IAP (Frankfurt) and Kress GmbH (with LANL input) and fabricated by Kress. The design of the RFQ transport line is complicated by the fact that it has to merge with the H^- transport line. The RFQ specifications that are relevant to the MEBT design are: RF frequency = 201.25 MHz, beam energy = 750 keV, RFQ maximum output emittance (rms, norm.) = 0.023 π cm-mrad, and maximum input current = 35 mA. The goals for the MEBT physics design are to minimize beam loss and emittance growth while maintaining the longitudinal bunching produced by the RFQ, under the constraint that the common transport for the 2 species not be modified. A discussion of the overall LANSCE RFQ project is given in [1].

PHYSICS DESIGN

Figure 1 shows the beam envelope and phase spread for the $5\varepsilon_{rms}$ beam from a TRACE-3D [2] simulation.

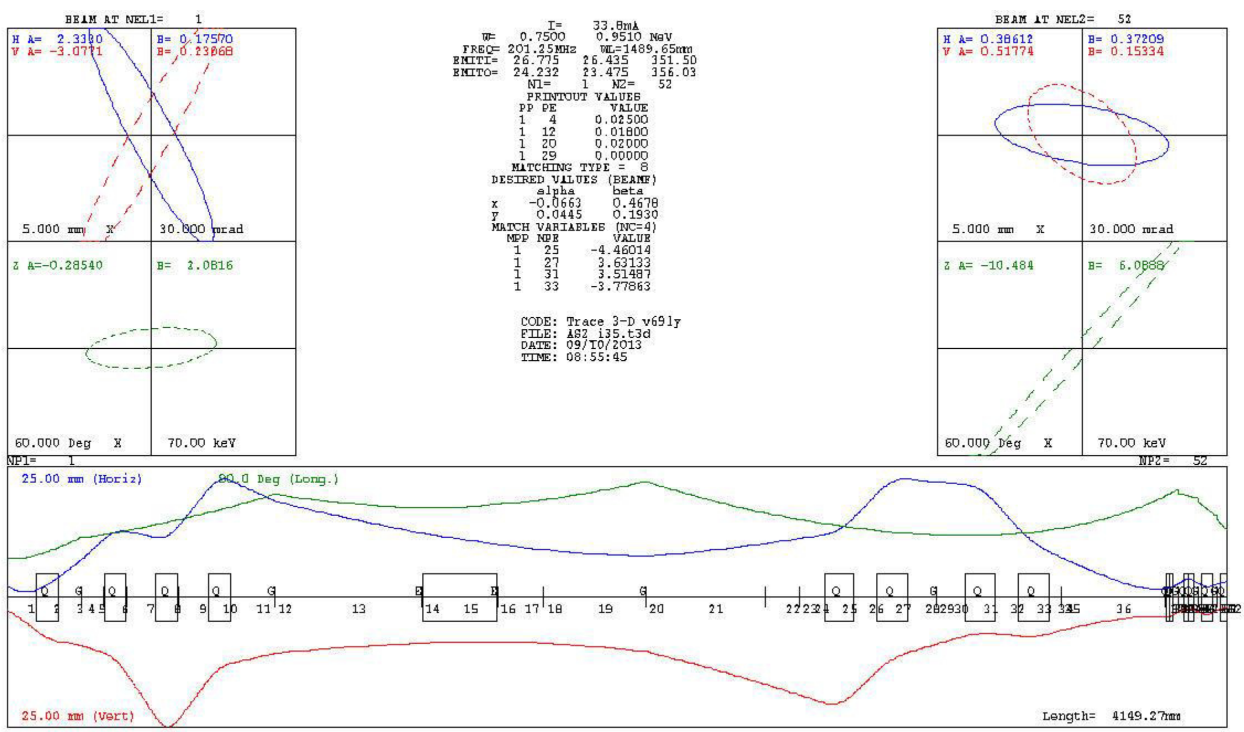

Figure 1: TRACE3D beam envelope for the $5\varepsilon_{rms}$ beam in the MEBT for ~34 mA.

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The total length of the MEBT, 4.15 m, is much longer than would normally be desired. Figure 2 shows the present layout of the 2 transport lines and their merger before injection into the DTL.

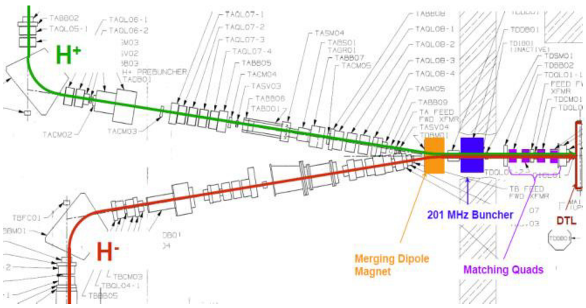

Figure 2: Present H^+/H^- CW injector layout.

The input beam for the TRACE simulation uses the output beam Twiss parameters from a PARMTEQM [3] RFQ simulation. The beam current is 33.8 mA at 750 keV. The rms normalized transverse emittance is 0.021 π cm-mrad and longitudinal rms emittance is 0.07 π MeV-deg. The RFQ beam is transported to the existing 9^o bending magnet (element 15 in Fig. 1) using 4 quads and 2 quarter-wave bunching cavities [4]. We chose these cavities because they are compact. They require about 3 kW of RF peak power for 25 kV of cavity voltage. The 9^o bending magnet is where the 2 species merge. Everything downstream of the bending magnet currently exists and will not be physically modified. Part of the design process is to have the beam small in the main buncher (MB) cavity (element 20) to manage the emittance growth due to non-linear RF fields. However, we found that if we insist on a waist in both transverse planes at the MB then there is too much beam loss due to scraping elsewhere in the MEBT. The asymmetric position of the waists allows us to have an acceptable beam size in the MB and at the same time minimizes the maximum beam size elsewhere. The first 4 quadrupole magnets are used to position the waists and the last 4 quadrupole magnets match the beam transversely into the DTL. Careful inspection of Fig. 1 shows that there is room for a 4th buncher in the middle of the last 4 quads but it has been decided not to use that space for a buncher because of our constraint to leave the existing common transport unmodified. The design as shown does not have a deflector for beam gating. In order to save on space we decided to put the deflector in the LEBT, upstream of the RFQ. The drift space just upstream of the bending magnet is not available for hardware because that is where the 2 merging beam lines come so close together that there is no available room transversely.

Longitudinal matching of the RFQ beam into the DTL is more challenging than the transverse match. The reasons are the long distant required to transport the beam and the limited allocation of beam line space for bunchers. Without space charge the longitudinal envelope equation for a drift can be integrated twice for the beam size. The result is,

$$\varphi(z) = z_o\,[(1+ z_o'\, z/z_o)^2 + (\varepsilon_z\ z / z_o^2)^2\,]^{0.5}\ 360/(\beta\lambda) \quad (1)$$

where $\varphi(z)$ is the beam size in degrees, z_o and z_o' are the initial longitudinal beam size and divergence, ε_z is 5 times the rms longitudinal emittance, β=v/c, and λ is the RF wavelength. If we consider the drift following a buncher, then z_o is the longitudinal beam size at the buncher and z_o' <0 is proportional to the buncher cavity voltage. If we differentiate (1) and solve for the position of the waist following a buncher we obtain,

$$z_{waist} = |z_o'|\, z_o / (z_o'^2 + \varepsilon_z^2/z_o^2) \quad (2)$$

Examination of (2) shows that for a given z_o and ε_z there is a maximum value for z_{waist} with z_o' being an independent parameter. This can also be seen in Figure 3 where (1) is plotted for 6 different buncher focusing strengths. The black line connects the waist positions (circles) for each case. For this example the farthest distance from the buncher where the beam is at a longitudinal focus is ~550 mm (magenta waist).

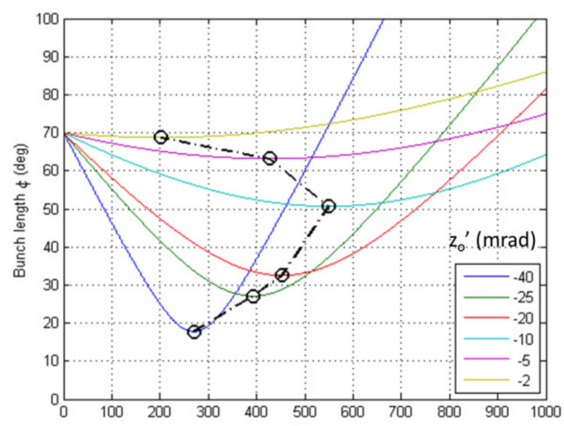

Figure 3: Bunch length downstream of a buncher cavity for 6 different focusing strengths. There is a limit to how far downstream the waist can be positioned.

The drift between the MB and the DTL entrance is larger than the farthest possible waist position downstream from the MB. Therefore, the beam cannot be focused to the proper size longitudinally at the DTL entrance using the MB and so the longitudinal match is less than ideal. However, our design gets the best possible match under the constraints and still results in a better capture by the DTL than is achieved presently with the DC beam produced by the CW.

Fig. 1 represents a point design for one particular current and emittance. We have checked that for lower currents and higher emittances we can still transversely match the beam into the DTL. However, a complication exists for dual species matching due to the common transport downstream of the 9^o bending magnet where a

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compromise must be found to match both beams using the final 4 quads. Ideally, one can set the quads nearest the DTL for matching the H^+ beam and then use H^- quads (upstream of the merge point) to match the H^- beam into the DTL.

PARTICLE SIMULATION RESULTS

After doing a preliminary design with TRACE 3D we check and optimize the design with the multi-particle beam dynamics code PARMILA [5]. The PARMILA simulations start at the entrance to the MEBT and end after the 2nd DTL tank where the beam energy is 40 MeV. Table 1 shows the results of the particle simulations for 2 different RFQ input beam currents and an input emittance of $\varepsilon_{n,rms}$ = 0.02 π-cm-mrad.

Table 1: PARMILA simulation results for 2 different beam currents. The quantities in the last row are the transmission through the RFQ, MEBT, and DTL respectively.

RFQ I input	35 mA	24 mA
RFQ I output	33.8 mA	23.5 mA
εx, εy (π-cm-mrad)	0.021, 0.021	0.022, 0.022
εz (MeV-deg)	0.070	0.064
MEBT I output	33.0 mA	23 mA
εx, εy (π cm-mrad)	0 .036, 0.029	0.029, .028
εz (MeV-deg)	0.25	0.146
DTL Tanks2- I output	26.6 mA	21.05 mA
εx, εy (π-cm-mrad)	0.079, 0.041	0.059, 0.034
εz (MeV-deg)	0.345	0.295
Vgap Bunchers (kV)	20, 15, 22	22, 13, 24
Iout / Iin : RFQ,MEBT,DTL	.966, .976, .806	.979, .979, .915

The estimated beam loss, emittance growth, and transmission shown in Table 1 meets our requirements. In particular, the capture of 91.5% by the DTL for the 24-mA case is better than the ~80% capture presently achieved during routine LANSCE operation with lower beam current (~10.5 mA).

The PARMILA phase space plots at the exit of the MEBT for the case of 33.8 mA out of the RFQ (1st column of Table 1) are shown in Figure 4. Note the large longitudinal phase spread due to the long drifts without buncher cavities.

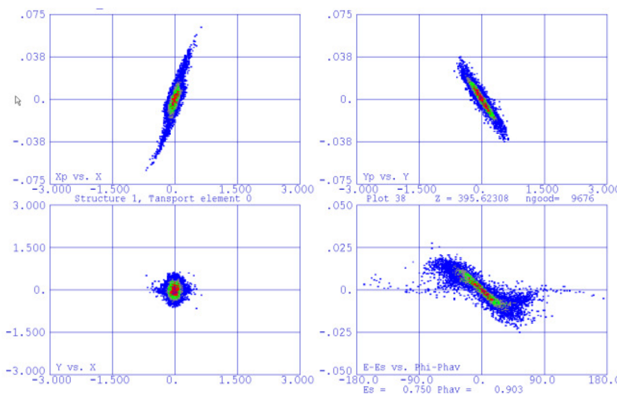

Figure 4: Beam phase space and x-y plots at the end of the MEBT for the case of 33.8 mA beam out of the RFQ.

SUMMARY

Design of a MEBT for the LANSCE H^+ RFQ project has been presented. Complications of the MEBT design because of the need to transport 2 species to the DTL has been discussed and addressed. A design using TRACE3D has been verified with particle simulations. The simulations predict good capture and transmission through the first 2 tanks of the DTL up to 40 MeV.

REFERENCES

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