# IMPROVEMENT ON PULSED MAGNETIC SYSTEMS AT SOLEIL

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### *Abstract*

Two “machine study” kicker systems (pingers) have been designed, built and installed on the SOLEIL storage ring. They will allow exploring the non linear behaviour of the storage ring by means of Frequency Map Analysis (FMA). This article describes the different design aspects of the two magnets and vacuum chambers, and of their fast high current pulsed power supplies, based on HV switches with MOS transistors. The electrical and magnetic measurements are presented. The second part of the paper focus on the modifications brought to the thick septum magnet system, for reducing the stray field seen by the stored beam. It also presents the different tunings investigated on the four injection kickers, in order to reduce the amplitude of the residual bump along the ring below 1/10th of the beam size. These adjustments are aimed to minimize the perturbation on the stored beam for the forthcoming Top-Up operation mode.

## MACHINE STUDY KICKERS

### *Beam Dynamics Specifications*

In order to probe the transverse non linear dynamics, two kicker magnets have been installed into the Storage Ring (SR) injection straight section during the summer 2007 shutdown period. The beam dynamics requirements were to be able to kick a 300ns bunch train (1/4 of the full SR time revolution = 1.181µs), independently in both horizontal and vertical planes. The available length in the injection straight section limits the vacuum chambers lengths to 850 mm and 550 mm. Table 1 presents the required deviation angles, and the resulting fields, at 2.75 GeV.

Table 1: Required Deviations and Calculated Fields

| | Active length | Angle | ∫ B dl | B nom |
|---|---|---|---|---|
| | mm | **mrad** | mT.m | mT |
| **Kicker H** | 600 | **2** | 18,34 | 30,56 |
| **Kicker V** | 300 | **0,6** | 5,50 | 18,33 |

It was also required that each kicker pulse acts only once over the 300 ns bunch train, with a flat top stability of ±5% of the field max amplitude. The pulse full width has to be ≤ 1.2µs (revolution period). The resulting pulses have a trapezoidal shape, with fast rise and fall times, as indicated in table 2.

Table 2: Pulses Time Requirements

| Flat top | | Transitions | |
|---|---|---|---|
| duration | tolerance | $t_{rise}$ | $t_{fall}$ |
| ≥ 300 ns | Bnom± 5 % | ~450 ns | ~450 ns |

### *Ceramic Vacuum Chambers*

Such fast transition times impose the use of ceramic vacuum chambers, with a thin metallic coating inside the alumina tube. So to preserve the storage ring impedance, the vacuum chambers have the same transverse aperture than those used inside the injection kicker magnets (internal HxV= 80x25 mm). The best compromise between small pulse distortion and reasonable beam thermal deposition, resulted in choosing a 0.5µm thick Titanium layer [1]. A forced air cooling is included in the magnets mechanics.

### *Magnets Design*

These fast kicker magnets are based on the window frame topology. It consists of a yoke of ferrite C cores (8C11), with a 1 turn stainless steel coil insulated and located by dielectric machined parts, around the ceramic vacuum chamber.

As for the other kicker magnets at SOLEIL, the machine study kickers are designed to be able to be baked out. They can be opened and closed easily without positioning degradation. Referred to their different functions, the horizontal kicker can be opened by horizontal symmetric movement of the two halves yokes (including the one turn half coil) guided by bars, while the vertical kicker can be opened by the vertical guided movement of each half, by two lifting screws. The electrical parts and the isolating distances are designed to support high voltage, at least up to 25 kV. The kicker magnets are enclosed inside EMC shielding in order to avoid perturbation on the surrounding devices.

The horizontal kicker (the largest deviation angle) has a 850 mm full length. Its mechanics is similar to those of the SR injection kickers [3], except for the HV insulation and for the coaxial cables connexion box. We made a specific development for the design of the Vertical kicker, which is shorter (550 mm full length) and very compact. The resulting inductances with very close geometry of the magnets allow to optimize the electrical parameters.

Table 3: Magnetic and Electric Characteristics

| | Coil Turn | Magnet inductance | Peak current | Charging voltage | PFL impedance |
|---|---|---|---|---|---|
| Kicker H | 1 | 2,0 µH | 1374 A | 19 kV | 12,5 Ω |
| Kicker V | 1 | 0,670 µH | 1488 A | 15 kV | 8,33 Ω |

### *Pulsed Power Supplies*

The choice of the Pulse Forming Line (PFL) - and transmission line - impedance is as usual determined, for each kicker system, by the ratio L/Z convenient to reach the required transition times. In order to use industrial HV connectors and cables, these impedances are realized by

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parallel association of the corresponding number of 50 Ω cables RG-218U type: 4 coax for kicker H, 6 coax for kicker V.

As for the fast Booster kickers [4], the scheme is based on a HV pulse forming line (PFL) switched on a non-matched load, which avoid to have a charging voltage double of the product $I_{Peak}*Z_{PFL}$. We use suited industrialized switch cards based on a serial-parallel association (13*16) of fast high voltage MOS transistors, but using another type of transistors enabling to drive more current and to present a lower $R_{dON}$.

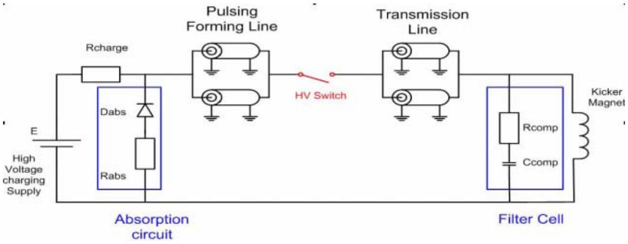

Figure 1: Basic electrical circuit.

The pulse shape of the kicker H was immediately good, but it reveals more difficult to tune for the kicker V, due to its smaller inductance value.

### *Magnetic Measurements*

The magnetic performances of each kicker were verified on a specific test bench with an x-y-z translation 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.

Table 4: Electric and Magnetic Measurements

| | **Kicker H** | **Kicker V** |
|---|---|---|
| $t_{rise}$ / $t_{fall}$ (0 - 100%) | 392ns / 515 ns | 361ns /380 ns |
| flat top length | 401 ns | 456 ns |
| flat top ripple | ± 0,85 % | ± 1,6 % |
| full length width | 1200 ns | 1200 ns |
| horiz transv homogeneity | 0,2% sur x=±32mm | ±0,5% sur x=±28mm |
| vert transv homogeneity | 0,2% sur z=±10mm | ±0,2% sur z=±10mm |
| effective magnetic length | 658 mm | 371,5 mm |
| **nominal** current/voltage | 1182A/16kV | 1101A/10,17kV |
| nominal angle/field integral | 2mrad/18,34mT.m | 0,6mrad/5,5mT.m |
| **max** current/voltage | 1632A/22kV | 2140A/20kV |
| max angle/field integral | 2,8mrad/25,4mT.m | 1,15mrad/10,6mT.m |

Both kicker systems exhibit an excellent linearity between the voltage control, its pulsed peak current, and the resulting field and deviation angle. They overpass the required deviation, due to the very good electric behaviour of the two pulsers and the larger effective magnetic lengths (especially for the vertical kicker). The low jitter (1ns) and pulse shapes are very stable.

### *Operating Status*

Our two fast machine study kicker systems, with HV full solid-state switches, are operated since December 2007 during the dedicated beam physics shifts for dynamic aperture measurement and FMA [4].

## IMPROVEMENT OF THE SR PULSED MAGNETIC SYSTEMS

The SOLEIL Top-Up operation requires perturbation to the stored beam below or equal to 10 % of the beam transverse size during injections. The identity between the 4 kicker pulses should then be better than 0.1% and the integrated stray magnetic field on SR axis, from the septum magnets, should be less than 12 µT.m [5].

### *Reduction of the Thick Septum Stray Field*

The thick septa stray field was measured in the lab at a maximum level of ±11µT.m. But after installation, we detected a bipolar beam orbit perturbation of ±150µm, indicating a ~±140 µT.m stray field induced by the thick septa. Different actions were conducted, since June 2007, to understand the stray field sources and reduce its effect on the stored beam. It was done with the help of the company MECA MAGNETIC [6]).

First we thought that the existing shields were insufficient: a new shielding made of a 1.5mm thick Mumetal was installed completely surrounding the stored-beam chamber. As the attenuation effect probed by the beam was too slight (<20%), during a shutdown we measured the magnetic fields around the septa and found up to 1.2mT close to the septa yokes. So we decided to enclose the downstream yoke in a 3x1.5mm thick shielding of Supra-36™, a higher saturation field alloy. But there was little improvement seen on the beam.

With a more sensitive magnetic probe we identify that the perturbed area was not the stored-beam chamber the closest to the septa, but just upstream of it. Shielding trials with beam confirmed it. So the upstream yoke has been also shielded with Supra-36 (May 2008). But the stray field was reduced only by a factor of 3.

Expecting a better attenuation, we considered the eddy currents generated, in the septa thin stainless steel chamber, by the main septa magnetic pulses. We measured surprisingly high induced currents: bipolar pulse up to ±220A along the septa thin chamber, and coming back to the Transfer Line chamber. Once grounded with short copper stained braided conductors, the measured current in the chamber was divided by 20.

After that the effective orbit distortion experienced by the beam was reduced to ±15µm in x and z, indicating a remaining bipolar stray-field of ±14µmT.m from the thick septa. Some more improvements are achievable.

### *Matching the 4 Kicker Systems*

The stored beam experiences the kickers pulsed field during 6 turns. The required identity between the four kickers pulses is below or equal to 0.1% of the peak field.

Table 5: Four Kickers Characteristics

| | | |
|---|---|---|
| Deviation angle | 7,6 | mrad |
| B nominal | 116 | mT |
| Active length | 600 | mm |
| Peak current | 5220 | A |
| Voltage | 7800 | V |
| Pulse width | 6,5 | µs |

After installation, the 4 injection kicker magnets were creating a significant residual bump on the stored beam, about 1 mm of horizontal orbit distortion.

We conducted successive adjustments concerning the peak field level, the trigger timing to each pulser, and also the pulse width and the pulse distortion of each kicker system. With a good resolution (16 bits controlled) and a good reproducibility ($\sim 10^{-4}$) of the HV PS, the peak level was easy to control. Based on the global timing system, the delay adjustment between each kicker is presently limited to 5.68 ns, but a more accurate (step<100 ps) device is foreseen. Altogether, the residual rms perturbation has been reduced to about 150 to 250 µm (depending on the bunch position along the train) as measured by a BPM downstream the injection straight section with a 12 m betatron function. At this location, the horizontal beam size is about 350 µm rms.

The adjustment of the half sine pulse width was performed by adding small value high voltage capacitors in parallel to the upper energy storing main capacitor. More difficult was the smoothing of the small default on the pulse rise and falling edges. The di/dt is sharp during the first µs, before getting the half sine shape. The falling edges are also different between kickers. We made systematic precision measurements on each kicker magnet, with a scope. We studied different ways for smoothing the shape distortions: tuning of the auxiliary resistors and capacitors in the pulsers, adjunction of saturating inductance between the main capacitors and the HV switches.

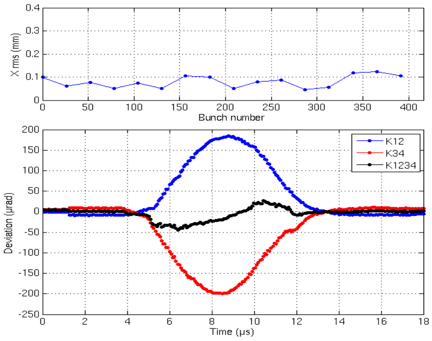

Figure 2: RMS horizontal residual oscillations (up) and kickers deviation (down).

In parallel, machine sessions were dedicated to the kicker adjustments since the beam is the most sensitive probe. Based on turn by turn analysis, with a set of 8 BPMs, we are able to reconstruct the pulse shape of the kickers. Without any BPM in between the four kickers, we are only able to get the mean profile for the combined effects of the two first K12 (=K1-K2) and of the two last K34 (= -K3+K4) including their polarity. After the second campaign of pulse profile matching by adding capacitors as well as saturating inductances we were able to reduce the residual distortion as depicted in figure 3. The rms amplitudes vary from 50 to 120 µm with a mean value of about 80 µm rms. It should be noticed that the kicker amplitudes were not optimised as shown by the large residual deviations observed (blue and red curves). The quite low residual distortions are mainly due to the cancellation between kickers together with the horizontal tune of 0.2 at the end of the pulse.

Further investigations have been done to evaluate the real pulse profiles experienced by the beam. We tuned the four kickers in order to remove at best any difference in amplitudes, delays and pulse lengths. The residual pulse profiles are plotted in figure 4. They still exhibit some spikes of 20 µrad peak (~0.3% from max amplitude) localized at the start and at the end of the pulse. The remaining oscillations are increased around 200 µm rms.

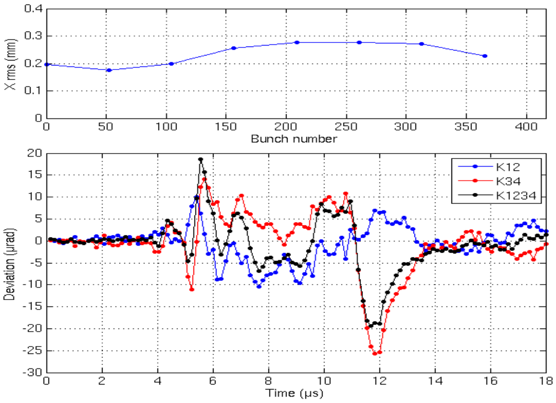

Figure 3: RMS horizontal residual oscillations (up) and kickers deviation (down).

This work has to be continued, in order to solve the pulse shape discordances and peaks. Beside, we also measured the vertical oscillations by the same scheme. They are of 60 µm rms and mainly due to a tilt (about 1 mrad) of the kickers that will be corrected.

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