NUMERICAL STUDY OF A COLLIMATION SYSTEM TO MITIGATE BEAM LOSSES IN THE ESS LINAC

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Abstract

The European Spallation Source (ESS) will be a 5 MW proton linac to produce spallation neutrons. A high power linac has a very low tolerance on beam losses, typically on the order of 1 W/m, to avoid activation of the linac components; hence, emittance and halo of the beam must be well controlled throughout the linac. A system of collimators in beam transport sections has been studied and tested as a means to mitigate the beam losses in several linacs. This paper presents the result of a numerical study of a collimation system for the ESS linac.

INTRODUCTION

The European Spallation Source (ESS) will be a spallation neutron source based on a 5 MW proton linac, planned to be constructed in Lund, Sweden [1]. During the operation of such a high power linac, beam losses must be avoided as much as possible to prevent damages and activations of its components. A commonly used criterion is to avoid uncontrolled beam losses over 1 W/m and a further detailed study has been performed for the ESS linac [2]. To control the beam loss, a linac must be designed carefully by taking into account influences from various errors [3] and also machine diagnostics must be prepared and performed properly prior to the operation [4]. In addition to the standard adjustments of the trajectory, transverse envelopes, cavity frequency, and cavity amplitude, a system of collimators in a beam transport section has been used or considered to mitigate the beam halo and beam loss in the downstream sections for other ion linacs, such as the SNS at ORNL [5] and the FRIB at MSU [6], and this led to study similar systems of collimators for the ESS linac as well.

Figure 1 shows the schematic layout of the ESS linac as of the end of 2011 [1]. It consists of several normal temperature and superconducting accelerating structures as well as several beam transport lines. Systems of collimators are considered to be placed in the medium energy beam transport (MEBT) section and/or high energy beam transport (HEBT) section. This paper presents a study of collimation schemes for the MEBT. A study of collimation schemes for the HEBT is presented in [7]. The study in this paper is done with the simulation code TraceWin [8] for the lattice and beam parameters in [1]. Please note that the design of the ESS linac has not been fixed yet [9] and particularly the MEBT is planned to be extended to include a chopper and various diagnostic devices. Hence, the focus of this paper is not to determine the final layout of the collimation system but rather to understand the underlying physics and investigate its feasibility.

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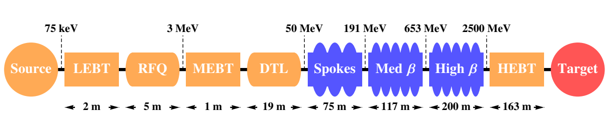

Figure 1: Schematic of the ESS linac as of the end of 2011.

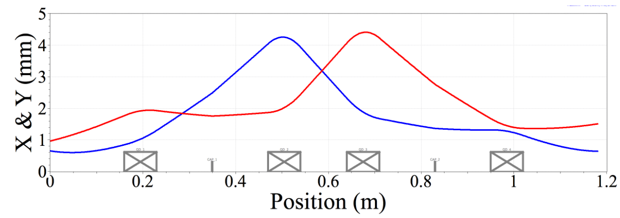

Figure 2: Schematic of the MEBT in the lattice of Fig. 1, consisting of four quadrupoles and two buncher cavities

COLLIMATION SCHEMES

We study two collimation schemes in this paper. The simplest collimation scheme in a beam line is to place multiple collimators separated by the same phase advance to effectively cover the whole angle of the particle distribution in the phase space. Figure 2 shows the schematic layout of the MEBT used in out study. In the limit of the zero current[1], the phase advance from the entrance of the second quadrupole ($s = 0.47$ m) to the exit of the forth quadrupole ($s = 1.02$ m) are about $110°$ in the horizontal plane and $85°$ in the vertical plane. In the scheme referred to as *90° Pair Scheme*, we place horizontal and vertical collimators at these two locations. In the simulation, a horizontal collimator consists of two plates occupying regions $|x| \geq d$, where d is the distance to the center of the beam. A vertical collimator is also defined in a similar way.

As seen in the following, the *90° Pair Scheme* does not work very effectively due to the strong space charge force in the ESS linac. However, by studying evolution of the beam distribution in the MEBT in detail, we could find a scheme which could effectively clean the beam halo with just one collimator for each plane (*Single Scheme*). In the next section, we discuss the evolution of the beam distribution in the MEBT to identify a good location for the *Single Scheme*.

[1]Particles in the halo have a small influence from the space charge force and hence their phase advance is close to the limiting case of the zero current.

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BEAM EVOLUTION IN THE MEBT

Dynamics of the beam in the upstream sections of the MEBT is quite complex [10] and the beam distribution going into the MEBT may not have a simple shape. However, an accurate estimation of the distribution going into the MEBT requires the information of the distribution coming out of the ion source and this information is not available yet. Hence, in the following study, we simply assume a beam with a six dimensional Gaussian distribution goes into the MEBT. Figure 3 shows the horizontal and vertical phase space distributions going into the MEBT (top) and the distributions transported to the end of the MEBT with the TraceWin (bottom). To study the evolution of the distribution in detail, we placed sample particles (points with colors) whose initial radii are 0.5σ, 1σ, $\cdots$, 6σ and initial angles are $\pi/8$, $\pi/4$, $\cdots$, 2π, if observed in the normalized phase space, and transported these sample particles as well. As seen in the figure, the final position of each sample particle depends not only on the initial radius but also on the initial angle due to the strong space charge force. Figure 4 shows the phase advances of the sample particles whose initial radii are 5σ and initial angles range from $\pi/8$ to π, constructed by observing the positions of these particles in the normalized phase space at each element location in the MEBT. The black solid curve in the figure represents the phase advance for the zero current limit. We can see that the particles as far outside as 5σ are still under the influence of the space charge force and the phase advances have a large variation depending on their initial angle. This is why *90° Pair Scheme* is inefficient.

The top two plots of Fig. 5 are the same as the bottom two plots of Fig. 3 but the particles only beyond 5σ are

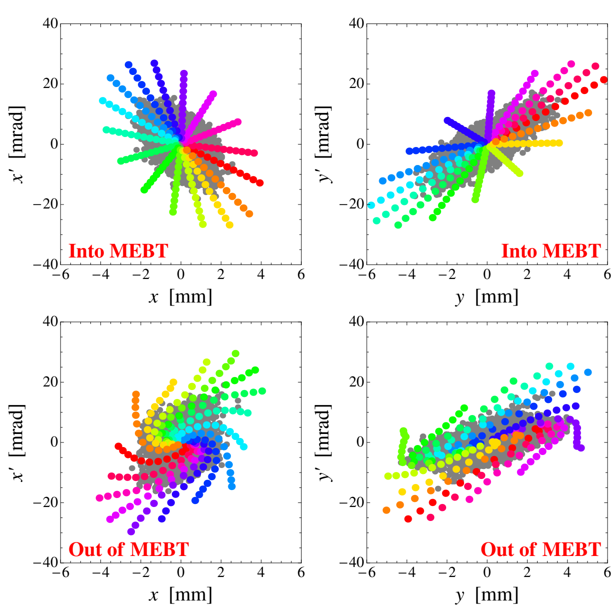

Figure 3: Particle distributions in the phase space going into the MEBT (top) and out of the MEBT (bottom). The gray parts represent the beam core.

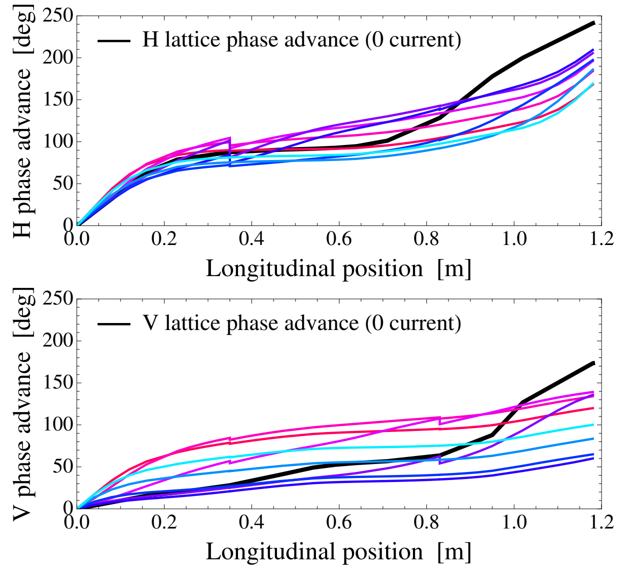

Figure 4: Phase advances of sample particles with an initial radius of 5σ. The color scheme is the same as Fig. 3.

colored this time. The bottom two plots show the horizontal phase space positions of these particle at $s = 0.16$ m (bottom-left) and their vertical phase space positions at $s = 0.04$ m (bottom-right). We can see that, if we place collimators at these two locations, we can clean most of these colored particles ending up beyond 5σ at the end of the MEBT. Hence, for the *Single Scheme*, we place one horizontal and one vertical collimators at these locations.

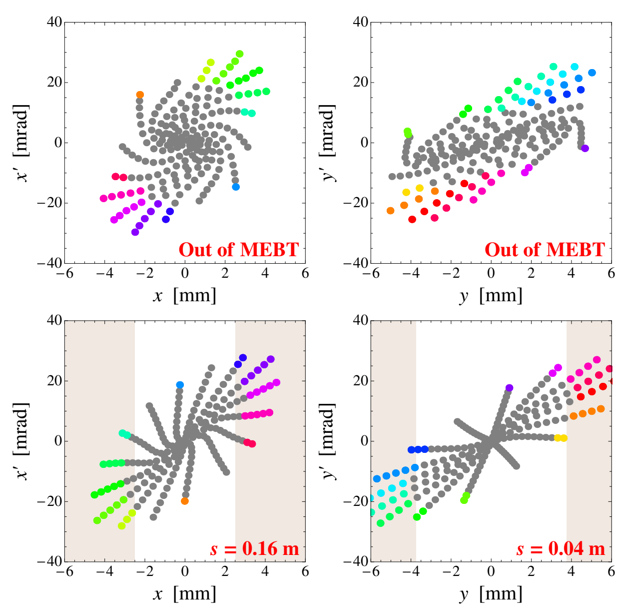

Figure 5: Sample particles ending up beyond 5σ at the end of the MEBT (top) and their phase space positions at the proposed collimator locations for the *Single Scheme* (bottom). Brown parts represent the collimator plates.

BEAM LOSSES WITH COLLIMATORS

In this section, we discuss how the proposed two collimation schemes work when the beam going into the MEBT includes the halo. We model a beam with the halo by adding particles with a four dimensional Gaussian distribution in the transverse planes but with an ideal energy and phase in the longitudinal plane. We choose that the intensity of the halo part is 1% of the main part and its RMS transverse sizes are twice of those for the main part. In the simulation, 2×10^6 particles are transported from the entrance of the MEBT to the end of the linac.

When the beam without the halo is transported, small beam losses under the 1 W criterion are observed in the MEBT and DTL but no loss is observed in the following sections (red bars in Fig. 6). When the beam with the halo is transported, the losses in the MEBT and DTL increase but still no loss is observed in the following sections (gray bars in Fig. 6). Please note that the loss at the transition point from the DTL to the following spoke cavity section increases to almost 10 W, which is ten times of the standard criterion. Blue bars in Fig. 6 shows the losses when the input beam has the halo but also the collimators of the *90° Pair Scheme* are used, where all the collimators are placed at 2.5σ from the center of the beam. If the collimators are placed this tightly to the beam, the losses could be suppressed to the level close to the case of no halo for the input beam. However, these collimators are absorbing a few hundred Watt of power (two peaks in the MEBT in Fig. 6) to achieve this level of suppression so this scheme is not very efficient as predicted in the previous section.

Figure 7 shows the result of the same study as Fig. 6 when we use the *Single Scheme* instead of the *90° Pair Scheme* (gray and red bars remain the same as those in Fig. 6). The *Single Scheme* could also reduce the losses to the level close to the case of no halo for the input beam. As foreseen in the previous section, this scheme is much more efficient than the *90° Pair Scheme* and only about 10 W of power is absorbed by the two collimators to acheive this level of the losses.

Due to the tight aperture in the DTL, the losses are observed only in the DTL in these particular simulations. However, when the losses are reduced with the collimators

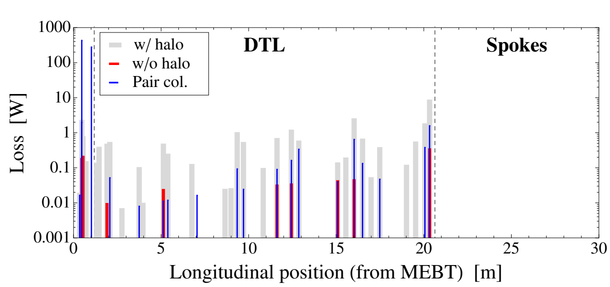

Figure 6: Beam losses for the *90° Pair Scheme*. The collimators must absorb as mush as a few hundred Watt to reduce the losses to the level of the no halo case.

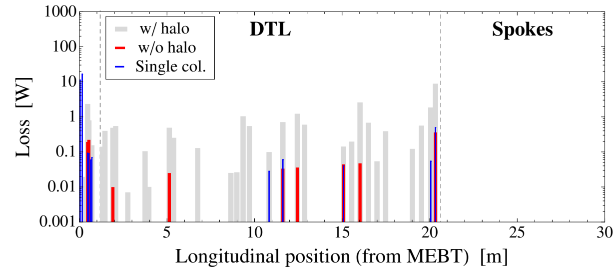

Figure 7: Beam losses for the *Single Scheme*. Each collimator only needs to absorb 10 W unlike the case of the *90° Pair Scheme*.

(with either of the schemes), the halo in the downstream sections of the DTL are also reduced. Therefore, the collimators in the MEBT could influence not only the DTL but also on the farther downstream sections.

CONCLUSIONS AND REMARKS

Two schemes of the MEBT collimation are studied for the 2011 version of the ESS linac. Due to the strong space charge force, the simple *90° Pair Scheme* does not work efficiently and instead the locations of the collimators must be determined by observing the evolution of the beam distribution in a great detail. Because the ideal locations highly depend on beam dynamics in the MEBT, upon making a decision of the final layout, a similar study must be repeated for the final version of the MEBT and also a more realistic beam distribution going into the MEBT, based on a realistic estimation of the beam distribution coming out of the ion source, is desired to be used in the simulation.

REFERENCES

[1] "ESS Conceptual Design Report", ESS Report No. ESS-2012-001, 2012.

[2] J. Stovall and L. Tchelidze, "Estimation of Residual Dose Rates and Beam Loss Limits in the ESS Linac", ESS AD Technical Note No. ESS/AD/0039, 2012.

[3] M. Eshraqi, "ESS Linac, Design and Beam Dynamics", WEPS061, IPAC'11, p. 2637, 2011.

[4] A. Jansson, "Beam Diagnostics for ESS", MOPPR045, these proceedings.

[5] D. Jeon *et al.*, "Formation and mitigation of halo particles in the Spallation Neutron Source linac", PRST-AB **5**, 094201 (2002).

[6] R. York *et al.*, "Technical Challenges in Design and Construction of FRIB", FROBN2, PAC'11, p. 2561, 2011.

[7] H. D. Thomsen *et al.*, "A High Energy Collimation System for the European Spallation Source", MOPPD072, these proceedings.

[8] R. Duperrier *et al.*, "CEA Saclay Codes Review for High Intensities Linacs Computations", ICCS'02, LNCS 2331, p. 411, 2002.

[9] M. Eshraqi *et al.*, "End-to-end Beam Dynamics of the ESS Linac", THPPP085, these proceedings.

[10] A. Ponton, "High Power Proton Linac Front-end: Beam Dynamics Investigation and Plans for the ESS", MOPS039, IPAC'11, p. 688, 2011.

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