BEAM DIAGNOSTICS FOR ESS COMMISSIONING AND EARLY OPERATION

A. Jansson, M. Eshraqi, S. Molloy,
European Spallation Source ERIC, Lund, Sweden

Abstract

The ESS linac design has evolved over time and is now quite stable. Recently, there has been a focused effort on developing more detailed installation and commissioning plan, and related to this, the plans for diagnostics has also been reviewed. This paper presents the updated diagnostics suite. Many of diagnostics systems will be developed by in-kind partners across Europe.

INTRODUCTION

The ESS linac optics design is placed under chance control, and has only seen minor adjustment in the recent years[1]. Lately, focus has been put on commissioning and early operations planning[2].

In the past year, a task force was put in place to review the diagnostics layout, with special focus on commissioning and early operation. The authors of this paper were the core task force members representing Diagnostics, Beam Physics and Linac Integration, although many others provided input. The task force recommended some adjustments to the previous layout[3]. Further minor adjustments have been made in discussions internally and with in-kind partners. Typically triggered by integration difficulties, and supported by further beam physics studies. This paper provides a cumulative summary of changes and reviews the current status.

DIAGNOSTICS LAYOUT

LEBT

The LEBT contains a Faraday Cup and an Allison Scanner (EMU) for determination of the phase space of the beam leaving the ion source. It also contains two non-invasive profile monitors (NPM's) based on luminescence. The primary purpose of these devices is position monitoring of the un-bunched beam, as well as making measurements of the transverse profile of the beam.

A Doppler Measurement device allows determination of the species fractions. This device will primarily be be used for source commissioning. If a source test stand is built after commissioning, it may be relocated there.

At the exit of the LEBT, integrated with the chopper dump, is an ACCT for current measurements. Beam entering the LEBT will be measured by monitoring the HV power supply current.

MEBT

The MEBT is intended to provide a very complete measurement of the phase space of the beam after bunching by the RFQ. The PBI suite includes three wire-scanners, two non-invasive profile monitors, and a bunch shape monitor. There is also a "slit & grid" system after the chopper dump to allow a 4-D transverse phase space measurement.

The MEBT also have 8 BPMs, one of which will be used as a fast current sensing device (using sum signal) to verify the chopping efficiency, complemented by a Fast Current Transformer (FCT) at the end of the MEBT..

There is one ACCT right before the MEBT, at the exit face of the RFQ. These devices allow measurement of the transmission through the MEBT, while an additional ACCT in the middle of the MEBT allows to identify monitor the unbunched beam from the RFQ (which is lost after the first few quads) as well as chopping losses (which happens in the latter part of the MEBT).

DTL

The DTL originally had three BPMs per tank. These have been redistributed to better match the phase advance in each tank, and the addition of two more BPMs in under discussion.

The two Faraday Cups (FC's) in the DTL are intended to be used as beam stops for commissioning and start-up of this section of the machine.

There are no profile devices foreseen in the DTL. This is due to the fact that beam physics studies show that incoming mismatches are not visible after the first tank, and so must be measured upstream of this [4]. In addition, the quadrupole magnets in the DTL section are PMQ's, and so there is no possibility of tuning the optics after installation.

The DTL inter-tank regions have provision to install additional Faraday Cups, as well as wire scanners and Non-Invasive Profile Monitors.

Cold Linac

The cold linac consists of the Spoke (SPK), Medium Beta (MBL) and High Beta (HBL) Superconducting Linacs. Between cryomodules, warm magnet doublets (Linac Warm Units, LWUs) also house the diagnostics. An ACCT between each section allows the transmission to be measured.

One BPM will be installed per LWU), and the BPM location within the LWU will alternate between the upstream and downstream ends. This serves dual purposes:

- even out the sensitivity for position measurement (by measuring at both QF and QD postions in both planes)

- provide two non-integer ratio time-of-flight baselines, which is required to determine the absolute beam energy from relative beam phase measurement without assumptions on integer phase wrap..

The exception to this is in the LEDP (the first LWU of this section) where two BPMs to allow sufficient coverage of the phase-space in this high phase-advance region. This is also the only location in the cold linac with no cavities between two cavities, allowing a time-of-flight measurement to be done during operations.

As a general rule, the separation in (zero current) phase between two adjacent BPMs should ideally be 90 degrees (or less) in the transverse planes, and the phase advance from a dipole corrector magnet to the closest downstream BPM close to 90 degrees. Since the phase advance per cell is reduced as the beam accelerates, this condition is always fulfilled.

The LEDP also houses a beam stop to allow commissioning of DTL tank 5. Two other beam stops, one located part way through the SPK and another one in the MBL is to allow low-power tuning during machine startup.

A set of three wire scanners each are foreseen in the beginning of SPK (to measure the beam from the DTL), and in the MBL (to measure the transverse phase-space after the increase in RF frequency from 352.21 MHz to 704.42 MHz), as these are major optics transitions.

In principle, Twiss parameters and emittance can be measured using a single wire scanner by means of the quadrupole scan method. While this would reduce the number of physical wires to be placed in the superconducting linac, which would at first glance be preferable due to concerns of wire breakage, the three wire method is preferred since

- The modulation of the quadrupole setting alters the beam envelope and has a risk to induce beam losses. Such losses are of concern particularly for the superconducting cavities since the losses could contaminate the cavity surface and eventually cause degradation of the cavity quality.
- Using separate wires placed at the appropriate relative phase advance reduces the number of wire scans per measurement, which reduces the risk of a wire breakage and prolong bellow lifetime.

At the transition from MBL to HBL, the lattice cell length is unchanged, so there is no major optics transition for the beam entering this section. As a result, only a single wire scanner is foreseen.

NPM's are foreseen to be co-located with some wire-scanner systems, with provisions made to install also in the remaining wire scanner locations. These devices provide value mainly in long pulse, high current mode when wire scanners cannot be used.

To measure the longitudinal phase plane, a Bunch Shape Monitor is also foreseen at the optical transition location entering SPK and MBL. Here, a longitudinal focussing scan analogous to the quad scan is foreseen.

HEBT & Dogleg

The HEBT and Dogleg employs the same LWUs at the cold linac, and has the same configuration of staggered BPMs. ACCTs between the sections measure transmission. An additional ACCT at the switching magnet verify that the beam is sent to the proper location.

A wire-scanner triplet will be installed in the HEBT. Due to the slow rate of phase advance in this region, these three devices require a large spatial separation. No co-located NPMs are foreseen here, as these wires scanners can be sfast and measure full power beam[5].

A2T (Accelerator-to-target beamline)

The A2T is more heavily instrumented than many of the previous sections due to its role in preparing the beam for impact with the Target, and verification that the beam parameters are within the required bounds.

ESS uses a raster scanning system to distribute the beam over the required area of the target[6]. The A2T optics are such that there is an optical waist in both planes 180 degrees downstream of the raster magnets, coincident with a cross-over point in the raster trajectory. This is the location of the neutron shield wall separating the accelerator enclosure from the target.

A wire-scanner in the middle of the raster system, at the action point of the raster magnets, measures the beam 180 degrees out of phase with the cross-over point in the Neutron Shield Wall (NSW). Therefore, this system can be used to confirm the transverse properties of the beam as it passes through the shield wall.

The final BPM is located at the cross-over point in the Neutron Shield Wall, and so should not see any deflections being introduced by the raster system. This BPM will be used to verify that the correct lattice is being used downstream of the raster system.

The operating frequency and field amplitude of the raster magnets will be verified through the use of B-dot loops installed within the magnets. This does not provide verification that the triggering of this system is coincident with the arrival of the beam, so additional BPM's are installed downstream of the raster system in order to view the rastered motion of the beam. The amplitude measured on these BPM's can also be correlated with the amplitude of the raster magnet field and the measured position on the target to provide additional information on beam propagation in this region of the machine.

Target Monolith

The beam parameters in the target monolith must fulfil defined requirements at the Proton Beam Window (PBW) and at the Beam Entrance Window (BEW), i.e., the target surface, both downstream of the NSW.

Therefore, instrumentation needs to be installed in the target monolith[7] in order to verify the precise location of the beam impact on the PBW and BEW, as well as to verify the population of the transverse tails.

Luminescent coating will be applied to the PBW and BEW, and an image of these surfaces will be brought to the outside using all-reflective optics path through the proton beam instrumentation plug[8], in order to measure the time-averaged beam-size at these locations.

A wire-grid system in the PBI plug will be installed as a complement and backup measurement of the transverse beam profile. This is in case of a failure of the luminescent coatings (e.g., due to excessive signal degradation over time).

An aperture monitor device (e.g., based on SEY or thermal measurements) will also be installed on the PBI plug in the Target Monolith.

LOSS MONITORING AND MPS

Many of the needs of the Machine Protection System (MPS) are served by beam diagnostics devices. The primary means of detecting loss in the warm linac is differential current measurement using the ACCTs. This will be complemented with neutron sensitive loss monitors. In the cold linac, ionization chambers are the main means of detecting loss. The best locations for the loss monitors are studied using simulations, and may be further adjusted as a result of experience from commissioning and early operations. Number of deployed detectors may also be updated.

Table1: Number of Diagnostics Systems by Linac Section (the "+1" for BCM and BPM refer to fast detectors)

	BLM	**BCM**	**BPM**	**Allison, Slit/Grid**	**FC/ Stop**	**WS**	**NPM**	**LBM/ BSM**	**Imaging**	**Aperture**
LEBT		1		1	1		2			
MEBT		3+1	7+1	1	1	3	2	1		
DTL	15	5	15		2					
Spoke	52	0	14		2	3	1	1		
Medium Beta Elliptical	36	1	9		1	3	3	1		
High Beta Elliptical	84	1	21			1	1			
HEBT	68	2	17			3		1		
A2T	15	3	14			1	1		2	2
Dump Line	6	2	3						1	1
Total	276	18	101	2	7	14	10	4	3	3

SUMMARY & ACKNOWLEDGEMENTS

Although reported by the core members of the PBI task force, the work of the task force, and subsequent adjustments to the diagnostics scope involved many people in beam physics, diagnostics and the linac group. Table 1 shows a summary of the current planned diagnostics suite.

The actual diagnostics devices will be built in collaboration with several partners, much of it done in the form of in-kind contributions to the ESS project. Past and present collaborators includes CEA Saclay, ESS Bilbao, INFN Legnaro, Sincrotrone Trieste, Oslo University, Cockcroft Institute, SLAC & DESY. Discussions are ongoing with further potential partners.

REFERENCES

[1] M. Eshraqi et al, "ESS linac beam physics design update", MOPOY045, IPAC16, Busan (these proceedings)

[2] ESS-0043907 Warm linac commissioning sequence

[3] ESS-0037620 PBI task force report

[4] ESS-0058035 Preliminary Ideas on the DTL Commissioning

[5] R. Veness et al, "Experience from the construction of a new fast wire scanner prototype for the CERN-SPS and its optimisation for installation in the CERN-PS booster", TUPB061, IBIC15, Melbourne

[6] H. D. Thomsen, S. P. Møller, "Performance of the ESS High Energy Beam Transport under Non-nominal Conditions", WEPRO074, IPAC 2014. Dresden

[7] Y. Lee et al," Lifetime and Operational Criteria of Proton Beam Instrumentation in the *ESS* Target Station", MOPMR021, IPAC16, Busan (these proceedings)

[8] M. G. Ibison et al, "Optical System Design for The *ESS* Proton Beam and Target Diagnostics", MOPMR043, IPAC16, Busan (these proceedings)