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ESS NORMAL CONDUCTING LINAC STATUS AND PLANS

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Abstract

The European Spallation Source (ESS) uses a linear accelerator to deliver the high intensity proton beam to the target station for producing intense beams of neutrons. The average beam power is 5 MW with a peak beam power at the target of 125 MW. The normal conducting linear accelerator (linac) operating at 352.21 MHz accelerates a proton beam of 62.5 mA from 0.075 to 90 MeV. It consists of an ion source, Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ), Medium Energy Beam Transport (MEBT), and Drift Tube Linac (DTL). The design, construction and testing of those structures is done by European partner labs as an in-kind contribution to the ESS project. This paper presents the status and plans for the ESS normal conducting linac.

INTRODUCTION

The ESS linear accelerator (linac) generates and accelerates protons to 2 GeV energy, delivering them onto a rotating tungsten target to create neutrons, via the spallation process, for use by research instruments [1]. The linac is composed of normal conducting structures followed by superconducting spoke and elliptical cavities. The layout of the ESS linac is shown in Fig. 1. The normal conducting linac (NCL) consists of an ion source, Low Energy Beam transport (LEBT), Radio Frequency Quadrupole (RFQ), Medium Energy Beam Transport (MEBT) and Drift Tube Linac (DTL). The NCL operates at 352.21 MHz frequency, 14 Hz repetition rate, with 62.5 mA peak beam current and 2.86 ms beam pulse length.

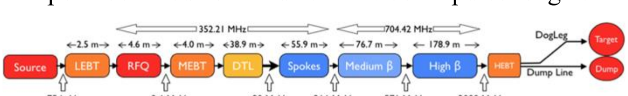

Figure 1: Layout of the ESS linac.

STATUS AND PLANS

The ESS facility is currently under construction, with the start of the user programme planned for 2023. The installation of the utilities and accelerator components in the accelerator tunnel and the klystron gallery is ongoing at ESS. All sections of the ESS NCL are presently under construction, while the ion source and LEBT are already delivered and installed at ESS. A brief description, status and plans for the ESS NCL are presented below.

Ion Source and LEBT

The ion source and LEBT are in-kind contribution from INFN-LNS, Catania, Italy. The source is a 2.45 GHz microwave discharge ion source with a flexible magnetic system [2]. The requirements include proton beam current of 74 mA, normalised rms emittance of 0.25 π.mm.mrad at the RFQ entrance, proton fraction of >75%, intra-pulse beam current stability of ±2%, pulse to pulse stability of ±3.5%, repetition rate of 14 Hz, beam pulse length of 6 ms from the source and 2.86 ms in the LEBT. The LEBT consists of two solenoid magnets with embedded steerers, and beam diagnostics to measure the beam current, emittance, position, and fraction. It also contains a fast electrostatic chopper to remove the first part of the beam pulse during which the plasma needs to stabilise. An iris with six movable blades reduces the beam current for running the linac in low-power mode.

The ion source and LEBT were installed and commissioned in Catania prior to the delivery to ESS. The range of possible extracted beam currents and stability were measured during the spring 2017 [3]. The current range with stable beam was 40-120 mA. With the nominal ion source settings, the fractions of the different ion species were 85%, 12% and 3% for protons, H_2^+ and H_3^+ respectively. With this proton fraction, the proton beam current was 85 mA. The measured stability was ±1.5% inside the beam flat top, and ±3% among pulses as shown in Fig. 2.

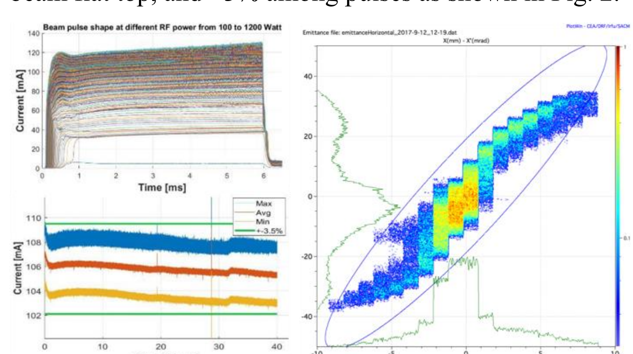

Figure 2: Ion source intra-pulse beam stability (top left), pulse-to-pulse stability (bottom left), and emittance at the RFQ entrance (right).

The ion source produced the nominal time structure of 6 ms pulse length and 14 Hz repetition rate, with the first 3 ms removed by the chopper. Beams with flat top pulse

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length in the range of 1-3 ms have been produced, without significant changes in the beam current.

The emittance was measured 150 mm downstream the LEBT-RFQ lattice interface. The measured emittance containing 99% of the beam current was 2.26 π.mm.mrad (see Fig. 2), which is within the required value. Further optimisations will be done during the beam commissioning phase at ESS.

The ion source and LEBT were delivered to ESS in Dec. 2017 and installed in Jan-Feb 2018 by INFN-LNS. A safety fence with lead shielding and access control is installed around the ion source to protect personnel from the high voltage and X-rays. This enables commissioning and operation of the ion source and LEBT while allowing access to the tunnel for installation. Figure 3 shows the ion source, safety fence and LEBT installed at ESS.

Figure 3: Ion source (left), safety fence and LEBT (right) installed at ESS.

A Safety Readiness Review with an external committee was successfully held at ESS in July 2018. The systems are now ready for the beam commissioning starting in Sep. 2018. The first plasma was obtained on Sep. 11, 2018 and is currently being conditioned. The commissioning and long-term tests of the ion source and LEBT will continue up to the delivery of the RFQ to ESS.

RFQ

The design, construction, installation and RF conditioning of the ESS RFQ is done by CEA/IRFU, France. It is a 4.6-meter long, four-vane accelerating structure designed to bunch and accelerate the proton beam from 75 keV to 3.62 MeV energy at a frequency of 352.21 MHz [4, 5]. The design is based on a sinusoidal evolution of the inter-vane voltage, which is increasing from 80 to 120 kV over the length of the RFQ. The RFQ is made of pure copper in five sections of 0.9 m each. The vanes are machined with 20 μm precision, then positioned and brazed with 30 μm precision. Two power couplers transfer the RF power to the cavity. The total required peak RF power is 1.6 MW. Each coupler is able to handle a maximum peak RF power of 1 MW.

A test stand, shown in Figure 4, has been built at CEA for testing and validation of various components of the RFQ [6]. A test cavity was used for the conditioning of the power couplers and validation of interfaces. The two power couplers and a spare have been successfully conditioned on the test cavity in March 2018, reaching 1 MW peak power, 14 Hz repetition rate and 3.6 ms pulse length.

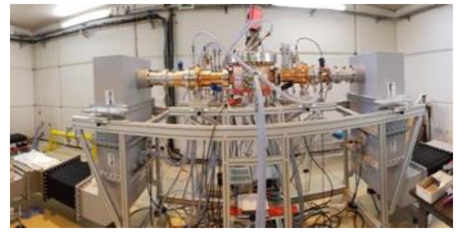

Figure 4: RFQ coupler conditioning test stand at CEA.

The prototypes of adjustable tuners are machined, brazed, and successfully tested. The water-cooling skid of the RFQ has been delivered to ESS in May 2018. It was installed and successfully tested in June 2018 (see Fig. 5).

Figure 5: RFQ water-cooling skid installed at ESS.

The machining of the RFQ vanes is ongoing. Each machining stage is first performed and validated on an aluminium mock-up before repeating it on the actual copper vane. Bead-pull measurements are done before and after the brazing of the vanes together for each section in order to verify the voltage law. A brazing mock-up has been prepared and successfully tested, including vacuum leak test, to validate the brazing process.

The RFQ will be first assembled and tested, excluding high-power RF, at CEA. The delivery to ESS is expected in Dec. 2018. The assembly and tuning in the tunnel is planned during Q1 2019. Once the RF system is available, the conditioning of the RFQ can start in Q3 2019. A temporary shielding wall will be installed across the tunnel at the location of the last DTL tank, to allow for installation of the superconducting linac downstream while the RFQ, MEBT and DTL are being commissioned.

MEBT

The design, construction, testing and installation of the MEBT is done by ESS-Bilbao, Spain. The 3.81-meter long MEBT [7] transports and matches the RFQ output beam to the DTL both transversally and longitudinally. The transverse focusing is done by 11 quadrupoles with embedded steerers, and the longitudinal matching is done by three buncher cavities resonating at 352.21 MHz and providing an effective gap voltage of 150 kV. A strip-line fast chopper removes longitudinal edges of the 3.62 MeV beam with a rise time of <10 ns, acting together with the slow LEBT chopper. The deflected beam is intercepted by an adjustable beam dump, which is designed to absorb a maximum peak beam power of 240 kW and 40 μs pulse length. A comprehensive set of beam diagnostics includes 8 Beam Position Monitors (BPM), 3 Beam Current Transformers (BCM), 2 Non-invasive Profile Monitors (NPM), 3 Wire Scanners (WS), a Longitudinal Beam Profile Monitor (LBPM), Slit-Grid emittance measurement unit, and a

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Faraday Cup (FC). A set of collimators along the MEBT are designed to scrape particles at large beam radii.

The first magnet [8] has been successfully tested and delivered to Bilbao in May 2018 (see Fig. 6). The remaining magnets will be delivered in Oct. 2018. All three bunchers [9] have been manufactured in stainless steel and copper plated (see Fig. 6). Vacuum, low-power RF and bead-pull measurements have been successfully done.

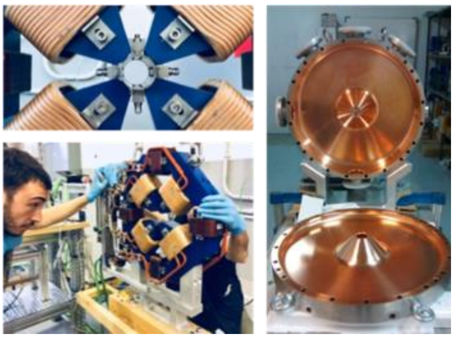

Figure 6: MEBT quadrupole with and without embedded BPM (top left, bottom left) and buncher (right).

The chopper and its vacuum vessel have been manufactured, and high voltage vertical integration tests have been successfully done in Bilbao achieving 5.4 kV with 6.3 ns rise time. The three WSs, the first set of collimators and their vacuum vessels have been received and tested in Bilbao. The BPMs have successfully passed vacuum tests and are currently being RF tested in Bilbao. The FC has been tested and integrated, including tests with 45 keV, 40 mA beam from the Bilbao ECR ion source.

Prior to the delivery and installation at ESS, the MEBT will be fully assembled in Bilbao in Q4 2018. This will allow verification of mechanical interfaces and validation of the assembly and alignment procedure. The installation in the ESS accelerator tunnel is planned for Q1 2019.

DTL

The design, constructions, testing, installation and RF conditioning of the DTL is done by INFN-LNL, Italy. The 39-meter long DTL is designed to accelerate the proton beam from 3.6 to 90 MeV and operates at a frequency of 352.21 MHz [10, 11]. Each of the five DTL tanks consists of 4 modules of ~2 m length and a diameter of 521 mm. The tanks are made of stainless steel with copper plated internal surface. The drift tubes contain a total of 89 permanent magnet quadrupoles (PMQ) and 30 steerers. Each tank is equipped with two power couplers to feed the required 2.2 MW peak RF power into the DTL tanks. A total of 123 post couplers have been integrated for field stabilisation during the tuning process. Active tuners control the resonance frequency during operation and tune the field distribution locally. DTL tanks contain 17 BPMs and the inter-tanks sections contain 5 BCMs and 2 FCs.

The machining of the DTL tanks and girders is ongoing. All four sections of the DTL tank #4 (first to be assembled and installed) are completed. One of the sections has been copper plated (see Fig. 7). The machining of the drift tubes is done at INFN in Legnaro and Torino. The PMQs and steerers are delivered to INFN-LNL and are being assembled into the drift tubes. The first batch of eight drift tubes have been brazed at INFN-LNL.

An aluminium mock-up model of the DTL has been produced by INFN-LNL in order to optimise the tuning procedure and to train the personnel. The tuning of the mock-up has been successfully accomplished (see Fig. 8).

Figure 7: First copper plated DTL section at GSI (left) and aluminium mock-up model of the DTL (right).

The assembly of the DTL tanks will be done in a dedicated workshop at ESS. The workshop is currently being installed in the klystron gallery technical area. The assembly of the first tank is planned to start in Nov. 2018 and the installation in the tunnel in Q2 2019.

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