[1]Wide-angle monochromatic x-ray beam shutter: a design study

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ABSTRACT

A novel design of a wide-angle monochromatic x-ray beam shutter is discussed. The shutter is designed as a compact unit capable of providing users with the means of shutting off the beam in secondary beamlines that are at an angle to the primary beamline and to each other. The single-unit design used the fact that all the secondary beamlines will be closed at the same time. The main challenge was to fit the shutter in the limited space of the existing Advanced Photon Source IMMW-CAT hutch. Space limitations led to the change in position of the actuator subassembly as compared to the standard shutter design. Although the actuator subassembly is placed underneath the shutter, fail-safe shutting is achieved by placing tungsten blocks above the beam while the shutter is open and using gravity to close the shutter in case of pneumatic failure. Redundancy required by safety concerns was achieved by duplicating the tungsten block/actuator subunits. Tungsten blocks of uneven length were used to counteract the increase in the center-to-center distance among secondary beamlines due to their angular offset. A special support table was designed to facilitate assembly and adjustability of the shutter position in the available space. To provide a radiation-tight hutch, a non-standard guillotine system was designed. In this paper, the design, specifications and optical ray tracing of the shutter assembly are presented.

1. INTRODUCTION

The IMMW-CAT at Argonne's Advanced Photon Source employs a transmission diamond as its primary monochromator in order to allow two experiments to run simultaneously, one using the monochromatic beam reflected from the diamond and the other using the beam transmitted through the diamond. The transmission diamond monochromator is located in a small shielded enclosure (D-hutch) that sits in front of the first experimental enclosure

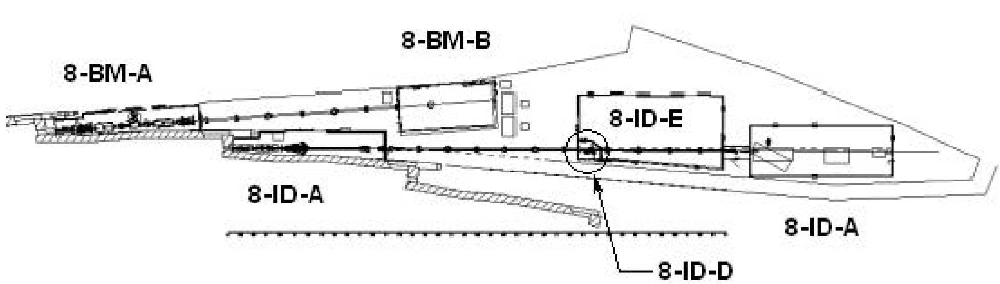

Figure 1. APS sector 8 beamline layout.

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(E-hutch) as shown in Fig. 1.[1] The diamond is typically employed in a symmetric Bragg scattering geometry. As shown in Fig. 2, monochromatic beam enters the monochromator (1), hits the diamond (2) and is deflected over a range of two-theta angles from 16 to 54 degrees or transmitted through it. Deflected beam is either transported to the E hutch if the wide angle shutter (3) is in "open" position or absorbed by a shutter beam stop if the shutter is in "closed" position.

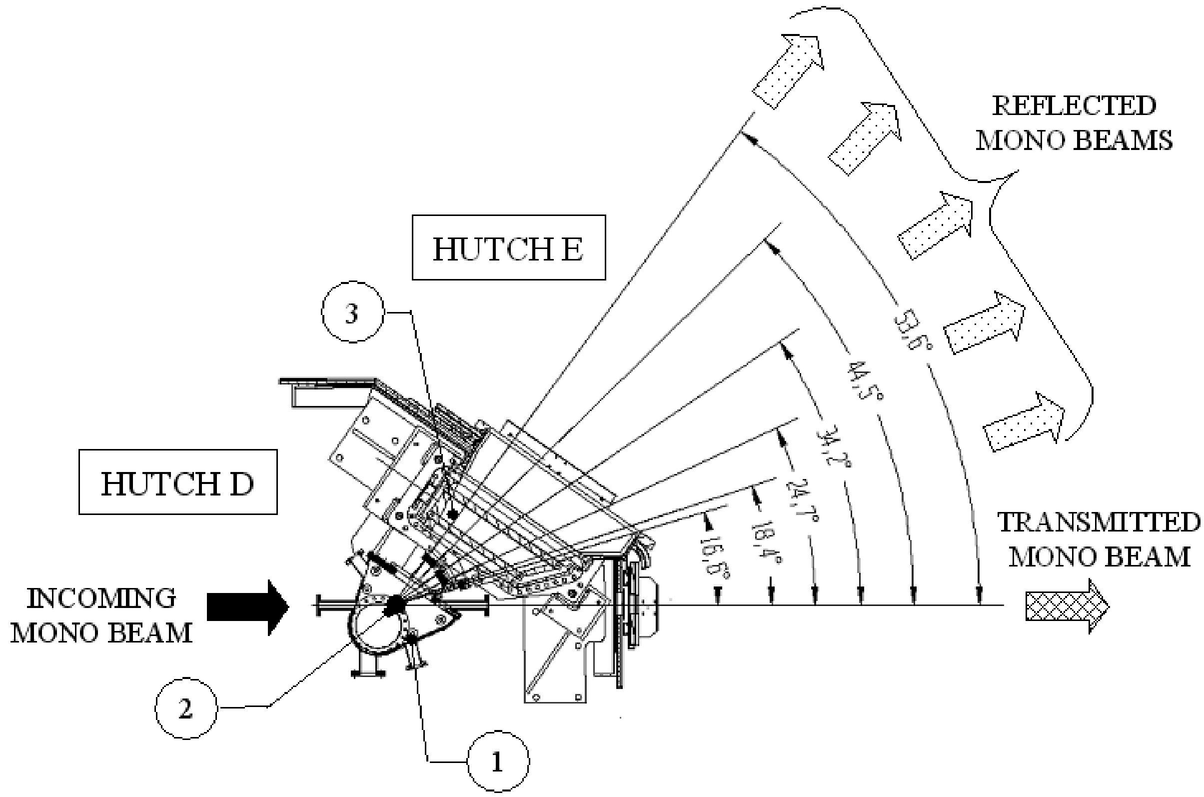


Figure 2. Ray tracing of transmitted and deflected monochromatic x-ray beams.

Transmitted beam is transported along a shielded pipe to a downstream enclosure (I hutch). This configuration was designed to allow fully independent operation of experiments in the E-hutch and I-hutch so long as both experiments can tolerate using the same energy or different harmonics of the same fundamental energy. In order to allow independent access to the upstream (E-hutch) and downstream (I-hutch) enclosures, two photon shutters are required. One shutter, just in front of the I-hutch, allows entry to the I-hutch when beam is being admitted to the E-hutch. Since this shutter is used to block an x-ray beam coming along a straight line, its design is standard and an APS standard component was employed. A second shutter is required to allow access to the E-hutch when beam is being taken in the I-hutch.

2. DESIGN REQUIREMENTS

The diamond monochromator, which directs beam into the E-hutch, employs only a single bounce. The single-bounce geometry has the advantage that it is a simpler monochromator than a double bounce and the beam undergoes a large deflection in the outboard direction allowing a large area of the E-hutch to be used for experiments. The disadvantage is that a shutter must be designed capable of blocking the beam over a wide range of exit angles (Fig. 2), depending on the energy of the experiment. In addition, to allow for vertical reflection from a liquid surface, it is necessary that the monochromator be capable of tilting the beam vertically over a range of a few degrees. The requirement for the blocking of the beam over a wide range of exit angles and space limitations imposed with the design of the D-hutch and already existing equipment (Fig. 3) necessitated a single-unit design of the shutter and its unorthodox shape. This in turn dictated a design of a nonstandard feedthrough chamber and guillotine-shaped shielding as integral parts of the shutter system.

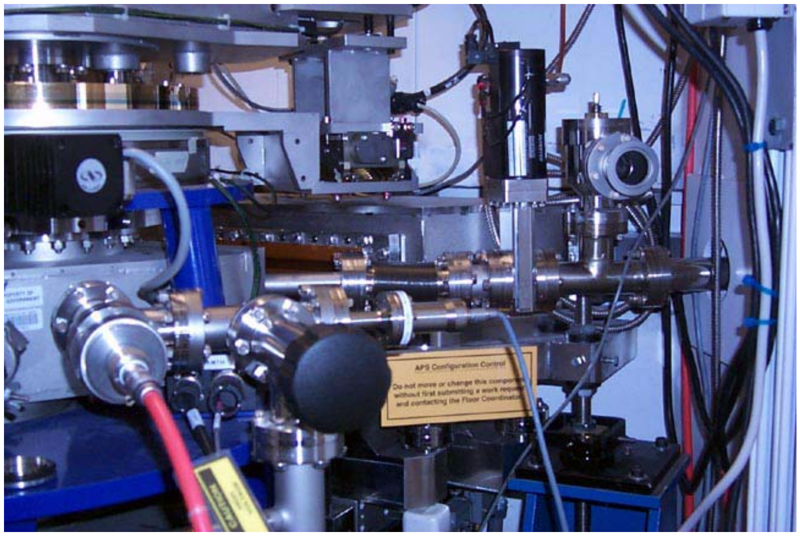


Figure 3. D-hutch after the wide-angle shutter system installation.

3. FUNCTIONAL DESIGN OF THE SHUTTER-SYSTEM COMPONENTS AND THEIR APPLICATION

The main challenge in the shutter design was to overcome space limitations and to provide the desired functionality of stopping low-energy monochromatic x-ray beams that could be deflected over a wide range of deflection angles. In order to be able to intercept the beams over the entire range of exit angles with the single beam stop, the shutter had to have a vacuum chamber broad enough to accommodate wide beam stops. Due to space limitations, a standard cylindrical-shaped vacuum chamber had to be abandoned and a unique-trapezoidal shaped chamber with rectangular flanges was designed. Due to the unique design of the shutter standard beam transport components and safety devices could not be used. As shown in Fig. 4, feedthrough vacuum chamber (2) and nonstandard guillotine (3) had to be designed together with the wide-angle shutter (1) in order to provide beam transfer from the D-hutch without radiation leaks into E-hutch. In the following, details of the design of all three shutter-system components are presented.

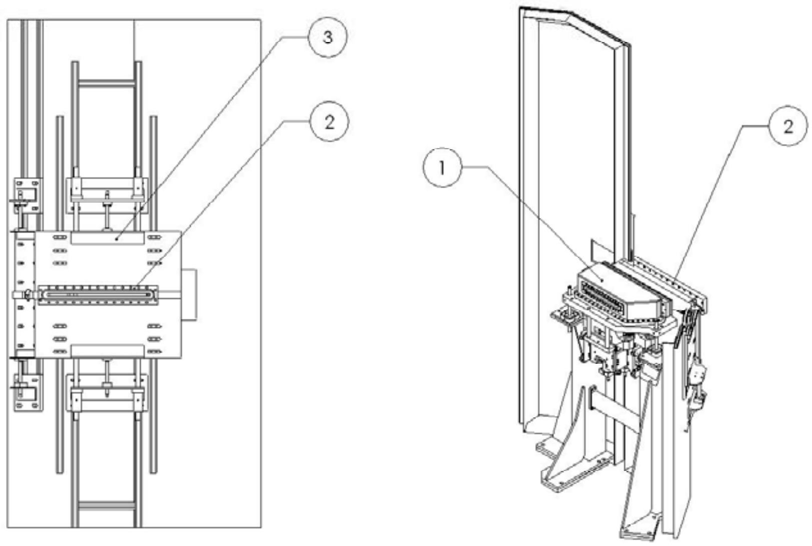


Figure 4. Wide-angle monochromatic x-ray beam shutter system.

3.1. WIDE-ANGLE MONOCHROMATIC X-RAY BEAM SHUTTER

The wide-angle shutter consists of seven major parts shown in Fig. 5. A trapezoidal UHV chamber (1) houses movable upstream (2) and downstream (3) beam stops and a fixed aperture (4). The chamber and all in-vacuum parts other than the beam stops are made of AISI 304 stainless steel and are electropolished. Beam stops are mounted on actuator base assemblies (5) and independently moved by actuator units (6). Actuator base assemblies serve as linear feedthroughs that connect moving parts inside the vacuum chamber with actuator units mounted outside the chamber. The vacuum chamber with actuator units is mounted on the specially designed support table (7). The beam stops are made of tungsten blocks that are 20 mm thick and 43 mm high, and each of them is capable of fully absorbing the monochromatic beam reflected from the crystal.[2] The upstream stop is 380 mm wide, while the downstream one is 470 mm wide. The downstream beam stop is longer than the upstream one to counteract the angular offset of the deflected beams. As they intercept low-energy monochromatic beams, the beam stops are not cooled.

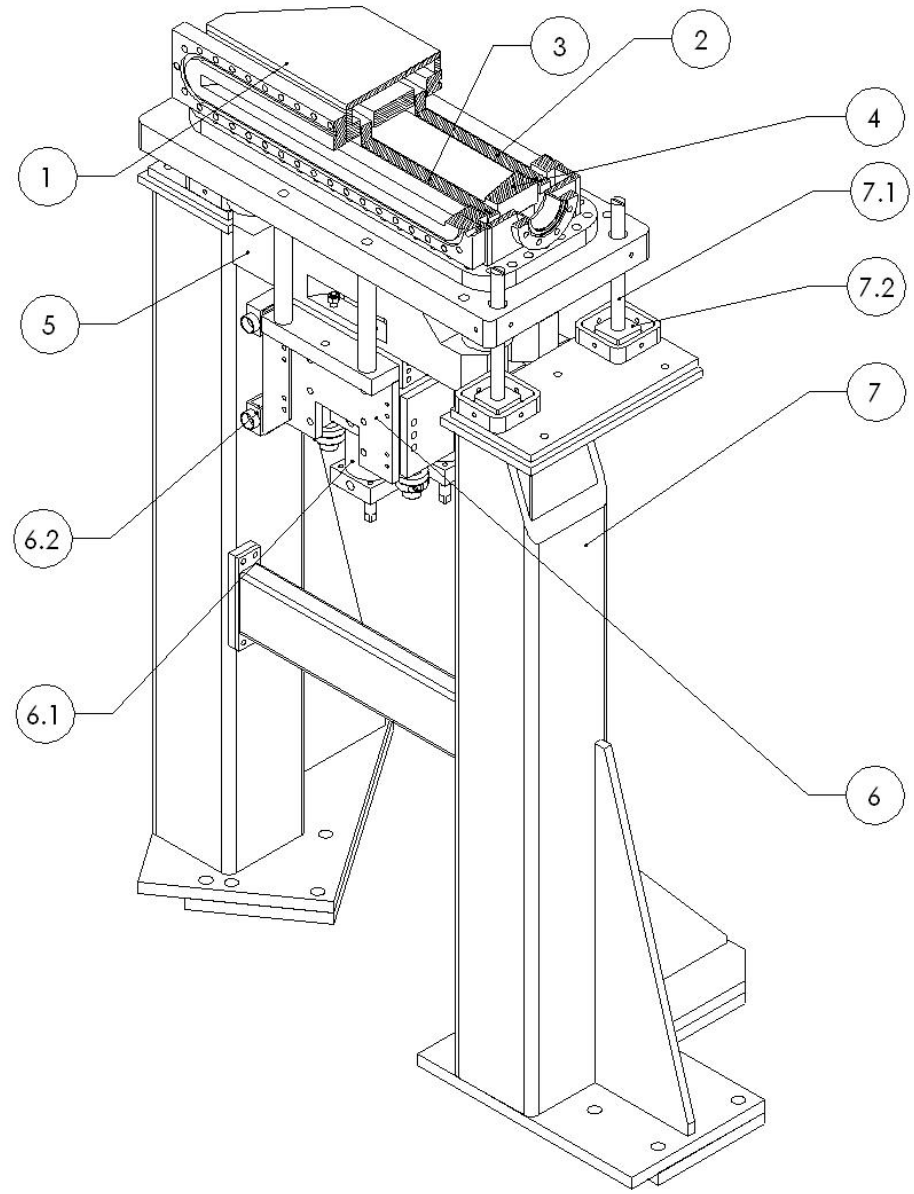


Figure 5. Wide-angle shutter assembly.

Two guided 33-mm-stroke air cylinders (6.1) provide the motion of each beam stop. Actuator units are interlocked to provide simultaneous motion of the beam stops and redundant protection. The standard actuator position in typical APS shutter designs is above the vacuum chamber,[3] but, due to the limited space available in this case, the actuator units of the wide-angle shutter had to be mounted below the chamber. Due to this arrangement, the cylinder rods are extracted and beam stops are positioned above the beam when the shutter is in the open position. In order to block the monochromatic beams the beam, stops move downwards due to retracting of the cylinder rods. When the shutter is in the closed position, the cylinders are fully retracted. The combined weight of the tungsten block and actuator base assembly exceeds several times the vacuum force acting on the actuator base. In case of loss of pressure in the pneumatic system, gravity pulls the tungsten blocks downwards into the closed position, thus providing fail-safe function. Also, both in open and closed positions of the shutter, the bellows are in the expanded condition and the spring force of the bellows helps gravity in case of loss of pressure. Limit switches (6.2) mounted on actuators indicate the open and closed

positions of the shutter. Two sets of limit switches mounted on each actuator provide redundant signals to the safety interlock systems for both up and down positions.
A special table (7) provides rigid, stable, and adjustable support for the shutter. The shutter is mounted on the table using three ACME-threaded rods (7.1) that provide vertical adjustment of the shutter of ± 65 mm. Sliding washers (7.2) provide the possibility of shutter position adjustment in the horizontal plane within the 6.5 mm adjustment radius.

3.2. FEED THROUGH CHAMBER AND GUILLOTINE-SHAPED SHIELDING SYSTEM

Due to the box shape design of the wide-angle shutter, the standard APS wall feedtrough and guillotine-shaped shielding elements could not be used. A box-shaped feedthrough chamber was designed (Fig. 6.). The shutter side of the chamber is trapezoidal and allows for passage of the beams deflected with various exit angles. The guillotine system side of the chamber is rectangular to allow a tight guillotine fit around the chamber regardless of the distance between the guillotine system and the hutch wall. The chamber itself (1) is made of AISI 304 stainless steel with 1/8" thick walls and is then shielded with a 1/4" thick lead shielding to prevent radiation leaks through the chamber walls. The part of the lead shield that sticks out from the guillotine is covered with a 1/16" thick Lexan cover. The chamber is supported with the support brackets attached to the D-Hutch inner wall.

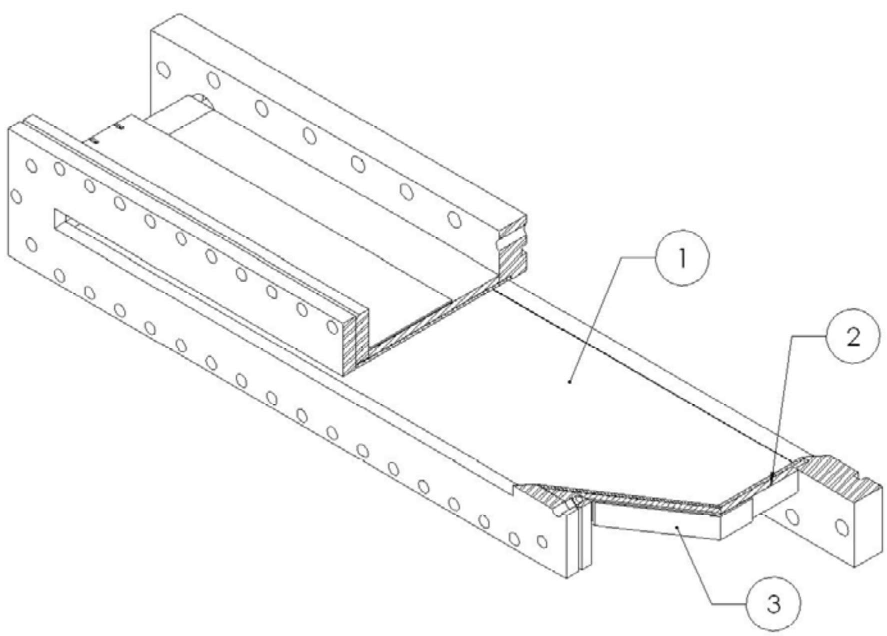


Figure 6. Feedthrough chamber.

The wide rectangular cross section of the feed through chamber required a very wide and thus heavy guillotine. The opening in the wall that extended beyond the wall corner and the neighboring standard guillotine also influenced the guillotine design. An extra wide guillotine system with the halves designed to tightly wrap around the rectangular neck of the feed through chamber was made (Fig. 7). One side of each guillotine half was slightly bent in order to overlap the neighboring guillotine and to provide a labyrinth and prevent corner leaks of radiation. Due to the weight of the guillotine halves a simple manual linear-motion height-adjustment unit was implemented to facilitate guillotine height adjustment.

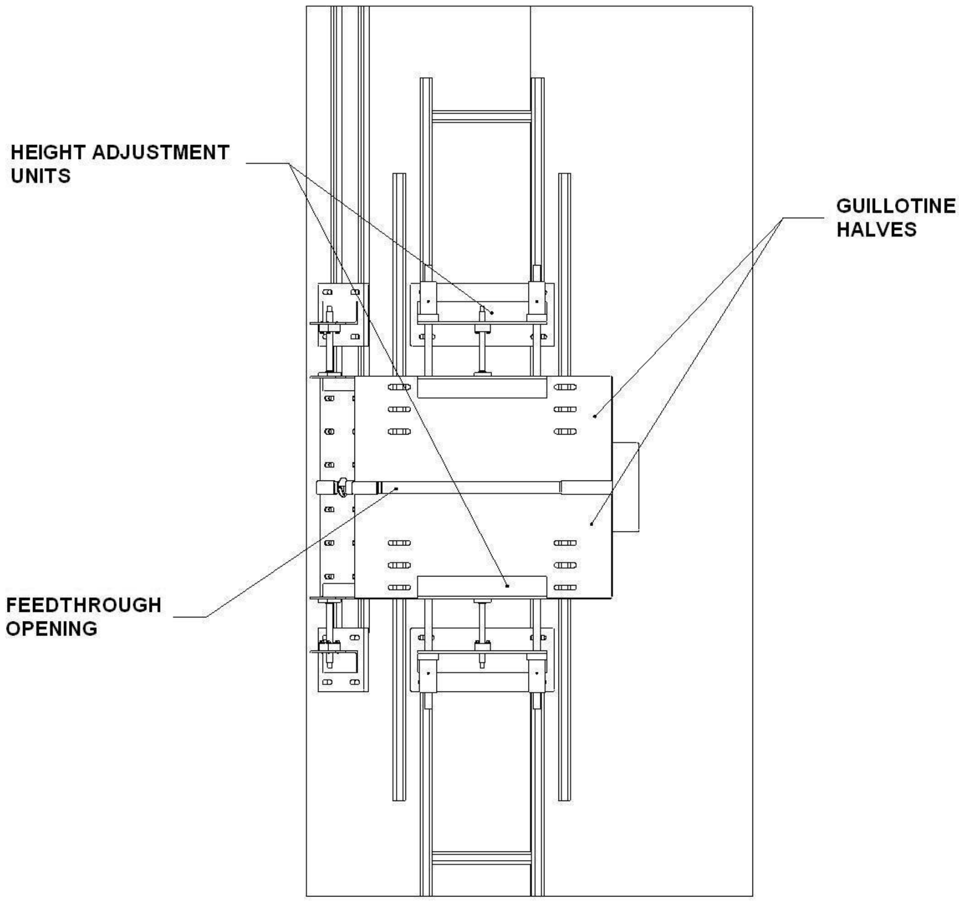


Figure 7. Wide-angle shutter guillotine

4. THERMAL AND STRUCTURAL DESIGN

The wide-angle monochromatic shutter is located 52 m from the APS insertion device source. Thermal load on the beam stops is minimal and does not exceed 13 mW. The beam footprint on the beam stops is a rectangle 1 mm wide and 0.5 mm high. Previous extensive thermal analysis and tests performed for the front-end and beamline components indicated that, due to the extremely small amount of heat deposited, the beam stops do not need to be cooled. Regardless, a thermal analysis was performed assuming that the heat deposited in the beam stops is conducted through the in-vacuum elements of the actuator base to the external elements and then transferred to the surroundings by natural convection. Calculated results (Fig. 8) show that all deposited heat will be successfully removed and that the increase of the beam stop temperature will stay below 0.5 K.

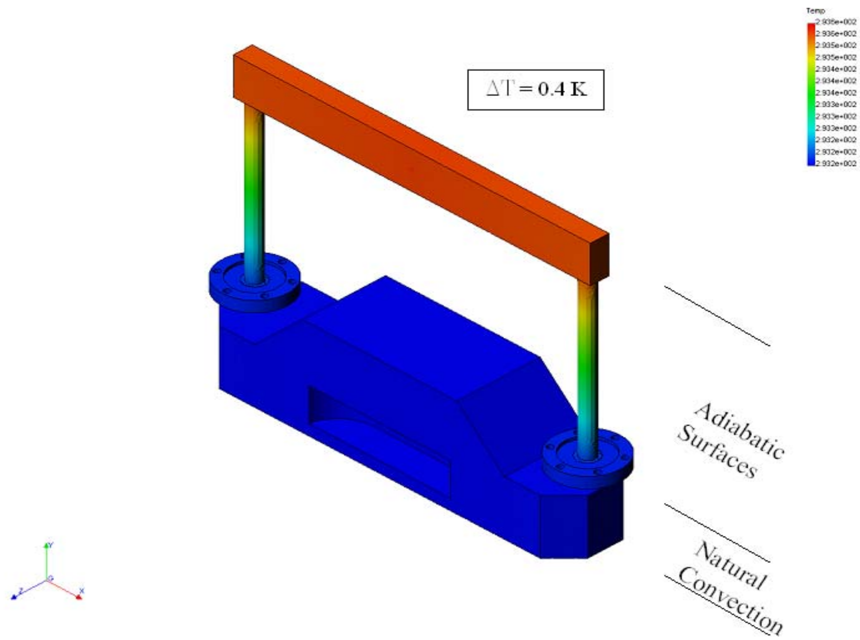
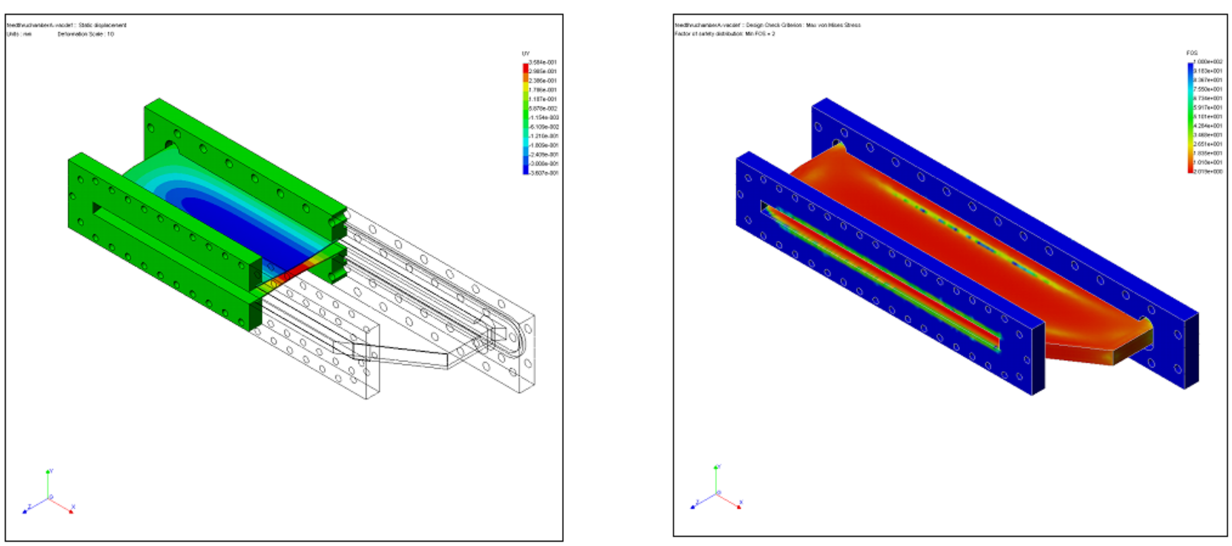


Figure 8. Results of steady-state thermal analysis.

The width of the feedthrough chamber and the fact that 1/8” thick plates were used to build it raised questions about the deformation of the top and bottom walls and the structural integrity of the chamber. An FEA analysis of deformation and stresses induced by the vacuum force indicated that the design is sound. Deformation of the top and bottom walls was below 0.6 mm thus reducing the clearance between the walls to 24 mm, which is still larger than 18 mm opening on the feedthrough flanges (Fig. 9a). Calculated stresses (Fig. 9b.) indicate that the minimal safety factor remains above 2.



a) deformation b) safety factor

Figure 9. Results of stress and deformation analysis.

5. CONCLUSION

The wide-angle shutter system was designed and built to allow independent access to the upstream (E-hutch) while the experiments with the beam transmitted through the monochromator diamond downstream (I-hutch) are ongoing. The shutter system was installed during the January 2002 shut down and successfully integrated into the insertion device beamline of sector 8 of the APS. The system is currently in operation.

ACKNOWLEDGMENTS

Work supported by U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38

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