CONCEPTUAL DESIGNS OF MAGNET SYSTEMS FOR THE TAIWAN PHOTON SOURCE

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Abstract

The National Synchrotron Radiation Research Center (NSRRC) at Taiwan is designing a 3 GeV energy with ultra-low emittance storage ring for the new Taiwan Photon Source (TPS). The storage ring has a circumference of 514 m with 24 periods of a double-bend achromatic magnet system. The conceptual designs of each magnet family to be used in the storage ring are optimized for operation at an electronic energy of 3.0 GeV. This investigation reviews the preliminary design and the core issue related to the accelerator magnet.

INTRODUCTION

A new 3 GeV synchrotron radiation machine is planned for the national synchrotron radiation research center (NSRRC) in Taiwan as part of the Taiwan Photon Source (TPS). The TPS was designed to have an ultra-low emittance and a high photon source stability machine. The storage ring has a circumference of 514 m with 24 periods of a double-bend achromatic magnet system. The magnetic system of the storage ring has 48 dipoles, 240 quadrupoles and 168 sextupoles magnets with various length and various families. The high accuracy of the magnetic field and the alignment of the magnets are required to ensure the very high performance of the photon source. Accordingly, the magnets must be designed and manufactured for the tight tolerances of the magnetic field and alignment errors to achieve the good performance and the stable operation. Table 1 summarized the magnetic system of the TPS storage ring. Figure 1 displays the part of the magnetic system in the storage ring.

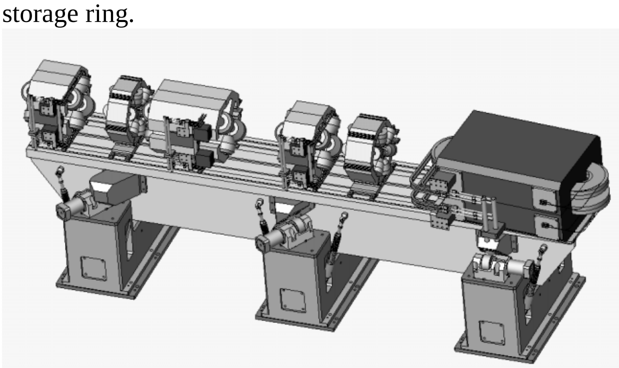

Figure 1: Schematic diagram of the magnets installed in the storage ring.

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STORAGE RING DIPOLE MAGNET

The TPS storage ring will be equipped with 48 dipole magnets and have a field of 1.38 T in the central gap of 46 mm at 3.0 GeV. Each 0.95 m long dipoles magnet yields a 7.5 degree bending angle with a small beam sagitta. The dipole magnets are H-type with a straight rather than curved core. Although straight magnets require a larger coverage the beam sagitta range by the good field region and need a wider pole. The construction is simplified and mechanical tolerances are more easily achievable. Beam dynamic investigations have established that the beam stay clear and the good field region in the central gap. The designed magnetic cross section must be accommodate the vacuum chamber and leave gap of 2 mm clearness between the magnetic gap width and the vacuum chamber for the thermal insulation during chamber baking.

The magnetic field calculations were made using the "OPERA" and "RADIA" computer programs to optimize the pole contours and the quality of magnetic field [1]. The field quality of the dipole magnet must be have an error of $\Delta B/B=\pm$ 2 x 0.01 % over a good-field region of $\pm$30 mm [2, 3]. The 4 A/ mm^2 current density of the water-cooled copper conductor is selected as trade-off between the material and the operating costs. Finally, the pole contour with 0.13 mm thick shims at its edges was optimized to maintain the field homogeneity with various excitation currents. Figure 2 and 3 present the calculated field strength and the homogeneity of vertical field along the transverse axis (ΔBy(x) / By(0)).

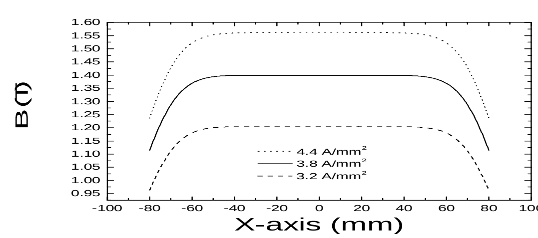

Figure 2: The distribution of vertical field in the medium plane with various current excitation.

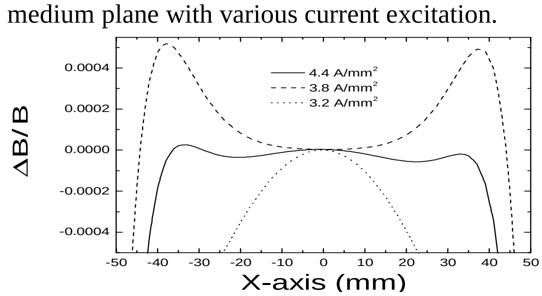

Figure 3: The field deviation of calculated results in the magnetic center.

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STORAGE RING QUADRUPOLE MAGNET

A total of 240 quadrupole magnets are grouped into eight families with three core lengths. The quadrupole magnet is required to produce a maximum gradient 0f 16.78 T/m with gradient field homogeneity of under 0.1 % over a bore radius region of ±25 mm. The geometry of vacuum chamber determines the quadrupole's bore radius [4]. The designs of the quadrupole magnet's cross sections are severely constrained to accommodate the vacuum chamber with its antechamber. Somewhere, the antechamber must be transversely extended into one of the 400 mm air gaps. The top and bottom halves of the quadrupoles are not connected with flux-return yoke; each half is connected mechanically with aluminum spacers between two halves to accommodate the vacuum chamber. The gradient quality was examined on the one-quarter of the geometry. The poles and shims are optimized using 2-D approximation. Figure 4 plots the homogeneous gradient field as a function of horizontal position at four vertical positions in the good gradient region. The field quality is consistent with the specified gradient throughout the required transverse region.

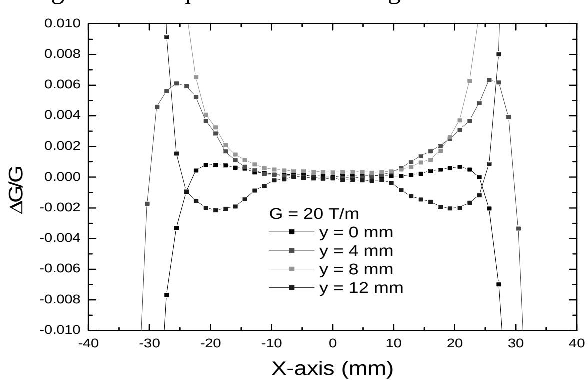

Figure 4: The homogeneous gradient field as a function of horizontal position at four vertical positions in the good gradient region.

STORAGE RING SEXTUPOLE MAGNET

The sextupole magnet is the most complex magnet design in the entire TPS magnet system. Correctors are incorporated in the sextupole magnets to save space and allow longer insertion devices to be used in the compact lattice. Therefore, the sextupole magnet must fulfill four functions. As well as sextupole windings, the magnet includes coils wound to perform vertical and horizontal steering as well as a skew quadrupole field in the same yoke. The bore diameter of 76 mm was determined by field quality specifications and the space constraint between the vacuum chamber and the pole geometry. A minimum clearance of 2 mm between the vacuum chamber and the adjacent pole is provided.

During simultaneous operation, four functions are exited in the magnet [5]. There are the sextupole, the vertical steering, the horizontal steering and the skew quadrupole. The magnetic field calculations are made for all of three configurations, accounting for the effect of additional excitation on the performance of the sextupole field as a function of the sextupole currents. Up to ~ 600 T/m^2 no interaction occurs between both exciting currents. Above this value, in the region where saturation is important. The additional excitation affects the sextupole strength. A wide pole yoke is chosen to prevent magnetic saturation when the sextupole and steering coils are excited simultaneously. Multipole coefficients of the sextupoles meet the field specifications. Figure 5, 6 and 7 shows the field configurations versus sextupole excitations.

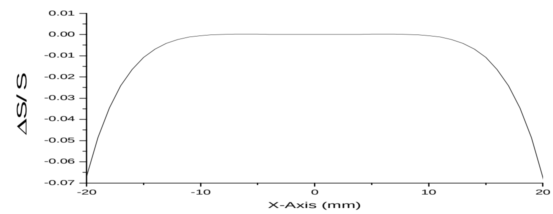

Figure 5: Predicted uniformity of the sextupole field strength of 640 T/m^2 in the transverse direction.

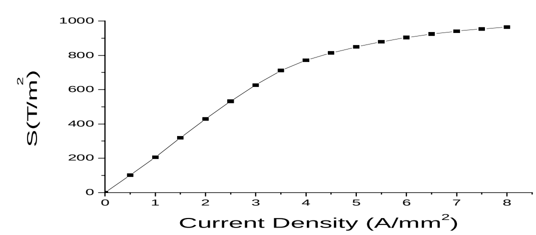

Figure 6: Calculated sextupole field strength as a function of excitation currents.

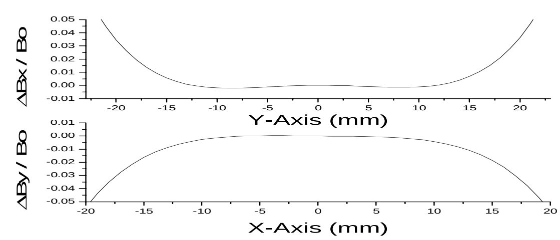

Figure 7: The calculated field distribution of the horizontal and vertical steering coils in the sextupole magnet.

CONSTRUCTION CONSIDERATIONS

The field saturation and the construction considerations of each magnet were checked at operating energies of 3-3.3 GeV. All magnet cores are assembled from 1.5 mm thick low carbon steel AISI 1006 laminations to distribute uniformly systematic variations in steel properties. The laminated core of the magnet is stacked. Magnets are made from laminations of the same cross section but different in core lengths. All magnetic cores are fabricated by gluing to avoid distortions in the core assemblies caused by the thermal effects of welding. The basic manufacturing approach is to maintain construction tolerances of 0.02mm for the iron pole contours of the magnets, which suffices to achieve a field error of approximately 0.1 % over the aperture.

The assembly of the half magnet using the stainless steel plates that hold the core is designed so that the upper magnet core can be moved to install the vacuum chamber. All ring coils in the magnet are used the vacuum impregnated process for the electrical insulation. Finally, the magnets are accurately fixed on the vertical and horizontal planes of the girder to position the magnets exactly [6]. All magnets, except the dipole magnets, must have a separate power supply to maximize the full flexibility of the operation of magnetic lattice.

CONCLUSIONS

The 3 GeV Taiwan Photon Source (TPS) project is at the beginning of the design phase. The conceptual designs of each magnet family for the TPS storage ring were examined. The pole profile of all magnets is optimized using the 2-D program in the RADIA and the OPERA to maintain homogeneity of the field. The field uniformity at $\Delta B/B=\pm 2 \times 0.01$ % in the dipole and $\Delta G/G=\pm 2 \times 0.1$ % in the quadrupole in a good-field region with a width of ±25 mm are predicted. The steering dipole and skew quadrupole coils incorporated into the sextupole magnets were designed to reduce the additional space required. The adequate steering coils could produce a satisfactory magnetic strength and a field quality of 1×10^{-2} in ±14 mm.

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Table 1: Main parameters of the storage ring magnets

	Dipole	Quadrupole	Sextupole
Quantity	48	240	168
Bending angle (deg.)	7.5	0	0
Magnetic length (m)	0.95	0.35/0.3 / 0.6	0.2/0.25
Bore radius (mm)	---	35	38
Dipole field (T)	1.38	0	0.035
Gradient field (T/m)	0	16.78	0.5
Sextupole field (T/m^2)	0	0	451
Field quality	$\Delta B/B \leq 1\times10^{-4}$	$\Delta G/G \leq 1\times10^{-3}$	$\Delta S/S \leq 1\times10^{-2}$
$\Delta\int Bds/\int Bds$	$\leq 10^{-3}$	$\leq 10^{-3}$	$\leq 10^{-3}$
Bending radius (m)	7.6418	---	---
Magnetic gap width (mm)	46	70	76
Good field region (mm) (HxV)	±30x15	±25 x 16	±15 x 15
Number of turns / pole	24	39	44
Conductor dimension (mm^2)	16 x 16	8 x 8	8 x 8
Coolant hole diameter (mm)	7	4	4
Current (A)	1127	146	243
Current density (A/mm^2)	3.9	1.8	3
Voltage drop (V)	12.8	15.8	22
Power consumption(KW)	13	2.3	5.4
Magnet weight (Kg)	3234	420	250
Inductance (mH)	9.5	33	5.6
Resistance (mΩ)	9.9	109	91
Water flow (l/min)	15.6	4.4	7.7
Coolant temp. rise ΔT (℃)	10	10	10
Water pressure drop (atm)	2.8	5	5.8
Water circuits /magnet	4	4	6

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