

DETERMINATION OF THE MAGNETIC CHARACTERISTICS IN THE INJECTION SEPTUM FOR THE METROLOGY LIGHT SOURCE*

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Abstract

The pre-accelerator microtron supplies an electron beam at 105 MeV for the Metrology Light Source (MLS) of the Physikalisch-Technische Bundesanstalt (PTB) in Berlin. The beam is delivered via the transfer line to the injection septum and then into the storage ring. This septum magnet has its stainless steel vacuum beam pipe placed inside a laminated silicon iron magnet core. Hence, the pulsed magnetic field (half sine) used for the beam deflection must propagate through the thin metallic beam pipe. During the commissioning of the injection process, it became apparent that the calculated nominal pulse current for this energy and geometry had to be increased by 30 % to achieve proper beam transfer and accumulation. Two problems were apparent. Firstly, the injected beam trajectory had to be set at an angle away from the main beam axis. Secondly, the beam transfer from the septum entrance to exit was disturbed. As a first measure, the septum current pulse length was extended from 35 μ s to 107 μ s. Further on, the septum magnet was insulated from the transfer line beam pipe by a ceramic brake. This paper reports on measurements of pulsed magnetic fields inside the septum magnet and the improvements with the injection process.

THE MLS STORAGE RING INJECTION

The septum magnet is placed in a straight section of 2.5 m where the injection line leads into the MLS storage ring.

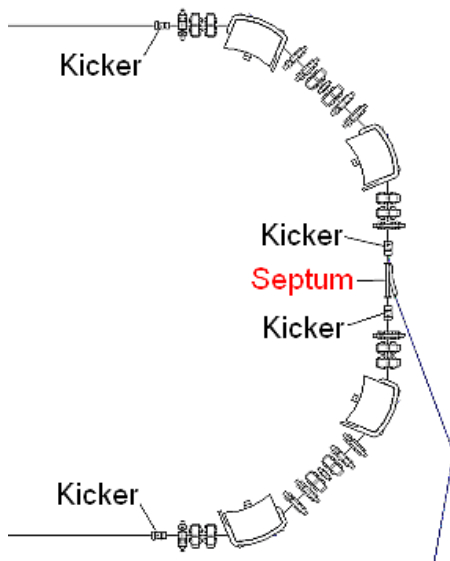


Figure 1: Schematic of $\frac{1}{2}$ MLS storage ring with injection

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Two kicker magnets are symmetrically attached to it where two other ones are placed in 6 m straight sections facing the ends of the achromatic magnet bows (Fig. 1).

For efficient electron beam accumulation, decaying magnetic leakage field must not exceed theoretical ascertained limits. These are specified as maximal permissible integral induction along the septum rail and with local pick-up coil (Table 1). While the injection system can deliver beam at 10 Hz repetition rate, the most efficient and highest value beam accumulation was achieved with 2 Hz repetition rate for the septum system.

Table 1: Specified Septum Design Parameters

Parameter / Description	Value
Deflection angle	$\alpha = 20^\circ$
Bending radius	$\rho = 2$ m
Mechanical aperture	9.4 mm \cdot 10.4 mm
Magnetic length	700 mm \pm 1.5 mm
Mechanical width	800 mm \pm 0.8 mm
Injection energy (max. specified)	E = 120 MeV
Max. permissible integral induction in antechamber, along septum rail	$5 \cdot 10^{-5}$ Tm
Max. permissible induction in antechamber, with local pick-up coil	$1 \cdot 10^{-4}$ T

Hardware Integration of a Ready-Made System

As the stray field requirements were stringent, it was decided to either purchase a system fitting the specifications or to take the effort for an in-house design based on previous experiences [1]. Because of the project progress and constraints in manpower, the preferred solution was to order an already developed septum system from the manufacturer Danfysik. Comparable septa showed good performance in other synchrotron light sources [2]. The septum passed factory acceptance tests and was installed in the MLS storage ring [3].

First Stage Commissioning Experience

For the first accelerator commissioning term, the septum was powered with a short half-sine septum pulse current of $\tau = 35$ μ s length as ordered. The intention for the specified very short pulse was to reduce stray fields outside the septum rail effectively and permit eddy currents damping in the septum rail and attached beam pipe. At this stage, the required pulse current amplitude was as high as $\dot{I} = 2380$ A for successful beam transfer through the septum magnet, about 30 % higher than the nominal value. The injected beam appeared distorted on

the fluorescent screen after the septum. To mitigate these effects, the pulse current length was extended to the technical limit of the pulser unit ($\tau = 107 \mu\text{s}$). The beam spot on the fluorescent screen, after the septum, was more focused (Fig. 2 left: short $35 \mu\text{s}$, right: long pulse $107 \mu\text{s}$).

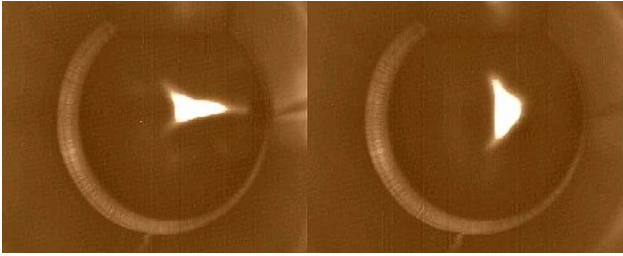


Figure 2: Screen after septum; for short and long \hat{I} pulse.

The pulse amplitude was $\hat{I} = 1780 \text{ A}$ for good injection conditions, near to the nominal value. The beam moved to the center, its distortion was reduced. Additional specifics were suspected as origins of the outward directed injection angle for optimal beam accumulation conditions.

Eddy Currents in Beam Pipe and Lamination

Since there was only one installed septum magnet available, but no test stand yet, the idea was that the eddy currents in the thin metallic beam pipe and in the lamination could be the primary reasons for the observed effects. The vacuum system could not be broken for field measurements at that time. However this assumption was in contradiction to the successfully passed factory tests.

The penetration depth for the 0.3 mm thin stainless steel injection channel pipe was estimated with equation (1). The calculated eddy currents could not explain the described injection and accumulation problems [4].

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

δ - penetration depth, electrical field is reduced to fraction $1/e$,
 f - frequency, σ - conductivity, μ - permeability

FIELD MEASUREMENT SETUP

When a spare part septum magnet was delivered, a new measurement campaign was started. This led into understanding of the discovered phenomenon.

Test Stand and Applied Techniques

A flow box provided the clean environment to allow the opening of the vacuum system without pollution. The magnet was investigated to reproduce the previous factory magnetic (**B**) field tests. The deflecting B_y -field in the injection channel was confirmed; the stray **B**-fields in the antechamber were not measurably small. Two long single winding pick-up coils, bent for the injection channel and straight in the antechamber, were taken for integral B_y -field measurements. Lumped pick-up coils were applied for local tests. The induced voltages were instantly integrated by a scope to derive flux values. B-field values were calculated by division by the coil area.

Improving Septum Installation

This septum design has a stainless steel beam pipe placed inside the septum magnet yoke and less demands on the vacuum system. One particularity of this septum magnet realization is that shorted secondary transformer coil with undesirable impacts can be formed. Danfysik used isolated supports to avoid such a loop within the magnet. But the first septum integration into the MLS storage ring provoked a secondary current path. Even though the septum magnet was not entirely shortened, this undesired low impedance current path was created over the girder local potential equalizations (Fig. 3).

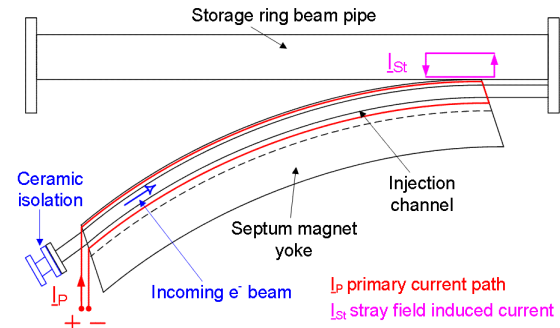


Figure 3: Schematics non-isolated integration.

The fault current path was disconnected by inserting a ceramic isolation part in the injection line beam pipe only. The remaining eddy currents are more localized and much smaller than the big fault current before. Hence the **B**-stray field inside the antechamber bore is reduced (Fig. 4).

Eddy currents, excited by the main current pulse have a different, longer time constant and can be reduced by applying full-sine excitation pulses. But this detail must be traded against double power dissipation [5].

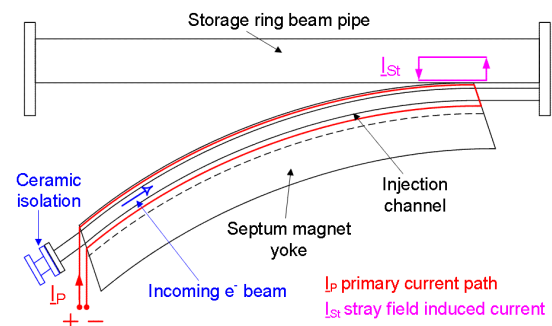


Figure 4: Schematics with ceramic insulation in injection.

RESULTS OF B-FIELD MEASUREMENTS

All qualitative measurements of stray fields and asymmetries were limited by the resolution of the measurement equipment and sensitivity of the procedures. Mechanical stability of the sensor is highly influential.

The limited cross section and few windings of the field probe led to low induced voltages, particularly with a tiny probe in the injection channel gap (8 turns, 1.1 mm diameter). The smallest applicable voltage range of the oscilloscope is 1 mV. Eddy currents in the adjacent storage ring beam pipe are difficult to measure. The

pulsar unit in the test stand produced either 58 μ s short or 149 μ s long pulses. Initially, the septum flanges were isolated and a long current pulse was used. The integral pulsed B_y -field for beam deflection was detected (Fig. 5).

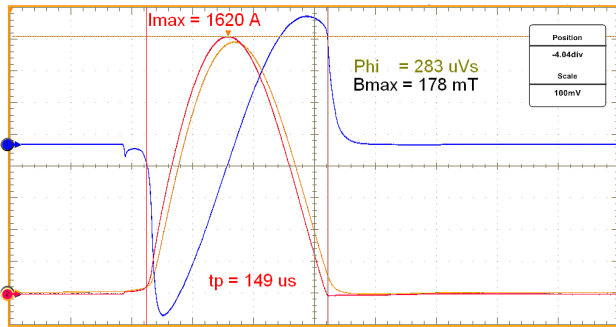


Figure 5: Pulse current, pick-up voltage, integrated flux.

Next, deflecting B_y -field was acquired point by point in the injection pipe with a transversal scan. A tiny probe was placed well inside the gap. The x-y plot shows the normalized B_y -field. Its deviation was only 1.8 % (Fig. 6).

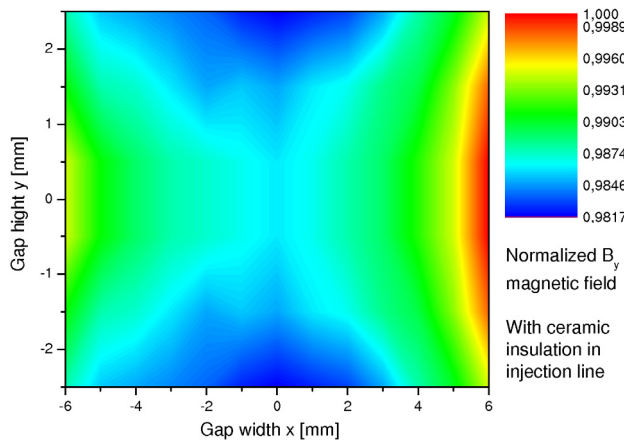


Figure 6: x-y plot of magn. field B_y inside injection pipe.

Copper cables between the flanges and a short pulse excitation were used, similar to the initial installation. Then the pulse current length was extended. At last the B_y -field was measured with isolated flanges. Fig. 7 shows that a short current pulse together with a secondary load reduces the B_y -field by 30 % near the septum rail.

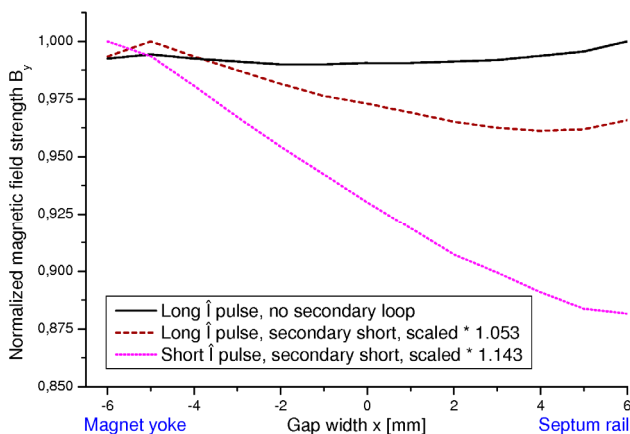


Figure 7: Horizontal B_y in vertical center of injection pipe

The effect is smaller with a longer current pulse and is nearly avoided without secondary load. The reasons for the beam distortions are non-typical pulsed multipoles in x and y direction. These are based on different effects: eddy currents and a secondary low impedance load.

SEPTUM PERFORMANCE REVIEW

The accumulation process is still influenced by very small remaining stray fields in the storage ring beam pipe. These were not measurable in the test stand because of too small probe signals. The highest repetition rate for beam injection was empirically tested and was increased from 0.2 to 2 Hz. This reduces the filling time to the storage ring target current before ramp-up. Before inserting the ceramic isolation into the injection channel, it was rather tricky to fill a beam current of more than 125 mA at only 0.2 Hz repetition rate, while now 200 mA are regularly accumulated with 2 Hz clock.

Although fluorescent screens have no true angle indication, after implementing the described changes, the injection angle seemed to be zero, straight ahead into the storage ring, not with an outward directed angle as before.

CONCLUSION

This plain, neat construction of a pulsed septum magnet offers a sound solution when correctly integrated. The common characteristic of pulsed septa of different types, e.g., eddy current or opposite current is that the excitation by short current pulses causes pulsed multipole fields that can neither be neglected nor easily compensated. Eddy currents are driven with their own time constants. These maybe overcome with innovative designs of DC septa [6].

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