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OPPORTUNITIES AND CHALLENGES IN PLANNING THE INSTALLATION, TESTING AND COMMISSIONING OF LARGE ACCELERATOR FACILITIES

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Abstract

Delivering major accelerator facilities requires complex project preparation, organisation and scheduling. Often, multiple factors have to be taken into account including technical, financial and political. This makes planning particularly difficult, but at the same time opens opportunities for improving and optimising the project prospects. In this paper, we discuss the major drivers governing the installation, testing and commissioning of major accelerators in general, with particular emphasis on the European Spallation Source (ESS) accelerator, currently under construction in Lund, Sweden.

INTRODUCTION

Large scientific projects throughout the world have become hallmarks of human achievement and triumph. For particle accelerators in particular, delivering successful facilities, is equivalent with not only pushing scientific and technological barriers and producing exciting scientific results, but also with overcoming civil engineering challenges while navigating complex project arrangements, tight schedules and limited budgets.

One such endeavour is the European Spallation Source currently under construction in Lund, Sweden. ESS is intended to complement the existing global neutron landscape and to meet the growing user demand for neutrons by providing the highest neutron flux in the world in a state-of-the-art facility [1]. When completed, a 5 MW accelerator will deliver a proton beam to a rotating tungsten target, which in turn will deliver a neutron beam to a wide array of instruments. Judging by the their scale and complexity, each of the three main parts of ESS (Accelerator, Target and Instruments) can be considered a large scientific project in its own right. Established as an international organisation, ESS is working with nearly 40 European partner institutions representing the member states which are committed financially to the success of the project.

ESS is soon to celebrate nearly a decade since the decision to host the project in Lund was taken. As we move from design and prototyping to manufacturing, installation, testing and commissioning, the challenges of delivering a successful, operational machine have become more clear. This paper will further give a brief description of the ESS linac and discuss the experience within the ESS Accelerator Division in developing a schedule that is deliverable, but also in line with the main ESS milestones.

THE ESS LINAC ARCHITECTURE

The ESS linac is designed to accelerate a 62.5 mA beam current at a 14 Hz repetition rate and a 2.86 ms pulse length [2]. It employs a normal conducting section (NC) up to 90 MeV followed by a superconducting section (SC) to the final energy of 2 GeV. The normal conducting section consists of a 3.62 MeV front end followed by a Drift Tube Linac (DTL). A microwave discharge proton source (IS) and a two solenoid low energy beam transport line (LEBT) with an extensive suit of diagnostics will form the initial beam, which is then matched into a 352.21 MHz four-vane RFQ. The medium energy beam transport line (MEBT) after the RFQ characterises and matches the beam to the DTL. In addition to the standard set of diagnostics, it also uses a fast chopper for beam current and pulse length control. The DTL consists of five tanks with permanent magnet quadrupoles (PMQs) housed in every other drift tube.

The SC linac has three main sections: the spoke (SPK), medium-beta (MBL) and high-beta (HBL). The spoke section ($\beta_{opt} = 0.5$) accelerates the beam to 216 MeV using 13 cryomodules (CMs) with two cavities per CM. The medium beta section ($\beta_g = 0.67$) accelerates the beam further to 571 MeV using elliptical cavities in a 9 CM configuration with four cavities per CM. Finally, the high beta section ($\beta_g = 0.86$) takes the beam to the final 2 GeV energy using 21 CMs with four elliptical cavities per CM. A linac warm unit (LWU) consisting of a quadrupole doublet with steering and diagnostics is placed between every two CMs.At the end of HBL, a high energy beam transport line (HEBT) will take the beam to the dump line (DMPL) and the tuning beam dump, or to an additional transport channel (A2T) and the target. A summary of the main ESS accelerator parameters can be seen in Table 1 and Figure 1.

Table 1: Main Parameters of the ESS Linac

Parameter	Value	Unit
Average Beam Power	5	MW
Maximum Beam Energy	2	GeV
Peak Beam Current	62.5	mA
Beam Pulse Length	2.86	ms
Beam Pulse Repetition Rate	14	Hz
Duty Cycle	4	%
RF Frequency	352.21/704.42	MHz
Machine Availability	95	%

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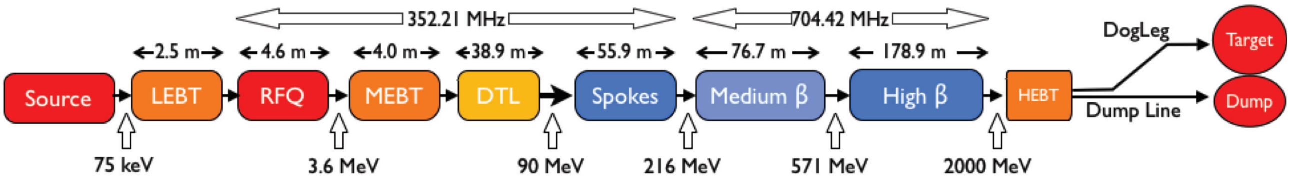

Figure 1: Schematic layout of the ESS linac.

INSTALLATION TESTING AND COMMISSIONING ASSUMPTIONS

Currently, the ESS project is going through a schedule re-baselining process. This is needed in order to reflect all the developments since 2013 when the initial roadmap to first neutrons was set and is being carried out by each individual sub-project. The priorities remain the same with the start of user programme being the primary driver. Figure 2 shows the proposed new timeline for the ESS project.

Installation

For accelerator in particular, this exercise offered a unique opportunity to develop a schedule that implements the lessons learned so far both at ESS and other facilities worldwide. The external boundary conditions are driven by the need to deliver neutrons as soon as possible, but also to start operating the machine, thus triggering different funding streams, so the schedule remains tight.

Internally, within the Accelerator Division, major changes were implemented reflecting some of the internal delays, many related to the challenges of having a new organisation building a machine on a greenfield site, but also delays from our partners. Like other projects worldwide, ESS has adopted an in-kind model, with multiple partners throughout Europe developing, prototyping, manufacturing and delivering various components. This is a powerful concept, allowing rapid access to cutting edge technology and know-how. While the advantages are undeniable, the schedule risks will always remain higher than having in-house control and will range from funding and procurement to capacity and priority issues. To have a better grasp on deliveries, at ESS every major component has a “Ready for Installation date” (RFI), which is frequently updated and checked such that potential delays and bottlenecks are identified early. At this stage of the project, not all RFI dates are contractual, so some delay risk remains.

The new baseline also needed to reflect the outcome of a recent value engineering exercise, where a decision was taken to initially install only 11 of the 21 HBL CMs, thus significantly reducing the accelerator scope. The beam energy is limited to 1.3 GeV and therefore the average beam power to 3.25 MW. The recovery of scope is planned after the start of user operation phase during shutdown periods [3].

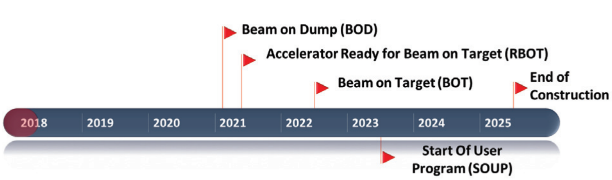

Figure 2: The proposed ESS project timeline.

The installation of utilities and services as well as marking, drilling, pulling and terminating cables is not trivial for a project of this size and a robust re-planning is also underway such that this work is coordinated with the delivery and installation of accelerator components.

A new installation schedule was therefore developed with an optimised sequence, that has the correct logic, but also takes into account safety measures and is sufficiently flexible to absorb inherent future delivery delays. Given the demanding schedule, the installation of the SC linac is planned to go in parallel with the commissioning of the NC part. This is possible by building a shielding wall separating the two sections and by having adequate access to both sides of the tunnel. The installation of the last DTL tank is postponed and it will be commissioned with the rest of the SC linac.

Testing

In terms of testing planning, one of the most important requirements is to have the right processes clearly defined. The ESS handbook for engineering management offers the general guidelines and ensures that all the reviews and gateways are established [4]. These range from generic design reviews to test readiness, safety readiness and system acceptance reviews. It is essential that the testing procedures and the required reviews are identified early such the relevant internal and authority issued permits are in place. Correct processes are also vital for creating a safe work environment. Finally, allocating adequate testing times is always beneficial in the long run.

Commissioning

Planning initial hardware and beam commissioning will always have a certain level of uncertainty given that this is the point where any prior oversights or integration problems will be discovered and often solutions will have to be found and implemented. At ESS, in preparation for the upcoming commissioning of the Ion Source and LEBT, a comprehensive plan has been developed listing all essential systems, the key dependencies, the required documentation as well as the critical overall parameters. Detailed plans were also made for each system verification step and every measurement procedure backed by preliminary simulations to help the commissioning team. All these essential early preparations can greatly reduce the schedule uncertainty [5].

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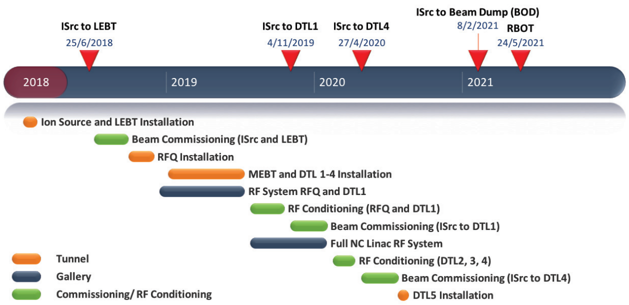

Figure 3: Simplified timeline of the NC linac installation.

PLANNING

Following the general guidelines and boundary conditioned mentioned above, a new installation, testing and commissioning plan has been developed. For the normal conducting linac, the Ion Source and LEBT have already been installed and beam commissioning will commence later this year [6]. The RFQ is scheduled for delivery and installation in Q4 2018, but RF conditioning and beam commissioning can only happen in the second half of 2019 due to the unavailability of the RF system. The first four DTL tanks are also scheduled for delivery and installation in 2019. The RFQ beam commissioning will include the MEBT and the first DTL tank, while commissioning up to the fourth DTL tank will continue in 2020, after the full RF system for the NC linac will be installed. Figure 3 shows a simplified timeline of the NC linac installation and commissioning plan.

The next major beam commissioning milestone is the beam on dump (BOD), which will see an operational SC linac and a 571 MeV beam sent to the tuning beam dump in 2021. The schematic timeline of the SC linac and the HEBT can be seen in Figure 4 and it consists of four major installation activities: the cryogenic distribution system (CDS), the SPK, MBL and two HBL CMs, the LWUs and the SPK and MBL RF systems in the gallery. After a beam commissioning period to the beam dump, the accelerator will be ready to send beam to the target, however, this also depends on the target availability. Any existing float at this stage will be used to install the remaining HBL CMs.

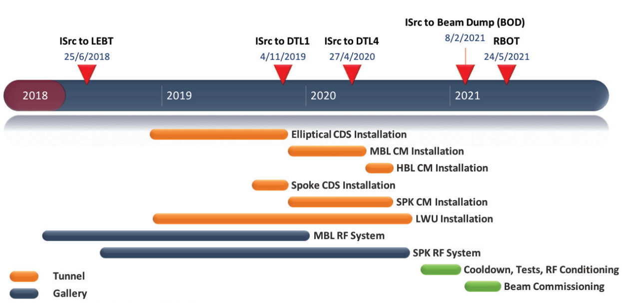

Figure 4: Simplified timeline of the SC linac, HEBT and A2T installation.

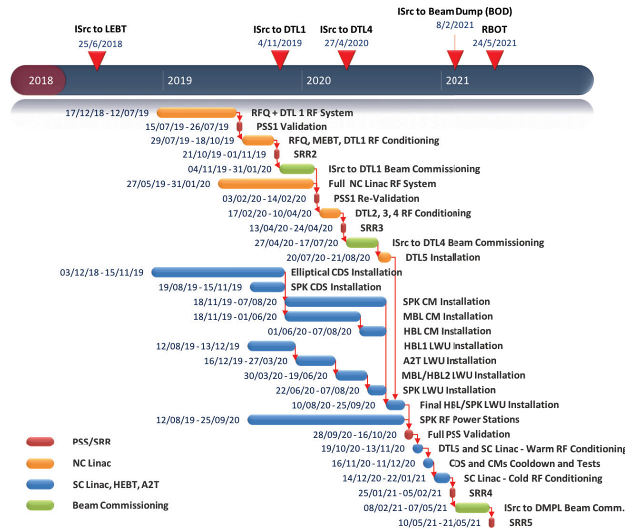

Figure 5: Schematic layout of the current ESS accelerator critical path.

In terms of schedule development, employing the right tools is similarly essential. The official planning tool at ESS is Oracle's Primavera P6 [7]. This is complemented by various risk analysis metrics for each individual delivery and Monte Carlo simulations to assess the overall risk and confidence level. The high level plan is further developed into a short and near term detailed plan allowing day by day tracking of activities. The critical and near critical path to beam on target is also continuously monitored and an example of the current critical activities can be seen in Figure 5. It should be noted that because the general approach at ESS is to plan using the most optimistic RFI dates while keeping the float centrally, the critical path will often change. Continuously updating the schedule with the latest developments is therefore essential.

CONCLUSION

A new accelerator schedule has been developed at ESS as part of the ESS project re-baselining exercise. We believe an appropriate installation sequence is in place with correct testing procedures and robust commissioning plans to meet the ESS high-level milestones while allowing smooth beam commissioning and machine start-up.

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