ISBN: 978-3-95450-207-3 doi:10.18429/JACoW-MEDSI2018-THPH27

MECHANICAL DESIGN OF A COMPACT NON-INVASIVE WAVEFRONT SENSOR FOR HARD X-RAYS

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Abstract

This work describes mechanical design of a prototype compact wavefront sensor for in situ measurement and monitoring of beam wavefront of hard x-ray beamlines. The system is based on a single-shot grating interferometer [1, 2] and a thin diamond single-crystal beam splitter. The beam splitter is designed to be inserted in the incident beam and oriented to diffract a fraction of the incident beam bandwidth into the interferometer, for wavefront measurement and reconstruction. The concept is intended to study the feasibility of a non-invasive wavefront sensor for real time wavefront monitoring and diagnostics, with possible application in adaptive mirrors for wavefront preservation and control [1, 3]. The design focus was on compactness to enable easy portability and implementation in a beamline.

Z8-83 OVERALL DESIGN

The wavefront sensor, see Fig. 1 and 2, was designed for in situ measurement and monitoring of beam wavefront of hard x-ray beamlines. It works by placing a single-crystal beam splitter into the incident x-ray beam and then using the grating interferometer to measure the diffracted wavefront in a non-invasive manner. The design is based on the designs in [1, 2] with the focus being compactness so that it could be easily implemented in any beamline. The entire assembly is only 26 kg (Table 1), which can be easily lifted by two people without lifting equipment. A total of 9 controlled stages were used in its various sub-assemblies and the camera and grating assemblies were designed to be manually positioned along the rotation arm. The support structure is modular such that the legs can be removed completely or replaced with longer legs all while maintaining alignment of the crystal rotation axis and main diffraction axis.

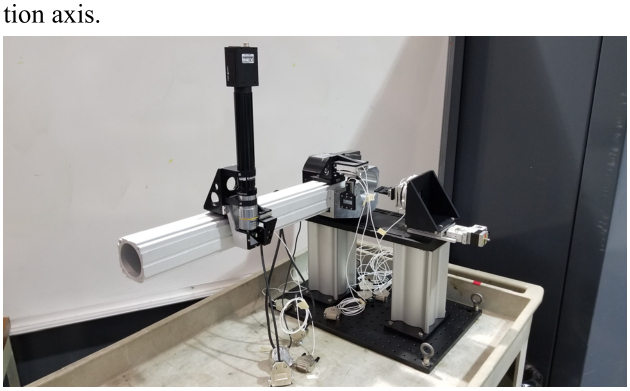

Figure 1: Fully assembled wavefront sensor.

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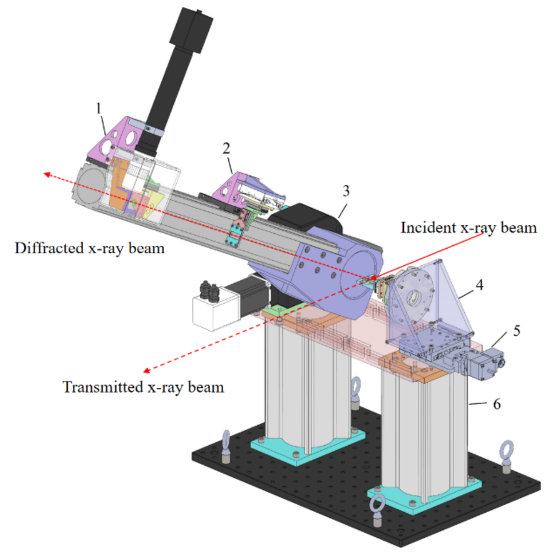

Figure 2: Complete assembly of Z8-83 wavefront sensor: (1) camera assembly, (2) grating assembly, (3) rotation arm, (4) crystal assembly, (5) Kohzu Precision Co. linear stage, and (6) modular support table.

Z8-830200 Crystal Assembly

The crystal assembly holds the single-crystal beam splitter, see Fig 3. A SmarAct SR-7021 rotation stage is used to rotate the crystal to diffract a fraction of the incident beam, all other stages are used for fine positioning alignment of the crystal. The crystal holder is designed with a U-shaped cut-out to let the incident beam pass through non-invasively.

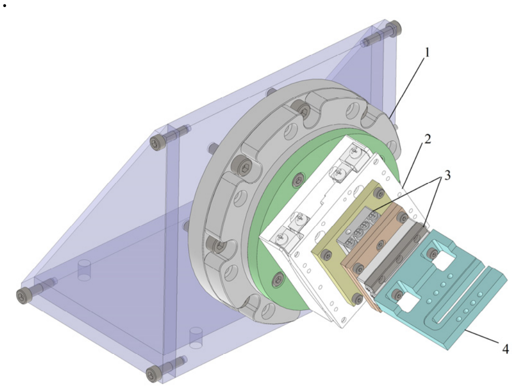

Figure 3: Z8-830200 crystal assembly: (1) SmarAct GmbH SR-7021 rotation stage, (2) SmarAct GmbH SGO-60.5 tilt stage, (3) SmarAct GmbH SLC-1730 linear stage, and (4) crystal holder.

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Z8-830300 Grating Assembly

The grating assembly can be seen in Fig. 4. It is placed between the crystal and the camera assembly. The grating holder is made as narrow as possible so that it can get as close as possible to the crystal.

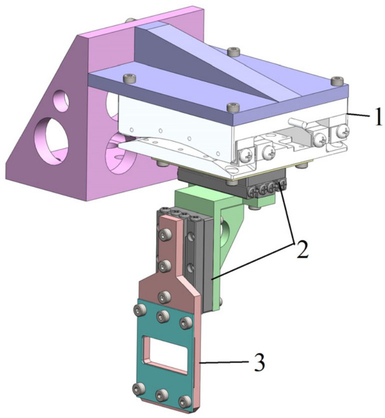

Figure 4: Z8-830300 grating assembly: (1) SmarAct GmbH SGO-60.5 tilt stage, (2) SmarAct GmbH SLC-1730 linear stage, and (3) grating holder.

Table 1: Specifications of Z8-83 Wavefront Sensor and the Commercial Stages Used in its Design

Specification	Value
Z8-83 Wavefront Sensor	
Volume (L x W x H) mm^3	(884x502x393)
Mass	25.9 kg
Controlled Degrees of Freedom	9
SmarAct GmbH SLC-1730 Linear Stage	
Smallest/Largest Step Size	1 nm/1.5 µm
Range	±10.5 mm
Mass	20 g
SmarAct GmbH SGO-60.5 Goniometer	
Smallest/Largest Step Size	0.7/7 µrad
Range	± 5°
Mass	140 g
SmarAct GmbH SR-7021 Rotation Stage	
Smallest/Largest Step Size	3.5/35 µrad
Range	∞°
Mass	400 g
Kohzu Precision Co. XA07A-R201 Linear Stage	
Resolution Full/Half Step	1/0.5 µm
Range	±10.0 mm
Mass	600 g
Aerotech® Inc. AGR50 Rotation Stage	
Resolution	58 µrad
Range	∞°
Mass	2.5 kg

Z8-830400 Camera Assembly

The camera assembly, Fig. 5, supports the camera (GS3-U3-120S6M-C, FLIR Integrated Imaging Solutions Inc.), 45° reflecting mirror (#45-595, Edmund Optics Inc.), 10X Mitutoyo objective lens with a 33.5 mm working distance (#46-144, Edmund Optics Inc.), and the scintillator. All of these components are enclosed by an opaque 3D printed plastic cover. The scintillator holder can be adjusted in the along the x-ray beam direction using an SLC-1730 piezo stage and the entire scintillator holder can be removed without disassembling any other components allowing for quick changes in scintillator types. The scintillator is clamped using a 3D printed ring, which is then held in place by a metal retaining ring.

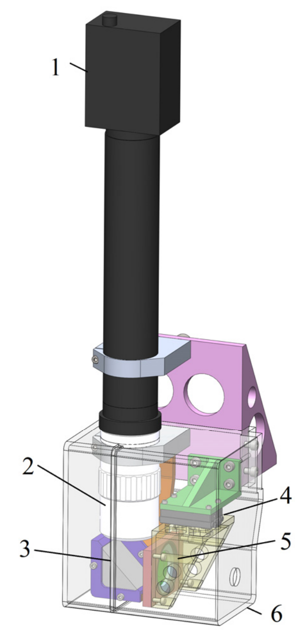

Figure 5: Z8-830400 camera assembly: (1) FLIR Integrated Imaging Solutions Inc. GS3-U3-120S6M-C camera, (2) Mitutoyo Co. 10X objective lens, (3) Edmund Optics Inc. #45-595 45° reflecting mirror, (4) SmarAct GmbH SLC-1730 linear stage, (5) scintillator holder, and (6) opaque cover.

ROTATION ARM DESIGN

The pitch arm assembly, Fig. 6, is mounted to a rotation stage (AGR50, Aerotech Inc.) for pitch rotation with 180° rotation range and 58 µrad resolution. Both the camera and grating assemblies are mounted to dovetail carriages (XT95P11/M, Thorlabs Inc.), which can be manually adjusted over a range of 438 mm on the rotation arm. A counterweight support extends through the aperture of the rotation stage to increase the structural rigidity of the pitch arm. The rigidity is increased due to the sliding fit contact between the counterweight support and the rotation stage aperture hole. In addition, this geometry allows for complete

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180° free rotation of the counterweight. Two counterweight position are required to utilize the entire working length of the arm and can be seen in Fig. 6.

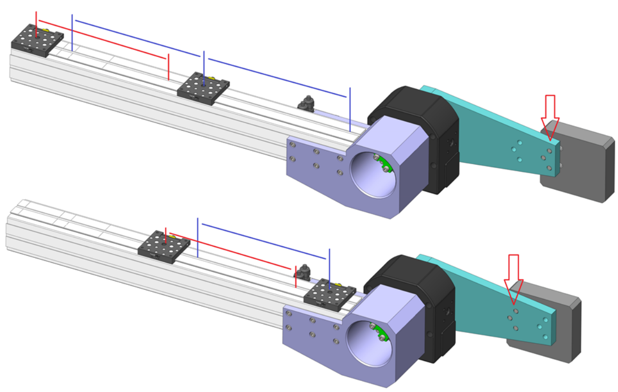

Figure 6: Balance configurations of Z8-830100 rotation arm with the potential positions of the camera assembly (red lines) and grating assembly (blue lines): (top) furthest extent configuration and (bottom) closest configuration.

FEA of Rotation Arm

There were concerns about the stability of such a long arm with the potential of a concentration of mass at the end. A design goal of >100 Hz for the first mode shape with the grating and camera assemblies at the extreme end of the arm was set. The grating and camera assemblies are represented by the points in the model and were modelled as extended inertia points to reduce model complexity.

In Fig. 7 it can be seen that the design goal was not achieved; this was due to weight constraints on the rotation stage. In Fig. 7 the first 3 mode shapes can be seen. The first mode of 50 Hz is much lower than the design goal, but looking at the mode shape it can be seen that the majority of the motion was in the counterweight and likewise with the second mode. It is the third mode that was found to influence the main arm the most and was at 94 Hz putting the design reasonably close to the design goal.

ACKNOWLEDGEMENTS

Work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

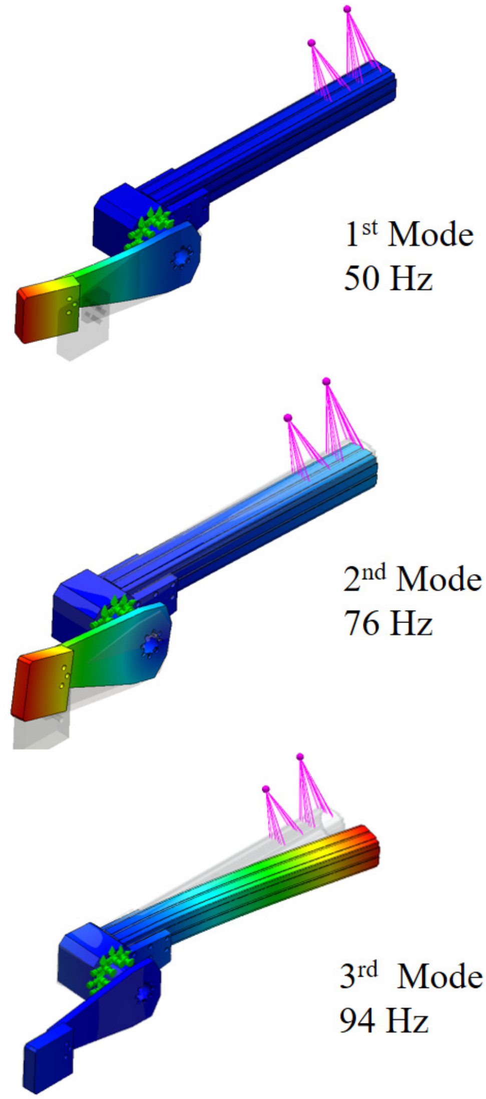

Figure 7: First 3 mode shapes of the rotation arm assembly.

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