Prototype and Design of High-Speed X-Ray Chopper

SLAC NATIONAL ACCELERATOR LABORATORY

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Scoping Out the Mission

The LCLS Detector Group has been tasked to test new detectors for LCLS II. The group has a **continuous x-ray** source at its disposal, but LCLS II detectors are designed to operate with the **pulsed x-ray** produced by the linac. In order to yield meaningful results, the detectors require a **chopper** to mechanically parse the incident x-ray beam into single **microsecond** pulses. Considering vacuum rotary motion feedthroughs, physical constraints, and detector photosensitivity, the goal of this project is to prototype and design an x-ray chopper.

Keywords: continuous, pulsed, chopper, microsecond

Design Considerations

Physical Size:
- The chopper should be no larger than 6 to 8 inches in diameter in order to fit inside a reasonably sized vacuum chamber.

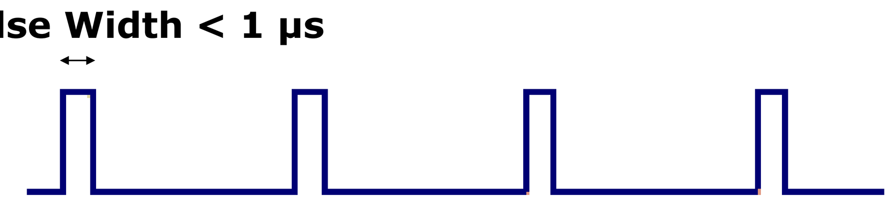
Vacuum Rotary Motion Feedthroughs:
- Commercially available ferromagnetic fluid feedthroughs can deliver up to 10,000 RPM into vacuum.
- Gear friction outgasses and contaminates vacuum.

Source Beam Collimation:
- The diameter of the incident beam will be much larger than the desired aperture width.

Goal

The goal of the chopper is to reduce the continuous x-ray source into 1 μs (0.000001 s) pulses at 10 kHz, as shown in the figure below.

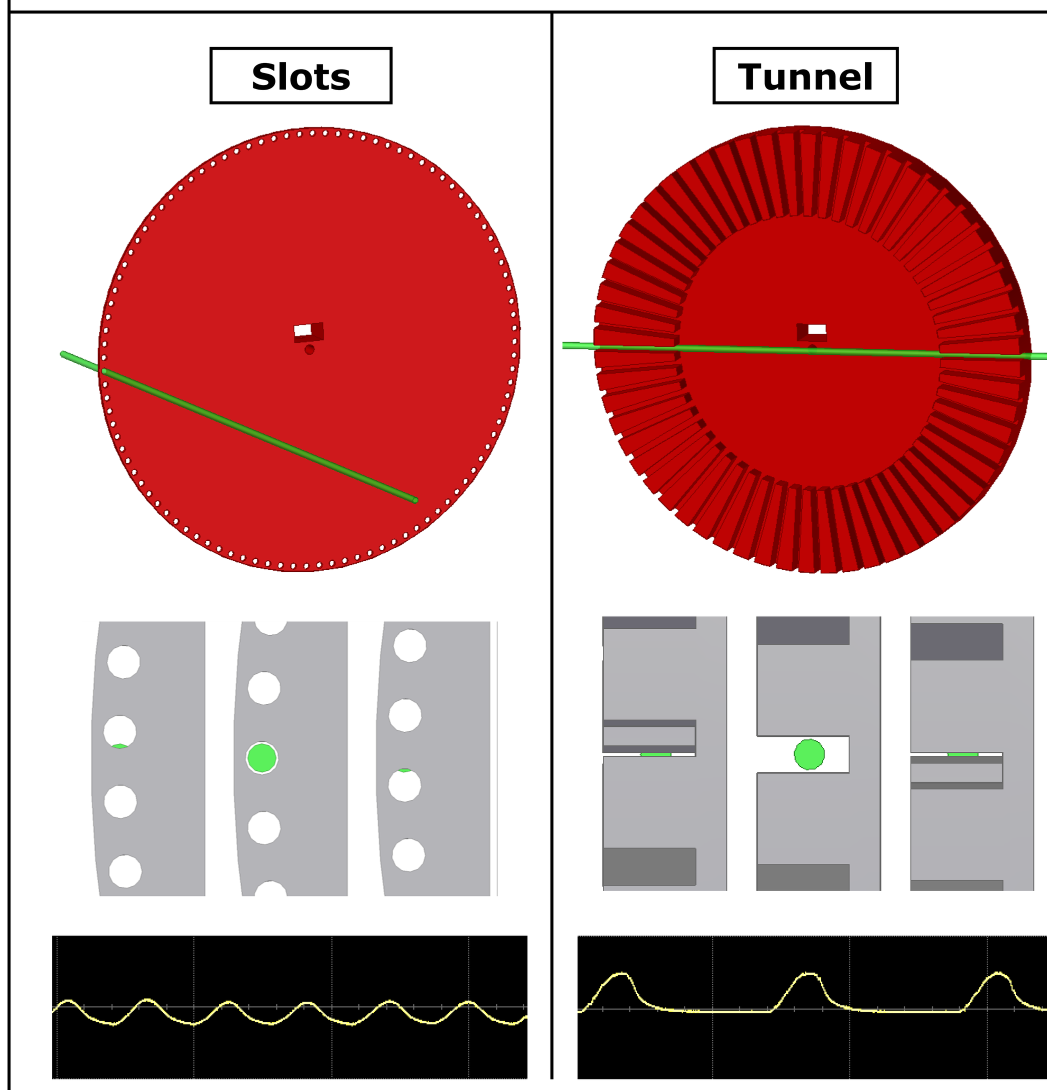
Pulse Width < 1 μs



Period = 100 μs (10 kHz)

Figure 1. *Ideal Signal*. Displayed above is the desired pattern of emitted x-ray light. High signals represent transmittance of x-ray light, while low signals represent blockage. This waveform can be simulated with a laser diode and an oscilloscope.

On the Chopping Board



Slots		Tunnel
1.95	**Chopper Radius at Aperture (in)**	2.00
0.03	**Aperture Radius (in)**	0.03
12	**Voltage (V)**	12
9800	**Motor Speed (RPM)**	6400
16.4	**Repetition Rate (kHz)**	6.4
58	**Predicted Pulse Width (μs)**	38
42	**Empirical Pulse Width (μs)**	42
• Large pulse width • Easy to machine • East to mount in vacuum • Low absorption efficiency • Light and thin	**Defining Characteristics**	• Small pulse width • More difficult to machine • More difficult to mount • High absorption efficiency • Heavy and thick

Figure 3. *Chopper Design Comparison.* The geometry of the tunnel chopper allows it to parse incoming light into pulse widths half as long as those produced by the slots chopper. Below each model is the waveform of the oscilloscope signal at the rated motor voltage.

Sizing the Motor

At a given rotation speed, the tunnel chopper experiences greater damping forces (ie: bearing friction and air drag) and demands greater motor torque than does the slots chopper. Accordingly, the new motor was sized to the demands of the tunnel chopper.

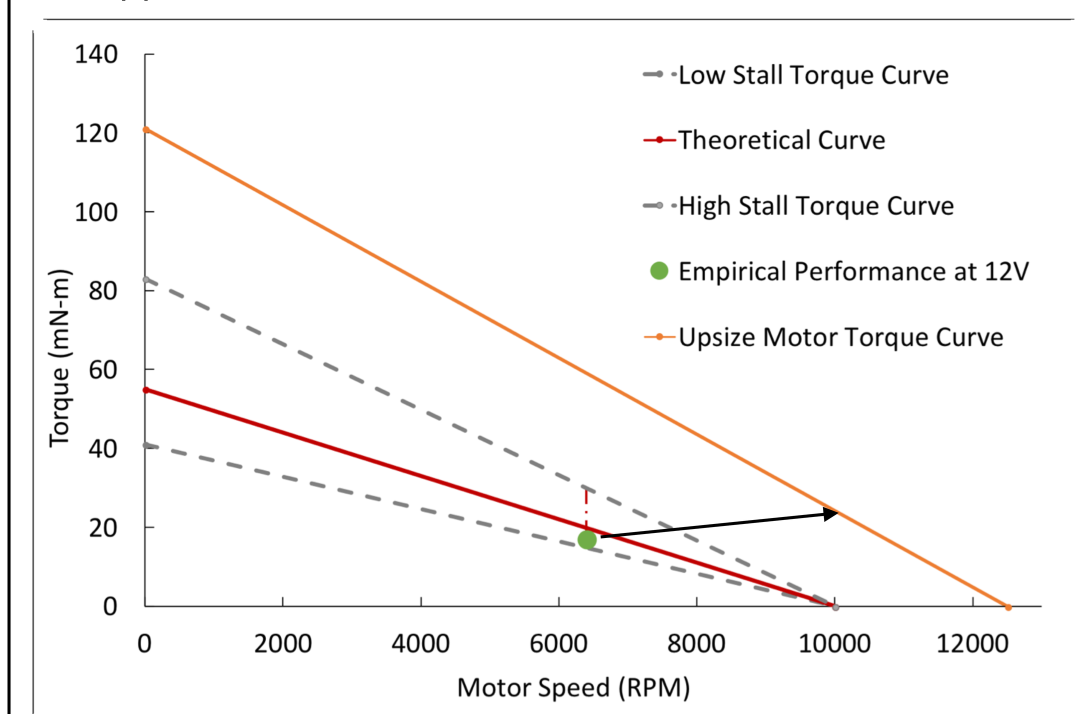


Figure 4. *Motor Sizing Curve.* Displayed above is the torque-speed curve for the motor used in the chopper prototype. The gray stall torque curves were determined empirically, while the red theoretical curve was determined using motor specifications. The orange curve represents a viable upsize option.

Printing a Prototype

The proof of concept of a chopper can be demonstrated using a functional prototype. The prototype makes use of a hobby motor, 3-D printed parts, Thorlabs laser optics, and a Hamamatsu photodiode. Figure 2 depicts the latest design of the chopper prototype. 3-D printed parts are rendered in color.

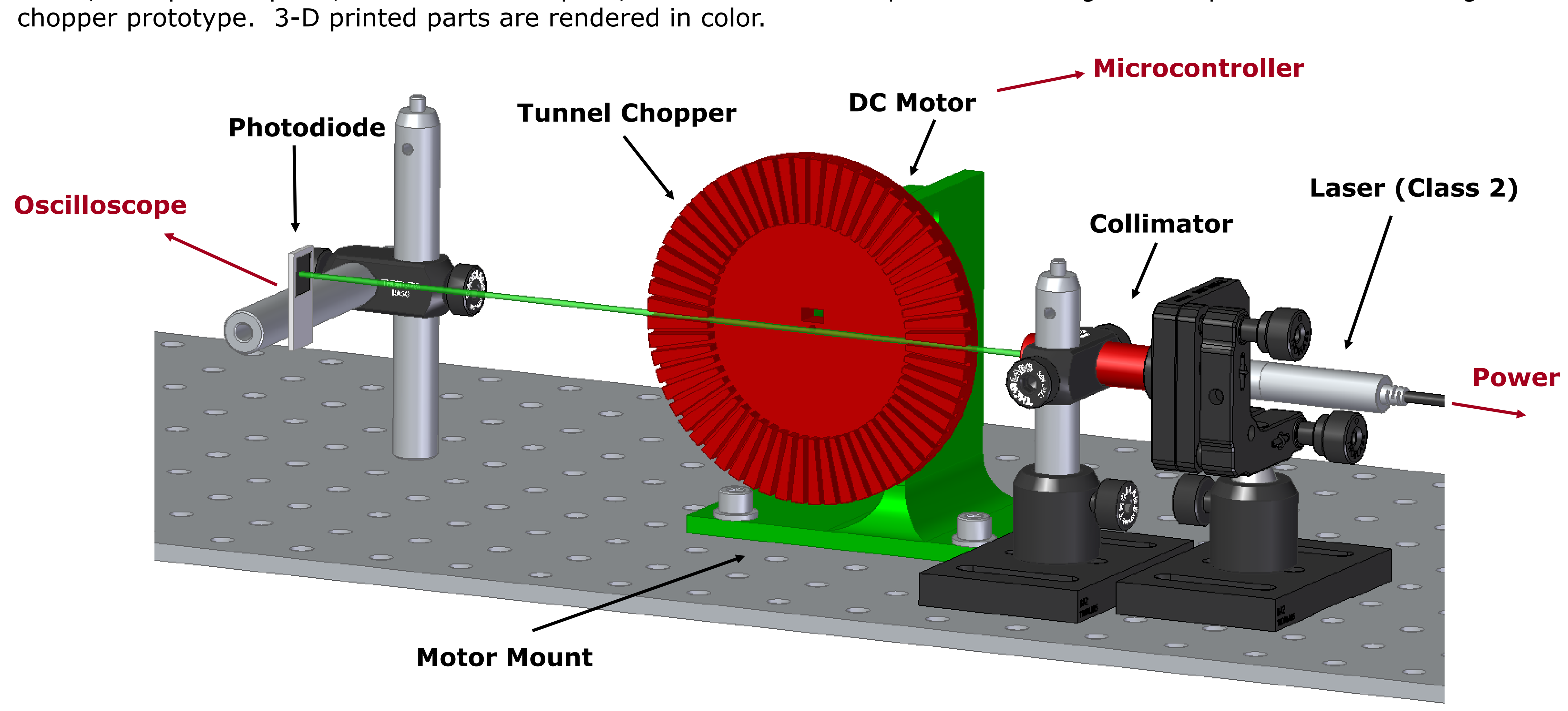


Figure 2. *Prototype Assembly*. Depicted above is the Solid Edge assembly of the chopper prototype. The laser diode (right), secured in a kinematic mount, emits a beam through the red collimator. The beam is then parsed by the rotating chopper (center) before striking the photodiode (left) in pulses. The motor (hidden) is driven by a power supply, through an Arduino microcontroller. Note that the model illustrates a moment of peak light intensity incident upon the photodiode.

Looking Ahead

As of the last completed design revision, the tunnel chopper has delivered a 42 microseconds pulse width, with the capability of going as low as 28 microseconds. The next revision features smaller apertures and a new motor, with a goal of achieving a 19 microseconds pulse width.

This prototype process has illuminated many design needs in regard to the ultimate mission of providing a chopper to pulse a continuous x-ray. As one progresses into the final design phase, one might consider the following improvements to the system:

Areas for Improvement	Mitigation
Speed Control	Implement closed-loop feedback from photodiode using Arduino
Laser, Collimator, and Chopper Alignment	Install bellows and stages
Vacuum Rotary Motion Feedthrough Speed	Research Julich technology
Chopper Size	Increase radius to 3 inches
Collimation	Research affect on light intensity
Resonant Frequency Vibrations	Install physical supports or damping mechanism
Chopper Stability	Determine vibration in horizontal plane using Keyence laser displacement sensor
Pulse Width	Research multi-part chopper systems

Figure 4. *Final Design Considerations*. The table above lists the topics to be addressed in the final design.

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