ELETTRA BOOSTER MAGNET POWER SUPPLIES: ONE YEAR OF OPERATIONS

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Abstract

The New Full-Energy Injector at Elettra, based on a 3 Hz, 100 MeV to 2.5 GeV Booster Synchrotron has officially started its operations since March 2008. The time schedule was fully respected notwithstanding the performance problems presented by some of the main magnet power supplies. The refurbishing plan, formally started at the end of the commissioning phase and carried on together with the manufacturer, has brought positive results in approaching the required specifications.

The paper will describe the progress of the refurbishing and the experience with the other magnet power supplies, including the positive performances of the in-house low-current (5 A) bipolar power supplies, especially designed for the linac pre-injector. A new version, fully digitally controlled, of these low-power power supplies will be adopted for some coils and magnets of the FERMI@Elettra project.

BOOSTER MAGNETS' POWER SUPPLIES

The magnets of the Booster-based new Full-Energy Injector of Elettra [1] are supplied by 28 separate Power Supplies (PS). Table 1 summarizes their output parameters while figure 1 shows the ideal waveforms of the output of each dipole PS – those of the quadrupoles are similar but with lower amplitudes. The sextupole and corrector power supplies must – in principle – be able to follow quasi-arbitrary periodic waveforms.

Table 1: Booster Magnet Power Converters

	I_{out} [A]	V_{out} [V]	# Units	Type
Dipole	15 - 800	+/- 1000	2	2Q*
Quadrupole	5 - 400	+/- 400	2	2Q*
Sextupole	+/- 70	+/- 70	2	4Q
Corrector	+/- 20	+/- 20	22	4Q

Avoiding mid-voltage equipment (i.e. to keep the peak output voltage below 1 kV) was one of the design goals for the booster power supplies. This was achieved supplying separately the coils of the dipole magnets with two low-voltage/high current power supplies. Each dipole power supply feeds 28 coils of separate magnets connected in series [2]. The two dipole power supplies are also mutually interlocked preventing their operation, in particular the cycling, if any of them is off.

All the power supplies use Pulse Width Modulation (PWM) techniques and supply the magnet strings directly, without White Circuits, as it was first done for the Swiss Light Source (SLS).

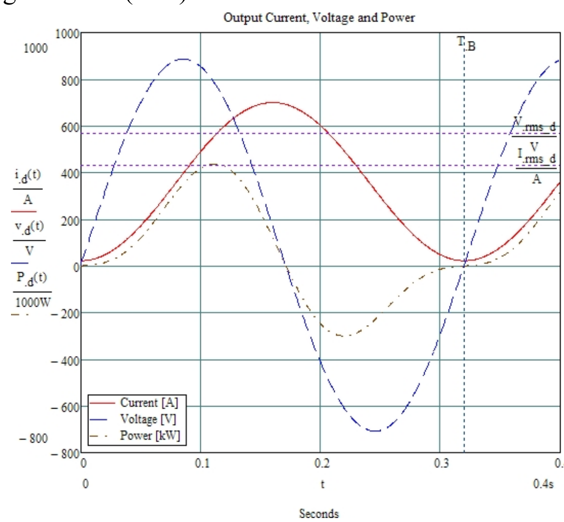

Figure 1: Ideal output waveforms for each dipole power converter at maximum extraction energy (2.5 GeV).

The Digital Control of the power supplies, developed at the Paul Scherrer Institut (PSI) for SLS, has become a *de facto* standard, widely used by other particle accelerators (see, e.g. [3] and [4]). This control, adopted also by Elettra, has been proven reliable and extremely flexible, allowing the "remodeling" of the output current waveforms by the machine specialists at Elettra according to the needs of the optics of the Booster to minimize the impact of the refurbishing of the main booster power supplies on the Elettra operations for Users [5].

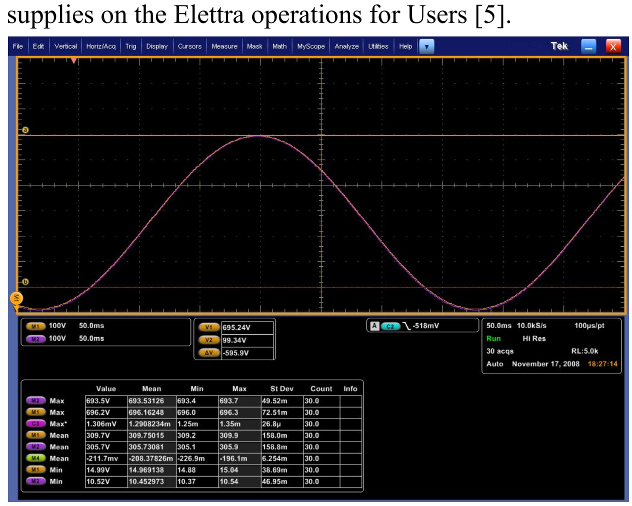

Figure 2: Actual output current waveforms of dipole power converter (two traces are overlapped) at maximum extraction energy (2.5 GeV).

* The power supplies operate – ideally – in 2 quadrant (2Q) mode, actually the chosen topology is a 4 quadrant one (4 Q – "H-Bridge" configuration) in order to improve output stage linearity for low output current (useful for the beginning of the ramp).

Figure 2 shows actual output current waveforms – overlapped one above the other – of the dipole power supplies from the minimum up to the maximum nominal values (corresponding to 2.5 GeV extraction energy). To reach this result several refurbishing activities were carried on.

BOOSTER PS REFURBISHING

Elettra resumed its normal operations on March 3rd, 2008 [6], providing the light for its Users, in agreement with the Booster Project time schedule and with no delays. Unfortunately, notwithstanding the efforts of the personnel of Elettra and of the manufacturer, at that date many hardware and operational problems on the power supplies of the main magnets – namely dipole, quadrupole and sextupole ones – were still present, preventing the operations at full current (i.e. maximum extraction energy) and nominal frequency (3.125 Hz). The inconveniencies became evident only during the tests on the actual loads during the start up and commissioning phases. At the beginning of March 2008 it was possible to operate the Booster – injecting into the Storage Ring – at 2.0 GeV (the nominal maximum energy is 2.5 GeV) with a repetition rate of 1 second [7].

The Refurbishing Plan

A refurbishing program was discussed with and implemented by the manufacturer along with the Elettra staff. The plan comprised hardware and software modifications and upgrades, aiming to improve the actual performances, the reliability and the operability of the power supplies, bringing them to meet the specifications.

The choice of adopting two separated power supplies for the dipole magnets and the modular structure of the power supplies with common sub-units for quadrupole and dipole PS [7] proved to be extremely helpful in minimizing the impact of some major faults occurred in the power supplies during the first months of the refurbishing on the overall operations of Elettra for the Users, never causing long downtime periods. On the other hand, the modularity itself created additional constraints, requiring each modification to be replicated on many sub-units. In addition, due to the operating schedule, following the beamtime allocation calendar of Elettra, the refurbishing process had to match the allocated Users' shifts, going on in parallel to the normal operation of the light source. In practice, since March 2008, about 10 shutdown weeks only – scattered along the year – were available. These conditions – number of activities and sub-units, along with the limitations on the availability of the power supplies – heavily impacted on the length of the refurbishing program.

Main Activities

During the commissioning period and the first months of the refurbishing phase, some severe faults occurred, causing additional delays and requiring the redesign and later substitution of some PCBs (printed circuit boards) in the cabinets and the power modules (sub-units) in order to improve the reliability of the power supplies.

A long and not yet completed optimization of the parameters in the regulation software was required in order to meet the specified repeatability among subsequent current pulses (corresponding to energy ramps of the electrons in the Booster) needed for a stable injection rate in the Storage Rings and eventually the Top Up operations.

BOOSTER PS: CURRENT STATUS

Thanks to the efforts during the previous months, since the end of November 2008 it is possible to operate the Booster power supplies reliably, allowing the full energy injection into the Elettra Storage Ring (the booster power supplies are ramped up to 2.5 GeV but extraction from the Booster is done "on-fly" either at 2.0 GeV or 2.4 GeV, according to the operating energy of the Storage Ring).

One of the goals of the new Full-Energy Injector of Elettra is the so-called Top-Up operation of the Storage Ring. Top-Up consists in keeping the current in the Storage Ring almost constant while the Users are normally working on the Beamlines. This is done by injecting as soon as the stored current falls below a set threshold. The reproducibility of the Booster PS is a key feature in achieving this target. Following the progresses of the refurbishing, some "frequent injections" tests – preliminary for more extensive Top-Up tests – were successfully carried on. Figure 3 shows a 5 ½ hours test at 2.0 GeV. The stored current was maintained at 242 mA with an automatic refill at 241 mA, the booster power supplies were kept ready for starting the ramps whenever needed.

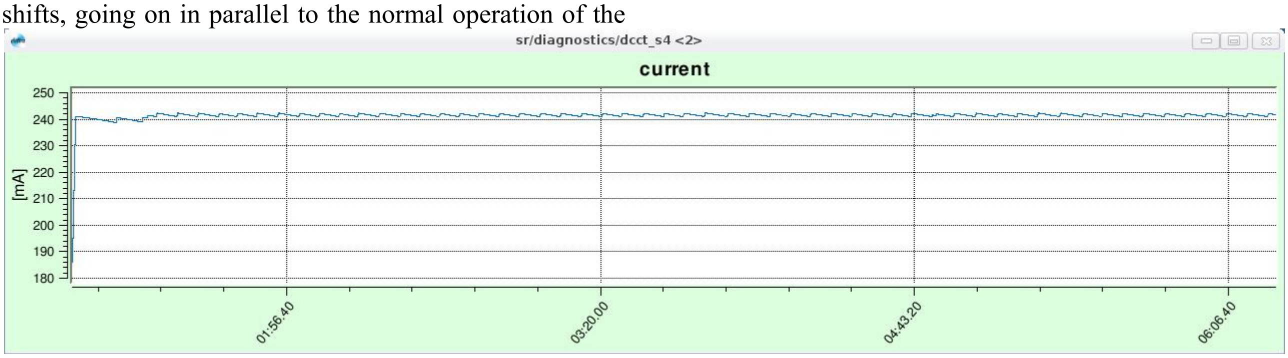

Figure 3: "Frequent Injection" tests at Elettra – for more than 5 hours the Storage Ring current is kept at 242 mA.

PRE-INJECTOR AND TRANSFER LINES

Besides the main magnet power supplies in the booster, about 100 magnet power supplies have been installed. The required characteristics allowed the use of commercial-off-the-shelf (COTS) power supplies in some cases; semi-standard products from a manufacturer in others while the bipolar power supplies were provided by another Synchrotron Laboratory and – for the small ones – following an Elettra in-house design.

Operation of Power Supplies

Besides some initial inconveniencies, mostly related to the control interface, promptly addressed and solved by the manufacturer, the COTS power supplies have not shown – so far – problems in their operation.

After a short time, some of the semi-standard power supplies presented a malfunctioning that prevented their use. A detailed and – also in this case – prompt inquiry by the manufacturer detected a defect in the production of some sub-assemblies and, besides replacing the faulty parts in the not-operating units, he offered to extend the modification also to the remaining – apparently not affected by the problem – power supplies of the lot. This refurbishing activity is still ongoing due to the extremely limited number of units composing the batches of power supplies that can be sent to the factory without affecting the operations of Elettra.

The bipolar power supplies had shown quite reliable operations. In particular the in-house design proved to be robust enough not to require any intervention since their first start-up [8]. In Figure 4 the single-card, 5 A bipolar power supply developed at Elettra is shown.

Figure 4: single board, 5 A bipolar power supply developed at Elettra (A2505).

Figure 5 illustrates the 4-channel layout in a 3U crate with the Ethernet connections and the two auxiliary power supplies – the "bulk" one for the main DC rail and the other one for supplying the control part on the boards independently from the power.

Figure 5: Crate containing 4 A2505 units with auxiliary "bulk" power supplies.

The positive results from the Elettra design encouraged the development of a new version of this type of 5 A bipolar power supplies to be adopted for some types of magnets (correction coils and small gradient quadrupoles) for the ongoing FERMI@Elettra Project [9].

CONCLUSIONS

In the previous sections, a short summary was given about the operations on the magnet power supplies installed at Elettra for the New Full Energy Injector.

The refurbishing activities on the main magnets power supplies in the booster have been shortly described.

The positive results and the achievements in the Booster operations were presented, including the good performances from a small (5A), bipolar power supply developed at Elettra.

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