COMBINED FIXED MASK, PHOTON SHUTTER, SAFETY SHUTTER, AND COLLIMATOR DESIGN FOR BXDS IVU AT THE CLS

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Abstract

The first shutter assembly outside of the Front End (FE) for Brockhouse X-Ray Diffraction and Scattering Sector (BXDS) beamline required a unique design solution to accommodate all components into the safety shutter position.

Located between the IVW high energy wiggler monochromator and POE1 wall, the total envelope size approximated 1 m x 0.660 m (LxW). Accommodating this smaller space required an alternative shutter design than traditionally used implemented at the CLS.

The alternative design combined the collimator (CLM), safety shutter (SSH), photon shutter (PSH) and Fixed Mask (FM) into one chamber. Finite Element Analysis (FEA) was conducted on the FM and PSH assembly to verify that geometric designs were adequate for reasonable operation in the beamline. FEA was used to determine the steady-state thermal and static-structural response in both operating positions. Missteer was analyzed for both operating positions to a maximum of 2.5 mm (commonly accepted missteer used at the CLS) from center. Finally, two extreme position (partially closed/open) analyses were completed for determination of potential, but unlikely operating conditions.

INTRODUCTION

The first In Vacuum Undulator (IVU) shutter assembly outside of the Front End (FE) for Brockhouse X-Ray Diffraction and Scattering Sector (BXDS) beamline required a unique design solution to accommodate radiation protection of the In Vacuum Wiggler (IVW) IVU secondary optical enclosures.

Located between the IVW high energy wiggler monochromator and the end of POE1, the total envelope size approximated 1 m in length and 0.660 m width. This space required the design and installation of a FM to protect and shield all downstream components, a PSH to absorb incoming beam, a SSH to close and isolate radiation for entrance into the downstream hutches, and a CLM to remove Bremsstrahlung radiation from escaping the IVU beamline. Accommodating a smaller space required an alternative shutter design than traditionally implemented at the CLS (Fig. 1). IVU shutter is located between 27 890 mm and 29 015 mm from the center of straight Cell 04. SPECTRA [1] was used to calculate the heat source data from parameters for the CLS Storage Ring (SR1) (with ring current 500 mA and field energy of 1 T).

The shutter precedes SOE2, POE2, and finally SOE3 along the beamline and has a total power absorption requirement of 1100 W (at 500 mA). The beam spot as seen by the combined shutter is directly apertured by Fixed Mask 3 from the FE.

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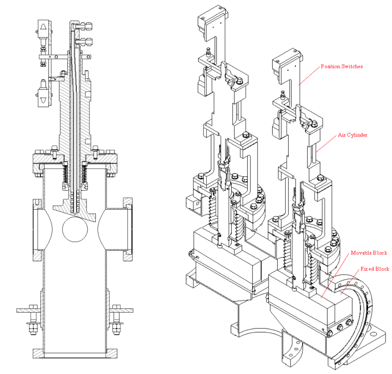

Figure 1: Typical CLS shutter designs. PSH (left) used most commonly in the FE is 300 mm in chamber length. SSH (right) used most commonly within the FE and POE of beamlines ranges between 500 mm–1200 mm in chamber length. And CLM (not shown) 400 mm in chamber length. Total length of a basic arrangement of these components exceeds the allowable space for the BXDS shutter location.

Design Objectives

The key design considerations for the shutter design, in addition the requirements stipulated within CLS Technical Specifications, are:

- The FM and PSH are combined into one component that will act as a photon absorbing surface as well as protection for the CLM/SSH.
- The SSH and CLM have been combined so that as one they block Bremsstrahlung radiation. The SSH must have a movable tungsten block directly in front of the collimator to prevent unintended Bremsstrahlung to pass by when in the closed position.

The FM-PSH must satisfy two operating positions:

- Open – allowing beam to pass through with clearance, while shielding IVW SOE2.
- Closed – stopping all beam energy produced from the IVU and missteered IVW rays. Stopping all associated radiation from the SOE2, POE2, and SOE3 enclosures.

PSH/SSH Requirements at the CLS

The below requirements are particularly important to the safety shutter set (PSH & SSH). The final design needed to ensure that both sets of requirements for the photon and radiation absorbing materials meet facility design expectations.

From "CLS Photon & Safety Shutter Design Specification 8.4.41.1 – Rev. 0" [2]:

- Transition from the open to the close position of either SSH or PSH must occur within 1 second.
- The PSH and SSH must be designed as 'fail safe'; loss of air pressure, electrical power, and/or external forces (atmospheric) must result in the absorber moving to the closed position

From "CLS Guideline for Analysis of Synchrotron and Electron Beam Absorbing Components 8.1.69.1 – Rev. 0" [3] Specific CLS facility cooling water properties are:

- Density: $971\,\mathrm{kg\,m^{-3}}$
- Specific Heat: $4179\,\mathrm{J\,kg^{-1}\,°C}$]

CLSI Facility Limits:

- Velocity: <=5 m/s
- T <= 10 °C (using bulk temp rise equations)

Heat load of the IVU beam was estimated using SPECTRA resulting in a power load of 1.1 kW. The allowable thermal film coefficient found from the cooling calculations is $10.475\,\mathrm{W^2\,m^{-1}}$ W/m2 with water supply velocity of 2.1m/s as per the CLS expected design requirements.

DESIGN SOLUTION

Combination of FM-PSH, SSH, & CLM

The design combined the CLM, SSH, PSH and FM into one chamber (Fig. 2). The total length of the chamber assembly is 680 mm with 6" CF flanges for entrance and exit ports. The chamber includes the basic regiment of CCG/TCG and rouging ports. The Ion Pump port (8" CF flange) accommodates a $300\,\mathrm{l\,s^{-1}}$ Varian Starcell, mounted from the bottom of the chamber.

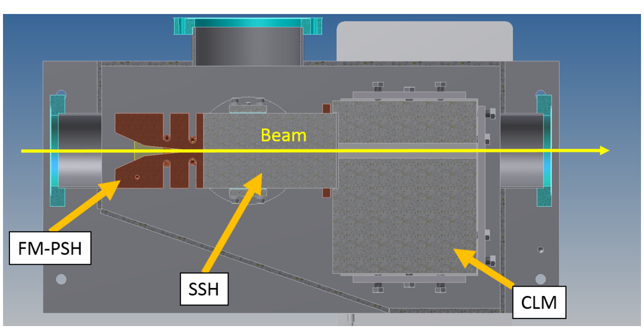

Figure 2: Plane view showing internal layout of the combined shutter. Beam passes left to right through the chamber.

The open position allows for all desirable IVU beam to pass through the combined shutter. The beam proceeds through the white beam transport, into the POE2 enclosure and finally into the SOE3 endstation. The closed position stops the beam and radiation from leaving POE1, while not hindering IVW operation.

To accommodate access to the chambers internal components, the lid is removed from above (Fig. 3). This arrangement was required after the shielding calculations for the IVW High Energy monochromator were complete. The interface between the location of the shielding and the required IVU CLM width was extremely snug. The required configuration allows access to the chamber without removing lead shielding, that would affect operation for the IVW high energy beamline.

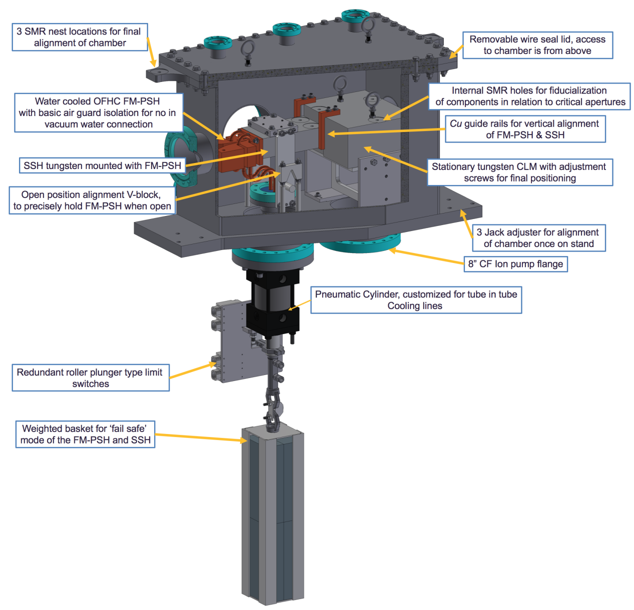

Figure 3: Illustration showing combined shutter design. Details are listed for unique design features.

The combined shutter includes a vacuum air guarded interface for the cooling water supply channels, preventing an in vacuum water connection.

An RTD is located on the surface of the FM-PSH for use in assessing the amount of heat absorbed on the FM-PSH during normal operation.

The combined shutter procurement was awarded to RMD Engineering (Saskatoon, Saskatchewan). Fabrication is estimated to complete Nov. 2016. Installation and testing to be completed during the CLS Winter shutdown.

FEA VERIFICATION

Methodology

Finite Element Analysis (FEA) using ANSYS 17.0 was conducted on the FM-PSH assembly to verify that geometric designs were adequate for reasonable operation in the beamline. FEA was used to determine the steady-state thermal and static-structural response in both operating positions. Missteer was analyzed for both operating positions to a maximum of 2.5mm (commonly accepted missteer used at the CLS [2] from center. Finally, two extreme positions (5 mm open and closed) analysis were completed for determination of potential, but unlikely operating conditions.

Analysis for the FM-PSH was performed on the full part and cooling water lines. With case by case specified target surfaces for imported heat flux. Heat flux data was calculated from SPECTRA, using beamline parameters for the IVU, and projected onto the FM-PSH model.

Grazing angle scaling was completed using APDL scripts to more accurately represent actual heat absorption. The main grazing surface (sides) is 6.04° from the sagittal (YZ-plane). The secondary grazing surface is 24.23° from the sagittal plane. The tertiary grazing surface is 3.01° from the sagittal plane. The root of the absorber is semi-cylinder in shape and was estimated to approximate the secondary surface angle. Heat flux was imported into workbench from SPECTRA derived files. Realistic heat source dimensions as defined by the FE FM3 are approximately 9.84 mm x 3.48 mm at the combined shutter location (28 524 mm from ID source).

Results

Fully closed the beam absorption resulted in acceptable values (Fig. 4) as described by the CLS Technical Specifications [2].

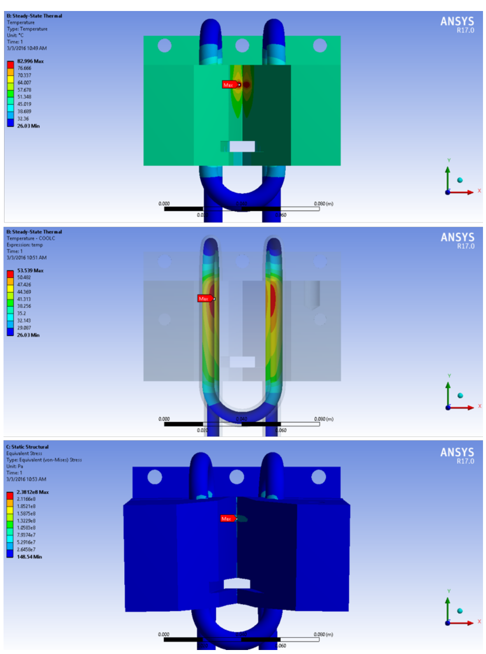

Figure 4: Fully closed results with maximum temperature (top) found to be 83 °C, cooling channel maximum temp of sidewall 54 °C, and maximum vonMises Stress 240 MPa of the OFHC FM root.

Missteer scenario, the beam is only partially absorbed resulting (Fig. 5) in heating along the edge aperture of the FM-PSH, still within acceptable CLS specifications [2]. Beam projections were rigidly transformed within ANSYS to apply heat flux load.

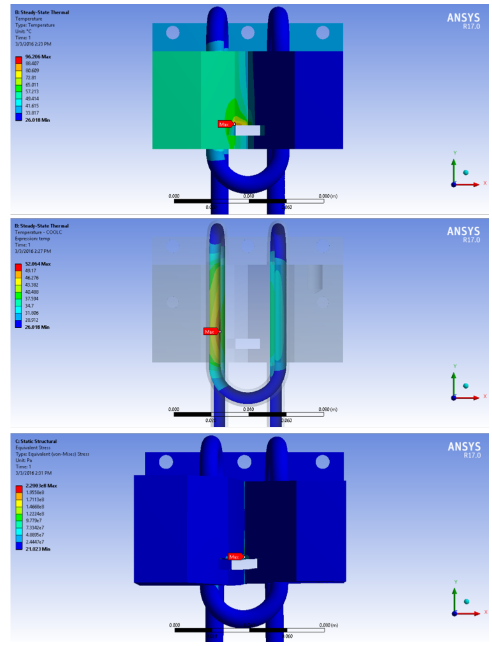

Figure 5: Partially open with missteer results with maximum temperature (top) found to be 97 °C, cooling channel maximum temp of sidewall 52 °C, and maximum vonMises Stress 220 MPa of the OFHC FM root.

CONCLUSION

The combined shutter design offers beam and radiation absorption in a considerably smaller space when compared to conventional CLS designs. The design and FEA provided verification of heat mitigation when the shutter experiences closed, open and missteer conditions.

ACKNOWLEDGMENT

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REFERENCES

[1] SPECTRA (version 10.0.7 64bit) `http://radiant.harima.riken.go.jp/spectra/`

[2] “CLS Photon & Safety Shutter Design Specification 8.4.41.1 – Rev. 0“, Canadian Light Source Inc., Saskatoon, Saskatchewan, Canada

[3] “CLS Guideline for Analysis of Synchrotron & Electron Beam Absorbing Components 8.1.69.1 – Rev. 0“, Canadian Light Source Inc., Saskatoon, Saskatchewan, Canada