SEPTUM AND KICKER SYSTEMS FOR THE SLS

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Abstract

A total of nine pulsed magnets are used in the Swiss Light Source (SLS) machine. The three septum magnets are eddy current designs with a sheet of magnetic screening material around the stored electron beam to reduce the leakage field integral below 50 μTm. The excitation waveform is a single-cycle sinewave pulse that is 150 μs long and up to 5kA peak. However, the total dissipation is only 3 J/pulse, and so the open loop pulse amplitude remains stable to within $+/-1\times10^{-3}$. There are four identical kicker magnets for injection into the Storage Ring. A symmetric bump is used in one of the long straight sections. The excitation waveform is a 6 μs half-cycle sine pulse up to 3kA peak. The emphasis was on achieving the best possible tracking in time of the magnet field waveforms so that the residual closed orbit disturbance is minimized for top-up injection. The pulsers give currents identical to within $+/-1x10^{-3}$. The magnetic fields, including the effect of the metallised ceramic chambers, were plotted in three orthogonal axes and in time, giving animated "movie" of the magnetic field behavior.

1 OVERVIEW

The original design choices for the SLS machine took full consideration of the experience gained in earlier synchrotrons. Firstly, the Booster extraction and Storage Ring injection occurs with a low emittance beam (small physical cross-section); this means that the septum thickness is not critical, and also that the septum magnet vertical aperture needs to be only 6mm. Secondly, a full 11m long straight section was made available for Storage Ring injection, without the complication of intervening multipole magnets; with this long straight, the injection kicker magnets require only 5mrad deflection angle, permitting operation at a modest current of 3kA. Lastly, the choice was made to place all the pulsed power supplies in the machine tunnel beside the magnets. This limited complexity but increased risk from radiation damage.

2 SEPTA

The SLS septum magnets are an in-vacuum, eddy current design. With the prototype magnet, the leakage field was in the range 0.1 to 0.5%, a typical result for eddy current septa. This value can be greatly reduced by adding a circular sheet of magnetic screening material.

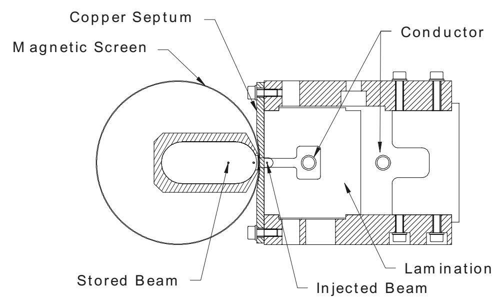

Fig.1: Cross section of the SLS eddy current septum, with circular magnetic screen.

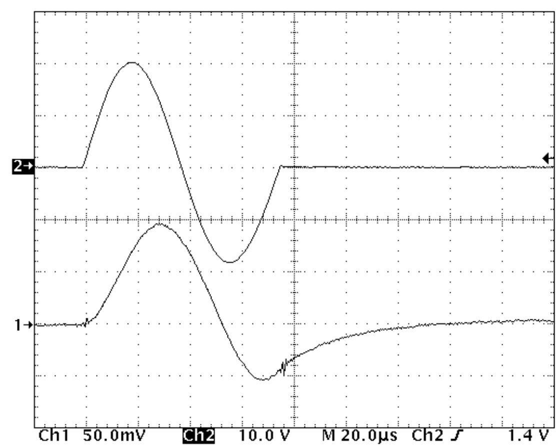

Fig.2: Typical septum measurement result. The upper trace is the main field of 1 T peak, the lower trace is the leakage field of 100 μT peak. Accurate measurements were critically dependent upon the performance of wide-band integrators for the pick-up coil signals.

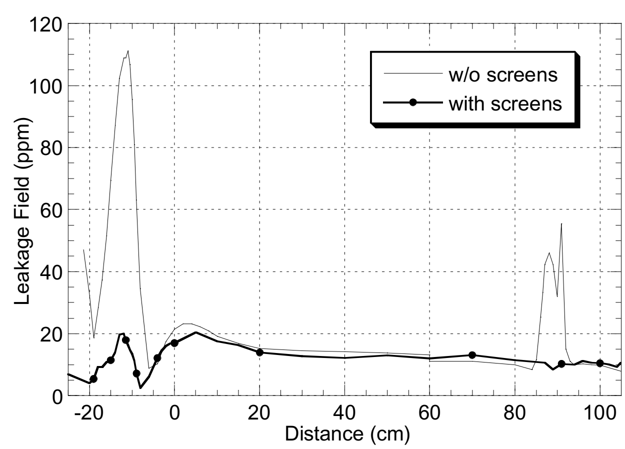

Fig.3: Septum leakage field along the stored beam axis, before and after insertion of the end magnetic screen.

With the addition of the magnetic screening material, the leakage fields peak at below 50ppm. In Fig.3, the magnet begins at x=0cm and ends at x=80cm. The high leakage fields occur, not where the magnet ends but rather where the magnetic screen ends. Additional transverse screening plates were fitted at the screen ends reduced these peak values, giving an integral which is well below 50 µTm. The key design feature is that the magnetic screen is a few centimeters longer than the magnet.

Previous eddy current designs use a unipolar pulse shape, giving a long decay time for the leakage field as a result of the circulating currents in the eddy current conductor. The SLS septa use a bipolar pulse, which suppresses this long tail. In addition, capacitor charge recovery in the pulser is achieved without additional components.

The short pulse length means that the total dissipation in the pulser and magnet combined is only 3J/shot, even with 5kA pulses. The low dissipation is beneficial; the open loop pulse amplitude remains stable to <+/400ppm and the pulse length to <+/-25ppm.

Early in the service life, one magnet developed a short because the Macor™ conductor insulators were rubbed by conductor movement. Mechanical measurements showed that, while the movement was only in the range of tens of micrometers, it was highly oscillatory. In addition, the short current pulse acted as a mechanical impulse. The bipolar waveform then gives twice the impulse strength as a unipolar waveform. The best solution was to accept the presence of an organic material in the Ultra High Vacuum (UHV), and so Vespel™ insulator pieces were used to replace the Macor™. The Vespel™ pieces have a rubbing loss which is over a thousand times lower than Macor™. In addition, the material is tough and can be clamped to the conductor, giving some damping of the mechanical oscillations.

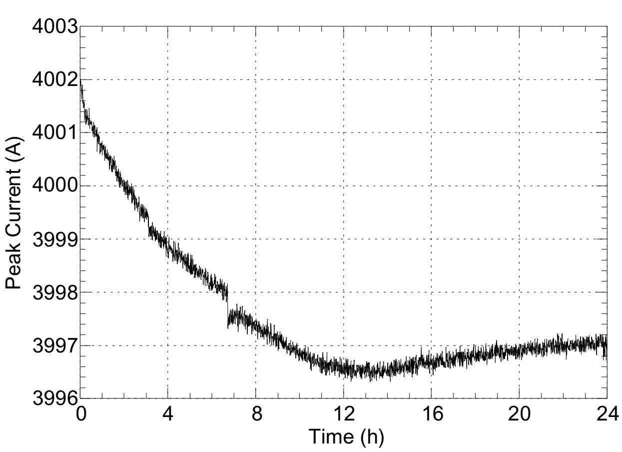

Fig.4: Plot of the peak septum magnet current, without water cooling. When water cooling is used, the stability is improved by a factor of three.

3 BOOSTER KICKERS

To limit the cost, the choice was made to accept a modest 200ns rise time for the Booster kickers. The vacuum tank design was copied from the SLS septum magnets. Inside the vacuum tanks are simple lumped-inductance ferrite magnets. As shown in Fig.5, the conductors have an "H" profile, and this profile fits into Macor™ insulation plates. In this way, none of the beam aperture is used for conductor supports. Air insulated thyratrons CX3604 and RG220 PFNs are used to generate the required rectangular pulse.

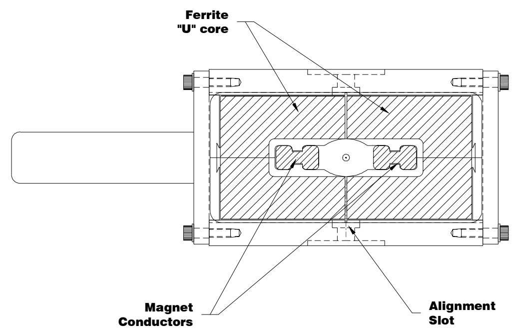

Fig.5: Cross-section of the SLS Booster kicker magnet.

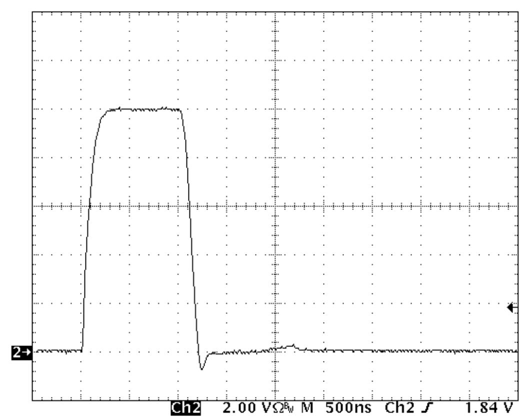

Fig.6: SLS Booster kicker magnet current pulse, 1µs long and 800A peak.

4 STORAGE RING KICKERS

The stored beam in the Storage Ring must be displaced by 17mm to permit accumulation of the electron beam coming from the Booster. The displacement required is a symmetric horizontal bump in an 11m long straight section, requiring four identical magnets and pulsers. However, the stored electron beam should remain stable to within tens of micrometers. Thus the four pulsed magnets that deflect the beam should have exactly the same magnetic field 3D and in time. The excitation waveform is a half-cycle sine, 6µs long and 3kA in amplitude, and requiring a 4kV charging voltage. As the pulsed magnetic field passes through metallised ceramic chambers, the resulting eddy currents deform the magnetic field.

A magnetic field mapping of all magnets was performed using a stable X-Z plotting machine driven with linear motors. This equipment was controlled using LabView software, and recorded 2D magnetic field plots, in time and with all three orthogonal magnetic axes. The results were dramatic "movies" of the growth and decay of the magnetic fields; a sample is shown in Fig.7.

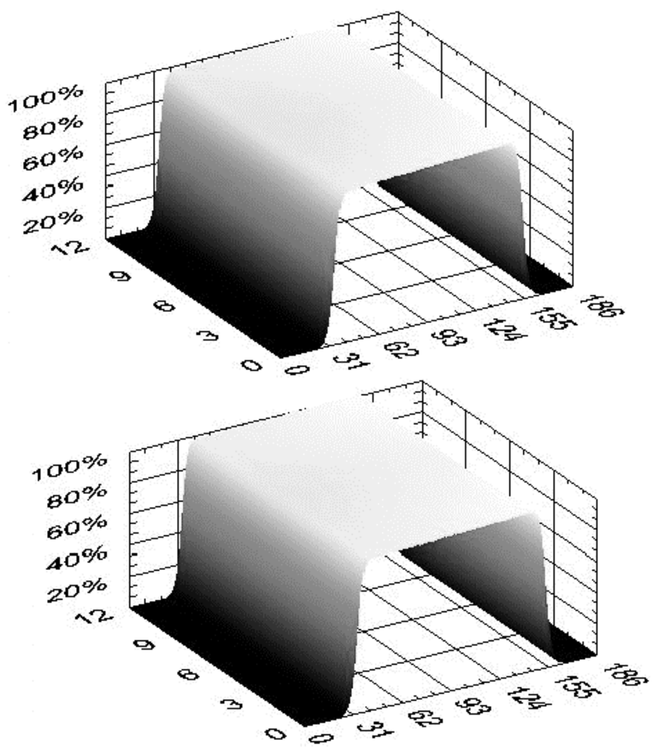

Fig. 7a: Sample results of pulsed magnetic field plots for two different kicker magnets at t=3.1µs, the time when the magnetic fields are at the maximum. The scale 0-12 is the transverse direction. The scale 0-186 is the longitudinal direction i.e. through the magnet.

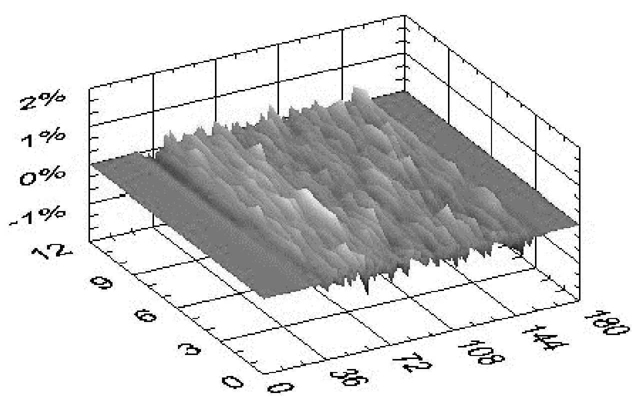

Fig. 7b: The difference between the two plots in Fig.8a, showing that these two magnets are almost identical.

The kicker magnets were built by ACCEL Instruments GmbH, and had inductances which were identical to $<10^{-3}$. The main difficulty is matching the resistivity of the metallisation on the inside of the ceramic vacuum chambers. The magnets that are currently in service have DC resistances of 0.843Ω, 0.849Ω, 0.926Ω and 0.837Ω. It is likely that the resistance differences can be compensated by connecting external trimming resistances, but this work has not yet begun.

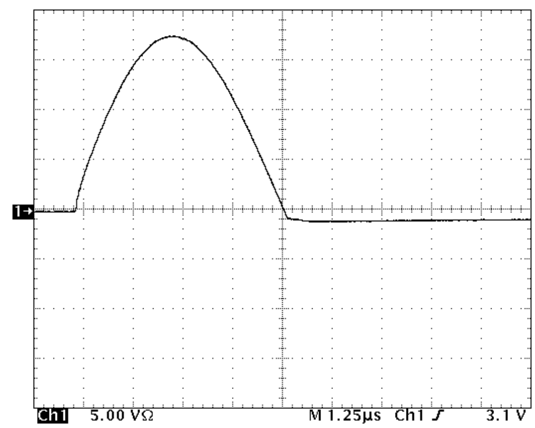

Fig. 8: Current pulse waveform for the Storage Ring kickers, with a peak value of 3kA.

The pulser uses a fast IGBT/diode switch assembly to discharge a dual coaxial capacitor assembly into the magnet load. The pulser is connected to the magnet with simple RG58 coaxial cables. These cables were found to give stable inductance, and the very short pulse length means that they can carry kiloamperes without damage. Digitization of fast waveforms to a precision below 0.05% would be difficult. We now have confidence that current transformer signals from two different magnets can be differenced with a simple resistive circuit with high repeatability. In this way, the difference signal can be amplified to show details in the range 0.001% of the main signal. By comparing pairs of pulsers, we are sure that the pulsers currents are identical to within $+/-1x10^{-3}$ during the complete pulse. The waveform in Fig.8 shows a negative tail. This tail occurs as current is passed through precision resistors so that the dissimilarities of the diode reverse recovery characteristics are completely suppressed.

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