ESS SRF LINEAR ACCELERATOR COMPONENTS PRELIMINARY RESULTS AND INTEGRATION

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Abstract

The European Spallation Source (ESS) is a pan-European project and one of world's largest research infrastructures based on neutron sources. This collaborative project is funded by a collaboration of 17 European countries and is under construction in Lund, Sweden. The 5 MW, 2.86 ms long pulse proton accelerator has a repetition frequency of 14 Hz (4% duty cycle), and a beam current of 62.5 mA. The Superconducting Radio-Frequency (SRF) linac is composed of three families of Superconducting Radio-Frequency (SRF) cavities, which are being prototyped, counting the spoke resonators with a geometric beta of 0.5, medium-beta elliptical cavities (β=0.67) and high-beta elliptical cavities (β=0.86). After a description of the ESS linear accelerator layout, this article will focus on the recent progress towards integration of the first test results of the main critical components to be assembled in cryomodules, then in the ESS tunnel.

THE ESS LAYOUT

ESS is a new facility composed of a 5 MW proton linac, a tungsten target to produce neutrons by spallation reaction and experimental neutron beam lines for multi-disciplinary users [1].

The choice of Superconducting Radio-Frequency (SRF) technology is a key in the development of the ESS accelerator. The SRF linac is composed of three families of cavity strings, which operate at 2 K. Figure 1 shows the spoke cavities section operating at 352.21 MHz, the medium-beta and the high-beta sections with elliptical cavities operating at 704.42 MHz. Cavities are housed in cryomodule separated from the following cryomodule by quadrupole doublet used for transverse beam control.

The superconducting linac lattice 2013 redesign permitted to optimize the layout of the linear accelerator using a transition energy of 90 MeV with the normal conducting linac and reaching 2 GeV at the target [2]. Hence, the requested cavities peak field was increased from 40 to 45 MV/m, and the beam current from 50 to 62.5 mA. The high cavities peak field combined with the high RF power of 1.1 MW for the elliptical represents a technical challenge for reaching 5 MW to the target.

PROTOTYPE RESULTS

ESS SRF accelerator achievements are driven by the collaborative effort of ESS, CEA-Saclay, CNRS-IPN Orsay, INFN-LASA, STFC-Daresbury, DESY, Uppsala and Lund Universities [3]. Since the main components are being fabricated by research institutes located outside the Lund area, the integration and interfacing of each resulting components must be carefully planned.

Each double-spoke cavity has 3 gaps with an accelerating gradient of 9 MV/m. The medium-beta and high-beta cavities shall reach nominal accelerating gradients of 16.7 and 19.9 MV/m, respectively. Each cavity family has been tested successfully up to the requested gradients [4].

IPN Orsay – Spoke Cryomodules

IPN Orsay have tested and validated the design of spoke cavity, power-coupler and cold tuning system. The prototype spoke cryomodule and its valve box were cooled-down to validate the cryogenic design. Figure 2 shows prototype cavities results of Romea and Giulietta, exceeding ESS requirements (Q_o>1.5 10^9 at 9 MV/m). Similar results have been reproduced in Uppsala.

Exhaustive SRF activities have been developed. In parallel, the RF processing of 4 power-couplers was performed at IPNO. The power-coupler, which reached 400 kW was assembled to the cavity Romea and shipped to Uppsala for high power test.

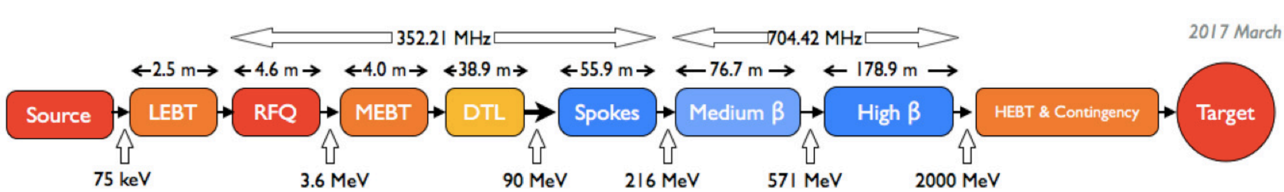

Figure 1: Layout of the ESS Accelerator. The SRF section is represented in blue.

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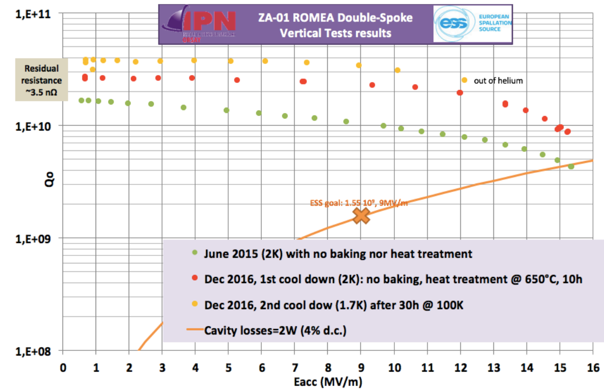

Figure 2a: Test results of the prototype cavity Romea.

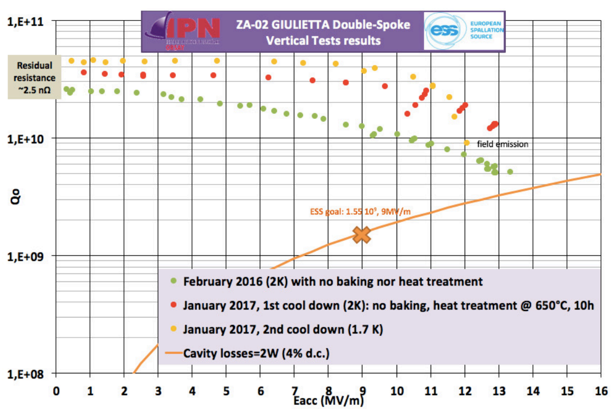

Figure 2b: Test results of the prototype cavity Giulietta.

FREIA Uppsala University- Spoke & Elliptical

The results of the spoke cavity tested in HNOSS horizontal cryostat with and without power-coupler is detailed in [5-6]. Warm and cold RF processing were conducted using IPN Orsay's control system, then FREIA's one, which has been validated. The maximum forward RF power was ramped up to 110 kW with a pulse length of 2.86 ms at 14 Hz to reach 9 MV/m. Figure 3 shows the pressure evolution ramping-up to 110 KW.

Lorenz-Force-Detuning compensation with piezo tuner will be studied during the next test campaigns of the complete spoke cryomodule, and with the high-beta cavity package test at 704.42 MHz. The control system will be adapted from LabView to Epics [7].

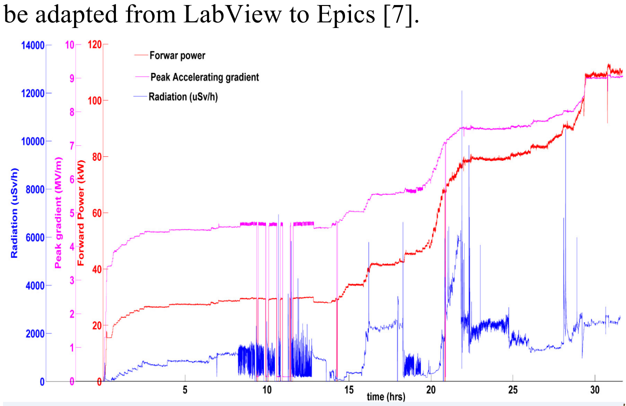

Figure 3: Cavity package conditioning history.

CEA Saclay - Elliptical Cryomodules

Two prototype high-beta elliptical cavities and six medium-beta cavities have been fabricated and tested in vertical cryostat in Saclay [8]. All higher order modes (HOMs) shall be at least 5 MHz away from integer multiples of the beam-bunching frequency (352.21 MHz) for any HOMs whose resonant frequencies are below the cut-off frequency of the beam-pipe. Hence, a stringent follow-up is applied to the medium and high beta cavity fabrication sequences.

Figure 4 shows the achieved medium-beta cavities accelerating gradient and the Q-curve after chemical and heat treatment with $1.9 \cdot 10^{10} > Q_0 > 3.2 \cdot 10^{10}$ and surface resistances ranging from 3.14 to 7.09 [9]. Field emission was observed above 9 MV/m (10^3 µSv/h) for the cavities ESS067P03 and ESS067P04.

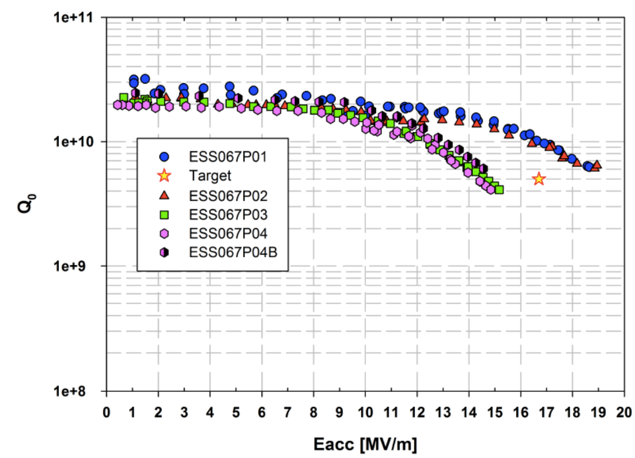

Figure 4: Vertical test ESS medium-beta cavity prototypes with tank (CW mode @ 2K).

The two prototype high-beta cavities exceeded the ESS expected nominal gradient of 19.9 MV/m and Q_0 of 5.10^9, as shown in Figure 5. The cavity P01 reached 25 MV/m. A new set of five high-beta cavities without HOM couplers are being fabricated and tested.

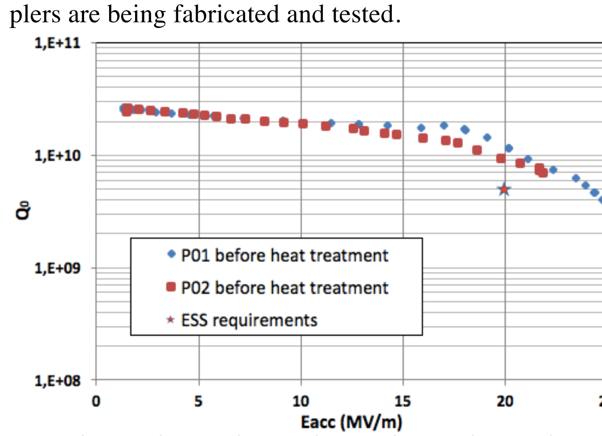

Figure 5: Vertical test ESS high-beta cavity prototypes.

Six power-couplers have been conditioned in forward and reflected power up to 1.1 MW at 1 Hz and at 14 Hz [10]. Figure 6 shows the conditioning at 14 Hz standing wave up to 3.6 ms, which corresponds to the maximum achievable electrical field on the ceramic windows. No outgassing occurred during these measurements.

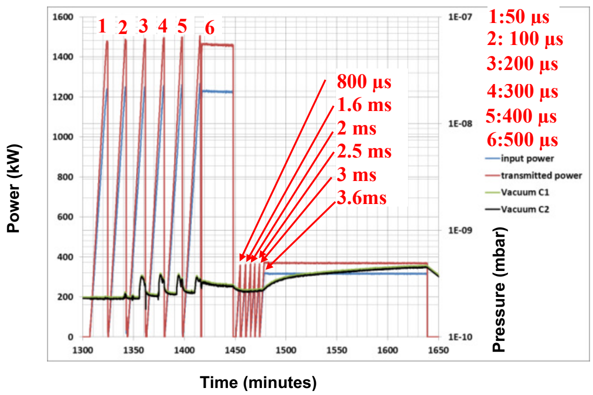

Figure 6: Power and vacuum (SW, 14 Hz).

Three CEA cavities and the LASA prototype cavity have been assembled to power-couplers and cold-tuning-system before being inserted into the Medium-beta Cavity Cryomodule Technology Demonstrator, M-ECCTD. The M-ECCTD will be tested by the end of 2017 in Saclay and beginning of 2018 in Lund Test Stand 2 [8].

A second High-beta technology demonstrator, H-ECCTD will also be assembled and tested in Saclay in summer 2018. The aim of those technology demonstrators is to validate the assembly procedures and the performance of each of the SRF components.

INFN-LASA – Elliptical Cavities

The complementary medium-beta cavity to equip the M-ECCTD has been successfully fabricated and tested in LASA [11-12]. Exhaustive studies of the medium-beta cavity have been studied in order to guaranty the integrity of the elliptical cryomodule interfacing with the ESS requirements and the series production [13-16].

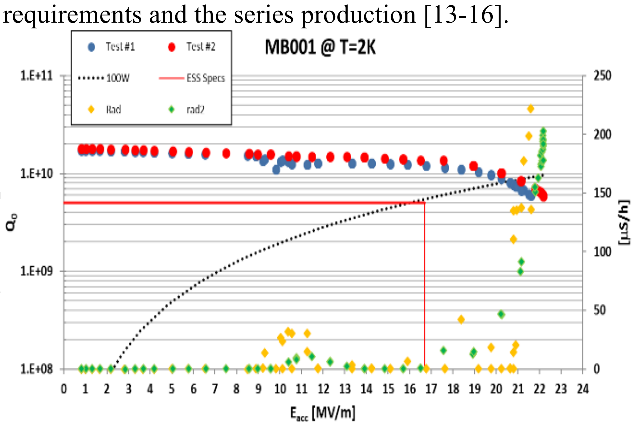

Figure 7: LASA first test result.

Figure 7 shows the Q_0 versus E_{acc} plots of the medium-beta prototype cavity, E_{acc} = 16.7 MV/m @ $Q_0 > 5{\cdot}10^9$. An accelerating gradient higher than 22 MV/m for $Q_0 > 5{\cdot}10^9$ has been reached and at accelerating gradient the quality factor was $Q_0 \sim 2{\cdot}10^{10}$. At 2 K the surface resistance R_s was close to 10 nΩ. An accelerating gradient higher than 22 MV/m at $Q_0 > 5{\cdot}10^9$ has been reached and at accelerating gradient the quality factor was $Q_0 \sim 2{\cdot}10^{10}$. The vertical test of the 36 medium-beta cavities will be completed in DESY vertical cryostats, after the insert serving to test the E-XFEL cavities will be modified. The 36 medium-beta cavities will then be shipped to Saclay to be integrated in the 9 medium-beta cryomodules. The first three cryomodules will be tested in Saclay test area in order to validate all procedures.

NEW TEST INFRASTRUCTURE AT STFC

The SRF collaboration depends on the growing expertise of STFC, who will fabricate and test 84 high-beta cavities to be integrated in the 21 high-beta cryomodules in Saclay and in the ESS tunnel after 2019. STFC has built a new vertical cryostat exhibiting 3 horizontal cavities, as shown in Figure 8. Cryoplant, control system, RF system, HPR, clean room will be operational by the end of 2017.

Figure 8: STFC vertical test stand.

ACKNOWLEDGEMENT

The author thanks the commitment of the IPN Orsay, CEA-Saclay, LASA, STFC, DESY, Uppsala and Lund Universities teams will be the actors of the SRF series cryomodule production. ESS SRF accelerator achievements are driven by the collaborative effort of talented engineers and scientists.

CONCLUSIONS

The ESS SRF collaboration has been established between ESS, CEA, CNRS, INFN, STFC, DESY, Uppsala and Lund Universities. This collaborative effort permitted to successfully test prototypes SRF components and launch the series production of the spoke and elliptical prototype cryomodules.

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