euspen's 16th International Conference &
Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Water-cooled heat load chopper for synchrotron experiments

Dave Arneson, Byron Knapp, Dan Oss

Professional Instruments Company, Hopkins, Minnesota, USA

Email: darneson@airbearings.com

Abstract
This paper describes an air bearing heat load chopper used to reduce the average power of synchrotron X-ray beams, protecting sensitive downstream equipment and samples while improving thermal stability of the mirror alignment. The beam is chopped by a water-cooled stainless steel slotted disk spinning up to 6 000 RPM. Water is supplied to the rotating disk via an air bearing fluid rotary union. In addition, the disk rotates in a protective vacuum chamber at pressures as low as 0.7 mPa accomplished using differentially pumped non-contact seals. Design considerations and test results for this chopper installed at synchrotrons in the USA and France are described. The jitter measurement demonstrated 2 parts per million speed stability.

Keywords: Synchrotron instrumentation, X-ray, crystallography, chopper jitter

1. Introduction

State-of-the-art synchrotron radiation facilities require the use of precision choppers to conduct experiments on a wide range of applications. Instead of tailoring the X-ray beam to suit the needs of each experiment, instrumentation, such as choppers, is used to modify the beam characteristics at the point of use. For example, rather than attenuating the beam intensity to a level that is safe for downstream equipment and samples, the average power is reduced using a heat load chopper. The reduced heat load downstream also improves thermal drift of the mirror alignment and allows continuous operation without overheating. The beam is chopped by a precision slotted disk that spins in a vacuum. This requires precision speed control to maintain synchronization of disk with the X-ray pulses. Design features for the chopper are described and better than 25 nanosecond jitter is demonstrated for speeds of 4 000 RPM, 5 000 RPM, and 6 000 RPM.

2. Design

The heat load chopper shown in Figure 1 is designed to block a 1.5 mm diameter, 520 W X-ray beam (power density 4.7 times greater than the surface emission of the sun [1]). The beam is chopped by a slotted disk that spins in a vacuum at nominally 5 000 RPM. Vacuum levels as low as 0.7 mPa have been achieved in the vacuum chamber via differentially pumped annular vacuum seals with 10 µm clearance. The 275 mm diameter 416 stainless disk shown is 7.6 mm thick with various slot widths between 0.2 % and 1.6 % duty cycle. Precise angular location of the slots is established during the EDM process using 180 tooth face gears and consistent and constant conditions. The heat blocked by the disk is removed by coolant pumped through the rotating shaft via fluid rotary union as shown in Figure 2. The seals and bearings of the rotary union are non-contact to avoid unwanted error motion, jitter, and wear. This is accomplished with tight clearance (7 µm) air bearings and capillary seals (15 µm). Coolant that leaks past the first set of capillary seals is contained by a second set of capillary seals and the positive pressure of the air bearing exhaust that carries the excess back to the sump.

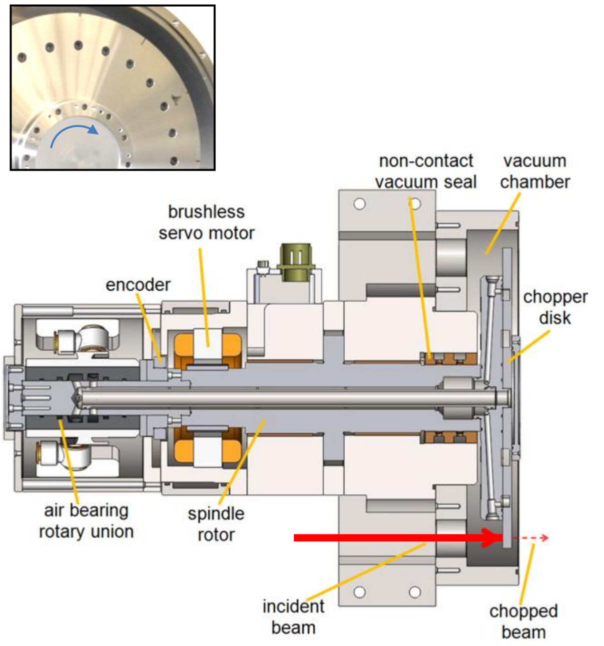

Figure 1. Cross-section of the air bearing heat load chopper showing precision design features. Inset shows slots configurations in disk.

Owing to their low error motions and torque ripple, precision air bearing spindles are the ideal choice for low-jitter choppers. The bespoke spindle used here is a captured thrust, groove compensated design with a vacuum chamber integral to the housing (Model ISO 4.5, Professional Instruments Company). A frameless brushless servo motor (MCS) and encoder (Model ERM 280, Heidenhain) is mounted directly to the rotor of the air bearing spindle. Spindle speed is controlled with a linear amplifier using Frequency Lock Velocity Control (Model LA2000, MCS). The reference signal for the control is supplied by the synchrotron facility's storage-ring reference clock enabling synchronization with the high speed chopper. The spindle is balanced with coolant flowing to the disk to better than ISO 1940 G0.1.

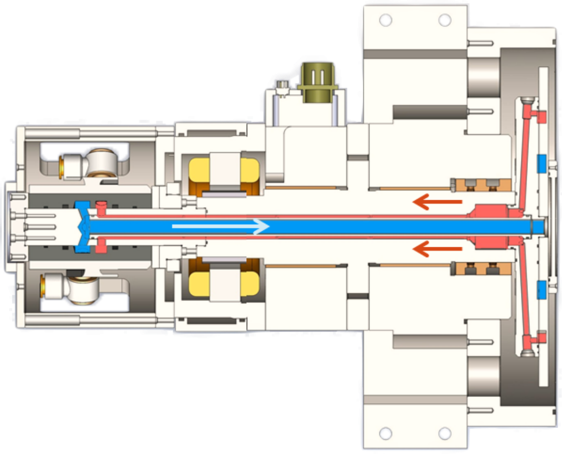

Figure 2. Cooling path follows inner channel to the disk. Warm coolant (2 °C temperature rise with a flow rate of 4 L/min and 520 W beam) is returned through the outer channel.

3. Speed stability methodology

Speed stability is evaluated by measuring the time required for 1 000 revolutions triggered by the rotary encoder's index (reference) mark. An HP 33120A Function Generator is used to simulate the storage-ring reference signal while recording the speed stability with the HP 5371A Time and Frequency Analyzer (150 picosecond RMS single shot resolution). The internal reference oscillator of the HP 5371A (10 MHz with 5 parts in 10^{10} per day stability) is used as the master clock for both instruments.

The vacuum chamber is evacuated to a partial vacuum of approximately 1-2 kPa during jitter testing. This partial vacuum is not ideal for X-ray transmission but it does sufficiently reduce disk windage for jitter evaluation. In use at a synchrotron facility, vacuum levels below 0.7 mPa have been obtained using differential pumping across two of the three stages of vacuum sealing. In addition, coolant was pumped through the chopper at a flow rate of 4 l/min to include any additional jitter caused by the flow.

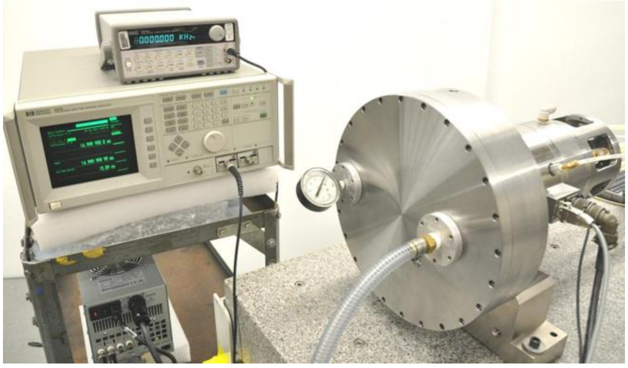

Figure 3. Jitter measurement setup. A function generator is used as the reference signal to the linear amplifier with Frequency Lock Velocity control while speed stability is recorded by the HP 5371A.

4. Results

Test results demonstrate speed stability better than 20 nanoseconds one standard deviation at a spindle speed of 5 000 RPM as shown in Figure 4.

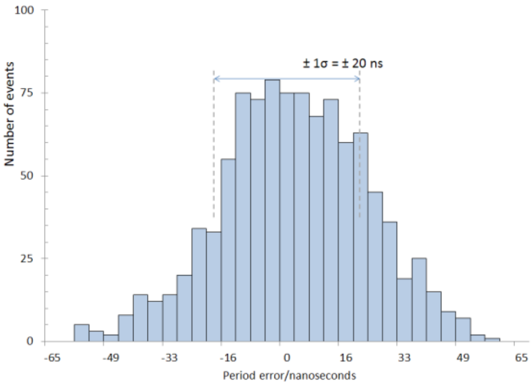

Figure 4. Result of the jitter measurement with 4 l/min water flow rate and spindle speed of 5 000 RPM. The standard deviation of the 1 000-point sample is σ = 20 ns.

The maximum jitter was 25 nanoseconds one standard deviation over the entire set of jitter measurements (4 000 RPM, 5 000 RPM, and 6 000 RPM). Jitter at each speed did not exceed a standard deviation of 2 parts per million relative to the period. Published results for a water-cooled heat load chopper using rolling-element bearings and ferrofluid seals exhibits 2 µs jitter at 6 000 RPM [2] – 3 orders of magnitude worse.

5. Conclusion

Design considerations and test results for a water-cooled air bearing heat load chopper with integral vacuum chamber are described. This chopper was recently installed at BioCARS Sector 14 of the APS at Argonne National Laboratory where it has been operating at vacuum levels as low as 5x10-6 Torr. The heat load chopper is necessary as it protects downstream equipment and samples from being damaged by the intense X-ray beam. Heat is carried away by coolant continuously pumped through the rotating disk via a non-contact air bearing fluid rotary union. Jitter measurements demonstrated 2 parts per million speed stability, or one standard deviation, σ, less than 25 ns at speeds of 4,000, 5,000, and 6,000 RPM.

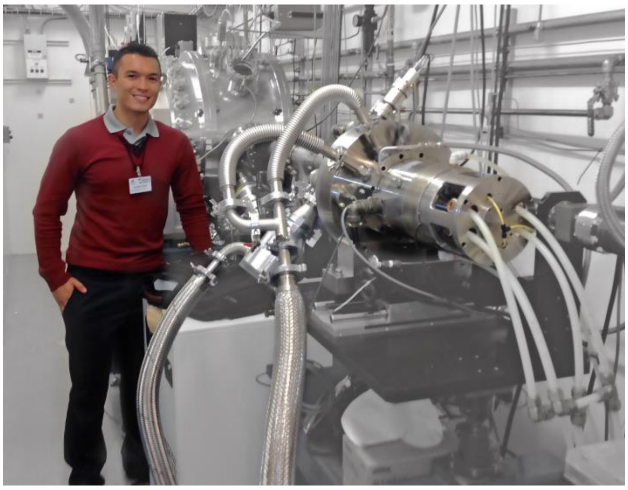

Figure 5. Heat load chopper at BioCARS installed in Sector 14 of the Advanced Photon Source at Argonne National Laboratory.

References

[1] Graber T, *et al.* 2011 BioCARS: a Synchrotron Resource for Time-resolved X-ray Science. *J Synchrotron Rad*. **18**: 658-70

[2] Cammarata M, *et al.* 2009 Chopper System for Time Resolved Experiments with Synchrotron Radiation. *Rev of Sci Inst.* **80** (015101): 1-10.