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The Design of a New Coaxial Water Cooling Structure for APS High Power BM Front End Photon Shutters

J. Chang, D. Shu, J. Collins, D. Ryding and T. Kuzay*

Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439 U.S.A.

ABSTRACT

A new UHV compatible coaxial water cooling structure has been designed for Advanced Photon Source (APS) high power bending magnet front end photon shutters. Laser-beam-thermal-simulation test results show that this new cooling structure can provide more than 1.56 kW total power cooling capacity with 12.3 W/mm^2 maximum surface heat flux. The maximum surface temperature will be lower than 116^{o}C.

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Design of a new coaxial water-cooled photon shutter

J. Chang, D. Shu, T. Nian, J. Collins, D. Ryding, and T. M. Kuzay

Argonne National Laboratory, Advanced Photon Source
9700 South Cass Avenue, Argonne, IL 60439-4815

ABSTRACT

A new ultra-high-vacuum (UHV) compatible coaxial water cooling structure has been designed for the Advanced Photon Source (APS) high-power bending-magnet (BM) front-end photon shutters. Laser-beam thermal-simulation test results show that this new cooling structure can provide more than 1.56 kW total power cooling capacity with 12.3 W/mm^2 maximum surface heat flux. The maximum surface temperature will be lower than 116 °C.

1. INTRODUCTION

The 7-GeV APS now under construction at Argonne National Laboratory (ANL) will be commissioned by 1995. At that time, the APS will have completed five insertion device (ID) and 16 BM front ends. The photon shutters are critical components of the BM front ends.[1] They protect the downstream vacuum valves and the safety shutters, which are not cooled, from damage by the high-power BM beam. The photon shutters are interlocked to close before closing the safety shutters and to open after opening the safety shutters.

There are two photon shutters in each BM front end. The first photon shutter is closer to the BM source than the second photon shutter and has to handle 1560 W total power with 12.3 W/mm^2 maximum power density corresponsive to 300 mA operation at 7 GeV particle beam energy.

2. DESIGN REQUIREMENTS

The photon shutters are designed to absorb the heat load from the 7-GeV, 300-mA BM source and operate for 100,000 thermal cycles without fatigue failure. The photon shutters should be able to close in 1 sec to protect the downstream fast valve against exposure to the high density heat load for more than 1 sec. Because the photon shutters are devices crucial to both the personnel and equipment safety, fail-safe design and the ability to indicate their fully opened and closed positions are critical. To assure the integrity of the UHV systems, water and vacuum joints are prohibited. Besides, the photon shutters must be compact in height so that they will fit into the BM front ends. Both the first photon shutter and the second photon shutter have been designed exactly the same to reduce costs.

3. PHOTON SHUTTER STRUCTURES

The photon shutter (as shown in Fig. 1) consists of three subassemblies: a cooling assembly (1), an actuator assembly (2), and a vacuum chamber assembly (3).

As shown in Fig. 2, the cooling assembly consists of eight components. The cooling block and tube (1) is made of one piece OFHC (oxygen-free-high-conductivity) copper. The interface stainless steel tube (2) is electron-beam welded to the cooling block and tube and is TIG (tungsten-inert-gas) welded to the 4-1/2" rotatable conflat flange (3). A copper mesh (8) developed at ANL is formed to the annular shape. Then, the sharp end of the inner tube (7) is press fitted into the through hole of the copper mesh and pushed inside the cooling block and

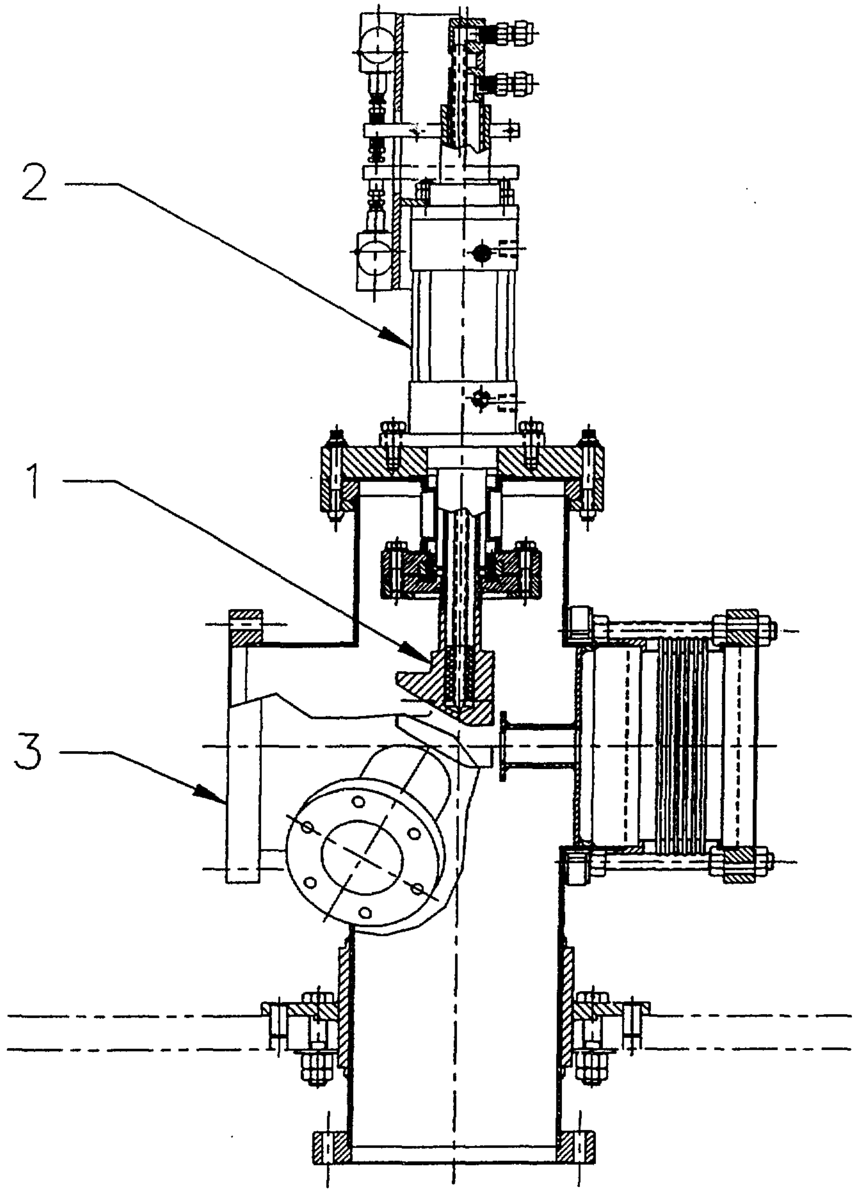

Fig. 1. Photon shutter of the APS BM front end: (1) cooling assembly, (2) actuator assembly, (3) vacuum chamber assembly.

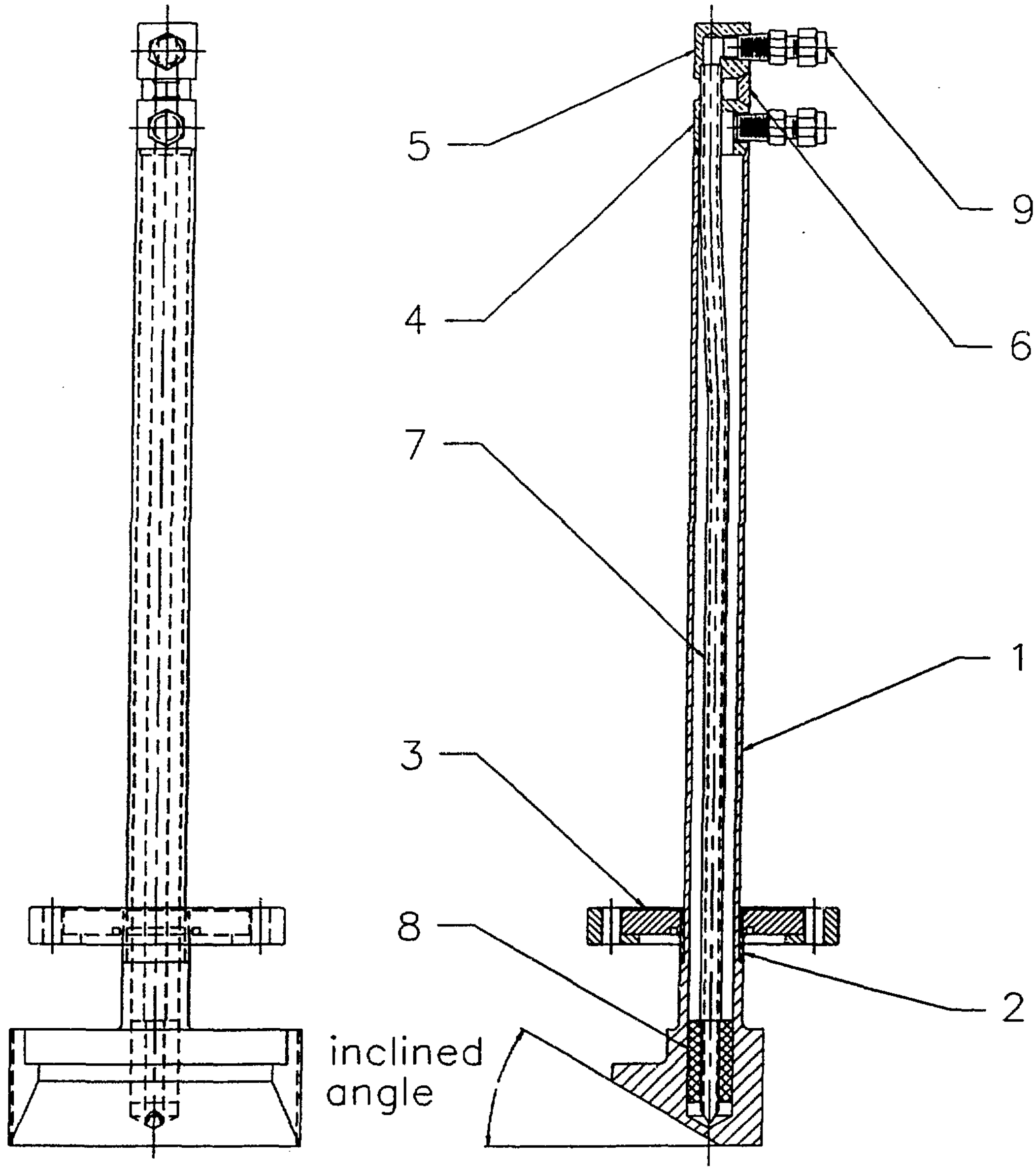

Fig. 2. Cooling assembly of the APS BM front photon shutter: (1) cooling block and tube, (2) interface stainless steel tube, (3) rotatable conflat flange, (4) exit port, (5) entrance port, (6) port support, (7) inner tube, (8) copper mesh.

tube. Finally, the exit port (4), the entrance port (5) and the port support (6) are welded to form a one-way flow path. Notice that all the water-sealed welding joints are not on the vacuum side of the flange. The male connectors (9) must be disconnected before assembling the cooling assembly with the actuator assembly.

The actuator assembly (as shown in Fig. 3) consists of seven major components. The pneumatic actuator (1) is a double-rod-end cylinder with a hollow rod of 1-3/8" O.D. and 1" I.D. The mounting plate of the actuator subassembly sits on the 8" conflat flange of the bellows and flanges weldment (2). The 4-1/2" conflat flange is connected to the rod by rod clamps (3), which grasp at the v-groove of the cylinder rod. The switch position clamps (4) are located at the rectangular groove at the upper end of the rod. On the switch position clamps, there are four adjusting screws (5), which can be adjusted individually and locked in position by the jam nuts. Each one of these four screws can activate one of the four mechanical limit switches (6) on the switch mounting bracket (7). There are two limit switches at both up and down positions to provide redundant signals for the safety interlock systems. In case of power failure or air failure, vacuum force and gravity force will close the photon shutter so that it is fail safe.

The tube portion of the cooling assembly can pass through the hollow rod of the actuator assembly. These two assemblies are connected by the 4-1/2" flanges and are mounted on the top flange of the vacuum chamber. In conclusion, the design allows the individual replacement of the cylinder, bellows and flanges weldment, or cooling assembly, if any one of them is not functioning. Also, the design shortens the total length of the photon shutter by putting the bellows inside the vacuum chamber and by passing the cooling tube through the hollow rod.

4. COAXIAL WATER COOLING

The coaxial cooling structure of the cooling assembly is a new design that combines jet cooling and mesh enhanced heat transfer. Cooling water flows into the inner tube from the entrance port of the cooling assembly. Then, the water flows out of the inner tube from its two side openings of the chamfered end. Making a 180-degree turn, the water flows into the coaxial annular passage formed by the inner tube and the outside hole. A jet flow has formed at this moment, and it greatly enhances the convective heat transfer locally. An OFHC copper mesh, which fills the gap between the two coaxial tubes, also helps create an effective turbulent flow and increased heat transfer surface, thus increasing the convective heat transfer throughout the length of the mesh.[2] Chamfering the end of the inner tube will assure that the water flow never is blocked even if the inner tube is pushed against the bottom of the hole. Machining a step on the O.D. of the inner tube is to prevent the mesh from being flushed up by the water.

5. THERMO-MECHANICAL ANALYSIS

The x-ray beam has a Gaussian profile in the vertical direction, as shown in Fig. 4. The narrow high density beam striking the photon shutter will result in high localized temperature gradients and even higher localized thermal stresses. ANSYS finite element analysis has been performed to predict the maximum temperature and maximum effective stress of the first photon shutter. The maximum power density at the second photon shutter is only about 60% of the first photon shutter; therefore, no new thermal analysis is needed for the second photon shutter.

We analyzed four designs to evaluate the effectiveness of the inclined surface angle of the cooling block. Tables 1 and 2 show the calculated results for h (convective heat transfer

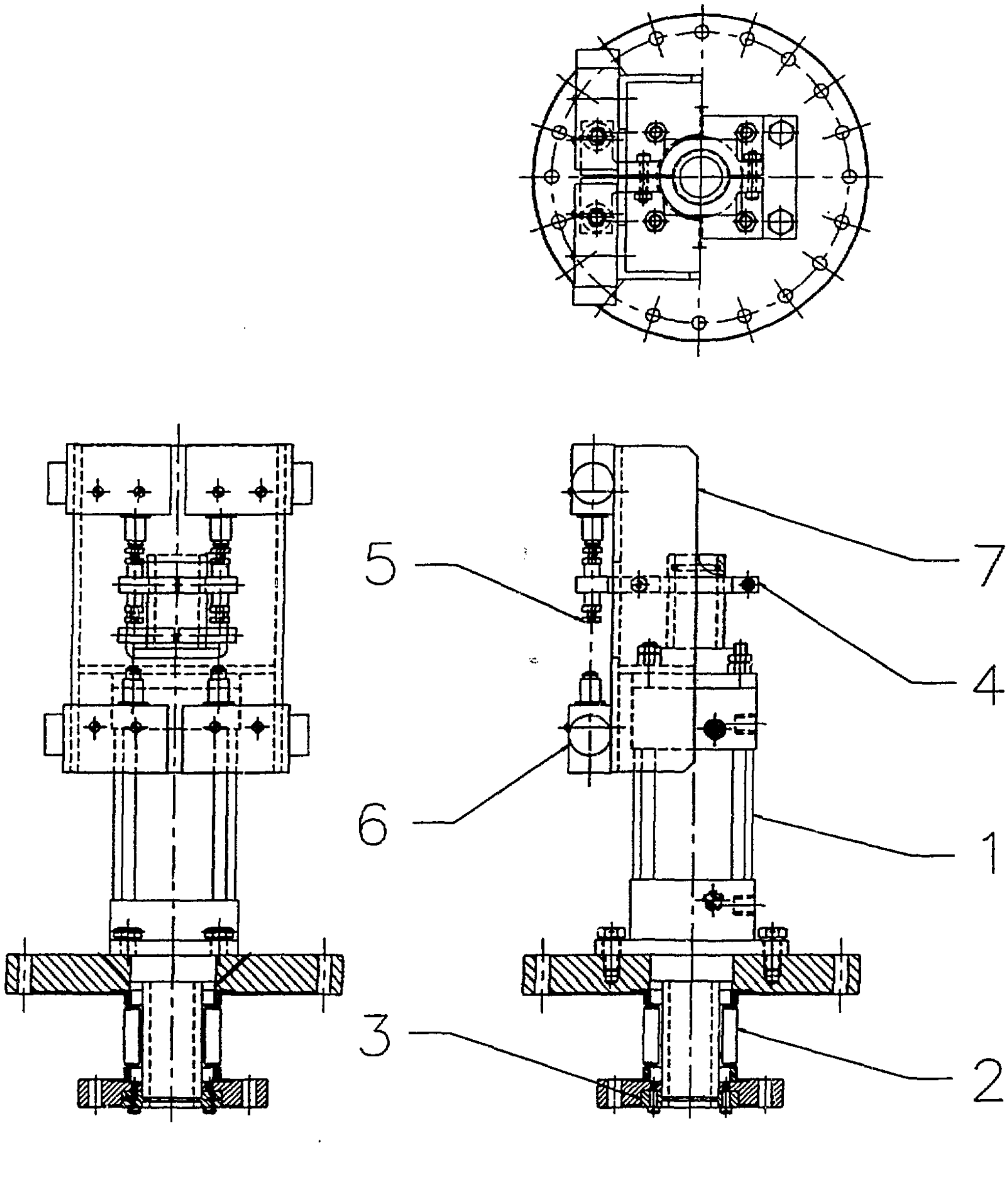

Fig. 3. Actuator assembly of the APS BM front end photon shutter: (1) pneumatic actuator, (2) bellows and flanges weldment, (3) rod clamps, (4) switch position clamps, (5) adjusting Screw, (6) mechanical limit switch, (7) switch mounting bracket.

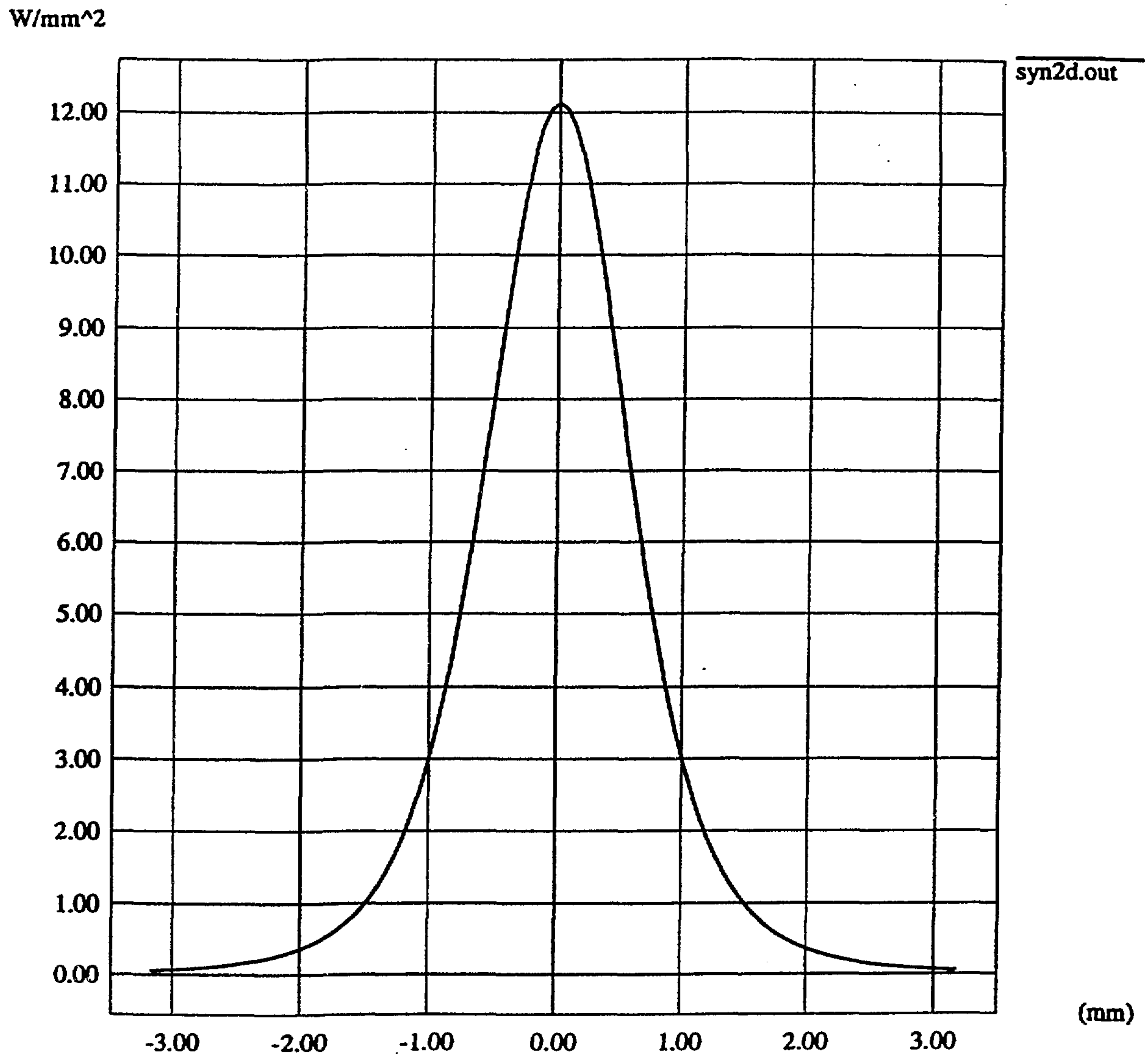

Fig. 4. Power density of the X-ray beam at 13.9 m from the 7-GeV and 300-mA, APS BM source.

coefficient) of 1 W/(cm^2 · ^{o}C) and 2 W/(cm^2 · ^{o}C) respectively. The inclined angles reduce the thermal gradient, thus, reducing the thermal stress from 16.5 ksi to 14 ksi. However, the maximum temperature drops only 7 ^{o}C. By increasing h from 1 W/(cm^2 · ^{o}C) to 2 W/(cm^2 · ^{o}C), the maximum temperature decreases 20 ^{o}C as shown in Table 3. There is no significant change in the maximum temperature for h greater than 2.

Decreasing the maximum temperature will increase the thermal fatigue life of oxygen-free copper (OFC).[3] For example, the fatigue strength of an OFC bar is about 23 ksi for 10^5 cycles at 100 ^{o}C and about 21.7 ksi for 10^5 cycles at 150 ^{o}C (the data were extrapolated). Therefore, a copper mesh must be used in this design to enhance the convective heat transfer.

Table 1. Calculated maximum temperatures and the maximum effective stress [h = 1 W/(cm^2 · ^{o}C)]

Design	Inclined Angle (^{o})	Maximum Temperature (^{o}C)	Maximum Effective Stress (ksi)
A	90	144	16.5
B	30	138	14.2
C	40	137	15.7
D	60	137	16.0

Table 2. Calculated maximum temperatures and the maximum effective stress [h = 2 W/(cm^2 · ^{o}C)]

Design	Inclined Angle (^{o})	Maximum Temperature (^{o}C)	Maximum Effective Stress (ksi)
A	90	123	16.5
B	30	117	14.5
C	40	116	14.0
D	60	117	16.0

Table 3. Predicted the maximum temperatures for design C at different values of the convective heat transfer coefficient "h"

Convective Heat Transfer Coefficient h [W/(cm^2 · ^{o}C)]	Maximum Temperature (^{o}C)
1	137
2	116
3	112
4	109

6. TEST RESULTS

A prototype of the cooling assembly (design C) has been built to verify the design. We used a 6.7 kW CO_2 laser with a 91 mm x 1.5 mm beam size to simulate the thermal load of x-rays at 13.9 m from the BM source. In order to exclude the heat loss from reflection and air convection, we measured the power absorbed by the cooling water. The actual laser beam power is about 30% higher. The maximum temperature of the cooling block is measured by an infrared video camera.

Table 4 shows the test results of the water flow rate versus the maximum temperature at 1.56 kW. Comparing analysis prediction in table 3 and test results in table 4, we find that an effective *h* of 2 W/(cm^2-^{o}C) at 2.5 gpm flow rate can be achieved.

Table 4. Test results of the maximum temperatures at different water flow rates

Water Flow Rate (gpm)	Maximum Temperature (^{o}C)
1.0	137
1.5	127
2.0	121
2.5	115
3.0	112
4.0	109

7. DISCUSSION

From the analysis and test results, we conclude the design of the photon shutter cooling assembly is adequate for the BM to operate at 7 GeV and 300 mA. A prototype of the photon shutter assembly is planned to be completed by the summer of 1993. Full scale tests will be carried out thereafter.

8. ACKNOWLEDGMENTS

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9. REFERENCES

1. D. Shu, J. Barraza, T. Sanchez, R. W. Nielsen, J. T. Collins, and T. M. Kuzay, "Front end designs for the 7 GeV Advanced Photon Source," *Nuclear Instruments and Method in Physics Research,* Vol. A319, pp. 63-70, North-Holland, 1992.

2. T. M. Kuzay, J. T. Collins, A. M. Khounsary, and M. Gilberto, "Enhanced Heat Transfer With Wool-Filled Tubes," *ASME/JSME 3rd Joint Heat Engineering Conference,* Reno, Nevada, March, 1991.

3. Hitachi Cable America Inc., "Hitachi Oxygen Free Copper, Application Technology."