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, 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 in order to extract 20 MeV proton beams as well as to match the proton beam into the higher energy part of the linac. 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 and is now under construction. This brief report discusses the design of the PEFP 100MeV linac as well as the MEBT.

PEFP PROTON LINAC

The Proton Engineering Frontier Project (PEFP)[1] 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, a 100 MeV DTL. The DTL structure divides into two parts. One is a DTL (called DTL1) whose energy range is from 3 MeV to 20 MeV. It is designed to operate with 24% beam duty. The other is another DTL (called DTL2) for 20 ~ 100 MeV with 8% beam duty[2]. There is a MEBT between two DTL structures which will be operated with different beam duties. The main purposes of the MEBT are extracting 20 MeV proton beams to the user group and matching proton beams into the DTL2. This work summarizes the beam dynamics design of the PEFP 100 MeV linac.

PEFP 3 MEV RFQ

PEFP RFQ is four vane type with 4 sections [3]. They consists of a radial matching section, a shaper, a gentle buncher, an accelerator, and a fringe field region. The whole structure is separated into two segments which are resonantly coupled for the field stabilization [4]. The RF power is fed into the cavity through two iris couplers in the third section. The main design parameters are given in Table 1 and Figure 1. The vane voltage is constant along the RFQ structure. The aperture radius is slowly increasing after gentle buncher which helps the current independent beam matching into the following DTL.

The beam dynamics is calculated by PARMTEQM code[5]. The result is given in Figure 2 for the configuration plots of the beam in the RFQ structure. The transmission rate has been improved to be 98.3% by applying the matched beam for the RFQ.

Table 1: The PEFP RFQ Parameters

Frequency	350 MHz
Input / Output Energy	50 keV / 3 MeV
Transmission Rate	98.3 %
Total Length	326.64 cm
Peak Surface Field	1.8 Kilpatrick
Output emittance (normalized rms)	0.22 π mm-mrad 0.11 π deg-MeV
Type	4-vane type resonant coupling

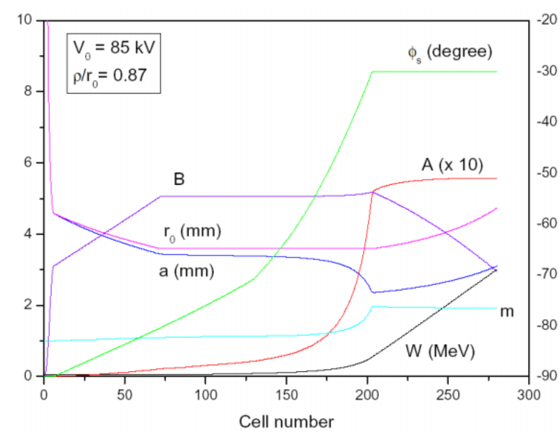

Figure 1: PEFP 3MeV RFQ design parameters: synchronous phase (f_s), accelerating efficiency (A), focusing efficiency (B), mid-cell aperture radius (r_0), minimum radius curvature (a), modulation (m), and particle energy (W).

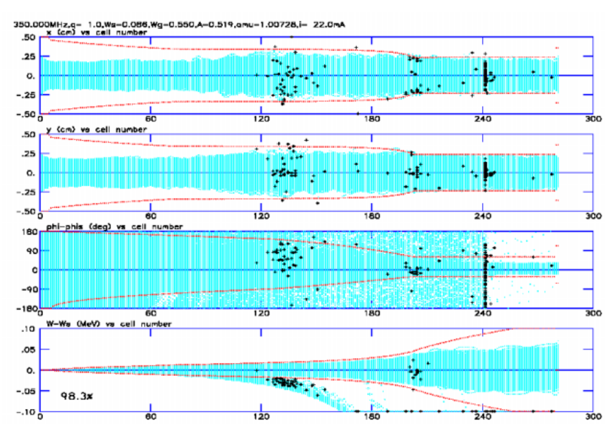

Figure 2: Configuration plot of the beam in PEFP 3MeV RFQ: PARMTEQM with 10,000 particles.

*This work is supported by the 21C frontier R&D program in the ministry of science and technology of the Korean government.
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PEFP DTL

The low energy part (3 MeV ~ 20 MeV) of PEFP DTL structures was designed for 24% beam duty. However PEFP decided to reduce the beam duty to 8% for the high energy part (20 MeV ~ 100 MeV) and the two different DTL structures are designed independently. Table 2 compares the design specifications of PEFP DTL1 and DTL2. The main change is the pulse operation of RF for DTL2 with lower beam duty.

First of all we decided the dimensions of the DTL 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. Figure 3 shows the resulting ZTT as a function of energy. The geometric parameters of PEFP DTL tanks are summarized in Table 3. For the efficient acceleration in DTL2, we increase the face angles of the drift tubes in DTL2 tanks. Since the space for installing quadrupole magnets is limited in the initial part of DTL1, we used the pool type magnets for DTL1. The hollow conductors are used for the quadrupole magnets in DTL2. The lattice is FFDD where the integrated field of the quadrupole magnets is 1.75 T. Tabel 4 and Table 5 show the cell numbers, lengths, output energies and required RF powers of PEFP DTL1 and DTL2 tanks, respectively. We used one 1MW klystron for driving 4 tanks of PEFP DTL1. The klystron operates in CW mode. Each tank of PEFP DTL2 is driven by one 1.3 MW pulsed klystron.

We use the PARMILA code [6] to simulate the proton beam going through the DTL structure. We used the simulated output beam of PEFP RFQ as the input beam of PEFP DTL. Figure 4 and Figure 5 show the input and output beams in phase spaces of PEFP DTL, respectively. Since there is a MEBT between DTL1 and DTL2, we need some matching process for the beam dynamics study in PEFP DTL2. Figure 5 is obtained by simulating proton beams in DTL2 after matching in the MEBT which is explained in the following section.

Table 2: 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

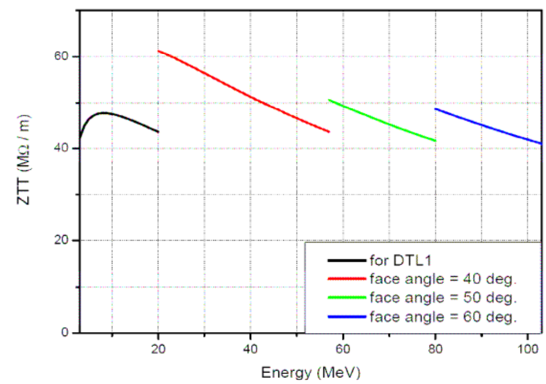

Figure 3: Effective shunt impedance per unit length depending on energy in PEFP DTL.

Table 3: Summary of PEFP DTL Parameters

Parameters	DTL1	DTL2
Tank Diameter (mm)	544.4	540*
DT Diameter (mm)	130	135
Bore Radius (mm)	7	10
Face Angle (degree)	10	40,50,60**
Stem Diameter (mm)	26	40
Post-coupler Diameter (mm)	26	
Lattice	FFDD	
Integrated Field (T)	1.75	

* 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 4: PEFP DTL1 tanks. The RF powers are given by the PARMILA calculation.

tank	Cell number	Length (m)	Energy (MeV)	Power (kW)
1	51	4.431	7.18	225
2	39	4.649	11.50	225
3	33	4.755	15.80	224
4	29	4.776	20.00	221

Table 5: 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

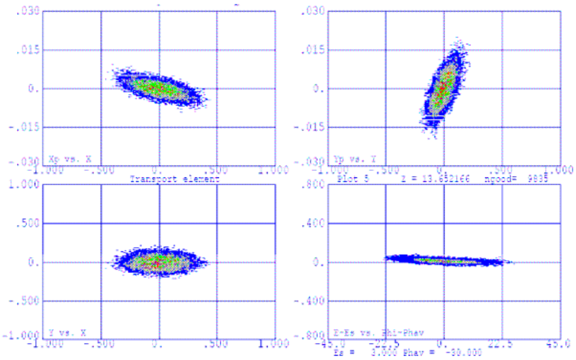

Figure 4: DTL1 input beam : 3 MeV.

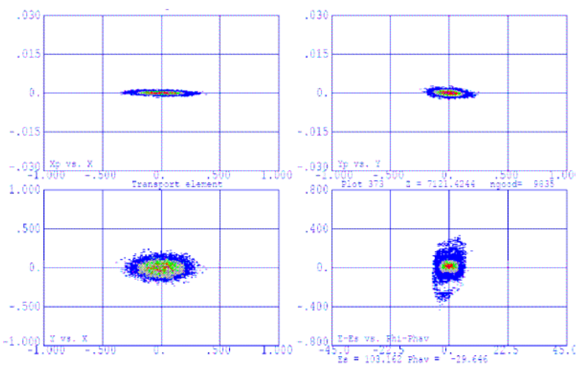

Figure 5: DTL2 output beam : 103 MeV.

PEFP MEBT

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 DTL2. In order to solve the matching problem, we will install a MEBT system which consists of two small DTL tanks[7]. Each tank consists of 3 cells and includes 4 quadrupole magnets. The 4 magnets in the first tank are controlling the beam size in the drift space where the bending magnet will be located for the beam extraction. The four quadrupoles in the second tank are matching 20 MeV proton beams into the DTL2. The buncher cavities are used for the longitudinal matching. Figure 6 and Table 6 represent the beam matching process using TRACE3D[8] and resulting parameters, respectively. The PARMILA simulation of the proton beam from DTL1 to DTL2 through MEBT is given in Figure 7.

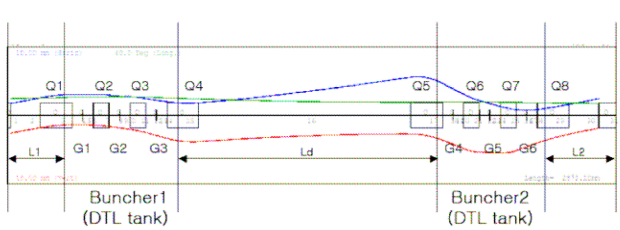

Figure 6: TRACE3D matching between DTL1 and DTL2.

Table 6: 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	97.59 cm
Q5	1.70 kG/cm * 15 cm	L1	27.25 cm
Q6	-1.85 kG/cm * 7.5 cm	L2	25.25 cm
Q7	-1.52 kG/cm * 7.5 cm		
Q8	-2.23 kG/cm * 15 cm		

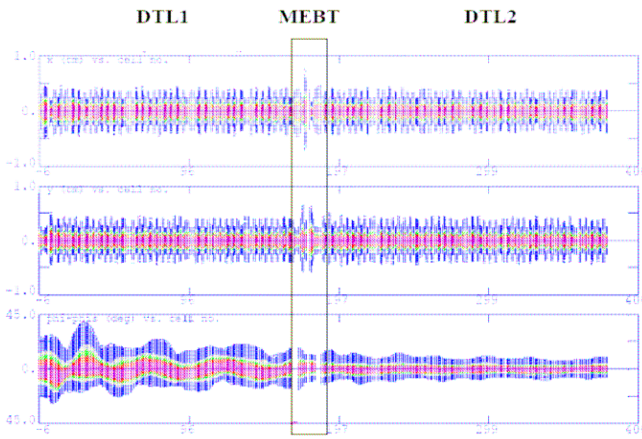

Figure 7: Configuration plot of the 20 mA proton beams from DTL1 to DTL2 through MEBT.

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