DESIGN AND OPERATION OF SLS2 THIN SEPTUM

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Abstract

In the SLS2.0 upgrade project at the Paul Scherrer Institute (PSI) the injector complex remained mostly unchanged, but we had to design three new storage ring injection elements: the thick septum, the thin septum and beam dump system. Because of the limited dynamic aperture of the upgraded machine, 1 mm septum wall thickness was necessary. To limit stored beam disturbance to 10% of the beam sigma, extremely low (< 8 μT) leakage field was required. To achieved this, we used a "sandwich" septum consisting of a copper sheet and a layer of soft magnetic material. In this way we achieved very good screening of the main field.

To power the thin septum, we designed a pulse generator based on a two-stage fast thyristors switch and a matrix capacitor. The latter was built using multiple commercially available ceramic SMD capacitors to avoid the risk of catastrophic failure of the oil filled foil capacitors. We successfully built and commissioned the thin septum and, it works reliably.

In this paper, we present design and operational results of the pulsed thin septum, including simulations and measured results of the main and leakage field. Beam based leakage field evaluation is described as well.

INTRODUCTION

The upgraded machine with limited dynamic aperture requires the septum magnet wall thickness of 1 mm [1, 2]. Very thin eddy current septum (Fig. 1) should ensure inserting the injected beam very close (~3 mm) to the stored beam. Powder cores are chosen for the magnetic circuit to cover the frequency and the field strength requirements. Septum should provide the required field and at the same time extremely low leakage field to limit stored beam disturbance. 3D electromagnetic numerical simulator CST® Studio Suite [3] was used to optimize the screening of the thin septum. A "sandwich" configuration (Fig. 2, top left) from a cooper sheet and a layer of soft magnetic material was chosen for the screening.

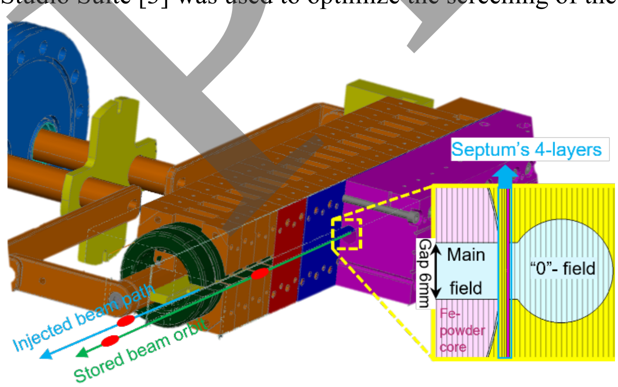

Figure 1: Septum magnet 3D drawing and cross-section of the simulated model. The blue line indicates injected beam path and the green line stored beam orbit.

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THIN SEPTUM SIMULATION

Having in mind small thickness of metal sheets that were used, fine meshing was necessary to provide reliable results. Local meshing gives the minimal number of mesh cells for geometry with thin layers. Tetrahedral mesh for the septum model is based on usage of different local meshing (Fig. 2, top right).

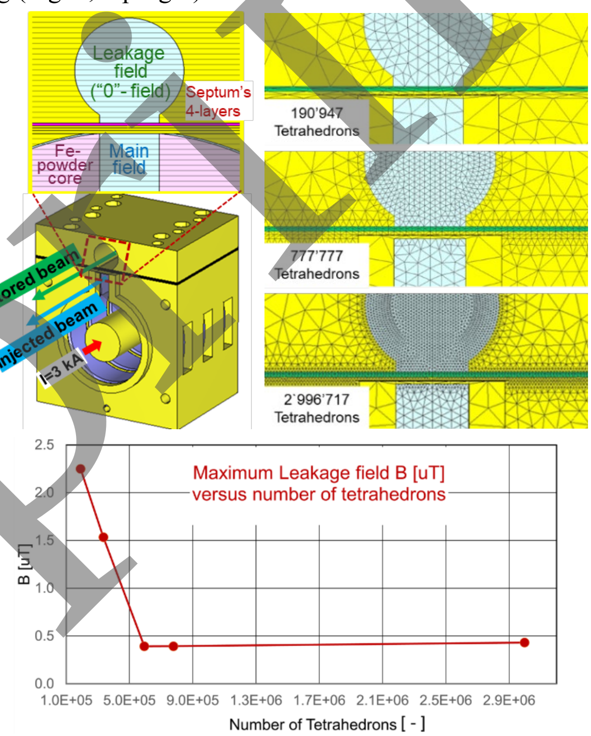

Figure 2: 3D CST® model and cross-section of a "sandwich" configuration with 4 layers used in parametric study (top left). Different mesh density based on different local meshing (top right). Influence of mesh size (number of tetrahedrons) on CST leakage field results (bottom plot) for thin septum excitation pulse of 3 kA amplitude.

Proper meshing is crucial to get consistent results. Diagram at Fig. 2 (bottom plot) shows that number of mesh cells up to 600'000 tetrahedrons significantly influences the result, but further increase (using smaller mesh size) has negligible influence.

For practical excitation pulse (sin wave with T=12.5 μs) one mm of copper does not provide the required screening (Fig. 3, top plot). No other engineering material (at room temperature) could provide significantly larger conductivity, respectively better screening. Eq. (1) shows steady state solution of skin depth (δ) for sine wave field. It can be easily seen that for a given frequency (f) skin depth (δ)

depends on material conductivity (σ) and permeability (μ). Using high-µ soft magnetic material [4] we can provide better screening than copper in the frequency range where it has significantly large relative permeability, despite of its lower conductivity. That was the reason to investigate using a "sandwich" configuration adding material with ferromagnetic properties. Different configurations were studied using one sin wave period of T=12.5 µs. For illustration few chosen results are shown in Fig. 3.

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}} \quad (1)$$

High-µ soft magnetic materials saturate very easily and can be used only at low fields. This is why we used first a copper sheet to screen most of the field and then we add high-µ soft magnetic sheet to further improve the screening. The credibility of the simulation results depends a lot on the correct material model. Choosing the proper model parameters for high-µ soft magnetic materials proved to be difficult since this information is usually not readily available.

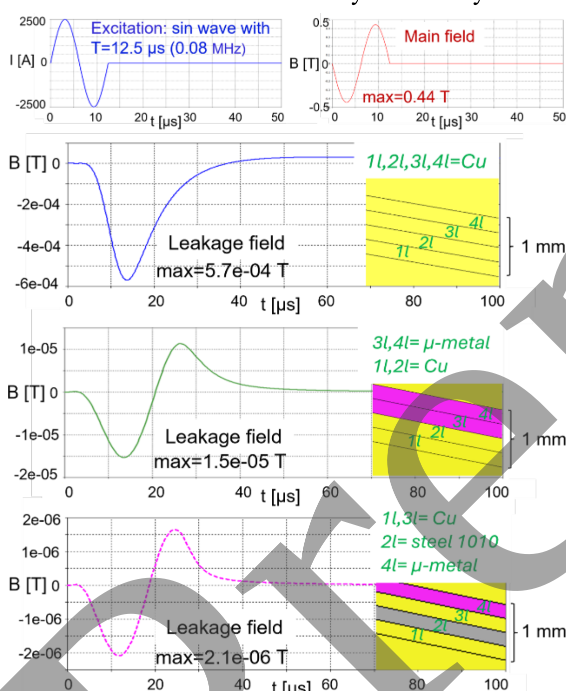

Figure 3: Excitation, main field and leakage field for different "sandwich" configurations and materials.

THIN SEPTUM PULSER DESIGN

Design of thin septum pulser (Fig. 4) includes some improvements and new technology in comparison to storage ring kicker pulser:

- New bi-directional optical fiber-based triggering.
- New two-stage solid state switch, based on fast HV thyristors (synergy with beam dump switch).
- New storage capacitor technology.

Bidirectional optical fiber-based triggering with trigger link monitor is developed (Fig. 5). To ensure the link is operational, optical trigger link driver decodes the local trigger pulse and the remote one, which returned from the optical receiver.

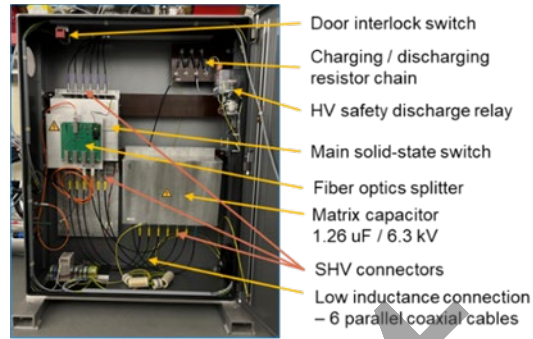

Figure 4: Thin septum pulser.

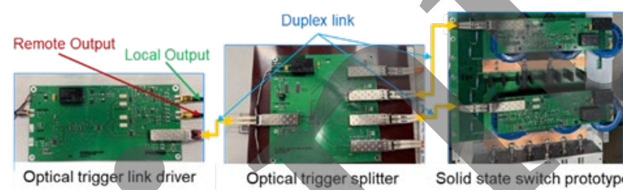

Figure 5: Optical trigger link driver, optical trigger splitter and solid state switch prototype.

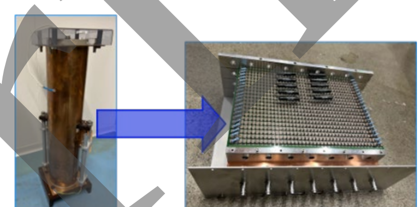
Figure 6: Oil impregnated foil capacitor (left). Matrix capacitor based on ceramic SMD capacitors (right).

For thin septum and beam dump magnet we developed low inductance, high current (10 kA), high current derivative (> 7 kA/µs) solid state switch (Fig. 5 right). It is based on very fast HV thyristors, produced by Excelitas [5, 6].

The standard oil filed capacitors are prone to failures that can result in fire. To increase safety a new matrix capacitor was built, based on multiple commercially available ceramic SMD capacitors (Fig. 6).

LEAKAGE FIELD MEASUREMENT

Measurement of leakage field in range of unity µT is very difficult. To gain confidence in the results, two measurement methods were used (Fig. 7):

- Induction coil
- Large bandwidth magneto-resistive sensor

Both methods give almost the same amplitude although the shape is not the same.

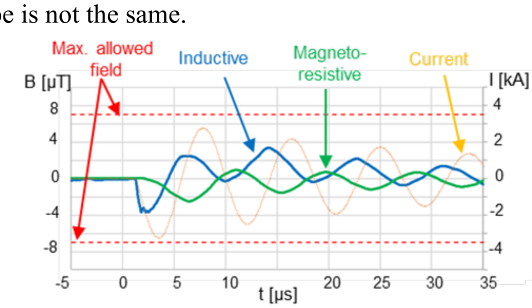

Figure 7: Measured leakage field using two measurement methods.

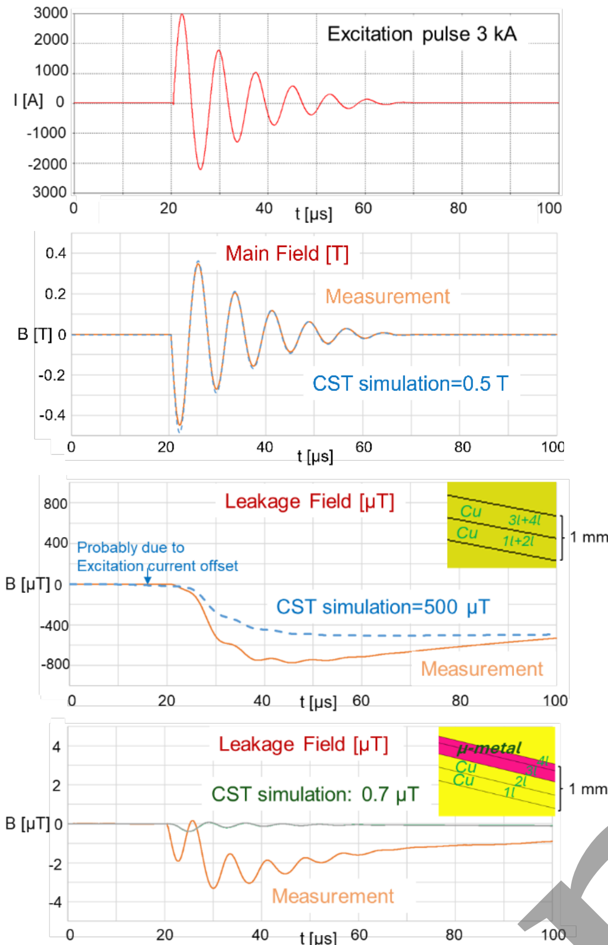

Figure 8: Simulation and measurement results for two "sandwich" configurations (1 mm copper, and copper + soft magnetic material): excitation pulse and main field (top plots) and leakage field (bottom plots).

In Fig. 8 top plot shows thin septum excitation pulse of 3 kA amplitude, that is required to generate the necessary main field (0.5 T). For this excitation pulse some chosen "sandwich" configurations were simulated and simulation results for main and leakage field were compared with the measured results using induction coil. The results for two configurations are shown in Fig. 8: one with two 0.5 mm thick copper layers and second one with four layers: two 0.3 mm thick copper layers and 0.25 mm and 0.15 mm μ-metal layers [7]. The "sandwich" structure does not influence the main field. We confirmed that such configuration (copper + μ-metal) can provide better screening performance compared to a copper septum with the same thickness, and two layers configuration (0.6 mm thick copper and 0.35 mm thick μ-metal layers [8]) was adopted.

OPERATION

Figure 9 shows thin septum installed in tunnel. Thin septum signal during the SLS2 operation is shown on Fig. 10. Injection disturbance on stored beam was investigated and beam based leakage field evaluation is done. Thin septum disturbance was measured with beam using a BPM in turn

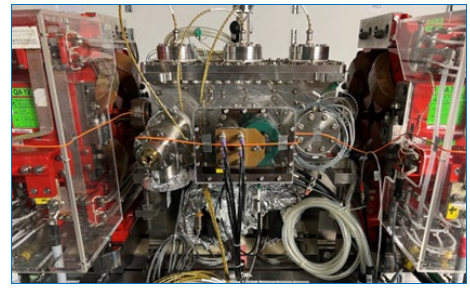

Figure 9: Thin septum in tunnel.

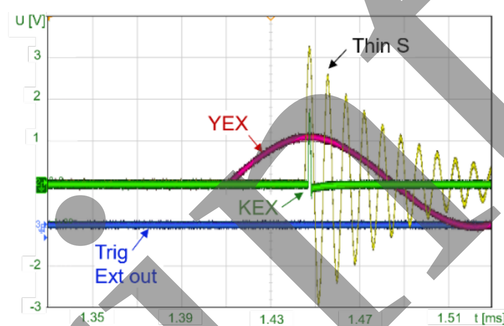

Figure 10: Thin S - thin septum signal during the SLS2 operation; YEX - Booster Septum Extraction pulse; KEX - Booster Kicker Extraction pulse.

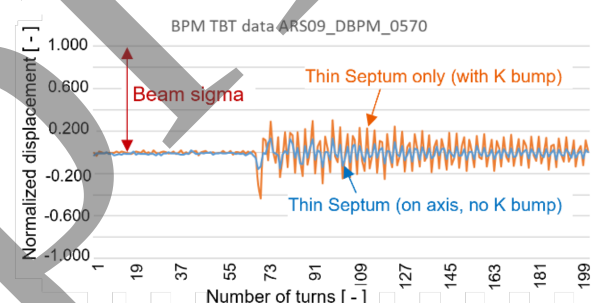

Figure 11: Normalized thin septum disturbance (beam sigma), orange – on the bumped orbit (bump kicker contribution subtracted) and blue - on axis (bump kicker off).

by turn (Fig. 11). Equivalent field disturbance is evaluated as the magnetic field integral to cause the residual beam disturbance in one turn. The measured beam disturbance on axis is 15% and on the injection trajectory (bumped orbit) 30% of beam sigma - equivalent disturbance field 3.6 μT.m, respectively 7.1 μT.m.

CONCLUSION

Thin septum is specially developed to meet the injection requirements for SLS2.0 limited dynamic aperture. The designed septum provides the required field and at the same time extremely low leakage field using a "sandwich" technics (copper + high-μ soft magnetic material), which allows us to surpass performance of traditional copper septa. In this way we achieved very good screening of the main field and managed to limit stored beam disturbance. Despite the measured equivalent disturbance slightly exceeds the set target (10% vs. 15% of the beam sigma), the thin septum performs fully satisfactorily. Since commissioning of SLS2.0 the thin septum works reliably.

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