Rotating crystal beam chopper developed at SRI-CAT

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Introduction

The small acceptance angle of a perfect Si(111) crystal has been exploited to build an x-ray beam chopper. The design goal for this beam chopper was to be able to pick out individual bunches from within the multibunch fill pattern of the Advanced Photon Source (APS) synchrotron storage ring. At the APS, this typically requires 'open' time windows of less than 150 ns. Additionally, the rotation of the beam chopper should be phase lockable to the orbital frequency of the storage ring.

Methods and Materials

<u>Beam Chopper Description</u>

The design employs a rotating 15 mm Si(111) crystal cube mounted onto the rotation axis of a high-speed precision motor, see Figure 1. The motor was manufactured by Speedring Systems, Inc. It was designed and balanced to rotate at only three speeds in order to ensure that the rotation frequency did not coincide with a motor resonance. The three selected rotation speeds are: 8145 rpm, 16290, rpm and 32580 rpm. Since there are two surfaces available for reflections, the corresponding transmitted x-ray pulse frequencies are 271.5, 543, or 1086 Hz. At the fastest rotation speed, the open time window is only about 12 ns.

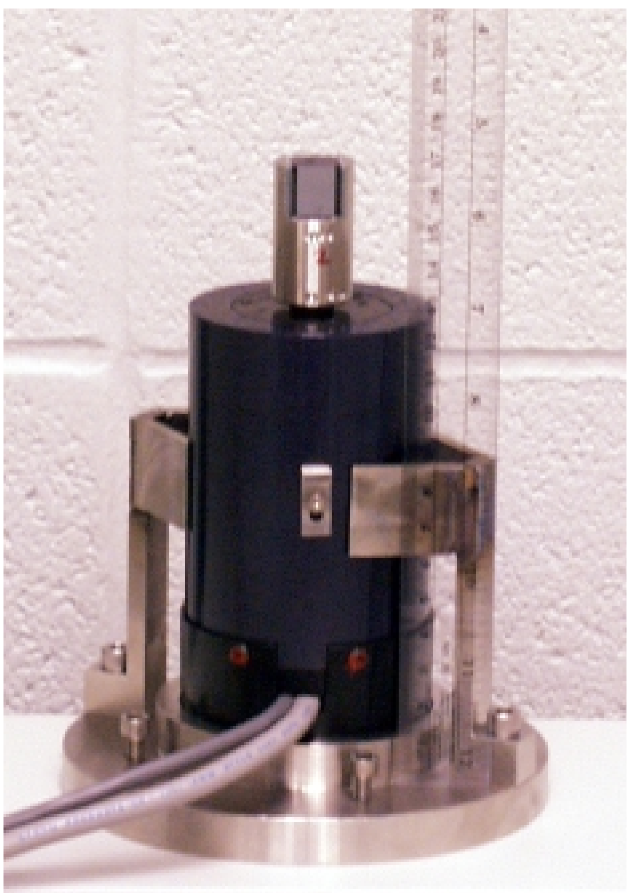

Figure 1: The rotating Si(111) crystal cube beam chopper sitting in its security holder.

The drive frequency for operating the motor controller is derived from the APS storage ring rf frequency and is supplied by the control room as the orbital frequency of the storage ring. This master clock frequency is sent to a frequency divider where it is divided by 1, 2, or 4 before being sent on to a high-precision pulse delay generator. The pulse delay generator allows for a shift of the phase between the position of the beam chopper transmission window and the storage ring temporal structure. The output from the pulse delay generator is sent to the beam chopper motor controller where it is divided by another factor of 500. This final frequency serves as the reference frequency for regulating the rotation speed of the motor.

<u>Manufacturer's Performance Test</u>

The motor design uses an encoder, built into the motor body, to sample the rotation speed of the rotor 500 times per revolution. A feedback circuit on the control card for the motor uses this sampling to regulate the motor speed. Such rapid sampling is necessary to ensure adequate speed regulation, especially at the slower rotation speeds.

At the rotation speed of 32580 rpm, the manufacturer has determined that the jitter in the time necessary to make one revolution is less than 1 ns. The jitter was measured by sampling the time required for one rotation of the motor rotor. Figure 2 illustrates the results for a sampling of 1000 events. Even at the slowest speed of 8145 rpm, this jitter is less than 3 ns. Hence, the rotational jitter, as measured by the time necessary for one revolution, is much less than the open time window permitted by the Darwin width of the rotating crystal. As a result, it is possible to phase lock the rotation of the crystal to the temporal structure of the APS storage ring.

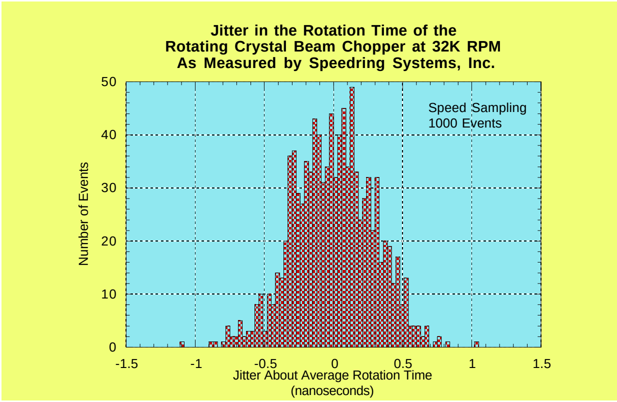

Figure 2: The measured jitter in the time necessary for a rotation of the motor.

Results

Performance Test

The performance test of the beam chopper consisted of: (a) demonstrating synchronization, or phase locking, of the transmitted x-ray pulse to the master clock frequency of the storage ring and (b) measurement of the effective rocking curve of the rotating crystal. During the first test, the storage ring was filled with a series of eight septets separated in time by 70 ns. The second test was performed using a fill pattern of singlets separated in time by about 150 ns.

A monochromatic beam of 10 keV photons was incident onto the Si crystal. The reflected beam was detected by using an avalanche photodiode (APD). The signal from the APD was recorded on a digital scope. The master clock signal was sent to a delay generator that has multiple outputs. One output was used to drive the motor controller. Another output was sent to the digital scope and used as a reference signal for measuring the synchronization and phase shifting of the beam chopper transmission with respect to the temporal structure of the storage ring. The results of this test are illustrated in Figure 3.

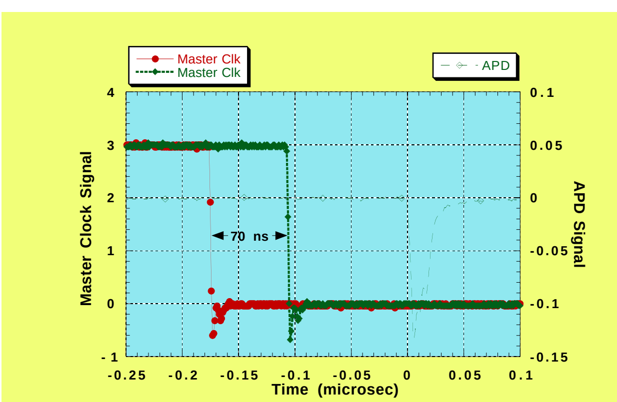

Figure 3: Since the open time window is only about 12 ns, changing the delay of the master clock by 70 ns moves the beam chopper transmission window from one septet onto the neighboring septet.

An important consideration for this beam chopper is how the crystal is stressed while rotating at these high speeds. The rocking curve was measured with the crystal at rest and while it was rotating at the two highest speeds. At rest, the rocking curve was determined to be 8.06 arc seconds. The rocking curve of the rotating crystal was determined by placing the singlet within the transmission window of the beam chopper. The time delay to the motor controller was then varied to sweep the transmission window over the rocking curve. For a static rocking curve of 8.06 arc seconds, the open time window for the two fastest rotation speeds should be 22.9 ns at 16000 rpm and 11.5 ns at 32000 rpm. Yet they were measured to be 42.5 ns and 23.4 ns, respectively, as illustrated in Figure 4. The data are being analyzed to determine the reason for these measured values.

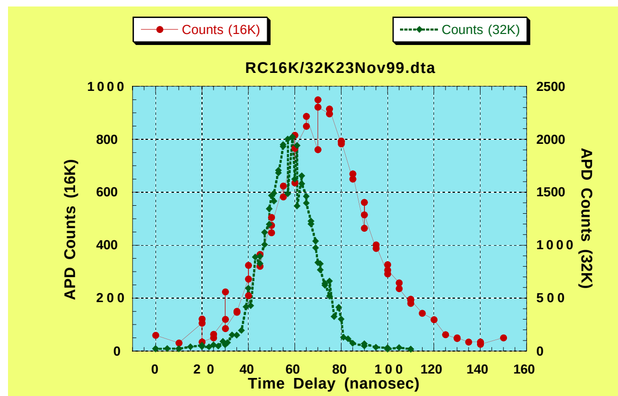

Figure 4: Rocking curve of the rotating Si crystal for the two fastest rotation speeds.

Discussion

This beam chopper can operate synchronously with the temporal structure of the APS storage ring. With an open time window of only 23 ns, experiments capable of subnanosecond time resolution are possible, since the bunch length of a singlet is about 50 ps.

Acknowledgement

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