DESIGN OF THE PEFP MEBT*

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Abstract

A MEBT system of the Proton Engineering Frontier Project (PEFP) has to be installed after the 20 MeV DTL where a beam extraction system will be positioned to supply 20 MeV proton beams to the user group. This implies a large drift space which can be a serious potential problem in the longitudinal beam matching between the DTL and the following accelerating structure. The MEBT consists of 8 quadrupole magnets and 2 buncher cavities. The initial 4 quadrupoles is controlling the beam size in the bending magnet for beam extraction. The transverse beam matching is achieved by the following 4 magnets. The buncher cavities are for the longitudinal beam matching.

INTRODUCTION

The low energy part of the proton engineering frontier project (PEFP) [1] consists of a ion source, a low energy beam transport (LEBT), a radio frequency quadrupole (RFQ), and four drift tube linac (DTL) tanks.

The 50 keV proton beams produced by the duoplasmtorn [2] are matched into the RFQ through the LEBT of two solenoids. The RFQ has been designed to accelerate proton beams from 50 keV to 3 MeV with transmission rate of 98.3 % [3,4]. The accelerating structure is separated into two segments that are resonantly coupled for field stabilization [5]. Four rods are installed at the end plates and the coupling plate to reduce the dipole perturbation.

The PEFP DTL consists of 4 tanks which accelerates 20 mA proton beams from 3 MeV to 20 MeV [6-9]. The maximum cell number is 51 of the first tank. The length of each tank is less than 5 m. The RF power of the DTL tanks is fed by an 1 MW klystron through iris-type couplers. The lattice structure is FFDD with the magnetic field gradient of 5 kG/cm and the effective field length of 3.5 cm. The initial four quadrupole magnets in the first tank have different field gradient values in order to match 3 MeV proton beams from the RFQ into the DTL in the transverse direction. For the longitudinal matching, the gap between the two accelerating structures has adjusted as small as possible after designing the zero current phase advance of the RFQ to be equal to the initial part of the DTL.

The following linac is also DTL (called DTL2) which accelerates proton beams from 20 MeV to 60 MeV. A main modification in the design of the new DTL tank is increasing the face angle from 10 degrees of the previous tank to 40 degrees for the efficient acceleration. The method to supply RF power into four DTL tanks suing an 1 MW klystron is same as the previous one. The focusing lattice also FFDD with the integrated field gradient of 1.75 T.

One of main purposes of the PEFP linac is supplying 20 MeV proton beams to the user group. Hence a beam extraction system is an essential component located between the last tank of the DTL and the following accelerating structure.

The PEFP MEBT has two important roles. One is matching 20 MeV proton beams from the end of the 20MeV DTL into the following accelerator in the longitudinal and transverse directions. The other is extracting 20 MeV beams from the main path of the beam in the PEFP linac into the 20 MeV beam line.

This work contains the basic idea and the design study of the PEFP MEBT system.

PEFP MEBT

The PEFP MEBT consists of 8 quadrupole magnets and 2 buncher cavities. The initial 4 magnets are controlling the beam size in the 45-degree bending magnet 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. We have also studied a modification of the MEBT using 6 buncher cavities with 8 quadrupole magnets. It can be realized by 2 DTL tanks with 3 cells.

Properties of Proton Beams

The beam emittances and the twiss parameters of the 20 MeV proton beam going out from the low energy DTL are given in Table 1. They the simulated result using the PARMILA code [10]. The unnormalized total units are used in this work for the TRACE3D code [11].

Table 2 contains the corresponding properties of the matched input beam of the first tank in the PEFP DTL2. It is calculated by the TRACE3D code. The values are for FFDD lattice in x-direction.

Table 1: Properties of 20 MeV output beam at the end of the low energy part of the PEFP linac.

	emittance	α	β
x	5.57 mm-mrad	2.92	1.11 mm / mrad
y	5.60 mm-mrad	-1.47	0.46 mm / mrad
z	614.2 deg-keV	0.31	0.14 deg / keV

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Table 2: The properties of the matched input beam of the first tank in the PEFP DTL2.

	emittance	α	β
x	5.57 mm-mrad	-2.61	0.98 mm / mrad
y	5.60 mm-mrad	1.79	0.57 mm / mrad
z	614.2 deg-keV	-0.05	0.13 deg / keV

Properties of Buncher Cavities

In usual cases, the MEBT is located between an RFQ and a DTL cavities where the beam energy is about 3 MeV. However it is 20 MeV in the PEFP case which places a heavy burden on the effective voltages (E_0TL) of the buncher cavities.

The transfer matrices for the drift space and the RF gap representing a buncher cavity are given as follows[11],

$$R_d = \begin{pmatrix} 0 & l \\ 0 & 1 \end{pmatrix},$$

$$R_c = \begin{pmatrix} 1 & 0 \\ k_z/(\beta_r\gamma_r)_f & (\beta_r\gamma_r)_i/(\beta_r\gamma_r)_f \end{pmatrix},$$

with

$$k_z = \frac{2\pi\,|\,q\,|\,E_0TL\sin\phi_s}{m_0c^2\,\overline{\beta_r}^2\,\lambda},$$

where l is the length of the drift space. The symbols, β_r and γ_r, are relativistic parameters. ϕ_s and λ represent the synchronous phase and the wavelength in free space.

In order to get some information about the effective voltage of the buncher cavity, we have studied a simple model with a drift space and an RF gap. The length of the drift space is fixed to be 120 cm. The ratio, $(-\alpha/\beta)$, at the end of the RF gap is given by the linear equation of the effective voltage: A + B × (E_0TL) where coefficients, A and B, are determined by the drift space and the RF gap, respectively. While B is almost independent of the beam energy, A is strongly depend on the energy. In our case, the value of B for 20 MeV proton beams is about 3.5 times larger than that for 3 MeV. If including the space charge effect, it is also increased by additional factor of 1~2 depending on the beam energy. This shows that the effective voltage to control 20 MeV beams in the longitudinal direction should be larger than the usual case where the MEBT is located between an RFQ and a DTL.

Simulation Result Using TRACE3D

Figure 1 shows the TRACE3D result of the matching process in the MEBT. The input and resulting parameters using in this study are given in Table 3. The effective voltages for the cavities are 628 kV and 428 kV, respectively. The values are larger values than the usual case as expected.

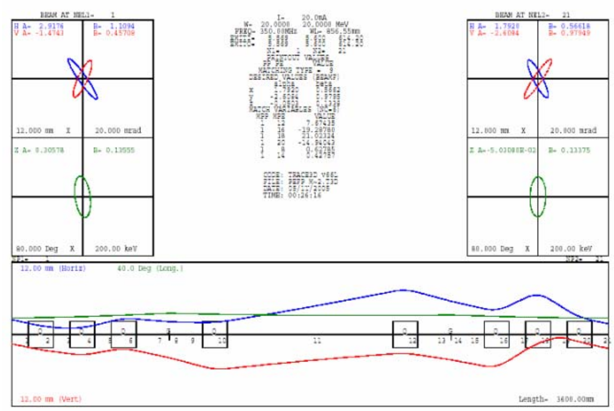

Figure 1: Matching of 20 MeV proton beams using the PEFP MEBT consisting of 8 quadrupole magnets and 2 buncher cavities.

Table 3: MEBT parameters for the beam matching between the DTL1 and the DTL2.

Parameters	Values
Effective length of Quadrupole magnets	15 cm
Drift space for beam extraction system	100 cm
Q1(field gradient)	-0.50 kG / cm
Q2	-1.20 kG / cm
Q3	1.70 kG / cm
Q4	-0.80 kG / cm
Q5	0.77 kG / cm
Q6	-1.93 kG / cm
Q7	2.10 kG / cm
Q8	-1.49 kG / cm
G1(effective voltage)	628 kV
G2	428 kV

Another MEBT scheme

It's possible to replace the single-cell cavities in the MEBT by the multi-cell cavities. One strong candidate is the DTL tank with 3 cells. Each tank contains four quadrupole magnets whose effective length and field gradient are 8 cm and 2.4 kG/cm. The length at the tank walls is increased to be 15 cm in order to control the beam under the specified values of the field gradient. Since a DTL tank can be replaced by the set of 4 quadrupole magnets and 3 RF gaps, the following discussion concentrates on the possibility of the new matching scheme with 8 quadrupole magnets and 6 buncher cavities using TRACE3D code.

Table 4 shows the resulting parameters of the matching process given by Figure 2. The drift space between the first (last) quadrupole magnet and the low (high) energy PEFP DTL is 140 cm. Other dimensions such as the length between magnets are obtained by PARMILA code. The effective voltages of the initial and final 3 gaps are selected to be equal to be 612 kV and 542 kV, respectively.

Table 4: MEBT parameters in the new matching scheme.

Parameters	Values
Effective length of Quadrupole magnets	8 / 15 cm
Drift space for beam extraction system	100 cm
Q1(field gradient)	-2.10 kG / cm
Q2	2.10 kG / cm
Q3	2.10 kG / cm
Q4	-1.34 kG / cm
Q5	1.80 kG / cm
Q6	-2.35 kG / cm
Q7	-2.33 kG / cm
Q8	1.27 kG / cm
G1 ~ G3(effective voltage)	612 kV
G4 ~ G6	542 kV

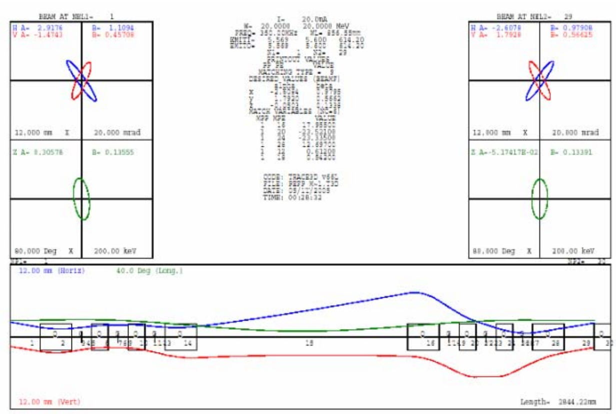

Figure 2: Matching of 20 MeV proton beams in the modified MEBT with 8 quadrupoles and 6 buncher cavities.

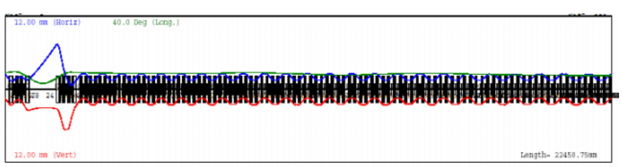

Figure 3: Beam simulation result in the modified MEBT and the following 4 DTL tanks using TRACE3D code.

Under this condition, the mismatch factors obtained by TRACE3D code are less than 0.001. Figure 5 shows the simulation result of the beam in the modified MEBT and the following 4 tanks of DTL2. It is calculated by TRACE3D code.

CONCLUSION

This work describes the basic idea and conceptual design of the PEFP MEBT. It is essential system in the linac because of the 20 MeV beam line after the low energy part of the PEFP linac. The MEBT consists of 8 quadrupole magnets and two buncher cavities. We have also studied the possibility of using the multi-cell cavity such as a DTL tank with 3 cells.

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