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THE STATUS OF THE ESS PROJECT

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Abstract

The European Spallation Source (ESS), currently under construction in Lund, Sweden, will be the world's most powerful linear accelerator driving a neutron spallation source, with an ultimate beam average power of 5 MW at 2.0 GeV. The LINAC accelerates a proton beam of 62.5 mA peak current at 4 % duty cycle (2.86 ms at 14 Hz). The accelerator uses a normal conducting front-end bringing the beam energy to 90 MeV, beyond that the acceleration up to 2 GeV is performed using superconducting structures. The accelerator is built by a European collaboration consisting of 23 European institutes delivering in-kind contributions of most hardware but also of services for installation and testing. More than half of the original 510 M€ for the accelerator budget being in form of in-kind contributions. This talk will give an overview of the status of the ESS accelerator and comment on the challenges the accelerator collaboration has encountered and how we together are addressing these challenges.

THE ESS PROJECT

The European Spallation Source is currently under construction in Lund, Sweden. When in full operation it will host some 800 experiment and 3000 scientists annually.

The ultimate goal is to build a 5 MW LINAC based long pulse (2.86 ms) neutron sourced operating at 14 Hz serving 22 instruments. However, due to budget constraints the accelerator power has been reduced from 5 MW to 2 MW, by reducing the energy from 2 GeV to 800 MeV.

The number of neutron instruments have also been reduced from 22 to 15, and some detectors have had their coverage reduced. The reductions in the accelerator and instrument scope have been made in such a way that it can be restored at a later stage.

The target station, on the other hand, is being built for the full 5 MW scope. The reduction in accelerator power and instrument scope is largely offset by a significant improvement in the moderator design [1], resulting in a neutron brightness at the level of the original 5 MW design, and meaning the facility is still expected to be world leading shortly after it becomes operational.

First beam on target is expected in 2025, with user operation of the first few instruments planned for 2026 and the full 2 MW LINAC and 15 instruments operational at the end of 2027.

Figure 1: Aerial photograph of European Spallation Source Site, taken in April 2022.

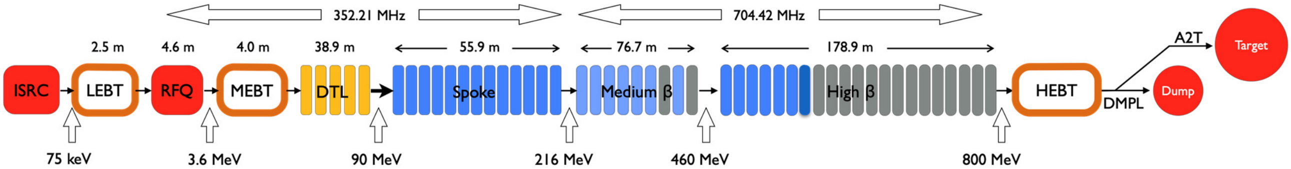

Figure 2: Foreseen LINAC configuration for 800GeV. Grey cryomodules will not be powered.

ESS LINAC

Design and Installation

The original ESS LINAC design was a 5 MW machine at 2GeV, consisting of an ion source, RFQ, 5 DTL tanks, 13 spoke cryomodules with two double spoke cavities each, 9 medium beta cryomodules with four 6-cell elliptical cavities, and 21 high beta cryomodules with four 5-cell elliptical cavities each, operating at a repetition rate of 14Hz and a pulse length of 2.86 ms [2].

While all foreseen cryomodules are still part of the construction project and will be installed in the tunnel, only 5 of the high beta cryomodules needs to be powered by RF to achieve the 800 MeV necessary to produce a 2 MW average power at the nominal pulse length and repetition rate.

Moreover, the initial beam on target is foreseen to be only 570 MeV. This was planned to be generated without using any of the high beta cavities, as the high beta cryomodules would not yet have been installed. However, due to production issues with some medium beta cavities and good progress on the high beta cavities, a configuration of 7 medium beta and 2 high beta cryomodules will be used initially. The remaining high beta cryomodules will be installed between during shutdown periods following first beam on target, and additional RF power to reach 800 MV will be installed before the start of the user program.

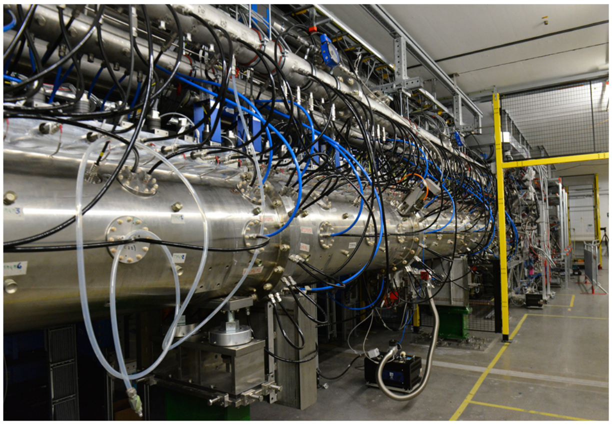

Figure 2: First tank of the DTL installed in the tunnel. The ion source cage can be seen in the background. Photo: Roger Erikson

Currently, the accelerator tunnel is separated by a temporary shield wall at the foreseen location of 5th DTL tank. In the superconducting LINAC part of the tunnel, the cryogenic distribution line is being installed. Cryogenic testing of the line is foreseen for the autumn, followed by cryomodule installation. In the normal conducting part, installation is done up the first DTL tank (see Fig. 2). This part of the tunnel is under PSS (personal safety system) control and commissioning activities are ongoing [3].

In the gallery, all RF systems for the normal conducting LINAC are installed, while installation and testing of RF systems is proceeding in the superconducting part. For the normal conducing LINAC and the elliptical SC cavities, klystrons are used (352 MHz and 704 MHz, respectively), while the spoke section use 352 MHz tetrode based amplifiers. The MEBT bunchers use solids state amplifiers.

In-Kind

Most ESS accelerator hardware is delivered as in-kind (IK) contributions. The main exceptions in terms of capital cost is the klystrons, the modulators for the elliptical cavity RF systems and the cryogenic plant, which were procured by ESS directly. Being a new organisation on a green field site, it would not have been possible to build the ESS accelerator without relying on the competence and manpower available at the 23 accelerator in-kind and collaboration partners. A description of the various in-kind contributions can be found in reference[4] and a summary of partner and contributions is provided in Table 1. At this point, most IK deliverables have been made for the first beam on target at 570 MeV. Deliveries of cryomodules is ongoing. Currently, eight spokes and six medium beam cryomodules have been delivered to ESS. Elliptical cryomodules are acceptance tested at ESS[5], while spoke cryomodules are acceptance tested at the FREIA Laboratory in Uppsala.

Commissioning Status and Plans

The ion source was first tested at ESS in the autumn of 2018 [6], having been previously tested in Catania [7]. The ion source and LEBT were recommissioned in autumn 2021, following some modifications as well as the installation of the RFQ and MEBT. First beam through the RFQ was achieved in November 2021[8], and nominal current first produced early this year. Due to limitations in the Faraday Cups used as beam destinations, only short pulses are possible past the LEBT. Commissioning of the first DTL tank is currently under way, and first beam to the Faraday cup behind this tank was achieved on June 1. For this, the Faraday cup was installed in a temporary location with longer drift space for the beam, and surrounded by local shielding. For more information on the status of the normal conducting LINAC and recent beam commissioning results, see reference [3].

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Table 1: Accelerator In-Kind and Collaboration Partners (Collaboration Agreements Marked with Asterisks)

Partner	Contribution
Aarhus Uni*	Beam delivery system, Cold linac wire scanners
Atomki	RF Local Protection System
Bergen Uni	Ion source expert
CEA	RFQ, Elliptical cryomodules, Allison scanner, Dopper monitor, IPMs, neutron BLMs
IJC Lab	Spoke cryomodules & cryo distribution line
Cockcroft Inst	Target imaging diagnostics
Daresbury Lab	High beta cavities, Linac warm units, Vacuum
DESY*	Diagnostics design, protyping and component production, Nb scanning
Elettra	Spoke RF power stations, Magnets and power supplies, Wire scanner electronics
ESS-Bilbao	MEBT, NCL RF, Klystron modulators
Huddersfield Uni	SCL waveguides and directional couplers
IFJ PAN	Manpower for installation and testing
INFN Catania	Ion Source and LEBT
INFN Legnaro	DTL
INFN Milano	Medium beta cavities
Lodz Uni	LLRF
Lund Uni*	LLRF, Modulator R&D, PRL temperature control, Diagnostics
NCBJ	Gamma Blocker, LLRF
Oslo Uni	Target imaging diagnostics
Tallinn Uni	Modulator design effort, uTCA platform
University West*	Target luminescent coating
Uppsala Uni*	Spoke cryomodule tests
Warsaw Uni	Phase reference line, LLRF
Wroclaw Uni	Cryo distribution

Following this phase of beam commissioning, the tunnel will be opened up to allow installation of the next three DTL tanks. Once these have been conditioned and commissioned with beam, which is foreseen next year, the temporary shield wall will be removed and the last DTL tank installed in its place. This last tank will be commissioned along with the superconducting LINAC, initially to the permanent tuning dump, and then to the target.

ESS TARGET

The ESS target is a 2.6 m diameter rotating Tungsten wheel consisting of 36 individual segments. The first target was recently delivered to ESS from Bilbao (see Fig. 3). Its outer rim was coated with a fluorescent material to allow imaging of the beam footprint. The target is currently undergoing pre-installation testing. Installation of the target wheel is scheduled for this autumn.

In the target monolith, the core vessel has been installed and neutron beam ports welded in place. The vessel that will hold the proton beam window (separating target atmosphere from beam vacuum) has been installed and connected, and the outer shielding has been stacked around and of top of this assembly. Stacking of the inner shielding will begin soon.

Figure 3: ESS target wheel recently delivered from Bilbao. Photo: Roger Erikson

The hydrogen cryoplant for the moderator has been delivered and the moderator assembly has been cold tested by the in-kind partner in Jülich. The moderator is a special low profile “butterfly” shaped design aimed at maximizing the neutron brightness [1]. The target is designed with an upper and a lower moderator with the target wheel in between, but only one moderator will be installed initially. The geometry of the initial upper moderator is slightly off from the optimal for the neutron beam guide geometry, as these have been designed for the ultimate moderator geometry and proton beam energy. The lower moderator will be installed at a later stage.

ESS INSTRUMENTS

The base scope for ESS instruments includes 15 instruments with difference specialization[9], although provisions are made for up to 22. These instruments will go through hot commissioning once first neutrons are available from the target and come online in a staged fashion, with the first ones being LoKI, ODIN, DREAM, BIFROST, which are expected to start user operation in mid-2026. In addition to the user instruments, there is a test beamline, which allows to evaluate the performance of the target and moderator in terms of neutron production.

Instrument construction is ongoing (see Fig. 4), and neutron beam port inserts, neutron guides and beamline shielding is being installed. The bunker housing the choppers and light shutters is also being assembled. The goal is to install all of the in-bunker components before first beam on target.

Figure 4: Photo of the South/East experimental hall showing ongoing construction of the ODIN and DREAM experiments (white) as well as the target bunker (blue) housing the choppers.

SUMMARY

The ESS project is progressing at a high rate, with buildings now finished and installation of major components ongoing across the site. Beam commissioning of the first part of the LINAC is under way, and a milestone was recently passed with first beam through the first DTL tank. First beam on target is planned for 2025, with first user operation expected to start in 2026. A major part of the technical scope of the project is delivered as in-kind contributions. Drawing on the manpower and competence of in-kind and collaboration partners is a key to success for a green field project like ESS.

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