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Adaptive indirectly cooled monochromator crystals at HASYLAB

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The high-heat-load monochromator, based on the HASYLAB (Hamburger Synchrotronstrahlungslabor) 'Torii' design, has been used successfully for 2 years at the BW2 wiggler beamline. The bowing of the reflecting surface induced by the heat load and water pressure is compensated mechanically. This is achieved by mounting the specially shaped crystal in a bending mechanism and by heat transfer from the directly water-cooled crystal. We present the latest step in the development of this design. The piezoceramic-driven actuators are replaced by actuators based on the thermal expansion of copper rods. The direct water cooling of the crystal is replaced by a safer indirect water-cooling scheme. Characterization results of the crystal are presented. The Si(111) rocking-curve width at 9.5 keV was measured to be 8.3 arcsec under 500 W heat load.

Keywords: heat loads; adaptive crystals; insertion devices.

1. Introduction

In order to utilize the full potential of high-power wiggler beamlines with large white-beam cross sections, a variety of monochromator crystal designs are in use. Either the crystal is efficiently cooled or the unwanted distortions are compensated by different means, which require external control mechanisms (Berman & Hart, 1991; Marot *et al.*, 1992; Schulte-Schrepping *et al.*, 1995; Quintana *et al.*, 1995). The basic idea of the HASYLAB (Hamburger Synchrotronstrahlungslabor) design described here is mechanical compensation of the heat-load-induced bowing of the reflecting surface. The specially shaped crystal is mounted in a bending mechanism; Fig. 1 shows the operating principle. The original set-up uses piezoceramic actuators to push the surface back into shape.

The piezotechnology available sets a limit to the force/travel ratio for an acceptable size of piezoelement. This gives a mechanical upper limit to the accessible heat load, while in principle much higher loads are acceptable. One way to solve this problem is to set a mechanical offset in the bending system. This affects the behaviour at low heat loads in the one- or two-bunch modes of DORIS with lower currents, but is a perfect solution for the default five-bunch operating mode of the storage ring.

2. Actuator design

The primary task was to replace the actuators of the adaptive crystal structure by elements providing a larger range of travel under heat load. An additional constraint is the space restrictions inside the already built and successfully used unit. The new actuator for the bending mechanism is based on the thermal expansion of a copper rod. This expansion mechanism is maintenance free, vacuum compatible and able to generate more expansion and force than needed in our application. The actuator is able to apply forces which are limited only by the tensile strength of the crystal.

Fig. 2 shows a side view of the whole set-up and an actuator in detail. The key elements of operation are the specially shaped crystal, the lever arms with two crossed elastic hinges and the electrically heated copper rods. In total, four actuators are attached to the crystal; two on each side are coupled to the wing-like extension of the crystal. In Fig. 3 a schematic plan view of the crystal and the actuators is shown. The copper rod inside the actuator is thermally insulated by ceramic spacers from the crystal and the base unit. A connection to a cooled part serves as a heat sink. The control system for the actuator is only able to heat the actuator, but has to rely on this passive cooling mechanism. This type of heat management for the actuator gives a response time of <1 min at all temperatures of the rod. The temperature of the copper rod is monitored and limited to 523 K. A signal proportional to the generated force into the crystal is measured by a set of strain gauges. They are wired in a full bridge scheme and attached to one of the elastic hinges (see Fig. 2). The control system for the whole assembly with four actuators is based on two programmable controllers. Each controller is responsible for two actuators on one side of the crystal. A separate microcontroller serves as an interface between these controller units and the experiment.

There are several modes of operation of the control system. The basic mode accepts one control voltage which is translated into a common default value for all four actuators. This voltage setting is experimentally determined by the smallest adjustable rocking-curve width which also provides a maximum in intensity. The smart mode will monitor the current of the storage ring, the primary aperture size and the energy setting of the mono-

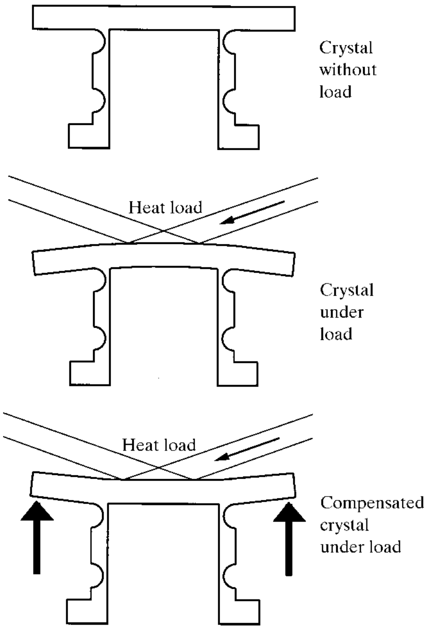

Figure 1
A side view of the monochromator crystal in different states of deformation. The principle of operation is independent of the actual cooling scheme. In the direct water-cooled case the water pressure adds to the deformation of the reflecting surface.

chromator. Using this input data the microcontroller will select the corresponding settings for the actuator controllers out of a stored parameter field. Up to now, parameter sets for variable beam currents have been recorded. The degree of dependency of the compensation on the energy setting in the usual energy scan ranges is small. In addition to the compensating modes, other types of operation are implemented. It is now possible to operate the crystal from the uncompensated state to an overcompensated state for meridionally focusing applications. The optionally available independent setting of individual actuators is currently not used. This might be necessary for higher-order crystal cuts with smaller intrinsic reflection-curve widths in the range of 1 arcsec or less.

3. Indirect cooling scheme

As enough force is available, an indirect cooling scheme was re-introduced in our crystal design. In this scheme the silicon cavity shown in Fig. 2 is filled with a large, cooled copper block. The top surface of the copper block is thermally connected to the back of the crystal *via* an indium–gallium eutectic. Because of its simplicity this scheme used to be the first design stage of water-cooled monochromator crystals. For use at insertion devices, however, it was discarded because of the low cooling efficiency. The overall heat-transfer properties of this coupled system (water, copper, indium–gallium, silicon) are worse than the direct water-to-silicon contact in our original design.

The new actuator system is also able to compensate this additional contribution to the bowing of the crystal. This indirectly cooled system is safer to operate; in particular, the silicone water sealings at the sides of our original design are no longer a potential cause of failure. The water-cooling system inside the monochromator tank remains the same as for the old crystal set-up.

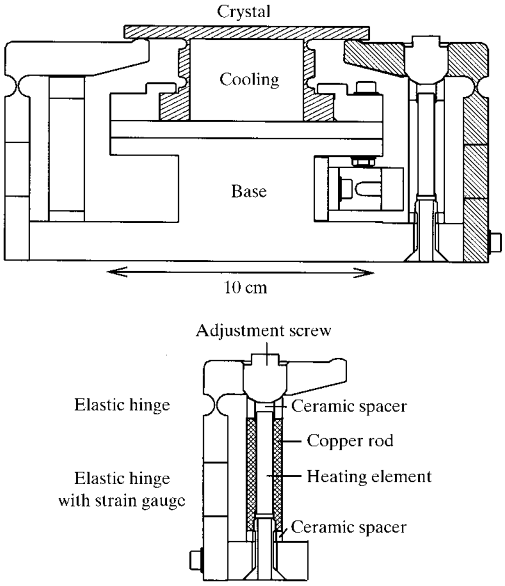

Figure 2
Top: a schematic side view of the key elements, showing the specially shaped crystal and two actuators in different degrees of detail. The cooling is either realized by a direct water flow inside the silicon cavity or by a water-cooled copper block and an indium–gallium coupling. Bottom: a detailed view of one actuator. The strain gauges attached to the elastic hinge measure the generated force.

4. Experimental results

The new crystal is installed in the double-crystal monochromator at the HASYLAB wiggler beamline BW2 (Drube *et al.*, 1995). We report the results for two modes of operation. In the direct mode the white wiggler beam passes a 130 µm thick carbon foil and hits the first monochromator crystal. In the mainly used mirrored mode the white wiggler beam is reflected by a gold-coated plane mirror at a glancing angle of 7 mrad and passes a 20 µm thick carbon foil. The intensity of the full monochromatic beam is measured by the photocurrent of a copper mesh located inside the beam path after the second crystal. Note that this measurement shows the integral performance of all parts of the crystal that are hit by the wiggler beam.

Up to a power of 500 W the rocking-curve width in the mirrored mode remains close to the theoretical value of the Si(111) rocking-curve width. The measured rocking-curve width is independent of the vertical beam size, as shown in Fig. 4. Si(111) rocking-curve widths at an energy of 9500 eV are always compensated to 8.3 arcsec. This value is close to the theoretical width of 7.9 arcsec. Fig. 5 shows the uncompensated and

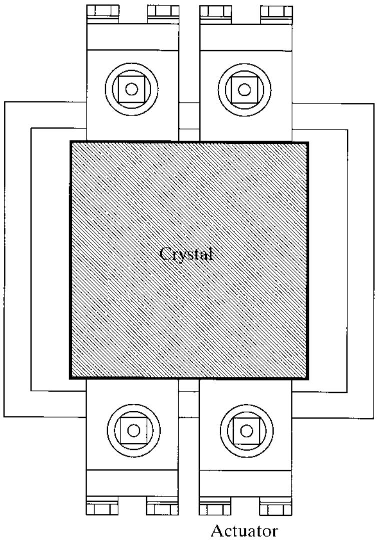

Figure 3
A schematic plan view of the whole unit. Two actuators are located below each wing of the crystal.

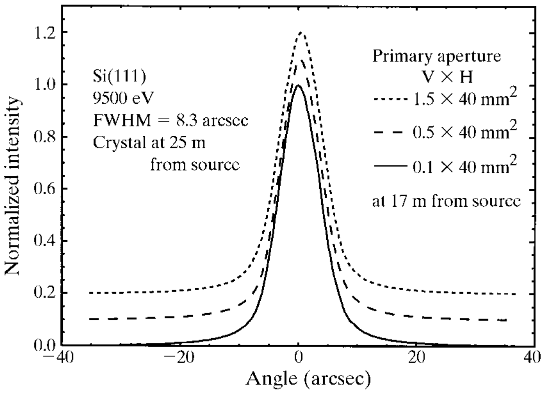

Figure 4
Rocking curves at different vertical sizes of the mirrored beam at the BW2 wiggler beamline. The optimized intensity is independent of the beam cross section. The plots have been offset vertically for clarity. The crystal is located 25 m from the source.

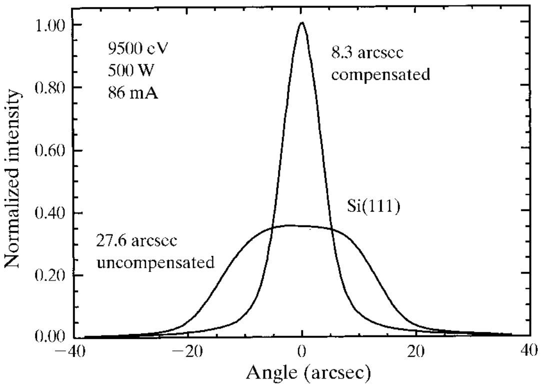

Figure 5

Rocking curves under a total power of 500 W in the mirrored beam. The uncompensated rocking-curve width of 27.6 arcsec is compensated to a near theoretical value of 8.3 arcsec.

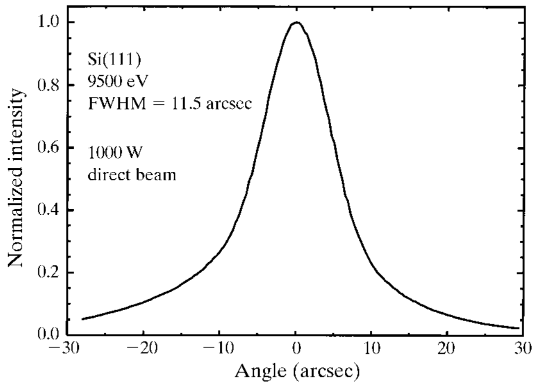

Figure 6

A rocking curve in the direct wiggler beam measured under an incident power of 1000 W. Compared to the theoretical value, the rocking-curve width is broadened by 3.6 arcsec.

compensated rocking curves for 500 W in the mirrored beam. In the direct beam under an incident power of 1000 W a broadening of 3.6 arcsec relative to the theoretical rocking-curve value is measured, as shown in Fig. 6.

5. Conclusions

The design described here provides a very stable high-heat-load monochromator crystal using indirect water cooling. Up to the 500 W available in the mirrored beam, the rocking-curve width stays close to the theoretical value, while at 1000 W in the direct beam, the rocking-curve width is broadened by 3.6 arcsec. The crystal is permanently installed and in operation at the HASYLAB wiggler beamline BW2. The introduction of this design to other insertion-device beamlines is underway. A special version with two independent first crystals [*e.g.* Si(111) and Si(220)] in one support will utilize the narrow BW1 undulator beam. The next step in the development of the HASYLAB insertion-device beamlines will challenge the crystal design with the request for higher collimation of the white beam. The demand for a narrow energy band in the monochromatic beam will additionally force the usage of higher-order crystal reflections.

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