FOUR MATCHED KICKER SYSTEMS FOR THE SOLEIL STORAGE RING INJECTION, A FULL SOLID-STATE SOLUTION OF PULSED POWER SUPPLIES WORKING AT HIGH CURRENT

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Abstract

The Top Up injection mode of the SOLEIL Storage Ring needs a very good matching of the four kicker magnet fields. But their implantation inside the straight section dedicated to SR injection imposed rather high field on each of the four kickers. This contribution describes the ceramic vacuum chambers and magnets design optimised to provide a very good identity of the four magnets. The pulsed power supplies, based on IGBT high voltage modules, designed to work at high current (5250 A-9000 V) could be located outside the SR tunnel. We highlight the specific development on all components specification and electrical scheme that permits to reach such a challenge.

INJECTION REQUIREMENTS

The SOLEIL Storage Ring injection is done by two septum magnets in a 12m long straight section, where the stored beam is moved near the injected beam by a Closed Orbit Deviation, generated by a set of four fast kicker magnets. The 2.75 GeV stored beam should be moved by up to 23mm, and each kicker magnet can be controlled individually, in field amplitude and time position, in order to optimise the injection. The falling time of the pulses, from peak to near zero, need to be less than three SR revolutions, i.e. $t_{fall} < 3.54$ µs, and pulse width < 7µs.

Table 1: Required and calculated characteristics

Nominal deviation	7.6	mrad
Field nominal	116	mT
Field integral (nom.)	69.6	mT.m
Length	600	mm
Falling time max	3.54	µs
Peak current	5220	A
Charging voltage	9	kV

VACUUM CHAMBERS DESIGN

We choose the technology of in air kicker magnets, compatible with the pulse rise time, easy to open, which permit the continuity of the vacuum chamber, even in case of magnet electrical failure. So ceramic chambers are required, with an adequate inner metallic coating [1]

The internal aperture of the ceramic chambers is fixed by beam dynamics requirements: HxV= 80x25mm.

Preliminary consultations with diverse ceramic suppliers determined the greater length it's possible to get and the optimal thickness of ceramic, with a good control of its geometry: ~800mm max length and 7mm thick.

As the required fields are important, it was essential to adjust the geometry of the vacuum chambers and of the magnets gap, in order to minimize the current and voltage of the pulsed power supplies. Moreover matched kicker systems require to control all magnetic and electrical parameters, with straight tolerances. So we fixed the specifications for the ceramic chambers supply with a set of tight dimensional tolerances (straightness, profile, concentricity, flatness), which permit to limit to <1mm the clearance of the ceramic chamber in the magnet, and to ensure a free 3 mm path for air cooling.

In fact the ceramic chambers supplied by PMB SA (78531 BUC, France), based on Saint-Gobain Ceramics alumina tubes, which are machined on external surfaces, exhibit the required tolerances on ceramic dimensions. And we got a much closed matching of the resistance of inner Titanium coating done by PMB: <1% at the end of sputtering deposit, ±7% maximum of dispersion after oxydation by air (our specification was ±10%). With such a coating thickness dispersion (±7%), the penetrating field amplitude dispersion was estimated below 1.5 10^{-3} [1].

The operating temperature of each ceramic is controlled by two PT-100 probes, to avoid excessive thermal rise.

MAGNETS DESIGN

Kicker magnets are one turn coil with ferrite core, with a window frame shape, as usual. Ferrite yokes are made of 8C11 C-shape pieces, which constitute two half symmetric magnet yokes, located each one on a plate which can be opened. To get a good matching of all the kicker magnets, we made a specific attention on the transverse dimensions and tolerances (<0.5% of dimension) and on the positioning of the ferrite cores and the coil parts (insulated and maintained by dielectric machined C parts). The goal was to control the parameters of the four magnets: inductance dispersion < 0.1% from one magnet to other, field transverse homogeneity <0.1% in most of beam aperture. All pertinent dimensions and tolerances were precisely controlled at each manufacture acceptance tests.

Each magnet include an air forced cooling, in the vertical plan, to avoid any overheating of the ceramic due to the intense beam image current. The whole magnet is enclosed in an electromagnetic shield, in order to avoid any EM perturbations to the environment.

The magnet design was also determined taking into account the electric design and SPICE simulations of the whole system, including pulser, coaxial transmission and magnet. These simulations permit to determine suited value of pulse correcting RC components. So an auxiliary insulated cabinet, of bottle shape, dedicated to the RC corrector circuit, is located below the magnet reference support, close to the cables connections to the magnet coil.

HIGH VOLTAGE SUPPLIES SELECTION

To get very stable and reproducible power pulses, the first condition is to charge the energy storing capacitors at the same voltage before each pulse. We defined detailed technical specifications, for 12kV-200mA HV supplies, requiring a charging voltage reproducibility of 10^{-4} at least, and secondly providing a ProfiBus interface for remote control. After having tested, in charging and switching situation, several products we could select HV supplies, commercialised by SEFELEC (France), from which we could verify that the charging final voltage, at 3 Hz repetition, has a better reproducibility than 5.10^{-3} of voltage amplitude.

PULSED POWER SUPPLIES DESIGN

As half-sine field pulses are required, the system is based on a resonant discharge circuit, switching the energy stored in a capacitor to the magnet inductance.

Our design takes benefit of the LURE-SLS collaboration in 1998-1999 for the construction of pulsers for SLS storage ring kicker magnets [2].

To get good operating and easy-to-service conditions, we choose to locate the pulsers out of the Storage Ring (SR) tunnel. This choice was done also to avoid solid-state switch disturbing or crashes near the radiation sources, as it occured in a first time at SLS with high voltage level. So the transmission paths became a technical question.

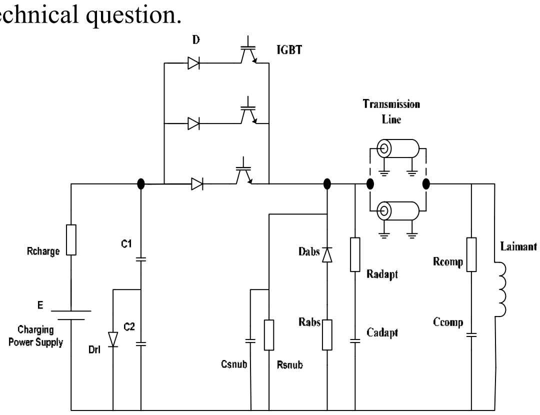

Figure 1: Kicker system basic circuit

Pulse energy is stored in the capacitors assembly, which is set in a coaxial copper tube in order to reduce and control the stray inductance. The association in series of two equivalent capacitors permits to avoid inverse voltage to each capacitor: when the pulse is discharged to the magnet, the upper capacitor voltage falls from HV to zero, and the down capacitor goes from zero to –HV.

These capacitors have been manufactured under our specification (by TPC-AVX), with a 15kV max operating voltage, and capacitance of 3.1 µF with the best identity between capacitors (<+/-1%). We measured, at a pertinent frequency (70 kHz), a dispersion of <5% on capacitance value over the set of 14 capacitors (except 2). Capacitors have been matched by set of two in series, which enabled to reduce the deviation of twins to 0.5% of mean value.

The switches are the more delicate elements to be chosen: they have to support high voltage, to ensure repetitive high current pulses without significant variations on current peak and shape, with a very low time jitter, and without failure in long term. Thyratron tubes (the classical solution) were considered not suited components for precisely matched kicker magnets, because of the drift of their characteristics with time and number of shots (time jitter, impedance), and also due to the price to replace them periodically.

We could find suitable solid-state modules manufactured by BEHLKE GmbH: IGBT switch modules; and fast HV diodes. Putting an HV fast diode in series with each IGBT switch, we could build switching arms with reverse blocking. Using three of these arms in parallel, we could build effective switches for our application (5500A max, 10kVmax), with security margin in voltage and peak current. However, as this type of IGBT switch module is a recent product, they are delivered without technical data sheet, which make their integration more difficult.

For the transmission of power pulses between pulser and magnet (estimated to about 8.5m before installation in the Storage Ring), many coaxial cables in parallel were chosen. For easy supply, it seems useful to select 50Ω cables with a sufficient conducting section, such RG-214U. SPICE simulations indicate the interest of putting 16 coaxial cables in parallel to transmit the 5220A peak pulses without excessive attenuation. Special RG-214U from OMERIN, with dielectric insulation and radiation reinforcement by Kapton sheets, according to our specification were used.

Some auxiliary circuits are necessary to prevent over-voltage on the solid-state components, and to damp fast reflection due to the coaxial transmission. The circuit topology and all components values had been calculated with SPICE simulation modelling, but we spent a few months on the first pulser prototype to accurate the different values in the pulser, and on the magnet connexion. Then the four final pulsers were built in house, and systematic measurements were done on each interesting point, specially to check the good equilibrium between the current pulses of each of the 3 switching arms.

As usual the transmission of trigger pulses from timing cards to the switch modules is done by optic fibre, that make immune from EMC perturbation. But from one trigger pulse to the three switch modules, an electrical signal with sufficient voltage and current has to be distributed: experience shows that 10V-1A trigger pulses are necessary for each switch module, and the dispatching circuit can be very sensible to electrical power switching perturbations, when this fast dispatching circuit is located indoor of the pulser cabinet (needed because electrical moulded cable of each module is only 20cm long).

To verify the good matching of the four kicker magnets, we need very effective matched pulse current monitors. Pulse current transformers are located in the magnet cabinet, on the connection going to earth. We ordered a set of fast pulse transformers, according to our specification, requiring a 0.1% identity.

MEASUREMENTS

First electrical measurements were made on every set of pulser connected by 8,5m long coaxial cables to its kicker magnet. These measurements demonstrated the operating of each system up to 5500A with 7400V, without problem. But pulse transformers, set by pair in reverse way on each magnet, show differences of <2% on the same magnet current, and equivalent differences between two different magnets. Positive information was to observe that our set of 16 coaxial cables in parallel gives significantly less attenuation than expected. So we can work at nominal peak current with less voltage.

We noticed a small disturbance at the beginning of the current pulse shape, for all the systems. This repetitive distortion was analysed to be caused by an oscillatory switching. Unfortunately the installation planning of SOLEIL storage ring didn't allow sufficient time to eliminate or strongly reduce it. We observed further its consequences on matching measurements by small difference at beginning of the difference signal.

During the magnetic measurements of each magnet, with its dedicated pulser, electrical measurements were done at 7500V (5650A) over long run without any failure or disturbing. We could even do linearity measurement of current and field integral, from 2,2kV to **8kV, giving up to 8.6mrad deviation** (+13% than required).

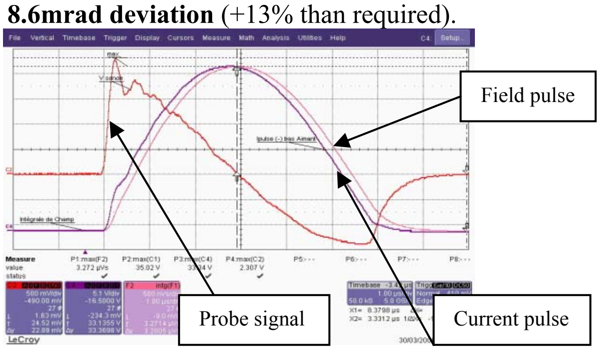

Figure 2: Current and field pulses measured.

Magnetic measurements have been done with a long coil of 0.4mm width, made of a FR4 long circuit, and with a short coil of 5 turns on a 3mm diameter dielectric core, for local field measurement. Each field probe is fixed, with adequate support, on an x-y-z translation bench, which allows 0.01mm spatial resolution, and 0.02mm precision and reproducibility. The probe signal, which is the derivative of measured field, is then digitally treated to eliminate noise and digitally integrated.

For each kicker magnet equipped with its ceramic vacuum chamber, we did a complete set of measurements:

- Linearity versus HV supply voltage set,
- Transverse horizontal homogeneity of the field integral, versus x position over ±30mm in the ceramic vacuum chamber (x=0 on magnet axis),
- Longitudinal profile of the local field, along the axis, from end to end of the ceramic chamber.

The magnetic field measurement **accuracy is of a few 10^{-3}** of the measured field. **We could not detect significant difference between each magnet**, above this accuracy level.

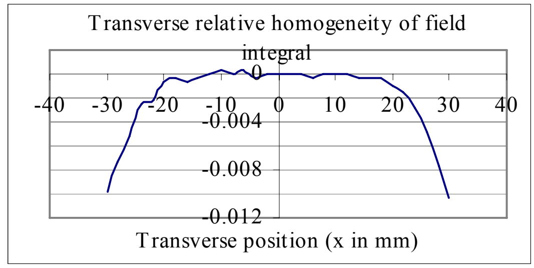

Figure 3: Transverse relative homogeneity of field integral

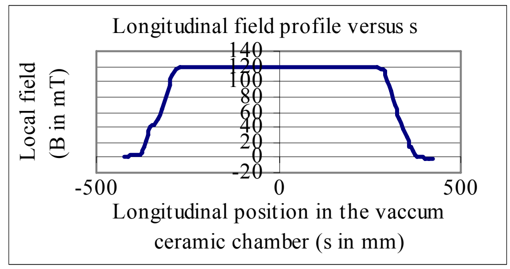

Figure 4: Longitudinal field profile versus s

Table 2: Magnetic measurement results

@Voltage	7500V
Peak current	5650A
Field integral	75mT.m
Transverse homogeneity	$<2.10^{-3}$ over ±24mm /axis
Local field (centre)	118mT
Magnetic length	654 mm

Magnetic measurements about **matching between two kicker magnets** give a signal of difference which has a peak of **3.9 10^{-3}** of the field pulses peaks.

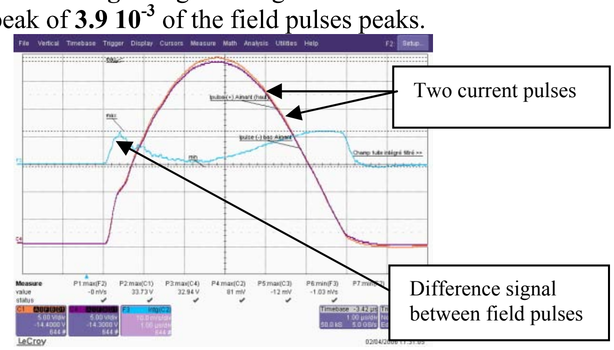

Figure 5: Field matching measurement between 2 kickers.

But the matching will be improved when we get matched pulse current transformers, and when we can eliminate the oscillation at the beginning of the pulse.

REFERENCES

[1] P. Lebasque et al, "Optimisation of the coating thickness on the ceramic chamber of the SOLEIL SR kicker magnets", these proceedings.
[2] C. Gough, M. Mailand, "Septum and kicker systems for the SLS", PAC 2001