

REQUIREMENTS FOR ESS SUPERCONDUCTING RADIO FREQUENCY LINAC

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Abstract

The European Spallation Source (ESS) is a pan-European project. It will be built by at least 17 European countries, with Sweden and Denmark as host nations. The Superconducting Radio-Frequency (SRF) linac is composed of one section of spoke cavity cryomodules (352.21 MHz) and two sections of elliptical cavity cryomodules (704.42 MHz). These cryomodules contain niobium SRF cavities operating at 2 K. Following a redesign of the accelerator, SRF linac design shall comply with a new set of requirements, like an increase of the beam current from 50 mA to 62.5 mA and an increase of the peak electrical surface field from 40 MV/m to 45 MV/m. Requirements and the main disciplines needed to construct this portion of the linac are presented.

INTRODUCTION

The ESS Superconducting Radio-Frequency Linac has been designed to deliver to the target a time averaged proton beam power of 5 MW at the completion, with a stage at 1 MW in 2019 [1]. The superconducting linac lattice redesign has permitted to optimize the layout of the linac using a transition energy of 90 MeV with the normal conducting linac and reaching 2 GeV at the target [2]. Figure 1 shows the layout of the linac [3]. The superconducting linac is composed of twenty-six double spoke cavities ($\beta=0.5$), thirty-six 6-cell medium- β elliptical cavities ($\beta=0.67$) and eighty-four 5-cell high- β elliptical cavities ($\beta=0.86$), as shown in Fig. 3.

The spoke cavities and elliptical cavities are gathered two-by-two and four-by-four in their cryomodules, respectively. The SRF linac is designed, prototyped and tested in partnership with the ESS, CEA-IRFU, CNRS-IPNO and Uppsala University. Several other key scientific institutions will join this partnership for the SRF linac series fabrication, testing, installation and integration, as part of the ESS In-Kind Contribution.

In this paper, we report the requirements needed to integrate the SRF cavities and cryomodules in the ESS linear accelerator.

DEFINING REQUIREMENTS

The ESS accelerator requirements are distributed in different levels.

The requirement Product Breakdown Structure (PBS) for the accelerator is shown in Fig. 2 and permits to identify:

- Level 1: overall ESS facility
- Level 2: system projects, e.g. the linac
- Level 3: linac sections, e.g. medium-beta linac (MBL)
- Level 4: disciplines, e.g. electromagnetic resonator (EMR)

The requirements for the SRF linac are defined for the SRF cavities and cryomodules using quality or so-called disciplines. The relevant disciplines for the SRF linac are electro-magnetic resonator (EMR), Radio-Frequency system (RFS), cryogenics (CRYO) and vacuum (VAC).

Each requirement is described in a comprehensible manner and shall identify either:

- The part of the system that performs the action.
- The action to be performed.
- The part of the system acted upon.
- Where the result of the action is sent/received.
- When the action is performed and/or when the action is not performed.
- The rationale - the reason or benefit achieved

Requirements can be tracked from ones higher up and typically correspond to a quantity, which can be verified by:

- Inspection of drawings, items, test reports.
- Demonstration of the action where there is no performance criteria.
- Measurement of the action where there is a performance criteria.
- Analysis, where none of the above is appropriate e.g. certain cases related to safety or risk.

Each requirement is then registered and traceable through a standards traceability management system, so-called DOORS [4].

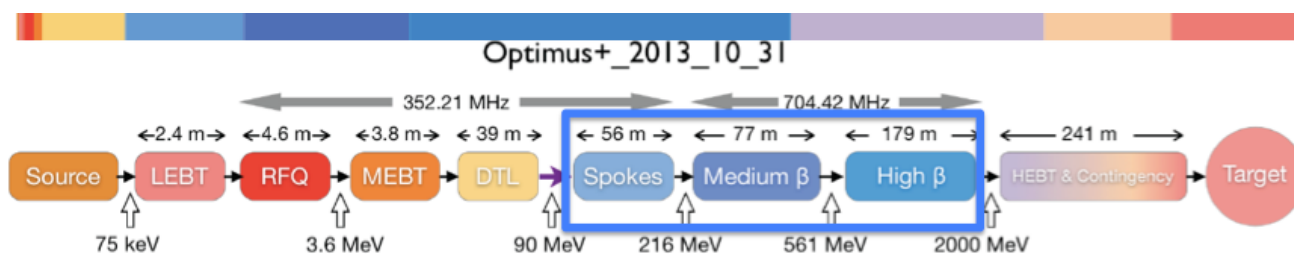


Figure 1: Block diagram of the Optimus+.

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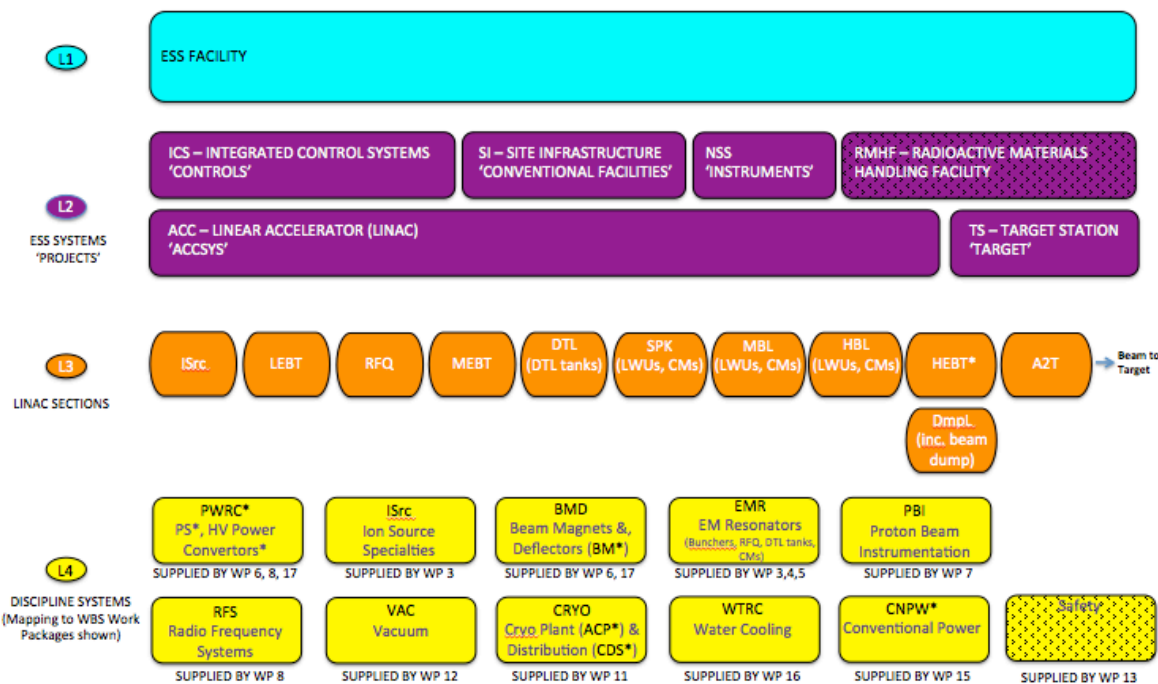


Figure 2: Product breakdown structure for the definition of requirements.

SRF LINAC REQUIREMENTS

The SRF linac is composed of three families of cavity strings, which operate at 2 K and accelerate protons from 90 MeV to 2 GeV. Figure 3 displays the three families of spoke cavity and elliptical cavities medium and high-beta [5-6]. Figure 4 gives the example of the spoke cryomodule [7-10]. It is worth mentioning that the two families of elliptical cavities will be housed in a similar cryomodule and that two spoke cryomodules could be replaced by one medium-beta or one high-beta cryomodule.

Hundreds of requirements have been identified to best integrate the SRF components in the ESS tunnel. The requirements are also used to define the interfaces with the conventional facilities, the control system and to define the operating modes for the ESS SRF linac [11]. The high level requirements were defined in order to optimize the layout of the ESS superconducting linac [3].

Interfaces requirements between the different levels and the different disciplines are being developed [12].

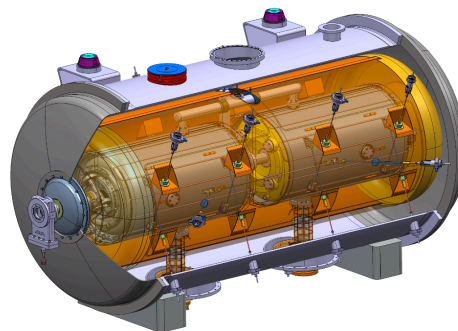


Figure 4: View of the spoke cryomodule.

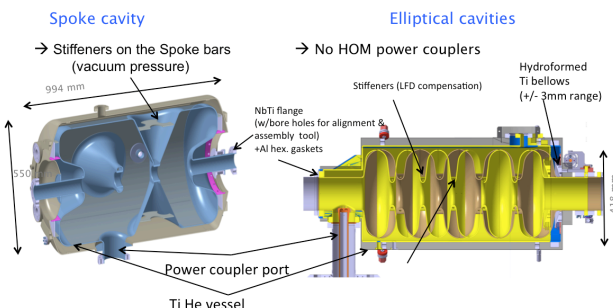


Figure 3: View of the spokes and elliptical cavities (medium and high-beta).

Electro-Magnetic Resonator

Beam optic studies drive the design of EM components in order to transfer energy from the RF sources to the beam. Hence, the SRF cavities and cryomodules are designed using requirements defined in Table 1.

Radio-Frequency System

The RFS requirements define the operating conditions of the high power RF sources and the low-level RF (LLRF) for the three families of SRF cavities. The RF sources provide the amplitude and the phase to the forward voltage wave to the beam through the power-couplers and the SRF cavities. The RFS system shall be capable of handling 100 % reflected power for the entire pulse length. The characteristics of the RF pulse are monitored and open-loops permit to synchronize the cavity frequency tuning with the beam pulse.

The mean time to repair (MTTR) and the mean time between failures (MTBF) are defined according to the overall availabilities requested for the linac.

Table 1: Cavity EMR Requirements

Requirements	Spoke	Medium	High
Frequency (MHz)	352.21	704.42	704.42
Geometric beta	0.50	0.67	0.86
Nominal Accelerating gradient (MV/m)	9.0	16.7	19.9
Epk (MV/m)	39	45	45
Bpk/Eacc (mT/MV/m)	<8.75	4.79	4.3
Epk/Eacc	<4.38	2.36	2.2
Iris diameter (mm)	50	94	120
RF peak power (kW)	335	1100	1100
G (W)	130	196.63	241
Max R/Q (W)	427	394	477
Qext	$2.85 \cdot 10^5$	$7.5 \cdot 10^5$	$7.6 \cdot 10^5$
Q0 at nominal gradient	$1.5 \cdot 10^9$	$> 5 \cdot 10^9$	$> 5 \cdot 10^9$

Cryogenics

The cryogenic requirements define the cooling capacity needed to maintain the proper operation of the superconducting cavities. The SRF cryomodules receive a distributed cooling capacity from the accelerator cryoplant through the cryogenic transfer lines and the valve boxes. For each family of cryomodule, the mass-flow, temperatures and pressures are required to optimize the linac operation. The static and the dynamic heat loads are controlled and used to define the overall cooling capacity of the cryogenic plant. The cryogenic requirements for the SRF linac also capture the restrict needs for the operation of the cryogenic plant.

Vacuum

Similar to the cryogenic requirements, the vacuum requirements permit to ensure a safe operation of the cryomodules. The beam vacuum is controlled to limit any possible contamination of the beam vacuum. Vacuum isolating valves are used on each side of the cryomodules.

Other Stakeholders

Of particular importance to a high power facility such as ESS is the operation of the Machine Protection System (MPS), which deals with very well through the requirements process, and allows the necessary functionality of the system to be clearly specified, without making assumptions regarding the architecture used to deploy this system. This functionality will be documented at a high level, with lower level requirements then being placed on certain aspects of accelerator equipment (i.e., detectors & actuators) at a lower level.

PROTOTYPING STATUS

The prototyping phase is on-going with the spoke and elliptical cavities. Cavities, power couplers, CTS and the main components of the cryomodules are being fabricated and tested. This important phase permits to verify most of the requirements thanks to technology demonstrators. The critical SRF linac technologies are prototyped in order to validate component design performances and their assembly phase before transferring knowledge to the industry for the series production. The functional analysis of the spoke and elliptical cryomodules will be validated and the operation modes will be tested and verified. The first spoke cavity is expected to be tested at high power in Uppsala University by the end of 2014, whereas the first medium-beta elliptical cryomodule shall be tested in CEA-IRFU by the fall of 2016.

CONCLUSION

Given the in-kind nature of the construction of ESS, where most of the equipment will be built by collaborating partners, the process of gathering high-quality requirements is of fundamental importance. They not only specify the functionality of the machine and document the status of the design; they also underpin the technical contracts that will be used to govern the contributions of many widely spaced laboratories and institutions.

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