POWER CONVERTERS FOR THE LLS SYNCHROTRON ACCELERATOR MAGNET SYSTEM

D. Beltran and J.A.Perlas
Power Supplies Group, Synchrotron Laboratory of Barcelona, LLS-IFAE
Edifici Cn, Campus UAB, E-08193, Bellaterra, Catalonia (Spain)

Abstract

This paper describes the design of the power converters for the magnet system of the proposed Synchrotron Light Source at Barcelona (LLS, formerly LSB). The power converter system is not fully commercially available, therefore our strategy will be to provide manufacturers with specifications and follow a tendering process, collaborating with them in the design and testing stages.

These converters can be classified in three groups according to their operational requirements: DC supplies (used mainly in the storage ring), AC supplies (used in the booster ring) and pulsed power supplies (used during the injection process). In order to achieve the specified values for the beam dispersion and emittance, the bending and quadrupole supplies have stringent precision and stability requirements. These are discussed in this paper.

According to the strategy presented above, a prototype power supply has already been built and careful precision tests have been done, which are also presented.

1 INTRODUCTION

The LLS synchrotron facility [1] has the classical accelerator structure consisting on a linac, a booster accelerator and a storage ring, which are connected by two transfer lines. Several beam lines will be available to the users of the synchrotron radiation for their experiments. The supply of power to the accelerator components must be designed to strict specifications in order to ensure the stability and optimal behaviour of the beam.

Here we review the specifications and the number of magnet power supplies needed in the LLS synchrotron. We will also describe the ideas for the topology employed in the interconnection of the various elements. The criteria that we have followed for determining the specifications of the power supplies are:

- Flexibility, in order to obtain a good tuning of the machine.
- Easy error recovery, avoiding any fall of the system even if a single or sub-group of power supplies is down.
- Optimize the cost whenever possible.

The magnet power supplies (MPS) cannot be bought as off the shelf items. Therefore, it will be necessary to provide manufacturers with our specifications and after a tendering process realize their manufacture. In fact, a prototype of power supply for a bending magnet of the main ring has already been built by a Spanish firm. This prototype is now on the testing stage, and we present here the first results of our evaluation.

2 MAGNET POWER SUPPLIES

The MPS can be classified in three groups on the basis of their operational requirement. These are:

- DC power converters. These are used in the storage ring and have stringent precision and stability requirements in order to achieve the specified field values. These feeders are DC current sources.
- AC power converters. These are used in the booster ring. When the current driving the magnets increases, the energy of a particle in the booster tracks the increasing magnetic field in a well defined way and, consequently, it is accelerated. These power supplies also have to be built to stringent specifications.
- Pulsed power supplies. These are distributed in the booster, in the main ring, in the flying line and in the transfer line. These supplies must generate current pulses every time that the bunches of particles are transferred from one accelerator to the next during the injection. The shape and width of the pulses will depend on the specific function of each magnet, but its repetition frequency will be constant (10 Hz).

The following sections describe the different types of power supplies needed by the LLS. These are described from the point of view of excitation type and grouped on the basis of similarity of requirements.

2.1 DC power supplies

DC power supplies [2] are used to drive the bending, quadrupole, sextupoles and corrector magnets in the main ring and also in the transfer lines. In Table 1 we list the main characteristics of these type of power supplies.

In the storage ring, all the power supplies are rated for operation at 2.5 GeV with a 10% safety factor. The cabling is important and has a non-negligible impact on the output voltage, which is increased by an additional factor of 10%, as shown in Table 1.

Table 1: Characteristics of the DC power supplies.

PS name	I_{DC} *(A)*	*Current stability 24 hours (ppm)*	V_{peak} *(V)*	P_{peak} *(kW)*	*Num*
Storage Ring:					
Ben_S	950	100	600	500	1
QC_S	400	200	10	3.3	24
QF_S	310	200	6	1.5	24
QD_S	300	200	3	0.73	24
SHV_S	230	1000	100	20	4
SA_S	110	1000	15	1.5	4
Hc1_S	±17	1000	25	0.33	22
XHV_S	±130	1000	20	2.1	166
Transfer Lines:					
B_F	15	100	16	0.2	1
Q_F	7	200	7	0.04	8
B_T	750	100	55	38	1
Q_T	450	200	8	3.1	8

I_{DC} is the nominal DC current delivered by the power converter, V_{peak} is the peak voltage supplied by the converter (including fast changes), P_{peak} is the maximum power that the converter supplies to the magnet, and *Num* is the number of power supplies needed. The names of the MPS are related with the function performed by the fed magnet:

- Ben_S: bending magnets,
- QC_S: central quadrupoles,
- QF_S: focusing quadrupoles,
- QD_S: defocusing quadrupoles,
- SHV_S: horizontal and vertical sextupoles,
- SA_S: auxiliary sextupoles,
- Hc1_S: horizontal "c" correctors,
- XHV_S: correctors in sextupoles,
- B_F: bending magnets in flying line,
- Q_F: quadrupoles in flying line,
- B_T: bending magnets in transfer line,
- Q_T: quadrupoles in transfer line.

2.2 AC power supplies

The power supplies of the booster synchrotron are mainly of the AC type. Two different configurations are used for AC magnet excitation [3]: the *ramping excitation* and the *resonant excitation* (also known as *White circuit* [4]). Because the required repetition rate of injection is 10 Hz, and *ramping circuits* can only provide lower repetition rates, we have to use White circuits. This is based on a parallel resonant circuit, where the resonant excitation reduces the load of the mains, whilst the current shape applied to the magnet is fixed. Since unidirectional magnetic field is used, a DC-bias current is added to the sine wave form. All the dipole magnets are connected in series (Ben_B in Table 2), in order to be energized synchronously by a single white circuit.

The dipole power converter will receive a trigger signal from the control system at the start of each new injection cycle and from this moment the supplied current will track the increasing beam energy.

Simultaneously, the quadrupole and sextupole converters must phase track the current applied to the bending magnets. This will be accomplished by using the dipole magnets current as a reference to drive the sextupole and quadrupole magnets.

Table 2: Characteristics of the AC power supplies.

PS name	I_{DC} / I_{ACpeak} *(A/A)*	*Current stability 30 min (ppm)*	*Peak stored energy (kJ)*	V_{peak} *(V)*	P_{peak} *(kW)*	*PRF (Hz)*	*Num*
Ben_B	950/940	100	88	3900	4300	10	1
Quad_B	200/195	200	7.5	1400	340	10	2
Sext_B	7.5/7.4	1000	0.04	215	2.1	10	2

I_{DC} is the nominal DC current delivered by the power converter, I_{ACpeak} is the peak AC current supplied by the converter, *Peak stored energy* is the peak energy stored in the magnet in a cycle, V_{peak} is the peak voltage supplied by the converter, including the reactive part, P_{peak} is the maximum power that the converter supplies to the magnet and *PRF* is the repetition frequency of the AC current. The name is related with the function of the fed magnet.

2.3 Pulsed power supplies

The pulsed power supplies feed three types of pulsed magnets: kickers, septa and bumpers. Because the functions performed for each type are different, their specifications are also different. This leads to the use of lumped circuits for kicker magnets and half-sine power supplies for the septum and bumper magnets [5].

The specifications for lumped circuits required to supply each of our kicker types are as summarized in the Table below. All of them are of DC type.

Table 3: Characteristics of the power supplies for kickers.

Magnet name	*PS name*	V_{DC} *(kV)*	I_{DC} *(mA)*	*PFN name*	*Length (m)*	Z_0 *(W)*	*Cabling*
Kicker1	K1	6	2	PFN1	6	16.4	1 single
Kicker2	K2	50	30	PFN2	6	16.4	2 parallel

V_{DC} is the nominal voltage of the HV-DC power supply, I_{DC} is the nominal current delivered by this supply, *Length* is the length of the pulse forming network, Z_0 is the characteristic impedance of the PFN (Pulse Forming Network) and *Cabling* is the number of cables and the connections required to produce an appropriate pulse shape.

With regards to the septa, that in the flying line must be powered by a converter (S1 in Table 4) with different characteristics to those needed in the transfer line (S2 in the same Table). The four septa magnets in the transfer line will be powered by two identical pulsed converters (S2), one for the two septa at the point of extraction from the booster, and the other for the two septa at the point of injection into the storage ring.

With regards to the four bumper magnets in the storage ring, they are powered in two pairs (1st and 4th and 2nd and 3rd) using two different power converters (B14 and B23 in Table 4).

Table 4: Power supplies for septa and bumpers.

PS Name	*I_{peak} (A)*	*Current stability 30 min (ppm)*	*V_{peak} (V)*	*P_{peak} (MW)*	*$P_{RMS\ pulse}$ (kW)*	*τ (µs)*	*Num*
Septa:							
S1	2630	1000	100	0.1	2	70	1
S2	7000	1000	1400	4.3	80	70	2
Bumpers:							
B14	7000	1000	4100	13	75	6.62	2
B23	5300	1000	3100	7.4	43	6.62	2

I_{peak} is the peak current during the half sine pulse, V_{peak} is the peak voltage in the magnet, P_{peak} is the peak power, both inductive and active, delivered by the converter to the magnet, $P_{RMS\ pulse}$ is the RMS power supplied to the magnet by the converter during the 100 ms pulse duration, τ is the half sine time duration, S1 and S2 are the MPS names for septum 1 and 2, respectively, and B14 and B23 are the corresponding names for bumper magnets 1 and 4, and 2 and 3, respectively.

3 PROTOTYPE DC POWER SUPPLY TESTS

A prototype 20 kHz switch-mode DC power supply has been built by a Spanish firm, for feeding one bending magnet of the main ring. In this section we present the results of a first evaluation.

The tests have been made using a different magnet from the prototype bending as load, and also a current (18.2 A) lower than the nominal one (950 A) since the absolute noise is essentially the same for the whole current range. The output current has been obtained using a precise (50 ppm) commercial DCCT* (DC Current Transformer), which produces a voltage proportional to the current. This voltage is measured by a high precision voltmeter.

In Fig. 1 we show the long term current stability of the prototype power supply. The points have been acquired every minute, and the voltage produced by the DCCT is integrated during a period of 200 ms, in order to reduce the ambient noise. Further noise rejection (to avoid ground loops) has been achieved by winding the output cable into a toroidal ferrite core.

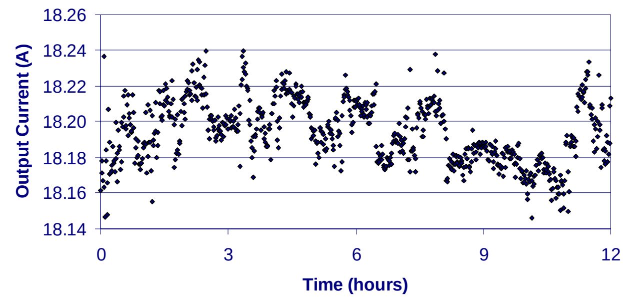

Figure 1. Long term stability of the prototype DC power supply.

As the DCCT conversion factor is 5 V per 1500 A, the current deviation is 94 mA peak-to-peak for a 12 hours period. This absolute drift results in 98 ppm of relative deviation for the nominal 950 A, which is inside our specifications.

4 CONCLUSIONS

The power supplies required by the LLS, and whose specifications have been summarized above, will be commercial products. These are either off the shelf items or readily manufacturable to our specifications.

In fact, a prototype power converter of the type needed to drive our bending magnets has already been designed and built in collaboration with the Spanish industry. This prototype is currently undergoing a thorough evaluation and testing and first results are already obtained giving the precision that we need for the accelerator.

We expect that by reducing, as explained above, the number of different power supplies to the minimum compatible with our technical requirements, substantial costs savings of scale will be achieved.

5 REFERENCES

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* In practice, the internal power converter DCCT itself (used for the digital control loop).