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FRONT END PHOTON SHUTTER WATER LEAK TO VACUUM AT THE CANADIAN LIGHT SOURCE

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Abstract

A leak in the Hard X-Ray MicroAnalysis (HXMA) front end (FE) Photon Shutter (PSH1) absorber was found and temporarily repaired with no delay in returning the CLS to normal operations. The leak was caused by a large amount of erosion to the interior surface of the cooling channel, due to excessive flow rates (>7.0 m/s). Similar photon shutters currently operating under similar conditions are at risk to fail (19 photon shutters in total). Due to damage they may have sustained operating under similar operating conditions, photon shutters of this design currently in service should be either examined or replaced.

INTRODUCTION

Leak Discovery & Repairs

July 2nd, 2016 Accelerator Operations and Development (AOD) discovered a vacuum event at the Canadian Light Source (CLS) for Storage Ring (SR1) cell 6. Initially, the event was believed to be a air leak located in either the SR1, Soft X-ray for Microcharacterization of Materials Beamline (SXRMB) FE, or the HXMA FE.

A collaborative decision was made to wait to find the exact location of the leak. The mechanical technicians first activated a scroll pump in an attempt to pump down the affected section. Water was discharged from the exhaust of the scroll pump, which indicated the water leak. After determining that the leak had originated in the HXMA FE, the technicians identified which components may have failed. By the afternoon, they had discovered a small pinhole leak on the absorber head of the first HXMA photon shutter (Fig. 1).

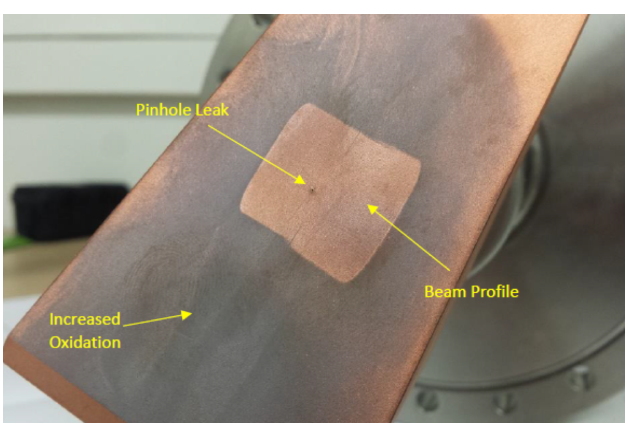

Figure 1: Illustration of the pinhole leak discovered on HXMA PSH1. Leak location is aligned precisely with water jet location of the tube in tube cooled absorber.

HXMA Front End Photon Shutter

Estimated heat load for the absorber was found to be 200 W–300 W (for 250 mA ring current). Fortunately, a spare photon shutter previously ordered for the Industry Development, Education, Applications, and Students (IDEAS) beamline was available that satisfied the heat load requirements. The replacement was a Phase II type photon shutter. Technicians oversaw the initial bakeout of affected components (lasting four days). The electron beam was activated to further improve the vacuum quality, using four injections per day to maintain current in the SR1. Equipment testing continued until July 12th, at which point the CLS resumed regular operation. The leak delayed standard start up procedures performed by AOD at the end of the shutdown by seven days, but beam was available to users as scheduled. The PSH1 had been operational since HXMA was commissioned in 2006 (Fig. 2). This type of absorber is similar to a Advanced Photon Source (APS) design and is used to stop bend magnet radiation from the SR1 dipoles when the HXMA Insertion Device (ID) and beamline are turned off. Cooling for the component is provided by running water

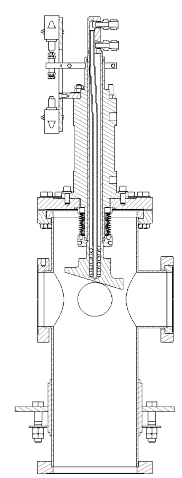

Figure 2: PSH1 absorber style from the front end location of HXMA beamline. The beam path as the absorber is shown is from left to right, with absorption of photon energy along the grazing surface of a tube in tube OFHC absorber.

through the head of the absorber. The leak developed at (or very near) the centre of the absorber's face (Fig. 1). There are six other photon shutters that employ this exact same design currently in use at CLS. There are also 12 photon shutters that are derivatives of this design. Their cooling system and operational parameters are almost identical. Therefore, it is necessary to identify why failure occurred, how it can be prevented, and/or if other components are at risk to fail.

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BACKGROUND

PSH1 Cooling

The HXMA PSH1 used cooling water supplied by the SR1 low conductivity cooling water (LCW). The maximum supply pressure is 150 psi, and the return is 35 psi. Table 1 details the flow parameters through the PSH1 at the time of failure. These flow parameters have been employed since 2011 for all PSHs of the same design within the CLS SR1. The cooling water system for the SR1 was not filtered for the first eight years of operation. A filter system was put in place in 2013. Since the installation, 24 filter bags of fine grain sediment have been removed from the cooling water system. It is not clear how long the sediment was travelling through the water pipes or the effect it had on the system. The sediment may have promoted erosion in the pipes by acting as an abrasive agent or removing the passivated oxidized layer and increasing corrosion.

Table 1: Flow Parameters through HXMA PSH1at the time of failure. Retrieved from CLS data archive and flow meters for the PSH

Parameter	Value
Flow Rate [kg/s]	0.21
Inner Tube ID [mm]	6.35
Inner Tube OD [mm]	9.525
Outer Tube ID [mm]	20.8
Supply Velocity [m/s]	7.12
Return Velocity [m/s]	0.82
Supply Re	55,000
Return Re	15,000
Pressure Drop [psi]	61

INVESTIGATION OF FAILURE

The PSH1 was cut apart to reveal its interior structure (Fig. 3). After visual inspection and discussions, cause was suspected to be degradation of the copper walls due to corrosion, erosion, or impingement damage. Operating conditions of HXMA PSH1 (at >7.12 m/s) exceeded CLS's maximum flow velocity standard of 2.5 m/s [1]. The typical maximum operating velocity of any cooling water channel in the facility is set at max 2.5 m/s.

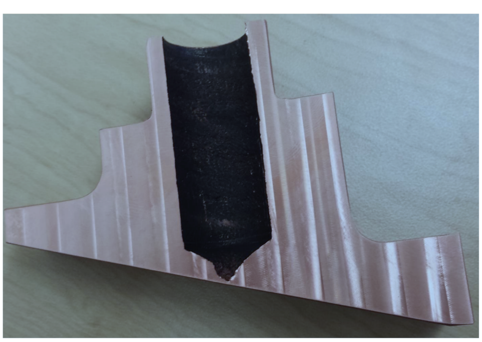

Figure 3: Section cut of failed PSH1, used to investigate extent of damage and location of erosion.

The HXMA PSH1 is based off of the APS design (Fig. 4). Jeffrey T. Collins, an APS employee, was contacted to determine if this style of photon shutter had a history of leaking. He was the lead author on a paper detailing the heat transfer benefits of using a coil insert for high heat load components [2]. APS has not dealt with such an issue before, but Jeffrey provided CLS with a report on a RF window that had suffered a pinhole water leak into vacuum [3]. The report explains that the RF window's cooling water caused large erosion-corrosion on the copper walls due to excessive flow rates (>5.3 m/s). The inner surface above the coil insert has random pitting. There is no distinguishable pattern that suggests the motion of the water was anything but chaotic. Further upstream from the coil insert, the etch marks are thicker, with longer black lines intermixed with the copper. Closer to the coil, however, the etch marks are smaller and closer together.

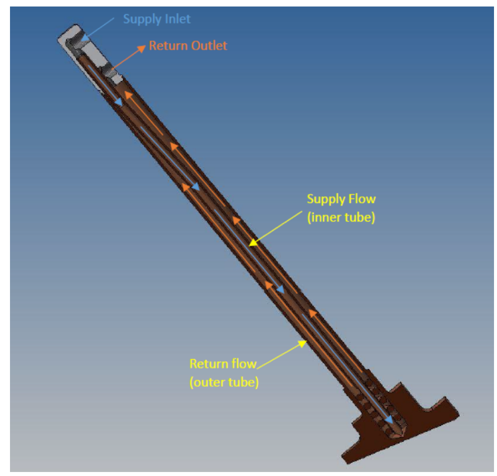

Figure 4: Illustration of the tube-in-tube configuration of PSH1. Cooling water enters from the inner tube and exits the outer tube passage.

At the very top of the coil, a hole on the wall of the inner tube formed, allowing water to escape into the return flow without travelling to the base cavity. The hole is roughly 4 mm long and 3 mm wide. The holes sits directly beneath the end of the coil (Fig. 5). There is significant material degradation around the hole and the pipe wall is very thin.

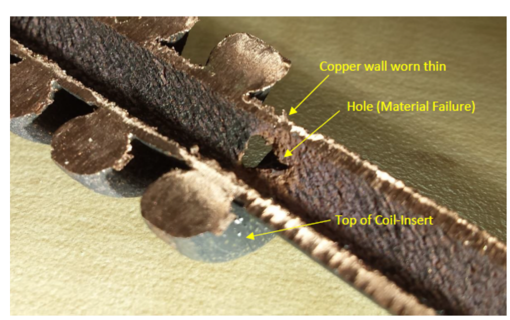

Figure 5: Section cut of eroded inner copper tube.

Facility Design and Updates

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DISCUSSION

The large amount of pitting was most likely caused by erosion-corrosion. The velocity of the water (7.2 m/s) was nearly three times the maximum recommended speed [1]. Excessive speed creates high amounts of turbulence that strips away the walls of the pipe. This was evidenced by the extensive pitting inside the inner tube, and smooth surface of the outer tube (where the velocity was reduced to 0.82 m/s). Inside the base cavity, where the supply flow makes contact with the inner absorber cavity, the erosion had a spiral profile. The disfigured surface at the base of the cavity appeared to be eaten away by a high velocity stream or vortex. Large amounts of localized turbulence can attack the pipe wall and absorber, carrying away material leaving a pitted surface [4].

The high velocity jet may have also caused cavitation on the inner surface of the absorber. Cavitation is the implosion of vapour suspended in a liquid against the surface of its container. The implosion of vaporous cavitation bubbles can cause significant pitting [5, 6]. Further analysis is recommended to determine the exact failure mechanism within the HXMA PSH1.

The mechanism causing failure of the sidewall (Fig. 5) is not well understood. Its effect on the system is difficult to determine for the following reasons:

1. 1. The hole formed at an unknown time in the absorbers' operation.
2. 2. The rate at which the hole grew cannot be determined.
3. 3. The flow pattern, velocity, and pressure drop due to the hole are unknown.

It is clear, however, that the location that the hole formed was unique. The hole sat right at the end of the coil, near a change in diameter on the outside of the tube. The pattern of erosion/corrosion on the inside surface changed abruptly on either side of the hole.

The hole may have formed for a multitude of reasons. There may have been localized turbulence as the fluid exited the spiral, increasing the rate of erosion-corrosion. Faulty brazing/soldering work between the coil insert and the tube may have weakened the tube wall. The hole may have formed along the edge where the tube diameter changed creating a larger stress concentration.

CONCLUSION

The HXMA PSH most likely failed due to excessive fluid velocity (7.12 m/s). This was evidenced by the inner pipe's extensive surface damage and the spiral crater that formed at the base of the absorber. The high velocity fluid resulted in erosion and/or erosion-corrosion within the pipe. A troublesome finding was observed with the sidewall hole within the inner pipe. The effects of this hole are not well understood and require further analysis.

The photon shutter's design is susceptible to erosion if excessive flowrates are used. The inner tube was too narrow to supply the necessary flowrate without exceeding CLS's maximum fluid velocity. The narrow tube's outlet created an impinging water jet on the absorber head that may have increased the rate of erosion.

Recommendations

To prevent further degradation in similar photon shutters, flow rate should be evaluated to determine if a lower velocity is adequate (reducing the likelihood of similar HXMA PSH1 failures). Continuing to operate under current conditions may lead to further absorber failures, water leaks, and vacuum leaks. Due to damage they may have sustained operating under similar operating conditions, PSH of this design currently in service should be either examined or replaced at the CLS's earliest convenience. PSHs installed during the Phase II expansion are similar in design and operating conditions; flow velocity settings should be reviewed, but these absorbers may not need replacement.

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