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HARDWARE COMMISSIONING WITH BEAM AT THE EUROPEAN SPALLATION SOURCE: ION SOURCE TO DTL1

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Abstract

The European Spallation Source (ESS) aims to build and commission a 2 MW proton linac ready for neutron production in 2025. The normal conducting section of the ESS linac is designed to accelerate a 62.5 mA, 2.86 ms proton beam to 90 MeV at 14 Hz. The section consists of a microwave-discharge ion source, Radio Frequency Quadrupole (RFQ) and 5-tank Drift Tube Linac (DTL). All sections are provided to ESS by in-kind partners from across Europe.

This paper reports the recent progress on the assembly, installation, testing and commissioning of the ESS normal conducting linac.

INTRODUCTION

The project to build and commission the ESS accelerator is progressing well. In particular, the Normal Conducting Linac (NCL) has been installed, RF conditioned and commissioned with full peak current beam up to the first DTL tank. A description of the ESS LINAC can be found in [1] and a previous status update here [2].

ION SOURCE AND LEBT

The ion source and Low Energy Beam Transport (LEBT) section, an in-kind contribution from INFN-LNS, Catania, was first operated at ESS in 2019 and now meets all specifications as far as can be measured at this stage. A maximum beam current of >74mA can be produced with a 3ms flat-top stable to ± 2%. Emittance has not yet been accurately measured but downstream transmission and beam size is consistent with expectation.

The source was disassembled for inspection in January 2022 and a fault with the repeller cable was discovered. Beam measurements after correction of this fault confirmed that the repeller had been unbiased during all previous commissioning at ESS and this was the cause of an over-estimation of the extracted current and its dependence on solenoid 1 current as shown in Fig. 1. Further details are given in [3].

Another fault was found on the LEBT collimator thermocouple. The thermocouple feedthrough is upstream of the LEBT BCM whereas the collimator is downstream. The thermocouple was providing a conductive path through the BCM so it has temporarily been disconnected.

A test-stand for ion source and LEBT testing and development is under construction at ESS. A complete spare ion source was provided by INFN and this will form the first phase of the test stand. The second phase will include the LEBT and duplicate solenoids, beam instrumentation and vacuum vessels are being procured for this. A hydrogen generator has also been purchased for the test stand and is under test in the vacuum lab. If successful, this generator will remove the hazards associated with the pressurised hydrogen bottle currently used on the ESS ion source. Further optimisation of source parameters will also be performed at the test stand, building upon recent studies of high-stability operation [4].

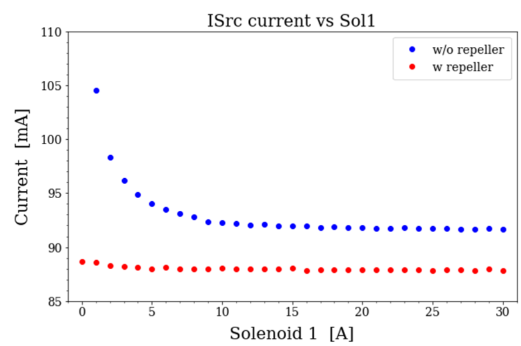

Figure 1: Effect of LEBT solenoid 1 on the measured ion source current with/without repeller bias.

The LEBT chopper is critical to the safe operation of the ESS LINAC since the beam extracted from the ion source is several milliseconds and the MEBT and DTL Faraday cups can only withstand 10-100 µs of beam. It is therefore important to note that the chopper has met all requirements and performed faultlessly during normal beam operations and beam abort scenarios.

The LEBT iris is equally important at this commissioning stage when low current diagnostic beams are required. The iris is a six-blade collimator used to control the beam diameter and thereby peak current. It has been tested extensively at ESS for normal operating modes and full aperture scans and has worked perfectly. However, a small water to vacuum leak has been detected and a new unit is to be manufactured with a revised design for cooling channel routes and connections.

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RFQ

The RFQ was provided by CEA Saclay and installed at ESS in 2020. RF conditioning to 112% of the nominal power was completed over seven weeks in the summer of 2021. Operation at nominal power achieved 96% availability and the cooling system maintained the cavity frequency to ±1.5 kHz. Stable RF can be recovered within 3 minutes after an interruption, consistent with expectations [5].

The cavity has been vented and opened twice for inspection and interventions on adjacent equipment. The vanes show small damage marks due either to electrical breakdown or beam loss, Fig. 2. The marks seem consistent with the experience of other labs and are not considered a concern. However, planning for production of a spare RFQ has already begun.

Figure 2: Condition of the RFQ vanes after RF conditioning and beam commissioning.

During beam commissioning of MEBT and DTL1, RF operation of the RFQ has been restricted to 100 µs pulse length to mitigate the risk of beam damage due to failure of the LEBT chopper. Extended testing of nominal operating conditions has therefore not been possible at this stage.

Beam loading effects have been studied, the cavity is sensitive enough to see just 2 µs beam pulses, Fig. 3. For 62 mA beam current, a voltage drop of ~18 kV and phase shift of 4° is observed. Compensation methods are under development but testing of a pulse-to-pulse adaptive feed-forward system has corrected the beam loading and stabilised the RF pulse to ±0.1 kV and ±0.2°.

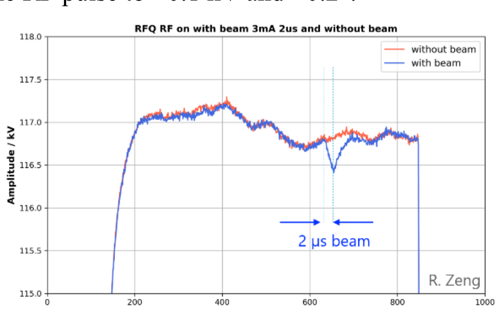

Figure 3: RFQ beam loading.

MEBT

The Medium Energy Beam Transport (MEBT) section, an in-kind contribution from ESS Bilbao, is fully operational except for some non-critical diagnostics [6]. A few leaks occurred on quadrupole water connections and most were easily repaired by new seals. One failure required the magnet to be disassembled so the coil could be taken to the workshop for soldering.

Alignment of the MEBT components has been challenging. Although good alignment was achieved during the factory and site acceptance tests, it was not possible to repeat this consistently after all cooling and electrical connections were made. Additional support brackets, shown in Fig. 4, have been manufactured and installed to improve quadrupole stability and transverse alignment to ±0.5 mm has been achieved which is sufficient for this stage of commissioning.

Failure of one of the MEBT chopper power supplies occurred in March 2022, a spare unit was installed and the failed supply returned to the manufacturer for repair. Investigation revealed some physical damage to the supply had occurred although the full failure mechanism is not understood. Bench measurements and potential redesigns of the supplies are in progress. While operating, the chopper has performed well controlling the beam pulse length to 1 µs precision.

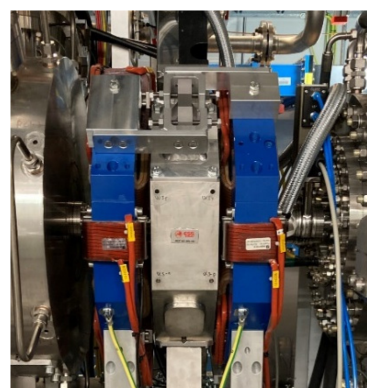

Figure 4: Additional alignment brackets installed on MEBT quadrupoles.

The MEBT contains 3 buncher RF cavities to maintain the longitudinal structure between RFQ and DTL. The bunchers were RF conditioned in 2021 at Bilbao before installation at ESS. Start-up of the cavities for beam commissioning was therefore rapid with the maximum 160 kV field level achieved within one day. The correct buncher phase of -90° was set up by beam time-of-flight measurements and then confirmed by comparing operating phase to the beam-induced phase with RF off, Fig. 5. The buncher cavities have a thermal transient of ~1 hour between RF off and maximum RF power (20 kW, 3 ms, 14 Hz). The cavities are equipped with tuners and feedback control has been developed to maintain cavity detuning to within 3 kHz during warm-up and operation.

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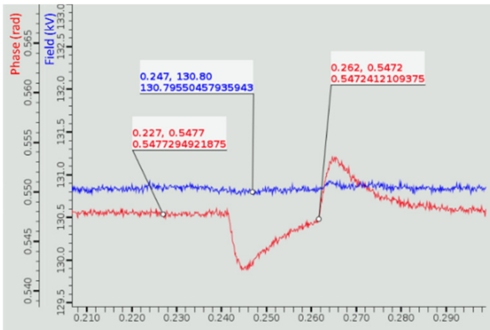

Figure 5: Beam-induced RF phase in MEBT buncher 1.

DTL1

The DTL1 cavity was installed in the ESS tunnel in summer 2021 and RF conditioning began in March 2022 after comprehensive testing of supporting systems including the RF power source, cooling water skid and control systems and interlocks. The full nominal average RF power was achieved in July 2022 after a total of 900 hours of RF operation and 105% of the nominal field was achieved with short pulse length [6].

Beam commissioning of DTL1 began in June 2022 in parallel with the final stages of RF conditioning. Validation and characterisation of RF, magnet and diagnostics systems was performed with a 5 mA, 5 µs, 1 Hz probe beam before ramping to full nominal beam current in July 2022.

Phase scans were performed to assess the longitudinal acceptance and results matched simulation well, Fig. 6. Over 90% transmission is possible between -40 and +60 degrees.

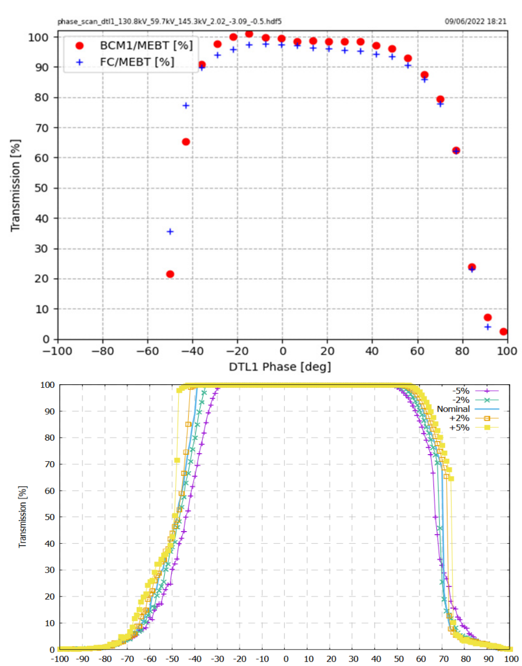

Figure 6: Measurement (top) and simulation (bottom) of DTL1 longitudinal acceptance.

A vacuum leak to atmosphere was discovered on one of the drift tubes during conditioning. The leaking tube contained a steering magnet and since these tubes cannot be brazed after magnet installation, electron beam welding of the cone is required. It is suspected that this weld has failed but further analysis is required to confirm this. A replacement tube was produced at INFN Legnaro and the failed unit replaced at ESS at the end of July 2022.

Beam loading for the nominal 62 mA beam current results in a 9% reduction in field and 8° phase shift in open loop operation. Using the same LLRF system as developed for the RFQ, this can be compensated to ± 0.5 % cavity field stability and ± 0.2° in phase.

BEAM INSTRUMENTATION

Critical beam measurement devices such as current monitors, beam position monitors and Faraday cups were all made available for first beam delivery. Full characterisation is on-going but all have worked well.

Preliminary measurements have also been possible on some non-critical diagnostics. Wire-scanner beam profile monitors [7] have been operated and shown sensible results Fig. 7. Further controls integration and hardware development is ongoing. The first measurements of emittance have been made in the MEBT at 60 mA and they show an emittance of 0.3 ± 0.1 mm.mrad close to the design value [1]. Further calibration checks and testing is needed to confirm these measurements with improved precision.

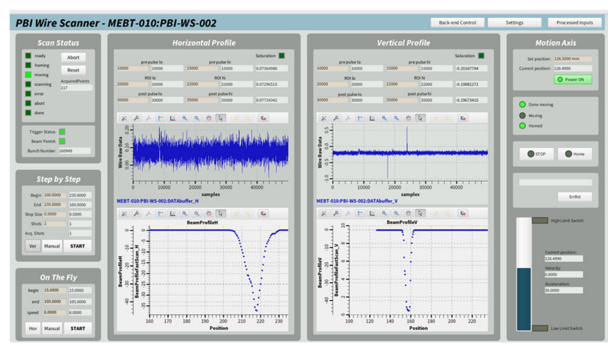

Figure 7: Preliminary wire-scanner measurement.

CONCLUSION AND NEXT STEPS

Beam commissioning up to the first DTL tank, an energy of 21.3 MeV has been completed at ESS. All major milestones have been met; all RF cavities have been conditioned to nominal average RF power and nominal peak beam current has been transported to the end of DTL and operated at the design 14 Hz repetition rate. Beam pulse lengths have been restricted to 50 µs or less downstream of the LEBT due to the limitations of the Faraday cups. Transmission efficiency has exceeded specification with typically 97% for the RFQ and over 99% for MEBT and DTL1.

Beam activities have now stopped to allow the installation of DTL tanks 2, 3 and 4 before December 2022. Further installation work and infrastructure developments will follow to allow RF conditioning to begin early in 2023 followed by beam commissioning to 73.8 MeV.

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REFERENCES

[1] R. Garoby et al., "The European Spallation Source Design", *Physica Scripta*, vol. 93, no. 1, p. 014 001, 2017. doi:10.1088/1402-4896/aa9bff

[2] C. Plostinar, "Status of the Normal Conducting LINAC at the European Spallation Source", in *Proc. 13th International Particle Accelerator Conference (IPAC'22)*, pp. 2019-2022. doi:10.18429/JACoW-IPAC2022-WEPOTK001

[3] L. Bellan, "Space Charge and Electron Confinement in High Current Low Energy Transport Lines", presented at Proc. 31st Linear Accelerator Conference (LINAC'22), Liverpool, UK, Aug.-Sep. 2022, paper TUOPA08, this conference.

[4] L. Neri and L. Celona, "High stability microwave discharge ion sources", *Sci. Rep.,* vol. 12, p. 3064, 2022.

[5] O. Piquet, "High Power RF Conditioning of the ESS RFQ" in *Proc. 13th International Particle Accelerator Conference (IPAC'22),* pp. 1189-1191. doi:10.18429/JACoW-IPAC2022-TUPOTK003

[6] A. Garcia Sosa, "Status of Testing and Commissioning of the Medium Energy Beam Transport Line of the ESS Normal Conducting LINAC", presented at Proc. 31st Linear Accelerator Conference (LINAC'22), Liverpool, UK, Aug.-Sep. 2022, paper TUPOJO14, this conference.

[6] F. Grespan, "High Power RF Conditioning of the ESS DTL1", presented at Proc. 31st Linear Accelerator Conference (LINAC'22), Liverpool, UK, Aug.-Sep. 2022, paper TUPOJO09, this conference.

[7] C. Derrez, "Wire Scanner Systems at the European Spallation Source (ESS)", presented at Proc. 31st Linear Accelerator Conference (LINAC'22), Liverpool, UK, Aug.-Sep. 2022, paper TUPOJO13, this conference.