Development of an on-axis-visualization stage to observe and align sample with an x-ray beam

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Abstract. An on-axis-visualization stage for accurate sample alignment respect to X-ray beam has been designed and implemented at the diffraction and absorption/fluorescence stations of the BM25-SpLine synchrotron beamline at the ESRF. It is mostly intended for studies involving heterogeneous samples where the analysis is restricted to a particular area of the sample. The OAV system provides a parallax-free image of the sample. This is accomplished by a front-surface mirror at an angle of 45° degrees to reflect the visible sample image 90° up to a zoom optics and digital colour CCD camera. A pinhole (PH) on the mirror in combination with a second PH 100 mm backward provides an on-axis collimated X-ray beam at image centre. The collimator is aligned to the beam axis by two angular and two translational high-precision motorized motions. The OAV stage is synchronized with the sample positioning stage, by a computer software so that the desired sample region is aligned on the X-ray beam by selecting it on the image produced by the video camera. In this work, a complete description of the on-axis-visualization system will be presented including the experimental determination of the alignment accuracy.

1. Introduction

The advent of high intense X-ray micro-beams offered by synchrotron sources provides a unique opportunity to study heterogeneous samples by means of X-ray diffraction and absorption techniques. Many disciplines deal with non-homogeneous samples. For instance, archaeometry studies are mostly performed on archaeological fragments that present decorations, incisions or small degraded areas. Corrosion studies also require high spatial resolution. However, in order to align the selected region from the sample to be studied, the X-ray micro-beam should be combined with a system that enables an easy and fast alignment. Several sample and X-ray beam alignment systems have been developed based on the use of laser beams [1] or profile monitor wires to define the beam position [2]. The main disadvantage of the profile monitors based on wires is that they are non in-situ devices so they should be removed from the X-ray beam once the alignment is performed. In the case of laser based alignment tools they generally use coated mirrors for optimal laser reflection that diminish considerably the X-ray beam intensity. In this present work we have developed a simple alignment tool based on an optical image processing system that works in a non-interference mode with the X-ray beam. The alignment tool enables a continuous visualization of the sample without degrading the beam properties, such as intensity, spot size, coherence, etc. The description of the alignment and
visualization stage together with the experimental determination of the alignment accuracy is described in the next sections.

2. Description of the on-axis visualization stage

A schematic layout and a picture of the on-axis-visualization (OAV) stage are shown in Fig. 1. The OAV consists of a front-surface mirror at an angle of 45° degrees that reflects the visible sample image 90° up to a zoom optics and digital colour CCD camera. A pinhole (PH) on the mirror in combination with a second PH 100 mm backward provides an on-axis collimated X-ray beam at image centre. In this way the OAV stage enables a continuous visualization of the sample without interfering with the X-rays. The beamline optics [3] as well as the first PH provides a virtual source smaller than the 45°-mirror PH in order to cut the background scattering. A key design specification was to provide easy access for replacement of the collimator/mirror plates from its mount. A kinematic pre-constrained mounting space-gap system has been designed to reach these specifications. Several mirror-plates with different PH dimensions are available in order to change the X-ray beam spot size. The collimator is aligned to the beam axis by two angular and three translational high-precision motorized motions. The zoom optics has a focus range that covers the distance between the mirror PH and the sample providing a parallax-free image of the sample. The OAV stage is synchronized with the sample positioning stage by computer software so that the desired sample region is aligned on the X-ray beam by selecting it on the image produced by the video camera. The dimensions of the complete stage (collimator and alignment tower) are 780 mm in height (Alignment tower = 300 mm, collimator = 100 mm and camera = 380 mm), 200 mm long and 100 mm wide. The weight is 10 Kg. Such a low dimension and weight enables its incorporation on a wide variety of experimental set-ups.

![Figure 1. Schematic layout (left) and real picture (right) of the on-axis-visualization stage. The combination of a pinholed mirror and a pinholed slit ensures the alignment of the optical and X-ray axis. The mirror which is placed at 45° reflects the optical image to a CCD camera. The low dimension and weight enables its incorporation on a wide variety of experimental set-ups.](image-url)
3. Experimental determination of the alignment accuracy

The developed OAV stage provides two different sample-x-ray beam alignment possibilities:

i) Non-axis video system. Such an approach is achieved by the combined use of the pinholed mirror and a phosphor screen placed at the sample position. In this approach the pinholed slit is not used. The X-ray position is obtained from recording with the OAV video camera the visible light emitted by the phosphor screen (Figure 2a). Then, after removing the phosphor screen, the selected region of the sample to be analyzed is moved to the X-ray position (Figure 2b). The alignment accuracy has been experimentally determined by using a 0.1 mm slit at the sample position. The alignment error is then determined by scanning the latter slit position along the perpendicular direction to the X-ray beam path. The beam intensity is monitored by an ionization chamber placed after the slit (sample). The alignment accuracy was determined for two different pinhole dimensions, 0.1 and 1 mm in diameter. The obtained alignment error was 10 µm and 100 µm for the 0.1 and 1 mm pinholes, respectively, as shown in Figure 2c and Figure 2d. The alignment error (10% of the pinhole dimension) is mainly given by the precision in the determination of the X-ray beam central position. Such an alignment approach has the advantage that it offers an easy and simple alignment procedure (no need of parallel alignment between OAV stage and x-ray axis and no need of changing the optic-zoom focus distance). However an important disadvantage is that such an approach is only valid for flat samples. In the case of non-flat samples a positioning error arises when selecting a sample region with a different sample-mirror distance than for the aligned region, as shown in Figure 3a. The sample positioning error becomes more important for larger differences in sample height, i.e., departure from ideal flat sample.

![Figure 2](image)

Figure 2. OAV stage alignment with respect to the X-rays for the non-axis video system (a) and (b), and for the on-axis video system (e) and (f). Alignment accuracy determination for both alignment procedures, using two sets of pinholes 0.1 mm and 1 mm. (c, d, g, h)

ii) On-axis video system. Such an approach is achieved by the combination of the pinholed mirror and pinholed slit. The optical axis is aligned with the X-ray axis when the X-rays go through both pinholes. The alignment is performed using the 3 translations and 2 rotations from the alignment tower and monitoring the X-ray intensity with an ionization chamber placed after the OAV stage. The sample alignment with respect to the X-ray beam is achieved by changing the optic-zoom focus distance in order to focalize the pinhole on the mirror (Figure 2e). Once selected the pinhole position, i.e., the X-ray position, the optic-zoom focus distance is moved back to the sample position. The sample region to be studied is then moved to the X-ray beam position (Figure 2f). The alignment precision was measured experimentally for a pair of pinholes of 0.1 mm and 1 mm, using the method described above. The obtained alignment error was 10 µm and 100 µm for the 0.1 and 1 mm pinholes, respectively, as shown in Figure 2g and Figure 2h. The alignment error (10% of the pinhole dimension) is mainly given by the precision in the determination of the pinhole central position. Such an alignment approach has the advantage that it is valid for non-flat samples (Figure 3b), which is, for
instance, usually the case in archaeometry studies. The disadvantage of such an alignment method is that the pinholes alignment respect to the X-ray beam becomes tedious, especially for the smallest pinholes dimensions.

![Diagram of Sample, Mirror, and Slit](image)

Figure 3. Schematic representation of the non-axis (left) and on-axis (right) video systems. A sample positioning error is present for non-flat samples when the non-axis-video system is used. Such a positioning error is larger for samples with large height differences. The on-axis-video system is valid for non-flat samples.

5. Conclusions

An on-axis visualization stage for sample visualization and alignment has been developed. It consists on a collimator based on the combination of a pinholed mirror, which deflects 90° de sample optical image, and a pinholed slit. The OAV stage alignment can be performed in the non-axis or on-axis configurations. The non-axis configuration has the advantage that it offers a fast and easy collimator alignment procedure. However it is only valid for flat samples. The on-axis configuration is valid for non-flat samples although the collimator alignment is more tedious. For both configurations the alignment accuracy is 10% of the dimension of the used pinhole, i.e., beam size. Hence 10 µm alignment accuracy is obtained for 0.1 mm beam size. Such a positioning error is mainly given by the precision in defining the centre of the x-ray beam or pinhole.

6. Acknowledgements

The authors are grateful to the SpLine staff for their assistance. The financial support of the CSIC and MINECO (PI201060E013 and MAT2011-2378) is also acknowledged.

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