ANGULAR POSITIONING IN THE NANORADIAN RANGE.

M. Renier, M. Nicola, Y. Dabin, L. Petit, J. Zegenhagen
European Synchrotron Radiation Facility, BP 220, 38043 Grenoble. FRANCE.

Abstract

We are currently developing a high resolution, fixed-exit post-monochromator for ID32, which will be operating at a pressure of 10-7 mbar. It features two independent 360 degree rotational axis mounted on x,y,z linear stages. The crystals on both axes will be positioned with an angular resolution better than 50 nrad and a long term stability and accuracy better than 100 nrad.
The extreme resolution is achieved in two stages: on top of a standard rotary table is mounted a flexure pivot controlled by a piezo crystal in a closed-loop active system linked to a high accuracy measuring device. The maximum accuracy of the angular encoders available on the market is still insufficient for the ultimate performance. Thus, a combination of laser interferometry and high resolution angular encoder is our unique choice. The limited angular range of the laser system required a newly developed, special mounting of the interferometric set-up.
The principle of operation of the post-monochromator, its design and the preliminary results of the tests on the prototype will be discussed.

1 Introduction

The ESRF ID32 beamline is dedicated to the research of the structural, chemical and electronic properties of surfaces, interfaces and films. It operates in an energy range from 2.7 keV to above 40 keV. The energy range will in the close future be extended down to 1 keV. The beamline design permits window-less operation from the source point (the electron beam in the storage ring) to the sample. The X-ray Standing Wave (XSW) in combination with Inelastic Scattering techniques in use at that beamline requires a highly collimated and/or highly monochromatic beam with considerable long-term stability.
At present, the ID32 beamline utilises one monochromator which will be complemented by a new high-resolution, in-vacuum post-monochromator. Its design should include two identical stages (for two crystals in the Bragg/Bragg or Laue/Laue geometries). The stages are mounted in the fixed-exit configuration. The final goal is to reach an energy resolution of 20 meV @ 20 keV in the XSW spectra.
The mechanical consequences for the crystals positioning devices are that an angular resolution of 25 nrad and a stability of 50 nrad over 1 hour must be reached. At 10 keV, the rotation of a Si [311] crystal by 25 nrad correspond to a ΔE of 0.6 meV in the spectral range.
These mechanical requirements go far beyond what is commonly used at the ESRF (i.e. rotary tables coupled to precision rotary encoders). In this paper we present a new concept utilizing a piezo-driven flexure-pivot, coupled to a laser interferometer. This assembly is mounted on a standard component rotation axis (Huber 410 rotary table coupled to a high resolution Heidenhain RPN 886 encoder). This concept is still under development at the Precision Engineering Laboratory (PEL); it will allow two modes of operation: high or ultra-high resolution, depending on which measuring device is used: encoder or laser interferometer. Preliminary results and conclusions are presented.

2.1 Measurements performed on standard components

2.1. Description of the preliminary measurements

An assembly including a Huber 410 rotary table [1] powered by a Micos SMC Taurus [3], a RPN886 Heidenhain encoder [2] and a home made flexure pivot driven by a PI 244.20 piezo-eletric actuator [4] was built in order to be fully characterized in laboratory conditions. The whole assembly was mounted on a large and heavy granite table at the PEL, with the following dimensions: (3600 x 1500 x 360) mm3. This table, which is stiff enough to allow all the mechanical and optical elements mounted on it to vibrate in phase, does not amplify the floor vibrations. The measured vibration amplitude is ≤ 2 µm pp and displays a maximum amplitude at 7 Hz [5].The ambient temperature is controlled at 20 ± 0.3°C.

The reference measurement device used is an AGILENT 5529A laser interferometer [6]. The main characteristics of the Huber 410 were confirmed as the level appearing in the manufacturer data sheet. The tests of the Heidenhain RPN 886 encoder were repeated 5 times. They showed that an ultimate angular resolution of 8.5 nrad could be reached with a 12 bit Heidenhain IK220 interpolation card. However, the measured Mean Reversal Error (MRE) reached 800 nrad and the measured accuracy was better than 1 µrad, which is 5 times better than what announced by the manufacturer! Unfortunately these two last values prevent this instrument from being used alone for our application. The friction in the instrument ball bearing provokes some deformations of the measurement board flexible supports and also a very little torsion of the transmission shaft. This mainly explains the MRE value that is rather large with respect to the ultimate resolution. It must be noted here that in view of the preparation of the instrument for the vacuum compatibility tests, the rubber shaft gasket had been removed. This was done mainly to reduce the outgassing rate but also to open the structure of the encoder and facilitate the pumping of the internal volume and finally to reduce the encoder internal friction.

The vacuum compatibility of the Huber 410 rotary table (UHV type) is guaranteed by the manufacturer and was not checked at the ESRF.

Heindenhain also proposes UHV compatible encoders but the model in our possession at the time of the tests were decided was standard. We therefore decided to measure its vacuum compatibility by putting it in a vacuum enclosure pumped by a 220l/s ion pump. The ultimate total pressure reached after 2 days of pumping was 5 E-7 mbar, of course without any bakeout. As said before the rubber gasket had been removed and the guiding ball bearing grease replaced by a fluorinated grease (Fomblin).
Independently, the thermal drift of the Huber 410 rotary table was measured. One of the results is shown in the Fig 1.

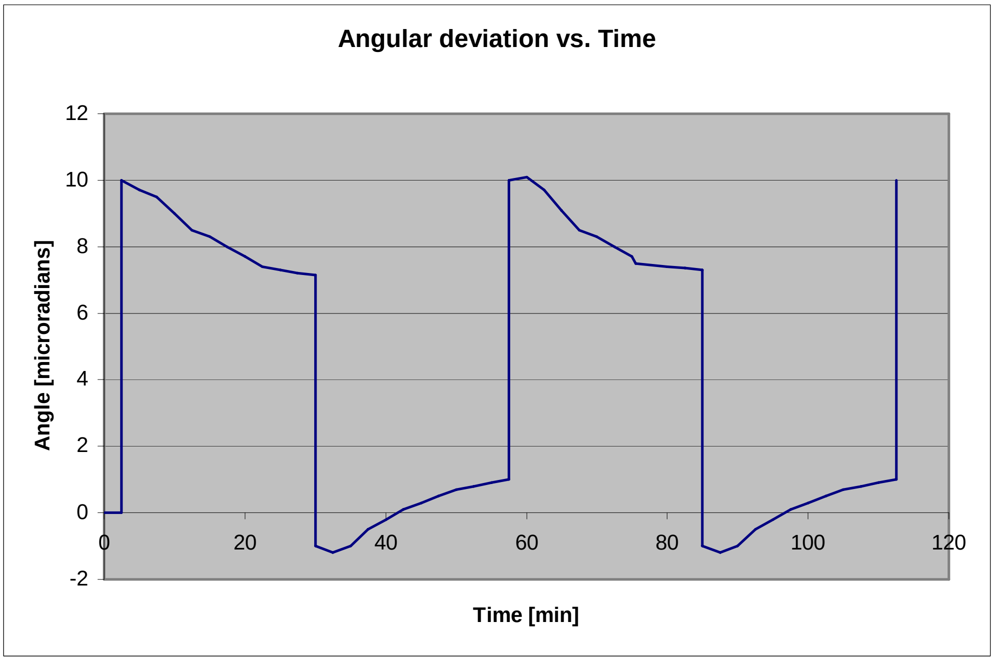

Fig. 1: Huber 410 rotary table thermal drift.

When the power is turned ON, a very small shock induces a 10 µrad rotation jump. Once in the new position, the table rotates slowly by more or less 3 µrad to finally stabilize around 7 µrad. After 30 min, the power is turned OFF and the table suddenly comes back in the start position and drifts by 3 µrad. After another 30 min. the power is turned ON again for a new equivalent cycle. During the experiment, the table stepper motor was supplied at the lowest possible intensity (around 700 mA) to limit its overheating while allowing its motion.

2.2 Analysis and discussion

We may drag some partial conclusions from the previous measurements:
First, the encoder resolution would be sufficient to control the optical component position at the ID32 beamline but the position hysteresis when the direction of the motion changes is by far too large; second, the assembly is vacuum compatible till 5 E-7 mbar and therefore differential pumping will be needed at both sides of the monochromator; and third, to reduce the thermal drift and the rotation jumps, the motor power supply shall be OFF most of the time and a micro-stepping controller should be used.

Consequently, to reach the specified resolution, accuracy and long term stability, additional devices are to be mounted in series, as shown in Fig. 2. They include a flexure pivot (ESRF design) coupled to its piezo-electric actuator (model PI 244.20; 20 µm excursion in our case); a laser interferometer (1 nrad resolution in its standard version) with a 300 mm long (to increase the angular resolution) arm made of Invar, supporting plane mirrors; a clutch system to decouple the interferometer from the rotating axis when it rotates more than 1 mrad, and two feedback loops: one for coarse adjustment ($\theta 1$) linked to the encoder, and one for fine tuning ($\theta 2$) linked to the interferometer.

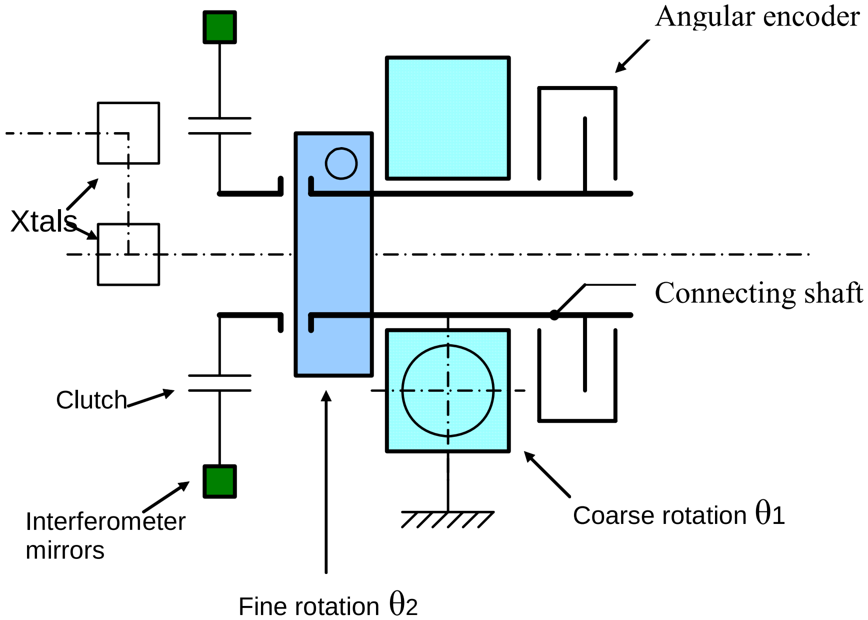

Figure 2: Principle of series mounting

We have chosen to use plane mirrors in lieu of cube corners to allow for lateral displacement in both directions by 50 mm (Y and Z displacement of the crystal supports). As a consequence, the detector active area limits the angular acceptance. This acceptance had therefore to be and has been measured. The results are reported in paragraph 6.

The assembly principle is illustrated in Fig. 3.

The resulting rotation of the monochromator crystal is consequently the sum of ($\theta 1 + \theta 2$). $\theta 1$ covers a complete revolution over 360º, whilst $\theta 2$ maximum excursion will be limited to 1 mrad by the angular acceptance of the laser interferometer and also by the maximum angular excursion of the flexure pivot. The control system will integrate two closed loops which will work independently. However, each time a new set position will be requested

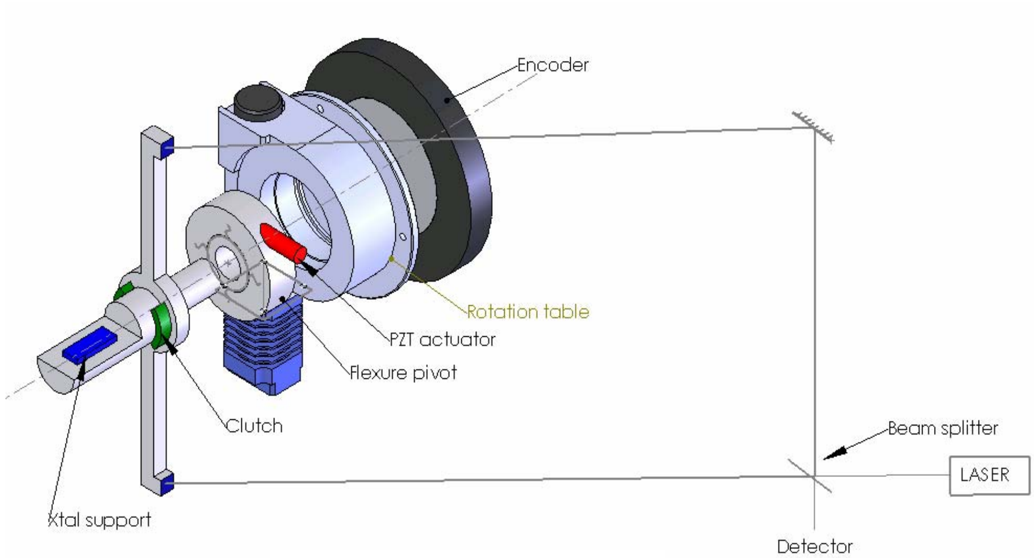

Fig.3 : Assembly principle

from the coarse adjustment ($\theta 1$), the fine tuning ($\theta 2$) will be automatically reset in its central position to allow for equivalent excursions in both directions.

Simultaneously, the clutch will be activated in order to free the interferometric arm supporting the two mirrors. As a consequence of the present set-up, when the flexure pivot rotates for fine tuning, the interferometric arm AND the encoder rotate because they are driven by the same shaft. The exact reading of the angular position must therefore be ($\theta 1_{initial} + \theta 2$). $\theta 1_{initial}$ is the high resolution absolute angular position as measured by the encoder before the $\theta 2$ relative motion induced by the flexure pivot and measured at ultra-high resolution by the interferometer.

3. Simulation of the optical set-up and maximum interferometer resolution.

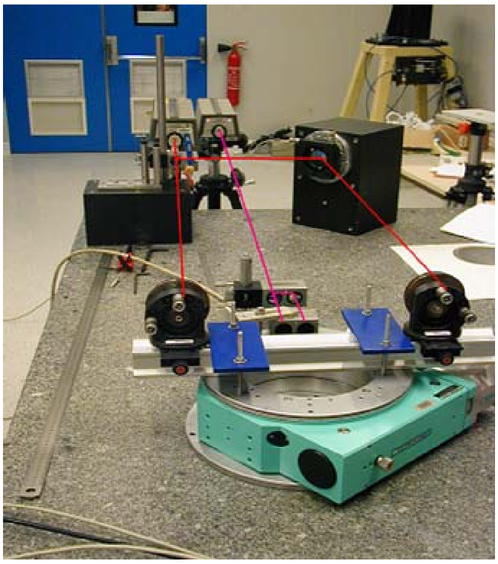

Fig. 4: Simulation of the optical set-up

A simulation of the optical set-up was performed at the PEL in the same laboratory conditions as before (Fig. 4). The goal was to measure the acceptance of the measurable angle of rotation and the functionality of the assembly using the Agilent 5529A laser interferometer and two plane mirrors distant by 300 mm. In the standard configuration the mirrors are distant by 32.61 mm and the specified angular resolution is 25 nrad.

The measured resolution was 3 nrad and the maximum range of measurement was3 mrad. In the real conditions of use, we may expect the optics bench being more elastic and vibration amplitudes being larger than 2 µm pp. Therefore the design of the optics bench will include a $2m^3$ concrete block linked to the floor and to the in-vacuum mechanical and optical components by six 80 mm diam. rods. The vacuum vessel will be linked to these rods by flexible membranes to achieve leak-tightness. This solution was chosen for its rather low cost as compared to an ultra-stiff frame which would necessitate more engineering and design efforts for comparable results [7]. The interferometer reference optics and the detectors will be kinematically mounted *in-vacuum*, on an Invar structure located at one end of the optics bench. The laser head will be *in-air* and its beam will enter the vessel through an optically polished window whilst the detector signals will exit the vessel through fiber optics.

Furthermore, thanks to the high vacuum environment in the real version, the disturbances induced by the air turbulences will be suppressed and hence the ultimate resolution should be more easily reached.

4. Monochromator axis final design.

The study and the design of the first monochromator axis have been completed (Fig. 5). They were followed by its manufacture and assembly (photograph in Fig. 6).
The design has been optimised to increase the stiffness at its maximum possible and at the same time to reduce the overall dimensions of the system. It includes the rotation axis described above, the interferometric arm with its two plane mirrors, the clutch, a vertical (Z) translation over 25 mm and a lateral (Y) translation of the same order. A linear encoder (also visible on the final drawing, Fig. 5) controls each linear translation.

A Picomotor [8], visible at the left of the drawing, will permit the χ movement (tilt) of the crystal support. The whole assembly will be sliding along longitudinal rails allowing for a 1 meter long excursion (X translation).

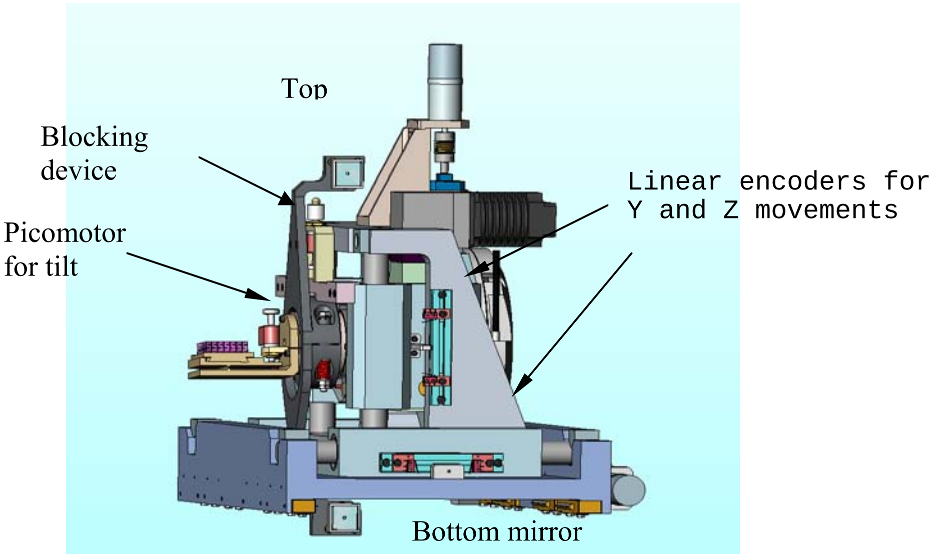

Fig. 5: Design of the 1st monochromator axis.

The clutch system (Fig. 7) will be a spring-loaded clamping device comprising two jaws that will squeeze the main rotation shaft between three hard steel rods sliding in a V-shaped groove in the main shaft. All the parts in sliding contact will be optically polished to avoid "stick-slip"effects. Two piezo-electric actuators will open the clamp and free the interferometric arm when the main shaft will rotate more than 1 mrad, that means when the rotation table is activated. During that time, the interferometric arm is kept in the vertical position by an active blocking device (visible just above the clutch on the drawing Fig.6)

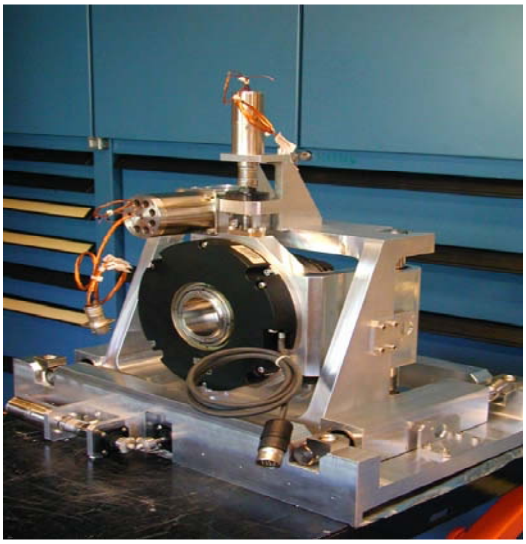

Fig. 6: Photograph of the 1st. axis.

Except for the clutch system, the complete first axis assembly is manufactured and assembled. Preliminary measurements are currently being conducted.

5. Conclusions

Several conclusions may be drawn from the preliminary tests.
First, even if the clutch system design is still to be validated, we have proven the feasibility of this challenging project with the present design. The angular resolution reached (3 nrad) in laboratory conditions is more than satisfactory. The precision clutch system allows for a complete revolution of the monochromator axis.
Second, we may expect an ultimate pressure in the complete monochromator assembly pumped by a 400 l/s in the low E-6 mbar range.
And third, the monochromator system will present a good versatility for the users. It will allow for two modes of operation: high resolution simply using the rotary table and the encoder in a closed control loop, and ultra-high resolution by adding the flexure-pivot and the interferometer control in a second level close-loop control.

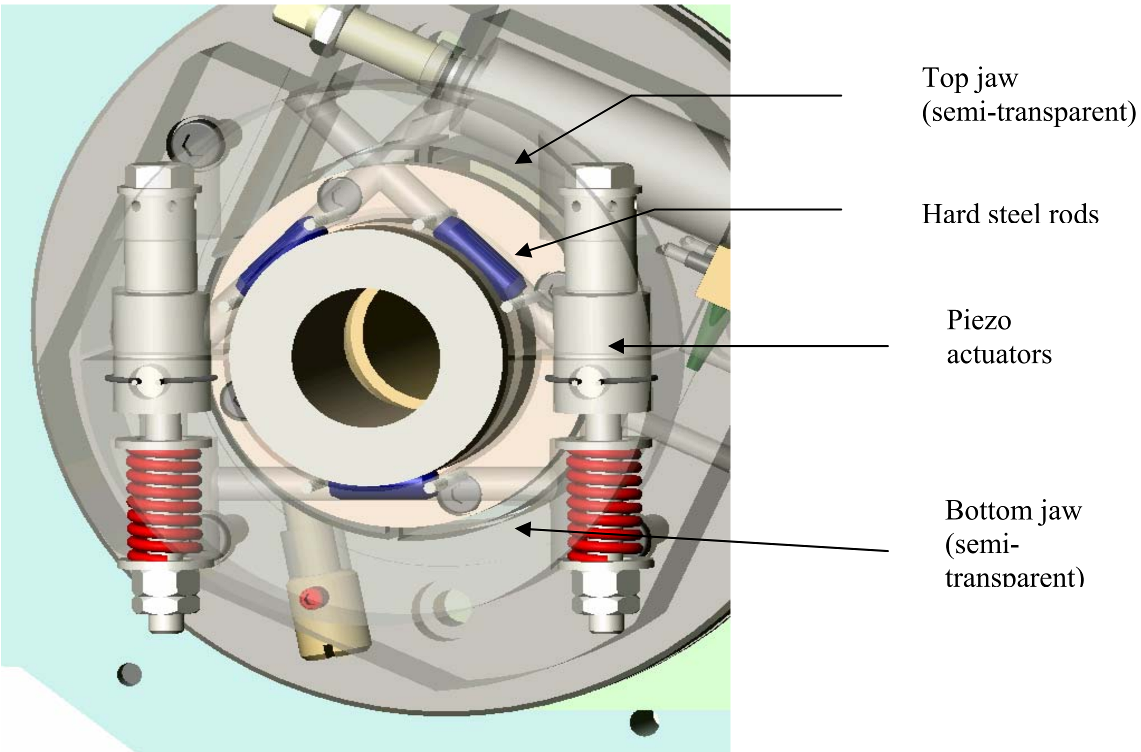

Fig. 7: Clutch system.

A user-friendly control software is being developed to help the operators of the monochromator to find the beam, to optimise its size and location, and to define the energy following the two modes of operation.

6. Acknowledgments

We warmly thank our colleagues R. Grattier, H. Isern, K. Larsson, T.L. Lee, and H.P. van der Kleij for providing valuable ideas, advices and assistance as often as necessary.

References

[1] HUBER Diffraktionstechnik GmbH & Co. Germany.
[2] Dr. Johannes Heidenhain GmbH, Germany
[3] SMC Taurus is a trademark of MICOS GmbH, Germany
[4] PI is a trademark of Physik Instrumente Gmbh & Co., Germany
[5] Vibrations at the ESRF. Zhang L. et al, proceedings PAC2001, 4-5, 2620-2622
[6] Hewlett Packard Co. Palo Alto, California
[7] P. Bernard et al., "Design and characterization of a light frame KB table and comparison with a concrete block support", Proc. MEDSI 2002, Argonne, Illinois, USA. 287-298.
[8] Picomotor is a trademark of Newfocus Co. California