DESIGN OF BEAM-TRANSPORT LINE BETWEEN THE RFQ AND THE DTL FOR THE JHF 200-MeV PROTON LINAC

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Abstract

The medium-energy beam transport line (MEBT) for the JHF linac has been designed using the modified TRACE3-D code, aimed at perfect matching, clean chopping and good beam quality. The line consists of eight quadrupoles, two bunchers and two choppers with a total length of 2.3m. The multiparticle code PARMILA is used to check the beam dynamics of the design. A radio frequency deflector (RFD) has been adopted in the chopper. The RF deflector cavity was designed using MAFIA code and the electromagnetic field distribution, including fringe field, is applied in the TRACE3-D simulation. The RFD deflection is amplified three times by a following defocusing quadrupole. An analysis of unstable particles during the RF transient time is conducted, with a result of an unstable particle ratio of 0.08% at the exit of the 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, for the reason that the lost particles induce strong radioactivity on the machine, and hence exclude the necessary manual access to it for maintenance during its long-term operation. 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 loss[2].

The 500μsec-long macropulses from the ion source need to be chopped into sub-pulses for injection into the following 3GeV ring. After chopping, the macropulse consists of 278nsec-long pulses and 222nsec gaps in between the pulses. The chopped pulses should have a clean cut at the head and tail to avoid beam losses during injection to the ring. During the rising and falling time 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 mentioned essential tasks: beam matching and chopping. It consists of quadrupoles, bunchers and RF deflectors. The beam is deflected by the RF deflectors and then stopped by a beam scraper when the MEBT is operating in the chopping mode. To conserve the beam quality, the line should not be too long and the beam needs to be well focused without large-amplitude oscillation, which induces beam halo. The line must also leave sufficient space for the beam diagnostics and elements connections. 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 30mA case and Type B for the 60mA case for upgrading in the future. The MEBT design is proposed with a total length about 2.3m, as shown in Fig. 1. In the beam-profile plot at the bottom of the figure, the beam centroid offset in the x-direction by the RF deflector is depicted by the dark line. 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 element 18. Then, in the next step, the unchopped beam is further transferred so as to match with the acceptance of the DTL. The matched-beam phase spaces are shown in the up-right plots of the figure. In this design, the beam matching and chopping are fulfilled in a separate section. This can benefit beam tuning during operation.

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

* On leaving from China Institute of Atomic Energy

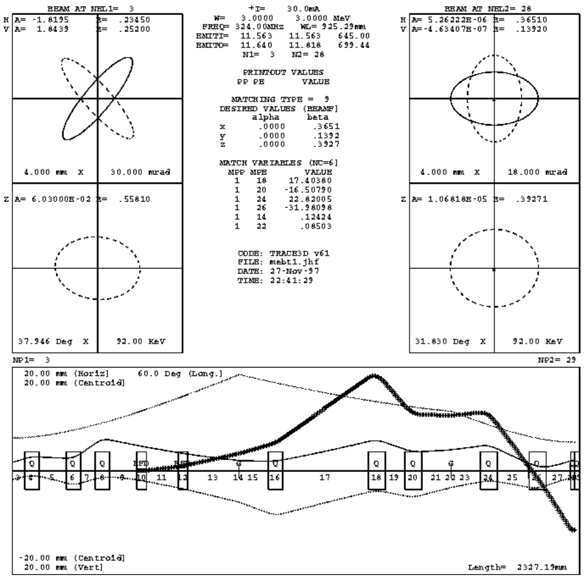

Fig. 1, TRACE3-D output of the MEBT for Type A. The up-left gives the input beam phase spaces and the up-right gives the matched beam with DTL. The bottom shows the beam profiles in z, x and y directions respectively. The dark line traces the beam centroid offset by the two RFDs. The element numbers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

The edge separation between the chopped and unchopped beam is 6.6 mm at the dump, since both of the RF deflectors have a deflecting field of 1.4 MV/m. This large separation is contributed from not only the two RF deflectors, but also from the fourth quadrupole - element 16. The deflection is initiated by the two RF deflectors at an angle of 5.3mrad for each, and is then amplified three times by the quadrupole. Downstream of the quadrupole, the deflection angle becomes 33.1mrad. This means that a major deflection is obtained from the quadrupole instead of the deflector. Owing to this reason, the RF deflector does not requires much RF power for 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 beam centroid is far more distant from the quadrupole's axis than is the beam envelope at the Q magnet, it gives a larger defocusing for the beam centroid, but less defocusing for the beam envelope. 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.

The beam emittance growth for the unchopped 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 5%, 18% and 11% in the x, y, z directions respectively. It is noticed from this figure that emittance increase in the y-direction mainly occurs in the section with the first buncher and element 17. Thus the first three Q magnets are adjusted so as to avoid generating a large beam envelope in the y direction in order to reduce any the nonlinear effect from the buncher.

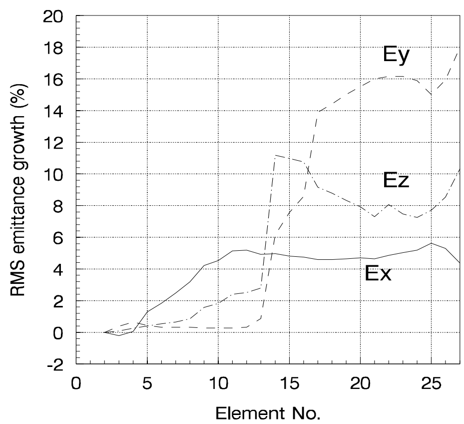

Fig.2. RMS emittance growth vs. the beam line elements for Type A

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 1.8MV/m is needed to generate a 5.9mm 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 4%, 16%, 16% in the x, y, z directions, respectively.

3. CHOPPER DESIGN

The RF deflector is very compact and can provide a high deflecting field. Owing to these characteristics, an adequate deflection can be obtained in such a short beam line. An RF deflector of 432MHz for JHP was designed and a test model was made[6]. In the present MEBT, the 324MHz RF deflector was designed by MAFIA. Because the required RF power P is inversely proportional to R_s/Q_0, with Rs being the transverse shunt impedance and Q_0 the unloaded quality factor:

$$P = \frac{V^2}{\omega_0 \tau \left(R_s / Q_0 \right)}$$

for the rising time τ and a certain deflecting voltage V, the optimized geometry should have a R_s/Q_0 as large as possible for low power and short rising time. The cavity geometry is found with Rs = 4.8MΩ and Q_0= 10,990. To get a rising time of less than 10ns, the cavity should have the loaded Q_L of about 10. So the required RF power for the RF deflector in Fig. 1 is reasonably about 21 kW.

4. ANALYSIS ON UNSTABLE PARTICLES

It is very crucial for the chopper to have as few unstable particles as possible during the RF rising and falling time. It is noted that the beam will not become totally unstable particles during the transient time because the scraper at 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 time, PARMILA simulations with 5000 particles in uniform initial phase space ware conducted. A particle scraper with full width of 20 mm in the x-direction is positioned at element 18. As the RFD field increases toward its full value of 1.4 MV/m, the unstopped particle ratio in a bunch declines, as the curve shows in Fig. 3.

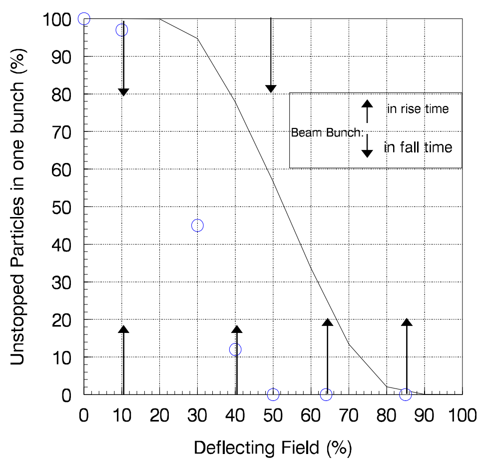

Fig.3 Unstopped particles ratio in one bunch vs the deflecting field variation. The arrows indicate the bunch distribution during the RF rising and falling time. The line indicates at the entrance of DTL and the circles the exit of DTL.

In order to obtain a quick rising and falling 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 rising and falling time in terms of the required full field. Even through it needs power two-times higher, the solid RF power source is still within the commercially available range. There are four micro-bunches during the rising-time when the required full-field value is reached. Also only two bunches appear during falling 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 are almost totally stopped by the scraper. On the other hand, when the field is less than 30-%, the unstopped beam is still within 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, a part of the beam particles is unstable, because some of them can still be stopped by the scraper.

During the rising 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 falling time one bunch is subjected to a field of 50%. Thus, only 58% of particles in the one bunch become unstable. Totally, during transient time, 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 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 2.3m, owing to application of RF deflecteor. With the help of a quadrupole the chopper has a high deflection efficiency. The unstable particle ratio in the RF transient time can be reduced to 0.08% at the exit of the 50MeV DTL.

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