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ESS Accelerator Status and Commissioning Plans

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The European Spallation Source (ESS), currently under construction in Lund, Sweden, will be the brightest spallation neutron source in the world, when its driving proton linac achieves the design power of 5 MW at 2 GeV. Such a high power requires production, efficient acceleration, and almost no-loss transport of a high current beam, thus making design and beam commissioning of this machine challenging. The linac could also be used for projects like the ESS Neutrino Super Beam (ESSNuSB), currently an ongoing project to study the viability of using the ESS linac as a driver for a neutrino beam by interleaving a H- beam with the protons and further increasing the machine average power to 10MW. The ion source and LEBT commissioning happened already in 2018/2019 and will continue with the RFQ in 2021, MEBT and all DTL tanks in the following year. This talk will summarise the status of the linac project and commissioning, with focus on the normal conducting linac plans.

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[*] Speaker

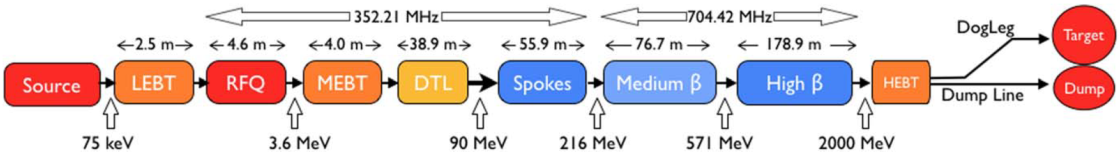

Figure 1: Layout of the ESS Linac. Blue color indicates a section of superconducting cavities.

1. Introduction

The European Spallation Source (ESS) will be a spallation neutron source in Lund, Sweden, based on a superconducting proton linac with an unprecedented 5 MW beam power [1]. Figure 1 shows a layout of the ESS Linac. The linac consists of normal-conducting accelerating structures, three sections of superconducting cavities, and low, medium, and high energy beam transports lines (LEBT, MEBT, and HEBT). The normal-conducting accelerating structures include an ion source (ISrc), radio frequency quadrupole (RFQ), and drift tube linac (DTL). This part of the linac is referred to as the normal-conducting linac (NCL) as a whole. The section with the spokes, medium and high beta cavities is referred to as the Superconducting linac (SCL). Table 1 summarizes the high-level parameters of the linac. It features a very long pulse length of 2.86 ms and relatively low repetition rate of 14 Hz, making the duty factor of the machine 4%. The very high peak current of 62.5 mA and the final energy of 2 GeV makes the above mentioned 5 MW average power for the 4% duty factor. During early years of operations, the linac is planned to be operated at a lower final energy and average power of 800 MeV and 2 MW with missing RF sources for the final part of the linac due to various project constraints.

Table 1: ESS Linac High-level Beam Parameters (Two values are listed for the average power and maximum beam energy for design and initial operations.)

Parameter	**Unit**	**Value**
Average power (design)	MW	5
Maximum energy (design)	MeV	2000
Peak current	mA	62.5
Pulse length	ms	2.86
Repetition rate	Hz	14
Duty factor	%	4

The ESS linac project is presently in the phase when component productions, installations, hardware testing, and beam commissioning are conducted in parallel. For the NCL, the list of milestones achieved in the present and past years include completion of tuning and RF conditioning of the RFQ and also completion of tuning of the first tank of the DTL (out of five). As of writing this paper, the next stage of beam commissioning up to the MEBT section is about to happen. This paper presents the overall strategy for the ESS linac beam commissioning, as well as highlights from works for the NCL, including the beam commmissioning of the ISrc and LEBT on the ESS site, conditioning of the RFQ and current installation works happening around the facility.

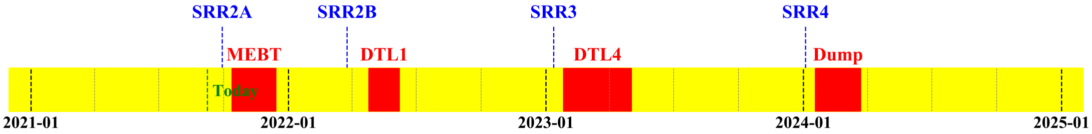

Figure 2: An overview of the near-term beam commissioning stages. Each commissioning step follows a Safety Readiness Review (SRR), where readiness of safety related systems are reviewed.

2. LINAC Installation Overview

In ESS linac construction is a collective effort of many countries and is driven by an in-Kind model. In this model, laboratories from the member countries are responsible by the design, construction and delivery of many of the components. The ion source is an in-Kind from INFN-LNS in Italy [2], the RFQ an in-Kind from CEA in France [3], the MEBT components are from ESS Bilbao in Spain [4] and the DTLs were designed, built and are being installed by INFN-LNL, aslo from Italy [5].

At the time of this paper all equipment up to DTL tank 1, in the NCL, are already installed but outside of the tunnel many other equipment are being delivered verified and tested. In parallel to all commissioning work installation in the tunnel (around the Superconducting Linac sections) and in the Klystron Gallery continues.

The RF distribution line installation is completed and all the waveguides are in place [6]. Modulators for all the NCL cavities are also installed and are being tested as well as the Low Level RF. The solid state amplifier for the MEBT buncher cavities are already in place and waiting to be tested. The cryo distribution line for the elliptical cavities [7] is also fully installed and the Spokes cryo distribution installation is under way. The phase reference line is fully installed and tested [8].

The spokes cavities started to be delivered to FREIA lab in Uppsala to be characterized [9], while the Medium and High Beta cryomodules will come directly to ESS to be characterized in the RF Test Stand 2 [10, 11]. All the Linac warm units, which are room temperature part located in between each cryomodule in the superconducting sections, are already installed in the tunnel. Work on cabling and connection of the controls for each equipment in the tunnel is progressing steadily and will continue in parallel to commissioning, element installation and tests.

3. Beam Commissioning Strategy

The overall strategy for beam commissioning of the ESS linac was presented in the past [12, 13] and remains to be valid with adjusted schedule (Fig. 2). As recent beam commissioning of other hadron linacs, the ESS linac adopted the staged approach with six stages until the beam will be sent to the target for the first time. This approach allows troubleshooting of systems with beam as early as possible and also does for gaining operational experiences of the linac. The linac will be equipped with a comprehensive set of permanent diagnostics devices, including those measuring beam profiles and emittances at multiple locations. Compared to the approach of fully characterizing the beam with temporary diagnostics devices on a test-bench, this approach allows gradual ramp-up of performance over years.

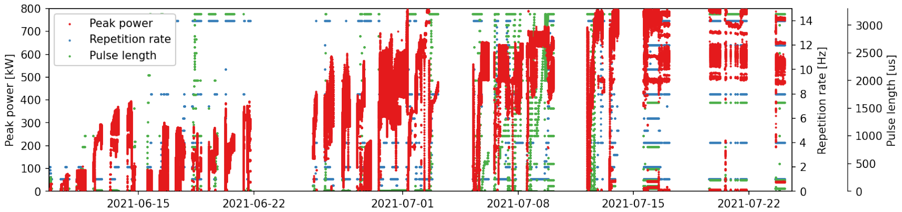

Figure 3: RFQ high-power conditioning history.

3.1 ISRC and LEBT Commissioning

The ISrc and LEBT of the ESS linac went through the first round of beam commissioning in 2017 at INFN-LNS, who is the in-kind contributor of the ISrc and LEBT [2]. Then went through the second round of beam commissioning on the ESS site from September 2018 to July 2019. The results from the commissioning on the ESS site were reported in [14]. The main results from this last commissioning stage shows a very stable a reliable source that can produce the design current for the ESS linac. What remains to be understood is a much bigger measured emittance, than the designed values.

3.2 RFQ Conditioning

An 8-week conditioning period was held at ESS for RF conditioning of the RFQ provided by CEA [3]. During this period, it was successfully demonstrated that the RFQ can stably operate at 112% of the required RF power as shown in Fig. 3. At nominal power, 96% up-time was achieved over a 12-hour test run. It was also demonstrated that the cooling skid performance exceed design specifications and was able to maintain the cavity frequency to ±1.5 kHz during stable operation. More studies and test will likely continue in parallel with commissioning work on the next phases until the RFQ is fully ready for continuous operations.

4. Final Remarks

The ESS linac will at completion be the world's most powerful proton linac with a proton energy of 2 GeV and a beam power of 5 MW. The next step during the year of 2022 is to complete the commissioning of the NCL, in parallel with installation of infrastructure in the RF gallery and the SCL sections. Start of the neutron production is scheduled by 2025 and the user scientific program by the following year.

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