MEBT DESIGN FOR THE JHF 200-MeV PROTON LINAC

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Abstract

The medium-energy beam-transport line of 2.7 m long for the JHF 200-MeV proton linac was designed. It consists of eight quadrupole magnets, two bunchers and two RF choppers, and has two purposes: matching the beam from the RFQ with the acceptance of the DTL; chopping the beam to produce a gap of 222 nsec between pulses of 278 nsec for the injection into the following rapid-cycling ring. The JHF proton linac is an intense beam accelerator with an average current of 0.2 mA in the first stage and of 0.8 mA for the future upgrade. Therefore, the key point in the MEBT design was focused on the control of the beam emittance growth in the beam line and the beam loss during transient times of the chopper. An RF deflector is utilized for the chopper owing to its characteristics of high deflecting field and compactness. The beam edge separation between the chopped and the unchopped beams reaches to 6 mm with a deflecting field of 1.6 MV/m. The field distribution (both E and B) of the RF deflector from MAFIA calculation is directly read into the modified TRACE3-D for the beam line design. The beam losses during RF transient times of the chopper, analyzed by both LEBT and PARMILA codes, are less than 0.08% at the exit of the 50-MeV DTL.

1 INTRODUCTION

In the JHF linac the beam intensity is high in terms of both the pulse current and average current[1]. Therefore, beam-loss control is a very essential requirement in the accelerator design. Beam-quality degradation mainly occurs in the low-energy sections. It has been realized that beam matching is of great significance for minimizing the emittance growth and avoiding beam-halo formation, which has been recognized as one of the major causes for beam losses[2].

The 500 μsec-long macropulses from the ion source need to be chopped into sub-pulses for injection into the following 3-GeV ring. After chopping, the macropulse consists of 278 nsec long pulses and 222 nsec long gaps in between the pulses. The chopped pulses should have a clean cut at the head and tail to avoid beam losses during injection into the ring. During the rise and fall times of the chopping field, however, there are some unstable particles, which are partially deflected; they may be accelerated to high energy and lost or get into the ring. Therefore, a fast-chopper design is being pursued in order to decrease the number of unstable particles.

The medium-energy beam-transport line (MEBT) between the RFQ and DTL has been designed to accomplish the two tasks: beam matching and chopping. It consists of quadrupoles, bunchers and RF deflectors. To conserve the beam quality, the line should not be too long and the beam needs to be well focused without large-amplitude oscillation. The line must also leave sufficient space for the beam diagnostics. The RF power requirement for the RF deflectors should be within the capability of the up-to-date solid RF power supply.

In this report, the design details are delineated. At first, the MEBT design is proposed in the second section. Section three describes the RF cavity of the deflector. The fourth section presents analysis of unstable particle. Finally conclusions are drawn out.

2 DESIGN OF THE MEBT

In order to describe the beam-deflection behavior, TRACE3-D[3] has been modified so as to include a new element: RF deflector. The field distribution in the cavity is calculated from MAFIA[4] and directly read into TRACE3-D. In this way, the fringe E&H fields beside the deflecting electrode can be taken into account.

The output beam from the RFQ is assumed to have the parameters listed in Table 1. Type A stands for the 30 mA case and Type B for the 60 mA case for upgrading in the future. The MEBT design is proposed with a total length about 2.7 m (Fig. 1). In the beam-profile plot at the bottom of the figure, the beam centroid offset in the x-direction by the RF deflectors is depicted by the dark curve. The beam dump will be positioned at the element 18 for the chopped beam. The design procedure has two steps. At first, the beam line up-stream of the element 18 is designed aimed at the largest separation between the unchopped and chopped beams at the element 18. Then, the unchopped beam is further transferred so as to match with the acceptance of the DTL.

Table 1. Input beam parameters at the MEBT entrance.

Parameters	Type A	Type B
I (mA)	30	60
$\varepsilon^{x,y}_{RMS}$ (πmm-mrad)	0.187	0.375
ε^{z}_{RMS}(πMeV-Degree)	0.133	0.266

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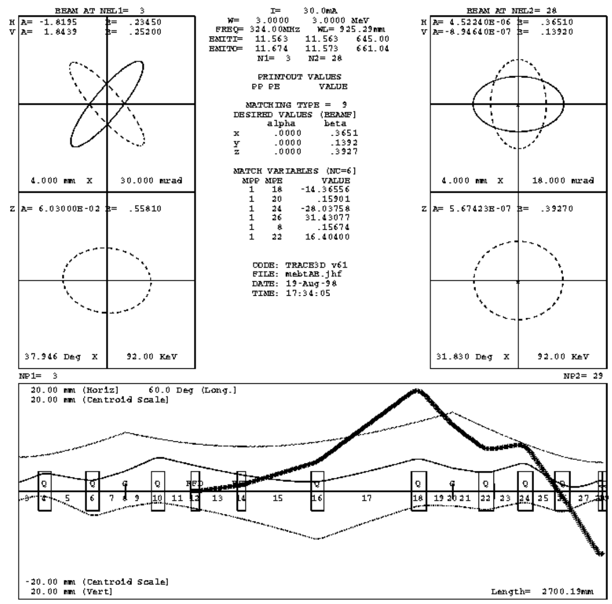

Fig. 1, TRACE3-D output of the MEBT for Type A. The up-left gives the input beam phase spaces and the up-right gives the matched beam with DTL. The bottom shows the beam profiles in the z, x and y directions respectively. The dark curve traces the beam centroid offset by the two RFDs. The element numbers are denoted under the beam axis.

The edge separation between the chopped and unchopped beam is 6 mm at the dump, when both of the RF deflectors have a deflecting field of 1.6 MV/m. This large separation is contributed from not only the two RF deflectors, but also the fourth quadrupole-element 16. The deflection is initiated by the two RF deflectors at an angle of 6 mrad for each, and is then amplified more than two times by the quadrupole. Downstream of the quadrupole, the deflection angle becomes 30 mrad. Owing to this reason, the RF deflectors do not require much RF power for an adequate deflection.

The first three Q magnets also contribute to the realization of the large separation. They should be adjusted for a small beam profile in the deflecting direction at the fourth Q magnet. Since the deflected beam centroid is more distant from the quadrupole's axis than is the undeflected beam envelope at the Q magnet it gives a larger defocusing to the deflected beam, but less defocusing to the undeflected beam. The first three quadrupoles should also keep the beam envelope in this section not too large in the y-direction in order to avoid any large emittance growth in this direction. In the RFD section, the beam size in the x-direction must be smaller than the gap between the deflecting electrodes so as to avoid beam losses on the electrodes.

In case that the beam emittance from the RFQ is larger than the assumed value for Type A, a relatively larger initial emittance between Type A and Type B for 30 mA beam was input into the designed beam line. The result shows that the same beam line is still applicable. Of course, the edge separation becomes smaller (about 3.6 mm for the input rms emittance of 0.25 πmm-mrad). But it is still sufficiently large for chopping the beam.

The beam emittance growth for the undeflected beam has been studied by means of PARMILA[5] simulation with 10,000 particles. Figure 2 shows the RMS emittance variation versus the element of the beam line. The beam has an RMS emittance growth of 7.7%, 9.5% and 4.8% in the x, y, z directions respectively.

The same beam line can also be used for input beam Type B. Only a very slight adjustment in the gradient of the Q magnets and the bunchers is necessary for large deflection and matching. For Type B, a higher deflecting field of 2 MV/m is needed to generate a 5-mm beam edge separation, due to the fact that the beam envelope is larger than that in Type A. The PARMILA run shows that the RMS emittance increases by 10%, 6%, 8% in the x, y, z directions, respectively.

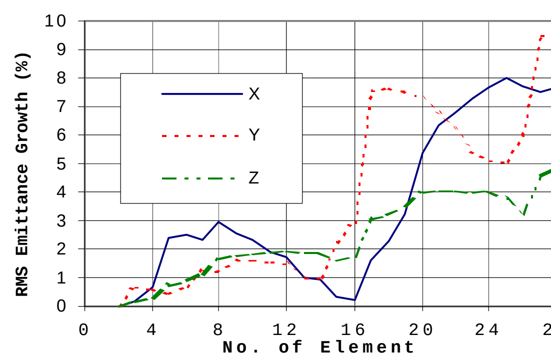

Fig.2. RMS emittance growth vs. the beam line elements for Type A.

3 RF CHOPPER DESIGN

A 324-MHz RF deflector cavity was designed and a cold model was tested[6]. The design philosophy is a low power demand from an RF power source and a fast rise time during pulse transient time. To hit the first target, the cavity geometry was optimized for maximum Z/Q_0 with MAFIA code under the limitation of the beam size; here Z is the transverse shunt impedance and Q_0 the unloaded Q value. To reach a fast rise/fall time, the cavity is heavily loaded by two coupling loops as input/output ports. Simulation with HFSS code shows the cavity can reach a very low loaded Q of 10 by means of two large loops with the size of 75×218 mm in the maximum-flux plane. To generate the deflecting field of 1.6 MV/m in the electrode gap, an input power of 22.2 kW is demanded from an RF power source, according to HFSS simulation. If the loaded Q becomes 15, the demanded power decreases to 14.8 kW. An additional power is needed to account for the deflection of the beam bunch with a half phase-length about 25° (see Fig.1). Therefore 1.2 times of power are required.

An aluminum cold model cavity was manufactured for demonstration of the low loaded Q. The results show a good agreement with the simulation: the measured Q_L=9.7.

4 ANALYSIS ON UNSTABLE PARTICLES

It is very crucial for the chopper to have as few unstable particles as possible during the RF rise and fall times. It is noted that the beam will not become totally unstable particles during the transient times because the scraper at the element 18 in Fig. 1 can stop some part of the particles in a beam when the RFD field is not at its full amplitude. To investigate the unstable particles during the transient times, PARMILA simulations with 5000 particles in uniform initial phase space were conducted. A particle scraper with an aperture of 20 mm in the x-direction is positioned at the element 18. As the RFD field increases toward its full value of 1.6 MV/m, the unstopped particle ratio in a bunch declines, as the curve shows in Fig. 3.

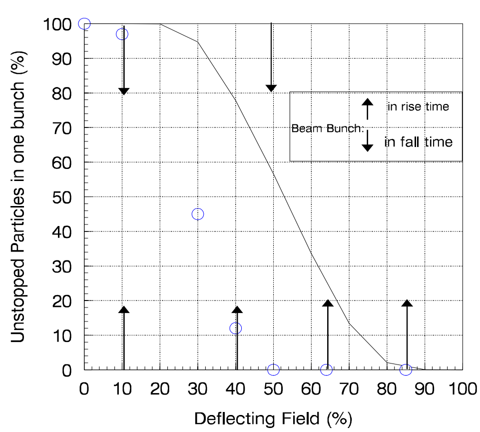

Fig.3 Unstopped particles ratio in one bunch vs. the deflecting field variation. The arrows indicate the bunch distribution during the RF rise and fall times. The curve indicates the ratios at the entrance of DTL and the circles those at the exit of DTL.

In order to obtain a quick rise and fall time, an improved method was proposed. The initial amplitude of the incident RF field to the cavity is 1.4 times the required full field. Some time after saturation, it is adjusted to one time the required full value. A rapid phase shift of 180^0 is added at the time just two or three periods before the power is turned off. These methods speed up the rise and fall times in terms of the required full field. Even though it needs an rf power two times higher, the solid RF power source is still within the commercially available range. Then, there are four micro-bunches during the rise time when the required full-field value is reached. Also only two bunches appear during fall time. These bunches meet the field amplitude, as denoted by the arrows in Fig.3.

When the field is more than 80% of the full value, the particles in a micro-bunch are almost totally stopped by the scraper. On the other hand, when the field is less than 30%, the unstopped portion of the particles can be injected into the acceptance of the DTL, according to TRACE3-D simulation. Thus only during the field-variation time from 30% to 80% of the full value, the beam will become unstable. However, not all the particles in the beam become unstable, because some of them can still be stopped by the scraper, as illustrated in follows.

During the rise time, two bunches at field of 10% and 85% amplitude do not become unstable beams. The other two bunches at 40% and 65% field amplitude partially contribute to the unstable particles. During the fall time one bunch is subjected to a field of 50%. Thus, for this bunch, only 58% of the particles become unstable. Totally, during transient times, the particles in 1.6 bunches become unstable at the exit of the MEBT.

A further investigation concerning the behavior of the transmitted unstable particles in the following 50-MeV DTL is conducted by means of the LEBT and PARMILA codes. Three scrapers are mounted in between the three DTL tanks with a slit full width of 6 mm. At the exit of the DTL, the ratio of the transmitted unstable particles is further reduced to less than 0.08% by the scrapers, as denoted by the circles in Figure 3. Also the scrapers do not block the unchopped beam.

5 CONCLUSIONS

The MEBT for the JHF linac is designed for matching and chopping the beam. The beam line is compact with a length of 2.7 m, owing to application of RF deflector. With the help of a quadrupole the chopper has a high deflection efficiency. The unstable particle ratio in the RF transient times can be reduced to less than 0.08% at the exit of the 50-MeV DTL.

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