THE HIGH ENERGY BEAM TRANSPORT SYSTEM FOR THE EUROPEAN SPALLATION SOURCE

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Abstract

The high energy beam transport for the European Spallation Source (ESS) is described. ESS is currently in its design update phase, which will end ultimo 2012. The ESS will be a high power (5 MW) proton accelerator with the purpose of producing high intensity neutron beams through spallation [1]. We have used the TraceWin code to design the beam optics throughout the high energy beam transport section in accordance with the design objectives.

INTRODUCTION

Neutrons are by their very nature one of the ultimate probes for investigations of material properties. As diverse topics as molecules, medicine, plastics and proteins can be investigated. The extent, to which details can be studied, depends on the obtainable neutron flux, and spallation sources are today the favoured source.

The main parameters for ESS are given in Table 1 and the layout of the ESS include: 1) an ion source, 2) a low energy beam transport system, 3) an RFQ accelerating from 75 keV to 3 MeV, 4) a medium energy beam transport system, 5) a warm linac section accelerating to 50 MeV, 6) a superconducting linac section for acceleration to 2.5 GeV, and 7) finally the high energy beam transport (HEBT) system.

This study concerns the preliminary design of the transport of the beam from the exit of the linac to the target, and includes the expander system designed to provide the requested beam footprint at the target. Furthermore, some comments on the tune-up/commissioning beam dump and the proposed HEBT collimation system will be given. The layout of the ESS HEBT is not yet finalized, and several boundary conditions have not been frozen. Hence several of the elements of the HEBT are still to change.

Table 1. ESS Main Parameters

Energy	Pulse length	Power	Rep. rate	Current
2.5 GeV	2.86 ms	5 MW	14 Hz	50 mA

THE HEBT BASELINE

Optically, the HEBT is divided into four functional sections (cf. fig. 1): 1) a straight underground section (HEBT-S1) to accommodate a collimation system and space for additional cryo-modules for a power or energy or reliability upgrade. 2) A semi-vertical bending section denoted HEBT-S2 bringing the beam from the underground linac tunnel to the target 1.6 m above ground level. 3) A third horizontal section (HEBT-S3), which includes the expansion system to provide the requested beam footprint, and 4) a short horizontal section for a beam dump to be used for, accelerator tuning and commissioning.

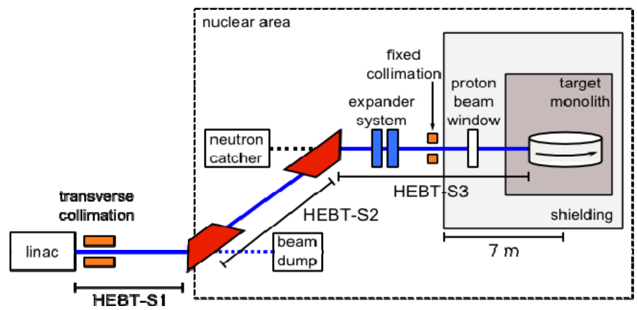

Figure 1: Layout of the linac to HEBT to target interface.

The different elements of the transport system have been designed and optimized to obtain the desired beam sizes, phase advances or Twiss parameters at specific locations. All simulations have been performed using TraceWin [2]. Multi-particle simulations of 100.000 particles have been performed. Space charge are included in all simulations, however this has almost no effect on the transverse motion and a minor effect on the longitudinal motion.

The horizontal and vertical beam envelopes for the HEBT are shown in Fig. 2 and the main parameters for the magnetic elements are given in Tab. 2.

Collimation is placed in the beginning of the HEBT, which allows us to reduce the aperture of all the magnetic elements throughout the HEBT. A quadrupole aperture radius of 40 mm has been chosen, which is roughly 20rms$_{x,y}$. All the chosen magnet apertures result in pole tip fields are within the limits of conventional magnets.

HEBT-S1

To facilitate future upgrades and to minimize losses, the linac focusing structure [3-5] has been kept through S1. The HEBT as designed provides ~ 40 meters space for additional cryo-modules. We suggest a collimation system at the beginning of the HEBT to remove possible beam halos generated in the upstream linac and subsequently reduce losses in the HEBT. The baseline design repeats three periods of the high-beta linac structure and one of these will be used for collimation. The remaining two cryo-modules may either provide an energy increase of ~0.25 GeV or a decrease in the accelerating gradient of the high beta section by ~12.5%.

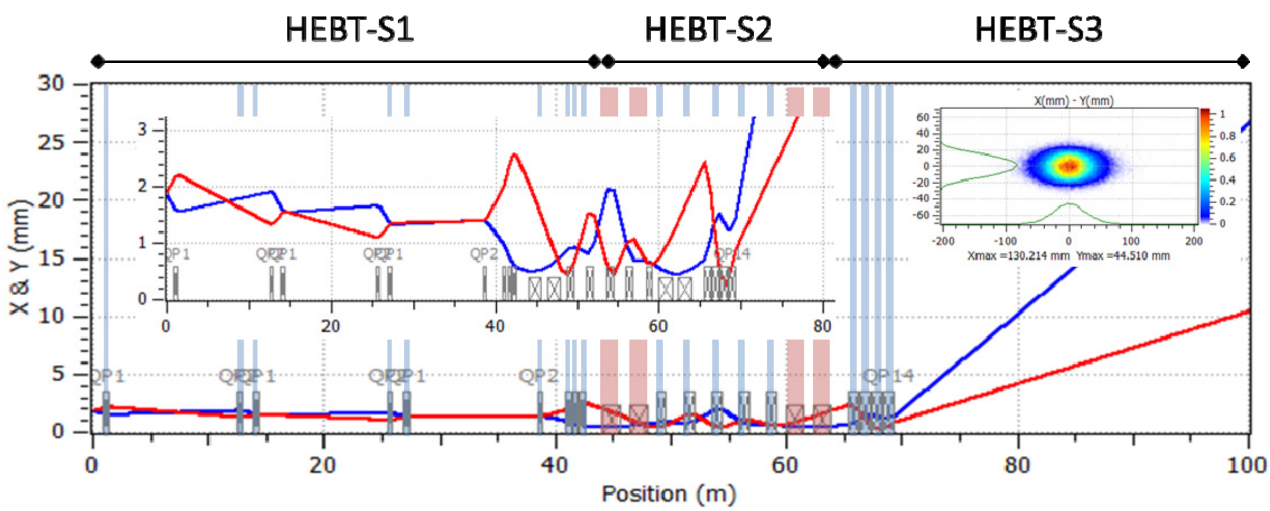

Figure 2: The horizontal (blue line) and vertical (red line) beam sizes (1rms) throughout the HEBT based on a multi-particle simulation of 100.000 particles. The colours denote the type of magnetic element: red = dipoles and blue = quadrupoles. The insets show a zoom-in of the beam sizes (left) and the particle distribution at the target (right).

HEBT-S2

The purpose of section S2 is to transport the beam from the underground HEBT-S1 to the target level 1.6 meters above ground. It will have a system of double bends which results in a change of the focusing structure and introduces a vertical dispersion. HEBT-S2 can be kept overall achromatic by a more or less FDO- or FODO-like structure. A FODO-like structure is chosen as it requires less quadrupoles. The designed HEBT has an elevation of 6.5 meters obtained by 2x2 12° dipoles and five quadrupoles. The elevation of 6.5 meters might still change during the building and tunnel design, and if another elevation it is needed, due to architectural or construction requests, this section will have to be adjusted and re-optimized.

Table 2: Parameters of the HEBT Magnetic Elements

Element	parameters
dipoles	length = 1570 mm aperture (total gap) = 40 mm x 80 mm strength= 1.47 T
quadrupoles	length = 400 or 800 mm aperture (radius) = 40 mm pole tip field < 0.48 T

HEBT-S3

After the beam has been brought up to the target level, another straight section will transport the beam onto the target. The HEBT-S3 baseline design (Fig. 2) includes a simple quadrupole defocusing quartet which produces the desired beam profile at the target. The dimensions and profile of the target footprint are determined by the choice of target, and our beam envelopes are designed to include 99% of the beam intensity within ±70 mm horizontally and ± 25 mm vertically.

The life time of the target is expected to be highly dependent on the beam footprint, i.e. the maximum peak current density, the intensity gradient, and the extent of beam tails. For the (slowly) rotating target wheel, we see no advantage of reducing the tails (as compared to a Gaussian distribution) in the horizontal direction. However, any reduction of the vertical tails and increase in the flatness of the distribution is expected to augment the target lifetime and reduce damage on the target cooling system placed above and below the target wheel. Thus, we propose a profile, which is Gaussian in the horizontal direction and flat in the vertical direction. This can be obtained by octupoles. For more information on the choice of footprint dimensions and alternative expander methods see [6]. The beam envelopes and intensity distribution at the target obtained with the addition of an octupole are shown in Fig. 3 and the octupole parameters are given in Tab. 3.

Table 3: Parameters for the HEBT-S3 Octupole

Element	parameters
octupole	Length = 800 mm aperture (radius) = 25 mm pole tip field = 0.35 T

To separate the vacuum system of the HEBT-S3 from the target area, a proton beam window will be installed. Since this is positioned further upstream of the target the beam current density at this element will be significantly higher. A vertically folded beam profile will also reduce the stress of this critical component.

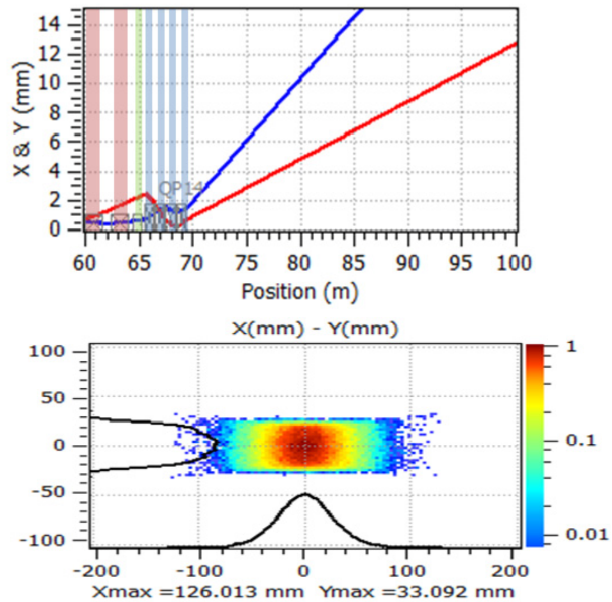

Figure 3: Top: The horizontal (blue line) and vertical (red line) beam envelopes from the position of the last two bending magnets of HEBT-S2 to target, the colors denote the type of magnetic element: red = dipole, blue = quadrupole, and green = octupole. Bottom panel: The beam intensity distribution at target.

Another restriction imposed on HEBT-S3 it the high radiation level from back-streaming neutrons from the target. This means that all magnetic elements mounted here have to be extremely radiation resistant and allow remote operation and exchange. The aperture of the octupole is reduced compared to the rest of HEBT magnets to obtain a high field. This will unavoidably lead to higher losses at this element, as compared to the upstream HEBT elements, but we expect these losses to be small compared to the amount of neutrons from the target.

COLLIMATION

The aim of the ESS is to provide an intense proton beam on target, but some of the protons will inevitably be lost and a strategy for how and where these losses occur have to be developed in order to keep the maximum beam loss below 1W/m for hands on maintenance. In principle both longitudinal and transversal collimation should be designed and installed. However, the momentum spread of the beam is relatively low (< 0.12%) and the dispersion in the HEBT-S2 is small, which makes it difficult but presumably also unnecessary to include an effective momentum collimation. Therefore, only transverse collimation is proposed to capture halos formed in the linac and to protect components downstream from single stray pulses. In order to produce an effective transversal collimation system, a set of two horizontal and two vertical collimators, each consisting of a left/right or upper/lower collimator, positioned with a phase advance of around 90 degrees apart will be installed in HEBT-S1. The sacrifice is losing one of the three repetitions of the linac cells, which could be used for future upgrades. Finally, eventual beam tails formed in the HEBT will be caught by a set of fixed collimators just before the proton beam window, needed to protect both the proton beam window and the main target.

BEAM TUNE-UP DUMP

A relatively small beam dump, for initial commissioning of the linac and for future daily tuning will be installed in the line of sight of HEBT-S1. The HEBT beam dump line will include a simple quadrupole expansion system analogous to the base HEBT-S3 quadrupolar expansion system. A reduced power will be obtained at the dump by a combination of a lower repetition frequency and shorter pulse length. At a repetition rate of 1 Hz, a maximum pulse length for a 20 kW dump will be 160 µs. No significant changes in the beam due to RF beam loading etc. are expected after some tens of µs.

CONCLUSIONS

The ESS HEBT baseline design has been described. The design criteria have been discussed and the preferred solution for each functional section shown. One of the most critical components in a spallation source is the target and an expansion scheme which will produce a more uniform intensity distribution at the target and reduce the tails of the intensity distribution significantly has been presented. The next task is to study the stability of the lattice towards misalignments and dipole and quadrupole errors and thereafter to minimize these unwanted fluctuations by the addition of steerers.

REFERENCES

[1] S. Peggs, “The European Spallation Source”, PAC’11, New York, USA, FROAN1 (2011)

[2] R. Duperrier, N. Pichoff and D. Uriot, “CEA Saclay Codes Review for High Intensities Linacs Computations”, ICCS, Amsterdam, The Netherlands, April 2002, p. 411 (2002)

[3] M. Eshraqi *et al.*, “Design and Optimization of ESS LINAC”, IPAC’11, San Sebastian, Spain, September 2011, WEPS060 (2011)

[4] M. Eshraqi *et al.*, “ESS LINAC, Design and Beam Dynamics”, IPAC’11, San Sebastian, Spain, September 2011, WEPS061 (2011)

[5] M. Eshraqi *et al.*, “Design and Beam Dynamics Study of Hybrid ESS LINAC”, IPAC’11, San Sebastian, Spain, September 2011, WEPS062 (2011)

[6] H. D. Thomsen *et al.*, “The Beam Expander System for the European Spallation Source, IPAC’11, San Sebastian, Spain, September 2011, THPS031 (2011)