Power Supplies for the 500-MeV Booster Synchrotron at the Brazilian Synchrotron Light Laboratory - LNLS

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***Abstract* - The Brazilian Synchrotron Light Laboratory (LNLS), located in Campinas-SP, has commissioned its 500-MeV booster synchrotron machine. In this paper, we present an overview of the magnet power supply system comprised by precise (better than 10 ppm) current supplies ranging from 5A to 300A, with powers from a few watts to 126 kW, and current ripple of 0.02 % to 0.1 % relative to the maximum current. As the booster also operates as a storage ring, a special ramped-current power supply had to be designed for the dipole magnets in order to accomplish both requirements of fast ramping up (1.9 s) and precise DC operation.**

I. INTRODUCTION

The Brazilian Synchrotron Light Laboratory (LNLS) [1], located in Campinas-SP, has constructed a 1.37-GeV storage ring facility for research on UV and X-ray, and has successfully operated it since July 1997. Since then, and until March 2001, injection into this storage ring had been made from a 120 MeV linear accelerator (LINAC).

In 1998, the construction of a booster synchrotron machine was proposed [2] in order to make injection into the 1.37-GeV storage ring at a higher level: 500 MeV, and since then the construction of the building blocks for this new accelerator has begun. Assembly of the new accelerator at the experimental hall started in May 2000 and the 500-MeV booster synchrotron machine was put into regular operation in June 2001 [3].

Injection of 120-MeV electrons into the booster is now made from the LINAC. After each injection, electrons are accelerated up to the ejection level of 500 MeV by means of ramping up the current in the 12 dipole magnets.

With the introduction of the booster machine, a new set of high-stability current power supplies had to be constructed for both the new injection and extraction electron transport lines and the booster itself. Table I lists the power supplies' main characteristics.

TABLE I: Characteristics of the LNLS power supplies for the new booster and transport lines

Magnets	Current (A)	Max. Mean Out. Voltage (V)	Current Stability	Ripple (mA)	Number of power supplies
120 MeV Injection Transport Line					**09**
H Correctors	± 10	± 10	10^{-5}	± 1	02
V Correctors	±10	± 10	10^{-5}	± 1	03
Quadrupoles	10	10	10^{-5}	± 1	03
Dipoles	20	50	10^{-6}	± 10	01
Booster					**29**
H Correctors 8 mrad	± 6	± 10	10^{-5}	± 1	03
H Correctors 2.5 mrad	± 5	± 10	10^{-5}	± 1	07
V Correctors 1.5 mrad	± 5	± 10	10^{-5}	± 1	06
Quadrupoles	10	21	10^{-5}	± 10	08
Skew Quadrupoles	10	21	10^{-5}	± 10	02
Sextupoles	10	26	10^{-5}	± 10	02
Dipoles	300	420	10^{-5}	± 120	01
500 MeV Extraction Transport Line					**11**
H Correctors	± 10	10	10^{-5}	± 1	02
V Correctors	± 6	10	10^{-5}	± 1	03
Quadrupoles	10	15	10^{-5}	± 1	05
Dipoles	250	50	10^{-6}	± 250	01

Fig.1 Final installation of the low power current supplies.

Fig. 1 shows an overview of the final installation, in the power supply room, of some of the new low-power supplies for correctors, quadrupoles and sextupoles used in the booster and electron transport lines.

All power supplies were designed, developed and constructed by the Power Electronics Group at LNLS according to the requirements given by the Accelerator Physics Team. Additionally, spare power supplies were constructed for all the low-power supplies ranging from 5 to 20 A.

II. POWER SUPPLY TOPOLOGIES

Taking into account the developments in switched-mode power supplies (SMPS), we tried to use this topology whenever possible in order to reduce costs, size and weight of the final power supplies.

A. Correctors

For all the correctors and some of the low-voltage quadrupole power supplies, we make use of a topology which combines very low-cost SMPS used in personal computers (PC) with a series-linear regulation stage.

Small circuit changes were introduced into the original PC power supplies in order to make them suitable for our application, where a variable output voltage of the SMPS is required, according to the desired load current.

Bipolar load current regulation is accomplished by complementary bipolar-junction transistors (BJT) in series with the load. For the entire load output current range, Vce voltage across these BJTs is kept constant at 2 Vcc, depending on which BJT is regulating the load output current. In this way, internal power consumption is greatly reduced (see Fig. 2).

Fig. 3 shows the internal view of the assembly of one of the corrector power supplies.

Current load is measured by means of a shunt. Current regulation is simply achieved via a proportional-integral (PI) control. Another feedback loop monitors the Vce voltage across the BJT under conduction and controls the duty-cycle of the PC power supply in order to keep the Vce voltage constant over the full range of current variation.

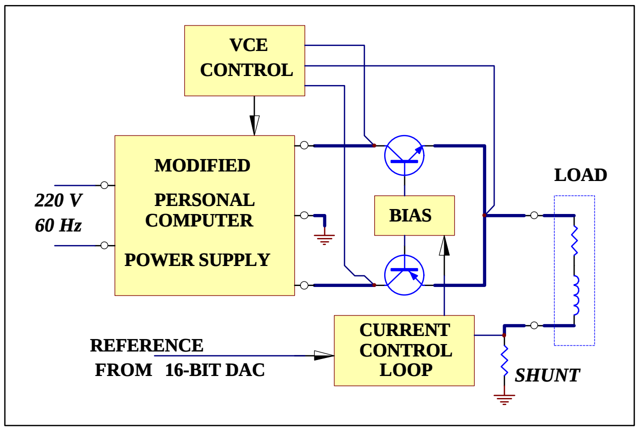

Fig. 2: Block diagram of the corrector power supply.

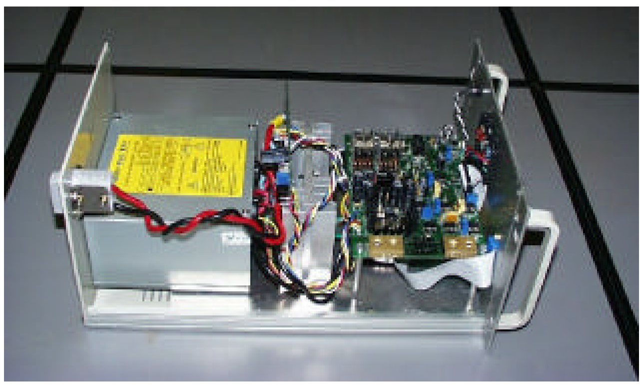

Fig. 3: Corrector power supply internal assembly.

B. Quadrupoles, Sextupoles and Injection Transport Line Dipoles

Due to the requirements of high stability, low ripple, fast response to the ramped reference, and immunity from mains perturbations, we have chosen a topology that makes use of an off-line 45-kHz half-bridge DC/DC isolated converter (see Fig 4) followed by a rectifier and low-pass filter. The resulting isolated DC voltage is then applied to a chopper stage that finally controls the load current by means of a current limit modulation (CLM). In this way, current ripple is kept constant for all the load current range.

The chopper duty-cycle is easily monitored and another control loop modulates the pulse-width at the DC/DC converter in order to keep the mean duty-cycle of the chopper stage constant at 50 %, over the range of operation of these current power supplies.

In order to obtain a high degree of precision (better than 10 ppm), long-term stability, and isolate the control electronics from the load, a DC Current Transformer (DCCT) is used to measure the load current.

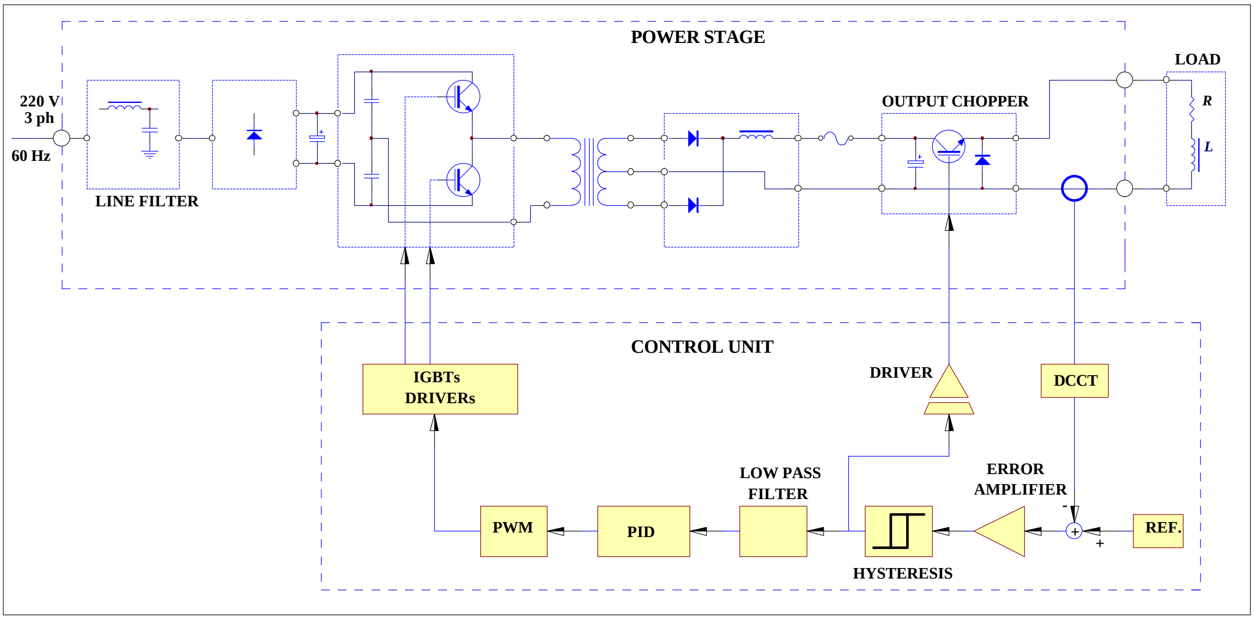

Fig. 4: Block diagram of the quadrupole and sextupole power supplies.

Fig. 5 shows de final assembly of one of these power supplies intended to be used in the 10A, 20 V range. In case of any necessary upgrades, this power supply can be used with a 1.5 kW output without any changes in the switching components except for the high-frequency power transformer, which has be to rated to the output current and voltage.

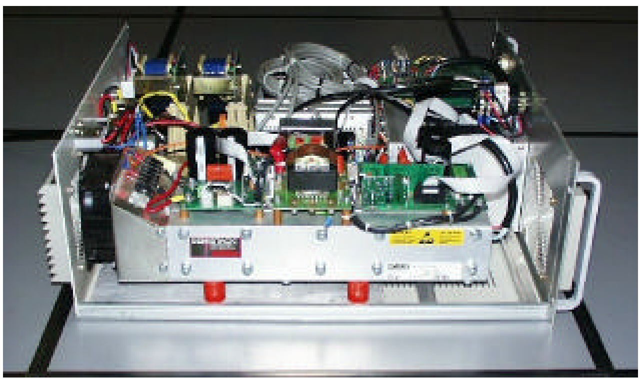

Fig. 5: internal assembly of the quadrupole power supply

As can be seen in fig. 6, the output voltage and current have a high-frequency content. This helps to reduce the magnetic field ripple even more, since the iron used in the electromagnets is not capable of responding to such high frequencies.

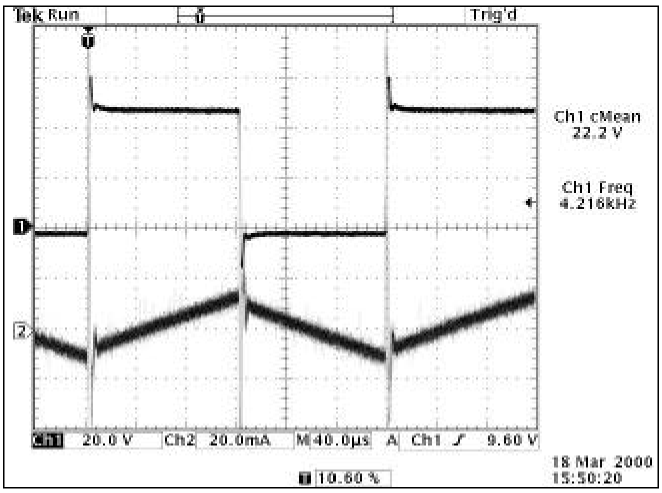

Fig. 6: For a mean output current of 10 A. Top trace: output voltage. Bottom trace: output current ripple.

C. Booster Dipoles

For the current and power involved, the 12-dipole booster current power supply was the most challenging one to design and test. As the booster machine must also operate as a storage ring with a constant current of 300 A in this power supply, we had to guarantee many conflicting operational aspects such as:

- Capacity of fast (1.9 s) ramping from injection (57 A) to extraction (277 A) levels (see Fig. 7)
- Mean null tracking error during ramping up
- High stability in short and long-term operations
- Low ripple ± 60 mA (see Fig. 8)
- Low fall time for the load current at the end of the ramping process.

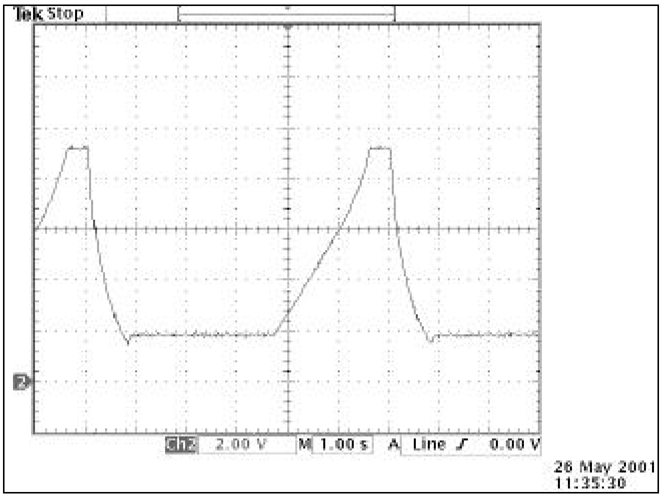

Fig. 7: Typical ramping process of the 12-dipole booster power supply (60 A/div.).

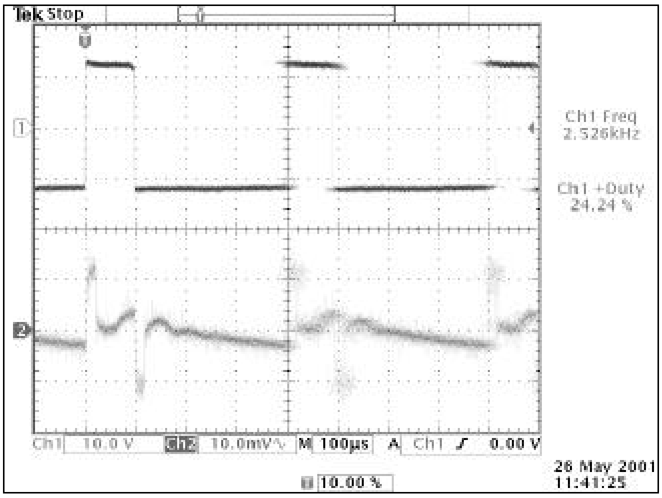

Fig. 8: for a load current of 57 A. Top trace: SMPS control output signal. Bottom trace: current ripple (300 mA/div)

This current power supply (see Fig. 9) is composed of a series association of a 6-pulse thyristor power supply and a SMPS with 12 chopper modules working in parallel. A similar scheme has been in operation with the 270-kW power supply that feeds the dipoles at the 1.37-GeV storage ring [4] with much less voltage (90 Vcc) at the chopper stage.

In the design we have made for this power supply, a voltage of 300 Vcc feeds the power modules, which share the total current among them. Precise current regulation and tracking during the ramping-up time is accomplished by the CLM method. Output voltage at the 6-pulse thyristor bridge is varied so as to keep a mean duty cycle of 50 % at the SMPS stage.

SMPS modules are turned on and off sequentially 3.2 µs apart from each other so that the dv/dt voltage applied to the load and cabling is kept at an acceptable level that does not generate enough EMI to disturb other delicate equipment and scientific instruments.

During ramping up, the SMPS modules provide for the fast response of the power supply following the current reference as long as the duty-cycle remains under control. During the ramping up process, the SMPS modules must also provide for the load voltage steps needed either to feed the reactive (1.56 H) power to the load at the beginning, or to reduce the voltage applied to the load at the end of it.

After the ramping up and extraction times, load current must decrease to the injection level as soon as possible for the machine be ready for another cycle of injection/extraction. To overcome this problem, the DC switch (shown in fig. 9) opens and a resistive bank of 2.2 ohms/22 kW is put in series with the dipoles, in order to decrease the characteristic L/R time constant of the load. In this way, repetitive cycles of a 6-second long period have been achieved, although the power supply would spend only about 3 seconds to complete this cycle.

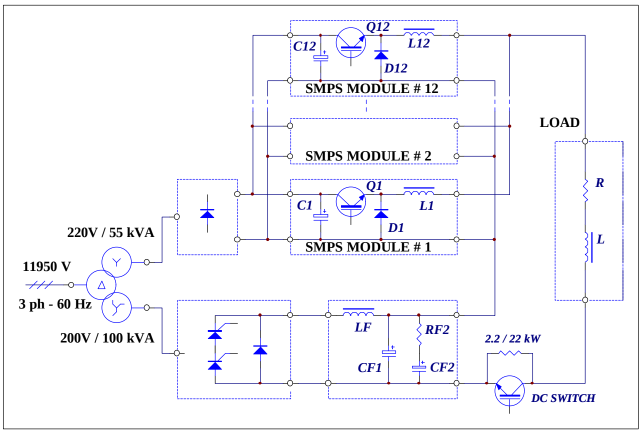

Fig. 9: Basic configuration of the booster dipole power supply.

Fig. 10 and 11 show the final assembly of this current power supply at LNLS.

Fig. 10: Front view assembly of the 12-dipole booster power supply, showing the control rack, the thyristor bride and its LCR filter.

Fig. 11: Rear view assembly of the 12-dipole booster power supply showing the 12-SMPS modules.

D. Extraction Transport Line Dipoles

This power supply (Fig. 12 and 13) consists mainly of a SMPS working as a buck converter. Load current regulation is accomplished by the CLM method.

Six modules of IGBT choppers working in parallel share the total load current. In order to reduce the dv/dt applied to the load, the IGBTs are turned on and off sequentially with a delay of 1us.

Maximum load current is 250 A and the current ripple is kept constant at ± 250 mA, for the full range of operation of this power supply. Although for normal transport of electrons, this power supply works with a load current of 220 A.

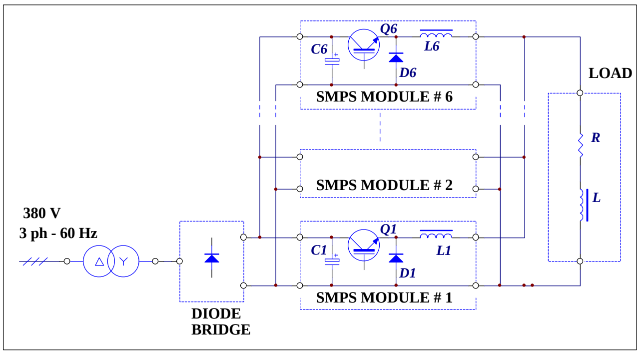

Fig. 12: power diagram of the 2-dipole current power supply of the extraction transport line.

Fig. 13: the 2-dipole current power supply of the extraction transport line.

III CONCLUSION

The results of the design, construction and operation of the power supplies set for the booster synchrotron machine at LNLS have been presented.

The booster synchrotron machine is under operation since June 2001 and the power supplies' performances have demonstrated the capabilities of the Power Electronics Group at LNLS in proposing original ideas and implementing them on high power and, at the same time, very precise power supplies.

IV. ACKNOWLEDGEMENTS

Mr. F.P. de Oliveira Junior's technical support during the construction, testing and commissioning of the power supplies is greatly acknowledged.

V. REFERENCES

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