DESIGN CONSIDERATIONS FOR THE TPS PULSED MAGNETS SYSTEM

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Abstract

The Taiwan photon source (TPS) requires highly precise and stable pulsed magnets for operation in the top-up mode of injection. Ten pulsed magnets are used for injection and extraction of the electron beam in the booster synchrotron and the storage ring. Four septum magnets outside the vacuum and with a thin vacuum chamber are chosen for simple maintenance in air; these magnets of eddy-current type are operated with a full sine-wave current pulse of duration 300 μs at 3 Hz. The leakage field of the septum magnet at the orbit of the circulation beam is calculated to be less than 0.1 % of the main field in the gap. Two in-vacuum kicker magnets for the booster and four identical kicker magnets for the storage ring are adopted. Considerations for the design of these kickers are described to minimize the field errors; their field characteristics are presented.

INTRODUCTION

The electron beam of the booster synchrotron is injected from the 150-MeV linear accelerator and accelerated to operating energy 3 GeV, with a repetition rate 3 Hz. The beam at full energy is then transferred through the transfer line to the storage ring. According to the booster design, the electron beam is injected into the booster synchrotron along the axis, involving an injection septum (length 0.8 m) and a quick kicker magnet (length 0.5 m) to place the beam on that booster axis. After the electron beam is ramped to energy 3 GeV, the beam at full energy is extracted from the booster in one turn period using a kicker magnet (length 1.2 m) and a septum magnet (length 1.6 m).

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 straight section (length 12 m) to inject the electron beam into the storage ring. Four kicker magnets in the straight section generate a deflection 4.5 mrad; they can kick the stored beam a distance 16.2 mm from orbit center toward the septum edge, and then bump the stored beam back to the orbit center. While the electron beam is being injected into the storage ring, the shutters of the photon beam-line remain open. For reasons of radiation safety, the pulsed magnet should be designed to be highly stable for operation of injection in the top-up mode. The main parameters of the pulsed magnets for the storage ring operating at 3 GeV are given in table 1.

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Table 1: Main parameters of the pulsed magnets for the storage ring.

Parameter		Kicker	Septum
Number	unit	4	2
Magnetic length	mm	600	800
Bend angle	mrad	4.5	65.45
Vertical aperture	mm	35	13
Horizontal aperture	mm	90	20
Peak field	Tesla	0.075	0.82
Peak current	A	2150	9792
Current pulse	μs	5.18	300
Current shape	sine	half	full
Pulse repletion rate	Hz	3	3
Peak field stability	%	0.1	0.1

KICKER MAGNET DESIGN

In the booster synchrotron, injection of the electron beam involves a kicker magnet of length 0.5 m, and extraction a kicker magnet of length 1 m. The booster kicker works with only single-turn operation. The pulse duration of the kicker magnet is required to be less than one revolution period, 1.65 μs. The injection kicker is operated at 150 MeV for an energy and deflection smaller than for the extraction kicker operating at 3 GeV. The main parameters of the kicker magnets for booster operation are given in table 2.

Table 2: Main parameters of the booster kicker magnets.

Parameter		Injection Kicker	Extraction Kicker
Number	unit	1	1
Magnetic length	mm	500	1000
Bend angle	mrad	30	4
Beamaperture(hx v)	mm	35x20	35x20
Peak field	Tesla	0.03	0.0396
Field waveform		Flat top 1000ns	Flat top 1000ns
Field rise time	ns	x	150
Field fall time	ns	150	x
Peak current	A	383	632

The booster kicker magnets are of window-frame ferrite inside a vacuum vessel. Ferrite of type CMD 5005 Ni-Zn of magnetic ceramics and for high-vacuum application is used. A simulation of the field of the pulsed magnet was performed with nonlinear transient software (OPERA-2D). The distributions of the maximum field of the booster kicker magnet were simulated with a 1.3-μs rectangular current waveform. The magnet geometry is optimized at a gap width 20 mm and yields field homogeneity within a range 35 mm. The distribution of the maximum field along the transverse direction is shown in Fig 1. The excitation current has a waveform with a 1.3-μs rectangular pulse. To avoid difficult constraints on the time jitter, rise and fall periods 150 ns are considered to be conservative. For reliable operation, the kicker power supply operates at a maximum charging voltage less than 25 kV. Injection and extraction kickers are capable of operating at currents up to 632 A, with a maximum rate corresponding to 1000 ns with fall and rise periods 150 ns to match the booster revolution period.

The kicker magnet for the storage ring is optimized according to its strength of magnetic field and its length. The maximum strength 9.6 mrad of the kicker is estimated only for on-axis injection during commissioning. The maximum field distributions in the central region are calculated with a 5.18-μs half-sine current waveform. The waveform of the excitation current is a 5.18-μs half-sine pulse up to 2150 A. The field distribution along the transverse direction in the middle plane is calculated as shown in Fig. 1. The homogeneity remains within 0.5 % in the region $x = \pm 33$ mm.

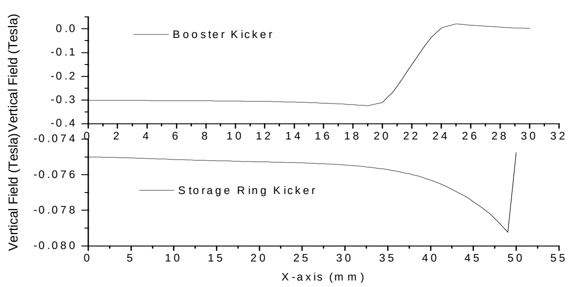

Figure 1: The magnetic field distributions of booster kicker and storage ring kicker along the transverse direction. 0 is the center of magnet.

A prototype of the kicker magnet for the storage ring is shown in Figure 2. The kicker magnet is a window-frame ferrite magnet with transverse symmetry; the core material of this magnet is ferrite of type CMD 5005 Ni-Zn. A ceramic vacuum chamber is used in the inside housing of the magnet; the aperture is 90 mm x 33 mm and the length of the ceramic is 750 mm. The inner surface of the ceramic chamber is coated with titanium to carry the image current of the beam. The coating thickness has been evaluated from the field attenuation, the powers deposited from the beam and from excitation [1]. A 2-μm coating was eventually selected. As field errors are generated by eddy currents due to the uniformity of the coating, a uniform coating would adversely affect the field uniformity of the kicker.

To compensate deviations of the field strengths, each kicker is to be operated with its own individual power supply. The mismatch between kicker pulses and the time jitter of the pulsed-magnet system should be minimized. The waveform of the timing jitter current with the pulsed power supply less than 3 ns has been running at the Taiwan light source in top-up operation [2]. To decrease the horizontal closed distortion, an alignment accuracy less than 5 μrad of the kicker magnet is considered. According to the operation of injection magnets performed for the Swiss light source, a precise alignment was required to fine-tune the beam orbit based on the beam operation [3]. A mechanism with fine adjustment is designed to eliminate field errors in the vertical plane.

Figure 2: The prototype of the storage ring kicker magnet.

SEPTUM MAGNET DESIGN

The septum magnets of similar design used for injection and extraction of the booster and the storage ring are C-type dipole magnets, and are located at the end and the start of the transfer lines. A magnetic length of 1.6 m and strength 0.82 T is required to produce a bending angle 130 mrad for normal operation. The booster injection septum with smaller field strength is required at 150 MeV. A booster injection septum (length 0.8 m) is operated with magnetic field strength 0.2 T. The main parameters of the septum magnets for booster operation are specified in table 3. The septum magnet is of C type, laminated and operated in air. The configuration of the septum magnet is shown in figure 3. The septum plate with the vacuum chamber is to be movable in a small range 3-5 mm to decrease the bumper distance of the kicker.

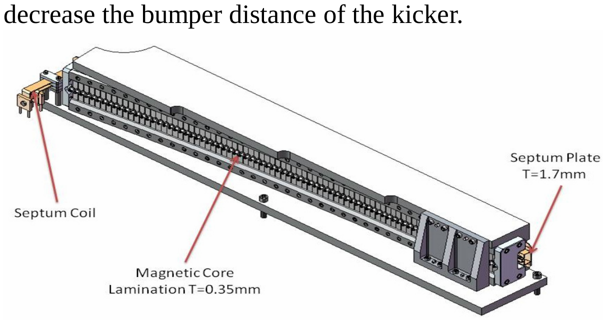

Figure 3: Configuration of septum magnet.

The septum magnet with a gap of width 13.5 mm is considered for the field simulation. It is desirable to maintain the exciting current under 10000 A and to decrease the EMI wave propagation. Because these septum magnets are located near the orbit of the beam, a stray magnetic field would disturb the operation of the stored beam. To separate the main field in the gap region from the zero fields in the external region, only a thin septum plate of thickness 3.5 mm is permitted. The leakage field of a septum magnet at the orbit of the circulating beam is desired to be less than 0.1 % of the main field in the gap [4]. The septum magnet is operated with a 300-μs pulse at repetition rate 3 Hz. A full-sine-wave current pulse is chosen to make a long tail in the stray field decrease rapidly, so as to decrease effectively the maximum stray field [5]. The main parameters of septum magnets for the booster operation are given in table 3.

Table 3: Main parameters of the booster septum magnets.

Parameter		Injection Septum	Extractio n Septum
Number	unit	1	1
Magnetic length	mm	800	1600
Bend angle	mrad	314	153
Beam aperture (hx v)	mm	20x13	20x13
Peak field	T	0.2	0.96
Field waveform	Sine	Full	Full
Septum thickness	mm	3.5	3.5
Stray field outside septum		<30 μTm	<30 μTm
Peak current	A	2317	11123

Software (OPERA 2D) was used to simulate the pulsed field of the septum with or without magnetic screens. The simulated result of the stray field outside the septum plate is shown in figure 4. The leakage field was in the range 3 – 60 G. To decrease the stray field, an additional magnetic screening sheet (thickness 0.5 mm) is enclosed between the septum magnet and the vacuum chamber. The maximum leakage field (1 G) from the septum magnet with the shielding sheet is found to be significantly decreased as shown in figure 4. Figure 5 show the leakage field at various times; the decay time of the stray field is evidently decreased. The simulated stray fields at the bump beam position (x=3 mm) are about 1 G, and on the stored beam orbit center (x=19.92 mm) about 0.2 G.

CONCLUSIONS

To achieve a precise and stable magnetic field strength for operation in the top-up mode of injection, all aspects of design of pulsed magnets have been considered. The septum magnet with a conductor plate of thickness 1.7 mm and a magnetic shield sheet of thickness 0.5 mm are permitted to separate the main field in the gap region from the zero fields in the external region. The results of simulation show that the stray field outside the septum edge is much less than 0.1 % at any time. An appropriate pulsed power supply with rectangular and half-sine current shapes for the kicker magnets, respectively, is intended to provide a reliable operation. Fine adjustment of the kicker magnet and the movable septum are considered based on measurements of the beam.

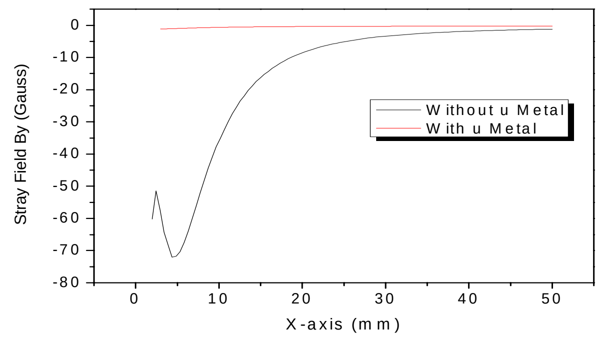

Figure 4: The stray field distribution outside the septum magnet are calculated with/without the shielding sheet.

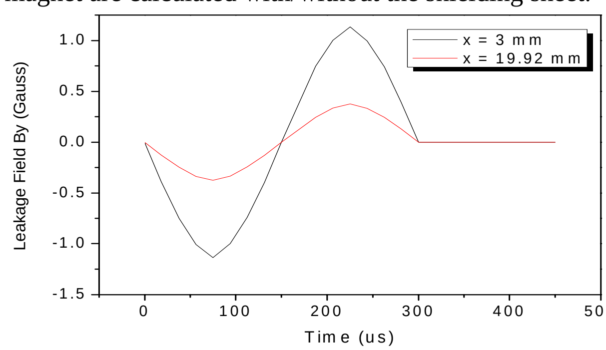

Figure 5: The simulated stay fields in the decay time are shown at the bump orbit position and the stored beam orbit center.

REFERENCES

[1] C.K. Chan, et al., "Design of the TPS injection system PAC2009, Vancouver, Canada, May 4-8 2009"
[2] Chyi-Shyan Fann, Justin –P, Chiou, San-Yuang Hsu and Kou-Bin Liu "A Kicker pulse power supply with low jitter" Proc. EPAC2004, pp 1387-1389.
[3] C. Gough, M. Mailand, "Septum and kicker systems for the SLS" Proc. PAC2001, pp3741-3743.
[4] C. H. Chang, C. S. Yang et al., "Design of the pulsed magnet for TPS" Proc. EPAC 2008, pp3514-3516.
[5] D. Shuman, W. Barry, S. Prestemon, R. Schlueter, C. Steier, G. Stover, LBNL, Berkeley, CA, USA "Stray field reduction of ALS eddy current septum magnets" Proc. PAC 2005, PP3718-3720.