Nano Radian Angular Resolution Flexure Stage For ID28 Post-monochromator

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Abstract

On ESRF Beamline ID28 a post-monochromator was required downstream from the silicon (111) pre-monochromator to further reduce the heat load on the very high-energy resolution back scattering monochromator. A silicon channel cut crystal with a higher reflection order (331) was selected for this post-monochromator. The rocking curve width of this reflection is very narrow (typically between 2 & 5 micro radians). Hence the angular resolution of the crystal positioning mechanics should ideally be less than 1 micro radian.

A novel flexure stage driven by a high resolution DC mike linear actuator was designed & developed to give an angular resolution of 0.1 micro radians. The design incorporates a circular cartwheel flexure stage with a radial thin blade that gives a very large de-multiplication to the movement of the linear actuator.

This paper presents the design of the flexure stage, the finite element analysis, and the measured results obtained in the laboratory.

1. Introduction

The general layout of ESRF Beamline ID28 is shown in figure 1, and the optical schematic is shown in figure 2. The Beamline is dedicated to inelastic scattering experiments, focusing on the study of phonon dispersions in condensed matter.

There is a high heat load silicon 1,1,1 pre-monochromator at 51m from the source. The x-ray beam is further monochromatised by a backscattering monochromator at 73m from the source. This has a flat silicon crystal operating at a Bragg angle of 89.98° and utilising a high order energy reflection (e.g. 11,11,11). It produces a monochromatic beam with an energy resolution of $2x10^{-8}$. The beam is then focussed by mirrors and Be lenses to the sample position at 44m from the source. Behind the sample there is a horizontal spectrometer with a 7m arm.

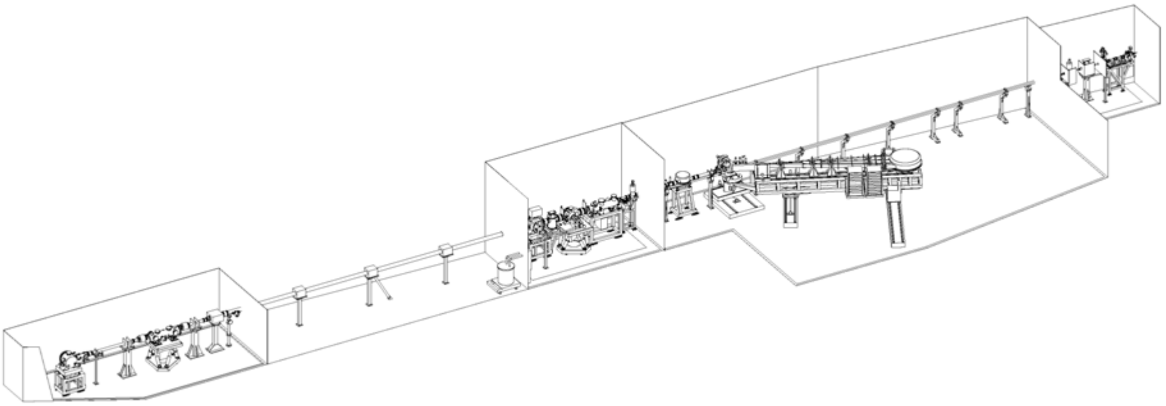

Figure 1: General Layout of ESRF Beamline ID28

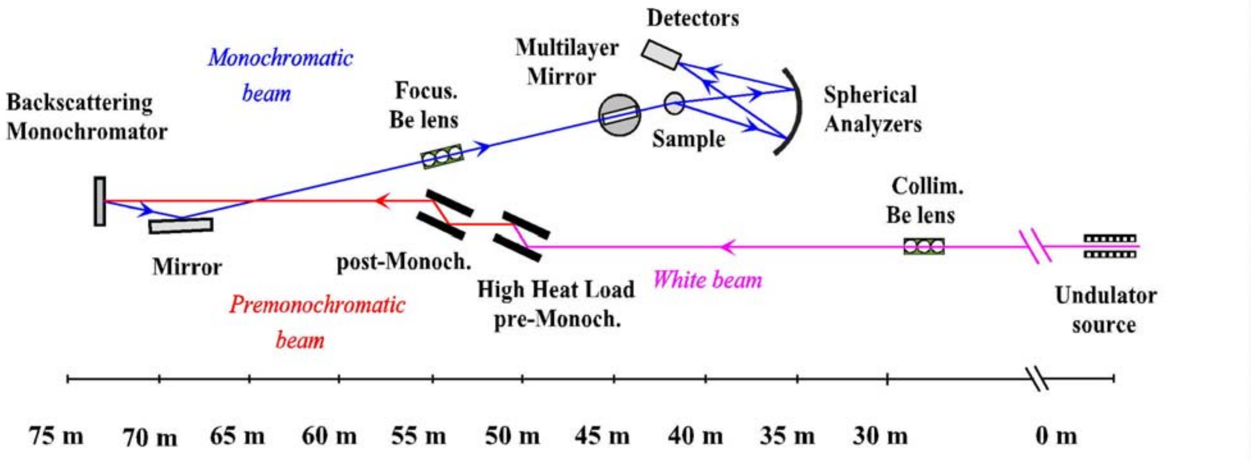

Figure 2: Optical Schematic of Beamline ID28

2. Need for a Post-monochromator

In order to successfully produce a monochromatic beam with a very high-energy resolution of $2x10^{-8}$, the backscattering monochromator crystal has to have a temperature stabilisation in the order of 1mK. Differences in temperature greater than this will produce non-homogeneity of the crystal lattice (d spacing) and a degradation of performance. This was indeed observed when the thermal heat load was increased gradually.

Consequently there was the need for the post-monochromator positioned directly behind the pre-monochromator to further reduce the heat load on the crystal of the backscattering monochromator. A silicon channel cut crystal with a higher reflection order (331) was selected for this post-monochromator. The rocking curve width of this reflection is very narrow (typically between 2 & 5 micro radians). Hence the angular resolution of the crystal positioning mechanics had to be less than 1 micro radian.

3. Design of Flexure Stage

Figure 3 shows the general assembly of the post-monochromator vacuum vessel. The incoming pre-monochromatised beam is deflected 6mm vertically upwards by the channel cut silicon crystal. A free passage is required for the returning backscattered mono beam. The UHV vacuum vessel has an internal diameter of 500mm and it sits on a support frame (not shown) with a vertical translation to position the crystal at the beam height of 1400mm from the floor.

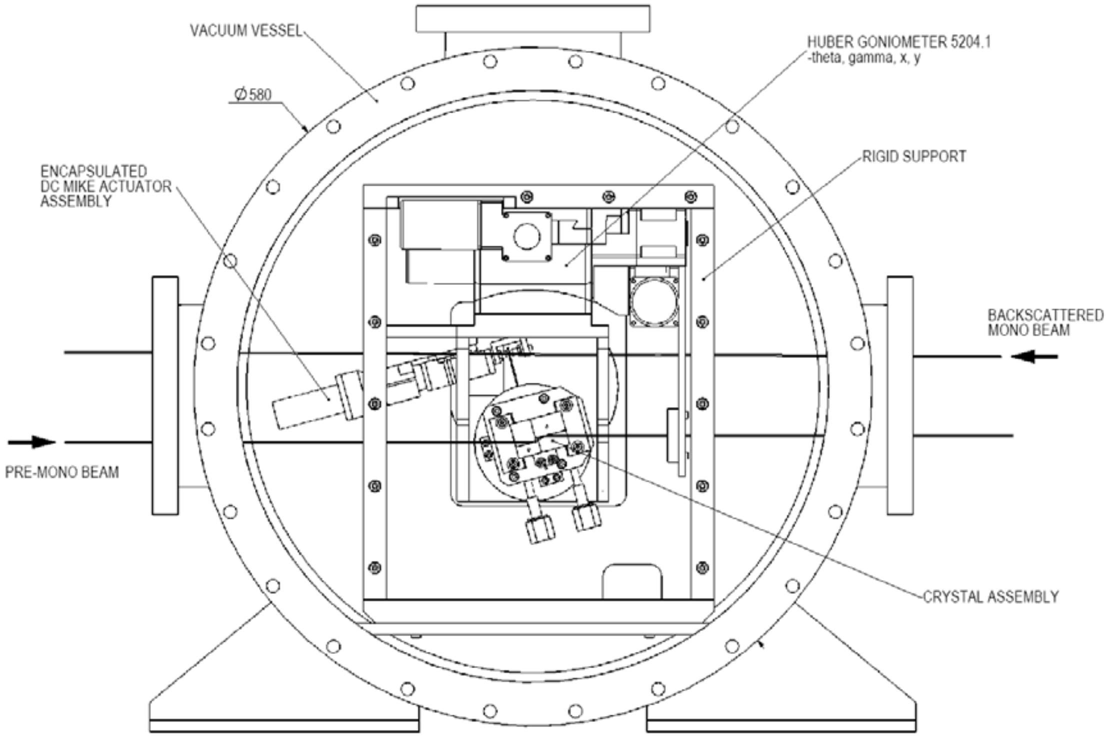

Figure 3: General Assembly of Post-Monochromator

The Beamline uses a number of fixed energies between 13 & 22 keV. Consequently the Bragg angle for the 331 reflection varies from 19 to11 degrees. A Huber goniometer 5204.1 provides this angular range to the crystal. It also provides a rotation to correct the roll of the crystal, and a linear translation to move the crystal in and out of the beam.

The assembly shown in figure 4 achieves the precise crystal rotation. This is mounted onto the Huber goniometer.

A DC Mike linear actuator pushes a 1mm thick stainless steel blade, which is rigidly fixed to a flexure. The actuator is tangential to the flexure. Figure 5 shows this flexure stage. The crystal is mounted onto a gas cooled copper heat exchanger, which in turn is mounted onto the moving part of the flexure

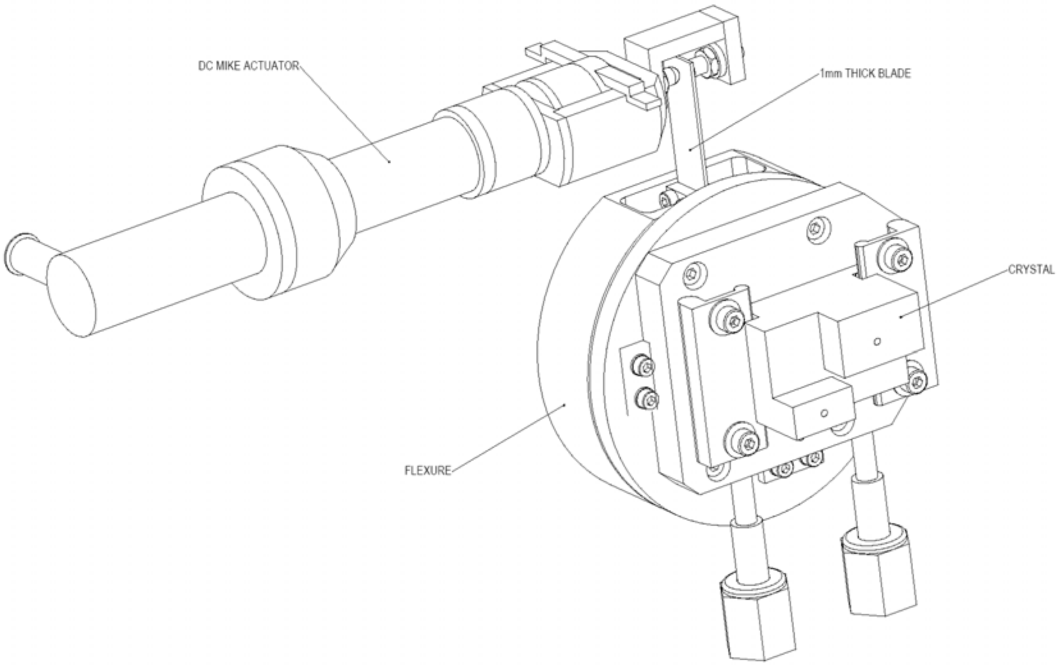

Figure 4: Crystal Assembly

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The DC Mike actuator is supplied by Physik Instruments. This actuator is not suitable for UHV and it has therefore been encapsulated inside a vacuum body with a bellows feedthrough. It has a course of 10mm with a design resolution of 0.059 microns, which is achieved by the integral encoder. The actuator is at a radial distance of 80mm from the centre of rotation of the flexure. Thus with a rigid connection between the actuator and flexure the angular resolution for one motor step is only 0.059/80000 = 0.74 micro radians. However we have used a thin blade of only 1mm thickness that flexes under the action of the actuator. This blade is effectively acting as a reducer and greatly increases the angular resolution of this device to 0.05 micro radians or less. The finite element analysis in section 4 describes this further.

The flexure as shown in figure 5 has 4 equally spaced flexure hinges. It has been made by spark erosion from a single block of precipitation-hardened stainless steel. The blade is clamped onto the internal part of the flexure through an opening in the top of the flexure.

The vacuum vessel, its support table, the Huber goniometer, and the encapsulated DC Mike actuator were recuperated from a previous project thus making this post monochromator an inexpensive project.

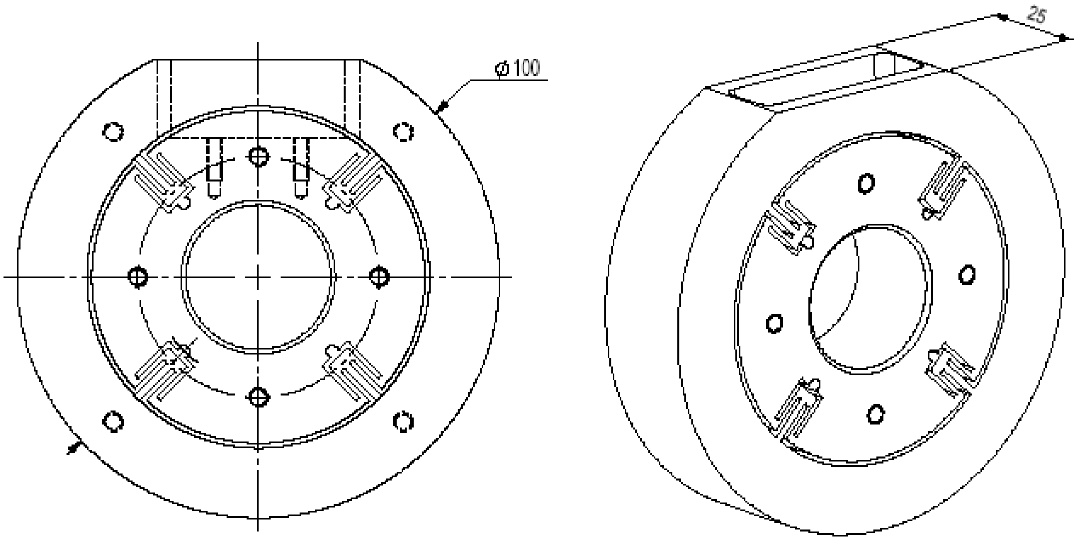
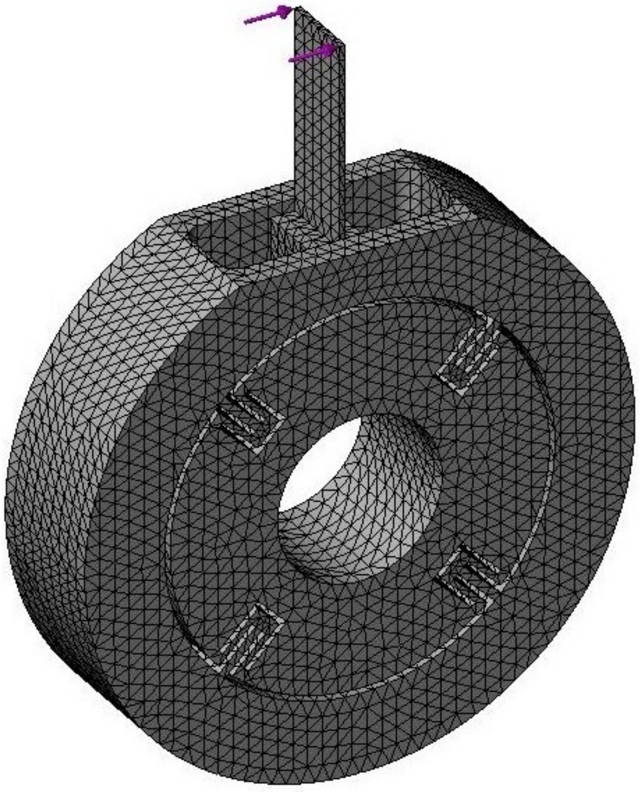


Figure 5: Flexure

4. Finite Element Analysis

Actuator Force = 10 N



Outer Circumference Fixed

Figure 6: Finite Element Model & Mesh

The finite element model shown in figure 6 was created to analyse the deformation of the flexure and blade assembly. These 2 components were considered as a single part. The outer circumference of the flexure was constrained in all directions, and a force of 10 N was applied at the end of the blade where the linear actuator pushes the blade. (The DC Mike can push up to 40 N.) There were 59000 brick elements in the model. The analysis was done using CosmosWorks. The analysis allowed the thickness & length of the blade, and the thickness & length of 4 flexure hinges to be optimised.

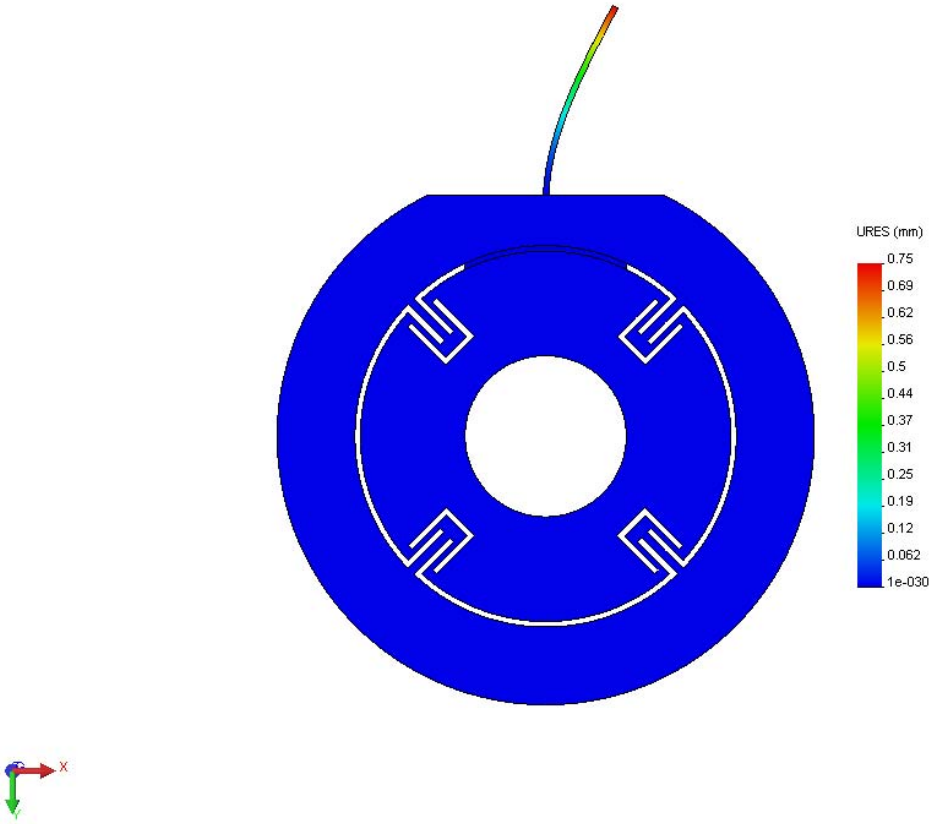


Figure 7: Deformed Model

Figure 7 shows the deformed shape of the model (deformation magnified) for a 10 N actuator force. The actuator end of the blade deflects 0.75mm, whereas the end attached to the flexure deflects by only 0.9 microns. The flexure rotates by 23 micro radians. The maximum stress in the blade is 141 N/mm^2.

Thus for a 0.1 micro radian rotation of the flexure, the deflection required at the actuator end of the blade is 0.1 x 0.75 / 23 = 0.00326 mm = 3.26 microns. The corresponding number of actuator motor steps is 3.26/0.059 = 55.

Clearly a design resolution of 0.1 micro radians can be achieved, and an even smaller resolution should be possible. Also a range of 50 micro radians can be easily achieved.

5. Laboratory Measurements

The crystal assembly was tested in the Precision Engineering Laboratory of the ESRF prior to installation on the Beamline. A laser interferometer was used to measure the rotation of the flexure under action of the DC Mike actuator. Regular rotation increments of 0.1 micro radian (and even 0.05 micro radian) were observed. The number of motor steps required for 0.1 micro radian was 42, which is somewhat less than that predicted by the finite element analysis.

6. Conclusion

A novel nano radian flexure stage has been designed and developed. An angular resolution of 0.05 micro radians has been measured in the laboratory. This flexure stage has been used on the ESRF Beamline ID28 in the post monochromator.

7. Acknowledgements

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