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INITIAL PERFORMANCE OF THE BEAM INSTRUMENTATION FOR THE ESS ION SOURCE AND LEBT

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Abstract

The European Spallation Source (ESS) is currently under construction in Lund (Sweden), and its 5 MW of average beam power at repetition rate of 14 Hz will make it five times more powerful than other pulsed neutron-scattering facilities [1]. High-energy neutrons will be produced via spallation by 2 GeV protons on a tungsten target. A complete suite of beam diagnostics will enable tuning, monitoring and protection of the proton accelerator during commissioning, studies and operation. As an initial step toward neutron production, the Ion Source (ISrc) and the 75 keV Low Energy Beam Transport Line (LEBT) have been installed. For the commissioning and characterization of this first beam-producing system, a subset of the ISrc and LEBT diagnostics suite has been deployed. This includes the following equipment: a Faraday cup, beam current transformers, an Allison Scanner emittance measurement unit, beam-induced fluorescence monitors, and a Doppler-shift spectroscopy system. Beam instrumentation deployment and performance verification, as well as the operational experience during the initial beam commissioning, will be presented.

INTRODUCTION

The Ion Source (ISrc) and the Low Energy Beam Transfer (LEBT) line is installed [2] and is being commissioned at ESS, Lund Sweden. During the commissioning phase [3], the beam diagnostics instruments are installed in the commissioning tank, temporarily placed in the position of the RFQ after the collimator, and in the permanent tank between the two solenoids, as depicted in Fig.1. The ESS ISrc [4] and the LEBT diagnostics systems [5] provide beam accounting through beam current measurements with a Faraday Cup (FC) and two current transformers as Beam Current Monitors (BCM). Beam species fractions are measured with a Doppler-shift spectrometer (DPL). With no RF structure to provide a signal for typical beam position electrodes, Non-invasive Profile Monitors (NPM) are installed to measure the transverse position and provide beam centroid measurements at two locations, in the permanent and the commissioning tank. Further details about the beam properties are given by distribution measurements. Beam profile is measured by the NPMs, while emittance is measured invasively by two Allison scanners as Emittance Measurement Units (EMU) located in both the commissioning tank and the permanent tank [6].

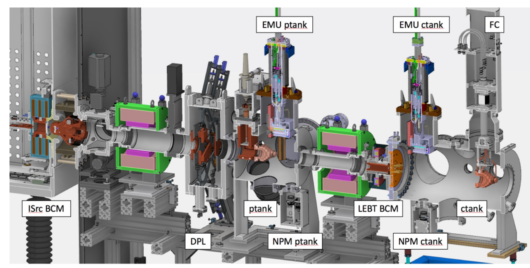

Figure 1: ESS LEBT commissioning configuration.

SYSTEMS PERFORMANCE VERIFICATION

Beam Diagnostics instrument performance is verified primarily in the lab. Each instrument's acquisition chain is then verified without beam during cold check-out, finally enabling beam tests. Verification results are stored in NEXUS HDF5 format using predefined meta-data fields. This common structured electronic data format is handled by a test and measurement database managed by the ESS Controls group. The first beam extracted from the ISrc was measured by the BCMs and FC in September 2018. The ISrc and LEBT diagnostics systems initial performances are presented hereafter.

Beam Current Monitors

Two AC Current Transformer (ACCT) sensors from Bergoz are used and previously described in [7]. The ISrc BCM measures the current from the High Voltage Power Supply (HVPS) to the ISrc high voltage platform, while the LEBT BCM measures the beam current at the location of the LEBT collimator.

Each ACCT includes an extra winding for calibration purposes. A precision current source is used to manually calibrate the two ACCTs with the two calibration windings being connected in series. The calibration process consists of correction/compensation of the ACCT scale factor, DC level and droop factor. The BCM system design is based on a Bergoz ACCT-E module and on the microTCA platform [8]. BCM specifications include 1 MHz overall bandwidth

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(with the ACCT cable being shorter than 20 m), ± 1% Full Scale (FS) accuracy, 1% (RMS) FS BCM noise, and 1% signal overshoot. Lab tests and beam measurements confirm consistency with the specifications.

Faraday Cup

The LEBT Faraday Cup (FC) was used for beam current measurements either in the permanent or commissioning tank. The FC withstands the full beam power (i.e. 6 ms long proton pulses, with a repetition rate of 14 Hz and 75 mA beam current). The FC motion control, the RMS noise (< 100 µA) and the bandwidth (of 10 MHz) of its acquisition chain was verified using a precision current source. The current signal is calibrated in the range of [0, 100] mA. The optimum FC repeller bias voltage was found after scanning during beam tests to be (V_{FC} > 600 V). The current readings from the FC and the two BCMs upstream were compared in several source configurations. As a representative example, the current pulses are reported in Fig. 2, with maximum current values of 85 mA and 76 mA measured in the ISrc BCM and FC, respectively. We have measured less current in the LEBT BCM, possibly due to electrons from gas ionization, and also produced by the proton beam, hitting the small-diameter end of the cone. These assumptions have to be confirmed by simulations and experimentally once the electrostatic repeller at the end of the LEBT is installed. Further information about the beam transmission can be found in [9].

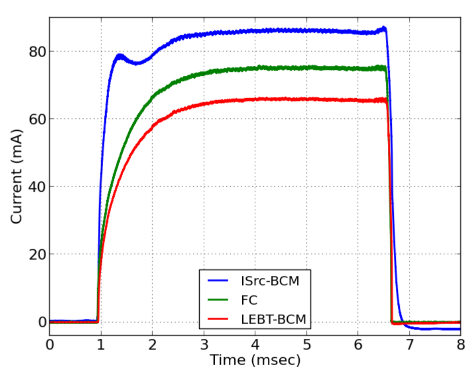

Figure 2: Beam current measurements using BCMs installed in ISrc and LEBT, and the FC installed in the commissioning tank.

Non Invasive Profile Monitor

NPMs are usually designed for profile measurement of a high power beam. However, for the LEBT, NPMs are mainly designed to measure the beam position [10]. The required accuracy is 100µm. Fiduscialised NPM assemblies have been deployed on the LEBT so that each of their projected optical axis meets the beam reference axis. The resulting uncertainty in the beam position measurement is evaluated to be < 50 µm over a 50 mm range in all beam positions.

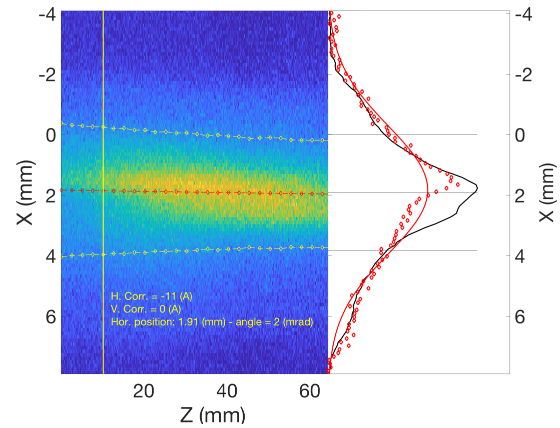

Figure 3: Image from the Horizontal NPM unit, showing a projection of the beam trajectories over the horizontal axis. The integrated profile together with its fit using a Gaussian function is shown on the right. The beam center trajectory, red diamond dash line is shown together with the beam size, white diamond dash line.

Verification tests were then performed with beam, using the steering magnets in the first solenoid. It was shown that the position measurement uncertainty is also dependant on the signal to noise ratio (SNR) of the image. For the tests performed SNR> 25. So the precision of the position measurement is better than 1% [11]. Figure 3 presents an image from the Horizontal unit. Beam positions and angles as measured with the NPM while scanning the solenoid vertical corrector have been studied. Figure 4 shows the results of scanning the corrector and measuring beam position with the downstream NPM. The statistical RMS variations on the position and angle are 10 µm and 0.1 mrad respectively. The precision and accuracy of the instrument permits the correction of systematic errors on the beam trajectory due to magnetic element misalignments and field errors.

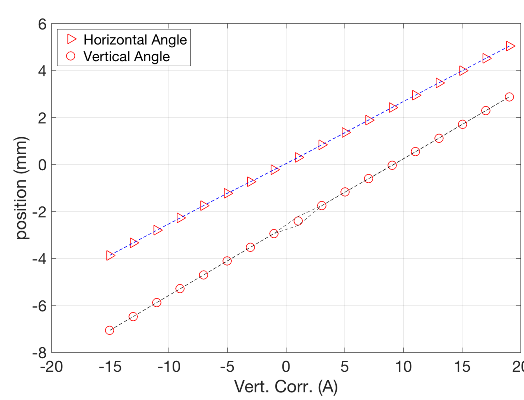

Figure 4: Position and angle measured by the NPM during scans of an upstream corrector.

The NPM can measure the beam profile and beam size, and aid setting the lattice, by comparison with the machine

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model. The beam profile along the trajectory can be used to measure the emittance and lattice parameters [11], so this provides a control point of the beam parameters at the entrance of the RFQ.

Emittance Measurement Units

The LEBT EMU, an in-kind contribution of CEA Saclay (France), has been deployed in the ESS tunnel in May 2018. It is an Allison scanner, using entrance and exit slits, electrostatic plates and a Faraday cup [12]. This instrument has the following specifications: time resolution of 1 µs, angular resolution better than 0.5 mrad, and an angular acceptance better than ± 100 mrad. The performances of one of the two units have been verified in Catania [13]. Following the system's initial deployment in Lund, its controls architecture has been further aligned to ESS standards [2]. This alignment includes: the migration of monolithic proprietary motion controls to a modular in-house ESS solution built from Beckhoff Ethercat I/O modules; the migration of local physical hardware to virtual infrastructure where appropriate; and installed micro TCA hardware infrastructure to allow porting of the data acquisition platform from VME hardware at a later date.

First emittance measurements during verification with beam for the solenoid setting with the beam current of 85 mA showed a converging beam ($\alpha = 5.01$) at permanent tank, and a divergent beam at the commissioning tank. ($\alpha = -3.66$), see Fig. 5 and 6. Matching at the RFQ interface based on emittance sampling is further detailed in [14] and [15].

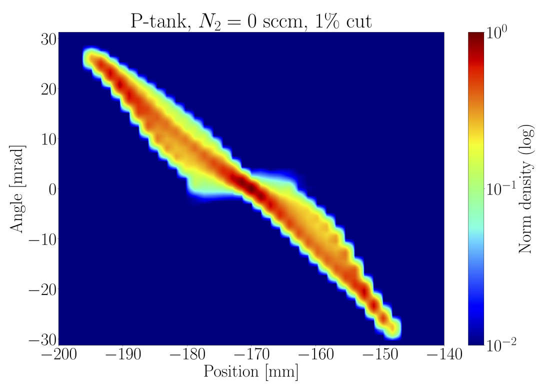

Figure 5: Emittance in the permanent tank

The angular scan range was set -70 mrad to +70 mrad with 1 mrad resolution , while position is scanned by 1 mm step. The resolution of the instrument remains to be verified, among other critical parameters to improve the diverging beam.

Doppler Shift Fraction Measurement

The measurement of the fraction species (H^+, H_2^+ and H_3^+), is performed by means of the Doppler shifted emission spectrum of the neutralized particles [16]. The instrument is based on a spectrograph optimized to acquire the Doppler shifted spectrum with the highest sensitivity. After

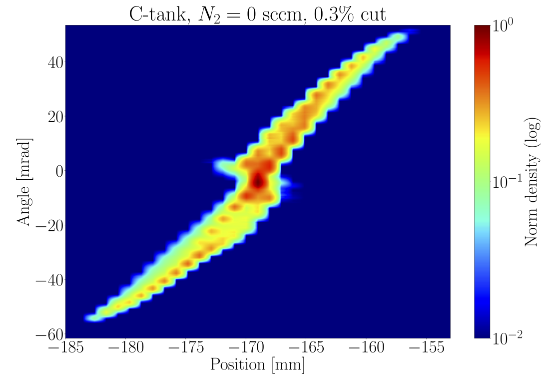

Figure 6: Emittance in the commissioning tank.

a spectrum is acquired, the peaks are fitted by a 3-Gaussian function, from which the centers measure and verify the corresponding species, the widths are related to their momentum spread, and the total integrated peak intensities are used to calculate the fractions. The fraction measurement accuracy is 1% and the instrument delivers a measurement for all pulses up to 14 Hz. The commissioning of the instrument has been performed in 2017 at INFN Catania [16], and it is now installed in Lund, ready for use following configuration of a thermal interlock that protects the in-vacuum mirror.

OUTLOOK

Beam diagnostics instruments will be relocated to the permanent tank, before the installation of the RFQ, in place of the commissioning tank. By then, a set of remaining verifications and upgrade activities will be completed: The BCM system will be upgraded to more powerful electronics and an ESS standards compliant firmware. Machine protection features will be added [17] and the complete system will then be verified again. NPM cameras in the commissioning tank will be handed over to the operation team once validated. The Allison scanners validation will be completed. Finally, the DPL system's verification completion will allow species fraction measurements.

ACKNOWLEDGEMENTS

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