ESS SUPERCONDUCTING RF COLLABORATION

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Abstract

The European Spallation Source (ESS) project is a neutron-scattering facility, currently under construction by a partnership of at least 17 European countries, with Sweden and Denmark as host nations. The ESS was designated a European Research Infrastructure Consortium, or ERIC, by the European Commission in October of 2015. Scientists and engineers from 50 different countries are members of the workforce in Lund who participate in the design and construction of the European Spallation Source. In complement to the local workforce, the superconducting RF linear accelerator is being prototyped and will be constructed based on a collaboration with European research institutes: CEA-Saclay, CNRS-IPN Orsay, INFN-LASA, STFC-Daresbury, Uppsala and Lund Universities.
After a description of the ESS collaborative project and its in-kind model for the SRF linac, this article will serve to introduce the linac component first results.

ESS COLLABORATIVE PROJECT

ESS Project and Early Cooperation Agreement

The global scientific and technological motivation for the ESS is to build a powerful spallation neutron source to provide solution to some of the pressing scientific and engineering problems, by understanding materials at their atomic and molecular level. To permit such a scientific venue, the large-scale project ESS proposes a new type of collaborative project, based on a synergy between institute expertise and governmental financial support [1]. The ESS facility is funded by a collaboration of 17 European countries, with the host states (Sweden and Denmark) providing 50 percent of the construction cost whilst other member states are providing financial support mainly in terms of in-kind contribution from institutes or industries of the given countries. The ESS construction phase started in July 2014, aiming at producing first neutrons by 2020. During this period, England, Germany, France, and Italy are the major partners of ESS 1.846 billion Euro investment.

In the case of SRF accelerator components two collaboration agreements have been initiated in 2011 by ESS: The first collaboration was established with Uppsala University to test prototype SRF cavities and develop the RF amplifier stations at FREIA Laboratory. The second collaboration, "Cooperation Agreement in the field of neutron and accelerator sciences to the ESS Design Phase" was based on experience of CEA-IRFU and IPN Orsay in the design and construction of superconducting accelerating structure, and achieved the goal to kick-start the ESS design update phase. The main purpose of the agreement was to enable an early start of design, prototyping and testing of key parts of the ESS accelerator before the in-kind contracts and other contributions could be secured from the future member states. The agreement covered design, prototyping and testing of superconducting accelerating structures and a normal conducting low energy Radio Frequency Quadrupole accelerating structure for ESS. Technology demonstrators are being designed, fabricated and tested for the spoke and the elliptical cavities and cryomodules. Those demonstrators validate the technologies to be implemented in the ESS SRF linac [2]. This prototyping phase involves the design, fabrication and testing of 3 spoke cavities [3], 8 elliptical cavities and power-couplers [4], which have been assembled and tested into cryomodules. RF sources in Uppsala is also part of the collaborative agreement, from 2011 [5]. Hence, IPN Orsay and CEA Saclay are intensively involved in ESS project by leading the design of the spoke and elliptical cryomodules of the linac, respectively.

In 2014, LASA joined the ESS SRF collaboration and proposed a new RF design for the series medium-beta cavities and gave momentum to the ESS SRF collaboration.

The 26 series spoke cavities and 13 cryomodules are the responsibility of IPN Orsay and will be tested in Uppsala university, whereas series elliptical cavities and cryomodules involve multiple European partners as described later.

Spoke Cavity Cryomodule

The ESS spoke superconducting linac consists of double-spoke cavities (β=0.5) to accelerate the beam from the Drift Tube Linac (DTL) at 90 MeV up to the 216 MeV at the entrance of the elliptical cryomodule section. The spoke cavities provide 1) the capacity to transfer energy from RF system to the beam, 2) the capacity to confine the protons longitudinally, and 3) the capacity to steer protons longitudinally. Figure 1 shows the prototype spoke cavity design and its calculated surface electromagnetic field.

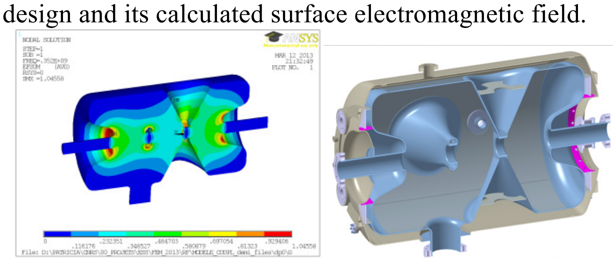

Figure 1: Spoke cavity design [3].

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IPN Orsay executed the design and prototyping work required for the development of the spoke section of the ESS accelerator. The challenge was to achieve a robust and reliable design of this new type of accelerating structures, compatible with the ambitious operating parameters of the ESS accelerator. The cavity design was achieved in 2012 with an optimized electromagnetic and mechanical configuration (Fig.1), allowing to efficiently accelerate proton beam at 9 MV/m. Three prototype spoke cavities have been tested at IPN Orsay and in Uppsala in dedicated cryostats. In parallel, four power-couplers and cold-tuning systems were tested. A string of two equipped cavities with two power couplers will finally be assembled at IPN Orsay before being delivered and tested in Uppsala by the end of 2017. Figure 2 shows a 3D drawing of the prototype spoke cryomodule and its valves box.

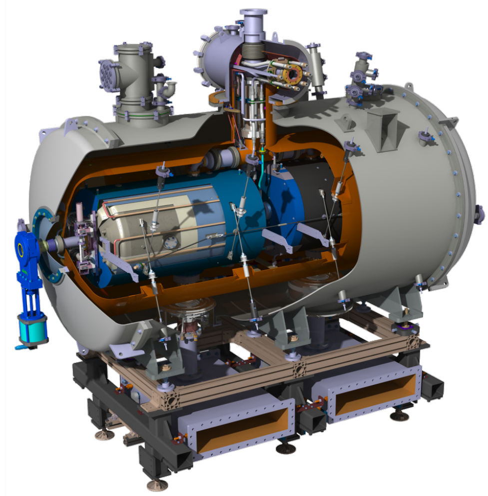

Figure 2. View of spoke cavity cryomodule.

Elliptical Cavity Cryomodule

The ESS Elliptical superconducting linac consists of two families of elliptical cavities: the medium-beta cavities (β=0.67) to accelerate the beam from the spoke linac at 216 MeV up to the 571 MeV at the entrance of the high-beta elliptical cryomodule section, which is composed of 84 elliptical cavities (β=0.86) [4]. The high-beta cavity is designed by CEA and the medium-beta cavity by Lund University in close collaboration with CEA. The design of the cryomodule completed by CNRS (Fig. 3) is based on the SNS concept with an aluminium space frame and titanium rods holding the cavity string.

Due to the large number of elliptical cavity cryomodules, and to comply with the In-Kind process, several partner institutions have been selected by the ESS to complete the implementation of 9 medium-beta cryomodules and 21 high-beta cryomodules in the cold linac. The production of prototypes and series elliptical cryomodules is distributed between several institutions as shown in Table 1. The medium-beta and high-beta series cavities will be fabricated and tested by INFN and STFC, respectively, before being shipped to CEA for assembly into cryomodules. Then, cryomodules will be shipped to Lund Test Stand (TS2) [5] to be tested at high-power in collaboration with the IFJ PAN Polish institute, before being installed in the ESS tunnel.

Table 1: Distribution of the In-Kind Contribution for the elliptical cryomodules

Activities	IKC
Prototype M- and H-beta cryomodule	CEA Saclay
Series M-beta cavities production	INFN LASA
Series H-beta cavities production	STFC
Cryomodules components production	CEA Saclay
Cryomodules assembly	CEA Saclay
RF power tests	ESS Lund

Each cryomodule houses four cavities operating at 2 K and 704 MHz. LASA and STFC are providing the medium-beta and high-beta elliptical cavities, respectively. The elliptical cavities are assembled with their fundamental power couplers and cold tuning systems, before being inserted into cryomodules in CEA Saclay, using the experience learned from the E-XFEL project.

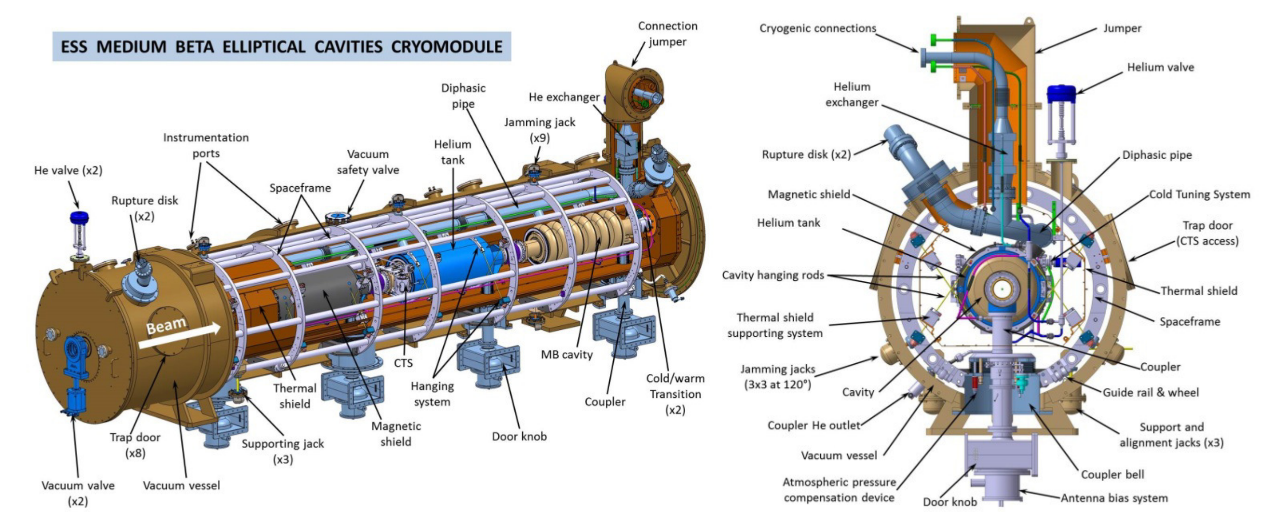

Figure 3: Design of the ESS elliptical cryomodule.

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COLLABORATION DELIVERABLE

Beyond the signature of 7 In-Kind agreements, the collaboration technical and administrative proof of concept has been achieved with the design fabrication and test of the spoke and elliptical cryomodules technology demonstrators. The SRF components performance measurement and successful assembly, permit to launch the fabrication of every series cyomodule components after numerous improvement at several steps of the components life-cycle. ESS has lead the effort to coordinate the interfaces between each partner institutions and the technical requirements to integrate those components on the cold linac.

In the framework of the early collaboration agreements, the spoke cavities and cryomodule have been assembled and tested at different stages in IPNO and Uppsala. The spoke SRF configuration, a cavity package (cavity, power-coupler, cold tuning system) has been validated in IPNO and in Uppsala horizontal cryostat (HNOSS) [5]. Figure 4 shows the spoke collaboration in front of the HNOSS.

Two high-beta, six medium-beta cavities and ten 1.1 MW power-couplers have been designed and tested by CEA. Then, four cavities-packages are assembled in the equipped vacuum vessel to the prototype named M-ECCTD (Medium-beta Elliptical Cavity Cryomodule Technology Demonstrator).

LASA fabricated and tested a new design prototype bare cavity in close collaboration with the industry. To limit technical risk and to validate series cavity performance, the LASA plug-compatible cavity has been added to the CEA cavities string, before being assembled into the M-ECCTD.

In addition, one high-beta cavity package (resonator, power-coupler, cold tuning system) undergoes test in HNOSS to validate the high-beta configuration for STFC.

Figure 4: Spoke cavity package collaboration.

Figure 5 shows the assembly of the cavity string before insertion inside the thermal shield of the M-ECCTD.

In addition, STFC-Daresbury is contributing to this momentum with the commissioning of new infrastructures to test their high-beta cavities.

Lessons-learned and status report of each partner activities are followed-up on a weekly basis, to ensure an effective collaboration.

A Quality-Assurance process has been established to track the fabrication and non-conformities of components. ESS is developing a data-base to collect the engineering documentation, and aiming at operating and repairing the cryomodules, once installed in the ESS tunnel.

Figure 5: Elliptical cavity cryomodule string assembly.

CONCLUSION

The ESS SRF collaboration has been established between CEA, CNRS, INFN, STFC, DESY, Uppsala and Lund Universities and provided its first deliverables with the fabrication, assembly and testing of the spoke and elliptical prototype cryomodules. Extensive SRF activities have demonstrated the proof of concept of the series SRF linac.

Deliverables of the cooperation agreements have established the design criteria for the spoke and elliptical cavities and power-couplers. The resulting prototypes have permitted to validate the technical feasibility of key components, and permitted the signature of in-Kind contracts.

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