FAST KICKER SYSTEMS FOR THE SOLEIL BOOSTER INJECTION AND EXTRACTION, WITH FULL SOLID-STATE PULSED POWER SUPPLIES

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Abstract

The Booster of SOLEIL needs injection and extraction kicker systems with fast transition times, good flat top and low jitter, to allow satisfactory transfer efficiencies. So all the kicker systems have been optimized, to fulfil the specifications and to permit the use of solid state switching electronics. This contribution presents the ceramic vacuum chambers and magnets design, the specific pulse forming scheme and the realization of the pulsed power supplies working up to 20 kV. Electrical and magnetic measurements results of kickers systems are given, and also its operation status since the first SOLEIL Booster injection in July 2005.

BEAM DYNAMICS SPECIFICATIONS

The injection kicker is dedicated to put on the Booster axis the 100 MeV beam coming from the Linac, downstream the Eddy current septum magnet deviation. It has to provide a deviation of 12.95 mrad nominal, with a large range of possible variation (for the best setting of injection, and also according to different Linac beam energies).

The extraction kicker has to achieve only a small extracting deviation of 1.5 mrad nominal, because extraction is prepared by a slow closed bump, but the 2.75GeV energy imposes greater peak current and charging voltage values.

In the two cases a good flat top of >300ns (equal to the Linac macro-pulse length) is needed. But for the injection kicker, only the falling time is important, even though for extraction the requirement concerns only the rise time.

Table 1: Required and calculated characteristics

	Injection	Extraction
Nominal beam energy (GeV)	0.100	2.75
Nominal deviation (mrad)	12.95	1.5
Field integral (mT.m)	4.32	13.8
Nominal field (mT)	7.2	23
Time parameters	Flat top 300 ns T fall ≤200 ns	Flat top 300 ns T rise ≤200 ns
I peak (A)	252	730
V supply (kV)	6,5	19

MAGNET DESIGN

We designed two identical kickers for injection and extraction of the Booster. We realise the adaptation of the pulser and the voltage power supply value in each case. The rise time or the fall time of the current is tuned for each case in detail with the compensation and absorption circuits.

This fast kicker magnet is based on the window frame topology. It consists of a yoke of ferrite C cores (8C11), with a 1 turn coil insulated and located by dielectric machined parts, around a ceramic vacuum chamber [1]. The magnet is designed to be easily opened in two parts, without rupture of vacuum.

As it is a high voltage magnet, it's very important to adjust all the dimensions, of the magnet and the ceramic chamber, closed to what is it just necessary for the beam. In these cases the internal max aperture of the vacuum chamber are determined by the local bump at extraction: so the internal aperture is 40*16 mm.

So we could design a geometry giving the required field with a voltage below 20 kV. But all parts of the magnet are designed to support high voltage operating (<25 kV).

The ceramic vacuum chamber consists of a ceramic tube, equipped with two metallic transitions and two flanges. A Titanium coating is deposited on the inner surface to avoid electrical charging and breakdown hazard, along the ceramic. Titanium coating thickness is less than 0.2 µm to authorise fast rise and fall time of field pulses.

The ceramic thickness is equal to 6 mm, which seems to be the minimum required to achieve a satisfying straightness (alumina thickness was determined after preliminary contacts with suppliers). Ceramic chambers have profile and straightness tolerances less than 1 mm along the chamber length.

A specific effort was made on mechanical design and manufacturing with low tolerances values, which were strictly controlled during the final manufacture acceptance tests, particularly the transverse and longitudinal flatness.

Figure 1: Ceramic chamber realisation.

PULSED POWER SUPPLIES

The basic specific circuit for generating magnetic field pulses of quasi rectangular shape is showed in figure 2. This scheme is issued from the MIMAS injector of Saturne synchrotron (SACLAY). It's based on a HV pulse forming line (PFL) switched on a non-matched load, so we don't need to have a charging voltage double of the product Ipeak*Z_{PFL}, Z_{PFL} being the characteristic impedance of the PFL and the transmission line. However the circuit needs a compensation RC connected directly to the magnet inductance, in order to get correct rise time, and an absorption circuit (Dabs, Rabs) to damp the reverse pulse reflection.

A Pulse Forming Line (PFL) is charged to a voltage E by a power supply and then discharged by a HV switch via a transmission line into the magnet. Such a scheme authorises to get fast rise and fall times of the current pulses with a peak value (on flat top): $I\ peak = \frac{E}{Z}$.

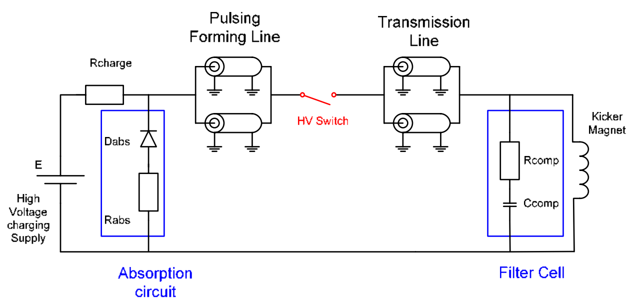

Figure 2: Basic electrical circuit.

The base of our realisation was to reduce the number of different components between injection and extraction pulsers, and specifically use the same standard power supply for both equipments.

Charging the PFL is equivalent to charge a capacitor. At the beginning the load is a short circuit and progressively the voltage can increase slowly with a law:

$$V_{PFL} = E\left(1 - e^{-\frac{t}{\tau}}\right)$$

where: $\tau = R_{charge} * C_{PFL}$.

C_{PFL} is the equivalent value of the PFL given by the cable characteristics (100 pF/m gives 2*7 nF = 14 nF for two lengths of 70 m in parallel)

The Rcharge value is a compromise between the peak current value of the power supply and the charge duration delay imposed by the repetitive frequency. 1 MΩ is a good compromise in our case.

The standard data sheets of power supply give parameters with a resistive load. So we wrote detailed technical specifications for the HV power supplies, requiring the lending of the proposed supplies for tests in pulsed mode. We tested some power supplies with a representative test bench of our application before validating the best convenient equipment. We choose a standard 30 kV – 20 mA power supply with an internal limitation to 25 kV adapted to the extraction kicker constraints. The theoretical characteristics of the diverse manufacturer power supplies were looking very similar but in fact, we observed great differences on the dynamic behaviour between the tested solutions.

As a characteristic impedance of 25Ω is convenient, regarding to achievable rise and fall time, the PFL is realised with two lengths (2*70 m) in parallel of RG220 50 Ω coaxial cables rolled up on a metallic drum. The cable length is determined by the pulse duration.

The interest of our realization is to use solid state switch, with the purpose to avoid significant drift with time and number of shots, and also to suppress the additional costs of auxiliary power supplies, high voltage trigger circuit, and periodical replacement of switch, as it is with thyratrons used commonly for high voltage switching.

We could find, with A2E Technologies-ENERTRONIC, suited industrialized switch cards base on a serial-parallel association (13*16) of fast high voltage (500V), low current (25A DC) TO220 MOS transistor without heat sink to realise 5 kV – 1 kA switch [2]. The series association of 5 cards allowed obtaining the necessary 25 kV – 1 kA switch. The control of this association is done very simply with a specific driver connected to all the MOS via a transformer. Electric insulation, between the driver and each stage of MOS, is provided by the cable insulation.

To control this switch less than 40 W are required without complex cooling system.

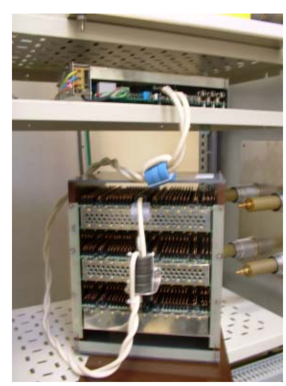

Figure 3: HV switch with its driver box (up).

In order to avoid excessive power current pulses distortions, it is important to get a quite short transmission line between the pulser and the kicker magnet. Locating each pulser cabinet on the roof of the Booster just above its magnet (inside the tunnel), and passing the coaxial cables through the concrete radiation shielding quite directly, we could reduce to 8 m the transmission line in the case of injection kicker, and to 6.5 m for the extraction kicker.

The filter RcompCcomp is coupled in parallel as near as possible to the magnet in a specific cabinet, connected directly on its top, closed to the connection box of the HV transmission cables

To measure the power current pulses, we put a BERGOZ pulse transformer inside the magnet equipment.

The components values Rabs, Rcomp, Ccomp, and the stray inductance of the connections were tuned during the tests to optimise the pulse current waveform in each case. In addition, accurate tuning and a lower impedance (~48Ω) of coaxial cable than expected enabled to reduce the charging voltage necessary to reach the required currents.

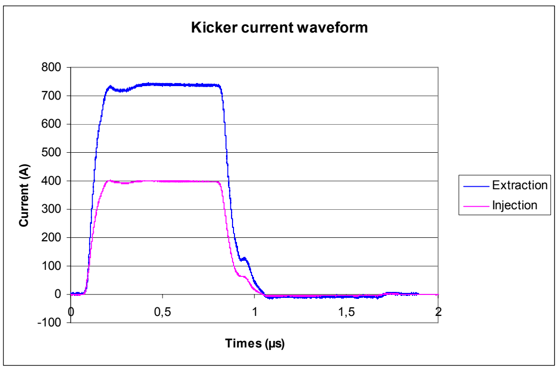

Figure 4: Kicker Booster Current waveform.

On the injection kicker, the commutation constraint concerns the fall time. With the circuit optimisation, we obtained a flat top stability over last 300 ns ± 0.6 % and a 200 ns fall time from 100% to <5 %.

On the extraction kicker, we focussed the adjustment on the rise time and accepted to deteriorate the fall time in order to maintain a good flat top. In this case, we reached a rise time less than 170 ns from 0 to 100 % with a flat top stability over first 300 ns of ± 0.8 % including a residual undulation on the beginning of the flat top. On this equipment, the high voltage value (20 kV) gives more difficulties on the components choice.

MAGNETIC MEASUREMENT

The magnetic performances of each kicker were verified on a specific test bench with an x-y-z translations coil position. With specific coils, we measured the derivative signal of the field. With a digital scope, the probe signal was integrated to obtain the field amplitude.

We built a one turn long coil (0.4mm width, 780 mm long) with a circuit board to measure the field integral inside the vacuum chamber. These measurements show a very appreciated transverse homogeneity in horizontal ($\Delta\int Bdl \Big/ \int Bdl < \pm 0.35\%$) at (z = 0), which is of the same order than our magnetic measurement accuracy.

A second probe with a 5 turn cylindrical coil (3 mm diameter) was used for the measurement of local field along the central axe and some plan.

In each case, the main local field measurement was made on the central position, because we can't appreciate notable variations in the other position of the vacuum chamber except at the extremities.

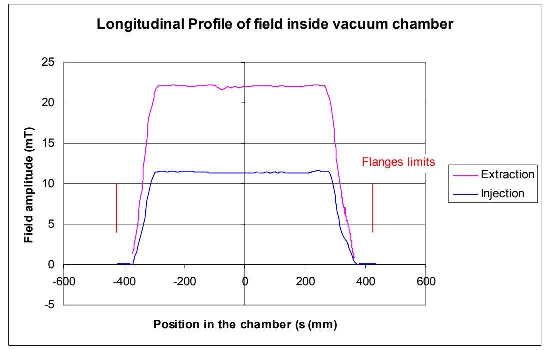

Figure 5: Longitudinal profile of the field inside the vacuum chamber.

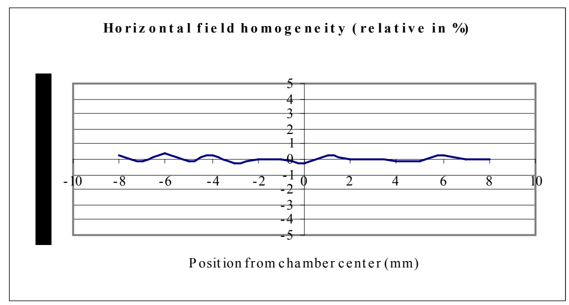

Figure 6: Horizontal field homogeneity.

Table 2: Measured magnetic parameters

	Injection	Extraction
@ voltage (kV)	9.4	17.7
peak current (A)	389	730
B mean in flat top (mT.m)	11.50	22.05
$\int Bdl$ (mT.m)	8.15	14.42
Magnetic length (mm)	654	653.87

OPERATING STATUS

Our two fast kicker systems, with HV full solid-state switches, have been operating without any problem from July 2005. They give a good reliability to the Booster injection and extraction, and for the Storage Ring commissioning. The low jitter (1ns) and pulse shapes are very stable.

REFERENCES

[1] P. Lebasque, M.P. Level, R. Nagaoka, C. Mariette, L. Cassinari, J.P. Daguerre, C. Herbeaux "Optimisation of the coating thickness on the ceramic chamber of the SOLEIL SR kicker magnets", Synchrotron SOLEIL, Saint-Aubin, France, EPAC 2006.

[2] « Dispositif de commande d'un commutateur à grille isolée de fort courant, et commutateur d'impulsions comportant un tel dispositif » N° E.N. : 94/14704 du 7 décembre 1994. Inventeurs: Daniel Chatroux, Rodolphe Guidini, Yves Guidini.