ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF087

THE FIRST EXPERIENCE AND RESULTS OF BEAM DIAGNOSTICS DEPLOYMENT AT THE ESS ACCELERATOR

V.Grishin, E.Bergman, B.Cheymol, C.Derrez, T.Grandsaert, H.Hassanzadegan, A.Jansson, H.Kocevar, O.Midttun, S.Molloy, J.Norin, T.Shea, C.Thomas, European Spallation Source ERIC, Lund, Sweden
W. Ledda, Vitrociset s.p.a., Rome, Italy
Olivier Tuske, Franck Senee, CEA, Saclay, France

Abstract

The European Spallation Source (ESS) will produce neutrons for science by subjecting a tungsten target to the high-intensity proton beam from a superconducting linear accelerator [1]. A complete suite of beam diagnostics will enable tuning, monitoring and protection of the accelerator during commissioning, studies and operation. As an initial step toward neutron production, the Ion Source and the 75keV Low Energy Transport Line is installed on the ESS site in Lund, Sweden. To support the commissioning and characterization of this first beam-producing system, a subset of the full diagnostics suite is deployed. This includes the following equipment: a faraday cup, current transformers, an emittance measurement unit, beam-induced fluorescence monitors, and a Doppler-shift spectroscopy system. All aspects of the deployment experience, from acceptance testing through installation, verification, and commissioning will be presented.

INTRODUCTION

The European Spallation Source will provide the highest average intensity proton beam from a superconducting linear accelerator to produce spallation neutrons: high average beam power 5 MW, high peak beam power 125 MW, high availability 95% (Figure 1).

The normal conducting part of linac will accelerate the beam coming for the ion source up to 90 MeV. It consists in an ECR ion source, a Low Energy Beam Transport line (LEBT), a radio frequency quadrupole (RFQ), a Medium Energy Beam Transport line (MEBT) and a drift tube linac (DTL).

The IS and LEBT is in-kind contribution of INFN-LNS, Italy and currently installed in ESS tunnel (Figure 2) [2].

Figure 2: IS & LEBT in ESS tunnel

At the exit of the LEBT, the beam has an energy of 75 KeV (Figure 3).

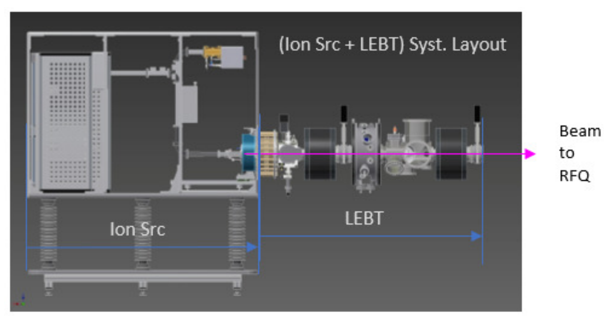

Figure 3: IS&LEBT layout.

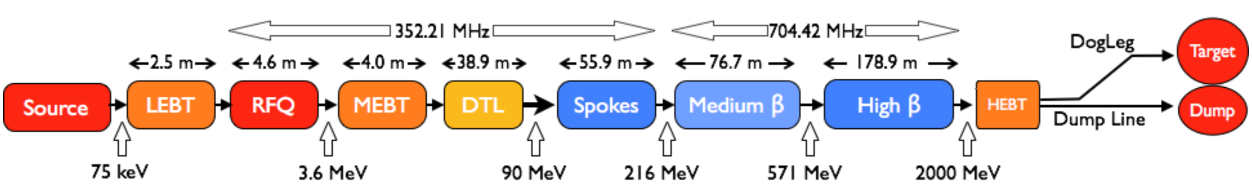

Figure 1: ESS linac.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF087

TECHNICAL CHALLENGES FOR IS&LEBT BEAM DIAGNOSTICS SYSTEMS

The integration strategy had to be tailored and adapted to the situation. All standards were not fully defined. Not all processes were established. Due to schedule pressure we were advised to keep moving forward. Expertise of teams involved allowed to mitigate potential risks. Example of continuous improvement through lessons learned is beam-induced damage of the emittance measurement unit (EMU) (Figure 4).

Figure 4: Molten tungsten of Emittance Measurement Unit.

EMU operated without the beam instrumentation experts and without the complete verification of the system. One of the learned lessons is to invite the experts to establish "safe" beam condition prior to increasing duty factor.

Following the ion source and LEBT beam line elements installation in the ESS tunnel in January 2018, the first controls elements are being deployed in the beam instrumentation racks.

LONG HAUL CABLES

Long haul cables are being deployed and terminated in the front-end building (FEB) area according to the beam instrumentation team instructions. For example, beam current monitor (BCM) ACCT signal from front end (FE) to rack mount electronics are conduit by Heliax cable RFS SCF38-50JFN LSHF, low attenuation for 1MHz (Figure 5). Electromagnetic interference (EMI) concerns, in overall it is preferable to have them well shielded as a triaxle cable, however it is possible to use conduit on coaxial cable instead as a complement.

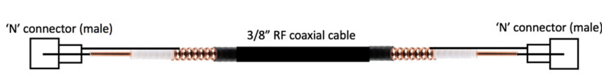

Figure 5: LEBT BCM signal cable.

For cable between the toroid and front end the two beads should be installed at each end of the cable (Figure 6):

- A MnZn ferrite bead. Toroid BW = 1 MHz (max), the signal is low pass filtered at ~13 MHz in the ACCT interface unit (AIU)

- An iron-based nanocrystalline alloy bead. The alloy grade should preferably be a soft B-H loop.

The cable shielding net should be connected to the body of the BNO connector.

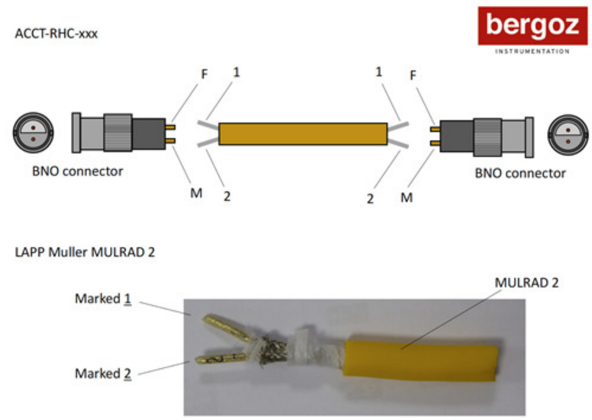

Figure 6: LEBT BCM Toroid cable.

EMITTANCE MEASUREMENT UNITS

One of the two LEBT EMU units was commissioned at INFN-LNS during the last week of January 2017 [3]. The other unit has been damaged. Currently the LEBT EMU one unit is in Lund (Figure 7), one is in Saclay for repair.

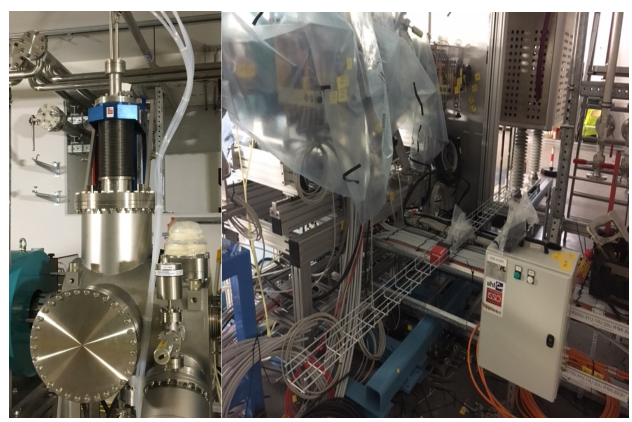

Figure 7: LEBT EMU and the patch box in Lund tunnel.

The EMU, coming from the in-kind contribution of CEA Saclay (France) has been first system fully deployed (Figure 8).

Some challenges during the re-installation of the EMU control into the differently sized Lund rack included reorganizing the electronics and manufacturing new mechanical supports for some of the equipment (Figure 9).

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF087

Figure 8: the EMU controls rack has been fully deployed to ESS FEB rack.

The refitting of a complex system such as the EMU also included issues of electrical safety, e.g. adding fitting protective covers for electrical parts. During the move to the new rack, focus was put on maintaining full functionality of the CEA/Catania setup while at the same time preparing the equipment for porting to the ESS Lund standard components, e.g. Ethercat control of actuators, and using a μTCA environment for data processing. In-rack cabling is being installed before final system's tests can be performed.

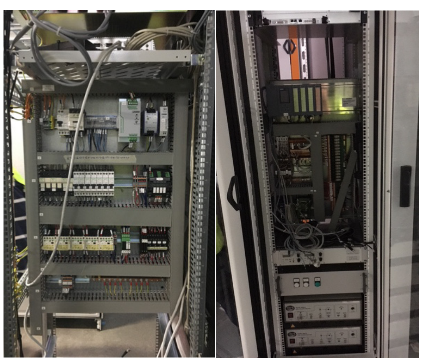

Figure 9: From CEA/Catania set-up to ESS FEB rack.

FARADAY CUPS

The LEBT Faraday Cups (FC) is the primary diagnostic used for the ion source and LEBT commissioning. The FC is designed in order to withstand the full beam power at the exit of the ion source.

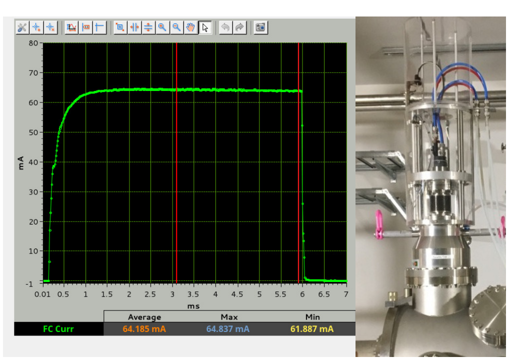

Figure 10: FC commissioned in Catania and in LEBT at ESS tunnel.

FC commissioned in Catania (Figure 10). Machine Protection System (MPS) switches for LEBT FC are ready to be mounted. A study is ongoing with Pantechnik to mount the same spring-based system as on the MEBT FC to the LEBT one, in order to prevent movement in-beam if actuator pressure is lost.

LEBT NON-INVASIVE PROFILE MONITOR

The Non-invasive Profile Monitor (NPM) is designed here to measure the beam position with accuracy better than 100µm [4]. The unit system is based on a camera that is imaging the residual gas fluorescence induced by the beam, and which is surveyed. Fiducialisation of the instrument permits to position the camera in such a way that the centre of the image corresponds to the nominal beam axis. The figure 11 shows one of the units, composed of a camera, a motorised objective lens, and fiduscial points.

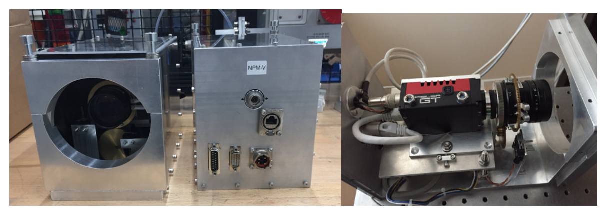

Figure 11: LEBT NPM Horizontal and Vertical units.

To deploy this system, the performance verification has been done in the lab, with survey equipment. The main aspect is to ensure the accuracy of the beam position. The bench test results showed that the accuracy in measuring the position in a global reference system matches the required 100µm. Long-time tests have also been performed, moving the lens to ensure repeatability. After more than 1000 movements, the measured position of the object is repeatable with accuracy better than 0.1% of a pixel.

DOPPLER SYSTEM UNIT

The Doppler system unit (DPL) measures the beam species fraction, by means of a spectrograph. The spectra from the beam induced gas fluorescence also contains electron capture events. The fluorescence emitted during electron capture is Doppler shifted, since the particles are moving with respect to the instrument. The spectrograph and the coupling optics have been designed to deliver the best possible sensitivity and the best possible resolution [5].

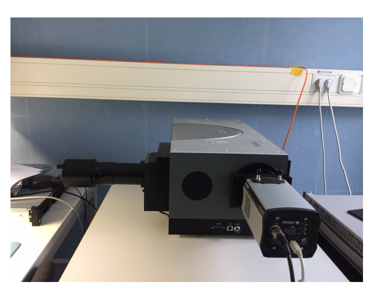

Figure 12: LEBT DPL.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-WEPAF087

The system is shown in Figure 12. It shows the spectrograph, its matching entrance optics and the high sensitive camera. The gas fluorescence is collected by optimised optics assembly and a specially design optical fibres bundle that illuminates the whole spectrograph slits. The collecting optics permits to collect light in a narrow angle with the same efficiency from all points of the observation volume covering the 100mm diameter of the vacuum chamber.

VERIFICATION STRATEGY FOR BEAM DIAGNOSTICS SYSTEMS.

The verification of the performances of the beam instrumentation systems is a critical section of the LEBT installation. The large number of beam instruments in the ESS LINAC requires a well-defined verification workflow and optimization for series acceptance automated testing, from individual field replaceable units' verification to complete systems tests with and without beam.

A detailed test setup and characterization procedure has therefore been produced at ESS for each beam instrument in the LEBT, along with exact measurements conditions. Results are stored in NEXUS HDF5 format using predefined metadata fields. This common structured electronic data format is handled by a test and measurement database managed by the controls group at ESS. Moreover, the use of a common data management system allows tracing back acceptance tests results to laboratory measurement devices, preparing installation batches and extracting added value and installation progress information.

Before implementing a system's test-bench, a test plan is defined from each system components' performances requirements. The corresponding test design document is validated by the system lead to ensure all test requirements are correctly translated. Test coverage is then reviewed, a possible risk assessment is performed if a full coverage is not reached. The actual test system sequence is then implemented in Python using a modular approach.

Emphasis is put on sequential testing using tests timestamps in the produced test-benches in order to state "the instrument is installed and ready for beam" with enough confidence. Systems' components are installed as soon as an installation slot is available, allowing the Beam Instrumentation team to gain experience and progress on the installation learning curve at a fast pace.

During debugging, the relevant tests in each system's acquisition chain are repeated until satisfactory results are obtained. If a problem is well identified and can be isolated within its layer, there is normally no need to repeat all of the sequentially following tests.

Once a system is entirely deployed in the ESS tunnel, a cold check out is performed: this procedure includes testing of the whole instrument on all architectural layers: monitor, front-end electronics, cables, μTCA -electronics, timing, data treatment, publishing, network transmission and machine protection interface. This test will be required after each machine cool-down, and at least once after each shutdown. This test is done without beam.

Commissioning with beam of the verified LEBT systems can then be performed, limiting the amount of shifts needed for this step. The tests with beam aim at eventually verifying the instrument and its control chain under real-world conditions, as well as to verify the correctness of the integration for machine operations. Initial comparisons and cross-calibrations are performed in order to gain confidence in the instrument and start identifying performance limiting factors.

CONCLUSION

IS and LEBT are the first elements, result of a strong collaboration of different teams. We have had issues, of course! We have to extract many good lessons from them in order to avoid the same mistakes. IS and LEBT are the starting point from which ESS has to improve methodology, structure, process and knowledge. The synergy between all parties is essential to avoid decision has to be reconsidered. We have to improve communication with partners. The current schedule: ready for beam on target date is 24 May 2021 with beam on dump at 570 MeV 8 February 2021.

ACKNOWLEDGEMENTS

The authors would like to thank the INFN-LNS team, in particular Lorenzo Neri for their support.

We thank the CEA team for their precious support in the work on the LEBT EMU.

The authors thank Evangelia Vaena and Frithiof Jensen for great support in cable databases.

We would like to thank our Polish collaborators for their support, in particular Krystian Bec and Wojciech Wierba.

REFERENCES

[1] European Spallation Source Technical Design Report, ESS-2013-001, Lund, Sweden

[2] L. Neri et al., Beam commission of the high intensity proton source developed at INFN-LNS for the European Spallation Source, Journal of Physics: Conference Series, Volume 874, conference 1

[3] O. Tuske at al., ESS emittance measurements at INFN Catania, Proceedings of IPAC2017, MOPAB023, Copenhagen, Denmark

[4] C.A. Thomas et al., Design and implementation of non-invasive profile monitors for the ESS LEBT, Proceedings of IBIC2016, TUPG80, Barcelona, Spain

[5] F.Senee et al., Development and commissioning of the Doppler-shift unit for the measurement of the ion species fractions and beam energy of the ESS proton source, Proceedings of IPAC2017, MOPVA037, Copenhagen, Denmark.