DESIGN OF PULSED MAGNETS FOR THE TAIWAN PHOTON SOURCE

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Abstract

The Taiwan Photon Source requires highly stable pulsed magnets for operation with injection in the top-up mode. An injection of the electron beam into the storage ring is performed with a septum magnet and four identical kicker magnets. All pulsed magnets are designed for injection into the 3-GeV storage ring. The kicker magnet is excited with a 5.18-μs half-sine current waveform. Here we describe the design of the kicker to minimize field errors. A septum magnet outside the vacuum is chosen to facilitate maintenance. The leakage field of the septum magnet at the orbit of the circulating beam is calculated to be less than 0.1 % of the main field in the gap. The septum magnet with a stainless-steel vacuum chamber (thickness 0.4 mm) is tested to operate at 2 Hz. The field performance, stray fields and the effects of the eddy current on the septum magnet are presented.

INTRODUCTION

The Taiwan Photon Source (TPS) is designed to provide a highly stable and ultra-bright beam of photons from a 3-GeV storage ring. For full utilization of the capability of the photon source by users, the TPS has established the operation with injection in a top-up mode, similar to operation of the 1.5-GeV storage ring in Taiwan Light Source [1]. For the operation of injecting a low-emittance beam, the pulsed magnets should be designed to allow a precise and reliable operation to minimize perturbation of the stored electron beam and to ensure highly efficient injection. Due to consideration of the accelerator geometry, the booster synchrotron and the storage ring share the same tunnel, of circumference 518 m. A short transfer line connects the two rings. The electron beam is injected into the storage ring from the inner side of the ring through a septum magnet outside the vacuum. Fig. 1 shows the layout of the section of the TPS storage ring for injection. A septum magnet and four kicker magnets are used in a straight section (length 12 m) for injection of the electron beam into the storage ring. The principal parameters of the pulsed magnets for operation at 3 GeV are given in table 1.

Table 1: Main parameters of the pulsed magnet

Parameter		Kicker	Septum
Number	unit	4	1
Magnetic length	mm	600	800
Bend angle	mrad	4.501	65.45
Vertical gap	mm	35	15
Horizontal aperture	mm	90	20
Peak field	Tesla	0.075	0.82
Peak current	A	2150	9792
Peak voltage	V	4200	350
Current pulse	μs	5.18	300
Current shape	sine	1/2	1/2
Magnet induction	μH	2.2	2
Pulse repletion rate	Hz	2	2
Peak field stability	%	0.1	0.1

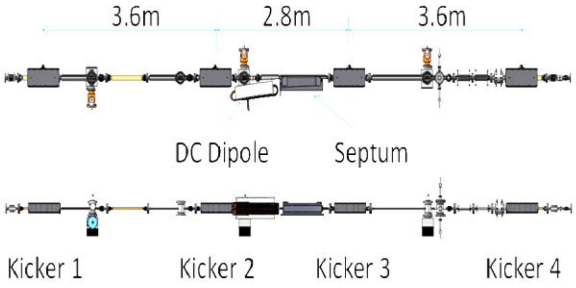

Figure 1: Layout of TPS storage ring injection section.

KICKER MAGNET DESIGN

Four kicker magnets in the straight section generate a 4.5-mrad deflection angle that can kick the stored electron beam a distance 16.8 mm from the orbit center, but the electron beams passing through these four kickers should be bumped back to the center of the orbit and kept stable to within tens of micrometers. As part of the design and construction of a precise and stable magnet, the kicker magnet has an optimized length and magnetic-field strength. The kicker magnet is a ferrite magnet with a window frame. The cross section of the kicker magnet is shown in Fig. 2. In the core material of the kicker magnet is used ferrite of Ni-Zn type (CMD 5005). As shown in Fig. 2, the core consists of the upper, lower and middle plates. The excitation waveform has a 5.18-μs half-sine pulse with a current up to 2150 amperes. Each kicker will be operated with an individual power supply to compensate the deviations of the field strengths [2]. The pulsed power supplies are placed in the storage ring tunnel beside the magnets. A pulse voltage below 5 kV is

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*This work was supported by the National Science Council of Taiwan under Contract No. NSC 96-2221-E-213-002-MY3
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designed so that there is no need of special insulation and for more reliable operation. The one-turn coil of low inductance is made of copper bar (thickness 5 mm) of which the dimension is 5 mm × 30 mm. The coil dimensions should maintain the tolerance within 0.05 mm and the magnetic inductance within 0.05 %. After being wound with Kapton tape for insulation between turns, the copper conductor will be potted with epoxy. To decrease the vibration of the coil and to improve the stability of the inductance during pulsed operation, the copper coil is glued onto the ferrite inner surface to hold the coil.

The ceramic vacuum chamber is used in the magnet inside the house; the aperture is 90 mm x 34 mm. The length of ceramic is 750 mm, and five ceramic chambers in total are used for four injection kickers and one transverse/longitudinal feedback kicker. The inner surface of the ceramic chamber is coated with titanium to carry the image current of the beam. The power dissipation due to this image current has been estimated. The coating thickness has been evaluated from the field attenuation, the power deposited in the beam, the power deposited in excitation and the cooling efficiency [3]; a coating of thickness 2 μm was therefore selected. The field errors will be generated by eddy currents due to a uniform coating. A uniform coating would thus adversely affect the field uniformity of the kicker.

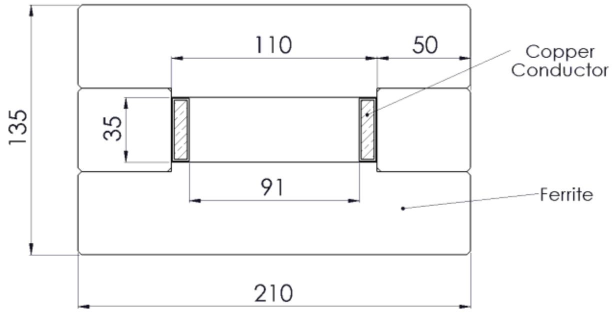

Figure 2: Cross section of the kicker magnet.

SEPTUM MAGNET DESIGN

To bend the injected beam into the storage ring, a magnet of length 1.6 m with magnetic field strength 0.82 T is required to produce a bend angle 130.9 mrad. To maintain a small power consumption of the septum magnet, a short septum magnet and a DC dipole magnet together produce the bend angle 130.9 mrad. Considering the space constraint between two kickers, injection into the storage is realized with a septum magnet of length 0.8 m and a DC magnet of length 0.8 m, with deflection angles both 65.45 mrad. A curved dipole magnet with a core of C type and gap width 16 mm has been designed to have a homogeneous field within a range 40 mm. The dipole magnet operates with a DC power supply and low-carbon solid steel is used for the yoke. Injection into the storage ring in a top-up mode requires a minute level of leakage field at the path of the stored beam. A septum magnet outside the vacuum is chosen to decrease the difficulty of pumping down to ultra-high vacuum in the storage ring [4]. The septum magnet is designed to have a homogeneous field in the gap and a small or zero leakage field outside the gap so that the circulating beam is unaffected.

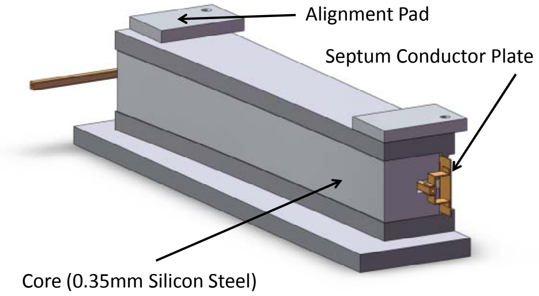

Figure 3: Configuration of septum magnet.

A thin septum conductor plate of thickness 2 mm is allowed to separate the main field in the gap region from the zero fields in the external region. The gap width 15 mm of the septum magnet is optimized to increase the injection efficiency. The septum magnet is operated with a 300-μs pulse at repetition rate 2 Hz. The leakage field at the orbit of the circulating beam is required to be less than 0.1 % of the main field in the gap. The field simulation of the septum magnet was performed with OPERA-2D software [5]. The core with a frame of C-type is made of laminated silicon steel of thickness 0.35 mm as shown in Fig. 3. The field distribution along the transverse direction is indicated in Fig. 4.

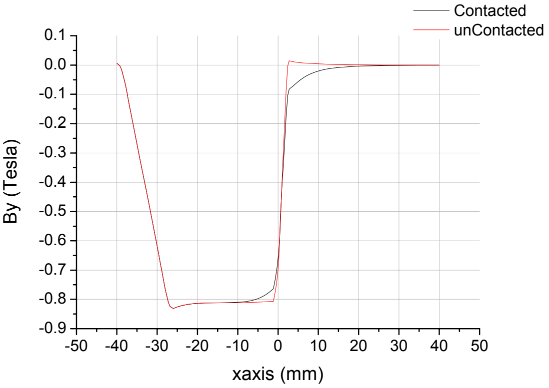

Figure 4: Calculated distribution of the field along the transverse direction with and without the conductor plate in contact with the pole edge.

To hold the thin septum conductor plate, a copper plate with a wider gap was attached on the front face of the iron pole, but the field strength in the gap near the pole edge was found to decrease significantly and to leak more stray field to the external region due to contact between the conductor plate and the iron pole. The field distribution along the transverse direction is calculated in Fig. 4.

To investigate the requirement of the magnetic field, the stray field was tested and measured on an existing septum magnet. Field measurements were performed with a search coil, of which the sensor is a 20-turn loop of diameter 5 mm. Fig 5 shows the measured profile of the magnetic field on the transverse axis of the septum magnet. The large leakage field is caused by the copper plate attached to the iron pole of the septum magnet. To eliminate the stray field, discrete slots along the longitudinal direction are used in the slots in the copper plate to narrow the current path of the copper plate. The current consequently flows in the middle region of the copper plate. The leakage field outside the septum then becomes small. Fig. 5 shows that the leakage field was in a range -0.2 % to 1.4 % before and after cutting the discrete slots. The leakage field can also be decreased with a magnetic screening sheet, for which purpose an additional thin magnetic screening sheet (thickness 0.5 mm) is circulated around the stored beam area for magnetic shielding. The maximum leakage field from the septum magnet with the shielding sheet is measured as shown in Fig. 5. Nearly 0.1 % of the peak field is observed 10 mm from the centre of the stored beam. The integrated stray field at x=10 mm is measured to be less than 0.0024 T-m.

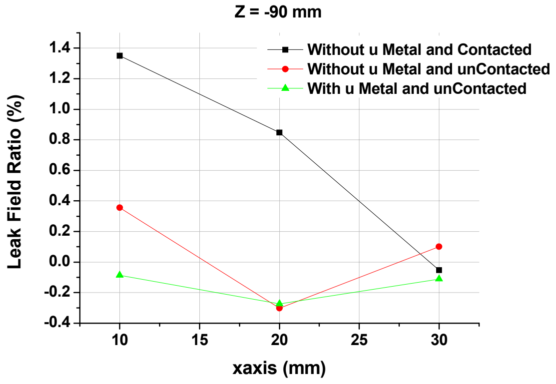

Figure 5: Ratio of leakage field from the septum magnet measured with and without the shielding sheet.

Inside the gap is a formed, curved, beam vacuum tube, made of stainless steel with wall thickness 0.4 mm. The vacuum chamber serves to conduct the electron beam. The vacuum tube is necessary for electrical insulation and can be grounded to avoid an accumulation of charge on the vacuum tube. The vacuum between the transfer line and the storage ring must be separated. Isolation between the BTS and the storage-ring vacuum is provided in the BTS line end with foil (Kapton, thickness 0.1 mm). Eddy currents are generated in the thin vacuum chamber. Field strength approximately 1 % peak was attenuated inside the vacuum chamber region. A small thermal heating causes the tube to rise to 45 ^{0}C in operation at 2-3 Hz. The effects of the eddy current on a thin vacuum chamber are minimized at a small repetition rate, 2 Hz.

CONCLUSIONS

The design of all pulsed magnets is optimized to achieve the precise magnetic-field strength for operation with injection in the top-up mode. The kicker magnet with a ceramic vacuum chamber is excited by a 5.18-µs half-sine current pulse. The design and construction of the magnet have been considered for stable operation. The septum magnet with a conductor plate 2 mm thick and a magnetic shield sheet 0.5 mm thick allow the main field in the gap region to be separated from the zero fields in the external region. The septum magnet with a vacuum tube is tested to operate at 2-3 Hz. Nearly 0.1 % of peak field is observed 10 mm from the septum plate. A vacuum tube of thickness 0.4 mm was selected to satisfy the field attenuation and excessive thermal heating loss at a small repetition rate, 2 Hz.

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