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Contributed paper

Sphere of confusion of a goniometer: measurements, techniques and results

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In the diffraction community, the goniometer is the main part of the diffractometer, essential for orienting the samples. To characterize the goniometer, the sphere of confusion (SoC) has been measured. The SoC describes the minimal sphere that enclosed the measurements. This essential information is very important for the diffractometer users. In collaboration with Symetrie Inc., Soleil Synchrotron and the CEA, the SoC has been measured with three different metrology methods. These three measurement techniques and the associated results are discussed in this article.

1. Introduction

A goniometer has been designed and fabricated in collaboration with Symetrie Inc. (Nîmes, France) for the Multi-Analysis on Radioactive Samples (MARS) diffractometer at Soleil Synchrotron. This goniometer consists of two rotation (one at 100 rpm) and three translation stages with measured exactitude less than ±3.0 μm according to ISO 230-2 for the sample alignment, mounted on a third rotation stage. This heavy-duty positioning system can carry a 5 kg sample holder and it is enclosed in a 600 mm diameter (Figure 1).

In order to obtain reliable diffraction data, the accuracy of the sample orientation must be done very precisely. The sphere of confusion (SoC) is defined as the minimum spherical volume covering all possible locations of an infinitely small object at all possible goniometer orientations (Davis, Groter & Kay 1968). The SoC is generally described by the diameter of the sphere, but sometimes the radius is also used to define the SoC (He 2009). The accuracy of the goniometer is described by the diameter of the SoC within which the intersection point of the three axes can be contained when moving any or all of the three axes arbitrarily. In fact, the three axes will, in general, not intersect at the same point, or not intersect at all, but merely come very close to each other. In this light, when moving all the three axes, the

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whole measured points, representing a cloud point, define an 'error volume' and the SoC value is deduced from this volume. For the acceptance test of the goniometer of Symetrie Inc., different methods of measurements have been realized to determine the point cloud of the 'error volume'.

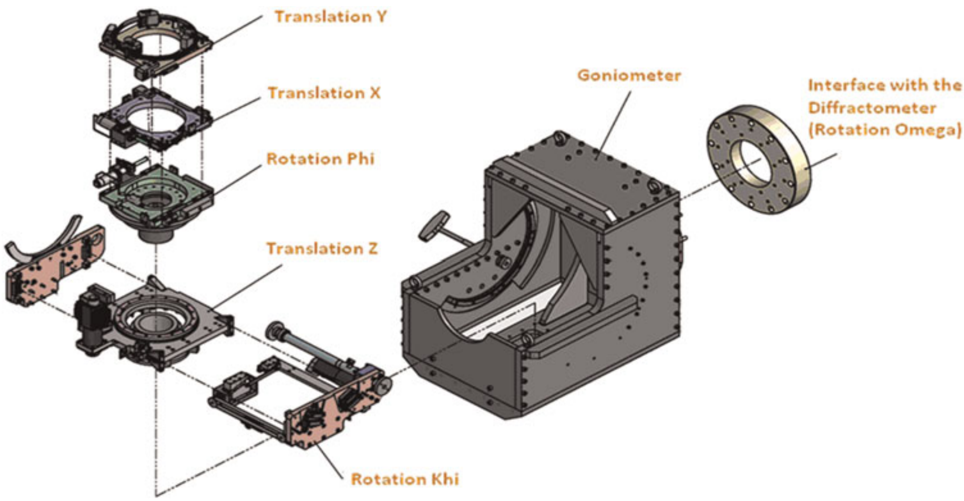

FIGURE 1. Exploded view of the goniometer.

2. Description of the measurement methods

Usually, a ball gauge is used to define the centre of rotation of machine set-ups with several rotation stages. For the goniometer, the SoC was measured using a ball gauge attached to the Phi-rotation stage. Using the centre of the ball gauge, each point of the cloud is measured and defined thus the shape of the 'error volume'. For this operation, the ball gauge should be physically placed in the best possible location on each axis.

There are several methods to measure the centre of the ball gauge. But the goal consists of always measuring a point (described by three co-ordinates) in a Cartesian coordinate system (reference). The choice of the reference is important and should be defined precisely. Results can differ if a reference constructed from the floor or one attached to the system structure has been chosen.

The different methods used to qualify the SoC of the goniometer are: a method by using a coordinate measuring machine (CMM), an optical method using an autocollimator and measurements with three linear sensors.

Measurements have been made with the goniometer installed on a CMM machine (Figure 2), then installed on the MARS diffractometer (for the two other measurement methods).

3. Results and discussion

There is more than one method to find the SOC from the point cloud, depending on the method chosen to compute it. For example, one method would be to consider the most remote points of the point cloud and to fit a sphere on these points; another method would be to find the barycentre of the point cloud, and to determine the radius by the distance between the barycentre and the most remote point from it.

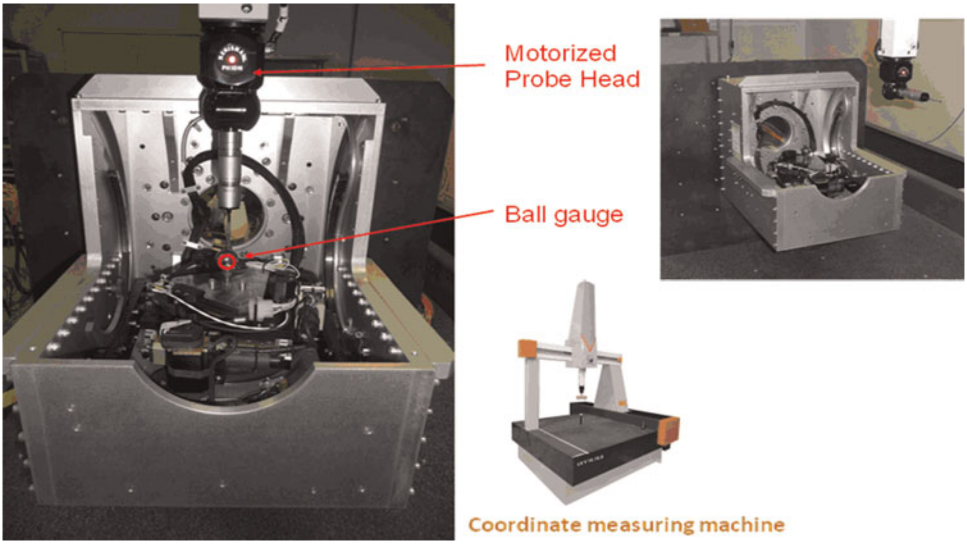

FIGURE 2. Goniometer on the coordinate measuring machine.

Due to the lack of a particular shape, the minimal error volume fits badly in a sphere. That is to say, if the points measured are fitted in a sphere, a lot of volume is accounted without the presence of any points. In our case, the point cloud fits well in a parallelepiped, but this cannot be a general method because in some cases the parallelepiped has a bigger volume than the sphere.

In our case, the method chosen is rather quick and simple, and gives important characteristics in the user reference frame of the minimal volume error: the distance between the most remote points, the range of the projections of the point cloud on each axis of the reference frame and the middle points of these projections.

To better understand, the point cloud is presented in a 3D plot (figures 3) and the projections of the point cloud are plotted on the planes of the reference frame. This is very helpful to determine some special limited movements' range in which positioning error is minimum. Also, these projections allow us to distinguish an overall shape of the error point cloud and we can foresee to compensate a first-order component of the error by using the movements of the translation axis of the goniometer.

The volume enclosed by the parallelepiped containing all the points and having its faces parallel to the user reference is roughly half of the volume of the sphere. A discontinuity appears in the plot that seems to be due to two potential zones that attract the error domain in particular zones of the Khi movement.

The results of the measurements give a distance between the most remote points of 37 μm with the three-sensors method and 39 μm with the optical method.

Knowing the shape of the 'error volume' better instead of representing it by the SoC (a sphere and its diameter) allows us to take it into consideration when performing an experiment. For example, if the error volume is highly anisotropic, the interesting direction of the sample can be positioned in configuration where the 'error volume' is minimal. By this way, this knowledge allows engineers to develop some instruments, as for example, hexapods, complying with the requirements of the scientists.

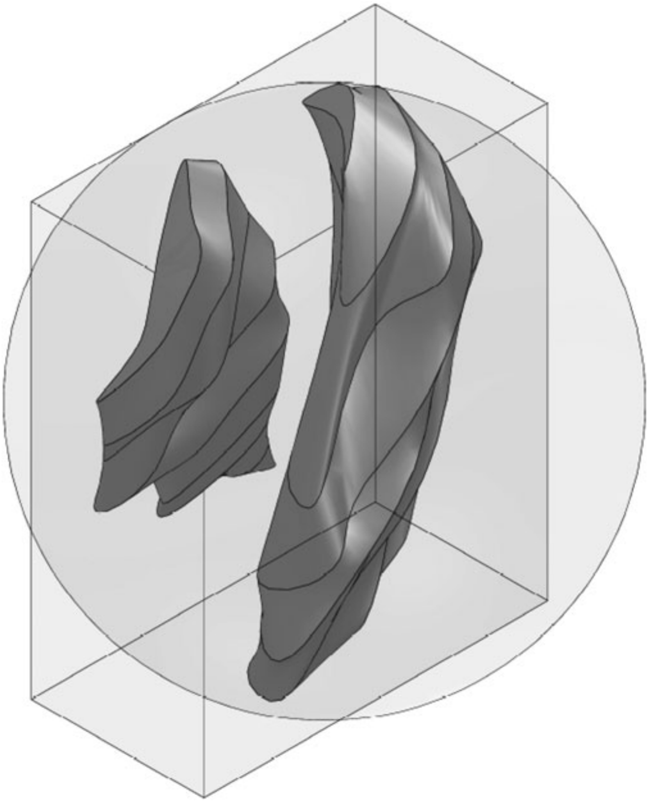

FIGURE 3. Plot of the ‘error volume’.

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