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THERMOMECHANICAL ANALYSIS OF SESAME HIGH-HEAT-LOAD FRONT ENDS COMPONENTS

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Abstract

New front-end beamline components at SESAME are designed to handle the high heat load produced by the insertion devices. A mini gap wiggler will be installed for the Material Science Beamline and the front end will receive 5.0 kW of total power and 7.79 kW/mrad^2 of peak power density. The power produced by the insertion device was simulated using SynRad+[1], a software using Monte Carlo simulation to simulate the synchrotron radiation from either an insertion device or any magnet source. The surface power density distribution generated by this software can be mapped directly to an FEA software to conduct a coupled thermo-mechanical analyses. The design, modelling, power source simulation and FEA analysis of the fixed mask, shutter and filter for the material science Beamline front end will be presented in this paper.

INTRODUCTION

SESAME is a third generation light source located in Allan Jordan operating with a 2.5 GeV electron beam and a design current of 400 mA. A mini gap wiggler as a source for the material science beamline will be installed and can deliver a power of over 5.0 kW with a peak power density of 7.79 kW/mrad^2 at 12 mm magnetic gap. The design of the fixed mask, shutter and filter had been done to handle the high heat load generated from the wiggler source, the upstream and downstream dipole magnets, to protect the first optical components in the beamline.

POWER CALCULATION

Mini-Gap Wiggler Parameters

The mini-gap wiggler will be installed in one of the storage ring long straight sections and the gap will be adjusted to 12 mm, the wiggler parameters shown in table 1 and power distribution in Figure 1.

Table 1: Mini-gap Wiggler Parameters

Overall length	2 m
Minimum magnetic gap	8 mm
Period length	60.5 mm
Number of poles (Np)	63
Maximum field (B_{max})	1.84 T
Effective field (B_{eff})	1.63 T
Deviation parameter (K)	8.6
Critical energy (E_c)	7.0 keV

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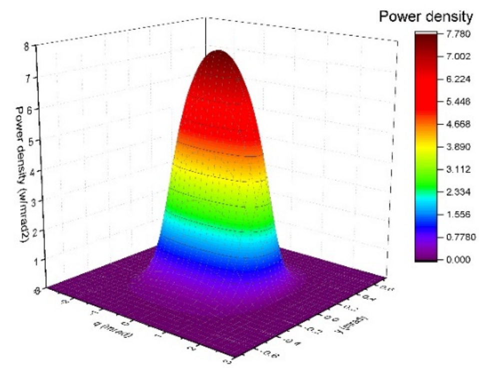

Figure 1: Power distribution of the mini gap wiggler at 12 mm gap.

Power Calculation

The power calculations had been done using SynRad+, a software using Monte Carlo simulation to simulate the synchrotron radiation from either an insertion device or any magnet source. The surface power density distribution generated by this software can be mapped directly to an FEA software to conduct a coupled thermo-mechanical analyses. The benefit from using this type of simulation is to take the whole length of the insertion device as a distribution of source points, which give us more accurate results than the traditional way of assuming one source point. Also, in this type of simulations, we can introduce the effect of the heat load produced by the upstream and downstream dipole magnets as shown Figure 2.

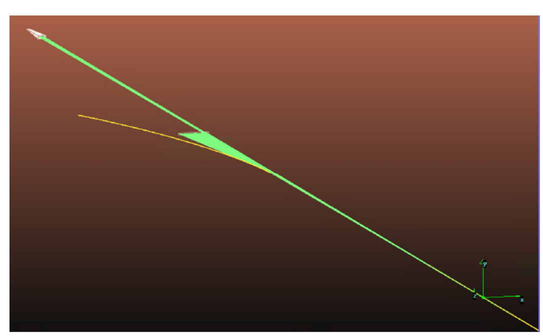

Figure 2: SynRad simulation for the wiggler source with upstream and downstream dipole magnets.

In order to have more accurate results, the tapered shape of the fixed mask had been introduced in the simulation and the power distribution has been calculated at each taper face. An example of the SynRad output is given in Figure 3 which shows the power distribution at the fixed mask from the wiggler and dipole magnet source.

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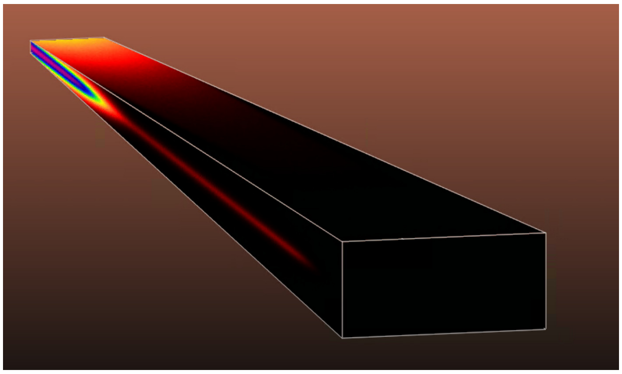

Figure 3: Power distribution at fixed mask, it shows the power distribution delivered from the wiggler and dipole magnet sources.

THERMAL ANALYSIS

Failure Criteria

Failure criteria of the fixed mask and photon shutter are used as [2]:

- The maximum stress in copper thermal absorber should be smaller than twice the ultimate tensile strength of the copper σ_{VM}^{max}<850 MPa for Glidcop.
- The maximum temperature on the Glidcop body temperature should be less than 300 °C.
- The maximum temperature on the water cooling channel walls should be less than water boiling temperature at channel pressure.

Fixed Mask

Fixed mask is the first high heat load components in front end to shape the beam coming from the mini gap wiggler. The fixed mask will be manufactured from a Glidcop ® Al15 block with a rectangular tapered tunnel fabricated using wire EDM technology to allow the beam to pass through. The tapered angle equal to 1.5° and had been defined in a way to allow the fixed mask to absorb half the total power delivered from wiggler, upstream and downstream dipole. There will be four grooved channels next to each surface defining the aperture to cool the fixed mask. Figure 4 shows the design of the fixed mask.

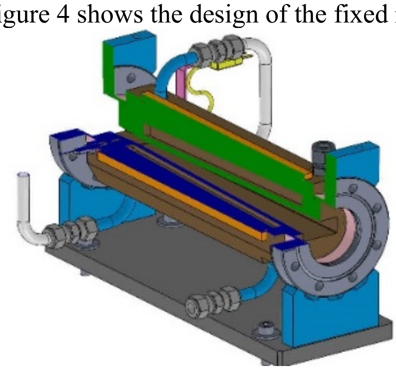

Figure 4: Fixed mask design sectional view.

The fixed mask will absorb a total power of 2.6 kW, the maximum temperature on the shutter body will reach 69 °C as shown in Figure 5, thermal stress peaks to 183 MPa corresponding to an equivalent total strain of 0.14%.

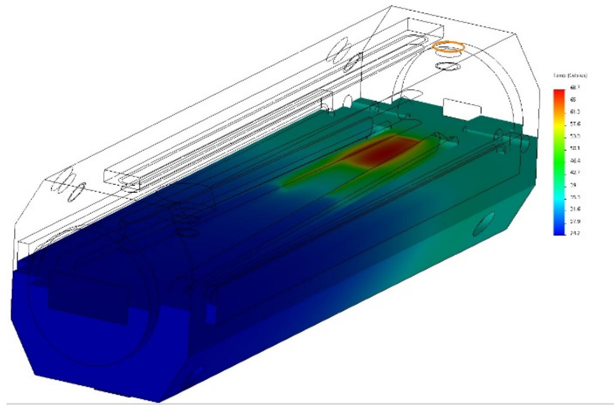

Figure 5: Fixed mask maximum temperature distribution.

Photon Shutter

The photon shutter designed in a way to protect the beamline downstream components from the synchrotron radiation either when the beamline is not in operation, in emergency case or when the beamline in service. The absorber design based on ESRF design [3] and consists of two brazed Glidcop ® Al15 blocks. There are two positions for the shutter: the first one, when the front end is open, allows the synchrotron radiation defined by the fixed mask to pass, the second one with the shutter closed will force the side water cooled tapered to absorb all the synchrotron radiation at incidence angle of 3°. Figure 6 shows the design of the photon shutter.

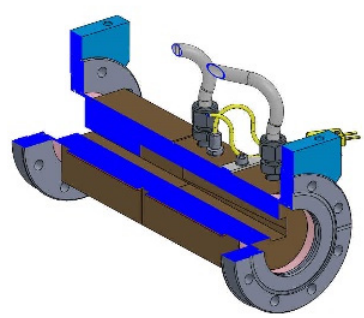

Figure 6: Photon shutter sectional view.

The shutter will absorb a 2.4 kW, the maximum temperature on the shutter body reaches 84 °C as shown in Figure 7, the thermal stress peaks to 137 MPa corresponding to an equivalent total strain of 0.105%.

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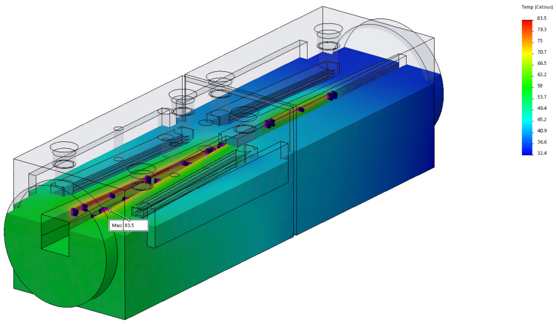

Figure 7: Shutter maximum temperature distribution.

Rotating Filter

The rotating filter is based on the SLS design [4] and is shown in Figure 8. The idea of the filter is to remove the soft X-rays and reduce the power which will be delivered to the first mirror. The rotating filter is a commercially available cylindrical crucible made from the glassy-carbon material Sigradur G [5], material properties listed in table 2. The filter is rotated using a drive shaft equipped with two bearings with silicon nitride ceramic balls [6].

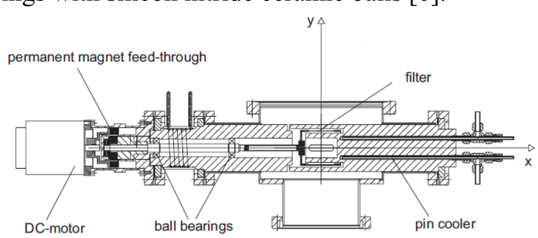

Figure 8: sectional view of rotating filter.

The drive motor is mounted outside the vacuum, and the torque is transmitted to the drive shaft via a permanent-magnet feed-through.

Table 2: Material Properties of Sigradur G

T (°C)	20	1000	2000
ρ (g/cm^3)		1.42	
K (W/m/°C)	6.3	11	12
α (°C^{-1})	$3x10^{-6}$	$4x10^{-6}$	$5x10^{-6}$
C_p (J/g/°C)	0.5	1.9	2.1
ε		0.3	
E (N/mm^2)		$3.5x10^4$	
S_f (N/mm^2)	260	>260	>260

The cooling of the carbon filter is achieved by radiation to affixed black-oxidized copper jacket (emissivity of 0.6) which is cooled via four 8 mm blind holes with inserted tubes for incoming and outgoing water. The filter thickness is 2 mm and the total power absorbed is equal to 1.6 kW, the maximum temperature of the carbon filter equal to 1240 °C and the copper jacket 94 °C as shown in Figure 9.

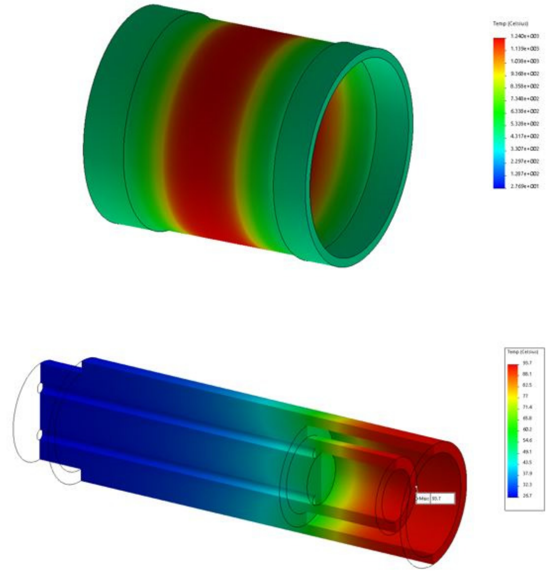

Figure 9: Filter cup and fixed jacket maximum temperature of 1240 °C and 94 °C respectively.

CONCLUSION

The design of the fixed mask and photon shutter has been done in order to handle the high heat power delivered from the mini gap wiggler. Glidcop material will be used for the body with side water cooling grooved channels. The power simulations have been done using SynRad and the results directly mapped to the FEA code which give us a very accurate results. The front end filter will be made of Sigradur G and will be cooled via radiation to a copper cooled mask.

The simulations show that the front ends components will be safe to be used for the mini gape wiggler source.

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[6] W. Kaika, GMN Paul Müller Industrie GmbH, D-90411 Nürnberg, Germany, http://www.gmn.de