

BEAM INSTRUMENTATION FOR THE EUROPEAN SPALLATION SOURCE

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Abstract

The European Spallation Source, which will be built in the south of Sweden, is a neutron source based on a 5 MW, 2.5 GeV proton LINAC. The project is currently in the design update phase, and will deliver a Technical Design Report at the end of 2012. Construction is expected to begin in 2013. This paper discusses the initial beam diagnostics specifications, along with some possible instrument design options.

INTRODUCTION

The European Spallation Source was sited in Lund, Sweden, at a meeting in Brussels 2009, following long selection process that also included Spain and Hungary as final contenders. At this point, there are 16 member states represented in the ESS steering committee.

The ESS is currently in a pre-construction phase, with the goal of updating the 2003 (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. An overview of the project status is presented in these proceedings [2].

PRELIMINARY SPECIFICATIONS

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/dynamic range to protect the machine from damage in case of (worst case scenario) uncontrolled fast beam loss.
- The beam position needs to be measured with an accuracy of a couple per cent of the beam size, or about 0.1-0.2 mm. The measurement should have a response time to changes of the order of 1 μ s or better.
- The time of arrival, or phase, should be measured to a fraction of a degree of RF phase, or about 2-4 ps. A fast response to changes is not needed to phase the cavities, but may be useful for e.g. LLRF studies.
- The beam size needs to be measured with an accuracy of 10% or better. The beam size is about 2-3 mm at the available locations. The measurement can be an average over the 2 ms LINAC pulse.
- The bunch length needs to be measured with an accuracy of 10% or better. The measurement can be taken as an average over the pulse, or on a single

bunch in the train. There is no need to measure the bunch length of all bunches individually.

- 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%. Since non-linear elements may be used in the final focus, this requirement is best expressed in terms of beam density rather than size.

Clearly, these specifications will evolve during the design update phase.

PRELIMINARY DIAGNOSTICS LAYOUT

The current "Baseline 2010" optics of the LINAC was presented at the end of 2010 [3], and has now been placed under formal change control. Based on this baseline, an initial assessment of beam diagnostics needs for the different LINAC sections has been made

LEBT

The baseline LEBT is 1.6 m long and employs two solenoids for focussing. It will also house a slow chopper to trim the beginning and end of the beam pulse. In the LEBT, there is a desire to measure the source emittance, as well as the beam intensity (current) at entry and exit. Also, the beam position should be measured at two (or preferably three) locations to determine position and angle into the RFQ. Since at this point the beam has no RF structure for pick-ups to detect, this may be done with interceptive devices such as harps or wire scanners. A slit scanner to measure emittance could be implemented using the same harps/wires. A movable Faraday cup may also be required.

RFQ

The RFQ is 4.7 m long, and has no space for diagnostics. The transmission will be measured using instruments in the LEBT and MEFT.

MEFT

The MEFT is currently 1 m long, and consists of 2 FODO cells. Here there is a desire to measure the emittance out of the RFQ, which may be accomplished using a slit scanner or a set of 3-4 harps or wire scanners.. Also, beam position and angle needs to be measured, as well as intensity (current) out of the RFQ and into the DTL. Halo monitors may also be needed here, as well as a movable Faraday cup and/or beam dump.

Fitting all of these instruments, while at the same time allowing space for collimation of the RFQ beam, may require lengthening the MEFT.

DTL

The baseline Drift Tube Linac (DTL) is 19 m long and consists of three tanks. It is very similar to the Linac4 DTL. All drift tubes inside the tanks contain permanent magnet quadrupoles, and therefore the only space for diagnostics is between the tanks. The beam intensity (current) and position will be measured at these locations. There is a single quadrupole between each tank that could house a stripline BPM for this purpose. For beam loss monitoring, about 30 detectors are needed., using a combination of ionization chambers, fast scintillator/PMT detectors and neutron detectors.

Spoke Cavity Section

The spoke cavity section is 61 m long and consists of 15 cryomodules. Each cryomodule corresponds to a cell of the doublet lattice, and houses two quadrupoles. Here, it is foreseen to have one dual plane position pick-up and about three loss monitors per cell. In addition, there should be transverse profile monitors in the first four cells to measure transverse matching, and bunch length monitors in the first three to measure longitudinal matching. A beam current monitor at the beginning of the section is also foreseen, and a second current monitor in the middle of the section may be useful.

Low Beta Cavity Section

The low beta elliptical cavity section is 59 m long and consists of 10 cryomodules. As in the spoke cavity section, each cryomodule corresponds to a cell of the doublet lattice, and houses two quadrupoles. Here as well, it is foreseen to have one dual plane position pick-up and about three loss monitors per cell. A beam current monitor is foreseen at the beginning of the section, as well as transverse profile monitors in the first four cells and bunch length monitors in the first three.

High Beta Section

The high beta elliptical cavity section is 169 m long and consists of 14 cryomodules. Like the previous two sections, the cryomodules corresponds to a doublet lattice cells, and the basic instrumentation plan is the same as for the spoke and low beta sections.

HEBT

The HEBT is about 100 m long. It employs a FODO lattice with 11 cells, and 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. Instrumentation needs here are essentially identical to the three cryogenic sections, except fewer BLMs (2 per cell) are required since there is no shielding effect from cryomodules. An extra profile device (e.g. harp) will be placed at the end of the HEBT, just before the target. Additional instrumentation may also be needed to monitor and tune up the achromatic bend.

Target and Dump

It is critical that the beam delivered to the target has the right distribution. A local beam density that is too high may lead to target damage. Therefore, a target beam distribution monitoring system is needed. A similar system may also be used to monitor the beam size on the tune-up beam dump.

INITIAL COMMISSIONING

It is foreseen to use a temporary, movable diagnostic bench to commission the LINAC as it is being built up. It may be possible to reuse parts of the Linac4 diagnostics bench, if it becomes available, because of the similarities between the two front-ends.

Commissioning scenarios will be developed during the Design Update, including diagnostics specifications for commissioning with low intensity beam.

CRYOMODULE INTEGRATION

The baseline ESS LINAC has a continuous cryostat and cryogenic magnets. This yields a significantly reduced number of warm-to-cold transitions, and thus a lower cryogenic heat load, as compared to an SNS-type segmented layout with warm magnets. However, the lack of warm space also means that any diagnostics must be integrated into the cryostat. This leads to undesirable project dependencies, as beam diagnostics development must precede and/or be tightly coordinated with the cryostat design. Moreover, for some types of measurements, no established method or device exists that is proven to work in cryogenic conditions. To add warm space in some, but not all, locations might require multiple cryomodule designs for the same kind of cavity.

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). 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. It may become the baseline solution in the near future.

INSTRUMENTATION OPTIONS

Beam Position Monitors

The beam position system may use strip lines or buttons, depending on the location. Processing will be narrow band, with a bandwidth of about 1 MHz. It is assumed that the BPM system will also provide the time of arrival (phase) information needed to tune the LINAC.

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.

Transverse Beam Profile

The ESS LINAC accelerates protons rather than H-, so a photo-neutralization based laser wire is not an option. This poses a challenge, particularly in the cold LINAC where physical wires are disfavoured due to contamination concerns. Nevertheless, at this point, the best option appears to be a wire scanner used with a special short diagnostics pulse. Calculations from the SNS indicate that the wires should survive pulses of about 100 us, although these calculations should be redone for ESS parameters. Alternative methods for measuring beam size at ESS will be investigated, with the aim of avoiding the use of physical wires.

Longitudinal Bunch Shape

Bunches in the ESS LINAC are very short (10-40 ps), and therefore options to measure the bunch length are limited. Electro-optical techniques are fast enough but may not be robust against radiation damage. Feschenko-style bunch shape monitors (BSM) may be the best option. Ideally, they would be combined with the wire scanners, by sharing the same space and wire positioning mechanism.

Halo

Options to measure halo include wire scanners at high gain, active (instrumented) scrapers and vibrating wires.

Target Beam Spot

A solution similar to the SNS system [4], 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 it 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, both in terms of sensitivity and location for various types of measurements. An overview of the various types of instruments currently planned in different parts of the LINAC is given in Table 1.

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.
- [3] M. Eshraqi et al, "Beam Dynamics & Design of the ESS linac", ICFA Workshop on High Intensity and High Brightness Beams, Morschach, Switzerland, 2010
- [4] T. J. Shea, "Status of Beam Imaging Developments for the SNS Target", DIPAC'09, Basel, Switzerland.

Table 1: Overview of Current Instrumentation Plans. Numbers are Approximate and Subject to Change

Section	Beam Loss	Beam Position	Beam Current	Transverse Profile	Emittance	Bunch length	Faraday Cup	Halo
LEBT			2	3	1		1	
RFQ		-	-	-	-	-	-	-
MEBT		4	2	3	1		1	2
DTL	30	3	2					
Spoke	45	15	1	4		3		tbd
Low Beta Elliptical	30	10	1	4		3		tbd
High Beta Elliptical	42	14	1	4		3		tbd
HEBT	22	11	1	5		3		tbd