Kicker and Septum Pulsers 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 a new 500 MeV booster synchrotron injector. In this paper, we present an overview of the septum and kicker pulser circuits now in operation. Half-sine wave septum current pulses range from 6.1 kA to 7.3 kA with pulse widths up tp 80 μs. Injection and extraction kicker circuits are capable of delivering currents up to 650A and 1.2 kA, with fall and rise times consistent with the booster revolution period of 112 ns. With the introduction of the booster, a new set of three-kicker magnet pulsers rated to 1 kA also had to be installed in the 1.37-GeV main synchrotron storage ring.**

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 the booster synchrotron was proposed [2] 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. Commissioning of the 500-MeV booster synchrotron started in April 2001 [3], and this machine is currently in operation since June 2001 with a 0.17 Hz repetition rate.

With the introduction of the booster synchrotron, a new set of kicker and septum pulsers had to be constructed for both the new injection and extraction into/from the booster. All pulsers were designed, developed and constructed by the Power Electronics Group at LNLS according to the requirements given by the Accelerator Physics Team.

II. SEPTUM PULSER TOPOLOGY

All the septum pulser circuits are based on half-sine wave and high-current generators. A capacitor bank is constantly and precisely charged to the specified voltage necessary to obtain the desired peak current. At the time the high-current pulse is to be produced, a thyristor discharges the capacitors into the septum magnet and a half-sine wave resonant cycle starts. Table I lists the main characteristics of the septum circuits.

All septum magnets have similar construction: ferrite window frame in vacuum. Ferrites are of type Mn-Zn (ρ=150 Ω.m) MN-67 from Magnet Ceramics [4].

A. The Septum Pulse Generators

All the septum pulse generators have the same basic configuration (see Fig. 1). The number of energy-storage capacitors is changed according to the desired peak of current pulse, and respected for each capacitor's maximum peak current (800A).

A prototype of the chosen topology was put into operation with peak currents of 8 kA, without showing any failures, for over 1 million pulses at a repetition rate of 1 Hz, which corresponds to a 5-year estimated time of operation.

The type of capacitors used plays an important role in the expected lifetime. A first attempt to use polyester metallized capacitors failed after some hours of operation when some capacitors were damaged. A second and successful attempt was made using self-healing metallized polypropylene capacitors.

TABLE I: Electric characteristics of the septum pulsers.

Septum	Function	Maximum Capacitor Voltage (V)	Peak Current (kA)	Pulse Width (μs)	Pulser Capacitance (μF)	Magnet Inductance (μH)
YSI03	thin injection into booster	430	7.5	52	300	0.51
XSI01	thin extraction from booster	470	6.13	64	300	1.03
XSG02	thick extraction from booster	530	6.13	75.8	300	1.54
XSG05A	thick injection into ring	550	7.1	64	300	1.03
XSG05B	thick injection into ring	550	7.1	64	300	1.03
XSI06	thin injection into ring	450	4.77	53.1	200	1.03

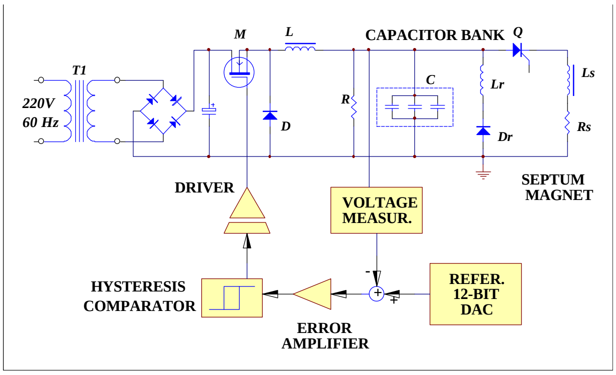

Fig. 1: Basic topology of the septum pulser

In applications with such a high peak current, distributed gate thyristors must be used. In our case, we have exhaustively tested the Westcode R305CH16-F2H0 thyristor, which was finally put into operation for all septum pulsers.

A recovery circuit (Dr and Lr) is added in order to recover some of the energy present at the capacitor bank, which presents an opposite voltage at the end of the half-sine time. This helps to reduce the total loss and avoids the recovery being done via the septum magnet.

Fig. 2 shows a typical waveform of a current pulse with a peak of 8 kA.

Voltage on the capacitor bank is stabilized via a Voltage Limit Control (VLC) that keeps this voltage swinging between two precise and fixed limits (100 mVpp) over the whole range of operation. This makes the capacitor bank voltage insensitive to variations in the mains voltage, since the MOSFET is turned on and off only to keep the mean capacitor bank voltage constant.

Due to the low repetition rate (0.17 Hz) of the booster, the power dissipated in the septum coil is negligible.

Septum pulsers are placed as close as possible to the septum magnet in order to minimize stray fields and additional inductances. Connection between pulser and septum feed-through is made through a coaxial connection.

Fig. 3 shows the rear view of a pulser assembly in one of the septum pulsers installed in the machine.

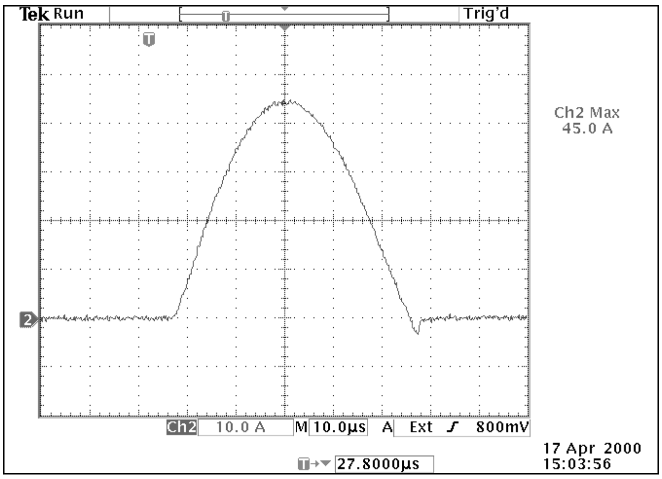

Fig. 2: Typical pulse current of the septum circuits (1780 A/div).

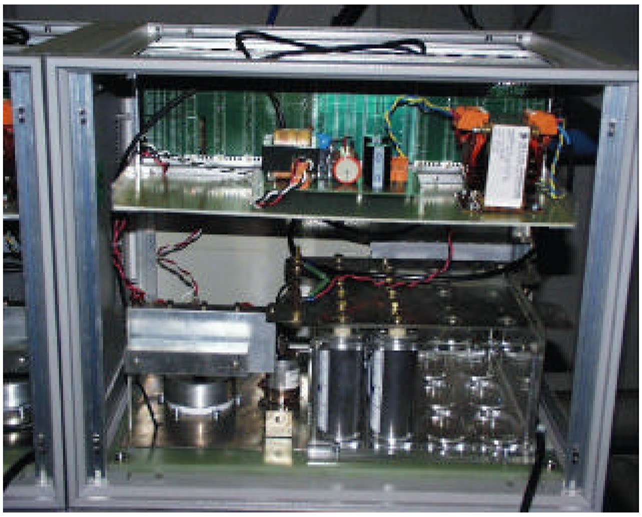

Fig. 3: Assembly of one of the septum pulsers.

III. KICKER PULSER CIRCUITS

In order to provide for fast injection/extraction of the electron beam into/from the booster machine, small pulsed magnets are used to produce the magnetic field strong enough to make the electron beam deviate from its original orbit. These magnets are called kickers and must have very fast and high-current pulsers in order to produce these magnetic fields.

Fig. 4 is the diagram of the implemented "Delay Line Pulser", which makes use of RG213 coaxial cables as a Pulse-Forming Network (PFN). In this diagram, *V1* is a high-voltage (up to 30 kVcc) regulated power supply from Glassman. Charging of the PFN is made via a high-resistance circuit *Rc* (1 MΩ) in order to avoid continuous conduction of the thyratron after a pulse has been produced. As the pulse repetition rate is quite low: 0.17 Hz maximum, power losses on the resistive charging of the PFN are negligible.

In order to reduce the rise time for the extraction kicker, a 500 pF peaking capacitor (*Cp*) was added to the design of this kicker pulser. An overshoot of 10 % at the rising of the current at the extraction kicker seems to be tolerable and has an acceptable effect on the extracted beam, although a faster rise time would be desirable.

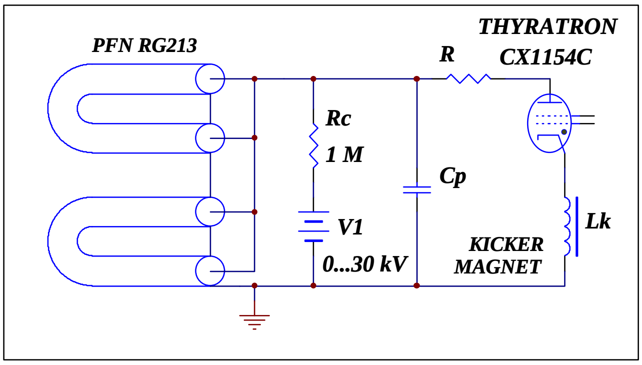

Fig. 4: Kicker pulser diagram.

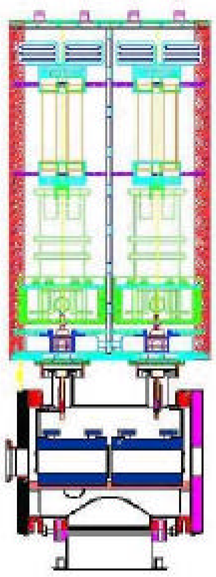

Fig. 5: Kicker pulsers' mechanical diagram.

Careful attention was paid during the mechanical design (see fig. 5) of the thyratron housing in order to reduce the EMI and provide for a low-inductance circuit since the thyratron itself greatly contributes to the total stray inductance of the pulser. A pipe of forced air cools the thyratron's cathode flange. Thermostat protection shuts down auxiliary circuits and the high-voltage power supply in the case of overheating.

During the production of the kicker pulses, the thyratron auxiliary circuits are isolated from the cathode potential by means of CMD-5005 ferrite rings in which five turns of the output auxiliary wires are coiled. This provides for an instantaneous high-impedance circuit for the duration of the pulse.

Auxiliary thyratron circuits for driving the grids, filament and reservoir power supplies were also designed, developed and constructed by the Power Electronics Group at LNLS. Booster kicker circuits are based on the design of a Delay Line Pulser, where the thyratron is electrically floating from the ground basis [5].

In such applications, fast rise and fall times are of major importance and, because of the intrinsic inductances of the kicker magnets, we had to split the magnets in two 125-mmm halves, each one having its own pulser but the charging high voltage still remains the same for both submodules, which are pulsed simultaneously.

Kicker magnets are of the window frame type inside a vacuum vessel. Both kickers have an aperture of 30 x 50 mm. CMD-5005 high-frequency ferrites from Magnet Ceramics were used.

Injection and extraction kicker mechanical designs are the same and so are the topologies of the pulser circuits, although the injection kicker pulser does not make use of the peaking capacitor.

Table II lists the main parameters of operation for the injection and extraction kickers.

TABLE II: Parameters of the booster kicker pulsers

Parameters	Injection	Extraction
Max. PFN voltage	30 kV	30 kV
PFN impedance	25 Ω	12.5 Ω
Flat-top current	0.58 kA	1.11 kA
Rise-time (10% to 90%)	26.8 ns	40.2 ns
Flat-top duration	220 ns	152 ns
Fall-time (90 to 10%)	46.6 ns	85 ns
Cabling length (m)	25	20
Peaking Capacitor (pF)	0	500

In order to reduce the reflected voltage applied to the thyratron at the end of the pulse duration, and to match the PFN impedance, non-inductive resistors in parallel are used in series connection with the thyratron and the kicker magnet.

Fig. 6 and 7 show the current pulses at the kicker circuits.

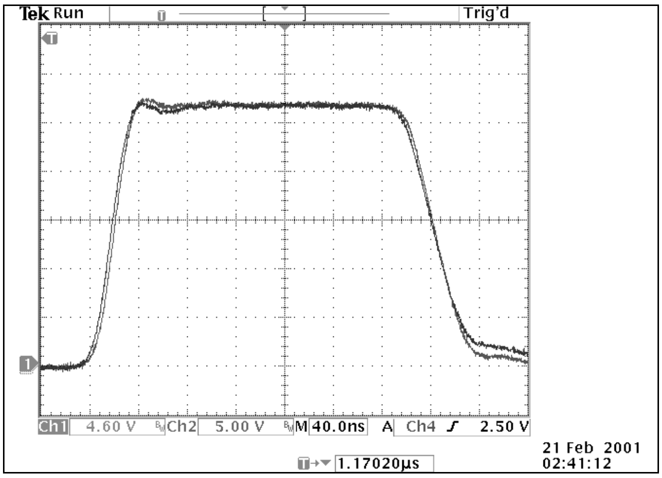

Fig. 6: current pulses on the injection kicker magnets (110 A/div).

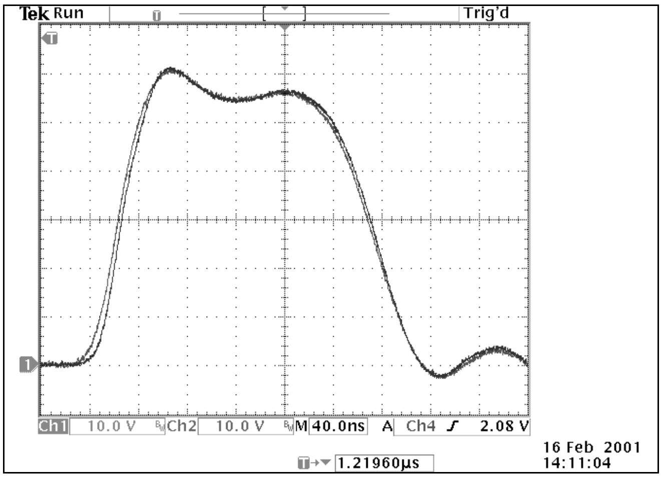

Fig. 7: current pulses on the extraction kicker magnets (200 A/div).

Fig. 8 and 9 shown the final assembly of the kicker pulsers in the booster machine.

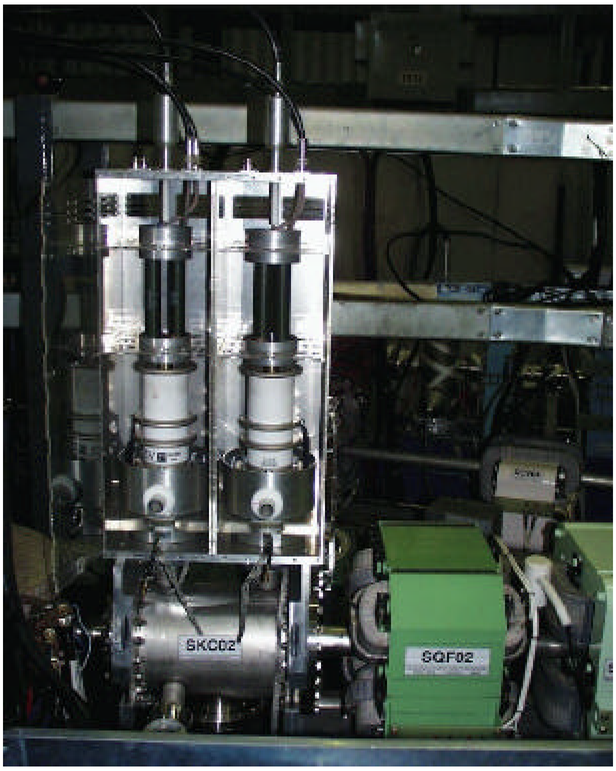

Fig 8: Final assembly of the kicker injection pulser in the booster ring, with some of the thyratron housing's panels open.

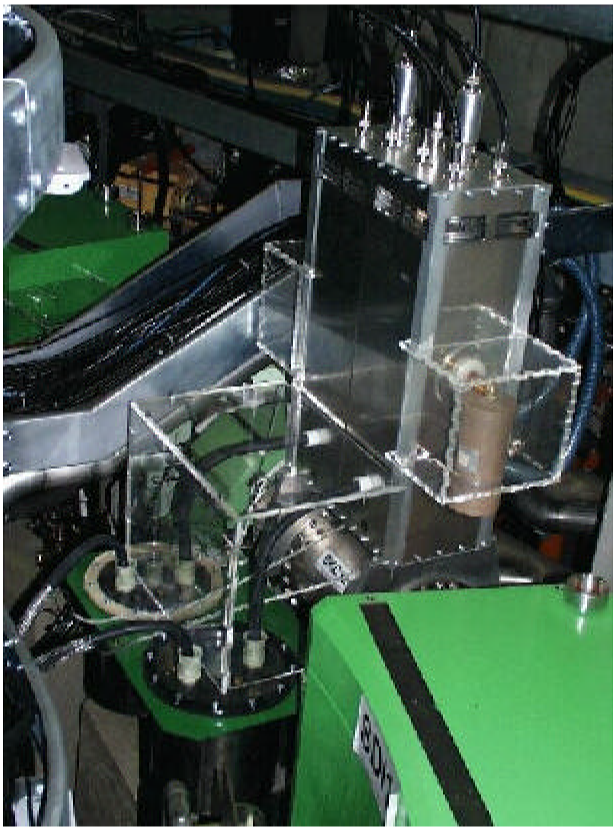

Fig 9: Final assembly of the kicker extraction pulser in the booster ring.

IV. NEW STORAGE RING KICKER PULSERS

With the introduction of the booster machine as an injector for the 1.37-GeV main synchrotron storage ring, three new kicker magnets had to be installed in this storage ring.

For these pulsers, we have chosen a topology of a discrete PFN with LC components, since the rise and fall times are not as critical as they are for the booster machine. The thyratron, in this new scheme has the cathode level grounded, what simplifies the assembly. The storage ring kicker pulsers' main characteristics are summarized in table III and their basic electrical diagram is shown in fig. 10.

TABLE III: Storage ring kicker pulsers' main characteristics.

Maximum PFN voltage	24 kV
PFN impedance	10 Ω
Flat-top current	1 kA
Rise time (from 10 % to 90 %)	100 ns
Flat-top duration	200 ns
Fall time (from 90 % to 20 %)	230 ns

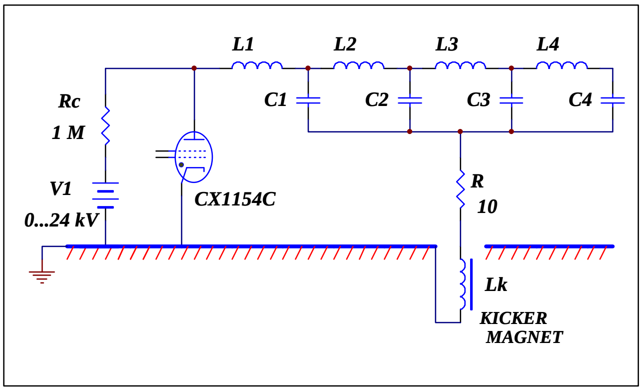

Fig. 10: Storage ring kicker pulsers'diagram.

Fig. 11 shows the internal view of the kicker pulser, where one can identify the PFN's components, the matching resistors, and the thyratron.

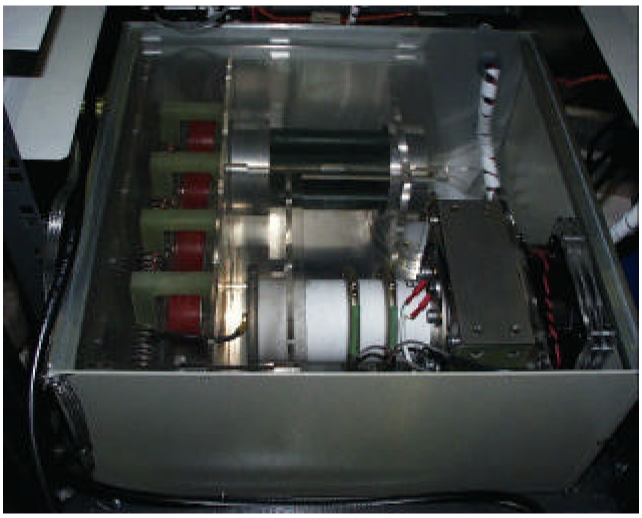

Fig. 11: internal view of the storage ring kicker pulser

Fig. 12 shows superimposed waveforms of typical current pulses produced by the three different kicker pulsers. As can be seen, their waveform shapes match each other to a high degree, which is important to the final performance of injection of electrons into the main storage ring.

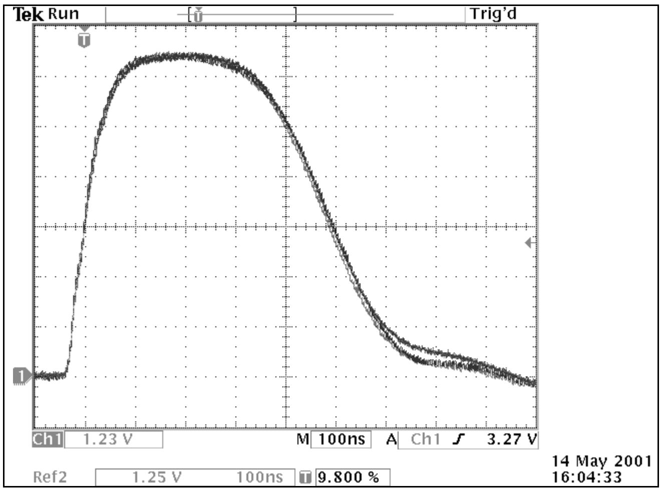

Fig. 12: waveforms produced by the new storage ring kicker pulsers. 125 A/div

V. REFERENCES

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