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ESS NORMAL CONDUCTING LINAC STATUS AND PLANS

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Abstract

Efficient and low loss beam acceleration in the European Spallation Source (ESS) linear accelerator (linac) gives rise to specific technical challenges in the normal conducting (nc) section. The nc linac creates high current proton beams, produces the macro and micro structures (formation of the pulse and bunches respectively) of the beam and accelerates the latter up to 90 MeV before injection in the superconducting (sc) linac. Design and construction of the different components of the nc linac are part of a broad collaboration involving experts of various labs in Europe. Beam commissioning of the warm linac in the ESS tunnel is foreseen at the beginning of 2019.

INTRODUCTION

The ESS aims at becoming the world's most powerful neutron source at the end of the decade. The spallation neutrons are produced by a 5 MW proton beam hitting a solid, rotating tungsten target [1]. The acceleration of the proton beam up to a final energy of 2 GeV is ensured by a ~ 400 m Radio-Frequency linear accelerator (RF linac) whose main characteristics are 14 Hz repetition rate, 62.5 mA peak beam current and 2.86 ms beam pulse length. The layout of the ESS linac can be seen in Fig. 1.

The linac [2] is composed by a sequence of nc structures followed by sc cavities hosted in cryomodules [3]. The nc part of the linac, while giving only 5 % of the power to the beam, has to produce very high quality beams before injecting into the sc linac. The layout of the nc linac and the main technical challenges will be explained. The design and the construction of the warm linac as part of a broad European collaboration is presented in the following. Status and plans for construction and installation will finally be given.

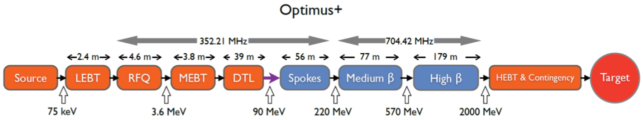

Figure 1: Layout of the ESS linac.

LAYOUT AND TECHNICAL CHALLENGES

General Layout

The proton beam is *produced and accelerated* to 75 keV in a Microwave Discharge Ion Source (MDIS) which is followed by a dual solenoid Low Energy Beam Transport line (LEBT) [4] *transporting and matching* the beam into the Radio-Frequency Quadrupole (RFQ). The latter *accelerates to* 3.62 *MeV, focuses and transforms the beam pulse in a train of bunches* at 352.21 MHz [5] to allow rf acceleration in the subsequent structures. The beam is then *transported* through the Medium Energy Beam Transport line (MEBT) [6] and *matched* into the Drift Tube Linac (DTL) [7]. The DTL finally *focuses and accelerates* the beam up to 90 MeV in 5 tanks of 8 m each.

In order to allow efficient matching with acceptable and controllable beam loss during operation, the LEBT and the MEBT, even given the reduced space available, are equipped with a set of diagnostics for current, energy and phase space measurements [8].

Technical Challenges

The main goal of the warm linac is to inject high quality proton beams with a given time structure and sufficient energy in the sc linac.

The required peak beam current on target is 625 mA. As a result, proton transport through the warm linac is very challenging due to *high space charge forces* acting on the beam. In particular, performing the injection of the matched beam into the RFQ requires to understand theoretically and experimentally how much the ionization of the residual gas by the proton beam reduces the space charge of the beam itself: the so-called space charge compensation (scc) process. In addition, reducing the development of halo is mandatory to avoid hazardous losses, which must remain below 1 W/m at high energy, therefore requiring good beam matching between sections since mistmatch is known to be one of the main mechanisms of halo production. The RFQ is also foreseen to perform efficient bunch capture with negligible production of longitudinal tail that potentially transfers into transverse halo and losses. In the MEBT collimator strategy is being studied to intercept part of the transverse halo [9]. Challenges in terms of beam performances are summarized in Tab. 1 (see [10] for a deeper analysis).

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Table 1: Nominal Beam Performances Requirements (99 % means that values are foreseen for 99 % of the nominal current). Emittances are Normalized.

Sections	**Nominal performances**								
	Output energy [MeV]	**Extracted current** [mA]	**Proton fraction** %	**99 % ellipse area Trans.** [π·mm·mrad]		**99 % divergence Trans.** [mrad]			
IS	0.075 ± 0.00001	74	> 80	< 1.8		< 80			
	Output energy [MeV]	**Input design current** [mA]	**Beam transmission** [%]	**99 % Ellipse area Trans.** [π·mm·mrad]		**Transverse Twiss parameters** α	**Transverse Twiss parameters** β [mm/mrad]		
LEBT	0.075 ± 0.00001	74	> 95	< 2.5		1.02 ± 20 %	0.11 ± 10 %		
	Output energy [MeV]	**Input design current** [mA]	**Beam transmission** [%]	**99 % ellipse area Trans.** [π·mm·mrad]	**99 % ellipse area Long.** [π·deg·MeV]	**Transverse Twiss parameters** α	**Transverse Twiss parameters** β [mm/mrad]	**Longitudinal Twiss parameters** α	**Longitudinal Twiss parameters** β [deg/MeV]
RFQ	3.62 ± 0.01	70	> 90	< 2.43	< 1.60	−0.05 ± 10 % (H) −0.31 ± 10 % (V)	−0.21 ± 10 % (H) 0.37 ± 10 % (V)	0.48 ± 10 %	613 ± 10 %
MEBT	3.62 ± 0.01	63	> 99.3	< 3.00	< 1.66	1.34 ± 8 % (H) −4.19 ± 8 % (V)	0.21 ± 7 % (H) 0.77 ± 7 % (V)	−0.12 ± 50 %	274 ± 7 %
DTL	> 89	62.5	~ 100	< 3.20	< 1.79	−2.34 ± 10 % (H) 2.33 ± 10 % (V)	5.20 ± 8 % (H) 4.74 ± 8 % (V)	−0.17 ± 110 %	32 ± 13 %

The required pulse length is 2.86 ± 0.001 ms due to Machine Protection System (MPS) [11] purposes. In order to reach this precision, the beam pulse is cleaned to remove the transient coming from the rise time of the IS with a *two-step-chopping scheme: a slow and a fast chopper* with a voltage rise time of 100 ns and 10 ns in the LEBT and the MEBT respectively. Even though the rise time of the LEBT chopper seems short, the scc, and thus the matched beam parameters into the RFQ, are expected to be recovered, after the chopper is turned off, within a tens of microseconds [12]. Likewise, 10 ns in the MEBT might appear fast given the required pulse length precision. However, a very fast rise time is mandatory in order to reduce the risk of losses due to partially kicked bunches during the transient of the MEBT chopper voltage which might be transported after the MEBT chopper-dump [13].

Table 2 gives a summary of the pulse length requirements from the ion source to the MEBT indicating the maximal pulse length and the minimal pulse flat top length. The flat top is reached when the following stable conditions are met: the nominal current is produced with fluctuations of less than 3.5 % within the pulse after the IS and the matched beam parameters given in Tab. 1 are produced.

Table 2: Nominal Beam Pulse Requirements.

Section output	**Total pulse length [ms]**	**Flat top length [ms]**
IS	< 6	> 3
LEBT	< 2.88	> 2.86
MEBT	2.86 ± 0.001	2.86 ± 0.001

Another technical challenge is the ability to produce different levels of currents [14] to allow a wide range of neutron production modes. A collimator will be installed in between the solenoids of the LEBT. With 6 independent blades, the collimator system shall be adjustable in order to produce on target at least 10 steps of currents ranging from 6.5 to 62.5 mA with a maximal step size of 6.3 mA and a precision of 1 mA.

COLLABORATION

The ESS warm linac design activities have been conducted with the expertise of a broad European collaboration (see Fig. 2): INFN/LNS for the IS-LEBT, CEA-Irfu for the RFQ, ESS-Bilbao for the MEBT and finally INFN/LNL and INFN/Sezione di Torino for the DTL.

Negotiations are currently being held between ESS and the relevant member states to define the level of their in-kind contribution to the different nc linac sections during the construction phase.

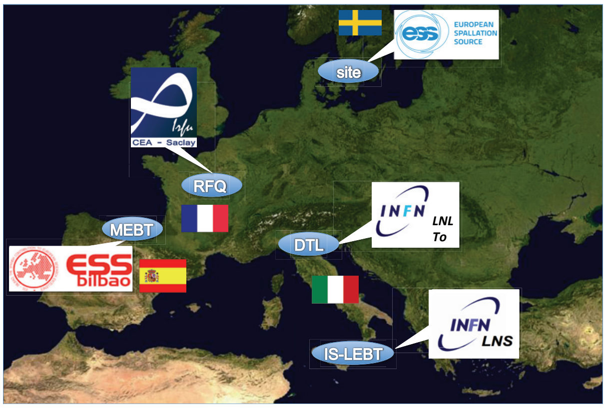

Figure 2: The NC linac collaboration.

STATUS AND PLANS

Status

- The preparation of the test stand area for the IS has been achieved in the INFN/LNS premises. The high voltage platform is being equipped in order to install the

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ion source body whose executive drawings are being completed.

- The LEBT lattice is in a very advanced stage with focus on the mechanical integration of the vacuum systems and the beam diagnostics. Emphasis is put on the definition of the interface region between the LEBT and the RFQ where sit among other systems a beam current transformer, a vacuum gate valve, a repeller electrode, the dump for the chopped beam and its cooling system and a potential vacuum pump port to limit the gas load into the RFQ.
- The beam dynamics and RF designs of the RFQ have been completed. Thermomechanical analysis is ongoing to define the cavity water cooling scheme and the corresponding cooling skid. In addition, prototypes of a RF power coupler loop, a vacuum grid and a movable tuner are under study. They will be tested under high RF power to validate the RFQ design choices.
- The MEBT lattice is in a very advanced stage with focus on the mechanical integration of the vacuum systems and the beam diagnostics. Moreover, tests are being performed on the buncher cavity prototype (see Fig. 3) including copper plating and RF characterization. Detailed engineering design for the magnets has started. Different technologies for the chopper system are also being investigated and thermomechanical calculations on the chopper dump and the halo collimators are being performed.
- The beam dynamics, RF and mechanical design of the DTL are being finalized. In parallel to design activities, 3 DT prototypes, equipped with a Permanent Quadrupole Magnet (PMQ) that can be seen in Fig. 4, a magnetic steerer and a beam position monitor respectively, are under construction. Machining is achieved in the mechanical workshop of INFN/Sezione di Torino and assembly and brazing are handled in INFN/LNL.

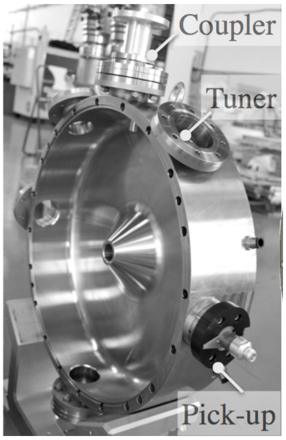

Figure 3: Picture of the buncher prototype after machining.

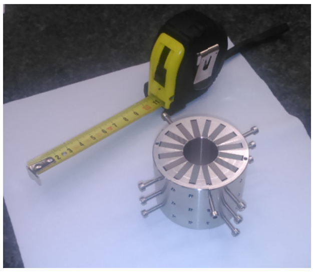

Figure 4: Picture of the DTL PMQ prototype.

Plans

Main milestones of the nc linac are reported in Fig. 5

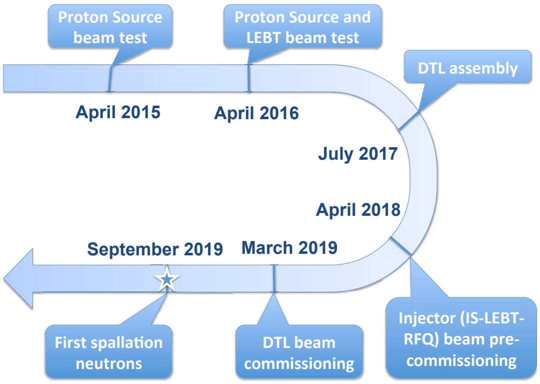

Figure 5: Warm linac main milestones.

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