BEAM DIAGNOSTICS FOR ESS

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Abstract

The European Spallation Source (ESS), to be built in the south of Sweden, will use a 2.5 GeV superconducting linac to produce the world's most powerful neutron source. The project is currently in a pre-construction phase, during which the linac design is being updated. This paper describes the current plans for beam diagnostics in terms of requirements, number and locations of different systems, and possible technical solutions.

INTRODUCTION

The European Spallation Source (ESS) is a 5MW linac-based neutron source, which will be built in Lund, Sweden. There are 17 member states represented in the ESS steering committee at this point.

The project is currently in a pre-construction phase. A conceptual design report [1] was recently released, and a technical design report along with an updated cost estimate is planned for the beginning of 2013. An overview of the current project status is presented in these proceedings [2].

DIAGNOSTICS REQUIREMENTS

Some of the most important requirements for the ESS beam diagnostics are

- The beam loss monitoring system needs sufficient sensitivity to keep average losses below 1W/m, and should be able to provide an abort signal in 5us in case of excessive losses.
- The beam position should have a resolution of a couple per cent of the beam size, or about 0.1 mm. The measurement should have a response time to changes of the order of 1 μs 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% of the beam size (which is about 2-3 mm at the available locations). The measurement can be an average over the 2 ms LINAC pulse for non-invasive methods.
- The average 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 density on the windows, dumps, and target need to be measured with an accuracy of 10%.

These specifications may evolve during the design update phase.

CURRENT DIAGNOSTICS PLANS

The ESS LINAC optics is placed under configuration control, and, the latest baseline layout was released in May 2012 [2]. The assessment of diagnostics needs have been adjusted accordingly.

LEBT

The details of the LEBT design are still under discussion. The baseline LEBT is 2.1m 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.

MEBT

The MEBT[3] will be 3 meters long and consists in 3 triplets, a fast chopper will also be installed in the MEBT. In this line, the 6D beam phase space will be measured. The transverse beam emittance will be measured with a slit and grid system, similar to the LINAC4 slit design. The longitudinal beam profile measurement will be performed with a Beam Shape Monitor (BSM), likely of the Feschenko type.

In addition, a set of 4 wire scanners will be used to measure the beam profile and transverse halo, 6 BPMs will be for TOF and position measurement, and finally two BCT will be inserted et the beginning and at the end of the line for intensity and transmission measurement. A movable Faraday cup and/or beam dump may also be needed to avoid losses in the DTL section during measurement.

DTL

The current baseline Drift Tube Linac (DTL) consists of four tanks. It as evolved from a Linac4-like design towards a more SNS-like design. This has some important consequences for the diagnostics. The magnetic lattice now has empty drift tubes allowing for the introduction of in-tube BPMs. Moreover, the inter-tank regions no longer have powered quads, so there is space for a diagnostics box housing a wire scanner and a faraday cup.

Superconducting Linac

The entire cold linac is a doublet lattice with one or two cryomodules per cell, and dedicated space for beam

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diagnostics between the warm magnets in the doublet. Here, it is foreseen to have one dual plane position pick-up per magnet and three loss monitors per cell. In addition, each major section (spoke, medium beta and high beta) should have 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 each section is also foreseen.

HEBT

The HEBT[4] is about 100 m long. Most of it employs the same doublet lattice as the high-beta elliptical lattice, but with missing cryomodules. 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.

Target and Dump Spurs

At the end of the HEBT there is a switching magnet that can send the beam either to the target of the tune-up dump. The target spur has 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. Additional instrumentation may be needed to monitor and tune up the achromatic bend. A profile device (e.g. harp) will be placed at the end of the line just before the target.

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. The same is true for the proton beam window, which separates the accelerator vacuum from the target helium atmosphere. A similar system may also be used to monitor the beam size on the tune-up beam dump.

INITIAL COMMISSIONING

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

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.

INSTRUMENTATION OPTIONS

Beam Position Monitors

Most of the BPMs will be of the button type, similar to the ones at XFEL. Several variants of button BPM will be needed due to different aperture in the MEBT (32mm), Spoke section (60mm) and Elliptical section (100m) of the linac.

In the DTL drift tubes, special strip line BPMs will be needed. These will likely be based on the corresponding design for the SNS. A third type of wide-aperture, linear BPMs may be needed in the beam expander section before the target.

Essentially the same readout electronics will be used for all BPMs 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, as well as an estimation of the beam intensity.

Beam Loss Monitors

Ionization chambers will be the main beam loss detector. SNS or CERN LHC type detectors may be used, and are currently being evaluated. Fast PMT-based detectors and neutron detectors will also be used in some locations.

Transverse Beam Profile

Wire scanners will be used with a special short diagnostics pulse. In the warm linac section, the calculations show that carbon wire will survive if the beam pulse is reduced to 100 us and 1 Hz repetition rate, nevertheless the thermionic emission can be an issue in the MEBT.

Recent studies performed at GANIL show that carbon wires are incompatible with superconductive cavities, so tungsten wires are foreseen for wire scanners in the cold linac. Due to the lower stopping power at high energy, these wires will survive if they used with a short diagnostic pulse.

Above 200 MeV, the profile will be reconstructed by sampling the shower created by the wire with a segmented scintillator; the type and the geometry of the detector are still under studies.

Alternative methods for measuring beam size at ESS will be investigated, with the aim of avoiding the use of physical wires as much as possible, and allowing the measurement of beam size during regular operations. Methods in investigation are residual gas ionization (IPM) [4], luminescence (LPM) [5] and an electron scanning method [6].

Longitudinal Bunch Shape

Bunches in the ESS LINAC are very short (10-40 ps), and therefore options to measure the bunch length are limited. The very short bunch length, combined with a relatively low velocity and wide aperture mean that Feschenko-style bunch shape monitors (BSM) may be the best option. Several variants of such a monitor will be evaluated.

Halo

Halo measurement will be performed at different locations. These measurements are foreseen in the MEBT and in the transition between the warm linac and the cold linac. For this, wire scanner with high gain and high dynamic range can be used.

In the cold linac, this method cannot be used and different options are under investigation like diamond

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detector or Cerenkov fiber, both detectors are not able to measure the beam profile.

In the HEBT line, a wire scanner with a telescope in counting mode can be used to measure beam profile and transverse halo.

Within the target monolith, thermocouples surrounding the physical aperture will be used to measure position of the beam envelope.

Target Imaging

Building on the experience at the SNS, imaging systems will be developed to monitor the beam at the window, target, and dumps. The baseline solution employs luminescent coatings on beam-intercepting surfaces. Due to the challenges presented by the ESS application, alternative and redundant solutions are also being explored. These include gas fluorescence, wire grids, and optical transition radiation.

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 Conceptual Design Report

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

Section	BLM	BCM	BPM	Slit (H+V)	Grids (H+V)	FC	WS	Non-invasive/ optical/ imaging	Halo	BSM
LEBT		2		1	2	1		1		
MEBT		2	6	1	1	1	4		2	1
DTL	30	4	8			4	4			
Spoke	42	1	28				4	4	2	3
Low Beta Elliptical	48	1	32				4	4	2	3
High Beta Elliptical	45	1	30				4	4	2	3
HEBT (to switch)	23	2	32				4	4	2	3
Target Line	26	2	14		1		2	4	3	
Dump Line	9	1	6		1		1	2	1	
Total	223	16	156	2	5	6	27	23	14	13

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