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POWER CONVERTERS FOR THE ESS WARM MAGNETS: PROCUREMENT STATUS

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Abstract

In the frame of the Italian In-Kind collaboration for the construction of the European Spallation Source (ESS), Elettra Sincrotrone Trieste research center is in charge, among all, of the provision of the power converters for the warm magnets of the superconducting part of the linear accelerator and of the proton beam transport line. The procurement process is running for all types of power converters. The first components have been delivered to ESS already in March 2018, while the Dipole and Quadrupole power converters are under construction. The first batches have been factory tested and shipped to Lund. The corrector power converters have been manufactured and are currently tested and calibrated at Elettra before their delivery to ESS.

NEUTRON SCIENCE AND ESS

Neutrons are an unbeatable tool for probing matter not only at surface level but also deeper in the sample. Europe hosts two world-leading sources, and ESS, currently under construction, will continue this relevant role of Europe in neutron scattering [1]. A detailed description of ESS design is given in [2]. ESS consists of a proton linac, a target, and a set of instruments.

While the civil works are still running for the target building (Fig. 1), the construction of the proton linac is started inside the tunnel [3], as well as the installation of the equipment racks in the gallery. Most of the linac hardware is provided as in-kind contributions from accelerator laboratories across Europe (currently, 23 partner institutions from 10 countries are involved) [4].

Figure 1: Aerial view of ESS site (April 2019, Photo: Perry Nordeng/ESS).

ELETTRA IN-KIND CONTRIBUTION

Elettra contributes with hardware on the proton accelerator [5]. In particular, Elettra is in charge of the procurement (including, in most cases, the design) of the conventional electro-magnets [6], and their associated power converters (PC) to be installed in the warm units along the superconducting (SC) part of the linac (LWUs), the Accelerator-To-Target (A2T), and Dump Line (DmpL). The following Figure 2 reports the number and the types of magnets. (Q-Quadrupole, C-Corrector, D-Dipole) in the above-mentioned sections of the linac.

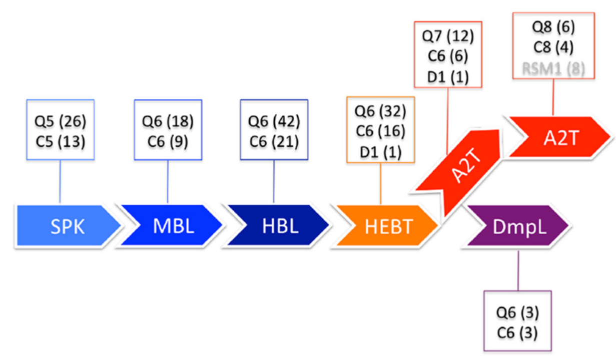

Figure 2: SC structure of the linac with magnet types.

Unipolar (PCD1 and PCQs) or bipolar (PCCs) power converters energize all magnets individually and independently, with the exception of the two dipoles D1 connected in series. As reported in a previous article [7], we consider magnets and power converters as two parts of the same system, optimized as a whole. The following Table 1 summarizes the magnet types, their number, and the associated PC types.

Table 1: Magnets and PC for LWUs and Beam Transport

Magnet Type	Magnet #	PC Type	PC #
Q5	26	PCQx	26
Q6	95	PCQx	95
Q7	12	PCQx	12
Q8	6	PCQ8	6
D1	2	PCD1	1
C5	13	PCCx	26
C6	55	PCCx	110
C8	4	PCCx	8

The corrector magnets C5, C6, and C8 are H+V combined magnets, each requiring two separate, Four

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Quadrant (4-Q), i.e. bipolar in both current and voltage, power converters.

The overall optimization of the magnet/PC systems has led to supply eight different magnet types with three PC types (two PCQx units in parallel implement one PCQ8). Tables 2 and 3 report the required main characteristics of the two unipolar and, respectively, of the bipolar PC types.

Table 2: Unipolar PC Types

	PCD1	PCQ8	PCQx	Unit
Model	NGPS-1	NGPS	NGPS	
Topology	4 in //	2 in //	1	module
Max Iout	400	400	200	A
Max Vout	100	50	50	V
Stability (24 h)	±50	±50	±50	ppm
Efficiency (nom. Power)	≥85	≥85	≥85	%

Table 3: Bipolar PC Types

	PCCx	Unit
Model	A2720	
Topology	H-Bridge	
Max Iout	±16	A
Max Vout	±22	V
Stability (24 h)	±50	ppm
Efficiency (16 A/20 V)	≥90	%

DIPOLE AND QUADRUPOLE PC

In the Technical Specifications, we suggested to adopt a modular solution in order to minimize the number of different PC types. The temporary consortium OCEM-Energy Technology with CAEN, that won the tender for fabrication, followed this indication and proposed the standard model "NGPS" with minor adaptations to meet the specifications.

PC Configuration

Each quadrupole Q5, Q6, and Q7 is energized by a single NGPS (50 V / 200 A) module. Two modules in parallel supply the required current to a Q8 quadrupole magnet. Four modules "NGPS-1" (100 V / 100 A), connected in parallel, will energize the two series-connected D1 dipoles.

The parallel connection of the modules follows the standard "Master + n Slaves", and is achieved via optical fibers. Figure 3 shows the PCD1 during the tests in factory. The "Master Unit" is on top and remotely controlled via standard Ethernet TCP-IP (the yellow cable). The three "Slave units", connected among them and to the "Master" in "daisy-chain" configuration, sit below. An additional, external polarity switch, directly managed by the "Master Unit", installed in the same rack with the four units, will allow reversing the current flow in the D1 magnets for achieving the complete de-gaussing of the dipoles.

Status of the Procurement

Due to the relevant number of units (133 NGPS as PCQx, 12 NGPS for the six PCQ8 and four NGPS-1 for PCD1), production, testing, and shipping to ESS were divided in four batches. The first one comprised the PCD1, one PCQ8, and three PCQx. The following two batches included PCQx only. The fourth batch comprised the remaining PCQx and five PCQ8.

Figure 3: PCD1 during the factory acceptance tests.

All batches have been successfully factory tested, and three of them are already at ESS. The last one, at the time of this paper, is almost packed and ready for shipping. Figure 4 shows 18 NGPS tested and ready for packing.

Figure 4: NGPS tested and ready for packing and shipping to ESS in OCEM-Energy Technology premises.

CORRECTOR PC

We effectively used the experience acquired realizing the successful bipolar power supplies for FERMI, the Free Electron Laser source at Elettra [8], in designing an improved version of the FERMI bipolar power converters. The new, 4-quadrant, 400 W power converter, named "A2720" [9], has a better efficiency that allows natural air convection for cooling, and removing the major source of failures, i.e. the fans [8]. The A2720 is the power converter

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type proposed to and accepted by ESS for all corrector magnets [7].

A2720 Configuration

The A2720 DC/DC units (see Fig. 5), as well as the sub-racks hosting them, have been manufactured following a "built-to-print" strategy by EEI. Due to installation needs, there are 38 3U, 19" sub-racks for hosting the 144 DC/DC boards (four sub-racks host 2 units, instead of 4). The external AC/DC bulk and auxiliary power supplies are commercial ones and have been already delivered to ESS and randomly tested.

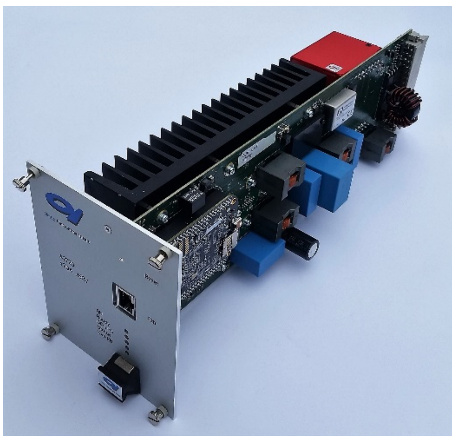

Figure 5: One A2720 channel, on the rear of the card it is visible the large heatsink cooling the H-Bridge.

Status of the A2720 Procurement

At Elettra, we thoroughly tested a complete crate, the "Pre-Series", to verify its performances before launching the mass production (Fig. 6).

Among several tests, we ran a very long stability test – starting from cold – over 12 days, monitoring the output current (set to 8 A) and the room temperature (average 15 °C). Figure 7 reports the results of this stability test. The "cloud" of points is the output current while the continuous line overlapped is the ambient temperature. The two horizontal lines include all output current readings and they are 0.5 mA apart, corresponding to 31 $ppm_{pk\text{-}pk}$ referred to the nominal current of 16 A. The temperature varied down to about 6.5 °C

At the time of this paper, the manufacturer has delivered all A2720 cards and sub-racks to Elettra, and we are currently running the performance tests and calibration of each unit before shipping them to ESS.

Figure 6: Two pre-series A2720 channels (in their sub-rack) under test in the specifically prepared rack.

CONCLUSION

We have reported the status of the procurement of the magnet power converters for the final part of the ESS linac. The unipolar PCs for the dipole and quadrupole magnets have been factory-tested and most of them are already at ESS. The Elettra-design corrector PCs, manufactured by an external company (and tested by us on a pre-series), are already at Elettra, in the phase of performance testing and calibration, prior their shipping to ESS.

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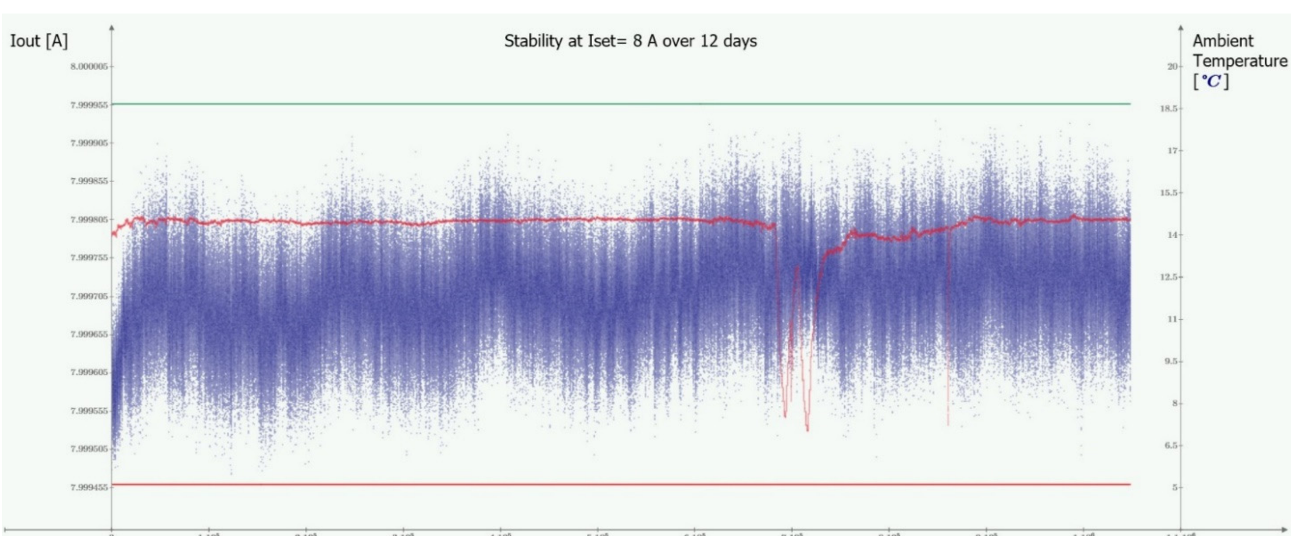

Figure 7: output current stability test over 12 days, along with the ambient temperature recording. The current (the "blue cloud") remains within 0.5 $mA_{pk\text{-}pk}$, corresponding to 30 $ppm_{pk\text{-}pk}$ referred to nominal output current (16 A).

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