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Design and Analysis of a Wiggler Magnet System for the PEP- II B-Factory LER

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Abstract- The Low Energy Ring (LER) of the PEP-II B-Factory will use wiggler magnet systems for emittance control and additional damping. The wiggler baseline is a set of 11 individual iron core, water cooled, dipole magnets designed to operate at 1.6 T and generate 400 kW of synchrotron radiation. Space has been provided to add a second wiggler with an additional 400 kW of synchrotron radiation if more damping is needed in the future. A copper vacuum chamber is used with continuous antechambers connected to both sides of the beam chamber via slots. Synchrotron radiation dump surfaces and distributed vacuum pumping are located in both antechambers. We describe the design and analysis of the wiggler magnets and the salient features of the vacuum chamber and dumps.

WIGGLER DESIGN CONCEPT

The PEP-II B-Factory employs wiggler magnets for beam emittance excitation and synchrotron radiation (SR) damping. Two LER straight sections have chicanes with space provided at the center for wiggler installation (see Fig. 1). Each chicane is formed by four dipole magnets and these chicane bends play an important role in emittance adjustments. By varying the betatron phase advance between pairs of chicane dipole magnets, the wiggler contribution to overall emittance can be maximized.

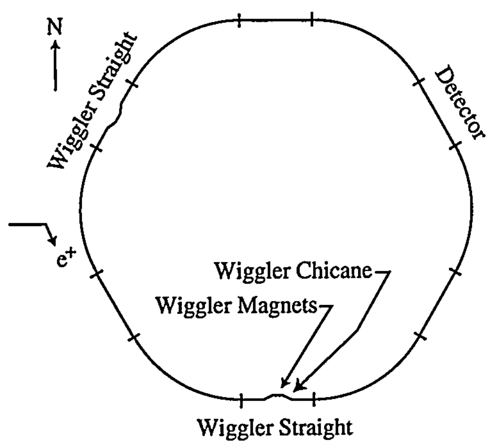

Fig. 1. Wiggler locations in the LER.

The beam lattice layout of both wiggler chicanes are identical with beam transport magnets used to shift the beam toward the center of the ring as shown in Fig. 2. The chicane bend angles are the same as standard LER bend magnets (1.875 degrees) and they are connected in series with the LER string dipole magnets. Both wiggler chicanes will be installed for start-up, but only one wiggler magnet system will be installed for initial operation with a positron beam current of 3 amperes. If additional SR damping is needed in the future, a second wiggler magnet system will be inserted into the LER. If both wigglers are installed the total wiggler system is capable of producing a maximum of 800 kW of SR damping.

The wiggler vacuum chamber is approximately 25 m long and the material is copper. Continuous antechambers are connected to both sides of the beam chamber via slots with SR dump surfaces and distributed vacuum pumping located in both antechambers. The SR produced by the wiggler magnets is intercepted by these water cooled dumps which are an integral part of the copper vacuum chamber. In the wiggler magnet area the vacuum chamber thickness is minimized to reduce the magnet pole gap. Stiffening ribs are used between magnets to compensate for the material removed from of the vacuum chamber.

The PEP-II B-factory magnet system is an assembly of 11 dipole electromagnets which are connected in series electrically with alternating polarities. These magnets are individual "H-type-dipoles" which are mounted onto a rigid girder located below the magnets. The wiggler period is not an important parameter for this SR damping application. Therefore, dump heating considerations were used to choose the iron core length and spacing between magnets. A longer than "typical wiggler" iron core length was chosen to develop wide angle SR fans. The wide angle fans produce a wide distribution of SR which deposits most of the SR onto the vacuum chamber sidewalls immediately downstream of the wiggler. This wide distribution of the SR lowers the heating per unit area on the dump surface and therefore lowers the dump temperatures and stresses.

The spacing between magnets (drift space) was kept to a minimum (0.29m) and was driven by the coil width and coil-

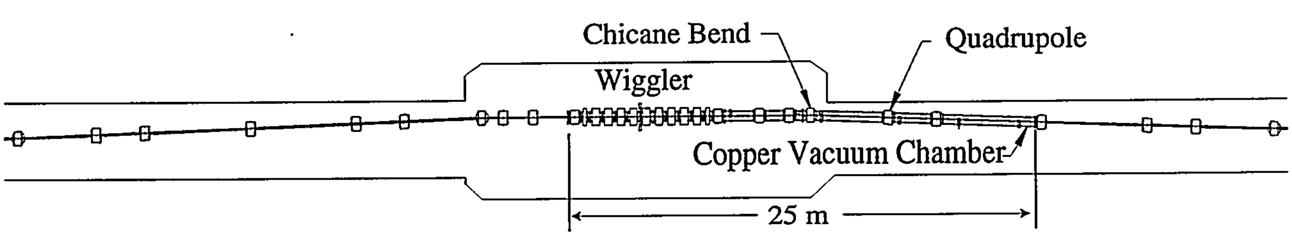

Fig. 2. Wiggler chicane layout.

to-stiffener clearance required for vacuum chamber bake-out. The wiggle width is also a function of iron core length, drift space length and dipole field. For this design the wiggle width is approximately 1.5 cm at the design field of 1.6 T.

WIGGLER MAGNETIC DESIGN

The wiggler magnets are conventional water cooled, iron core, electromagnets designed to generate vertical fields. The field directions reverse between adjacent magnets which will produce a series of reversing positron beam bends (wiggles) in the horizontal plane. All magnets have been designed to operate at approximately 500 amperes DC with a vertical central field of 1.6 T. Both end magnets are half magnets with 20 cm long iron cores while the 9 middle magnets are full magnets with 40 cm long cores. The same primary coil cross-section and steel lamination shape are used for both end and middle magnets. The spacing between iron cores is constant at 29 cm. The two end magnets will have single layer trim windings wound onto the outside of the primary windings. The trim windings have been sized to provide a horizontal beam adjustment of ± 2 milliradians. Iron core chamfers will be used to shape the magnet end fields to give a constant B•dl integral over the good field width of 60 mm. The final end chamfers for the magnet ends adjacent to the drift spaces and free ends will be determined empirically using an iterative approach of magnetic mapping and chamfer adjustment followed by remapping.

A plan view of the wiggler magnet assembly and the trajectory of the positron beam is shown in Fig. 3. In the figure, the wiggler is off-set 0.75 cm with respect to the centerline of the straight. This offset is equal to one half of the nominal wiggle width of 1.5 cm. Both of these dimensions are approximate in that stray field in the drift space between magnets was neglected to simplify computations. The same simplifying assumption was also made in deriving equations (1-4) which were used to calculate the wiggle shape and the SR produced by the wiggler magnet system.

$$\alpha = 0.30\frac{BL}{E} \tag{1}$$

$$w = \frac{L\left[1-\cos\left(\alpha/2\right)\right]}{\sin\left(\alpha/2\right)} + d\tan\left(\alpha/2\right) \tag{2}$$

$$l = \frac{n\alpha L}{2\sin\left(\alpha/2\right)} + \frac{nd}{\cos\left(\alpha/2\right)} \tag{3}$$

$$P = 1.266E^2B^2LI \tag{4}$$

where,

α = wiggler magnet bend angle (radians)
B = magnetic field strength (Tesla)
L = magnet iron length (m)
E = beam energy (GeV)
w = wiggle width (m)
d = drift space between magnet cores (m)
l = nominal wiggle path length (m)
n = number of full magnets
P = total synchrotron radiation power (kW)
I = beam current (amperes)

The wiggle path length of the positron beam is an important parameter for this colliding beam application. The particle orbit lengths of the two recirculating rings must be equal. When the wiggler is operating, the particle path length through the wiggler increases. This increase is compensated by decreasing the arc radius elsewhere in the LER.

A cross-section of the wiggler magnet is shown in Fig. 4. The inside iron width of the magnet is driven by the wide vacuum chamber while the coil width is driven by the spacing between magnet cores. The magnet core spacing is minimized to keep the wiggle width and path length small, leading to a generous space available for magnet pole shaping. The iron core lamination was designed for a 1.6 T

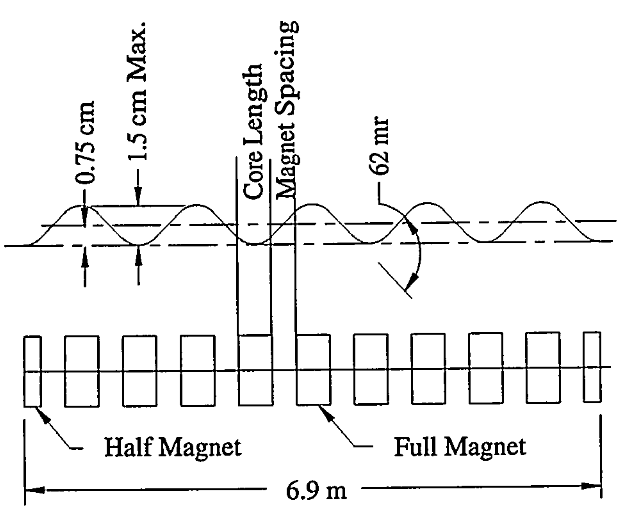

Fig. 3. Wiggler plan view and beam trajectory.

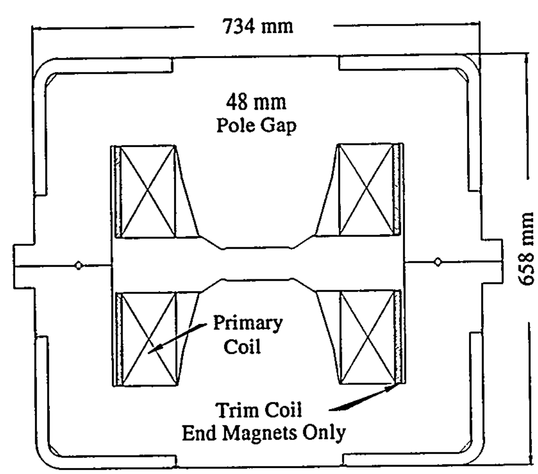

Fig. 4. Wiggler magnet cross-section.

TABLE I
WIGGLER MAGNET DESIGN PARAMETERS

SYSTEM:		
Nominal Beam Energy	3.1 GeV	
Nominal Central Field	1.6 Tesla	
Maximum Central Field	1.7 Tesla	
Wiggler Period	1.38 m	
Number of Periods	5	
PRIMARY COIL:		
Conductor (Al)	1.27 cm square	
Cooling hole	0.635 cm dia.	
Amp-turns per pole	32540	
Turns per pole	60	
Nominal Current	526 amp	
Current at 1.7 T	569 amp	
Current Density	412 amp cm^{-2}	
	full size	half size
Conductor Length	190.5 m	142.6 m
Nominal Voltage	24.03 V	18.02 V
Nominal Power	12.7 kW	9.5 kW
TRIM COIL:	(end magnets only)	
Conductor (Al)	0.635 cm square	
Cooling hole	0.315 cm dia.	
Maximum Amp-turns	4000 maximum	
Turns per pole	20	
Maximum Current	100 amp	
Maximum Adjustment	$\pm$ 2 mr	
IRON CORE:		
Type	laminated	
Material	low carbon steel	
	full size	half size
Core Length	40 cm	20 cm
Pole Tip Type	shimmed	
Pole Tip Width	11.2 cm	

central field and peak fields of 1.65 T in the iron. A shimmed pole tip is used to shape the field in the gap which reduces the total amount of flux in the return yoke. The pole shape was optimized for the 1.6 T design central field. Table I summarizes the magnet parameters.

Magnet coils are layer wound with an even number of layers which locates both electrical leads and cooling water connections on the side of the coil away from the vacuum chamber. Aluminum was chosen as the conductor material because of compatibility with an existing cooling water system. Wiggler end magnets also have water cooled aluminum trim coils wound onto the outside of the primary windings.

Magnetic field requirements are defined within an elliptical good field region with a 60 mm major axis and 40 mm minor axis lying on the horizontal and vertical axes of the magnet respectively. The nominal design central field of 1.6 T has an allowable deviation of one part per thousand along the horizontal axis within the good field region. In addition, the harmonic multiple requirement normalized to the fundamentals is also set at one part per thousand. A quarter-symmetry two-dimensional magnetic model of a wiggler dipole was analyzed for field uniformity and harmonic contributions using POISSON [1]. The pole shape, shown in Fig. 4, was designed to meet the field uniformity requirements and minimize saturation in the iron. Fig. 5 shows the field lines for the 1.6 T nominal design case. In general, the field values in the iron are below 1.65 T with a few locations, namely corners, experiencing slightly higher values. The structural angle, located at the outer corners of the magnet (see Fig. 4), was not included in the magnetic model because of its limited direct contact width the iron laminations. Fig. 6 presents the calculated field along the horizontal axis normalized to the central field with the center

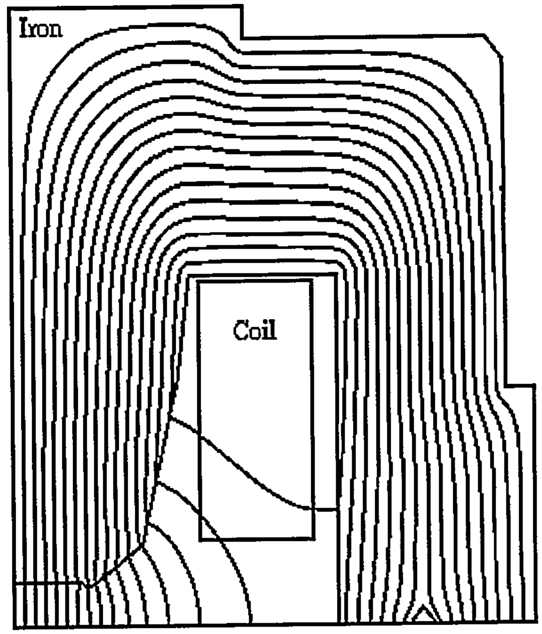

Fig. 5. Flux lines calculated with POISSON for a 1.6 T central field.

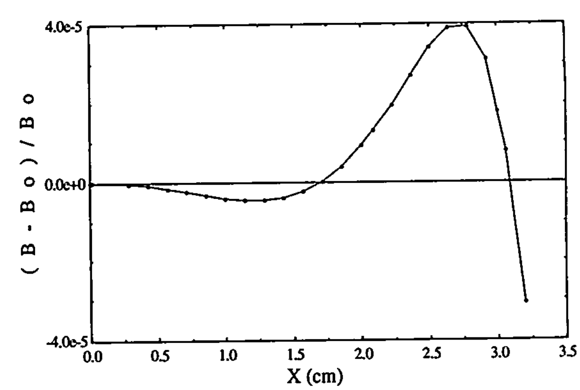

Fig. 6. Field on the horizontal axis normalized to the central filed.

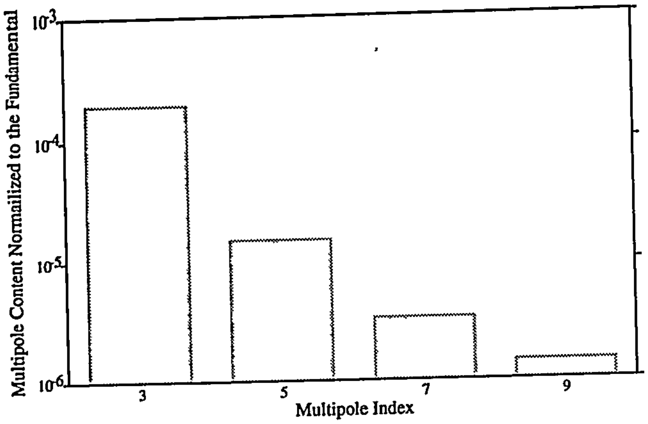

Fig. 7. Multipole contributions normalized to the fundamental.

of the magnet as the origin. In the 3.0 cm of interest, the field is very uniform and has a normalized variation from the central field less than 4.5 x 10^{-5}. The harmonic contributions to the field were calculated on a 2.15 cm radius and are presented in Fig. 7 in bar-graph form with each multipole contribution normalized to the fundamental dipole. Higher multipoles were calculated, but were quite small and were not included in the figure. Figs. 6 and 7 indicate that the field uniformity and multipole contributions are well within the design requirements. Although no specific magnet efficiencies were defined, the calculated wiggler dipole performs well. Three dimensional field calculations were also performed using AMPERES [2]. Results from the 3-D calculations help determine the initial shape of the magnet core end chamfers. These chamfers will shape the magnet end fields and bring the field uniformity within the defined tolerances.

VACUUM CHAMBER DESIGN [3]

The wiggler vacuum chamber consists of a 90 mm by 40 mm elliptical beam aperture with continuous SR slots on both sides. The SR slots are sloped at 8 degrees forming water-cooled dump surfaces to absorb the SR power. Continuous plenums with distributed Non-evaporable Getter (NEG) pumps are located behind the dump surfaces (See Fig. 8). SR from the wiggler poses two problems for the vacuum system. First, photo-desorption generates a large gas load (5 x 10^{-6} Torr-l/meter) which must

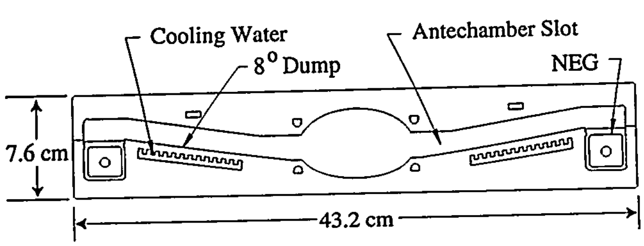

Fig. 8. Vacuum chamber cross-section.

be effectively pumped by the NEG system. Beam-line pressure calculations predict an average vacuum pressure of 3.4 nTorr which is well within the wiggler vacuum system design goal of 10 nTorr. The second problem is the thermally induced stresses at the dump surface. A thermal/structural analysis of the vacuum chamber was done using the ANSYS finite element code. A 200 psi cooling water pressure, atmospheric pressure and synchrotron radiation heating were applied simultaneously to the thermal/structural model. Thermal analysis results show peak temperatures of 117 C and 87 C on the dump surface and cooling water channel surface respectively. The cooling water channel surface temperature is well below the coolant boiling point and film boiling will not occur. The highest thermally induced stress is a compressive stress in the longitudinal/beam direction (principal stress) and it is due to the localized SR heating. The heated stripe would like to grow longitudinally, but the remainder of the vacuum chamber constrains the growth and compressive stresses develop in the heated area.

SUMMARY AND FUTURE PLANS

The wiggler magnet system described in this paper will be used as an effective method of increasing damping and emittance control of the PEP-II B-factory. Longer than "typical wiggler" magnet core lengths have been used to spread the synchrotron radiation into wide angle fans that give a wide distribution for synchrotron heating. The preliminary design/analysis of the wiggler has been completed and detailed design is progressing. Detailed design will be completed in 1995 and all fabrication work will be done in 1996. A final design review is planned for this summer.

ACKNOWLEDGMENTS

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REFERENCES

[1] POISSON Code Group, Los Alamos National Laboratory, NERSC CRAY Version, 1995.

[2] AMPERES, Integrated Engineering Software, SUN SPARC Version, 1995.

[3] J. Heim et al., 1995 Particle Accelerator Conference and International Conference On High-Energy Accelerators, paper titled, "Wiggler Insertion Of the PEP-II B-Factory LER", to be published.