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A kHz heat-load shutter for white-beam experiments at synchrotron sources

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A heat-load shutter capable of frequencies from one to several tens of kHz and window times from 10 µs up to 1 ms is described. In the current configuration the water-cooled shutter absorbs ~99% of the heat generated by the white beam. It has been successfully used for extended periods synchronized with a Jülich pulse-selector operating at 946 Hz. The temperature of the pulse-selector remained constant during a three-day continuous operation. Flexibility is provided by the interchangeability of the chopper disc.

Keywords: heat-load shutter; synchrotron instrumentation; white-beam experiments.

With the increasing performance of modern synchrotron facilities, there is a continuous need for further development of beamline instrumentation. The intense X-ray beam generated by insertion devices implies that beamline components are exposed to a substantial heat-load, especially during white- or pink-beam experiments. We describe a water-cooled heat-load (HL) shutter with a helium exchange gas, which has been successfully used at the NW14 beamline at the Photon Factory Advanced Ring at KEK. The design has features in common with the high-speed chopper described previously (Gembicky *et al.*, 2005); however, the current HL shutter is designed to operate with its axis perpendicular rather than parallel to the X-ray beam.

The primary function of the shutter is to reduce the heat-load on downstream components. Experiments were performed using an ultrafast Jülich chopper/pulse selector (Wulff *et al.*, 2002) installed immediately downstream from the HL shutter. As the disc of the ultrafast pulse selector rotates in a vacuum, heat is transferred from the chopping disc mostly by radiation. In white- or pink-beam Laue experiments this leads to heat build-up during sustained operation, necessitating frequent interruptions of the experiments to avoid unsafe operating conditions. This is highly undesirable given the limited time available for time-resolved experiments.

To minimize the cost of the HL shutter a standard servo track-writing spindle manufactured in small series by Professional Instruments (Minneapolis, MN, USA) was used. The spindle assembly was attached to a chopper chamber designed and constructed at the University at Buffalo.

A machine drawing of the spindle assembly with mounted disc is reproduced in Fig. 1. The chopper wheel is a bronze disc of diameter 146.1 mm (5.75′′) with eight equally spaced 1.016 mm (0.040′′) wide and 2.54 mm (0.10′′) deep slots. As a maximum speed of ~10000 r.p.m. is adequate for operation of the HL shutter, discs can be exchanged in the field without further balancing if a different configuration is desirable. The tandem arrangement of the HL shutter and the pulse selector is shown in Fig. 2.

The chopper chamber is cooled to ambient temperature by a water flow. Heat is transferred from the chopper disc to the chamber by convection through the helium exchange gas. The chopper disc temperature is monitored by a miniature infrared sensor (Raytek MID10), connected to a computer *via* an RS232 interface.

The complete assembly is mounted on an *xz* translation stage (horizontal in the direction of the spindle axis, which is perpendicular to the X-ray beam, and vertical) to allow precise positioning of the slots in order to maximize the transmitted X-ray flux.

In order to synchronize the HL shutter with the downstream pulse selector a reference signal from the 508.58 MHz RF ring frequency is supplied to a 77k16 programmable pulse counter (DIGITEX Laboratory, Japan), which divides the RF signal by 8400. The output is fed to the motor controller. The pulse counter output can be phase-shifted relative to the reference signal in steps of $1/f_{RF}$. This provided a 2 ns-step resolution for phasing the HL shutter to the downstream pulse selector. The ultimate synchronization stability of the tandem chopper arrangement has been verified during a three-day uninterrupted operation. During this period the HL shutter remained synchronized accurately with the Jülich chopper, which retained its starting temperature.

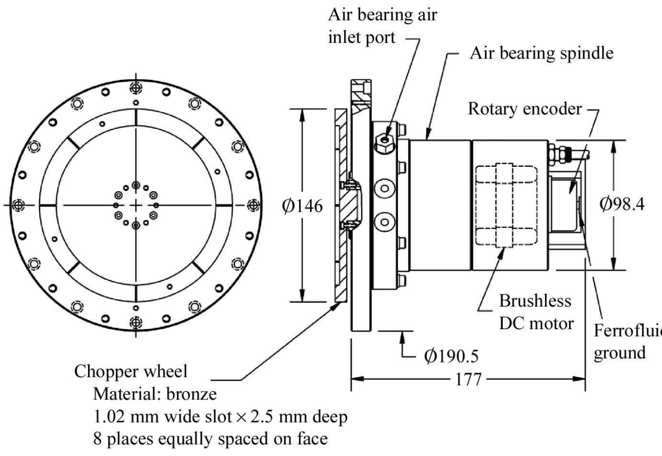

Figure 1
Machine drawing of the spindle assembly with mounted disc (courtesy of Professional Instruments Co, Minneapolis, MN, USA).

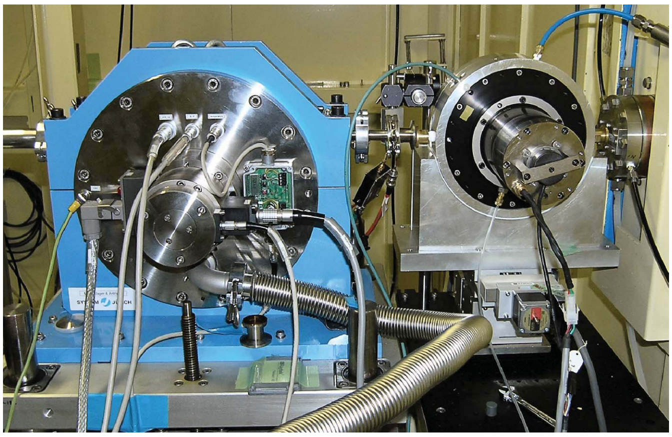

Figure 2
Tandem arrangement of the pulse selector (left) and the heat-load shutter (right) installed at the NW14 beamline at the Photon Factory Advanced Ring at KEK.

Since the HL shutter has eight openings per rotation, it is synchronized and locked to the downstream pulse selector at 7095 r.p.m., which reproduces the 946 Hz frequency of the Jülich pulse selector. At this speed the total window time (opening + closing) is ~20 µs. Therefore the HL shutter absorbs ~99% of the white-beam radiation, thereby decreasing the heat-load and radiation level to that of typical monochromatic experiments.

According to heat transfer estimates the new HL shutter is able to function up to a heat-load of 500 W, a value subsequently supported by experimental measurements at a 340 W heat-load. With further design improvement, this number could be doubled if desirable.

In general, the current design is appropriate for beamlines at which a variety of experiments are performed, so that the standard time structure of the synchrotron has to be altered specifically for time-resolved experiments. As the disc is readily exchangeable, it can be customized for experiments requiring repetition rates ranging from one to several tens of kHz and window times from 10 µs up to 1 ms. Additionally, the chopper disc material can be varied as desirable for specific experiments. Limitations are imposed on the disc material by tensile strength and thermal expansion requirements (Gembicky & Coppens, 2007).

Given that the shutter disc rotates in helium at atmospheric pressure, it is not intended for protecting the focusing mirror and other upstream components operating in an ultrahigh-vacuum environment. For this purpose, a shutter based on a ferrofluidic seal and fluid cooling through a rotating shaft has been successfully designed (Lausi *et al.*, 1995; Wulff *et al.*, 2002).

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