ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS043

ESS RELATED ACTIVITIES AT ELETTRA SINCROTRONE TRIESTE

A. Fabris†, D. Caiazza, D. Castronovo, M. Cautero, S. Cleva, R. De Monte, R. Fabris, M. Ferianis, S. Grulja, A. Gubertini, T. N. Gucin, R. Laghi, G. Loda, C. Pasotti, R. Visintini, Elettra Sincrotrone Trieste, Trieste, Italy

Abstract

Elettra Sincrotrone Trieste Research Center (Elettra) is one of the Italian Institutions, together with Istituto Nazionale di Fisica Nucleare (INFN) and Consiglio Nazionale delle Ricerche (CNR), committed to the realization of the Italian in-kind contributions for the European Spallation Source. Elettra contributions are concentrated on the proton accelerator and more specifically they concern the construction of the conventional iron-dominated electromagnets and related power converters to be installed in the superconducting part of the linac and in the High energy Beam Transport (HEBT), the RF power stations for the superconducting spoke cavity linac section and the wire scanner acquisition system for the beam diagnostics. This paper provides a description of the contributions and an overview of the status of the construction activities.

OVERVIEW

The European Spallation Source (ESS) [1] is a pan-European project with 13 European nations as members, including the host nations Sweden and Denmark. ESS was designated a European Research Infrastructure Consortium, or ERIC, by the European Commission in August 2015. Italy, founding member of European Spallation Source ERIC, has designated INFN, Elettra and CNR as the three national Institutions in charge for the realization of the in-kind contribution of the country to the project and in this framework INFN acts as Representative Entity (RE) of Italy in European Spallation Source - ERIC.

The research infrastructure is under construction in Lund, Sweden [2]. The project foresees the production of neutrons by spallation reaction of protons on a helium gas cooled tungsten rotating target. The proton beam will be produced by a linear accelerator which at the final stage will reach 2 GeV beam energy and 5 MW power.

Based on the know-how of the Laboratory and the needs of the project, Elettra has agreed to provide contributions to the construction of the proton accelerator. Elettra will contribute with magnets, power converters, radiofrequency (RF) power stations, diagnostics, installation and commissioning support. For all the contribution, except the one concerning installation and commissioning support, In-kind agreements have been signed and are now operative. It must be also noted that, in order to address the complex administrative issues involved, for the magnets, the power converter and the RF power stations, trilateral in-kind agreements needed to be established involving beside ESS and Elettra also INFN due to its role of RE of Italy in the ERIC. In this framework INFN has taken the task of issuing the main procurement tenders.

† alessandro.fabris@elettra.eu

MAGNETS

Elettra in-kind contribution scope includes the construction of the dipole, quadrupole and corrector magnets as reported in Table 1 [3]. This means a total of 213 magnets of different typologies. All magnets are normal conducting operated in DC mode.

Table 1: Magnets List

Type	Description	Quantity
Q5	Quadrupole for spoke linac	26
C5	Dual-plane corrector for spoke linac	13
Q6	Quadrupole for medium-beta linac, high-beta linac, high energy linac, beam transport and dump line	95
C6	Dual-plane corrector for medium-beta linac, high-beta linac, high energy linac, high energy beam transport and dump line	55
Q7	Quadrupole magnet for accelerator to target ramp	12
D1	Vertical dipole magnet for high energy beam transport and accelerator to target ramp	2
Q8	Quadrupole magnet for accelerator to target ramp	6
C8	Dual-plane corrector for accelerator to target ramp	4

For the magnet types Q5, Q6, Q7 and C5, C6, the magnetic design and the mechanical design has been performed by Elettra, while the finalization of the mechanical design, the productions engineering and the construction of the magnets is being performed by Danfysik. The completed magnets are then delivered to Elettra, where the magnetic measurements and characterization take place in a dedicate magnetic measurement laboratory (Fig. 1). After the tests, the components are then shipped by Elettra to STFC in UK where they are integrated in the linac warm units prior of being finally delivered to ESS in Lund. Construction is ongoing and the completions of the deliveries to STFC is planned for July 2019.

Q5, Q6, Q7 are water cooled quadrupole magnets. Their design, besides beam dynamics requirements, targeted to standardize the requirements for power converter. To this purpose, the design of all the quadrupole coils allows adopting the same conductor cross-section and the same maximum current, or rather the same maximum current density. Since Q6 and Q7 have the same bore diameter and the same good field region radius, these two quadrupoles

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS043

can have the same 2D magnetic design with the same lamination geometry, the same ampere-turns and two different yoke/magnetic lengths. C5 and C6 correctors are air cooled window frame combined horizontal/vertical magnets operating in DC mode. Since C5 and C6 correctors will be fed by only one type of power converter, the coils must use the same conductor cross-section and the same maximum current, or better to say the same maximum current density.

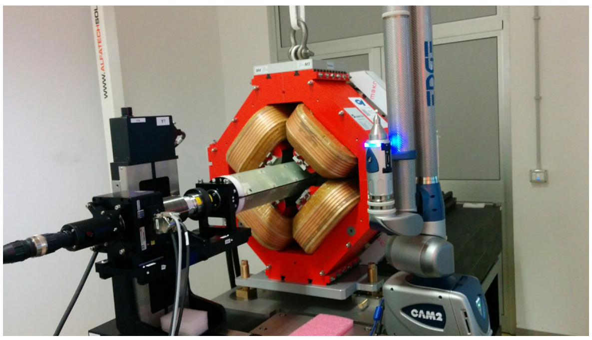

Figure 1: A Q6 magnet on the magnetic measurement bench at Elettra.

For the magnets of the accelerator to target ramp, i.e. D1, Q8 and C8, following the magnetic design and the mechanical model by Elettra, the magnetic design finalization, engineering, construction and validation has been assigned to Sigmaphi. The construction is in course and the delivery to ESS is schedule for end of October 2019. D1 and Q8 are water cooled. These magnets have large aperture to accommodate the vacuum chamber. For this reason, special attention has been payed to the ampere-turns calculations. The design effort has also aimed to keep the overall dimensions of the yoke of such magnets in a reasonable range. C8 correctors are air cooled window frame combined horizontal/vertical magnets.

POWER CONVERTERS

Elettra is in charge to provide all the power converters for the magnets contributed to ESS. Table 2 reports the full list. Thanks to the parallel development of magnets and power converters a high standardization and modularity has been achieved for both the DC power converters, for quadrupoles and dipoles, and for the 4-quadrants (4-Q) power converters for the correctors [4].

Each quadrupole magnet is powered by its own power converter [5]. The specifications for the power converters for the quadrupoles PCQ5, PCQ6 and PCQ7 are 200 A, 50 V, while for the PCQ8 the specification is 400 A, 50 V. The two series-connected dipole magnets D1 are powered by a common power converter which provides 400 A at 100 V. The power converters for the quadrupoles and dipoles are based on industrial products and are realized by a temporary consortium between Energy Technology and CAEN. As a result of the standardization and modular approach, the power converters PCQ5, PCQ6, PCQ7 and PCQ8 adopt the same 200 A/50 V unit: directly for PCQ5, PCQ6, and PCQ7; with two parallel connected units of two modules for PCQ8. PCD1 is based on four 100 A/100 V modules combined in a parallel connection. All the power converters for quadrupole and dipoles have been built and factory tested. Most of them have been already delivered to ESS in Lund with the last batch to be shipped by the end of May 2019.

Table 2: Power Converters List

Name	Magnet	Type	Quantity
PCQ5	Q5 quadrupoles	DC	26
PCQ6	Q6 quadrupoles	DC	95
PCQ7	Q7 quadrupoles	DC	12
PCQ8	Q8 quadrupoles	DC	6
PCD1	D1 dipoles	DC	1
PCC5	C5 correctors	4-Q	26
PCC6	C6 correctors	4-Q	110
PCC8	C8 correctors	4-Q	8

All 4-quadrant power converters (Fig.2) for the corrector magnets are standardized to the same specification, ± 16 A, ± 20V. These converters are an high-end development of a compact Elettra in-house design already adopted for about 300 units in operation at FERMI FEL, allowing to benefit of the successful return of experience of the user facility. A typical crate hosts four independent power converters. Construction of units and crates has been assigned to EEI and is now completed. The units are currently at Elettra for latest firmware uploading, calibration and full testing. Delivery to ESS will be completed during summer 2019.

Figure 2: One 4-Q corrector power converter.

RADIOFREQUENCY

Scope of Elettra contribution in this field is to provide the RF power stations for the twenty-six spoke cavities, which constitute the first section of the superconducting linac [6]. To allow an independent setting of RF amplitude and phase, a one RF source per cavity scheme is adopted. The RF power requirements range between 260 and 330 kW depending on the cavity position along the linac. Considering a safety margin for losses and redundancy, the specifications for the RF power stations have been standardised to 400 kW peak nominal RF power at 352.21 MHz. The operation is pulsed at 5 % duty cycle. The RF pulse has a nominal length of 3.5 ms, with a repetition rate of 14 Hz.

Each RF power station will consist of two equivalent transmitters with amplification chain composed of a 7 kW solid state driver amplifier and a 210 kW tetrode main amplifier stage. The two transmitters are combined with a 3

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS043

dB hybrid combiner. The block diagram of the station is shown in Fig. 3.

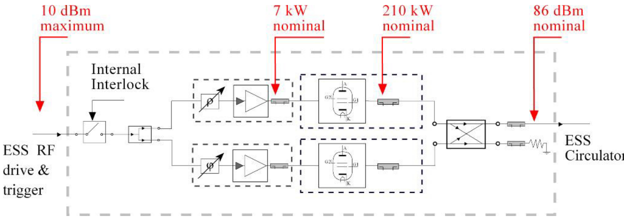

Figure 3: Block diagram of one RF power station.

The requirements on pulse stability and reproducibility involve a careful design of each subcomponent of the station, starting from the quality of the pulse provided by the solid-state driver to the power supplies for the heaters and all the electrodes of the tube. This is one of the driving concepts for the specification of the equipment and subassemblies. The two preamplifiers are based on a solid-state transistor-based amplification chain, water cooled. The main amplification stage is a tetrode tube TH595A from Thales, which is able to provide 210 kW at the required frequency and duty cycle once installed in a TH18595A RF cavity. The two tetrodes of each station share a common HV modulator for the anodes, while heaters and grids of each tube have their own power supplies for independent regulation. The modulator should have high voltage stability regulation and high reproducibility. The topology will be based on a commercial HV capacitor charger which charges a capacitor bank. The capacitor charger should have output voltage and current regulation and limitation capabilities. Low frequency harmonic and flicker reduction are also important aspects that are to be considered in the design.

The power station will be equipped with independent supervisory and interlock systems to safely operate the machine for personal and equipment safety. The station will be designed to be fully integrated in the ESS environment. Starting from the design, RAMI (Reliability, Availability, Maintainability and Inspectability) concepts are required to be integrated.

The finalization of the design and the construction as a turn-key system has been outsourced to European Science Solutions, Italy. The program foresees the construction of the first station by the end of 2019. This will be extensively tested at the contractor's premises in order to fully check and validate the machine and eventually optimize the performance. The construction will then proceed in batches with completion scheduled for end 2020.

DIAGNOSTICS

For the ESS beam diagnostics, Elettra contributes with the design and construction of the wire scanner acquisition system. Wire scanners are implemented for the measurement of the transverse beam profile. The system acquires the signal either electrical or optical when a thin metal wire is scanned across the proton beam. Being the amplitude of the signal proportional to the beam charge density, the beam transverse profile may be obtained by plotting the signal amplitude versus the wire transverse position.

The system that Elettra provides is composed of custom developed hardware (HW) modules and of integrated COTS (Commercial-Off-The-Shelf) units, linked together by means of an EPICS control and processing software. The HW modules are thirteen Analogue Front End (AFE), nine Optical Front End (OFE) (Fig.4) and the associated twenty-two Back-End (BE) modules. The AFE is used to read out the current from the single wire intercepting the beam; it is located in the accelerator tunnel to minimize the cable length and it is connected to the associated BE in the service gallery. The AFE is provided with a two channel input stage to cover the full dynamic range, reading out both wire ends. The OFE is used to acquire the light generated in the scintillator modules, located down-stream the wire scanner. It is as well connected to the associated BE, which has been fitted with 8 channels. The control and processing software, running under EPICS, is also part of the Elettra contribution to ESS. It is composed of a set of tabs, known as Engineering Panels, and of the User panel. The control software is interfaced on one side to the BEs, on the other side to the COTS units and to the standard ESS Motion Controller. Finally, also the design of the cable system for the wire scanner acquisition system is included in Elettra scope.

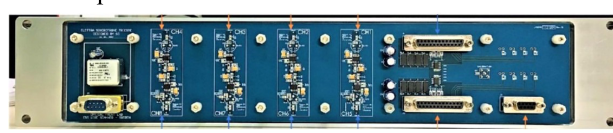

Figure 4: Optical Front End Assembly.

The construction of the hardware and associated control software is advancing and it will be concluded by the end of the year. A fundamental role in the development of the system has been played by the validation of the modules performed in a real accelerator environment. A measurement campaign was performed at CERN on Linac 4 in 2017, while successful vertical integration tests were performed at ESS Bilbao and at ESS in Lund. Elettra will also assist in the deployment and commissioning of the components.

CONCLUSIONS

An overview of the status of Elettra activities for the realization of the in-kind contributions to ESS has been presented. Following the signature of the in-kind contribution agreements, which was not straightforward, and the finalization of the design, the activities of Elettra are now concentrated on the realization phase. This involves all the work packages for the construction of components and equipment for the accelerator such as magnets, power converters, RF power stations and the wire scanner acquisition system. In parallel, the analysis is ongoing for the definition of the contents of the contribution to the activities related to installations and commissioning.

ACKNOWLEDGEMENTS

The authors would like to thank all the colleagues at ESS and INFN for their contribution to the progress of the activities for the realization of Elettra in-kind contributions.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPTS043

REFERENCES

[1] ESS https://europeanspallation.se

[2] R. Garoby *et al*, "The European Spallation Source Design", *Phys. Scr.* 93 (2018) 014001,Dec. 2017. doi:10.1088/1402-4896/aa9bff

[3] D. Castronovo, D. Caiazza, A. Fabris, R. Fabris, A. Gubertini, and G. L. Loda, "ESS Magnets at Elettra Sincrotrone Trieste", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper THPTS020, this conference.

[4] R. Visintini, M. Cautero, G. Göransson, C. A. Martins, and P. J. Torri, "Power Converters for the ESS Warm Magnets", in Proc. 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, pp. 3372-3374. doi:10.18429/JACoW-IPAC2017-WEPVA051

[5] R. Visintini, M. Cautero, T. N. Gucin, and C. A. Martins, "Power Converters for the ESS Warm Magnets: Procurement Status", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper TUPMP012, this conference.

[6] C. Pasotti, M. Cautero, T. N. Gucin, C. A. Martins, and R. A. Yogi, "Radio Frequency Power Stations for ESS LINAC Spoke Section", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper THPTS102, this conference.