DESIGN OF 20 MEV DTL FOR PEFP

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Abstract

We have designed a conventional 20MeV drift tube linac (DTL) for the Proton Engineering Frontier Project (PEFP) as a low energy section of 100MeV accelerator. The machine consists of four tanks with 152 cells supplied with 900kW RF from 350MHz klystron. We have also studied beam dynamics in this structure and designed focusing quadrupole magnets. The details of the DTL design are reported.

INTRODUCTION

In this paper, we have designed a conventional drift tube linac (DTL) to accelerate proton beam of 20 mA from 3 MeV to 20 MeV. The input beam for the DTL comes from the radio frequency quadrupole (RFQ) which is designed to produce the 3 MeV proton beam of 20 mA from the 50 keV beam of 23 mA. The normalized rms emittance in the phase space are given as 0.23 π mm-mrad for transverse direction and 0.15 deg-MeV for longitudinal direction.

The following sections include the general features of our DTL such as cavity design, beam dynamics, and quadrupole magnet (QM) design.

DESIGN LAYOUT

Structure

The available structures for the 20 MeV proton accelerator are a coupled cavity DTL (CCDTL), a super-conducting cavity linac, and a conventional DTL. The CCDTL has a merit that the QM can be located at the outside of cavity. Since the high shunt impedance structure should be operated at the higher frequency than that of RFQ, a matching section is necessary to compensate the structure/frequency change and the cavity becomes longer. For the super-conducting cavity, more R&D is necessary for lower beta region. Therefore the most suitable choice is the conventional DTL in spite of its disadvantage that the QM has to be installed even inside the short first drift tube in the first tank.

Frequency

The operating frequency of RFQ is 350 MHz and the conventional DTL is also working at the same frequency in order to make the matching easy between RFQ and DTL.

RF Power

The 20 MeV accelerator should be constructed within next 2 years, and should deliver the proton beam to users. With this schedule, the RF system for 20 MeV DTL should be separated from the other parts of the 100 MeV accelerator. From the construction cost viewpoint, one RF system for the DTL is preferred. The RF power is limited to 900 kW.

CAVITY DESIGN

To get the optimised information of DTL cavity, we use the DTLfish code which is an automated tuning program included in the Poisson/Superfish code group [1].

We have calculated the effective shunt impedance as a function of β (= v/c) under varying each parameters in order to get their optimal values to give the maximum shunt impedance. Table 1 and Figure 1 show the final design values of the geometrical parameters for the DTL cavities and the resulting plot of the effective shunt impedance under the selected parameter values. In this work, the tank diameter is determined after compensating the frequency increase by the stem effects.

Table 1. DTL design parameters

Parameter	Value
Tank diameter	54.44 cm
Drift-tube diameter	13 cm
Bore radius	0.7 cm
Drift-tube face angle	10 degrees
Drift-tube flat length	0.3 cm
Corner radius	0.5 cm
Inner nose radius	0.2 cm
Outer nose radius	0.2 cm
Stem diameter	2.6 cm
Frequency tolerance	0.001 MHz

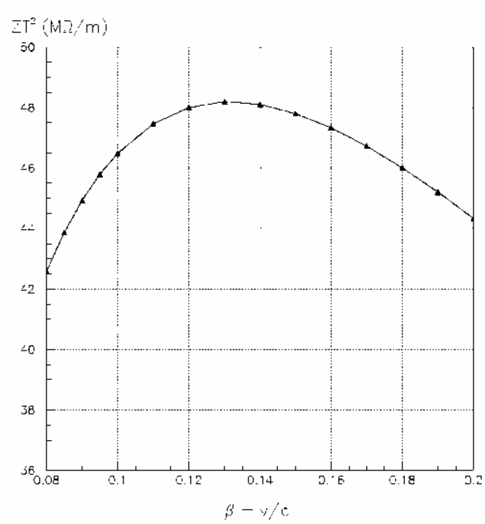

Figure 1. Effective shunt impedance

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Table 2. DTL parameters for each tank

	Tank 1	Tank 2	Tank 3	Tank 4
Energy range (MeV)	3.00 ~ 7.18	7.18 ~ 11.50	11.50 ~ 15.80	15.80 ~ 20.00
Number of cells	51	39	33	29
Tank length (cm)	443.1	464.9	475.5	477.6
Total power (kW)	225	225	224	221
Synchronous phase (deg.)	30	30	30	30
Quad. gradient (kG/cm)	5.0	5.0	5.0	5.0
Effective Quad. length (cm)	3.5	3.5	3.5	3.5
E_0 (MV/m)	1.30	1.30	1.30	1.30
Transit time factor	0.83	0.83 ~0.81	0.81 ~ 0.79	0.79 ~ 0.77

BEAM DYNAMICS

We use the PARMILA code [2] to simulate the proton beam going through the DTL structure.

DTL Geometry

Our DTL has been designed to accelerate proton beam of 20 mA from 3 MeV to 20 MeV via 4 tanks. The inter-tank length is 1 ↕ℓ. Table 2 shows the design results for each DTL tank. The cell number of each tank is determined by requiring that they use similar amount of RF power which is less than 225 kW. In the power estimate, we use the reduced values of the shunt impedance by the factor of 0.8. The largest cell number is 51 of the first tank which is a reasonable value for easy tuning process.

We select FOFODODO lattice structure where every drift tube includes one QM. The structure allows weak focusing magnet at the cost of large beam size.

We don't adopt the ramping in the accelerating field and the synchronous phase since the peak current is relatively low in this design. The magnitude of the peak surface electric field is designed to be lower than 0.9 times Kilpatrick field.

For frequency tuning and field stabilization, we will use the 8 slug tuners for each tank and one post coupler for every 3 drift tubes (tank1) and 2 drift tubes (tank 2, 3,4).

Result

Figure 2 shows the tendency of the emittance growth in the transverse and longitudinal directions. There is no serious change in the emittances.

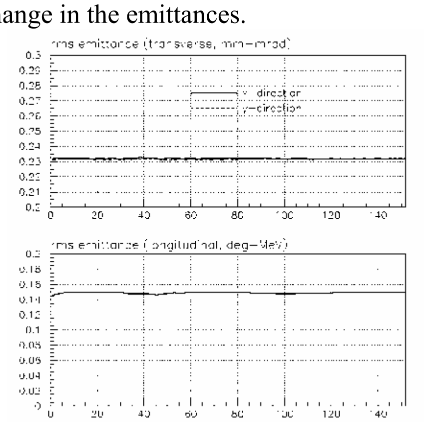

Figure 2. Transverse and longitudinal emittance profile

The maximum and rms beam size in the transverse direction are given in figure 3 which shows the betatron oscillation.

The zero-current phase advance per focusing period should be less than 90~ in order to avoid the envelop instability. In our case, it is designed for the phase advance to be below 75~ as shown in figure 4.

Figure 5 represents the output beam distribution at the end of the fourth tank. Even though we don't carefully consider the missing RF region between tanks, the plot shows that there is no abnormal signature such as large tail outside the beam core.

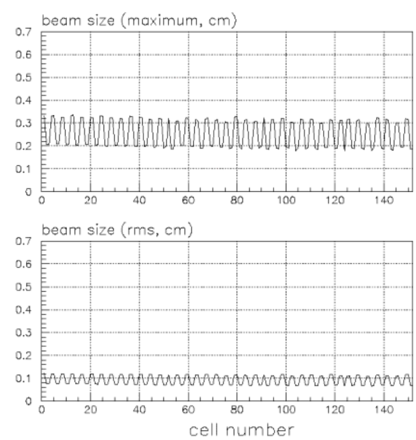

Figure 3. beam size in transverse direction

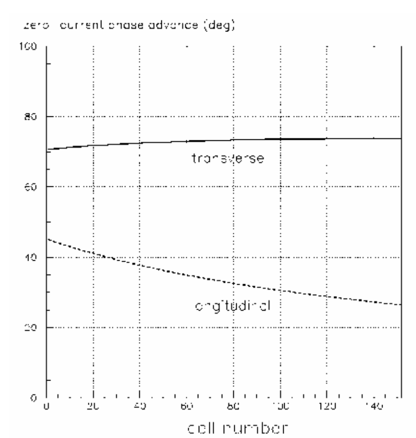

Figure 4. zero-current phase advance per focusing period

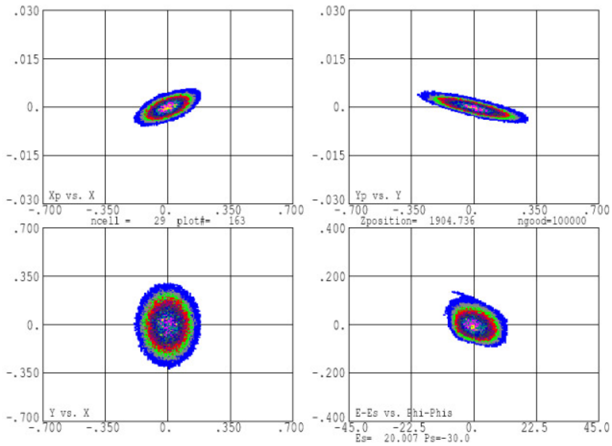

Figure 5. Configuration plot of the beam at the end of 4th tank

QUADRUPOLE MAGNET

The type of the QM installed in drift tubes can be either electromagnet or permanent magnet. Since our DTL will be operated with varying current from 0 to 20 mA, we choose the electromagnet where the focusing strength can be changed.

The required quadrupole strength GL is 17.5 kG/cm m. With 10% safety margin, we choose it as 20 kG/cm cm.

The first cell length is about 6.9 cm corresponding to one ↕ℓ. Considering fabrication of QM, its occupation rate in the drift tube can be 60% of the cell length. This means that QM should be shorter than 4 cm for the first drift tube. So, the special care should be required for the quadrupole design.

There are two different methods to overcome the limited space. One is using the electroformed hollow coil with water-cooling system which is developed in KEK[3]. This method is too expensive and complex to use it for our DTL. The other is using the transformer coil with external cooling system which is suggested in CEA[4]. Even though it isn't realized until now, we select the latter method since it is simple to make it.

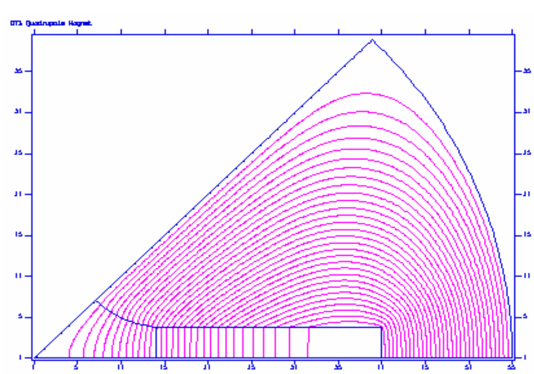

Figure 6. Quadrupole magnet field profile

Table 3. EMQ parameters

Parameter	value
Strength (GL)	20 kG/cm cm
External diameter	110 mm
Bore Diameter	20 mm
Pole length	30 mm
Good field diameter	14 mm (1%)
Multipole fraction	< 1%
NI for 20 kG	2,200 AT
Conductor	3 3 mm
Number of turns	8
Joule dissipations	600 W

Since the machining of the ideal hyperbolic pole shape for the QM is too complicated and expensive, we choose a circular pole which is optimised so that a good field aperture within 1% error occupies more than 70 % of the pole region and the multi-pole components in the good field region is less than 1% of the quadrupole component.

The figure 6 shows the optimised field profile in the quadrupole calculated by using the POISSON code [1]. We confirm that the iron core isn't saturated and the design is satisfied with the requirement for the good field region and multi-pole components.

Table 3 shows the main parameters of the designed electromagnetic quadupole (EMQ). The EMQ will be installed in every drift tube. Due to pool type cooling, we choose the thin conductor in order to secure the larger surface for cooling. However we have to study the thermal properties of this thin conductor and solve the heat problem under high current.

We will use 1010 low carbon steel for the iron core and use the discharge-machining method for manufacturing the pole shape. The transformer coil used as the conductor will be directly wounded on the iron core. After inserting EMQ into the drift tube, the OFHC copper end caps will be welded onto the drift tube by using the e-beam.

In conclusion, this article is a brief summary of a conventional DTL design for PEFP. The more detail of the design can be found in Ref 5.

ACKNOWLEDGEMENT

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