MECHANICAL DESIGN OF THE HER SYNCHROTRON LIGHT MONITOR PRIMARY MIRROR FOR THE PEP-II B-FACTORY*

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Abstract

This paper describes the mechanical design of the primary mirror that images the visible portion of the synchrotron radiation (SR) extracted from the High Energy Ring (HER) of the PEP-II B-Factory. During off-axis operation, the water-cooled GlidCop mirror is subjected to a heat flux in excess of 2000 W/cm^2. When on-axis imaging occurs, the heat flux due to scattered SR, resistive wall losses and Higher-Order-Mode (HOM) heating is estimated at 1 W/cm^2. The imaging surface is plated with Electroless Nickel to improve its optical characteristics. The design requirements for the primary mirror are listed and discussed. Calculated mechanical distortions and stresses experienced by the mirror during on-axis and off-axis operation will be presented.

1 INTRODUCTION

The design approach for the SR Light Monitor System has been described in detail[1] and is based on standard design parameters for the HER Arc Vacuum System[2]. The 3 A, 9 GeV electron beam is circulated around the HER through 192 dipole magnets with bend radii of 165m that each emit 55 kW of radiation. The SR is widely distributed in the arcs; the copper vacuum chamber outer wall intercepts up to 102 W/cm.

The shallow angle of SR incidence on the chamber wall, stringent impedance requirements and the magnet packing factor in the arcs lead to complicated design solutions. These factors adversely impact any designs that employ relatively large source-to-optic distances, crotch-style absorbers and "Y"- chambers such as those implemented by APS[3] and others. At SLAC, PEP had originally implemented a system that reflected the light back across the beam axis to optics on the inside of the ring perimeter. The system for PEP-II is similar in concept, but manages the SR heat loads in a slightly different fashion.

A GlidCop mirror and photon absorber replace a 190mm (7.5") section of the outer wall of the dipole vacuum chamber. During on-axis operation, the hot portion of the SR fan, estimated at 1 mm in height, passes through a shallow slot in the mirror imaging face and is intercepted in the GlidCop photon absorber. The heat load during imaging due to scattered SR, resistive wall losses and HOM heating is estimated at 1 W/cm^2. During off-axis imaging, the SR is incident on the mirror at nominally 4° to grazing, depositing up to 200 W/cm along the mirror face for 3 A, 9 GeV operation. This lineal power deposition corresponds to a heat flux of 2000W/cm^2. This power deposition may occur as high as 5 mm from the nominal HER beam axis.

2 MIRROR DESIGN DESCRIPTION

2.1 General Requirements

The GlidCop mirror and absorber combination have the following design criteria:

- Reliable on-axis imaging
- Withstand off-axis thermal loading
- In-situ adjustment and replacement capability
- Integrate into existing dipole chamber design
- Compatible with 10 nTorr UHV System
- Minimal impedance
- Provide SR masking

The general requirements cover three basic categories: optical, vacuum and mechanical requirements.

2.2 Optical Design Requirements

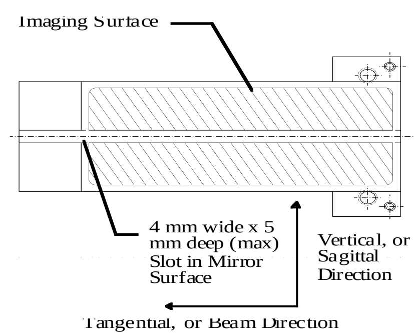

Figure 1 Optical Surface of the Primary Mirror

The imaging surface of the mirror is plated with Electroless Nickel (9% Sulphur, 180°C bath) to a maximum of 0.1 mm thick. Reliable imaging dictates fairly stringent surface quality including figure, slope error and surface roughness. The figure of the mirror after polishing is specified to be flat to $\lambda/40$ rms measured by He-Ne laser interferometry at 632.8 nm over the 81.2 mm x 34.9 mm (3.198" x 1.375") optical surface. The required slope error is specified not to exceed 5 μrad rms,

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corresponding to an rms slope of λ/5 over a 25 mm distance. The mirror roughness after polishing is acceptable if less than 10 Å rms.

Image quality near the slot is important to minimize the effects of edge scattering. Therefore, the specifications above apply up to 0.2 mm from the edge of the slot. This surface adjacent to the slot as well as a 2-mm-wide area along the outer perimeter of the imaging surface are not required to meet the surface quality specifications.

2.3 Vacuum Requirements

For 10 nTorr UHV systems, SLAC requires certified materials, cleanliness consistent with 100K class clean rooms, and no direct water-to-vacuum joints. These requirements are implemented to improve vacuum system reliability. In particular, welded or brazed joints that carry cooling water are air-guarded from the vacuum system.

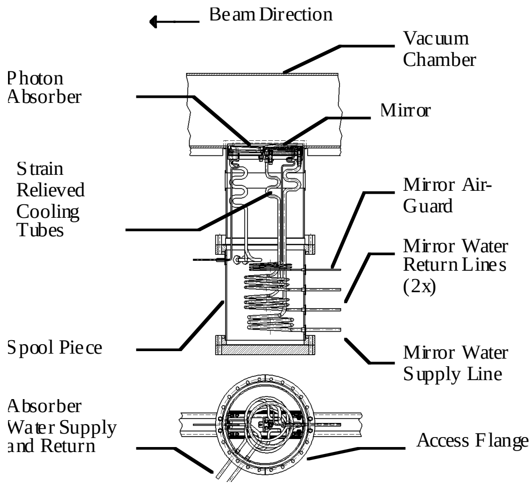

Figure 2 Mirror and Absorber Assembly

2.4 Mechanical Design Requirements

The key elements of the mechanical design consist of managing the thermal loads to facilitate reliable imaging, packaging the assembly in the dipole chamber geometry, providing in-situ alignment and repair or replacement.

For thermally loaded mirrors, substrate selection is dependent on three material properties: thermal conductivity, thermal expansion and yield strength. Manufacturing considerations such as metals joining, machining and optical preparation also drive material selection.

GlidCop , Molybdenum, Beryllium and Copper have been considered. While Molybdenum has very high yield strength and low thermal expansion, it is difficult to machine and join. Beryllium has relatively high thermal expansion but low yield strength. It too requires special care during machining. Copper has better thermal conductivity than even the best GlidCop, but has very low yield strength after brazing compared with GlidCop. GlidCop is chosen for its relatively high thermal conductivity, yield strength and relative ease of manufacture.

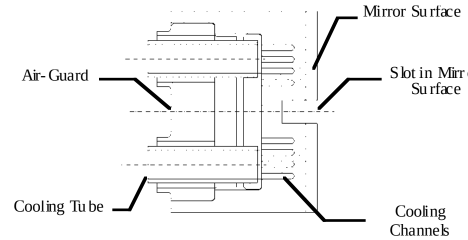

Figure 3 Section of Mirror at Cooling Outlets

Thermal distortion is minimized on the substrate by employing a cooling scheme similar to those implemented by DiGennarro et al[4]. The cooling passages are within 2.5 mm of the imaging surface and are evenly spaced in the sagittal direction. A flexible mount allows the mirror to expand 0.2 mm during off-axis operation.

Masking is required to avoid SR striking any surfaces at more than grazing incidence angles. During on-axis imaging, the chamber opening masks the upstream end of the mirror and absorber simultaneously. During off-axis imaging, the chamber masks the mirror and the mirror masks the absorber. Three RF seals, each masked by their immediate upstream components, bridge gaps between the chamber, mirror and absorber. By design, the leading edge of the mirror cannot inadvertently be moved beyond its masking point into the SR fan.

The mirror and absorber are attached with adjustable fasteners to a mounting plate. Yaw and roll of the mirror can be set to within ±1 mrad and ± 3 mrad respectively. Strain-relieved cooling tubes are routed from the back of the subassembly to a spool piece. The spool piece provides external water supply to the mirror and absorber. The air-guard, which eliminates water-to-vacuum braze and weld joints, has a small tube routed through the spool to the tunnel atmosphere. The assembly is inserted through a flange-to-rectangular-tube brazement that is electron-beam welded to the modified dipole chamber.

3 ANALYSIS

Modulus of Elasticity	131 GPa (19E6 psi)
Yield Strength (1 hr @ 1000°C)	303 MPa (44E3 psi)
Thermal Conductivity	365 W/m-°C
Thermal Expansion	16.6E-06/°C

Table 1 Mechanical Properties of GLidCop AL-15

The mirror must function reliably at low heat loads, 1 W/cm^2, and withstand high thermal stresses while intercepting the off-axis SR fan, 2000 W/cm^2. A 2D triaxial stress finite element model has been developed using ANSYS to help determine the optimum cooling geometry. Strategic water routing can markedly improve mirror performance. To provide symmetry during on-axis operation, all cooling channels are plumbed in parallel. A flow rate of 1 gal/min, corresponding to a heat transfer coefficient of 2 W/cm^2-°C, yields almost no bulk temperature rise during imaging for a ~35W total heat load. A conservative value of 0.8 W/cm^2-°C is used for the analyses, along with a bulk water temperature of 35°C.

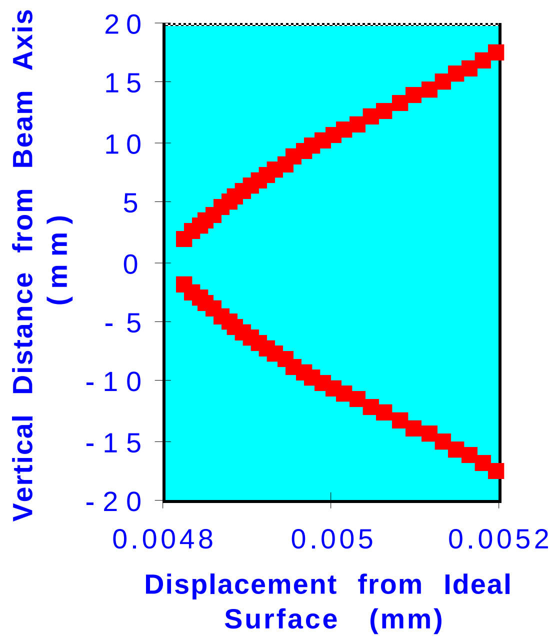

Figure 4 Distortions from Ideal Surface for 2.5 mm Deep Slot

The water passages are machined inward from the backside of the mirror. A cover is then brazed on to seal the passages. It is assumed that the cover is not thermally connected to each web between water passages, but only in the thick middle portion as well as the outer edges. This is a conservative assumption since the added thermal conduction and subsequent convection would lower the peak temperatures of the mirror for both loading cases. Also, hydraulic pressure has almost no effect on mirror surface figure or slope error.

3.1 On-Axis Imaging

The water passage number, height, width and depth (below the optical surface) directly affect the optical characteristics. Deeper slots reduce the mirror temperature during imaging but increase the estimated sagittal slope errors. The added surface area cools the backside and increases angular errors on the mirror face. Shallower slots raise the bulk temperature of the mirror adversely affecting the mirror figure, and produce higher peak compressive stresses during off-axis operation.

3.2 Off-Axis Durability

Peak compressive stresses due to the SR strike during off-axis imaging are estimated at 267 MPa (39 ksi). The hot-spot peak temperature is 196°C. This peak value is relative insensitive to the depth of the cooling passages. For 3A, 9 GeV operation, the peak stress is 89% of the quoted yield strength.

3.3 Three-Dimensional Effects

The sagittal slope error calculated is ~23 μrad for a 2.5mm deep slot. For reference, the installed mirror system must limit the tangential and sagittal slope errors to 15 μrad and 35 μrad respectively. The 2D analysis shows that increasing the depth of the slot markedly increases the sagittal slope error. At 5 mm deep, the slope error is more than an order of magnitude larger. A slope error of this size is clearly unacceptable for proper imaging.

The slot varies in depth from 0.5 mm at the leading edge of the mirror to 5 mm at its deepest. This axial slot depth variation requires three dimesional modeling to fully determine the mirror figure and slope errors. The operational stresses predicted by the 2D analysis will be comparable to the 3D calculations.

4 PLATING AND POLISHING RESULTS

The mirror has been plated and polished by SESO in France. The results of the plating and polishing are quite good, and the mirror finish and quality will be acceptable for use in the HER.

Optical Feature	Specified	Reported
Figure, rms (λ=632.8 nm)	λ/40	λ/30
Tangential Slope Error, rms	<5 μrad	<4 μrad
Sagittal Slope Error, rms	<5 μrad	<3 μrad
Roughness (Å rms)	< 10	7 to 8

Table 2 Specified and Reported Optical Characteristics After Plating and Final Polishing

5 CONCLUSIONS

The mechanical design of the SR Primary Mirror is capable of withstanding an off-axis hit of 2000 W/cm^2 at 3 A at 9 GeV. The reported optical quality of the mirror component is acceptable for operation. The operational optical quality of the mirror varies along the mirror surface with the depth of the slot. Further 3D analyses should be conducted and compared with operational results to determine overall mirror performance.

REFERENCES

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