Optical autocollimator for vibration measurements at Diamond I13 beamline

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Abstract. I13 is a 250 m long hard X-ray beamline for imaging and coherence experiments at the Diamond Light Source [1]. The beamline comprises two independent experimental branches: one for imaging in direct space using X-ray microscopy and one for imaging in reciprocal space using coherent imaging techniques. The mechanical stability is very important for implementation of increased capabilities at latest generation of long beamlines [2]. Therefore, the beam stability monitoring is essential part of the day-to-day operation of the beamlines as well as for analysis of mechanical instability sources for the Diamond II upgrade. In this paper we present the setup developed to measure mechanical stability of beamline based on optical autocollimator.

1. Introduction

Outstanding characteristics of fourth generation storage rings, such high brightness and coherence, enable advanced techniques that push frontiers in condensed matter physics, material science and biology. The lensless imaging techniques, such as ptychography, do not have a theoretical limit on spatial resolution that can be achieved and could push the boundaries of imaging to just a few nanometers and possibly to atomic scale (~1 nm). However, further progress requires extreme stability of experimental setup and vibration is often a problem causing poor quality of photon beams [3]. Therefore, vibration measurement, analysis, and control at long synchrotron beamlines is crucial for the full realisation of potential offered by fourth generation storage rings [4].

2. Optical autocollimator specifications, design, and parameters

Autocollimators are used extensively in optical metrology to precisely align components and measure deflections in an optical or mechanical systems [5]. Autocollimators utilise the principle of autocollimation: a collimated beam, which, by definition, has a small beam divergence, is directed to a plane reflecting surface, and its reflection back into the same system denotes the angular position of the reflecting surface with respect to the incident beam, when the target is precisely aligned incident and reflected beams reflect into each other. The incident (i.e., outgoing) beam is typically collimated by placing the light source in the focal plane of the lens system. The angular position of reflected beam is converted into a spatial position when it passes through the same lens system; the position of the resulting focused spot in a focal plane directly indicates the angular deflection of the reflecting surface.

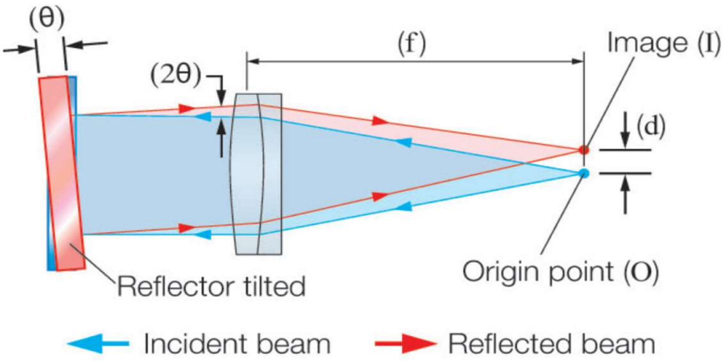

Figure 1. The principle of autocollimation for the deflection angle measurements.

Figure 1 illustrates the principle of autocollimation in more detail. Light from an origin point O is collimated by a lens system. If the incident collimated beam falls perpendicularly onto a plane reflecting surface, the light is reflected back along its original path and is brought to a focus at a point coincident with the origin point. If the reflecting surface is tilted at an angle θ, the beam is reflected at an angle 2θ, and the image I is displaced laterally from the origin O in the focal plane of the lens system. The amount of lateral displacement d is given by:

$$d = 2f\Theta$$

where f is the focal length of the lens, and θ is in radians.

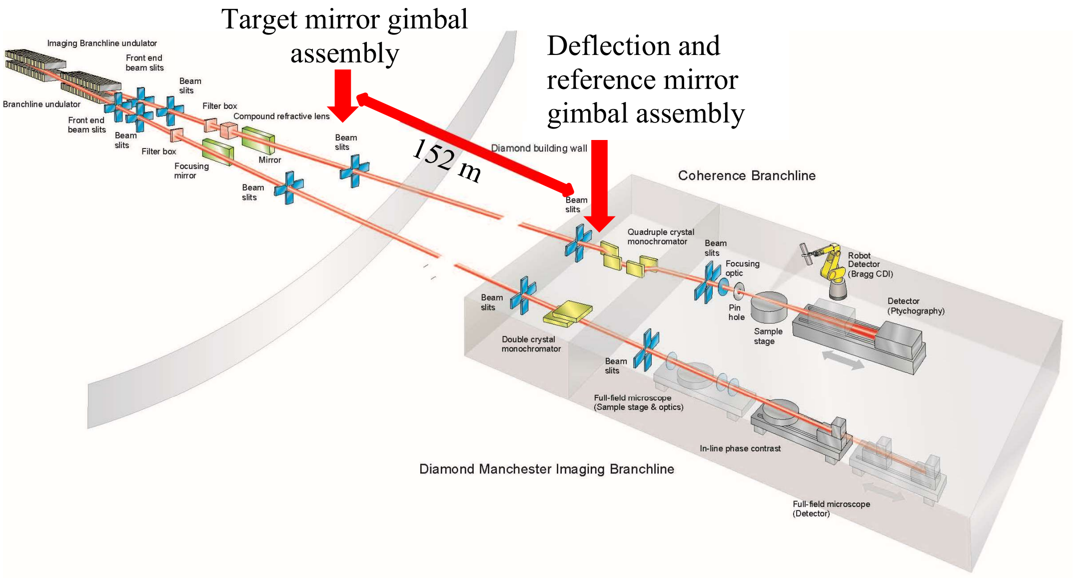

Figure 2. Schematic of the I13 beamline, the positions for the mirror gimbal assemblies are indicated by the red arrows.

In practical autocollimator implementations, the beamsplitter is used to separate the light source and the image sensor so both could be located in the focal plane of the lens system. Beam splitter directs light from an illuminated target graticule (typically a crosshair) located at the focal plane towards the lens system. After reflection by a target mirror, the light returns through the lens system and again passes through the beam splitter, forming an image of the target graticule on image sensor.

The autocollimator system is installed on I13 coherence branch as shown in Figure 2. It consists of following parts: autocollimator gimbal assembly, target gimbal mirror assembly, deflection and reference mirror gimbal assembly. The main purpose of the deflection mirror is to deflect light the along the beamline as the autocollimator assembly makes 90-degree angle with direction of X-ray beam propagation as shown in Figure 3. The reference mirror reflects part of the light beam back providing a reference for the target mirror. The target mirror is located 152 m away from reference mirror in the main synchrotron building. The autocollimator measures the angular deflection between reference and target mirrors which reflect the vibrations between external and main synchrotron buildings.

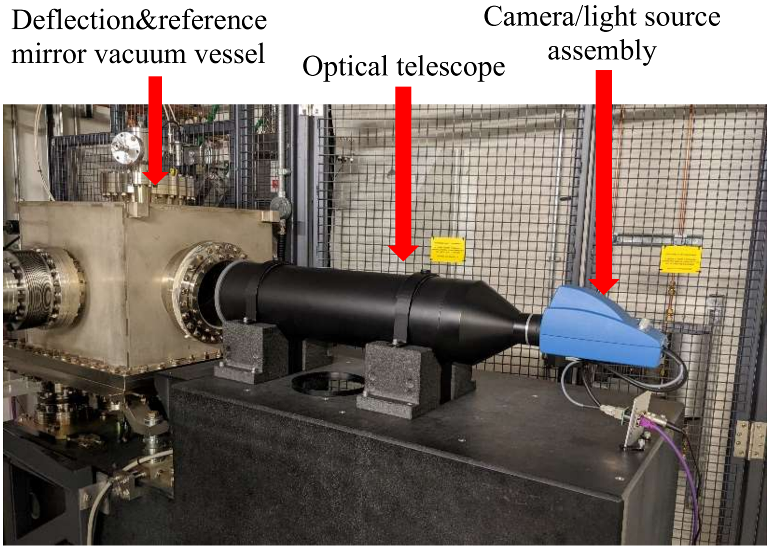

Figure 3. Photo of the autocollimator: deflection&reference mirror vacuum vessel, optical telescope and camera/light source assbely are indicated by red arrows.

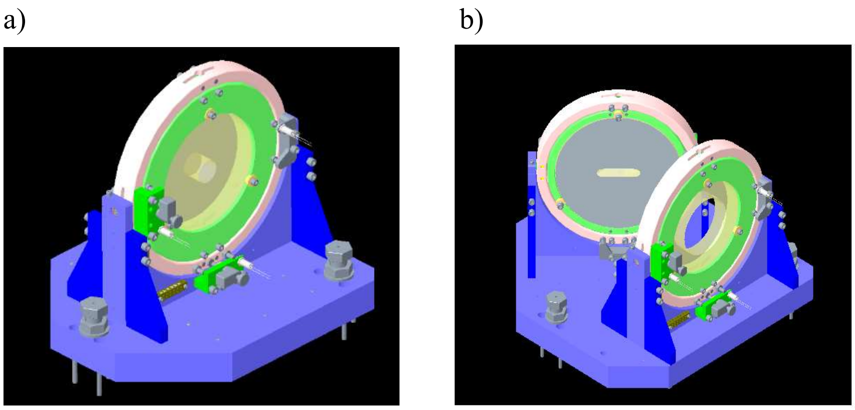

Figure 4. Target mirror gimbal assembly (a), deflection and reference mirror gimbal assembly.

The optical specification of deflection, reference and target mirrors are shown in Table 1. Reference and target mirrors have circular cut-outs for the X-ray beam to pass through, for the deflection mirror the cut-out is elongated in the horizontal direction since it makes 45-degree angle with the X-ray beam. The mirrors are made from Zerodur to minimise influence of thermal expansion on the measurements. All mirrors are UHV compatible and are motorised to allow tilt in vertical and horizontal directions using Newport 8301F piezo linear actuators.

Table 1. The optical specifications for mirrors

Surface quality	60/40, λ/10@632.8 nm
Coating	Protected aluminium
Material	Zerodur

Table 2. Optical autocollimator system parameters

Effective focal length	800 mm
Aperture	140 mm
Reticle size	30 µm crosshair
Resolution	0.01 arcsec
Accuracy	+/- 0.2 arcsec
Light source	LED 350 mA, 525 nm
Sensor type	Manta G-125B CCD camera
Sensor pixel size	3.75 µm × 3.75 µm
Sensor pixel array	1292(H)×964(V) pixels

The autocolllimator assembly was supplied by Trioptics Gmbh and consists of telescope, light source and the camera installed on granite base plate for stability. The parameters of the system are listed in Table 2. A high power Light Emitting Diode (LED) working at 525 nm is used as light source. Crosshair with 30 µm thick lines is used as target graticule which is illuminated by the light source and its image projected towards reference and target mirrors. In terms of angular resolution, one pixel corresponds to ~0.5 arsec of target mirror deflection. However, commercial software supplied with autocollimator enables angular vibration measurements via subpixel identification of crosshair location and tracking improving the system resolution to 0.01 arcsec. The dark image subtraction and averaging are also implemented in the software. The maximum frame rate is up to 20 Hz, limited mainly by the intensity of the signal reflected from the target mirror 152 m away from reference mirror. Figure 5 shows the autocollimator camera image with target and reference mirror reflections indicated.

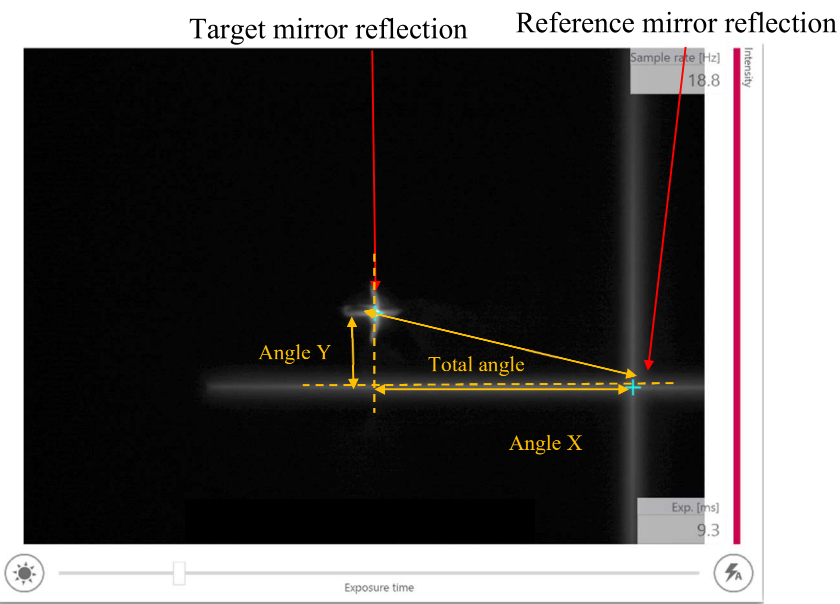

Figure 5. Autocollimator camera image with target and reference mirror reflections indicated.

The example of data obtained during autocollimator commissioning are shown in Figure 6. During relatively short span of measurements (~ 160 s), no strong vibration frequencies were identified. Note that in this case the camera frame rate was set at 6 Hz. More data and analysis of the vibration sources will be presented in a separate paper.

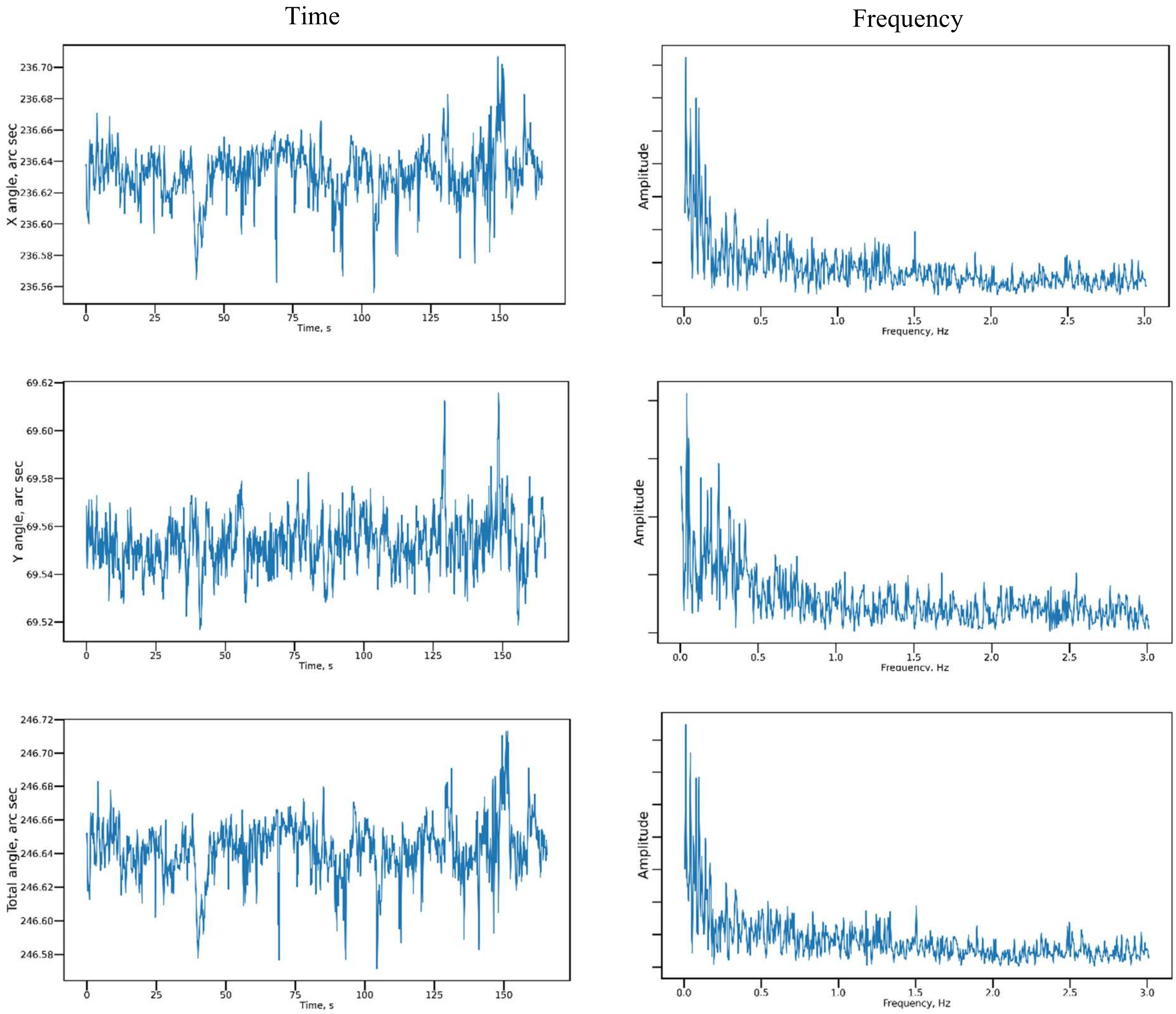

Figure 6. Typical data measured using autocollimator setup during commissioning.

3. Summary

A real-time vibration monitoring setup based on optical autocollimator has been developed and is available on I13 beamline. It is envisaged that autocollimator together with hydraulic leveling system and network of vibrometer sensors will provide a comprehensive diagnostics suite to measure and identify the sources of vibrations.

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References

[1] C. Rau, U. Wagner, Z. Pešić, A. De Fanis, Phys. Status Solidi 208, 2522 (2011)
[2] U.H. Wagner, A. Parsons, C. Rau, J. Phys.: Conf. Ser. 849, 012048 (2017)
[3] W. Grizolli, X. Shi, L. Assoufid, Opt. Lett. 44, 899 (2019)
[4] C. Houghton, C. Bloomera, L. Alianelli, J. Synchrotron. Rad. 28,1357(2021)
[5] J.-Y. Yuh, S.-W. Lin, L.-J. Huang, L.-L. Lee, J. Synchrotron. Rad. 23, 1232 (2016)