THE MEBT DESIGN FOR THE CHINA ACCELERATOR DRIVEN SYSTEM

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Abstract

The Medium Energy Beam Transport (MEBT) line plays an important role in transporting and matching the beam from the RFQ exit to the entrance to the next type of acceleration structures while provides enough beam diagnostics for beam commissioning and tuning. The beam dynamics design for the 1.5 GeV China Accelerator Driven System (CADS) is making great progress. In this paper, we will describe the design–both element choosing and beam dynamics study of the 3 MeV MEBT for the CADS project, the multi-particle tracking result with realistic particle distribution from the RFQ exit will also be shown.

INTRODUCTION

To meet the great demand of nuclear transmutation and power generation, the Chinese government is setting off the CADS project, which is aiming at constructing a 15 MW CW proton linac of 1.5 GeV and about 10 mA. The CADS project is structured into three stages from 2011 all the way to 2030s. The first stage is further divided to three steps: step-1 completes the main parts of two independent injectors to higher than 5 MeV by 2013, which include ion source, RFQ and super-conducting cavities, and the whole system should be running at CW mode; step-2 finishes the low energy part of the main accelerator and extends the beam energy to 25 MeV by 2015; step-3 completes the medium energy or the low β super-conducting cavities part of the main accelerator and extends the beam energy to more than 150 MeV with 10 mA CW reliable operation by about 2018 [1].

The two front end injectors—injector-I and injector-II—- of CADS will be designed and constructed independently by the Institute of High Energy of Physics(IHEP) and the Institute of Modern Physics(IMP), respectively. The beam dynamics design for the injectors and main linac design of CADS is making great progress. In this paper, we will discuss the design of the Medium Energy Beam Transport(MEBT) line of injector-I. This MEBT line transports and matches the 3 MeV, 325 MHz RFQ beam to the following Spoke-012 SRF cavity. The element choosing and dynamics study of this MEBT line will be discussed, the multi-particle tracking result will also be shown.

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MEBT DESIGN CONSIDERATIONS

According to the design of the CADS RFQ, the beam energy will be 3.2 MeV at the RFQ exit or in the MEBT [2]. This beam energy in the MEBT is sufficiently low for the space charge forces to have a considerable impact on the beam dynamics. In addition, coupling between transverse and longitudinal planes, RF defocusing and other causes will affect the beam dynamics too. Thus, in order to minimize the emittance growth and halo development along the line, the lattice optics have to be regular and provide strong and uniform focusing [3][4][5][6]. Transversally, the requirement is to generate regular betatron oscillation amplitudes as equal as possible in both planes, and this can be achieved by choosing the right quadrupole gradients. In the longitudinal plane, a strong and uniform focusing usually can be realized by adjusting the voltages of the bunching cavities.

On the hand, the MEBT line usually provides enough beam diagnostics for beam commissioning and tuning, thus, sufficient space has to be reserved for the instrumentation of diagnostic device. As the CADS linac will be running in CW mode, so no chopper line will be needed.

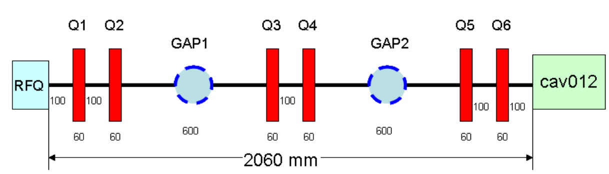

Figure 1: The layout of MEBT for CADS injector-I.

BEAM DYNAMICS

One possible layout of the MEBT line can be seen in Figure 1. This MEBT line is composed of three doublets (Q1 to Q6) and two bunchers (GAP1 and GAP2). The length of each quadrupole is 60 mm, the space reserved for each buncher instrumentation is 600 mm, total length of the MEBT line is 2.06 m. The beam diagnostic devices are expected to be installed in the spaces reserved in between every two elements in the MEBT line and the reserved spaces are assumed to be enough consulting the MEBT diagnostic device instrumentation spaces used in other projects[7][8][9].

The rms beam size in both transverse and longitudinal plane along the MEBT line is shown in Figure 2. The input beam parameters used in the matching are: beam energy

E=3.2 MeV, transverse emittance $\epsilon_{x,y}$=0.21 mm·mrad, longitudinal emittance ϵ_z=0.1775 mm·mrad, and the beam current is I=10 mA. The first doublet slows down the phase advance and ensures a smooth transition from the strong focusing provided by the RFQ, the following two doublets matches the beam to the entrance to the spoke-012 cavities in the transverse plane. Longitudinally, the two bunchers matches the beam to the spoke-012 cavities while keeps a smooth transition of the beam length. The design of the MEBT is symmetric, the drifts are chosen as short as possible while the space for beam diagnostic device instrumentation granted and the quadrupole gradient achievable. The lattice is optimized by keep the beam size or β functions in both transverse planes comparable thus to mitigate the emittance growth and beam halo development in the MEBT line as discussed in the previous section.

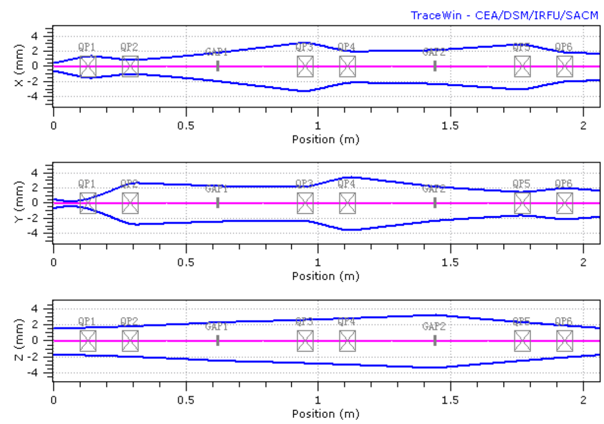

Figure 2: The rms beam size evolution in the MEBT line for CADS injector-I.

The main parameters of the elements in the MEBT line are listed in Table 1. The quadrupoles with positive gradients are focusing in x plane, while the ones with negative gradients are focusing in y plane or defocusing in x plane. Compared to the MEBT elements parameters selected for other projects, the requirements for the CADS element are considered to be achievable and relatively conservative.

Table 1: Main parameters of MEBT elements.

Element	Length (mm)	Radius (mm)	Field gradient (T/m) / Eff. voltage (kV)
Q1	60	25	38.5
Q2	60	25	-25.0
Q3	60	40	16.5
Q4	60	40	-16.1
Q5	60	40	14.5
Q6	60	40	-14.1
Buncher-1	600	20	31.4
Buncher-2	600	20	102.2

MULTI-PARTICLE TRACKING RESULT

The multi-particle tracking has also been carried out for this MEBT design with the real particle distribution generated at the RFQ exit. The number of particles at the RFQ exit is NGOOD=9873, and the distributions are shown in the upper plots in Figure 3. The ellipses in the plots show the Gaussian fitting result with 99% particles. We can see from Figure 3 that the particle distribution in the transverse planes are basically Gaussian, but in the longitudinal plane it is distorted from a Gaussian distribution and there are some halo particles around the beam core.

The particle distribution at the MEBT end is shown in the lower plots in Figure 3. The ellipses in the plots also show the Gaussian fitting result with 99% particles. We can see that after passing through the MEBT line, the transversal distributions are still basically Gaussian, but more halo particle are recognizable around the beam core. Longitudinally, the halo particles are still surrounding the beam core but their distribution are more like a Gaussian.

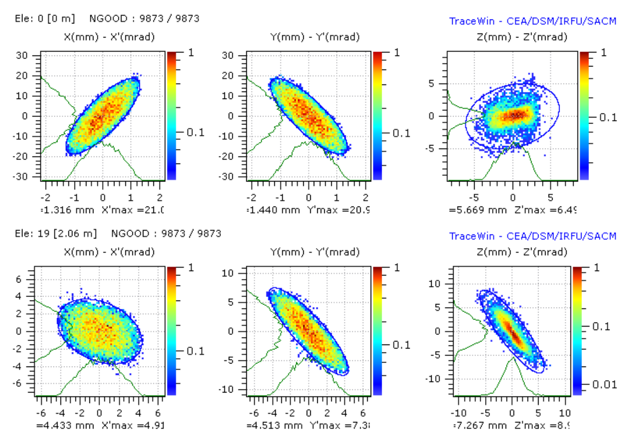

Figure 3: The phase space distributions at the RFQ exit (upper plots) and MEBT end (lower plots).

The rms emittance and halo parameters[10] evolution along the MEBT line are shown in Figure 4. The transverse emittance growth is 1% in the x plane and 2% in the y plane, respectively. The halo parameters are increased by 13% in the x plane and 39% in the y plane, and this growth in particle distribution non-uniformity is also considered to contribute to the emittance growth. The comparatively more uniform beam envelope evolution in the x plane, thus weaker space charge distortion to the beam distribution is considered to be the reason that why the emittance growth and the halo parameter increase in x is less than in the y plane.

In the longitudinal plane, the emittance is decreased by a few percent, while the halo parameters are kept basically the same. We consider this variation in the emittance is due to the particle distribution evolution, which causes the accuracy of the fitting result different, thus the rms emittance decrease.

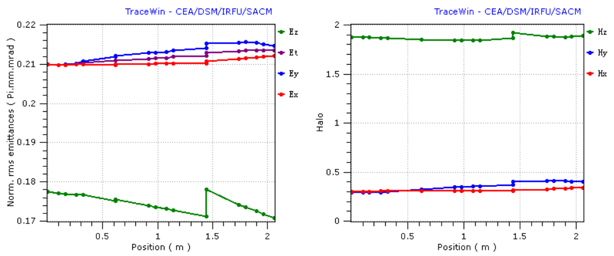

Figure 4: The emittance (left) and halo parameter (right) developement in the MEBT line.

CONCLUSION

In this paper we have studied the design of the MEBT line for the CADS project. The design criteria are introduced and detailed design of the MEBT for injector-I is presented. This MEBT design incorporates 6 quadrupoles and 2 buncher cavities for the uniform transporting and matching the particle to the spoke-012 cavities. The total length of this MEBT is 2.06 m.

Multi-particle tracking results with realistic particle distribution from the RFQ exit are shown. 1% and 2% of emittance growth is observed in the x and y plane, respectively. No longitudinal emittance growth is shown from the simulation. Beam halo growth in the x plane is 13%, while the growth is 39% due to the relatively non-uniformity evolution of beam envelope in the y plane. No further halo development is observed in the longitudinal plane.

The beam diagnostic device implementation scheme is currently under development, the detailed design will be described in later publications.

ACKNOWLEDGEMENT

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