Design of A Medium-Energy Beam-Transport Line With an Anti-Chopper for the JAERI/KEK Project

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Abstract

The medium-energy beam-transport line (MEBT) plays an important role in reducing beam loss in the JAERI/KEK project. A MEBT was designed two years ago, with good beam matching and lower beam loss. To further reduce beam loss during the transient time of the chopper to meet the new requirement from the DTL, a medium-energy beam-transport line with an anti-chopper has been designed. The 3.5m long transport line consists of nine quadrupole magnets, three bunchers and four chopper/anti-chopper cavities. It accomplishes two tasks: matching the beam from the RFQ to the acceptance of the DTL and chopping the beam to produce gaps for injection into the rapid-cycling ring, which follows the linac. An RF Chopper and an anti-chopper have been adopted in the lattice, resulting in a clean chopping effect, and no beam losses during the transient time. Details of the beam dynamics analysis are given.

1 INTRODUCTION

From the point of view of either the pulse current or the average current, the beam intensity in the linac of the JAERI/KEK project is high. Beam-loss control is a very essential requirement in accelerator design and performance to avoid strong radioactivity induced by lost particles. In the linac design of the JAERI/KEK project, the Medium-Energy Beam-Transport line (MEBT), between RFQ and DTL, plays an important role in beam-loss control. It accomplishes beam matching and chopping. These two tasks have a close relation with beam-loss control. Beam matching is very important to minimize the growth of emittance and avoid beam-halo formation, which has been recognized as one of the major causes for beam loss[2]. Clean chopping is also a key point for beam-loss control. In the JAERI/KEK project, 500 μsec long macropulses from the ion source needs to be chopped into sub-pulses for injecting into the following 3 GeV rapid-cycling ring. The sub-pulse consists of a 278 nsec long pulse and a 222 nsec gap. The chopped pulse should have a clean cut at the head and the tail of the pulse so as to avoid beam losses at later parts of the linac or during injection into the ring.

A MEBT for JHF was designed two years ago[1]. It has matching with the acceptance of the DTL, and by using fast RF deflectors as a chopper, it reaches very short rising and falling times. The beam loss during the transient time of the chopper is less than 0.08% at the exit of the 50-MeV DTL, with the help of three scrapers which were mounted between the three DTL tanks. However, in the final mechanical design of the DTL, it is found that there is no space to mount a scraper between the DTL tanks. In this case, much more unstable particles, which are partly deflected by the RF deflector during the transient time, may be accelerated to high energy and lost, or get into the ring. To keep a low beam-loss, it is necessary to further reduce the number of these unstable particles in MEBT. The adoption of an anti-chopper is a good choice for decreasing the number of the unstable particles. Theoretically, using an anti-chopper can cancel all of the unstable particles produced during the transient time.

Based on the previous design of the MEBT, a MEBT with an anti-chopper was designed. It accomplishes matching and chopping, and cancels any unstable particles. To maintain the beam quality, increasing the length of the transport line is not too much, in spite of adding of an anti-chopper. This is a benefit from the asymmetric design. The details of the design are discribed in this report.

2 DESIGN OF THE BEAM LINE

2.1 Feasibility of the Asymmetric Scheme

For returning partly deflected beams back to the beam axis by using an anti-chopper, the symmetric design is a direct idea of using an anti-chopper, just like in the case of the SNS MEBT[5]. When using a symmetric design, the arrangement of elements between the chopper and anti-chopper is symmetric. However, some extra elements are needed just to maintain the symmetry. The key problem is that the symmetric arrangement makes the envelope at the location of the anti-chopper hard to control, and the aperture of the anti-chopper is a bottle neck of the MEBT. For adoption of the asymmetric design, two points should be investigated first: can it be

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sure to return any partly deflected beam back to the beam axis? and finding the relation between the chopper and the anti-chopper.

Consider a beam line with two choppers and two anti-choppers. Let x be the deflection direction; (x_1, x_1'), (x_2, x_2'), (x_{a1}, x_{a1}') and (x_{a2}, x_{a2}') are the beam centroid of the two choppers and the two anti-choppers respectively, where $x_1 = 0$ and $x_1' = 0$. Let

$$R = \begin{bmatrix} r11 & r12 \\ r21 & r22 \end{bmatrix}$$

be the transfer matrix from the second chopper to the first anti-chopper; then,

$$\begin{bmatrix} x_{a1} \\ x_{a1}' \end{bmatrix} = \begin{bmatrix} r11 & r12 \\ r21 & r22 \end{bmatrix} \begin{bmatrix} x_2 \\ x_2' \end{bmatrix} . \qquad (1)$$

Assume that x_0' and kx_0' are the deflected angle provided by the chopper and the anti-chopper respectively, L is the distance between the two choppers and L_a is the distance between two the anti-choppers. One can obtain

$$x_2 = x_0' L \text{ and } x_2' = 2x_0' .$$

To deflect the beam back to the axis, it is required that

$$x_{a1} = kx_0' L_a \text{ and } x_{a1}' = 2kx_0' .$$

Combine with Eq.(1), we have

$$\begin{bmatrix} kx_0' L_a \\ 2kx_0' \end{bmatrix} = \begin{bmatrix} r11 & r12 \\ r21 & r22 \end{bmatrix} \begin{bmatrix} x_0' L \\ 2x_0' \end{bmatrix}$$

or

$$\begin{bmatrix} kL_a \\ 2k \end{bmatrix} = \begin{bmatrix} r11 & r12 \\ r21 & r22 \end{bmatrix} \begin{bmatrix} L \\ 2 \end{bmatrix} . \qquad (2)$$

Because Eq.(2) do not depend on x_0', we illustrate that, for any given L, L_a and k, any deflected beam can be deflected back to the axis. Since matrix R that satisfies Eq.(2) is not unique, there is space to optimize the design when the asymmetric scheme is adopted.

2.2 Design of the MEBT with an anti-chopper

A modified TRACE3D[1,4] is used to describe the deflection behavior of the chopper and the anti-chopper. It includes the element of an RF deflector. The field distribution of the deflector was obtained from MAFIA results, including the fringe fields beside the deflecting electode.

The beam parameters at the entrance of the MEBT (exit of RFQ) are listed in the table 1.

Table 1: Beam parameters at the MEBT entrance

I(mA)	$\varepsilon^{x,y}_{RMS}$(πmm-mrad)	ε^{z}_{RMS}(πMeV-degree)
50	0.200	0.150

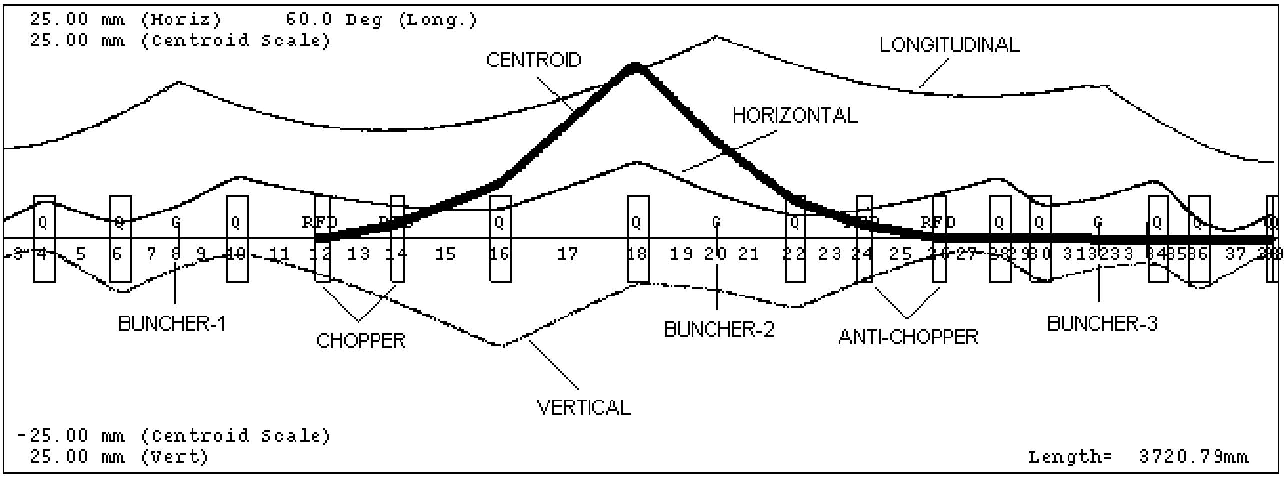

Figure 1: TRACE 3-D output of MEBT with an anti-chopper. The beam profiles in the z, x and y directions are shown respectively. The coarse line traces the beam centroid deflected by two RF choppers and two RF anti-choppers.

The first half of the beam line, upstream of element 18, is mainly aimed at obtaining a large separation between the chopped beam and the unchopped beam at element 18. In this part, the arrangement of elements remains the same as that of the previous MEBT design[1], and uses the same RF deflectors as a chopper. Regardless the head and the tail of a bunch, the edge separation between a full-chopped beam and an unchopped beam is 4 mm at the scraper, when both RF deflectors[3] have a deflecting field of 1.9MV/m (corresponding to 27KW power input). For deflecting the head and the tail of the bunch, much more power input is needed. The maximum capability of the up-to-date solid power supply is 30KW.

The second part of the beam line, downstream of element 18, should accomplish two tasks: returning a partly deflected beam back to the beam axis and matching the unchopped beam with the acceptance of the DTL.

An RF deflector is adopted as an anti-chopper. The electrode gap of the anti-chopper deflector increased to 12mm, while that of chopper deflector is 10mm. The larger gap is required to be sure no particles are lost on the electrode. In the design of figure 1, a deflecting field of 1.7 MV/m is adopted in the anti-chopper. To produce this field, the demanded power input is about 29 KW. When the power input of the chopper deflector is changed, tuning the beam-line parameter of element 18th to 25th can make Eq.(2) be satisfied, without changing the power input of the anti-chopper deflector. Thus, the power input of the anti-chopper deflector can be fixed. The other four quadrupoles, downstream of the anti-chopper, are used to match the transverse phase space to the acceptance of the DTL.

There are three bunchers in the beam line to keep the bunch length from increasing too much. Two bunchers are needed for matching the longitudinal phase space to the acceptance of the DTL. Three bunchers make it easy to control the bunch length at the deflector, and also make it possible to make the bunch length close to each other at the chopper deflectors and the anti-chopper deflectors.

2.3 Elements Used in the Beam Line

Table 2 gives the total elements used in the beam line with the anti-chopper, compared with the previous no anti-chopper beam line. Except for the deflector, all of the elements are the same as those used in the no anti-chopper beam line.

In the previous design, to decrease the number of the partly deflected bunches, the deflector reach a very fast rising time. Because of adopting an anti-chopper, it is possible to properly increase the rising time by changing the coupling of deflector cavity, to obtain higher deflection field.

Table 2: Elements used in the beam line

Anti-chopper	Q	deflector	Buncher	Length(m)
Yes	10	4	3	3.5
No	8	2	2	2.9

3 BEAM DYNAMICS SIMULATION

The beam dynamics of the beam line was studied using PARMILA. Figure 2 shows the simulation results of the emittance growth along the MEBT. Although an anti-chopper was added and the total length was increased to 3.5m, the RMS emittance growth is still less than 16%. No extra emittance growth exists compare with that of the previous no anti-chopper design.

Figure 3 shows the phase space of a 60% deflected beam at the entrance of the DTL. The partly deflected beam is returned back to the beam axis by the anti-chopper, within the acceptance of the DTL.

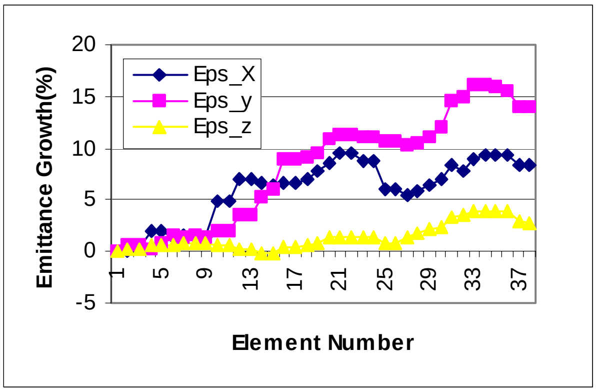

Figure 2: RMSEmittance growth along the beam line.

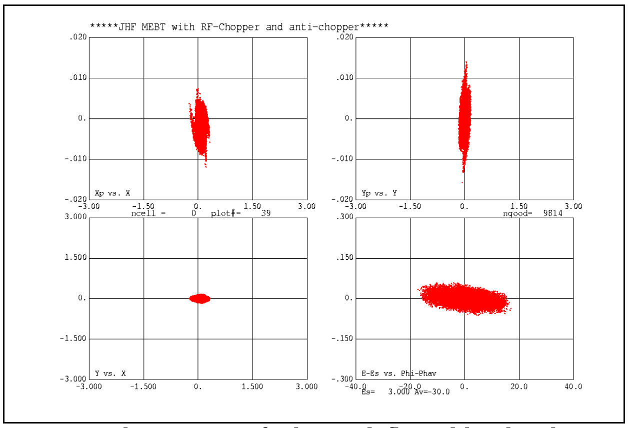

Figure 3: Phase space of a beam deflected by the chopper and the anti-chopper at entrance of the DTL.

4 CONCLUSION

Based on the previous MEBT design, a MEBT with an anti-chopper has been designed for matching and clean chopping beam. A simple analysis has illustrated the feasibility of an asymmetric scheme. The benefit from the asymmetric scheme is that the design is much more flexible and can use different deflectors for the chopper and the anti-chopper. Simulation results show that there is no extra emittance growth due to the use of an anti-chopper, and that all of partly chopped beam can be returned back to the acceptance of the DTL.

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