EFFECTIVENESS OF A SHIELDING CABINET ON THE STORAGE-RING SEPTUM MAGNET OF TAIWAN LIGHT SOURCE

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Abstract

To avoid a parasitic magnetic field in the stored beam, the pulsed-magnet system of Taiwan Photon Source (TPS) requires the stray field to be minute: the stray field from the storage-ring (SR) injection septum is required to be less than 0.1 % of the main field in the gap. The most common method to protect against a parasitic magnetic field is to use a highly permeable and conductive material, such as mu-metal. A 300-ms half-sine-wave pulse up to a current maximum 9922 A is supplied to a septum and results in an eddy-current loss in a magnet and a conductor during rapid charging of a magnet. Competition between an eddy-current effect and the magnetic permeability would produce a complicated phenomenon inside the magnetic-shielding screen and affect the shielding performance. We examined the performance of magnetic shielding of a shielding screen with OPERA 2D for varied geometry and thickness of the screen.

INTRODUCTION

Taiwan Photon Source requires highly precise and stable pulsed magnets for injection in the top-up mode. In the design of the storage ring, two septum magnets and four kicker magnets (each of length 0.6 m) are used in a full 12-m straight section to inject the electron beam into the storage ring [1][2]. If a 1.6-m AC septum magnet is in use, it must provide an angular electron-beam deflection 75.5 mrad. As the power-supply load for this AC septum is too heavy to manufacture, a DC septum is designed to decrease the driving voltage and current of the power supply from the AC septum. Figure 1 shows the layout of AC and DC septa magnets. The required magnetic fields for the AC and DC septa are 0.83 and 0.94 T, respectively; parameters of magnets appear in table 1.

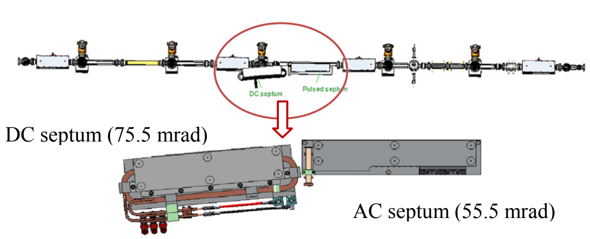

Figure 1: Layout of AC and DC septa for TPS storage injection.

Table 1: Parameters of Ring-injection Septa

Ring Injection	AC Septum	DC septum
Bend angle /mrad	55.5 /66.5	75.5
Mag. aperture /mm	22×15	22×18
Length /m	0.8	0.8
Nominal field /T	0.694 /0.831	0.94
Nominal current /A	8281 / 9922	597
Pulse shape	half sine	- (DC)
Pulse duration /μs	300	- (DC)
Inductance /mH	2.85	3.47
Capacitance / μF	3201	--
Driving voltage /kV	0.247 / 0.296	0.00429
Leakage field (AC)	< 0.1 %	< 2.5 G
Field error /%	~0.5 (p-p)	--

DC SEPTUM MAGNET

A DC septum is designed to resemble a dipole magnet (Figure 2); the central magnetic field is required to be 0.94 T. The smallest distance between the DC septum magnet and the storage-ring vacuum chamber is 15 mm; this limited space must contain magnetic shielding screens. The distance between a DC septum magnet and an electron orbit is gradually decreased, and the smallest distance is downstream from the magnet; the stray field from a magnet of length 0.6-0.8 m would thus have the greatest influence on the circuiting beam. To avoid a parasitic magnetic field affecting the stored beam, the integral stray field is required to be less than 50 μT m from the magnet of length 0.6-0.8 m. The stray field must hence be less than 2.5 G. Magnetic shields of two types were included in a calculation of the magnetic-field shield; one has the characteristic of a large magnetic saturation and the other one has the characteristic of a large permeability. (A BH curve is found in reference [3].) The stray field was calculated at the center of the beam orbit for varied shield metal and thickness (figure 3). The results demonstrate that the shield sheet with the characteristic of a large magnetic saturation would attenuate the magnetic field more than that with large permeability. The reason is that, when a shielding material is saturated, it cannot stop the penetration of magnetic flux. A single thick sheet can decrease the field to only 8 G for an attenuation 0.1 % of field ratio, which fails to satisfy the required criterion, 2.5 G.

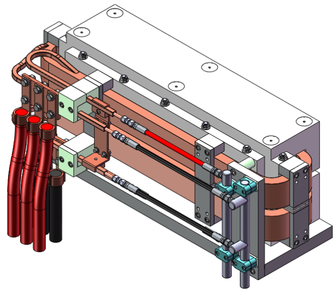

Figure 2: DC septum for storage-ring injection.

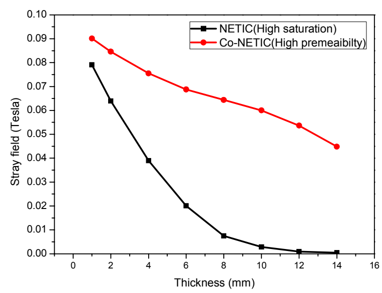

Figure 3: Estimated stray field versus thickness.

When a single thick shielding screen is placed too near the magnetic field, the shielding screen can become easily saturated. Magnetic flux from the saturated shielding screen can affect the magnet and cause distortion of the magnetic centre field. For four 10-mm magnetic shielding screens calculated near the DC septa magnet, the results appear in figure 4. A square shielding screen is the most easily saturated type; the pole of a magnet near the square shielding screen is much more readily saturated than a curved shielding screen (figure 5). The magnetic field distributions among four geometries prove that, when a curved shield is in use, the centre magnetic field is less influenced and the stray field can be less than for use of a square screen. Using a curved or square thin shield screen (thickness 0.36 mm) would cause no difference to the center magnetic field and the stray field.

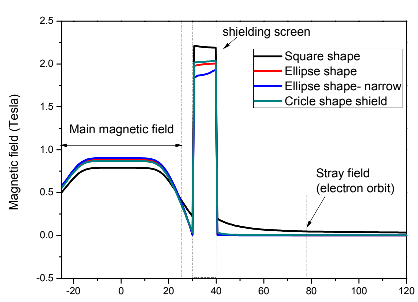

Figure 4: Distribution of magnetic field versus geometry of a magnetic shield sheet (thickness 10 mm).

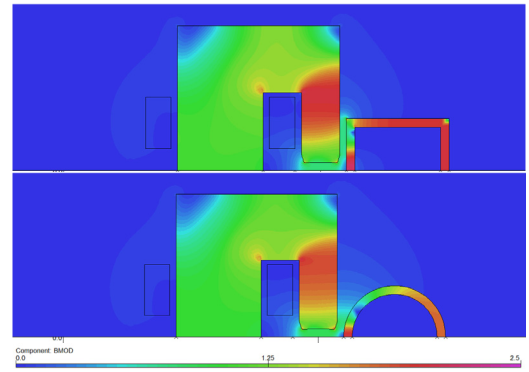

Figure 5: Distribution of magnetic flux versus geometry . (magnetic shield sheet of thickness 10 mm)

A multi-screen that consists of varied shielding characteristics can provide efficient magnetic shielding. Combinations of two shielding screens were considered for this application. An outer layer near the large magnetic field requires large saturation to prevent the penetration of magnetic flux. The inner shield screen requires large permeability to suppress the stray field. One important constraint concerns space; the distance between the chamber and the storage-ring vacuum chamber is only 15 mm. A 5-mm NETIC shield screen (large saturation characteristic) must thus be placed near the magnetic field and a 5-mm thick NETIC sheet can prevent an inside CO-NETIC sheet from magnetic saturation. The CO-NETIC sheet has permeability 450,000 and can maintain the field inside the shielding cover less than 2.5 G. For optimized shielding screens, elliptic shielding screens with two materials can minimise the magnetism less than 2.5 G at the beam-orbit position; the total space for the two shield screens is 12 mm.

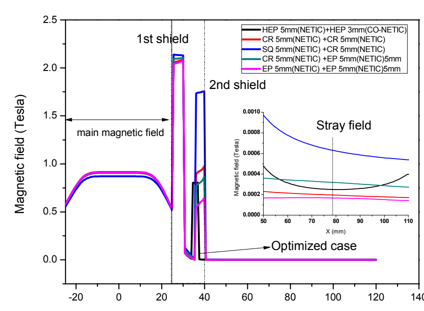

Figure 6: Various magnetic-field distributions for two magnetic-shield screens. (screen shapes -- CR circular, HEP horizontal elliptical, and SQ square)

AC SEPTUM MAGNET

A 0.8-m AC septum magnet is laminated from 0.3-mm CSC1300 silicon steel to avoid flows of eddy currents on the magnets. A septum conductor plate of thickness 1 mm is designed to separate the main field in the gap region from the zero fields in the external region. Inside the magnet, the required magnetic field is 0.81 T; on the other side of the conductor plate, the leakage field in the electron-circuiting orbit should be less than 0.1 % of the peak field. A half-sine-wave pulse of width 300 μs supplies the AC septum conductor; because of the short voltage pulse the conductor would experience a strong eddy-current effect. The AC septum was calculated with OPERA 2D; a detailed septum cross section is illustrated in figure 7. The model was performed in a transient time-varying analysis (TR) so that a current diffusion and eddy current effect in the conductor were calculated. The thickness of the magnetic shielding screen is 0.36 mm due to the tight space arrangement.

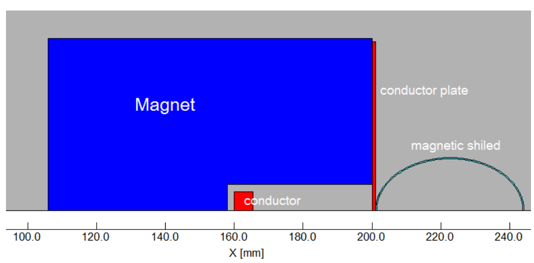

Figure 7: 2D model of a SR AC septum.

The eddy-current effect on the distribution of magnetic field can be seen in figure 8. When the eddy-current effect appears on the AC septum conductor, it improves the homogeneity of the magnetic field inside the magnet, and decreases the leakage field near the conductor region by factor of 5.5. Another design issue is based on the contact surface area of the septum plate. Through vibration caused by a short pulse, the conductor plate experiences a strong vibration, so must be fixed rigidly on the magnet. The larger is the contact surface area, however, the greater is the magnetic leakage generated. The leakage field depends on the length of the conductor plate as shown in figure 8. The conductor length, 12 mm, can decrease the stray field (electron orbit) to 0.5 % of the main field in the gap. This is the best performance of 0.36mm shielding screen .

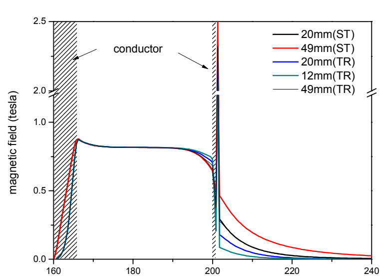

Figure 8. Length of conductor on the eddy-current effect and the magnetic-field distribution. (TR: transient time-varying analysis, ST: static analysis)

Magnetic shielding screens of varied shape and material were examined. Because the thickness is 0.36 mm, the shielding screen must be a thin sheet. The stray-field distributions or the stray field varying with time do not alter in shielding screens of varied shapes, but the peak of the stray field depends on the shielding material, due to the eddy-current effect on the shielding screen. The time lag, between the peak of the stray field and the magnetic field, for use with characteristics high saturation and high permeability in the shield screen is 60 μs and 15 μs, respectively.

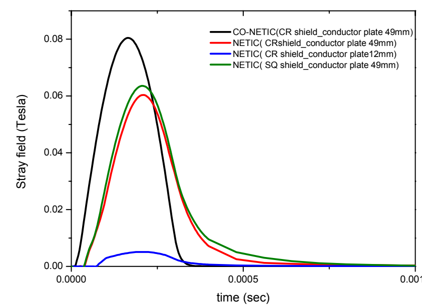

Figure 9: Temporal history of the stray field at the beam-orbit position.

CONCLUSION

The magnetic shielding screen for the pulsed septa magnets of the storage ring is designed to suppress a stray field at the electron-orbit center to be less than 0.1 % of the main field in the gap. For a DC dipole septum, the magnetism of the stray field is minimized when characteristics of high permeability and high saturation are used in combination with curved magnetic-shielding metals. An AC septum magnet is supplied with a power pulse of 300-μs half-sine wave. The eddy current on the septum conductor plate affects the stray field and the field homogeneity. A shielding material of thickness 0.36 mm with high-saturation characteristics is used. The septum conductor must have as small a length as possible to decrease the magnetic flux released from the copper conductor, but the contact surface should be rigidly fixed on the magnet. With a design of the shape of the magnetic shield and its thickness for a specified material and septum conductors, the leakage field can be controlled within 0.1 % of the leakage field.

REFERENCES

[1] C. H. Chang, *et al.*, " Design consideration for the TPS pulsed magnets system", PAC2009, Vancouver, Canada, May 2009.
[2] C. K. Chan, *et al.*, "Design of TPS injection system", PAC2009, Vancouver, Canada, May 2009.
[3] http://www.magnetic-shield.com/images/products /alloys/B-H.pdf.