Rotating Crystal X-ray Beam Chopper

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A new x-ray beam chopper has been designed and tested at the SRI-CAT 1-BM beamline of the Advanced Photon Source. This beam chopper takes advantage of the narrow acceptance angle for diffraction of a rotating crystal to produce transmission window times as short as about 10 ns. Precision control of the crystal rotation allows phase locking with the orbital frequency of the synchrotron storage ring. Hence, the transmission of short x-ray pulses for time-resolved experiments is possible with any fill pattern presently used at the Advanced Photon Source storage ring.

The beam chopper is illustrated in Fig. 1. It makes use of two (111) faces of a silicon crystal cube that is mounted on the axis of a high-precision, high-speed motor. The beam chopper was built by Speedring Systems, Inc., of Rochester Hills, Michigan, and is based on one of their commercially available air-bearing motors. The aluminum motor body is about 12.5 cm long and 6.5 cm in diameter. A mount for the motor body allows the beam chopper to be mounted to a Huber model 410 rotation stage. The beam chopper can be operated while mounted in any orientation.

The silicon cube is 15 mm on a side and is attached to an aluminum holder by epoxy. The edge of the holder extends slightly above the surface plane of the cube, limiting the acceptance angle of incidence to about 6.45 degrees and hence restricting operation to a photon energy of 17.5 keV or less. The aluminum holder and crystal combination was dynamically balanced to eliminate any unbalanced radial force on the motor axle.

The motor is designed to operate at speeds of 32,586 RPM, 16,293 RPM and 8,146.5 RPM. The rotation speed of the motor is controlled by a phase-locked loop. After turn on of the motor, full speed is achieved in a few seconds.

As with any precision beam chopper, the principal feature of operation is the high level of rotation speed control. This beam chopper uses a shaft encoder to sample the shaft position 500 times per revolution. These data are compared to a reference signal derived from an external clock drive frequency. The motor controller electronics adjusts the rotational motor speed until the encoder and reference pulses are synchronized in-phase. Due to the frequent speed corrections, short-term (1000 revolutions) speed variations of less than 5 parts per million can be achieved. The manufacturer has conducted a performance evaluation of the motor at the three design speeds of 32,586 RPM, 16,293 RPM and 8,146.5 RPM by sampling for 1000 rotations the time required to make one revolution. The jitter in the revolution time, measured as the deviation from the mean revolution time, is about ±1 ns at the highest speed and still only ±1.5 ns at the slowest speed.

The beam chopper was tested using a photon energy of 10 keV. It was set up to be in a nondispersive geometry with respect to an upstream double-crystal Si (111) monochromator. Since the theoretical rocking curve width for Si (111) at 10 keV is about 7.9 arc seconds (FWHM), the open window time for rotation at the fastest speed is expected to be about 11.2 ns, sufficient to transmit only one singlet at a time of the APS fill pattern. Measurement of the static rocking curves of each face was 7.7 arc seconds and 7.3 arc seconds for faces 1 and 2, respectively.

The dynamic (while crystal is rotating) rocking curve for each (111) crystal face was mapped out by delaying the drive frequency to the motor controller.[1] Delay steps of 2 ns were taken. The results are plotted on an absolute time scale in Fig. 2. Three observations are evident. First, the two faces have different rocking curve widths, differing by 0.4 arc seconds, in agreement with the static measurement. Second, the dynamic rocking curves are smaller than the static rocking curves. This is due to the position of the discriminator level of the detector system. And third, the rocking curves for the two diffracting faces are displaced in time with respect to one another. Since the two rocking curves are displaced on an absolute time scale, the effective open time window of the rotating crystal cube is larger when both crystal faces are

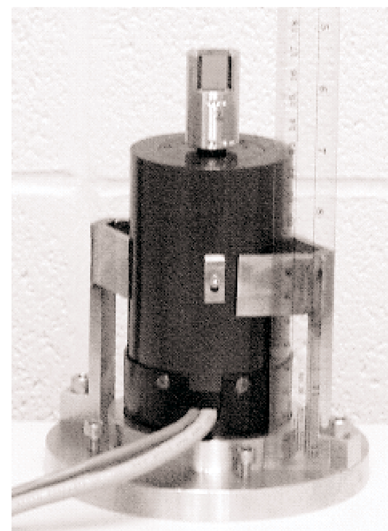

FIG. 1. Rotating crystal beam chopper. The silicon crystal cube exposes two (111) faces to the x-ray beam on each rotation of the motor. It is designed to operate at a maximum speed of 32,586 RPM, corresponding to an open time window of about 10 - 12 ns for 8 – 10 keV radiation.

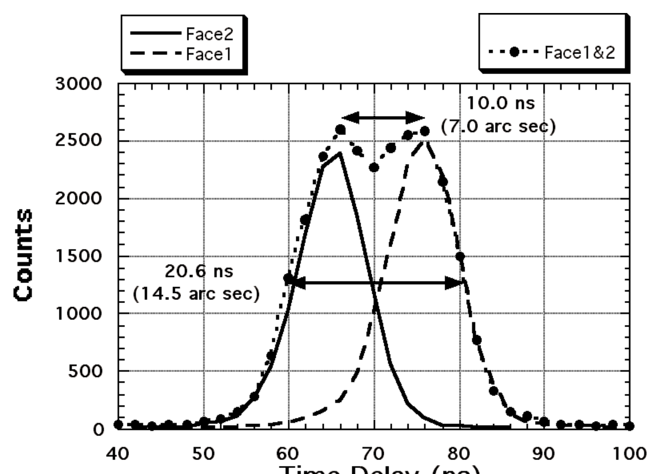

FIG. 2. Dynamic rocking curve from each face of the rotating crystal and from both faces together. The time scale is absolute. The rocking curve width for Face 1 is 10.1 ns (7.1 arc sec.). The rocking curve width for Face 2 is 9.5 ns (6.7 arc sec.). The effective rocking curve width for both faces summed together is 20.6 ns (14.5 arc sec.). The shift in time of the rocking curves of the two individual faces indicates that the two sets of diffractive planes of the crystal are angularly displaced with respect to one another by 10 ns (7 arc sec.).

used than when either face is used separately. The dynamic rocking curve obtained when recording signal from both crystal faces together is likewise illustrated in Fig. 2. As shown, an open time window of 20.6 ns (FWHM), or nearly double what was expected for a perfect crystal system, is obtained. The magnitude of the increased rocking curve width obtained when using both faces cannot be accounted for by induced strain in the rotating crystal. However, modeling based upon dynamic rocking curve widths obtained at the two fastest rotation speeds indicates that the increased rocking curve width may be attributed to the two sets of crystal diffracting planes being splayed from one another by about 7 arc seconds. Still, this increased open time window is adequate to select out single 50 ps pulses in all fill patterns presently employed at the APS.

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[1] A detailed description will appear in the Proceedings of SRI-2001, to be published in Review of Scientific Instruments.