THE LAYOUT OF THE HIGH ENERGY BEAM TRANSPORT FOR THE EUROPEAN SPALLATION SOURCE

A.I.S. Holm, H.D. Thomsen and S.P. Møller, Aarhus University, Denmark

Abstract

The status of the High Energy Beam Transport (HEBT) line for the European Spallation Source (ESS) is presented. The HEBT brings the beam from the underground linac to the target at surface level. The main design objectives of the HEBT, such as space for upgrades, producing the desired target footprint *etc*. are discussed and the preferred design is shown.

Large amplitude particles, a halo, are formed in the linac. Hence, every given value of the peak current density at the target is correlated with a certain power deposited outside the beam footprint. This correlation is studied and optimized.

Furthermore, first studies of the vertical stability of the beam footprint and profile on target due to misalignment or mismatch of the incoming beam are made.

INTRODUCTION

The ESS will, when built, be the brightest neutron source in the world. The neutrons are generated by a high power (5 MW) proton beam hitting a horizontally rotating tungsten target. The High Energy Beam Transport (HEBT) line is designed to transport the beam from the linac to the target, while keeping the uncontrollable losses small, below 1 W/m. At the same time the HEBT should provide the requested beam footprint on the target.

The lifetime of the target is mainly determined by the peak current density at the target surface. To reach the desired low peak current density at affordable power levels outside the requested beam footprint it is necessary to alter the shape of the beam particle distribution to a more box-like distribution than that exiting the linac. This can be obtained by utilising the non-linear effect of octupoles [1].

HEBT LAYOUT

The ESS HEBT consists of five sections with specific purposes and specifications.

1. A 100 m long straight section (HEBT-S1), which serves to reserve space for a future power upgrade (current or energy) and/or to increase the overall reliability by adding extra cryo-modules. A collimation system to remove beam halo and protect downstream components may be included here.
2. A semi-vertical dogleg section (HEBT-S2), which transports the beam from the underground linac tunnel to the level of the target while keeping the beam achromatic.
3. A second horizontal straight section, at the target level, (HEBT-S3). The purpose of this section is to match the beam to the requested footprint at the target whilst keeping the peak current density minimal.
4. A second underground section leading to a tuning and commissioning beam dump.
5. A beam line to a future second target.

The 3D-layout of the ESS HEBT is shown in Fig. 1. From the left, S1 divides into three separate lines. Two lines at the S1 level, one line for a second target station and one which goes to the tuning and commissioning beam dump. A third line transports the beam from the S1-level to the S3-level of the target. After the bend, at the target level, a long straight section provides the desired beam profile at the target. At the far right, the target monolith including the target wheel is shown.

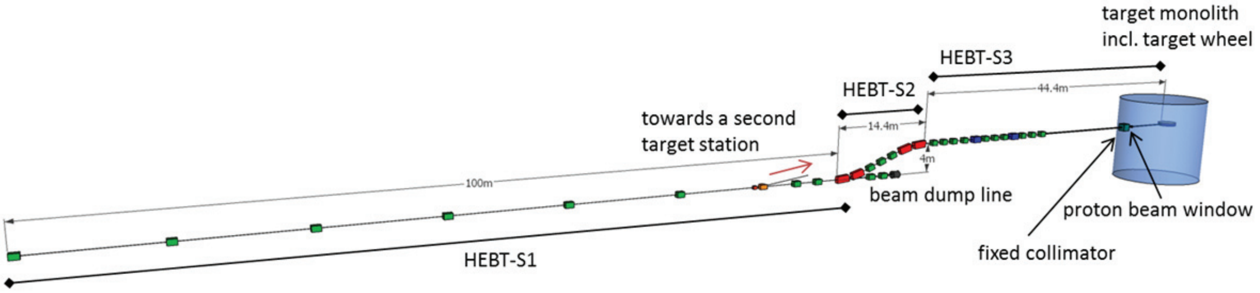

Figure 1: 3D-layout of the HEBT. From the left S1 which divides into a line for a second target station, a line to the tuning and commissioning beam dump, and a line which transport the beam to the level of the target. Following the vertical bending section is a long straight section which shapes the beam profile and at the far right is the target monolith including the target wheel. The colors denote different magnetic elements: green boxes are quadrupoles, red boxes are dipoles, and blue boxes are octupoles.

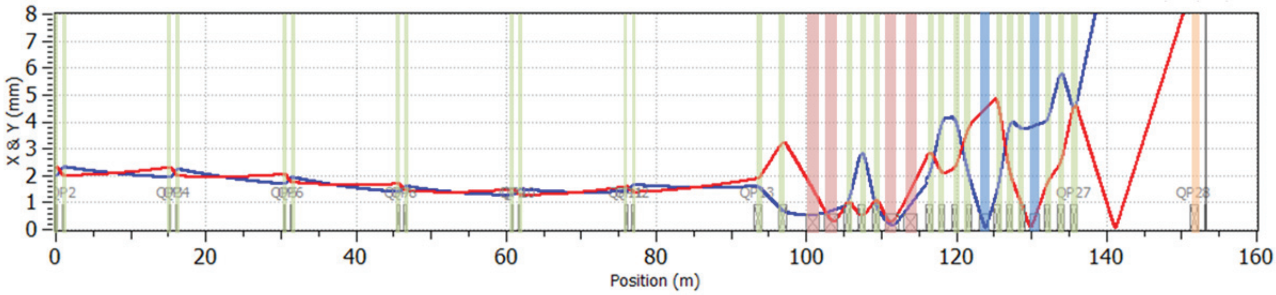

Figure 2: The horizontal (blue) and vertical (red) 1-rms beam envelopes throughout the HEBT. The colors denote different elements: green is quadrupoles, red is dipoles, blue is octupoles, orange is the fixed collimator and grey is the proton beam window.

BASELINE DESIGN

To verify the overall layout of the ESS HEBT, multi-particle ($5 \cdot 10^5$ particles) beam dynamic simulations have been carried out. All simulations are done using TraceWin/Partran [2]. The input particle distribution is a superposition of two 6D-Gaussians, a core and a halo distribution, with widths determined by the linac output (1.90 mm horizontally and 2.74 mm vertically).

$$input\ dist. \propto 0.99 \cdot e^{\frac{-x,y,z^2}{2rms_{linac}}} + 0.01 \cdot e^{\frac{-x,y,z^2}{2(5 \cdot rms_{linac})}}$$

The baseline rms-envelopes are shown in Fig. 2, the horizontal and vertical particle densities along the HEBT in Fig. 3 (A and B), and the obtained beam footprint in Fig. 3C.

In order to facilitate an easy future upgrade, the focusing structure of the high-beta-elliptical section of the linac has been kept throughout HEBT-S1. The current length of S1 is 100 m and six additional linac periods can be inserted. A transverse phase advance of ~35 deg/period has been maintained throughout this section.

S1 may additionally be used for collimation in order to remove beam haloes formed in the linac and to protect downstream components. For more information on this collimator system, see Ref. 3.

The HEBT-S2 is a system of two double bends and three quadrupoles and its sole purpose is to bring the beam from the underground linac tunnel to the target level, while keeping the line overall achromatic.

HEBT-S3 is designed in order to fulfil the requirements for the beam footprint and peak current density at the target. In order to obtain a peak current density of < 64 μA/cm^2 inside the requested footprint (160 mm x 60 mm) while keeping the power deposited outside the footprint low, non-linear components, *i.e.* octupoles are utilized [1]. In order to obtain a maximum effect of the octupoles and to keep the motion in the two planes decoupled, the expansion section has been designed so that a high ratio between the vertical and horizontal beam sizes is obtained at the position of the octupoles. Downstream of the last octupole, three quadrupoles are placed in order to spread the now folded beam over the desired footprint area.

For the design shown here, the peak current density is ~58 μA/cm^2 at the target for integrated octupole gradients of 2300 T/m^2 and 4800 T/m^2. As evident from Fig. 3 (A and B), not all the particles end up within the requested beam footprint and for the present design ~3.3 kW of power is deposited outside the target footprint. To protect the target region, *i.e.* the proton beam window, the target cooling system *etc.*, a fixed collimator will be placed upstream of the target region, which will intercept these large amplitude particles.

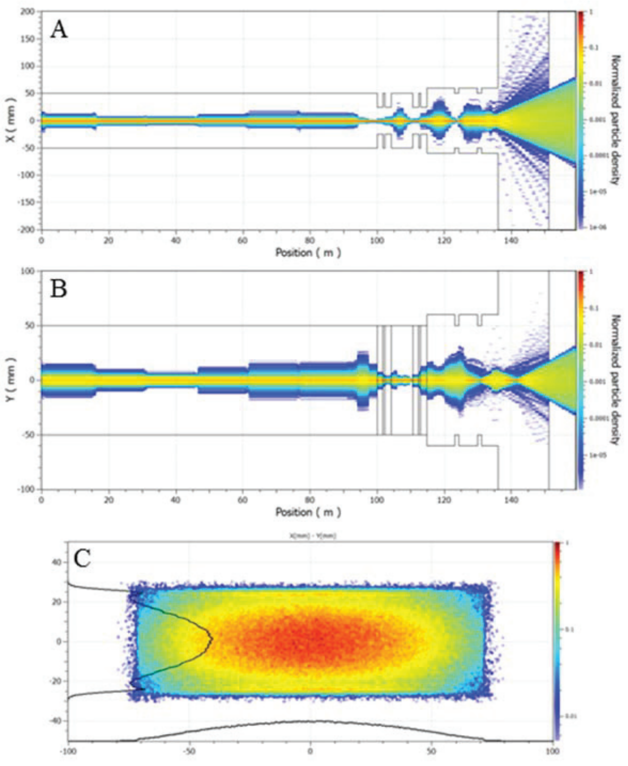

Figure 3: The normalized horizontal (A) and vertical (B) particle density along the HEBT and the resulting beam footprint at the target, with a peak current density of 58 μA/cm^2 (C). The projected beam profiles are shown on a linear scale. The vertical lines at 153 m (A and B) represents the fixed collimator, the power deposited here is 3.3 kW.

Power Deposited at the Fixed Collimator

For the future realistic beam, some kind of halo will always be present, and it will not be possible to obtain a perfect box or parabolic beam profile without particles outside the desired target area. Consequently, every given value of the peak current density is correlated with a certain amount of power deposited outside the beam footprint, and the lower the peak current requested, the higher the power deposited outside the footprint, i.e. on the fixed collimator.

For a given lattice design, the power deposited on the fixed collimator depends on the input particle distribution, *i.e.* the intensity in the halo distribution. The power deposited on the fixed collimator for the baseline design as a function of the amount of halo particles is shown in Fig. 4. The peak current density remains the same for the different halo to core particle ratios. For this double Gaussian input the power deposited on the fixed collimator depends linearly on the amount of halo particles and an extra 3.6 kW is deposited per percentage point of intensity added to the halo distribution. We expect that the future ESS beam will have a halo contribution between 0.5 and 1%.

The flatness of the beam profile, and in turn the peak current density, depends on the octupole strengths. The correlation between the obtainable peak current density and the power deposited at the fixed collimator has been investigated (see Fig. 4). For all octupole strengths the three spreading quadrupoles have been retuned. A decrease in the power deposit of ~25 % with respect to the baseline design results in a 25% increase in the maximum peak current density.

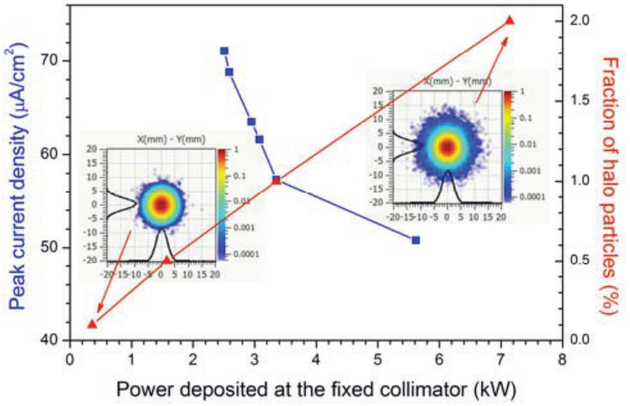

Figure 4: Peak current density at the target (left axis, blue squares) and percentage of halo particles as a function of the power deposited on the fixed collimator (right axis, red triangles). The insets show the input particle distributions for a halo contribution of 0.1% and 2%.

Beam Footprint Stability

As a first attempt to study the stability of the beam footprint with respect to non-nominal beams, the stability of the vertical beam profile has been investigated as a function of the vertical misalignment or vertical mismatch of the beam entering the vertically folding (and first) octupole (see Fig. 5). A 10 % mismatch in the vertical plane means that α_y and β_y are multiplied by 1.1^2.

When the beam is misaligned just upstream of the vertically folding octupole, the position of the steep edges and the beam center of the profile changes slightly. Following a vertical beam misalignment of 0.5 mm the edges and center position move 4-5 mm. Also the beam profile is no longer symmetric and a sharp shoulder appears at one side of the profile. Sharp peaks on the beam profile are acceptable from a target point of view if the intensity of these is below the allowed value for the peak current density. On the other hand if the beam entering the octupoles is mismatched, the position of the edges and centers are unchanged up to a 10% mismatch.

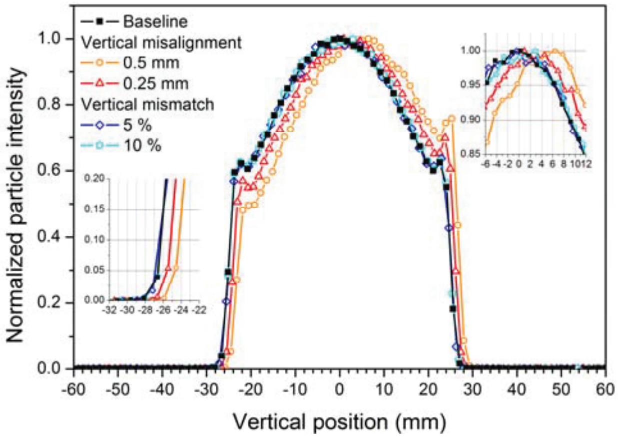

Figure 5: Comparison of the vertical particle distributions at the target surface for different degrees of vertical misalignment and mismatch upon entering the first octupole. The insets show zoom-ins of the edges (left inset) and centres (right inset) of the beam profiles.

CONCLUSIONS

The baseline design of the ESS HEBT has been presented. The main purpose of the HEBT is to provide the requested beam footprint and profile at the target. This is obtained by a combination of defocusing quadrupoles and beam profile shaping octupoles. However, some of the halo particles present in the linac beam will end up outside the requested beam footprint and will impact the fixed collimator. Finally, first studies on beam mismatch and misalignment are shown.

REFERENCES

[1] H. D. Thomsen et al., "The beam expander system for the European Spallation Source", IPAC'11, San Sebastian, Spain, September 2011, THPS031, p. 3478 (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 (2001).

[3] H. D. Thomsen et al. "A high Energy Collimation system For the European Spallation Source", IPAC'12, New Orleans, USA, May 2012, MOPPD072.