BEAM DYNAMICS OF THE PEFP LINAC*

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Abstract

The PEFP Linac consists of a 50 keV ion source, LEBT, 3 MeV RFQ, 20 MeV DTL called DTL1, MEBT, and 100 MeV DTL called DTL2. The MEBT includes two small DTL tanks, which match the 20 MeV proton beams into the DTL2, and a bending magnet, which extracts the 20 MeV proton beams to the experimental hall. We will present the full beam dynamics study from the entrance of the DTL1 to the end of DTL2 with the initial beam parameters obtained from a simulation study of the RFQ. Our study focuses on the longitudinal beam matching in order to compensate the missing RF effect between the two DTL tanks as well as the full beam matching between DTL1 and DTL2.

PEFP PROTON LINAC

The Proton Engineering Frontier Project (PEFP) is developing a proton linac which accelerate 20 mA proton beams up to 100 MeV. The accelerator consists of an ion souce, a low energy beam transport (LEBT), a 3 MeV RFQ, 100 MeV DTL. The DTL structure divides into two parts. One is 20 MeV linac which designed to operate with 24% beam duty. The other is another DTL for 20 ~ 100 MeV with 8% beam duty[1]. There is a medium energy beam transport (MEBT) between two DTL structures for different beam duties. The main purposes of the MEBT are extracting 20 MeV proton beams to the user group and matching the beams into the following DTL.

MATCHING FOR RFQ

First of all, we have studied the beam matching from a low energy beam transport (LEBT) into the RFQ. The parameters of the matched input beam are obtained by simple routine using MATHMATICA (Table 1). In the calculation, we assumed that the input beam emittances are independent of input currents: $\varepsilon_{x,y} = 0.2\ \pi$ mm-mrad in the normalized rms unit. Figure 1 shows the transmission rates in the RFQ depending onbeam currents. The PARMTEQM[2] code is used for beam simulation.

Table 1. Twiss parameters of matched input beams into the 3 MeV RFQ depending on the peak beam current.

Current (mA)	α	β(cm/rad)
0.1	0.77	4.09
1	0.77	4.09
10	0.80	4.23
20	1.00	5.20
40	1.09	5.56

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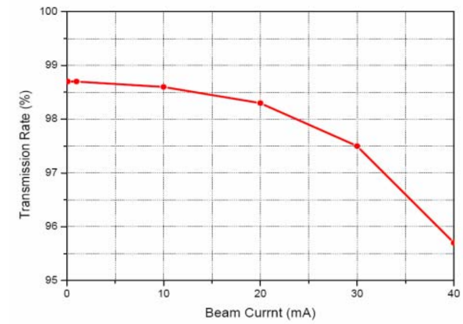
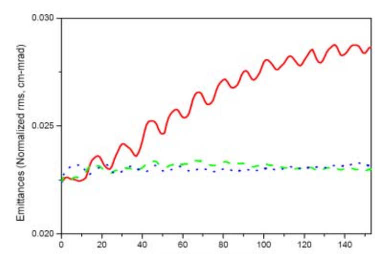


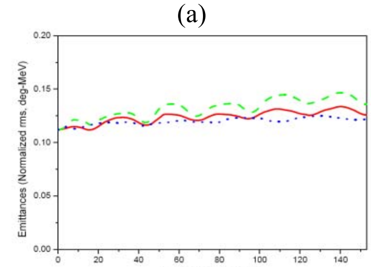
Figure 1. Transmission rates of the RFQ depending on beam currents.

MATCHING BETWEEN RFQ AND DTL1

We studied three different schemes of the beam matching between the RFQ and DTL1. The first case is that there is no matching tools in the drift space. The second is using one quadrupole magnet for easy beam control in the transverse directions. In these cases, the transverse beam matching is achieved by initial four quadrupole magnets in the first tank of the DTL1. The third one is using the four quadrupole magnets and two buncher cavities to match the beams in both the transverse and longitudinal directions. Figure 2 shows the emittance behaviors in the three cases. Since there is no strict constraint on the longitudinal beam property, we choose the second matching scheme for the full beam dynamics simulation from DTL1 to DTL2.



(a)



(b)

Figure 2. Transverse (a) and Longitudinal (b) emittances in DTL1: real (red), green (dashed), blue (dotted) lines for first, second, and third cases, respectively.

MEBT: MATCHING BETWEEN DTL1 AND DTL2

The PEFP MEBT[3] consists of 8 quadrupole magnets and 2 buncher cavities. The initial 4 magnets are controlling the beam size in the drift space where a 90-degree bending magnet is located for the beam extraction. The following quadrupoles are matching 20 MeV proton beams into the DTL2. The buncher cavities are used for the longitudinal matching. They are realized by 2 DTL tanks with 3 cells. Figure 3 and Table 2 represent the beam matching process using TRACE3D[4] and resulting parameters, respectively. The TRACE3D simulation of the proton beam from MEBT to DTL2 after matching is given in Figure 4.

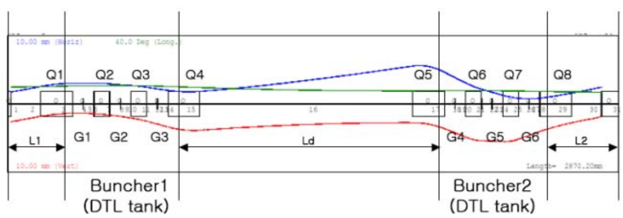


Figure 3. TRACE3D matching between DTL1 and DTL2.

Table 2. Parameters in Figure3 for beam matching between DTL1 and DTL2.

parameters	value	parameters	value
Q1	1 kG/cm * 15 cm	G1 ~ G3	304 kV
Q2 ~ Q3	1 kG/cm * 7.5 cm	G4 ~ G6	196 kV
Q4	-1.38 kG/cm * 7.5cm	Ld	75 cm
Q5	1.70 kG/cm * 15 cm	L1	16 cm
Q6	-1.85 kG/cm * 7.5 cm	L2	14 cm
Q7	-1.52 kG/cm * 7.5 cm		
Q8	-2.23 kG/cm * 15 cm		

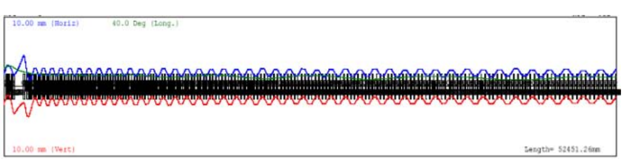


Figure 4. Beam simulation in the MEBT and DTL2: blue line in upper half plane, red line in lower half plane, green line between blue and green lines for horizontal (cm), vertical (cm), and longitudinal (degrees) beam sizes.

INTERTANK MATCHING IN DTL2

In the PARMILA[5] simulation in DTL2, we found that there is small oscillation of the longitudinal emittance in the high energy part (Figure 5). It can be modified by using the inter-tank matching[6] which compensates the missing RF effects in the gap between DTL tanks. We changed the synchronous phases in 3 cells located in the high energy end of a tank (-30-0.5 ϕ_1, -30-1.5 ϕ_1, -30-2.5 ϕ_1) and in the low energy end of the following tank(-30-2.5 ϕ_2, -30-1.5 ϕ_2, -30-0.5 ϕ_2). In the inter-tank matching study, we assumed the complete matching using two buncher cavities and four quadrupole magnets between the RFQ and DTL1 in order to reduce the longitudinal mismatch effects between RFQ and DTL1. The resulting phase values for inter-tank matching is given in Table 3. Figure 6 shows the emttance behavior after phase change for inter-tank matching. The emittance oscillation reduces significantly.

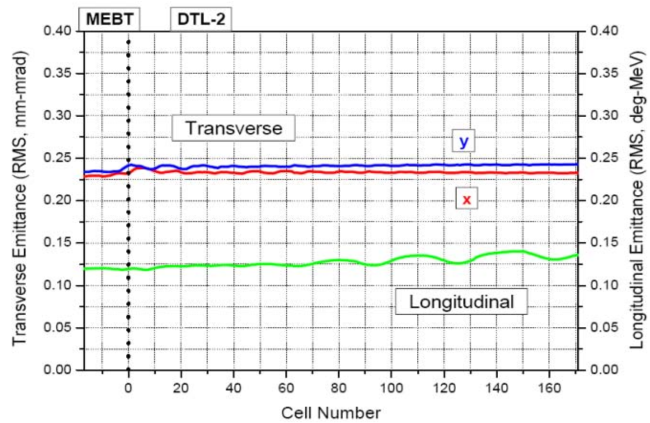


Figure 5. Transverse and longitudinal emittances without inter-tank matching.

Table 3. phase change for inter-tank matching.

tank	ϕ_1(degrees)	ϕ_2(degrees)
1 - 2	4.00	2.30
2 – 3	5.48	2.00
3 – 4	3.60	1.60
4 - 5	5.17	2.10
5 – 6	4.00	5.45
6 - 7	5.08	2.10

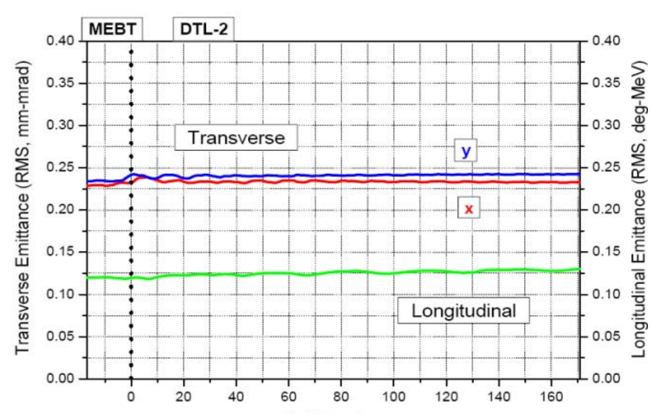


Figure 6. Transverse and longitudinal emittances with inter-tank matching.

BEAM DYNAMICS FROM DTL1 TO DTL2

We used PARMILA code for the beam simulation in the PEFP linac from the DTL1 (3MeV ~ 20 MeV) to DTL2 (20 MeV ~ 100 MeV) through MEBT. The simulated output beam of the RFQ is used for the DTL1 input beam. It is obtained by the PARMTEQM code. The matching scheme between the RFQ and DTL1 is the second case which adds a quadrupole magnet between two accelerators. The matching between DTL1 and DTL2 is achieved by the MEBT.

Figure 7 shows the configuration plot of the beam dynamics result. The upper and middle plots represent the proton beams in x-axis and y-axis, respectively. The particle behavior in $\Delta\phi$ space is given in the lowest plot. Figure 8 and Figure 9 represent the 3 MeV input beam of the DTL1 and the 100 MeV output beam, respectively. Each plot includes the particle distributions in x-x', y-y', x-y, and $\Delta\phi$-ΔE spaces. The rms and emittance beam sizes are given in Figure 10. Figure 11 shows the transverse and longitudinal emttances in the PEFP Linac.

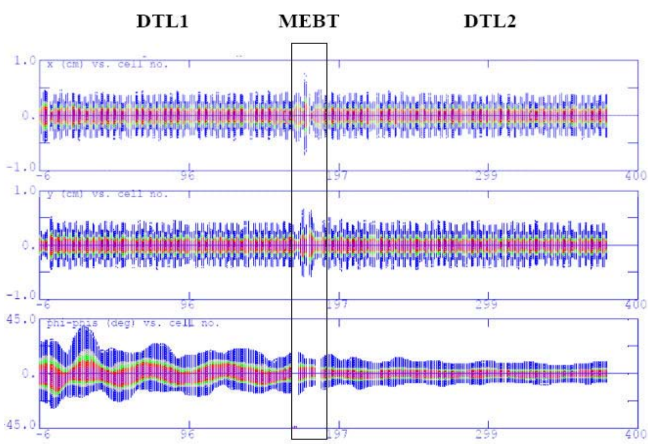


Figure 7. Configuration plot of the 20 mA proton beams from DTL1 to DTL2 through MEBT.

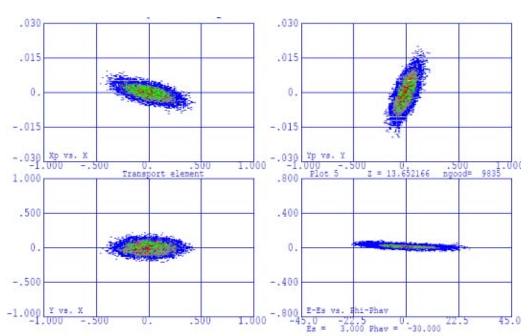


Figure 8. DTL1 input beam : 3 MeV.

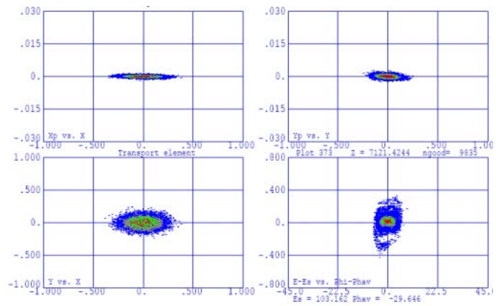


Figure 9. DTL2 output beam : 100 MeV.

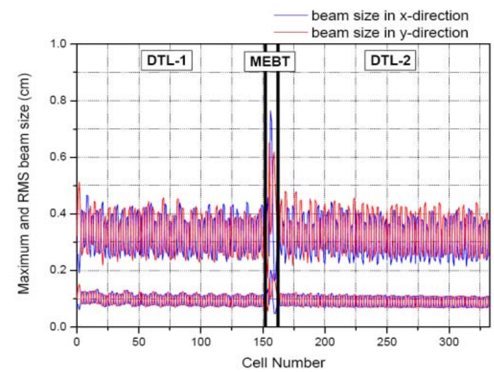


Figure 10. rms and maximum beam sizes.

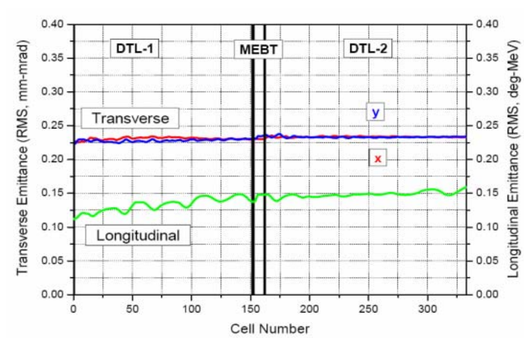


Figure 11. Transverse and longitudinal emittances.

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