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PREPARATION TOWARDS THE ESS LINAC ION SOURCE AND LEBT BEAM COMMISSIONING ON ESS SITE

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Abstract

Beam commissioning of the proton linac of the European Spallation Source begin in summer, 2018, from the ion source (IS) and low energy beam transport (LEBT), and continues in stages until 2022, when the first beam is sent to its spallation target. This paper presents the plan, status, and highlights of preparation works for the upcoming IS and LEBT beam commissioning.

INTRODUCTION

The European Spallation Source, currently under construction in Lund, Sweden, will be a spallation neutron source driven by a superconducting proton linac [1]. The linac accelerates a beam with a 62.5 mA peak current and 4% duty cycle (2.857 ms pulse length at 14 Hz) up to 2 GeV and thus produces an unprecedented 5 MW average beam power. Its normal-conducting front-end consists of an ion source (IS), radio frequency quadrupole (RFQ), drift tube linac (DTL), as well as low and medium energy beam transports (LEBT and MEBT) and accelerates the generated proton beam from 75 keV to 90 MeV.

Beam commissioning of the ESS linac will be conducted in stages [2–4]. The first and upcoming stage is for the IS and LEBT, planned to start in summer, 2018 and continue until fall. This paper presents the update plan of the IS and LEBT beam commissioning as well as some highlights of its preparation work.

IS AND LEBT OVERVIEW

The IS and LEBT are in-kind contributions from INFN-LNS. Prior to the delivery to ESS in December 2017, they were successfully commissioned with the beam at INFN-LNS [5–8]. This successful off-site commissioning allows for the beam commissioning on ESS site to start from verifications of the results from the off-site commissioning and spend the rest of available time for further optimizations against needs from the following sections.

Table 1 lists a possible set of operational parameters of the IS. Note that the operational parameters are ultimately determined after all the sections of the linac are installed and tested. The proton current larger than the nominal 62.5 mA is to take into account possible beam losses in the LEBT and RFQ. The off-site commissioning confirmed that the IS is indeed capable of producing this level of current. The

Table 1: ESS IS Possible Operational Parameters

Parameter	Unit	Value
Energy	keV	~75
Peak current (total)	mA	~85
Peak current (proton)	mA	~70
Proton fraction	%	~80
Pulse length	ms	~6
Pulse repetition rate	Hz	14
Duty cycle	%	~8

pulse length longer than the nominal 2.857 ms is due to the required ~3 ms stabilization time of the IS. The excess ~3 ms in the leading part is removed by a chopper in the LEBT, before the beam enters into the RFQ.

The LEBT is a focusing channel with two solenoids (Fig. 1). Each solenoid also houses coils of dipole correctors (*steerers*) of both planes. Tuning of the linac requires a beam with a much lower power than the nominal 5 MW. Standardized sets of limits in the current, pulse length, and repetition rate have been defined as *beam modes* according to use case [9]; an important function of the LEBT is produce the beam modes by adjusting the current and pulse length with its iris and chopper.

The LEBT houses a suite of beam diagnostics devices (Fig. 1). Most of them are either in the permanent tank, between two solenoids, or in the commissioning tank, temporary placed in the position of the RFQ. The AC current transformer (ACCT) and Faraday Cup (FC) allows current measurements. The first ACCT actually monitors the current extracted from the high-voltage power supply and thus indirectly provides the total current of the IS. The Doppler

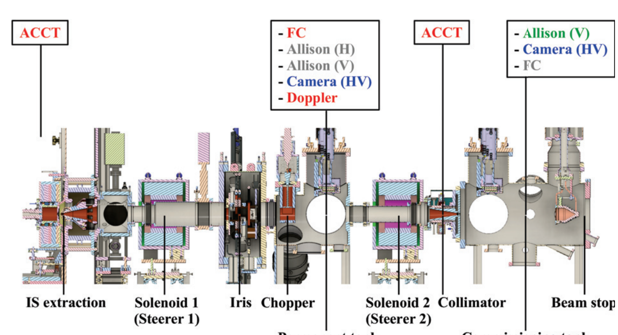

Figure 1: LEBT schematics with diagnostics devices.

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detector allows to measure fractions of ion species from Doppler shifts of the light induced by the beam. In total four cameras (one for each plane at two locations) also detect the beam induced light and allows to measure the profile and centroid position non-invasively. An Allison scanner type emittance meter allows to measure the phase space distribution in either the permanent or commissioning tank.

BEAM COMMISSIONING STRATEGY

Overviews on linac-wide beam commissioning plan were presented in [2,3]. One for the IS and LEBT being approaching, a further detailed plan has been developed but, due to limitation of space, we only discuss strategies for four crucial activities in this section. As already stated, the initial phase of the IS and LEBT beam commissioning consists of verifications of systems, which require the beam presence such as beam diagnostics devices, and those of the measured beam characteristics (current and emittance) during the off-site commissioning. Afterwards, we conduct the following optimization activities and the beam commissioning is concluded with long-term stability tests.

Beam Steering Having steerers and cameras at two locations for each plane allows a simple beam steering based on the measured trajectory responses. Ideally, we would like to cancel both position and angle errors at the RFQ interface and this requires the position error being canceled in the middle of the second solenoid. The location of the first set of the cameras is not far from the second solenoid and thus we are not far from this ideal situation.

Matching As many other RFQs, for the RFQ of ESS, transmission and matching at its entrance is highly correlated. Once we have the RFQ, good matching is achieved by simply scanning the solenoids and identifying the strengths for the best transmission. During the IS and LEBT beam commissioning, the emittance meter could be placed in the commissioning tank (see Fig. 1) but a ∼15 cm distance from the interface, together with a strong space charge and never-known space charge compensation level, makes it difficult to accurately reconstruct the phase space distribution at the interface. On the other hand, once the RFQ is connected, the emittance meter at this location is no longer available. Therefore, our strategy during the IS and LEBT beam commissioning is to sample as much of emittance meter data for a region of the two solenoids, where simulations predict good matching. This allows us to look back the data of the emittance meter for a given (or at least close) condition of the IS and LEBT, even after the connection of the RFQ.

Beam Modes and Intermediate Currents Productions Capability to produce the beam modes has to be verified during the IS and LEBT beam commissioning, before the beam is sent to the rest of the linac. For the chopper, its efficiency has to be carefully verified to prevent the unwanted part of the pulse leaking into the RFQ. During the initial power ramp-up phase of linac operations, the beam power is managed with current, whereas the pulse length and repetition rate are fixed to the nominal values of 2.857 ms and 14 Hz due to the demand from users. This requires multipole configurations of the linac for different currents, already from the LEBT, and thus the above mentioned matching process has to be conducted for intermediate currents as well.

Current Optimization The input current to the RFQ has to be adjusted so that the output becomes the linac-wide nominal value of 62.5 mA. This is because the sections after the RFQ are not designed for more than 62.5 mA. Transmission through the RFQ is obvious now known yet during the IS and LEBT beam commissioning and this requires to prepare several configurations of the IS and LEBT for different currents. Because of the iris, the IS itself does not need to fine-tune the current. However, extracting an excess amount of the beam could spoil the emittance [10] and so it is still ideal to extract just a right amount of current from the IS and avoid a use of the iris for production of the nominal current. The plan is to characterize the beam with the FC and emittance meter in the permanent tank and prepare several configurations of the IS, N_2 injection level, and iris in the beginning and later to test these configurations till the end of the LEBT (and eventually with the RFQ).

INSTALLATION AND TESTING

As of the time of writing this paper, installation of the IS and LEBT components is being finalized (Fig. 2). What is still ongoing is installation of cables and the IS cage, which provides protection from X-ray and high-voltage. Hardware commissioning of the components has been on-hold due to lack of electrical power in the tunnel but is anticipated to commence in early summer. An exception for the yet-started hardware commissioning is the control system, which is based on the EPICS framework and an in-kind contribution from CEA Saclay [11]. Its acceptance test was successfully performed already as a part of the off-site commissioning in September, 2017. Also on ESS site, trial connections to EPICS channels from a control room, using temporary power, were successfully conducted in April, 2018, making it ready for the full re-verification as soon as the power becomes available in the tunnel.

Figure 2: IS and LEBT installed in the ESS lianc tunnel.

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LEBT-RFQ MATCHING STUDY

As already discussed above, the solenoids scan for matching to the RFQ is a primary and repeated activity during the IS and LEBT beam commissioning. Its simulations have been presented in the previous series of this conference [10, 12] and an effort is ongoing to take into account further details as well as the conditions observed during the off-site commissioning. Figure 3 is a highlight of the ongoing simulation study, showing the transmission from the IS to the RFQ exit (up) and transverse normalized RMS emittance at the RFQ exit (down). In contrast to the previous simulations, the IS output beam was generated with IBSimu code [13] and has a ~80 mA proton current and ~0.135 π mm mrad normalized RMS emittance, reflecting a measurement during the off-site commissioning [6,7]. The transport in the LEBT and RFQ were simulated with the TraceWin code [14] and Toutatis code [15] for each as the previous simulations. The space charge compensation level was selected to be 95% as the previous simulations [10, 12]. Between the two regions with high transmissions, the one on the lower side, referred to as *weak-focusing regime*, is our operation region. The one on the upper side, referred to as *strong-focusing regime*, could have the same matching condition as the weak-focusing regime in terms of the RMS parameters but, because the beam is sharply forced in-between the two solenoids, the beam in this regime tends to have much worse halo. We can see in Fig. 3 that the region for a good transmission ($\gtrsim$80%) is very small, especially

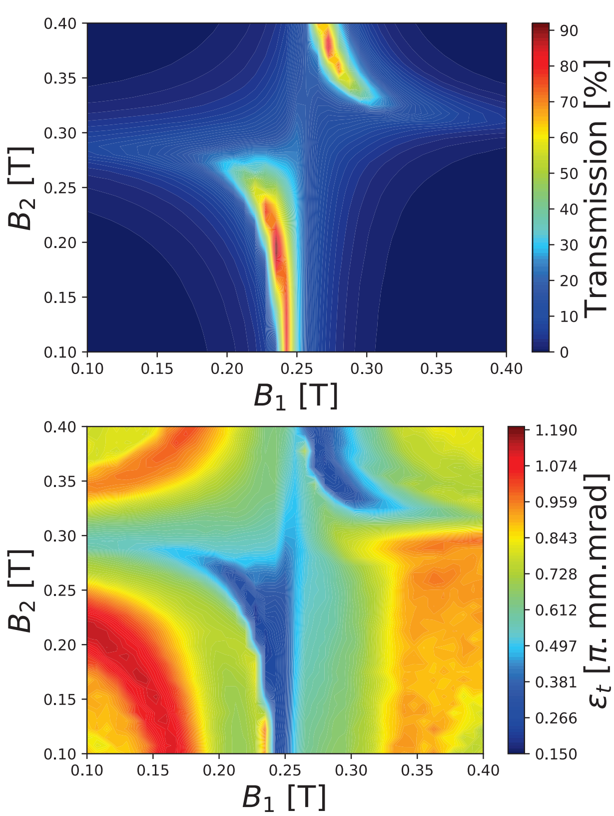

Figure 3: Updated LEBT solenoids scan simulation.

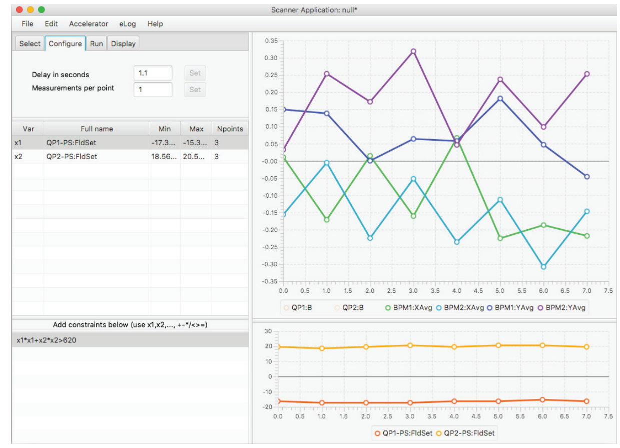

Figure 4: New scanner application based on JavaFX, allowing multi-dimensional scanning.

against changes in the first solenoid, and the emittance for this region is well preserved. This confirms that we can achieve good matching by simply optimizing the transmission through the RFQ.

Note that a recent analysis indicated that the space charge compensation could be lower than the assumed 95% [10]. Nevertheless, what matters is to understand how the best matched point moves agains changes in parameters such as the space charge compensation level and initial

HIGH-LEVEL APPLICATIONS

High-level applications of beam physics are crucial tools for efficiently achieving desired machine performance. Ones for the ESS linac [16] are built on the OpenXAL framework [17]. Current focus is on development of applications for the IS and LEBT beam commissioning but, in addition, the online model has been improved [18] and a new framework for applications, based on JavaFX, was developed.

For the IS and LEBT beam commissioning, a comprehensive application, which allows to control the IS parameters and LEBT magnets as well as to visualize data from the diagnostics devices, was developed [19]. A generic multi-dimensional scanner application, whose main use cases include the solenoids scan, was also developed (Fig. 4). These two applications were already tested in the control room by connecting to the virtual machine and are ready for the next step of testing with the real control system.

CONCLUSIONS

Beam commissioning of the ESS linac starts soon in summer, 2018, from the IS and LEBT. This paper presented the strategy for the IS and LEBT beam commissioning, focusing on optimizations for the needs from the following sections, especially the RFQ. Some highlights from the preparation works of installation, testing, simulation, and high-level applications were also presented.

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