COMBINED BEAM DYNAMICS STUDY OF THE RFQ AND DTL FOR PEFP

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Abstract

One of the goals of the proton Engineering Frontier Project (PEFP) is to get 20MeV proton beams of 20mA through a 3MeV RFQ and a 20MeV DTL. This work is related to the combined beam dynamics study of the low energy proton accelerators in order to test the validity of the connection of the independently designed structures as well as to study the MEBT for beam transportation.

INTRODUCTION

The low energy part of the PEFP linear accelerators is designed to accelerate the 20mA proton beam up to 20MeV through a 3MeV RFQ and a 20MeV DTL. It is the first phase of the development of the PEFP linac whose final goal is to supply the 100MeV proton beam of 20mA.

PEFP RFQ is a four vane type accelerator with 4 sections. It is designed to accelerate the 20mA proton beam from 50keV to 3MeV. However it has to be upgraded since the resonance frequency and the vane voltage profile have been different from the design values[1].

PEFP DTL consists of 4 tanks which accelerates the 20mA proton beam from 3MeV to 20MeV[2]. The focusing lattice structure is FFDD where the magnetic field gradient is 5kG/cm and the effective length of the field is 3.5cm.

The main purpose of this work is to find the beam matching condition between the RFQ and the DTL through the combined beam dynamics study. We have concentrated only on the transverse matching which can be achieved by the changing the quadrupole magnets in the DTL. After obtaining the transverse matching solution, the behaviour of the beam in the longitudinal direction has been studied. We have also investigated how the matching condition depends on the beam current. It is related to the zero current phase advance(ZCPA) per unit length of the different accelerating structures.

COMBINED BEAM DYNAMICS OF EXISTING RFQ AND DTL

We have used the PARMTEQM[3] and PARMILA[4] codes for the beam simulation of the existing RFQ and DTL. The number of macro-particles going into the RFQ is 10,000 of which 9928 particles are accelerated by the RFQ. They are directly used as the input beam for DTL simulation. Since large beam loss occurs in the DTL without matching[5], it's essential to adopt a suitable matching method before studying the combined beam dynamics.

We have used the first four quadrupole magnets as a matching tool by changing their field gradient. The drift space between the RFQ and DTL is 13.5cm for installing a diagnostic equipment like a BPM. A quadrupole magnet built in the space becomes an additional means to control the matching condition. TRACE3D code is used to get the matching solution. The result is given in Figure 1. The values of the field gradient of the magnets in the DTL are about –8.9kG/cm, 9.0kG/cm, 1.9kG/cm, 0.4kG/cm, respectively, when the magnet between the RFQ and DTL has the field gradient of 3kG/cm. Some values are too large to realize in our magnet design.

By adjusting the quadrupole magnets to the values, we have got the simulation result in the DTL. The beam radius in the first part of DTL becomes larger than that of the other part and 3 particles are lost in the matching process.

We have also studied the current dependence of the matching solution. The same ZCPA per unit length of the different accelerating structures is an essential condition to get the current independent matching solution[6]. The corresponding values of PEFP RFQ and DTL are about 4.2 deg/cm and 2.6 deg/cm, respectively. Since the values are very different, we can expect the matching solution depends strongly on the beam current. Figure 2 shows the growth of the transverse emittance in the DTL . The red, green, blue lines represent the different beam current going into RFQ: 1mA, 23mA, and 50mA, respectively. In the each simulation, we have used the matched input beam for the RFQ with different twiss parameters.

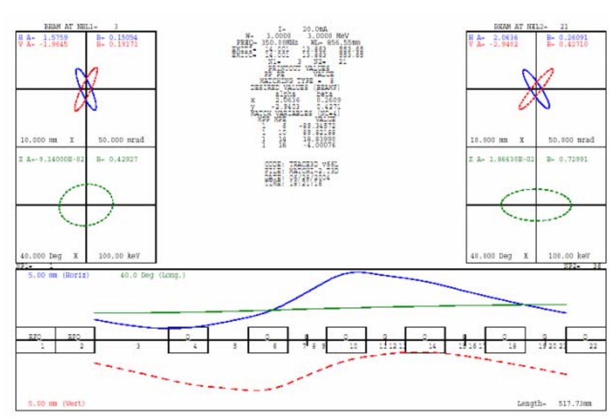

Figure 1: Trace3D result for matching solution for the existing RFQ and DTL.

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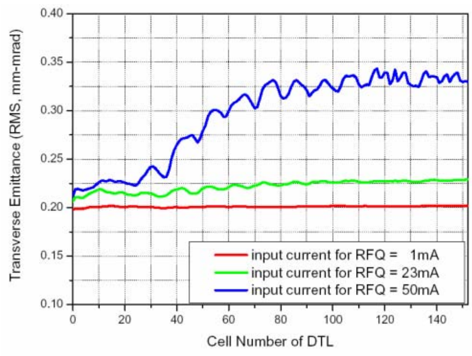

Figure 2: Growth of the transverse emittance in PEFP DTL . The input currents into RFQ are 1mA(red line), 23mA(green line), and 50mA(blue line).

The figure shows the matching condition is not good solution for the beam current of 50mA if focusing lattice at the first part of DTL is optimised for the beam current of 23mA.

COMBINED BEAM DYNAMICS OF NEW RFQ AND DTL

The new RFQ design is reflected the transverse matching condition by smoothly increasing the aperture radius in order to reduce the focusing strength. Then ZCPA per unit length at the high energy end of the RFQ has the similar value as that of the initial part of the DTL. We have also introduced the transition cell [7] at the end of the RFQ. It removes the energy uncertainty at the end of the RFQ and the following fringe field length can be used to control the RFQ output-beam for matching. The design parameter of the RFQ is given in Figure 3. The details of the new RFQ can be found in Ref.[1].

We have 5 free parameters for transverse matching: the length of the fringe field region, the 5 values of the field gradients of the quadrupole magnets one of which is located in the drift space between the RFQ and DTL and the others are in the first 4 drift tubes in DTL. The length of the drift space between the RFQ and DTL is fixed to be 13.5cm as in the previous analysis. We have used the TRACE3D code in order to find the matching solution. The results are given in Figure 4 and Table 1. In the process, the most serious constraint is that the design values of the field gradient and effective length of the quadrupole magnets are 5kG/cm and 3.5cm. The fringe field length and the position and the field gradient of the magnet between the RFQ and DTL are determined to produce the suitable RFQ output beam for the matching into the DTL within these limits.

Figure 5 and 6 shows the behaviour of the beam in the RFQ and DTL in the configuration space. The transmission rate is 98.3% in the RFQ and there is no beam loss in the DTL.

In order to investigate the beam current dependence of the matching solution, we have calculated the transverse ZCPA per unit length of the new RFQ which is about 2.4 deg/cm. It is very similar to the value of the first part of PEFP DTL which is 2.6deg/cm. Hence we can expect the matching condition can be applied to the other beam currents. Figure 7 shows the transverse emittance growth in the different RFQ input currents. Though we obtain the matching condition optimised to the beam current of 23mA, it gives an acceptable result for the 50mA beam. In the simulations, we have used the matched input beam of the RFQ for each beam current.

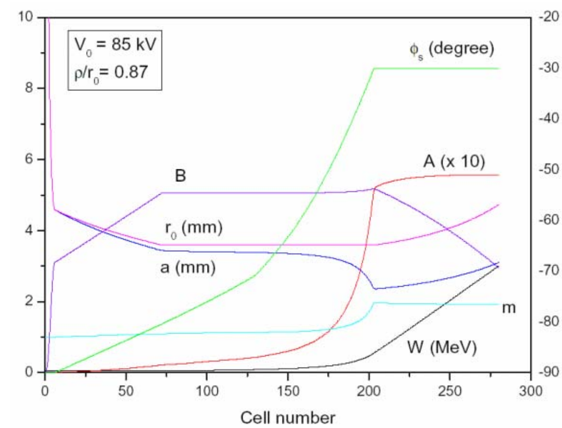

Figure 3: New design parameters for the modified RFQ.

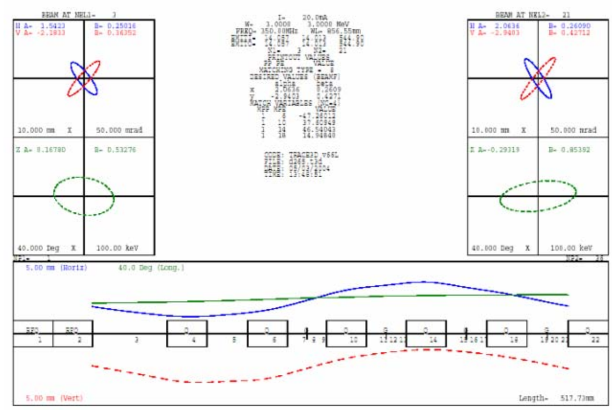

Figure 4: Trace3D result for matching solution of the new RFQ and DTL.

Table 1: Parameters for beam matching between the RFQ and DTL.

Length from the end of RFQ to the center of the magnet in drift space	8.25 cm
Effective length of the quadrupole magnets	3.5cm
Field gradient of the quadrupole magnet between the RFQ and DTL	-4.2kG/cm
Field gradient of the first four quadrupole magnets in DTL	-4.7 / 3.8 / 4.7 / 1.5kG/cm

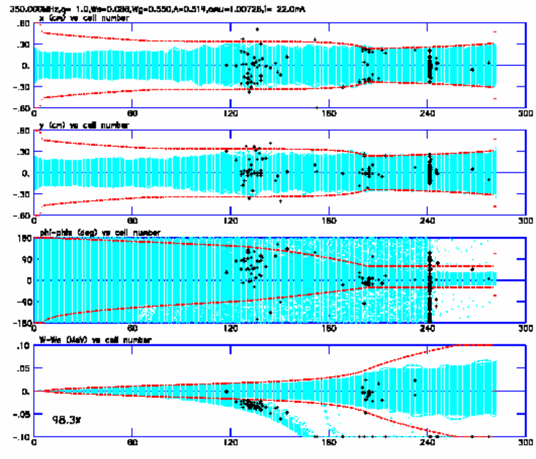

Figure 5: Configuration plot of the beam in the RFQ.

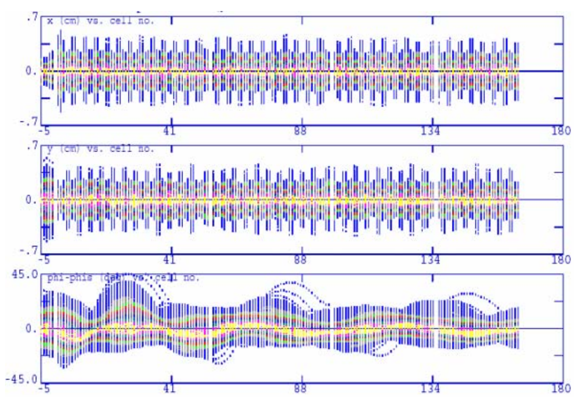

Figure 6: Configuration plot of the beam in the DTL.

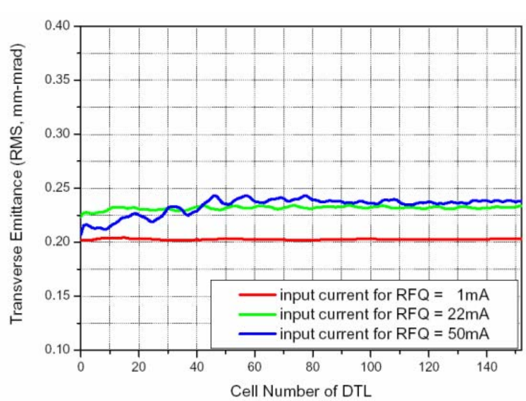

Figure 7: Growth of transverse emittance in the DTL.

Figure 8 shows the corresponding emittance growth in the longitudinal direction. Even for the input beam current of 23mA, it becomes larger than the initial value because there is no matching process in the longitudinal direction. We note that the beam size becomes relatively large and does not shrink at the high energy end of the DTL in the longitudinal direction as shown in Figure 6.

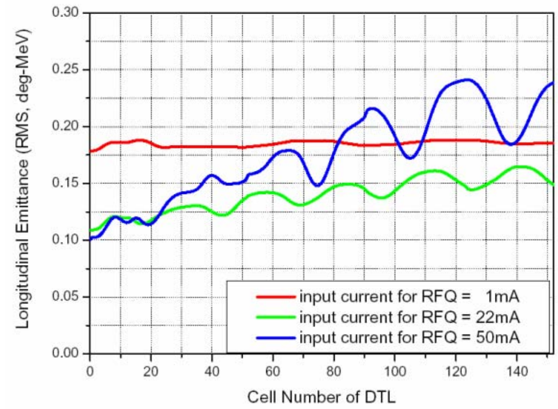

Figure 8: Growth of the longitudinal emittance in the DTL.

CONCLUSION

We have studied the combined beam dynamics of PEFP RFQ and DTL. The transverse matching condition between the accelerating structures can be found by adjusting the quadrupole magnets in the DTL. It can be achieved within the limit of design values of the quadrupole magnet. We note that the matching solution does not depend on the beam current. However the longitudinal behaviour of the beam is not so good since there is no matching process in the direction.

ACKNOWLEDGEMENT

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