HEAT LOAD FOR THE APS SUPERCONDUCTING UNDULATOR

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Abstract

The APS Upgrade calls for the development and commissioning of a superconducting undulator (SCU) at the Advanced Photon Source (APS), a 7-GeV electron synchrotron. The first SCU will be installed in June 2012. Until then, simulations such as SYNRAD3D will be used to understand and reduce the heat load on the cryo-system from primary and secondary photons. Current calculations predict that primary photons will distribute 0.290 W on the chamber walls of the cryostat. SYNRAD3D will be used to study the effectiveness of the proposed photon absorber (PA) in shielding the cryostat from primary and secondary photons. The work presented here compares the effectiveness of two designs proposed by APS.

INTRODUCTION

One of the goals of the APS Upgrade is to use superconducting undulators (SCU) in specified beam lines to produce hard x-ray beams. The first prototype, SCU0, will be installed in APS in June 2012. The SCU cryostat will be 2.0636 m long and contain the SCU0 magnet, length 0.340 m [1]. The total heat load on the cryostat cannot exceed 40 W from all heat sources [1]. To shield the cryostat from synchrotron radiation heating a photon absorber (PA) will be placed between a hybrid permanent magnet (HPM) insertion device (ID) and the SCU0 test undulator. There are two PA absorber designs that have been tested with simulations to determine their effectiveness in shielding the SCU cryostat from photon radiation. The first design maintains the shape and angle as the current PA, but it is moved into the chamber so that the tip is at x=18mm. The new design has the same on-axis length and minimum distance to the chamber axis but has an angle of 30 degrees instead of the current 19 degrees, see Table 1. The PA will be made of a water-cooled copper pipe, which can withstand up to 1 kW of power absorbed along its length.

Table 1: Comparison of the old and new PA designs

PA design	Angle (degrees)	on-axis length (mm)	Actual length (mm)
Old	19	75.73	80.09
New	30	75.73	87.45

SIMULATION SETUP

SYNRAD3D

Synrad3d simulates the production and propagation of synchrotron radiation in electron and positron storage rings [2]. The code generates macro photons in the bending magnets. As they travel around the ring the photons are allowed to reflect off the beam chamber walls based on photon reflection data taken from the Berkeley Center for X-ray Optics. The current reflectivity is based on an aluminum chamber that has 4 nm surface roughness and a 4 nm A_2O_3 layer, Fig. 1, and all reflections are specular and elastic. The APS chambers are not this smooth; the rougher surface will affect the reflection properties of the photons, see Synrad3d Modifications.

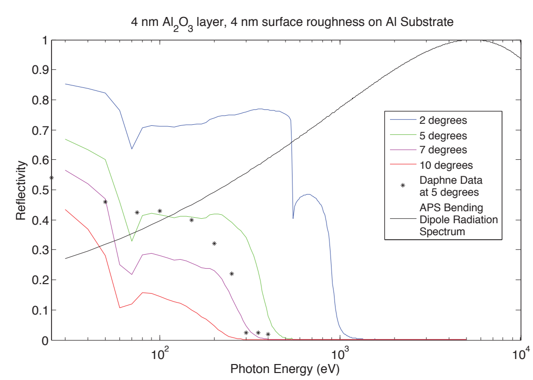

Figure 1: An example of the reflectivity of photons on a specified surface. All angles are grazing angles. Data was taken from the Berkeley Center for X-Ray Optics [3] and Daphne [4]

Simulation Input and Assumptions

A layout of part of the ID straight section is shown in Fig. 2. The first half of the drift section will have an HPM ID, the PA will be in the end box before the SCU cryostat to provide the best shielding. Some simplifications were made in the chamber design. There is no antechamber simulated in the main chamber before the HPM ID, but the chamber before the PA has been extended to simulate the presence of an antechamber in that drift section. Also the actual PA will have a small 4.88 mm-radius curve along its face. Instead, the face of the simulated PA is flat; this small change was shown not to effect the final results.

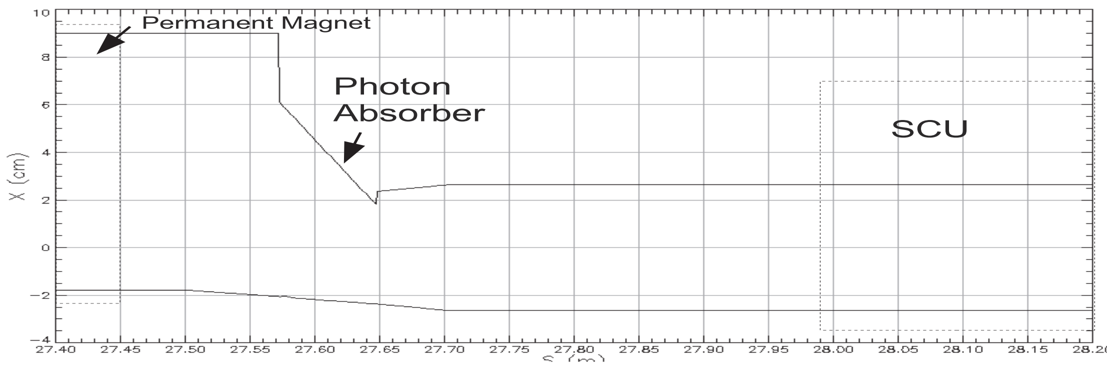

Figure 2: The design for the new PA. As shown, there is a HPM undulator before the PA and between the PA and the SCU there is room for a gate valve and a corrector magnet so that each of the undulators can be used independently.

RESULTS

Primary Photons

The primary function of the PA is to shield the SCU cryostat from high-energy primary photons. The only constraint needed on the PA to fully shield the outside wall of the SCU chamber is the distance from the center the PA extends into the chamber. Both the old and new PA extend to x = 18mm providing the same shielding for the SCU. The power absorbed on the SCU cryostat from primary photons was calculated analytically and from Synrad3d. The total power produced per bending magnet is calculated from equation 1,

$$P_{dipole}[W] = 14079 \times L[m] \times I[A] \frac{E[GeV]^4}{r[m]^2}, \quad (1)$$

where L is the length of the magnet, I is the current of the beam, E is the beam energy and r is the bending radius. There are two bending magnets which produce radiation that can be directly absorbed on the SCU cryostat as primary photons, a main bending magnet and a small minibend. The parameters of each can be found in Table 2.

Table 2: BM parameters each magnet per 100 mA

Bending Magnet	Bend Angle	Bending Radius	Power Produced
Main bend	77.5 mrad	39.41 m	6.65kW
Mini-bend	1 mrad	160 m	21.1W

The fraction of the produced power that is absorbed on the SCU is calculated by multiplying the fraction of the horizontal and vertical radiation fan that passes the PA and is incident on the top or bottom of the chamber. The horizontal fraction is calculated from $\theta_{PA}/\theta_{dipole}$ where $\theta_{PA} = 1.9mrad$ and $\theta_{dipole} = 77.5mrad$. The vertical opening angle is calculated by integrating $F(\gamma\psi)$ in equation 2[5]

$$\frac{d^2P}{d\theta d\psi} = \int_{\psi_1}^{\psi_2} \frac{1.44 * 10^{-18}}{\rho[m]} \gamma^5 F(\gamma\psi) d\psi, \quad (2)$$

where ψ is the vertical opening angle, θ is the horizontal opening angle and ρ is the bending radius of the dipole. Analytically primary photons deposit a maximum of 0.411 W of energy on the SCU. Simulations with synrad3d showed 0.290 W absorbed on the SCU, calculated from:

$$P = \text{Intensity} \times \text{Total Energy Absorbed} \times \text{Beam current} \quad (3)$$

The intensity is defined as the number of photons per electron divided by the number of photons simulated.

The simulation correctly integrates the photon energies along the chamber surface. The analytical estimate assumes a rectangular chamber, which overestimated the power by 35%.

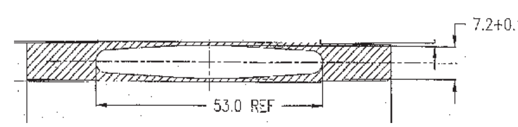

Figure 3: Cross section of SCU chamber.

Secondary Photons

Using equation 3 it is possible to calculate the power absorbed in the SCU by reflected photons. It was found that both PA designs provided the same amount of shielding from secondary photons, with 3.724 W and 3.773 W absorbed on the SCU from the old and new PA, respectively. Further analysis found that any photon that struck the PA was not absorbed in the SCU. This implies that the PA not only directly shields the cryostat but the slope on the PA directs the reflected photons away from the cryostat. This will be more fully discussed in a later section. Because none of the photons incident on the PA were absorbed on the SCU, and the total power on the cryostat is the same, both PAs are effectively able to shield the cryostat.

Effects on the Photon Absorber

Since both PAs provide the same amount of shielding, studies were done to compare the radiation effects on the PA. The old PA was pushed into the chamber 15.5 mm more then it was originally designed for. Therefore the leading edge of the PA is in the radiation fan from the main bending magnet. Using simple geometry, the outside edge of the radiation fan can be calculated. The old PA starts at x=44.07mm however the radiation fan stretches out to x= 60.1mm, this is shown in the large amount of power absorbed on the leading edge of the old PA in Fig. 4. The new PA was designed so that the leading edge is not in the bending magnet radiation fan. This keeps the PA from having a large radiation flux in a small section of the PA, rather the radiation is more spread out along the length, Fig. 4. Although the distribution is different the total power absorbed on either PA is within 3.6% of each other.

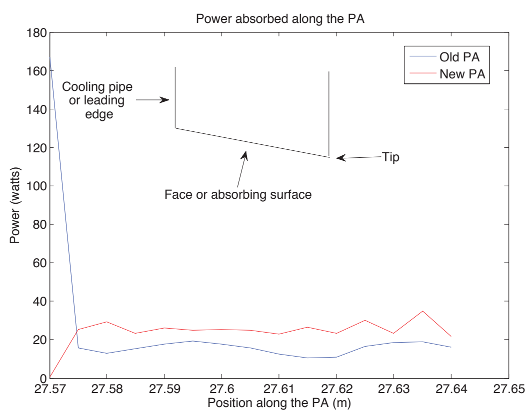

Figure 4: The power distributed along the length of the PA.

The angled PA means that the majority of photons strike with large grazing angles. The majority are incident on the PA with an angle equal to the PAs angle. Even photons that have reflected upstream on surfaces have grazing angles near the PA angle because the PA angle is large compared to the incoming photon angle. As seen in Fig. 5, each PA design has the majority of photons with a grazing angle equal to their angle, 19° for the old PA and 30° for the new PA. For the old PA with the photons reflecting off the cooling pipe, there is a flux of photons with near normal incidence angles. From Fig. 1 it can be seen that higher grazing angles means a lower reflectivity; therefore, around 97.5% of the photons incident on the PA are absorbed.

Table 3: Comparison of the old and new PA designs, per 100 mA

PA design	Total Power on the PA (W)	Percent of photons absorbed
Old	439.6129	97.52%
New	456.0181	97.3%

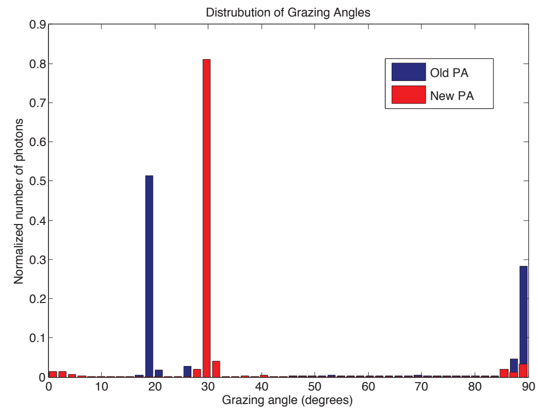

Figure 5: The grazing angle of photons incident on the PA.

SYNRAD3D MODIFICATIONS

Currently Synrad3d assumes a fairly smooth chamber surface [2]. However the surface of APS beam chamber has an rms roughness on the order of 200 nm. This rough surface will increase the diffuse photon scatters and the absorption of the photons. No diffuse scatters are currently being simulated. The photons absorbed in the SCU cryostat reflect off the chamber wall an average of 8.1 times before being absorbed. The rough surface increases the absorption rate of photons decreasing the number of reflections before they strike the cryostat.

CONCLUSIONS

Both PA designs are equally effective in reducing the secondary photon heat load. But due to the small angle of the old PA the leading edge is in the radiation fan from the main bending magnet. This high heat load on one section of the PA could decrease its effectiveness. This must be considered before finalizing the PA design.

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