BEAM DYNAMICS DESIGN OF THE PEFP 100 MEV LINAC*

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Abstract

The Proton Engineering Frontier Project (PEFP) is constructing a 100 MeV proton linac in order to provide 20 MeV and 100 MeV proton beams. The linac consists of a 50 keV proton injector including an ion source and a low energy beam transport (LEBT), a 3 MeV radio-frequency quadrupole (RFQ), a 20 MeV drift tube linac (DTL), a medium energy beam transport (MEBT), and the higher energy part (20 MeV ~ 100 MeV) of the 100 MeV DTL. The MEBT is located after the 20 MeV DTL to extract 20 MeV proton beams. The construction of the 20 MeV part of the linac was completed and is now under beam test. The higher energy part of the PEFP linac was designed to operate with 8% beam duty. This brief report discusses the design of the higher energy part of the PEFP 100MeV linac as well as the MEBT.

BEAM DYNAMICS DESIGN OF DTL2

One of the main characteristics of PEFP Linac is supplying 20 MeV proton beams for the low energy beam utilization. A 90 degrees bending magnet which is located after the 20 MeV accelerator for the beam extraction makes a serious potential problem in beam matching at the entrance of the higher energy part (20 MeV ~ 100 MeV) called DTL2. In order to solve the matching problem, we will install a MEBT system which consists of two small DTL tanks. Each tank includes 3 cells and 4 quadrupole magnets.

The low energy part (3 MeV ~ 20 MeV), called DTL1, of DTL structures was designed for 24% beam duty. However PEFP decided to reduce the beam duty to 8% for DTL2 and we redesigned the higher energy part of the linac for the more efficient acceleration under the 8% beam duty. Table 1 compares the design specifications of PEFP DTL1 and DTL2.

First of all we decided the dimensions of the DTL2 tanks and drift tubes (DTs) by studying how the effective shunt impedance per unit length (ZTT) depends on the geometry. The sensitive geometrical parameters are the tank diameter, face angle, DT diameter and bore radius. We additionally consider the installation of the quadupole magnet into the drift tubes when determining the DT diameter and face angles. Figure 1 shows the resulting ZTT as a function of energy. It also includes the shunt impedance of the DTL1 for completeness. The geometric parameters of DTL2 tanks are summarized in Table 2. We used the PARMILA code[1] in order to determine the tank length which is less than 7 m. Each tank is divided into three sections and driven by one1.3 MW klystron. Tabel 3 shows the cell numbers, lengths, output energies and required RF powers of PEFP DTL2 tanks.

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Table 1. Summary of PEFP DTL1 and DTL2.

Parameters	DTL1	DTL2
Resonant Frequency	350 MHz	
RF operation	CW	Pulse
Beam operation	Pulse	Pulse
Max. Peak Current	20 mA	
Pulse Width	2 ms	1.33 ms
Repetition Rate	120 Hz	60 Hz
Max. Beam Duty	24%	8%
Max. Average Current	4.8 mA	1.6 mA

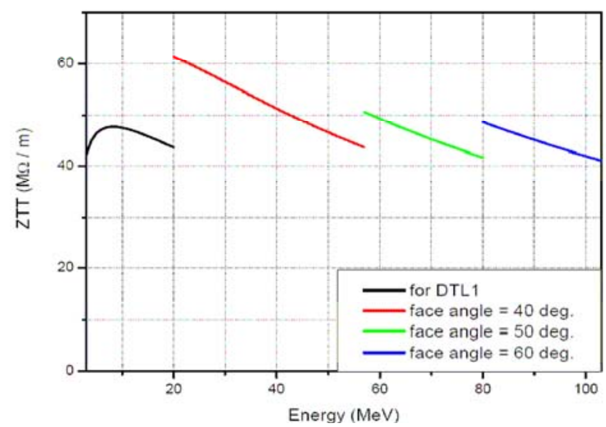


Figure 1. Effective shunt impedance per unit length depending on energy.

Table 2. Summary of PEFP DTL2 parameters.

Parameters	Values
Tank Diameter	540 mm*
DT Diameter	135 mm
Bore Radius	10 mm
Face Angle	40, 50 , 60 degrees**
Stem Diameter	40 mm
Post-coupler Diameter	26 mm
Corner Radius	5 mm
Inner Nose Radius	2 mm
Outer Nose Radius	2 mm
Flat Length	3 mm
Lattice	FFDD
Integrated Field	1.75 T

* The value will be modified after including the effects of slug tuners, stems and post-couplers on the frequency.
** 40 degrees for initial 3 tanks, 50 degrees for the following 2 tanks, and 60 degrees for the remaining 2 tanks.

Table 3. PEFP DTL2 tanks. The RF powers are given by the PARMILA calculation.

tank	Cell number	Length (m)	Energy (MeV)	Power (kW)
1	34	6.738	33.06	983
2	28	6.707	45.34	966
3	25	6.792	57.11	970
4	23	6.877	69.10	961
5	21	6.777	80.40	944
6	20	6.874	91.98	928
7	19	6.893	103.16	929

BEAM DYNAMICS DESIGN OF PEFP MEBT

The PEFP MEBT[2] 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 next accelerating structure. The buncher cavities are for the longitudinal matching. The system can be realized as 2 small DTL tanks with 3 cells.

Table 4 shows the emittances and the twiss parameters of the matched input beam for the redesigned PEFP DTL2 tank. We used the TRACE-3D code[3] for the beam matching. Figure 2 shows the matching process. Table 5 summarizes the values of the matching parameters which are given in Figure 2. Because three accelerating gaps represent a DTL tank, their effective potentials must have same value. Figure 3(a) and 3(b) represent the phase space plots of the ideal input beam and MEBT result, respectively. In this calculation we used the simulated output beam obtained by PARMILA code. Figure 4 show the TRACE-3D beam dynamics from PEFP MEBT to DTL2. Table 6 shows the geometrical dimensions of the small DTL tanks.

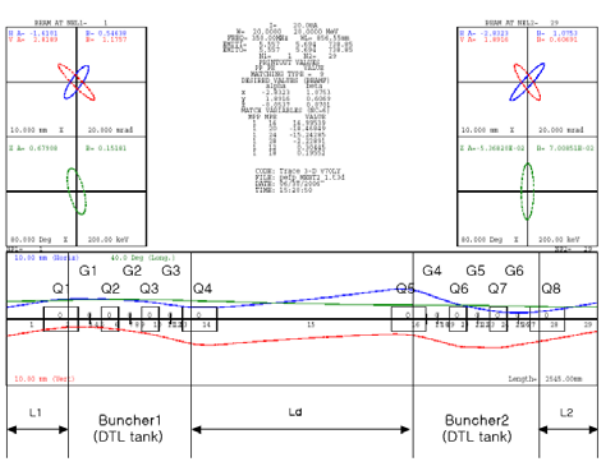


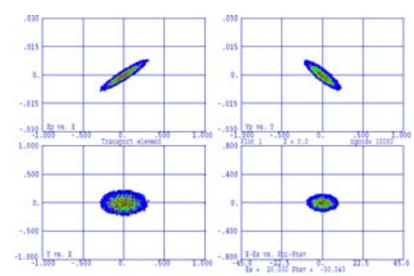
Figure 2. TRACE3D matching between DTL1 output beam and DTL2 input beam using MEBT.

Table 4. The matched input beam properties of PEFP DTL2 tanks in the normalized rms units.

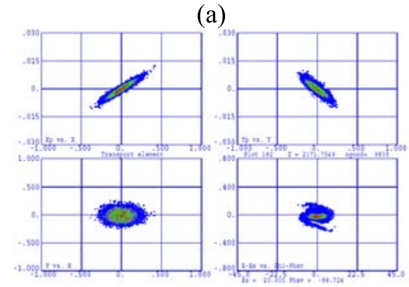
	emittance	α	β
x	0.23 π mm-mrad	-2.83	0.11 mm / mrad
y	0.24 π mm-mrad	1.89	0.06 mm / mrad
z	0.15 π deg-keV	-0.05	70.1 deg / MeV

Table 5. Matching parameters of PEFP MEBT.

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



(a)



(b)

Figure 3. Matched input beam of PEFP DTL2.

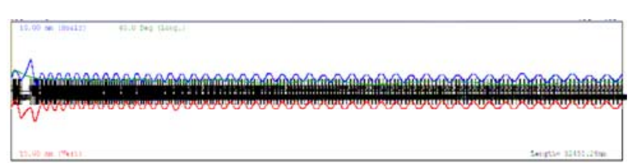


Figure 4. Beam simulation in the MEBT and DTL2: blue line in upper half plane, red line in lower half plane, green line between blue and green lines for horizontal (cm), vertical (cm), and longitudinal (degrees) beam sizes.

Table 6. Tank geometry of PEFP MEBT.

Parameter	Value
Synchronous Phase	-90 degrees
Cell length	174.0 mm
Gap length	35.5 mm
Tank length	522.1 mm
Power for tank1	33 kW
Power for tank2	14 kW

BEAM DYNAMICS IN MEBT AND DTL2

We used PARMILA code for the beam simulation in the PEFP linac in MEBT and DTL2. The simulated output beam of the DTL1 is used for the MEBT input beam. It is obtained by the PARMILA simulation. The 20 MeV beam properties depend on the matching scheme between RFQ and DTL1. In this design, the beam matching between the RFQ and DTL1 was achieved by adding a quadrupole magnet between two accelerators. Figure 5 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 6 shows the 100 MeV output beam. 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 7. Figure 8 shows the transverse and longitudinal emttances in the PEFP Linac.

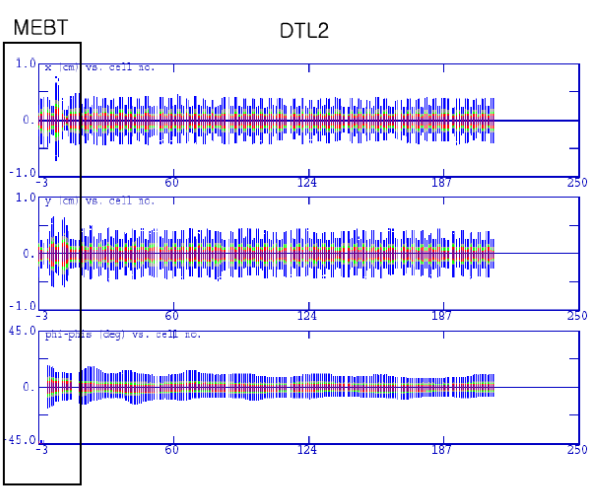


Figure 5. Configuration plot of the 20 mA proton beams in PEFP MEBT and DTL2.

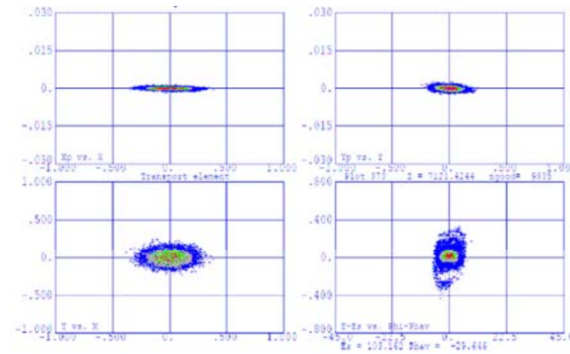


Figure 6. DTL2 output beam : 100 MeV.

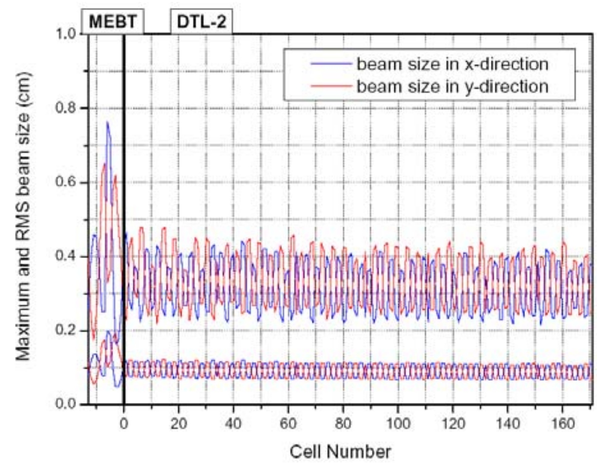


Figure 7. rms and maximum beam sizes.

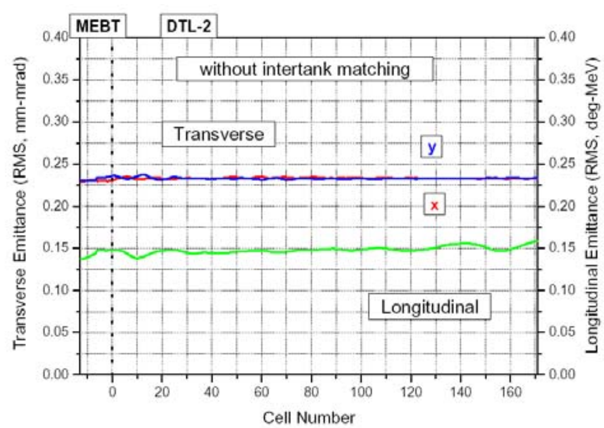


Figure 8. Transverse and longitudinal emittances.

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[2] J.H. Jang, Y.S. Cho, H.J. Kwon, Y.H. Kim, "Design of the PEFP MEBT", PAC 2005, Knoxville, May 2005.

[3] K. Crandall and D. Rusthoi, "TRACE 3-D Documentation", LA-UR-97-886.