MEASUREMENT OF INJECTION SYSTEM OF AC SEPTUM MAGNETS FOR TPS STORAGE RING

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Abstract

Taiwan Photon Source (TPS) is a 3-GeV third-generation light source that will be operated in a top-up injection mode. The leakage field of the septum magnet will have a huge impact on the injection performance. The septum magnets, which are parts of the injection system, comprise one AC and one DC mode magnets. The AC septum magnet was designed and constructed by the NSRRC magnet group. To verify the quality of the magnetic field and the distribution of the leakage field, a search coil probe and printed-circuit technology for long-coil probe measurement systems have been developed and implemented. This paper describes the system to measure the magnetic field, the results of mapping the magnetic field and the field-shielding performance of the AC septum magnet.

INTRODUCTION

The injection system of TPS consists of septum magnets of two types and four kicker magnets. They are installed in the first 12-m straight section to inject an electron beam into the storage ring [1,2]. Figure 1 shows the layout of the TPS storage-ring injection. To provide a low-emittance and highly brilliant beam, TPS decided to operate in a top-up injection mode; as a result, the strength of the leakage field of the septum magnets was designed to be less than 0.1 % of the main field (B_0) at the circulation centre of the beam orbit. To achieve this goal, we tried to adjust the cutting gap of the coil plate along the longitudinal direction, and applied μ-metal of various thickness and various materials to shield the storage-ring vacuum chamber to improve the field-shielding performance.

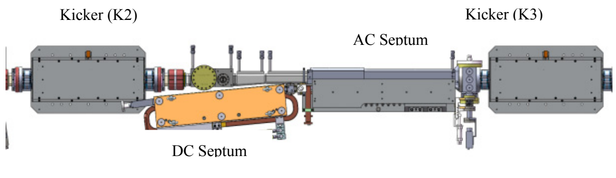

Figure 1: Layout of the AC and DC septum magnet for TPS storage-ring injection.

DESIGN OF AC SEPTUM MAGNET

AC septum magnets have two fundamental types – direct drive and eddy current. Based on TOSCA 2D simulated results, the direct-drive type operating with a power supply of half-sine waveform was chosen for the TPS project. The AC septum of direct-drive type magnet was designed and constructed by the NSRRC magnet group. Table 1 shows the parameters of the AC septum magnet.

Table 1: Parameters of AC Septum Magnet

Parameters	**Unit**	**Specifications**
Repetition rate	Hz	3
Energy	Gev	3.0
Bend angle	mrad	55.5
Magnet gap	mm	15
Length	m	0.8
Nominal field	T	0.694
Bend radius	m	14.4144
Nominal current	A	8281
Pulse shape		half sine
Pulse duration	us	300 us
Leakage field ratio	%	< 0.1

A core magnet of length 0.8 m is made of silicon steel (0.3 mm, CSC1300) lamination to avoid flows of eddy currents on the magnets.

To decrease the leakage field, we adjusted the cutting gap of the coil plate along the longitudinal direction; the cutting gaps are 40, 20 and 10 mm, labelled Coil-40, Coil-20 and Coil-10 respectively. These coil plates, shown in Fig. 2, have the same dimensions -- thickness 1mm, height 98 mm and length 890 mm.

According to the results of measurements of the magnetic field, the leakage integral field ratio (leakage field/B_0) of Coil-10 is better than that of the others.

If the vacuum chamber of the storage ring is not covered with μ-metal, the leakage field ratio can attain 0.81 %; this value is beyond specification. In our design, we attempted to use μ-metals of two kinds, Co Netic AA and Netic S3-6 [3], to decrease the leakage field.

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Based on the results from TOSCA 2D simulation and from measurement of the magnetic field, we chose Netic S3-6 for shielding. The space from the magnet wall to the vacuum chamber of the storage ring is less than 3 mm; details appear in Fig. 3. If we consider the SUS chamber of the septum magnet, the coil plate and the insulator thickness, μ-metal of two thicknesses (0.5 mm and 0.76 mm) can be used. With the use of μ-metal 0.5 mm thick, the ratio of the leakage field can be decreased to 0.02 %, which satisfies the specification.

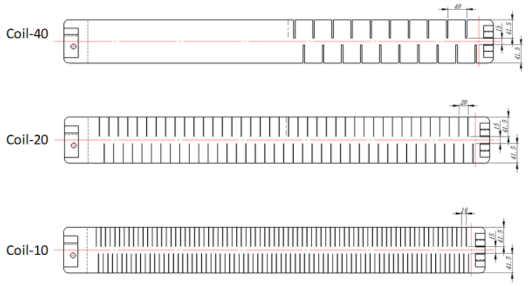

Figure 2: Cutting gaps of coil plates of an AC septum magnet.

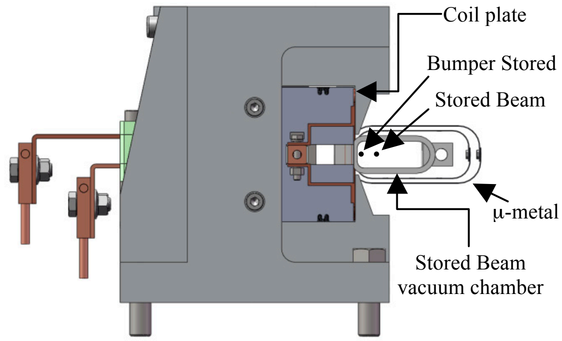

Figure 3: Cross section of an AC septum magnet.

MEASUREMENT SYSTEM

The measurement system consists of a pulse generator (DG535) and a digital oscilloscope (TDS3054B), shown in Fig. 4. The pulse generator provides two independent pulse outputs to a high-voltage power supply and a digital oscilloscope. The repetition rate of the output is 3 Hz. The digital oscilloscope has four independent channels, respectively using a BNC cable connected to a current transform (CT), a search coil or a long coil (CV) and a trigger signal.

The search coil and long coil use the same passive RC integrator, which is composed of a 2.2-nF capacitor and a 1-MΩ resistor. From equation (1), the sensitivity of the search coil is 37.35 G/mV, and of the long coil is 12.94 G mm/mV.

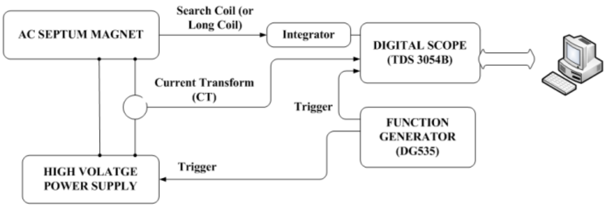

Figure 4: Schematic diagram of the AC septum magnet measurement system.

$$\mathbf{V_o} = \frac{\mathbf{AB_o}}{\boldsymbol{\tau}} \qquad (1)$$

Here A is the area of the coil sensor, and τ is the RC time coefficient of the integrator, and B_o is the peak field of the septum magnet.

The long loop-coil probe, which uses printed-circuit technology to lay out the curve along the longitudinal axis, has been designed with two curve probes. Probe 1 measures the on-axis magnetic field of the septum magnet that is the bending curve along the magnet. Probe 2 measures the leakage magnetic field of the bumper stored and the stored beam that is a straight curve along the magnet. The two probes have one turn loop of length 1000 mm and width 1.7 mm.

The diameter of the search coil is 5 mm, from winding thirty turns of enamel wire (thickness 0.5 mm). The coil was installed in a fibreglass probe and mounted on a stage movable in three dimensions; the movable range in the longitudinal axis is 600 mm, but 300 mm in both transverse and vertical directions. The definition of coordinates of the search-coil measurement system is shown in Fig. 5. The Z-axis marks the direction of the stored electron beam, the X-axis marks the transverse direction and the Y-axis marks the vertical direction; x,y,z = 0 defines the centre of the magnet.

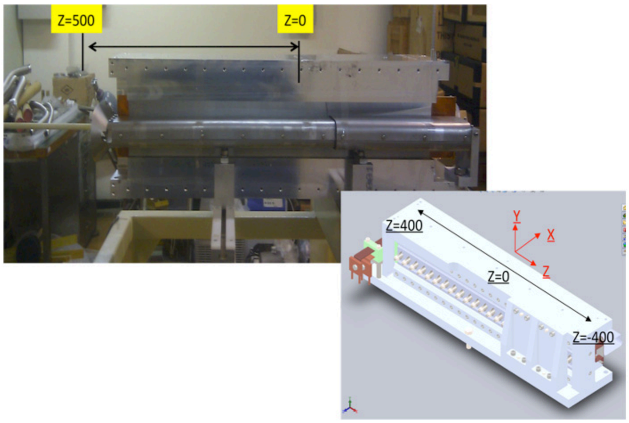

Figure 5: Definition of coordinate axes of the search-coil measurement system

FIELD MEASUREMENT RESULTS

The results of the field measurements from the long-coil system are summarized in Table 2. In the worst case, the septum magnet uses the Coil-40 coil plate and without μ-metal shield; the ratio of leakage field has a maximun value compared with other conditions. When Coil-10 coil plate and μ-metal of various thicknesses were used, we found that the leakage field ratio had almost the same values.

Table 2: Result of Integral Field Ratio in Various Conditions

(a) without μ-metal

Coil label	Unit	Bumper Stored	Stored Beam
Coil-40	%	1.9	0.63
Coil-20	%	1.4	0.4
Coil-10	%	0.81	0.18

(b) μ-metal thickness = 0.5 mm

Coil label	Unit	Bumper Stored	Stored Beam
Coil-20	%	-0.043	0.03
Coil-10	%	-0.02	0.01

(c) μ-metal thickness = 0.76 mm

Coil label	Unit	Bumper Stored	Stored Beam
Coil-20	%	-0.041	0.02
Coil-10	%	-0.02	0.01

Field measurement results from the search-coil system are summarized in Figs. 6-8.

For the vacuum chamber without a μ-metal shield, the leakage field along the longitudinal axis for varied coil plates are shown in Fig. 6. The Coil-10 with leakage field shielding performance is better than the others.

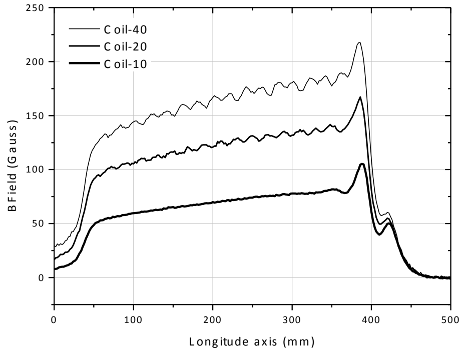

Figure 6: Variation of leakage field distributions with coil plate.

For other cases of magnet with the Coil-10 coil plate, the variation of distribution of the leakage field with the thickness of μ-metal is shown in Fig. 7. The leakage field was effectively eliminated within the range of the magnet core from 0 to 400 mm. The thickness 0.76 mm performs better than 0.5 mm.

To decrease the leakage field from z = 400 to 500 mm, we adjusted the position between the end of μ-metal to the end of the magnet core. As the distance shifted 3 cm, the leakage field decreased to similar values of the magnet core, as shown in figure 8. Based on this result, the range of the leakage field might come from the end of the coil plate.

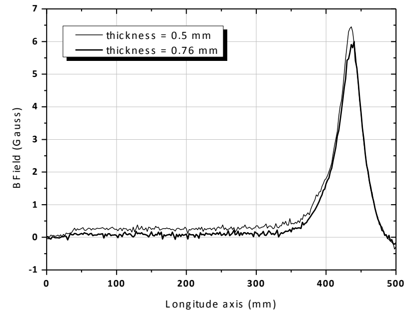

Figure 7: Variation of the distribution of the leakage field with thickness of μ-metal.

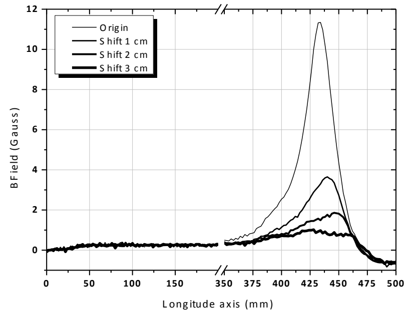

Figure 8: Variation of the distribution of the leakage field with shift of the end of the μ-metal to the magnet core.

CONCLUSION

The cutting gap of the coil plate can effectively decrease the leakage field; the thickness of the μ-metal has less influence on the leakage field.

Another source of leakage field source might be induced from the end of the coil plate. In the next stage, we will redesign the coil plate and improve the leakage field at the end of the magnet.

REFERENCES

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[2] J.C. Huang et al., "Shielding Effectiveness of a Shielding Cabinet on Taiwan Light Source Storage Ring Septum Magnet", PAC2010, Vancouver, Canada, May 2010

[3] http://www.magnetic-shield.com/