BEAM DIAGNOSTICS FOR THE ESS

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Abstract

The European Spallation Source (ESS) is a based on a 2.5GeV superconducting LINAC, producing a 5MW beam. Since it is optimized for cold neutrons, there is no accumulator ring, and hence no need for charge exchange injection. Therefore, unlike most other proposed MW-class LINACs, the ESS LINAC will accelerate protons rather than H- ions. This poses a particular challenge for beam size measurements in the superconducting section. This paper discusses the ESS beam diagnostics requirements, along with some possible instrument design options.

INTRODUCTION

In 2009, the Swedish city of Lund was chosen as the site for the European Spallation Source, following a selection process that also included Spain and Hungary as final contenders. Initially, there were 16 member states represented in the ESS steering committee. Recently, the UK was welcomed as the 17th member.

The ESS is currently in a pre-construction phase, with the goal of updating the non site-specific design report [1], producing a corresponding cost estimate, as well as securing the necessary permits and putting in place the local organization. For the accelerator, this will be done in the framework on the Accelerator Design Update (ADU) project [2].

BASELINE LINAC AND DIAGNOSTICS

The current "Baseline 2010" optics of the LINAC was presented at the end of last year [3], and has now been placed under formal change control. The high level parameters of the ESS accelerator are

- 5MW average beam power
- 2.5GeV protons (i.e. not H-)
- 50mA pulse current
- 352MHz bunch frequency
- 2.86ms pulse length
- 14Hz pulse repetition rate

The beam size along the LINAC varies in the range 1-4mm, depending on location, and the bunch length starts out at about 40ps, and decreases to 10ps towards the end of the LINAC.

Since a solid specification for beam diagnostics requires studies that will be done during the ADU, some working assumptions for beam diagnostics requirements are made in the meantime.

- The beam loss monitoring system needs sufficient sensitivity to keep average losses below 1W/m, and enough time resolution and dynamic range to protect the machine from damage in case of fast beam loss.
- The beam position needs to be measured with an accuracy of a couple per cent of the beam size.
- The time of arrival, or phase, should be measured to a fraction of a degree of RF phase.
- The beam size needs to be measured with an accuracy of 10% or better.
- The bunch length needs to be measured with an accuracy of 10% or better.
- Need to measure halo at the level of 10^{-5} or less of total beam.
- The beam profile on target needs to be measured with an accuracy of 10%. Non-linear elements may be used in the final focus to flatten the profile, so this requirement is best expressed in terms of beam density rather than size.

With the notable exception of BLMs, which need to have a fast response to catastrophic losses, it is assumed that the measurements can be an average over the pulse, although it would be useful (in particular for BPMs to be able to resolve differences in the head and tail. Clearly, these specifications will evolve during the design update phase.

SPACE AVAILABILITY

Source and Warm LINAC

The baseline LEBT employs two solenoids for focussing. It will also house a slow chopper to trim the beginning and end of the beam pulse. The detailed design is likely to evolve, and space for beam diagnostics is one of the parameters that need to be taken into account.

The baseline MEBT consists of 2 FODO cells, and is largely a placeholder at this time. Its design is currently under discussion. The MEBT will likely need to be extended from the current 1m length to allow for the necessary beam diagnostics, as well as a possible fast chopper.

The baseline Drift Tube Linac (DTL) consists of three tanks. Magnets occupy all drift tubes, and therefore the only possible location for diagnostics is between the tanks. There is a single quadrupole between each tank that could house a stripline BPM.

It is foreseen to use a temporary, movable diagnostic bench to commission the LINAC as it is being built up. The possibility of installing it in a permanent side spur at the end of the warm LINAC will be investigated.

Cold LINAC

In order to reduce cryogenic losses, the baseline ESS LINAC has a continuous cryostat and cryogenic magnets. This lack of warm space would mean that any diagnostics must be integrated into the cryostat, which poses problems, as beam diagnostics development must be tightly coordinated with the cryostat design. Also, for some types of measurements no established device exists that is proven to work in cryogenic conditions. To add

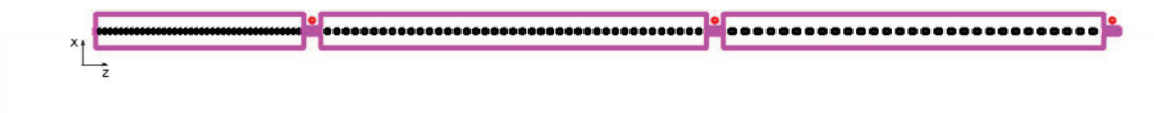

Figure 1: A simplified drawing of the drift tube tanks 1, 2 and 3. The lengths of the tanks are 4 m, 7.4 m and 7.3 m respectively. There is 30 cm in between the tanks and there are 38, 41 and 29 accelerating tubes in the first, second and third tanks respectively. Beam loss monitors are shown in red in the middle of the inter-tanks.

warm space in some locations might require multiple cryomodule designs. Therefore, it is proposed to use a hybrid cryomodule design, with a utility section between cryomodules that could be operated either at room temperature or cold (shield temperature). The magnets would still be cold, and located at the ends of the cryomodule. This solution would decouple the cryomodule design from beam diagnostics development, while still maintaining a single cryomodule design, and limit warm-to-cold transitions to maximise energy efficiency.

The spoke cavity section consists of 15 cryomodules, each consisting to a cell of the doublet lattice. The available space for diagnostics is 46cm in the baseline, likely to increase to 50cm in the hybrid design.

The low and high beta elliptical cavity sections consist of 10 and 14 cryomodules, respectively. As in the spoke cavity secton, each cryomodule corresponds to a cell of the doublet lattice. The available space for diagnostics is also the same as in the spoke cavity section.

HEBT and Target

The HEBT, which doubles as upgrade space, is about 100 m long, and consistes of 11 cells in the baseline. It concludes with an achromatic vertical bend to go from the LINAC tunnel level below grade to the target, which is at 1.6 m above the ground level. Here, there is ample space for diagnostics.

A target beam spot monitoring system is needed. The design for such a system needs to be coordinated closely with the target group, as it has implications for the target shielding.

DETECTOR CHOICES

Beam Loss Monitors

The beam loss monitor system will likely use a combination of ionization chambers, fast PMT-based detectors, and neutron detectors. Some beam loss monitors may need to operate at cryogenic temperatures, due to the shielding effect of the cryomodules, and the push to avoid unnecessary warm space. Diamond detectors may be an interesting option in those applications. Simulations will determine exact location, number and types of monitors used.

Preliminary simulation studies for determining the power deposition in different loss cases is currently ongoing. Several Monte-Carlo tools were chosen to cross check the simulation results. In this paper, some preliminary results are shown for the low energy part of the accelerator. The produced electromagnetic and nuclear showers are simulated and total power deposition is calculated. The low energy part of the accelerator is of a special interest, since it is, in general, harder to measure a loss signal in this region.

In Figure 1, a simplified geometry of the drift tube LINAC is shown. The geometry was constructed in Geant4 and the dimensions were taken from the Linac4 design. The lengths of the tanks are 4 m, 7.4 m and 7.3 m respectively and there is 30 cm in between each of them.

MARS [4] simulations were conducted to obtain the power deposition in the region of interest. Preliminary results for the first inter-tank region are presented in this paper. In Figure 2 the complete nuclear cascade showers are shown for 15 MeV protons hitting the beam pipe at 2 degrees. Black, green and red lines represent protons, neutrons and photons respectively. Both primary and secondary particles are tracked down to very low energies, to have reliable results.

In Figure 3 the results are given for the total deposited power. This shows that for this low energy region of the accelerator it's almost impossible to see the loss signal.

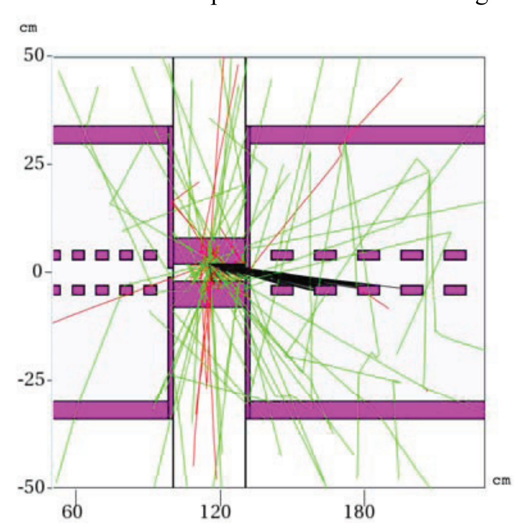

Figure 2: An electromagnetic and nuclear shower produced by 15 MeV protons incident to a beam pipe, at 2 degrees. xz cross section of the geometry is given. Black – protons, green – neutrons, red – photons.

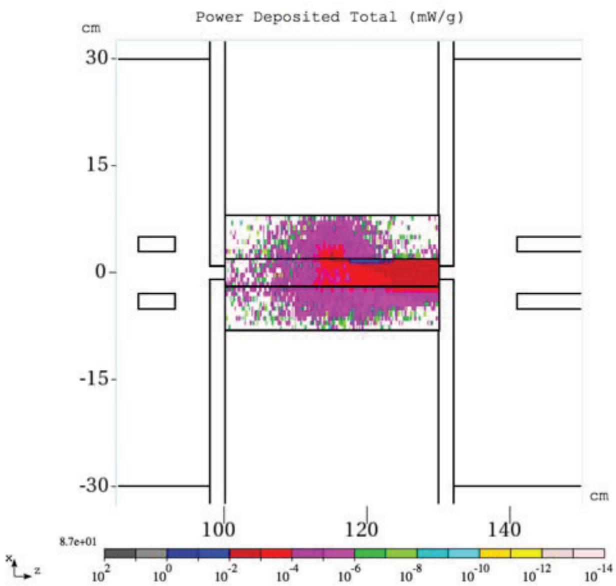

Figure 3: The total power deposited (in mW/g) in the first inter-tank region of the drift tube linac. 15 MeV proton beam hits the beam pipe at 2 degrees incident angle. The beam pipe and the surroundings are estimated to be around 6 cm wide.

Position and Phase Monitors

The beam position will likely use button electrodes, except perhaps in the front end. Processing will likely be digital, and need to have a bandwidth of about 1MHz. It is assumed that the BPM system will also provide the time of arrival (phase) information needed to tune the LINAC.

Transverse Beam Profile

The transverse beam size needs to be measured at transitions between major LINAC sections, in order to ensure emittance preservation. Measuring the transverse beam profile in a high power proton LINAC poses a challenge, as photo-neutralization based laser methods developed for H- cannot be used. Physical wires will break if subjected to too high intensity, and this is a concern particularly in the cold LINAC where wire fragments could contaminate the superconducting cavities. Before laser wires had been demonstrated as a viable technique, a fairly extensive study of wire scanners was made for the SNS SCL [5], indicating that a 32um carbon wire would be the best option. A prototype wire scanner, compatible with the strict SCL vacuum requirements, was also produced before the physical wires were abandoned for the SCL in favour of the laser wire.

In part based on this work, the baseline diagnostics chosen for ESS transverse profile is wire scanners used with a special short diagnostics pulse (of order 100us) at a reduced rate. Alternative methods for measuring beam size, including ionization profile monitors and luminescence monitors, will be investigated in parallel with the aim of avoiding the use of physical wires if possible.

Longitudinal Bunch Shape

Bunches in the ESS LINAC are very short, and therefore options to measure the bunch length are limited. A Feschenko type bunch shape monitors (BSM) [6] is likely the best option. Because it uses a physical wire, it carries the same concerns as wire scanners, especially when used in the cold linac. Note that, in principle, a BSMs could be used as a wire scanner, and this synergy should be investigated further. Alternative methods, such as electro-optical techniques will also be investigated.

Halo

Options to measure halo include wire scanners at high gain, active (instrumented) scrapers and vibrating wires. Possible places to evaluate these methods with beam include SNS and the Fermilab HINS.

Target Beam Spot

A solution similar to the SNS system [7], using a scintillating material deposited on the target nose, will be pursued at ESS. It may be possible to avoid the restriction of using a fiber bundle to bring out the image, by integrating an optical periscope into the design of the target shielding monolith. Potential alternatives (or complements) to the SNS approach would be to capture Optical Transition Radiation (OTR) from the proton beam window, or to coat the window with a scintillator. These options will also be investigated.

SUMMARY

This paper has outlined preliminary specifications for the ESS beam diagnostics, and discussed the types of detectors that could be used. Final specifications and more detailed designs will be developed for the design report at the end of 2012.

REFERENCES

[1] ESS Project Volumes, 2003, http://neutron.neutron-eu.net/n_documentation/n_reports/n_ess_reports_and_more/106.
[2] S. Peggs, “The European Spallation Source”, PAC’11, New York, NY, USA.
[3] M. Eshraqi et al., “ Beam Dymanics & Design of the ESS linac”, ICFA Workshop on High Intensity and High Brightness Beams, Morschach, Switzerland, 2010.
[4] N. V. Mokhov, “The Mars Code System User’s Guide”, Fermilab-FN-628 (1995).
[5] M. Plum, private communications.
[6] A. Feschenko et al., “Bunch Shape Measuring Technique and Its Application For an Ion Linac Tuning”, LINAC’86, Palo Alto, CA. USA.
[7] T. J. Shea, “Status of Beam Imaging Developments for the SNS Target”, DIPAC’09, Basel, Switzerland.