



# EXPERIMENTAL SHAPE OPTIMISATION OF BENT CRYSTALS

U. LIENERT<sup>1,2</sup>, S. HARTLAUB<sup>1</sup> AND A. FREUND<sup>1</sup>

**1 ESRF, EXPERIMENTS DIVISION, OPTICS GROUP**

**2 RISØ, MATERIALS RESEARCH DEPARTMENT,  
ROSKILDE, DENMARK**

We describe below a novel method that allows the slope error of bent crystals to be reduced down to the  $\mu\text{rad}$  range.

It is the task of X-ray optics to provide focusing and monochromatisation of synchrotron radiation within an appropriate phase space element prescribed by the experimental requirements. Bent crystals cover a wide range of applications and are used on many ESRF beamlines. To fully exploit the optical properties of bent crystals, the slope error should not exceed the beam divergence due to the source size, which can be as small as  $0.5 \mu\text{rad}$  (FWHM)[1]. Often the thickness of the curved crystal is much smaller than the illuminated length on the crystal and the curvature is produced by application of bending moments at the ends of the crystals.

With using existing techniques, simple bending theory is applied to calculate the width or thickness profile of the bent crystal to achieve the desired crystal curvature [2]. This approach imposes severe requirements on the accuracy of the theory and, more importantly, on the realisation of the model assumptions both regarding the crystal and the bending mechanism. We found that simple bending theory, standard crystal and mechanics manufacturing, and crystal mounting techniques do not meet the high precision required for ESRF beamlines. Although finite element analysis can be used to improve the calculations, the effects of strains in the crystal due to both the growth process and to the mounting technique cannot be predicted.

An empirical method has been developed that allows us to reduce the slope error down to the  $\mu\text{rad}$  range without requiring costly and time consuming micro-machining of the crystal or sophisticated bending mechanisms. The basic idea is to first

measure the local slope of a reasonably well-designed crystal and then to correct the remaining figure error experimentally by shaping the width of the crystal. The width profile can now be calculated by simple bending theory because the required correction is small compared to the absolute crystal deflection.

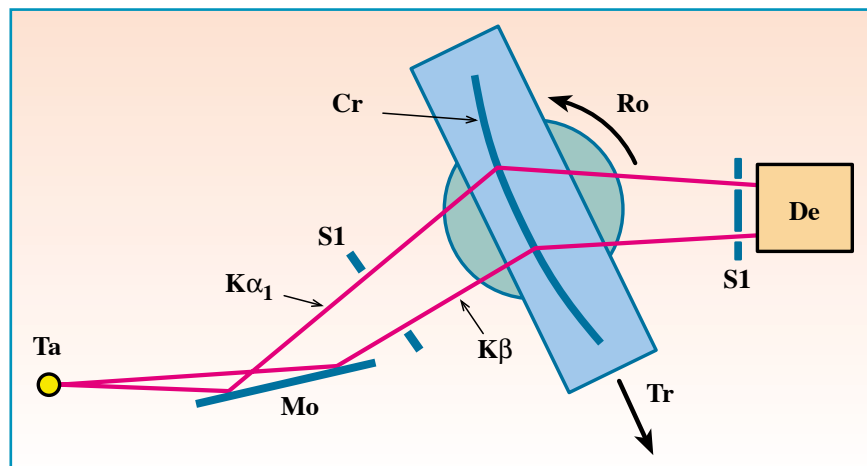
## MEASUREMENT OF LOCAL CURVATURE

Contrary to mirrors, curved crystals are characterised by the lattice plane orientation rather than by the surface profile. Therefore optical metrology is only an indirect tool. An X-ray tube based set-up was developed and is sketched in Figure 1. Traditionally, the bent crystal is translated through the monochromatic X-ray beam and the shift of the Bragg peak is a measure

of the local crystal slope. This method was improved to avoid errors due to the wobble of the translation stage: two characteristic X-ray lines impinging at different positions on the crystal are detected in non-dispersive two crystal geometry. Thus only one peak is obtained when a flat crystal is rocked, but the peak splits when the crystal is bent. The local crystal curvature is then calculated from the peak splitting and the distance of the lines on the crystal. Crystal strains produced by clamping are detected by a peak broadening close to the clamps. Laue geometry with almost normal incidence was chosen in this case to minimise systematic errors. Although errors due to wobble of the translation stage can be avoided, a precise rotation table with a linearity of at least  $1 \mu\text{rad}$  is still mandatory.

A Huber 410 rotation table equipped with a 250 mm long lever arm and a Heidenhain linear encoder meets this

*Fig. 1: Sketch of the developed set-up to measure crystal curvature. The symbols denote: Ta - Ag X-ray tube target, Mo - flat crystal monochromator,  $K\alpha_1$ ,  $K\beta$  - utilised characteristic X-ray lines, Sl - slits, Cr - bent crystal, Tr - translation stage, Ro - rotation table, De - scintillation detector.*





requirement. Figure 2 shows the measured bending radius and slope error of a sample crystal. The X-ray tube based set-up is indispensable for systematic studies but it cannot take into account heat load effects that might occur with synchrotron radiation. However, the variation of the local crystal shape still remains valid if the heat load only changes the average bending radius.

## TUNING OF THE LOCAL CURVATURE

Simple bending theory assumes that the local curvature  $1/\rho(x)$  is proportional to the local bending moment  $M(x)$  and to the inverse of the moment of inertia of the local cross-section  $I(x)$ . For rectangular cross-sections  $I$  is proportional to the beam width and to the cube of the beam thickness. Therefore the crystal width rather than its thickness is profiled to achieve best sensitivity. Crystals of rectangular shape and therefore constant width were bent cylindrically. The width profile for correcting the slope errors is simply given by the ratio of the average to the local bending radii times the average crystal width. Figure 3 shows a width profile thus obtained. To shape the width profile on the crystal, aluminium forms were first produced by a CNC-milling machine. The crystal was then sandwiched between the forms and ground manually following the profile of the forms.

Figure 2 shows the significant improvement of the figure error of the crystal due to the width profiling. This indicates that the grinding did not introduce strains that would affect the local curvature. The line width of the peaks on the X-ray set-up also showed no additional strain.

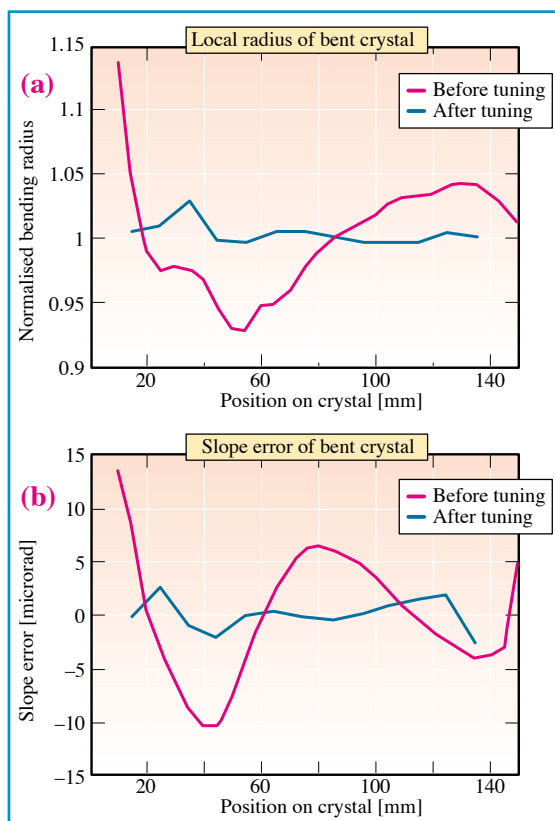
## CONCLUSION

This novel method permits a significant improvement of the slope error of bent crystals, down to the  $\mu\text{rad}$  precision. Standard crystal cutting and mounting techniques are sufficient. The method is not limited to cylindrical shapes. Any arbitrary shape (e.g. elliptical, logarithmic spiral) can be produced. ■

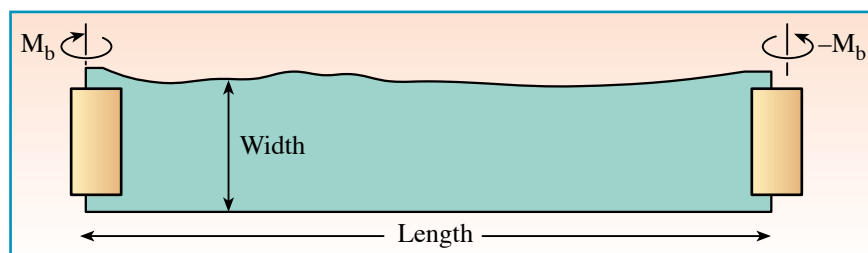
## References

- [1] C. Schulze and U. Lienert, *ESRF Newsletter* 25, 38 (1996).  
 [2] see, for example, H. Tolentino, F. Baudelet, E. Dartyge, A. Fontaine, A. Lena, G. Tourillon, *Nucl. Instr. and Meth.* 289, 307 (1989).

*Fig. 2: Comparison of figure error of the cylindrically bent crystal before and after width profiling. (a) normalised local bending radius  $\rho(x)/\rho_0$  - the average bending radius was  $\rho_0 = 50$  m. (b) slope error.*



*Fig. 3: A width profiled crystal. The crystal is 200 mm long, 1 mm thick and on average 40 mm wide. The crystal clamps and applied bending moments are indicated.*



## ACKNOWLEDGEMENTS

We acknowledge in particular the skilful crystal grinding by J.P. Vassalli and the continued support at the X-ray set-up by R. Hustache. M. Kretzschmer programmed the CNC machine and the High Energy Group contributed scientific and practical support.

## HERCULES 1998

The 8th session of the HERCULES course (Higher European Research Course for Users of Large Experimental Systems) will take place at the Maison des Magistères, CNRS Grenoble,

**from 22 February  
to 3 April 1998**

- session A: 'Neutron and synchrotron radiation for physics and chemistry of condensed matter'
- session B: 'Neutron and synchrotron radiation for biomolecular structure and dynamics'

Deadline for application:  
17 October 1997

**New:** in 1998 a limited number of **non-European applications** will be accepted to follow the **session B course**.

Information and application forms will be available at the beginning of July from:

Secrétariat HERCULES:  
M-C Simpson  
Maison des Magistères  
CNRS - BP 166  
38042 Grenoble Cedex 9  
(e-mail: simpson@polycnrs-gre.fr)