A LOCAL ACHROMATIC DESIGN OF THE C-ADS MEBT2

H. Geng*, Z. Guo, J. Tang, Z. Li, S. Pei, C. Meng
Institute of High Energy Physics, Beijing 100049, China

Abstract

The accelerator of China Accelerator Driven Sub-critical system (C-ADS) consists of two injectors to ensure its high reliability. The Medium Energy Beam Transport line-2 is an essential part of the accelerator to transport and match the beam from either injector to the main linac. This paper presents a local achromatic design, which uses four bending magnets, for C-ADS MEBT2. It is found that both transverse and longitudinal emittance growths can be well controlled to below 20% from MEBT2 entrance to the exit of the following superconducting spoke-021 section. The beam dynamics of MEBT2 will be discussed and the multi-particle tracking results will also be presented.

INTRODUCTION

The C-ADS project is aiming at constructing a 15 MW CW proton linac of 1.5 GeV at 10 mA [1]. To ensure its high reliability, two injectors will be adopted as each of them is a hot-spare of the other. The two front end injectors—injector-I and injector-II— of C-ADS 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 energy for both injectors are chosen to be 10 MeV [5]. The beam transport line from the end of the injector to the beginning of the main linac is called the second Medium Energy Beam Transport line (or MEBT2). Different schemes of MEBT2 has been studied to merge the beam from injector-I to the main linac and tried to avoid emittance growth as much as possible [3, 4]. It is found that bunching cavities are essential in MEBT2 to control beam length growth and thus longitudinal nonlinearity and longitudinal beam emittance growth. One straight forward way to control beam length is to add bunching cavities in the middle of MEBT2 bending section. By doing so, bunch length can be well controlled, but it also brings in the coupling of longitudinal and transverse planes in the dispersive section.

In this paper, we will discuss an alternative design of the MEBT2 line for injector-I. This MEBT2 line uses two local achromatic bending sections to bend the beam from injector-I to the main linac, and introduced bunching cavities in between the two bending sections to control beam length growth. Since the cavities are located at the place where the dispersion function is zero, the big coupling between longitudinal and transverse planes can be avoided. The element choosing and dynamics study of this MEBT2 line will be discussed, the multi-particle tracking result will also be presented.

* Email: genghp@ihep.ac.cn.

MEBT2 DESIGN CONSIDERATIONS

According to the plan of the C-ADS, the beam energy will be 10 MeV at the spoke-012 section exit or in the MEBT2 line. This beam energy is sufficiently low for the space charge forces to have a considerable impact on the beam dynamics. 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 [6-9].

One strict restriction in designing MEBT2 is the space for installing magnets near the converging point from two injectors to the main linac. A quadrupole magnet has a transverse half width of no less than 150 mm, a normal conducting bunching cavity has a length of about 300 mm and half width of 300 mm. So a small bending angle implies a long drift has to be saved before the converging point to reserve enough space for hardware installation. A long drift will cause bunch length growth due to de-bunching effect at low beam energy. A big bending angle helps with hardware installation space, but causes a big coupling between transverse and longitudinal planes, which may result in a big emittance growth.

Another restriction is the bunching cavity voltage. For normal conducting bunching cavities, the typical feasible effective voltage has been estimated to be around 160 kV due to the big heat load from the cw rf source. We are not considering super-conducting cavities as bunching cavities before the converging point because the effective voltage might be too high and also the SC cavities require large space both transversely and longitudinally for cryogenic system installation. As an effective voltage of about 300 kV will be needed in our design before the converging point, it is compromised by using two normal conducting cavities adjacent to each other to get the necessary voltage.

After the converging point, two modified SC spoke-012 cells are adopted to match the beam to the entrance of the main linac and provide backups for cavity failure. Spoke-012 instead of spoke-021 is chosen for two reasons. First, the cell length of spoke-012 is shorter than that of spoke-021, which helps in controlling the bunch length growth. The second is, the peak electric field is lower for spoke-012 cavities. A relatively low peak effective electric field means the required relative field level in spoke-012 cavities can be higher, which helps in avoiding multipacting effect in SC cavities. The SC solenoids have no back-ups as they are believed to be very reliable compared to the SC cavities.

The hot-spare feature of the two injectors also requires a branch of MEBT2 dedicated to transport the beam from the hot-spare injector to beam dump, this breach line will not be described in this paper.

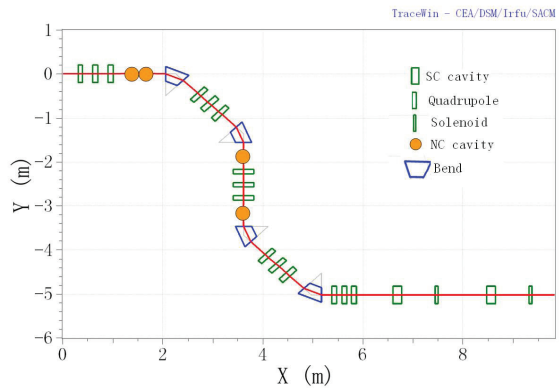

Figure 1: The layout of MEBT2 line for injector-1.

BEAM DYNAMICS

One possible layout of the MEBT2 line can be seen in Fig. 1. This MEBT2 line is composed of five sets of triplets, four bending magnets, four bunching cavities and two units of modified spoke-012 cells. The triplets are used to form achromatic bending section and control transverse beam size. Each of the bending magnets bends the beam by 45 degrees. The four bending magnets form two local achromatic bending section and bending the beam from the injector to the main linac line. All four bunching cavities are located at dispersion free space and are set at −90 degrees to control bunch length growth. The spoke-012 cells are modified such that the two SC cavities are adjacent to each other, one of them will be back up of the other. This configuration of cavities is chosen by comparison with the standard setup of spoke-012 cells, in which the two cavities are separated by one SC solenoid, and it is found that the new configuration can work better than the old one in the backup mode.

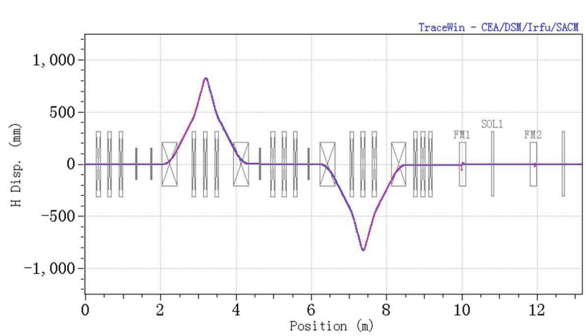

Figure 2: The dispersion function along the MEBT2 line.

The dispersion function along the MEBT2 line is shown in Fig. 2. As can be seen, the maximum dispersion is 0.83 m. The dispersion function is kept small to avoid big transverse and longitudinal couplings. When the beam parameters are changed, the local achromatic condition in the bending section will be kept and the other three set of triplets will be adjusted to form a round beam at the beginning of the first spoke-012 cell, then the the two modified spoke-012 cells will match the beam to the required parameters at the MEBT2 exit. The rms beam sizes in x and y planes are shown in Fig. 3. We can see that the maximum rms beam size in MEBT2 is about 5 mm.

For the longitudinal plane, two normal conducting bunching cavities are located before the first bend, and the other two are in the middle of the two achromatic section. It is tried that the cavities be evenly distributed to keep the maximum bunch length regular and as short as possible. The maximum effective voltage used for each cavity is 145 kV to save some margin. The rms bunch length is shown in the lower plot of Fig. 3. It is shown that the maximum rms bunch length is 7.5 degrees aside from the dispersion section.

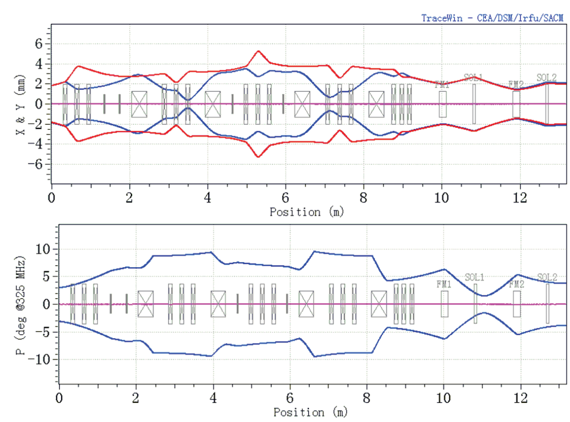

Figure 3: The rms beam size at x and y planes (upper plot) and the rms bunch length (lower plot).

MULTI-PARTICLE TRACKING RESULT

The multi-particle tracking has also been carried out for this MEBT2 design. The input beam distributions are generated by tracking the RFQ simulated particle distributions from the RFQ exit to the beginning of the MEBT2. The number of particles used in our simulations is 99072, and the distributions at the entrance and exit of the MEBT2 are shown in Fig. 4. The ellipses in the plots show the Gaussian fitting result corresponding to 5 times rms emittance. At the MEBT2 entrance (upper plots in Fig. 4), the particle distribution in the transverse planes are basically Gaussian and the particles has a relatively clear edge, while in the longitudinal plane it is distorted from a Gaussian distribution and there is a long tail containing many halo particles

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rotating around the beam core. After transporting through the MEBT2 line (lower plots in Fig. 4), there are more halo particles observable though the particle distributions are still pretty regular in the transverse planes. For the longitudinal plane, the long tail is smeared, while two claws are exhibited.

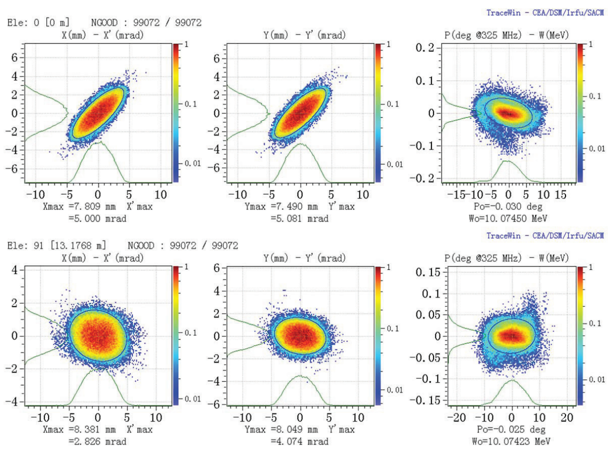

Figure 4: Particle distributions in phase spaces at MEBT2 entrance (upper plots) and exit (lower plots).

The rms emittance and halo parameters[10] evolution along the MEBT2 line are shown in Fig. 5. The transverse rms emittance growths are 8% in x plane and 3% in y plane, respectively. The longitudinal rms emittance growth is 17%. The halo parameters are increased by 17% in x plane and 6% in y plane, while it decreases by 26% in the longitudinal plane. As we can see that the vertical plane has the smallest emittance and halo growth since it is subjected to no nonlinear forces other than space charge effect. The emittance growth in longitudinal is the biggest among all three planes, part of the emittance growth comes from the distribution change of the particles in the longitudinal phase space. This effect can also be seen from the decrease of the halo parameters, which means the particles has become more uniform.

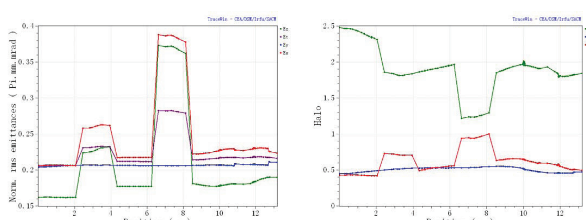

Figure 5: The rms beam emittance and halo parameters evolution along MEBT2 line.

CONCLUSION

In this paper we have studied a local achromatic design of the MEBT2 line for injector-I of the CADS project. The design criteria are discussed and detailed design of the MEBT2 is presented. This MEBT2 design incorporates 5 sets of triplets, four bends, 4 normal conducting bunching cavities and two modified SC spoke-012 cells for the uniform transporting and matching the particle from the injector-I to the main linac. The total length of this MEBT is 13.2 m, the transverse distance from the injector to the main linac is 5 m.

Multi-particle tracking results with simulated particle distribution tracked from the RFQ exit to MEBT2 entrance are shown. 8% and 3% of emittance growth is observed in the x and y plane, respectively. The longitudinal emittance growth is 17% from the simulation. Beam halo growth is 17% in x plane and 6% in y plane, while it decreased by 26% due to the relatively non-uniformity evolution of beam distribution and other nonlinear effects in the longitudinal plane.

Compensation could be done by switching to the other injector if any fault happens before the merging point, otherwise the compensation could be done by switching on the backup cavities in the modified spoke-012 cells. The modified spoke-012 cells can be operated at four different modes in total to fully compensate every cavity failure.

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REFERENCES

[1] Hesheng Chen *et. al.*, "ADS Accelerator Program in China", IHEP-FNAL Workshop on Proton Accelerator, Beijing, February 15-16, 2011.

[2] Z.H. Li, F. Yan *et. al.*, "Beam dynamics of China-ADS linac",Proceedings of HB2012, TH03A02.

[3] H. Geng, J. Tang *et. al.*, "Design of second medium energy beam transport line for China Accelerator Driven System", High Power Laser and Particle Beams, Vol 25, No. 3, 2013.

[4] Zhen Guo, Huiping Geng *et. al.*, "MEBT2 physics design for the C-ADS linac", Proceedings of HB2012, Beijing.

[5] Z.H. Li, F. Yan *et. al.*, "Beam dynamics of China-ADS linac", HB2012, TH03A02.

[6] J. Staples *et. al.*, "Design of the SNS MEBT", Proceedings of LINAC 2000, Monterey, CA , USA.

[7] C. Plostinar, "Front end MEBT studies for a high power proton accelerator", Proceedings of PAC'09, Vancouver, BC, Canada

[8] C. Plostinar, "MEBT design for the RAL front end test stand", Proceedings of IPAC'10, Kyoto, Japan

[9] H. Ouyang *et. al.*, "Study of the design of CSNS MEBT", Chinese Physics C, Vol. 33(7), P 583-589, July 2009

[10] C.K. Allen and T.P. Wangler, "Beam halo definitions based upon moments of the particle distribution", Phys. Rev. ST Accel. Beams, Volumes 5:124202, 2002