BEAM DYNAMICS STUDY OF THE LOW ENERGY PROTON ACCELERATORS FOR PEFP

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Abstract

The low energy part of the high current proton accelerators for Proton Engineer Frontier Project (PEFP) includes a 3MeV RFQ and a 20MeV DTL. This work is related with the combined beam dynamics study of the RFQ and DTL in order to test the beam transportation through the whole structure and gather the preliminary information of the MEBT.

INTRODUCTION

The low energy linear accelerators for PEFP consists of a 3 MeV RFQ under testing and a 20 MeV DTL under construction. They are the first part of the PEFP linear accelerators designed to accelerate 20 mA proton beam to 100 MeV.

The beam matching between the RFQ and DTL becomes serious since the RFQ is a relatively strong focusing structure than the DTL in the transverse direction. On the other hand, the longitudinal zero current phase advances between the accelerators are so similar that the longitudinal matching problem becomes relatively manageable.

The main purpose of this work is the combined beam dynamics study of the RFQ and DTL in order to find a simple solution of the transverse mismatch problem without introducing the complex MEBT.

In the next section, we have summarized the physical designs of PEFP RFQ and DTL. The following section includes a possible solution of the mismatching problem between the RFQ and DTL.

RFQ AND DTL FOR PEFP

PEFP RFQ is four vane type with 4 sections [1]. They consists of a radial matching section of 4 cells, 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 [2]. 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 beam dynamics is calculated by PARMTEQM code. 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 99.3% by applying the matched beam for the RFQ.

Table 1: The PEFP RFQ parameters.

Frequency	350 MHz
Input / Output Energy	23 mA / 20 mA
Input / Output Current	50 keV / 3 MeV
Peak Surface Electric Field	1.8 Kilpatrick
Power	417.9 kW Cu:350 kW, Beam: 67.9 kW
Transmission Rate	95.4 % *
Length	324 cm

*99.3% for the matched input beam.

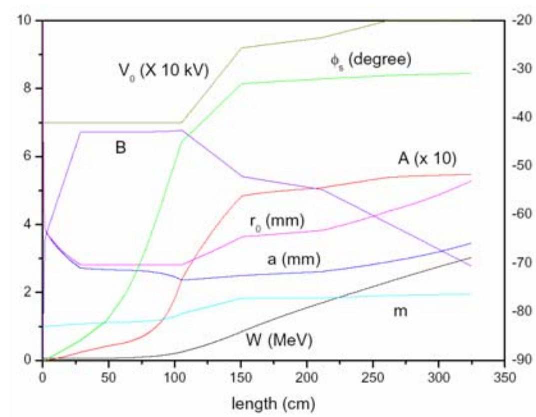

Figure 1: PEFP 3MeV RFQ Design Parameters: synchronous phase (ϕ_s), accelerating efficiency (A), focusing efficiency (B), mid-cell aperture radius (r_0), minimum radius curvature (a), modulation (m), and particle energy (W).

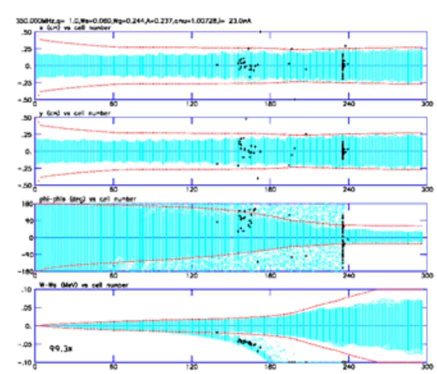

Figure 2: Configuration plots of the beam in the original RFQ.

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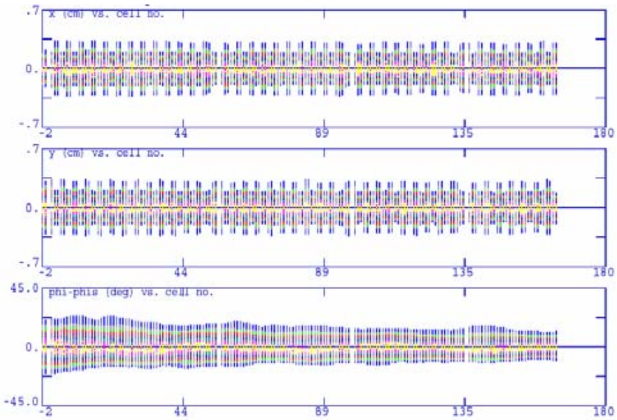

Figure 3: Configuration plots for the matched beam in PEFP DTL.

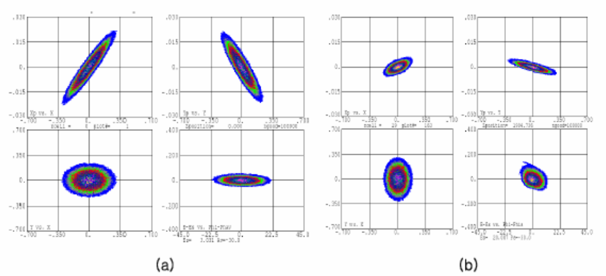

Figure 4: (a) matched input and (b)output beams for PEFP DTL.

PEFP DTL consists of 4 tanks which accelerates the 20 mA proton beam from 3 MeV to 20 MeV [3]. The total length is about 20 m and a 1 MW klystron will be used to supply the RF power. The lattice structure is FFDD with the magnetic field gradient of 5 kG/cm and the effective field length of 3.5 cm.

The simulation result obtained by PARMILA is given in Figure 3 for the configuration plots, and Figure 4 for the matched input and output beam.

MATCHING BETWEEN RFQ AND DTL

The zero current phase advances per unit length are given as 4.15 deg/cm at the high energy end of the RFQ and 2.55 deg/cm at the low energy end of the DTL. It implies that the output beam from the RFQ is over-focused than the desired input beam for the DTL. If we push the RFQ output beam directly into the DTL, the additional betatron oscillation occurs and the beam loss comes to 0.13 % as shown in Figure 5. It is beyond the designed limit of the particle loss, 1 ppm. The input and output beam in the trace space are given in Figure 6.

We have modified the last section of the RFQ in order to close it with weaker focusing efficiency. The new design parameters are given in Figure 7. The main change is the larger aperture radius for the reduced focusing efficiency. The configuration plot of the beam in the modified RFQ is given in Figure 8.

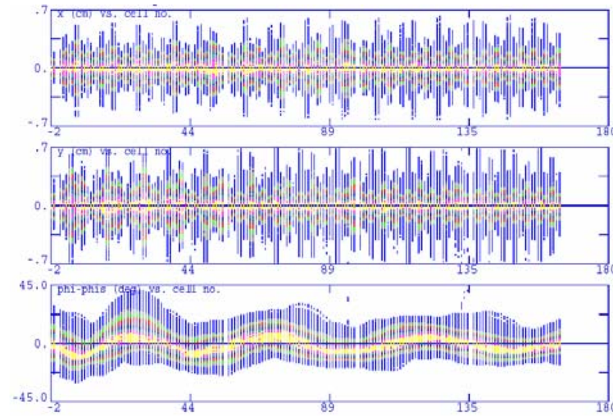

Figure 5. Configuration plots of the DTL beam when the RFQ output beam is directly used.

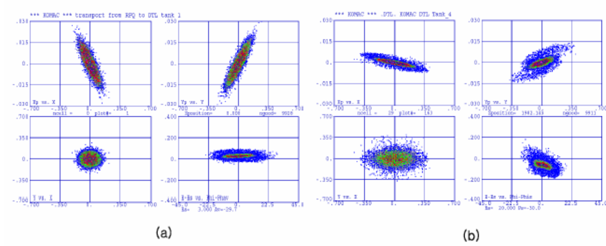

Figure 6: (a) input and (b)output beams for PEFP DTL when the output beam of the original RFQ is directly used.

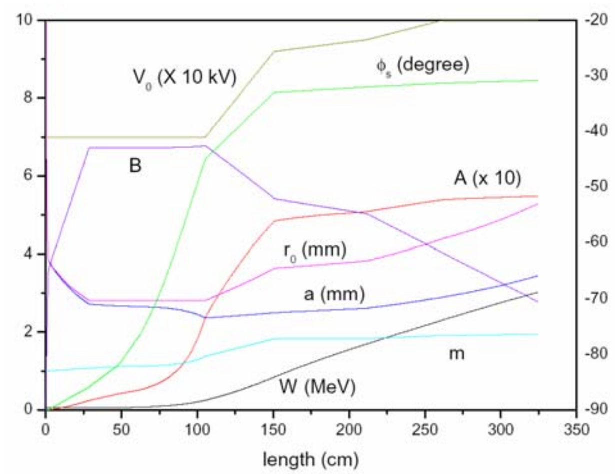

Figure 7: New design parameters for the modified RFQ.

We want to get the matched input beam for the DTL after one period of FFDD lattice structure in the DTL by selecting the suitable values of the following physical quantities: the effective length of the first magnet and the field gradients of the first four magnets in the DTL. Because of the geometrical reason like tank wall, it is essential to leave some space between RFQ and DTL. We have used the drift space of 4.5 cm in this work.

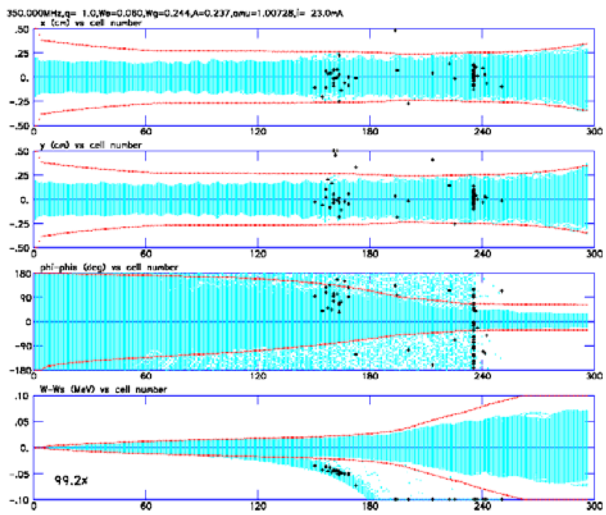

Figure 8: Configuration plots of the beam in the modified RFQ.

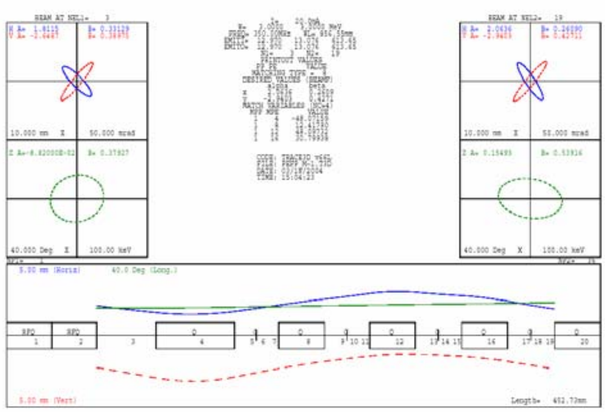

Figure 9: Trace3D simulation finding the matching parameters.

Table 2: Parameters of matching between RFQ and DTL.

Effective field length of 1st magnet in DTL	6.0 cm (design value: 3.5 cm)
Field gradient of the first four magnets in DTL	-4.8 / 1.2 / 4.8 / 3.1 kG/cm

The most serious constraint of the solution comes form the limited strength of the magnets in the DTL. The maximum field gradient of the normal conducting magnets used in the DTL is about 5 kG/cm and the space in the drift tubes containing magnets is not enough to give the large effective field length. Because of these constraints, it's impossible to get the matching parameters before modifying the RFQ.

The reasonable matching parameter set can be obtained by using the Trace3D code as shown in Figure 9. The resulting parameters are summarized in Table 2.

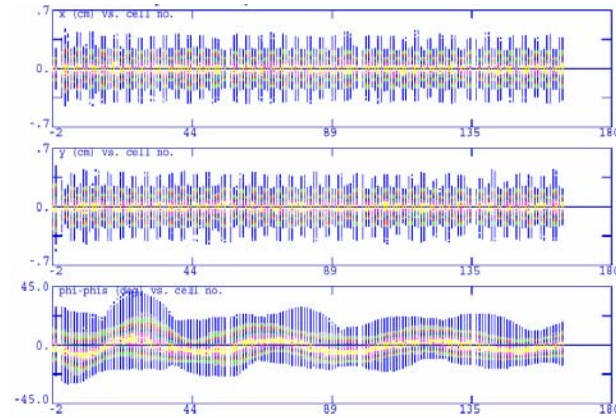

Figure 10: Configuration plots after matching.

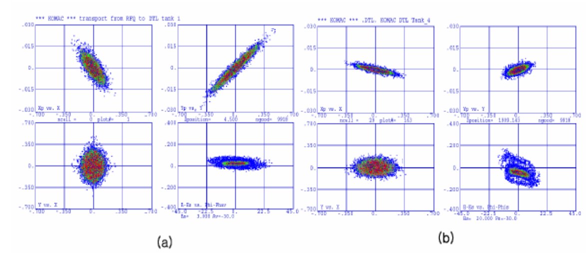

Figure 11: (a) input and (b)output beams for PEFP DTL after the RFQ design is modified and adapted the matching parameters.

We can get acceptable beam dynamics result by applying these modification to the initial part of the DTL and directly using the output beam of the modified RFQ. They are given in Figure 10 for the configuration plots and Figure 11 for the input and output beams. We note that the beam loss disappears in the new situation.

CONCLUSION

This work is related with the combined beam dynamics study of PEFP RFQ and DTL. In order to get the matched input beam for the DTL under the constraint of limited strength of the quadrupole magnets, we have modified the last section of the RFQ and selected some specific values for the field gradient of the first four magnets in DTL and the effective field length of the first magnet. However the longitudinal matching is not fixed in this framework.

ACKNOWLEDGEMENT

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