Journal of
Synchrotron
Radiation

ISSN 0909-0495

Received 29 May 2007
Accepted 13 September 2007

Internally cooled V-shape inclined monochromator

P. Oberta,[a]* V. Áč[b] and J. Hrdý[a]

[a]Institute of Physics, Academy of Sciences of the Czech Republic v.v.i., Czech Republic, and [b]Department of Physics, Alexander Dubček University in Trenčín, Slovakia. E-mail: oberta@fzu.cz

A simple variant of a Si internally cooled inclined X-ray monochromator of reasonable size is proposed. It has two inclined surfaces oriented into a V shape. This design substantially decreases the surface deformations introduced by radiation heat, and the size of the crystal is still feasible for a 50 mm broad impinging bending magnet or wiggler beam. The possibility of sagittal focusing of the diffracted beam is also discussed.

Keywords: inclined monochromator; heat load; internal cooling.

1. Introduction

The inclined X-ray monochromator was proposed for use with broad synchrotron radiation to reduce the impinging radiation power density from bending magnets and wigglers (Hrdý, 1990, 1992; Khounsary, 1992). A simple indirectly cooled inclined monochromator has been successfully tested by the APS group (Macrander *et al.*, 1992; Lee *et al.*, 1992). Finite-element analysis of an inclined crystal monochromator has also been performed at the APS (Assoufid *et al.*, 1995; Kushnir, 1994; Rogers & Macrander, 1993). The inclined monochromator was, and still is, successfully used at SPring-8 (Kamiya *et al.*, 1995) and a channel-cut version of it is also working at the ALOISA beamline at Sincrotrone Trieste. A further decrease of the impinging radiation power density was proposed by Smither & Fernandez (1994) by the combination of inclined and asymmetric diffraction. The principle of the inclined monochromator is shown in Fig. 1. The impinging power density may be reduced by choosing a suitable angle β between the surface of the crystal and the crystallographic planes. As compared with a symmetrical crystal ($\beta = 0^\circ$), the area of the footprint of the impinging radiation is increased $1/\sin\alpha$ times and thus the impinging radiation power density is decreasing by $1/\sin\alpha$ times ($\alpha = 90^\circ - \beta$) as shown also in Table 1. The second crystal must also be cut with the same angle β between the surface and the diffracting planes to give the diffracted beam its original shape.

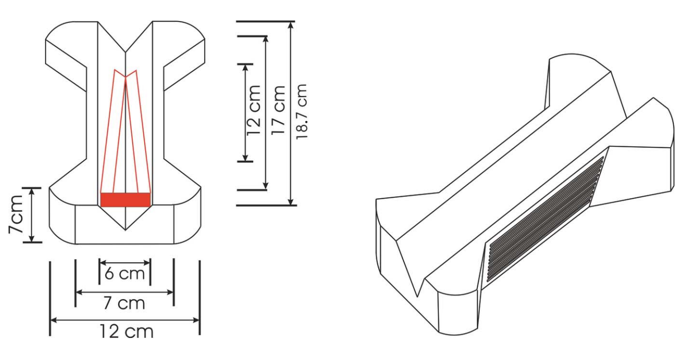

Figure 1
Enlargement of the impinging footprint and its dimensions on an inclined crystal.

If angle β is large, then a situation may occur where the size of the crystal must be larger than is feasible. One of the authors proposed a 'toothed' crystal monochromator as a variant of the inclined monochromator which can accept a broad beam without need of an extremely large crystal size (Hrdý, 1992; Hrdý & Pacherová, 1993). As was shown by Hrdý & Plešek (1998), the toothed crystal is more heat resistant than the symmetric crystal. In this paper we propose the simplest version of the toothed crystal monochromator which has only two inclined surfaces oriented in a V shape. Such a crystal may still be internally cooled and its size may be reasonable. The possibility of sagittal focusing of the diffracted beam is also discussed.

2. Inclined geometry design

In this paper we propose an internally cooled inclined monochromator with two inclined surfaces oriented into a V shape (see Fig. 2). As shown in Table 1, the angle α must be 30° to reach a reduction factor of $R = 2$, which is given by

$$R = 1/\sin\alpha. \tag{1}$$

The reason why we chose the factor of 2 is to keep the impinging radiation power constant if the storage-ring current increases twice, as is foreseen at the ESRF for example. In this case the V-shaped cut forms an angle of 60°. The V-shaped cut consists of two optical active inclined surfaces; therefore the area calculations in Table 1, the $B \times C$ area as shown in Fig. 2, must be divided by two. In this way, 8.43 keV radiation, which forms a (111) Bragg diffraction under a Bragg angle of 14.22°, creates a footprint of 50 mm × 180 mm. This implies that the required length of the crystal is 180 mm. This is still feasible. This crystal is suitable also for lower energies, because the Bragg angles are higher and the footprints are shorter. On the other hand, the higher energies would require a longer crystal,

Table 1
Comparison of beam and impinging beam footprint.

Θ is the Bragg angle, W × H is the dimension of the beam, s is the area of the beam, $B \times C$ is the dimension of the enlarged impinging footprint, s' is the area of the enlarged impinging footprint and $1/\sin\alpha$ is the reduction factor; see Fig. 1.

Θ (°)	α (°)	W × H (mm)	s (mm^2)	$B \times C$ (mm)	s' (mm)	$1/\sin\alpha$
14.2283	10	50 × 3	610.3	288 × 1118.9	3516.5	5.75
14.2283	30	50 × 3	610.3	100 × 341.7	1220.6	1.99
14.2283	45	50 × 3	610.3	70.7 × 197.3	863.0	1.41
14.2283	60	50 × 3	610.3	57.7 × 113.9	704.7	1.15
14.2283	80	50 × 3	610.3	50.7 × 34.7	619.7	1.01

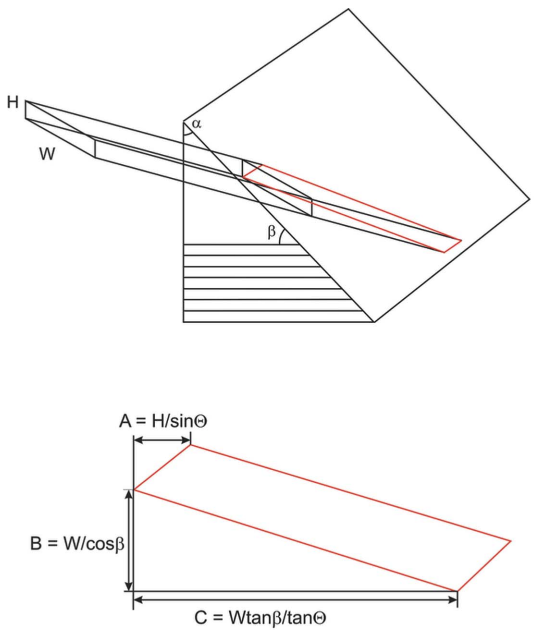

Figure 2
Design of the internally cooled inclined monochromator.

but very often for those energies even symmetric crystals work well because of larger footprints and lower absorption. Another possibility for higher energies is to switch to third-order diffraction which gives a shorter footprint.

It is often claimed that the alignment of the double-crystal inclined monochromator is somewhat complicated. The alignment of a double-crystal V-shaped inclined monochromator (Fig. 3) resembles more the alignment of symmetric crystals and should therefore be much easier. The two crystals are separated and the second crystal can be moved along the x and y axes independently to satisfy the geometrical conditions.

Direct internal cooling is provided by microchannels which are directly cut into the crystal. The dimensions of the microchannels are similar to those that we have produced in the past and are shown in Fig. 4. The cooling medium is demineralized water. The front and back of the monochromator is made more robust to guarantee the flatness of the crystal surface after the brazing by a Si block, through which the water will be distributed into the channels. The design should prevent the crystal from being deformed owing to the weight of these Si blocks. In principle, the V-shaped inclined monochromator could also be constructed as an indirectly water-cooled or liquid-nitrogen-cooled monochromator. This should solve the heat-load problem envisaged at the ESRF for bending-magnet monochromators when the current is increased. In the following chapter we present the results of a finite-element analysis (FEA) calculation for the internally cooled version.

3. FEA calculation

We performed FEA calculations of the internally cooled V-shaped inclined monochromator and compared them with FEA calculations of an internally cooled flat ($\beta = 0$) monochromator, commonly used by bending-magnet sources. In our calculations we used the technical parameters of BM05 at ESRF: a power of 120 W mrad^{-1}, power density of 1.35 W mm^{-2} and a maximum flux of 2.7 × 10^{13} photons s^{-1} mrad^{-2} (0.1% bandwidth)$^{-1}$. The calculations were made for four different angles, 18°, 24°, 45° and 55°; in this paper we present only those for 24° (low incidence) and 55° (high incidence). Fig. 5 shows a comparison of the surface deformations and the surface temperatures of these two mono-

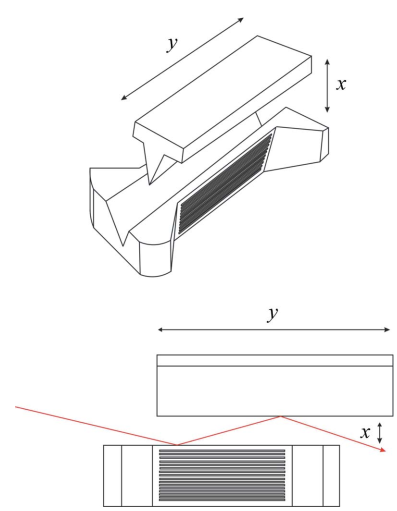

Figure 3
Setting of the two inclined crystals.

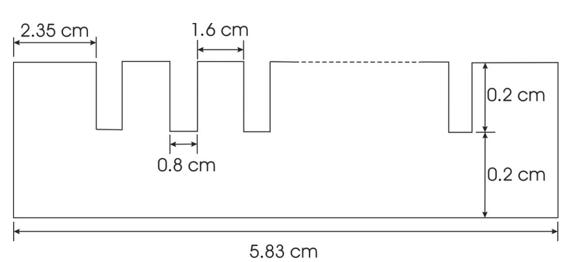

Figure 4
Scheme and dimensions of the cooling channels.

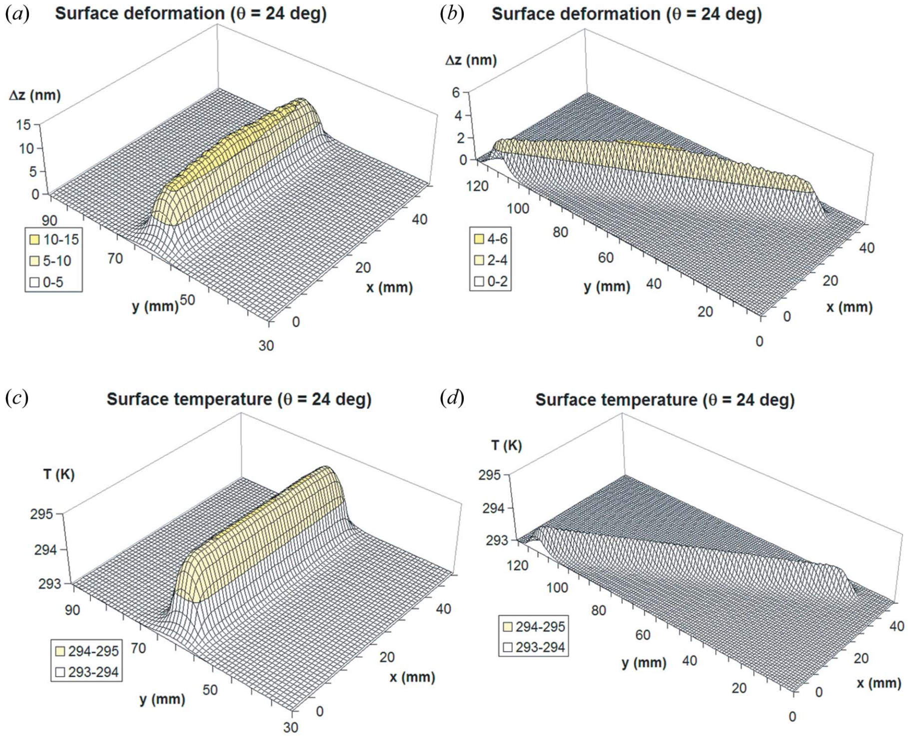

Figure 5
Surface deformation (a, b) and surface temperature (c, d) for the flat crystal (left) and the inclined crystal (right) and a Bragg angle of 24°.

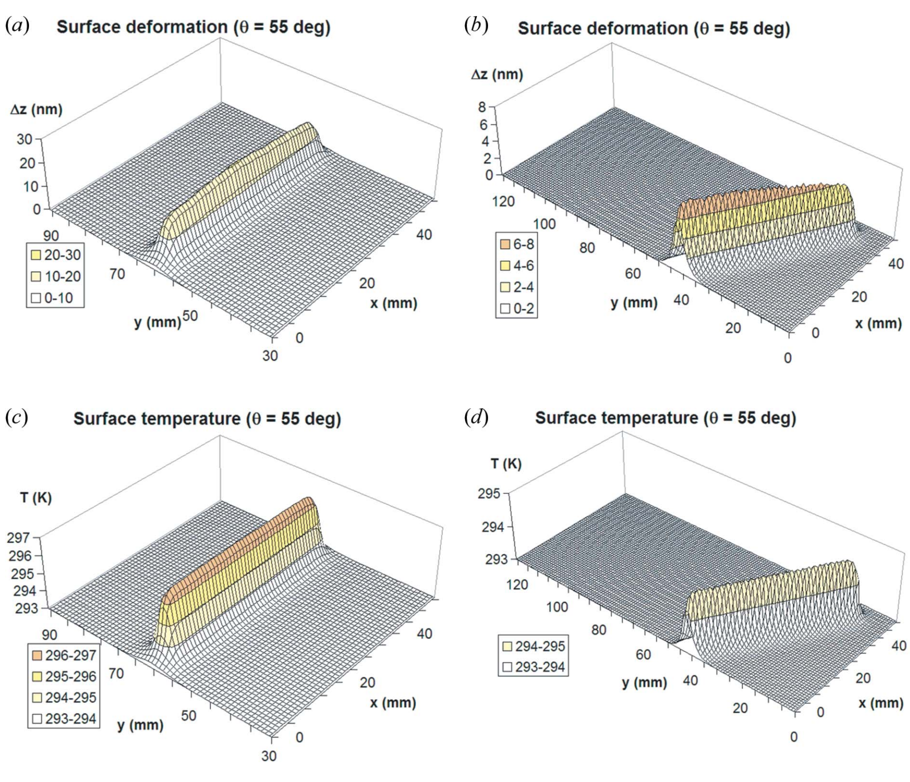

Figure 6
Surface deformation (a, b) and surface temperature (c, d) for the flat crystal (left) and the inclined crystal (right) and a Bragg angle of 55°.

chromators, with a 24° incident angle. It is seen that the surface deformation of the flat monochromator is 15 nm whereas the surface deformation of the inclined crystal is only 6 nm. The increase in the surface temperature stays at 2 K for both types of monochromator.

A major reduction of the surface deformations created by the irradiation of synchrotron radiation in the inclined case compared with the flat case occurs when the incidence angle increases. Fig. 6 shows the surface deformations and surface temperature for a 55° incidence angle. For this angle the beam area (footprint) on the monochromator is small and therefore the power density is high. The increase in the surface temperature of the inclined monochromator stays at 2 K (as for $\theta = 24°$), but the increase in the surface temperature of the flat monochromator rises to 4 K. The difference is even bigger when we compare the surface deformations, which are 8 nm for the inclined case and 30 nm for the flat case.

4. Sagittal focusing

Bending-magnet or wiggler radiation have large horizontal (sagittal) divergence and thus the sagittal focusing of the beam diffracted by a monochromator is very often necessary. This may be done either by a mirror or by the sagittal bending of the second crystal of the monochromator. As was shown by Sparks & Ice (1993), the sagittal bending of the second crystal is also possible when using an inclined monochromator. For a V-shaped inclined monochromator the sagittal bending might be realised if the second crystal had the shape of two symmetrical wings forming an angle of 2α. As this seems to be technically rather complicated, we propose another approach, which is shown in Fig. 7. The monochromator consists of two crystals. The first one is a three-bouncing channel-cut crystal. The first two reflections represent the V-shaped inclined monochromator discussed above. The beam after the second reflection has the same profile as the beam before the first reflection. The third reflection on the flat part of the

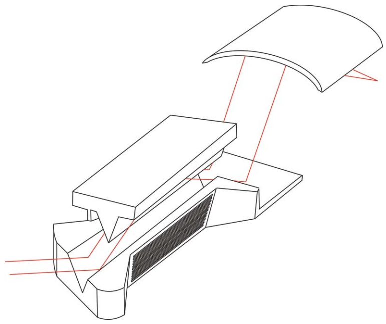

Figure 7
Internally cooled sagittally focusing inclined monochromator.

crystal is a symmetric ($\beta = 0$) reflection. The second crystal is a normal symmetric sagittally bent crystal. This solution simplifies a rather complicated configuration of four crystals (the first two inclined, the third flat and the fourth sagittally bent) which may be difficult to align. One can also imagine a three-crystal arrangement where the first and the second reflection, the second and the third reflection or the first and the third reflection occur on one channel-cut crystal.

The advantage of this solution is that only two axes of rotation are needed and the alignment is relatively simple. However, the manufacturing of the channel-cut crystal is complicated (but feasible) and requires a large crystal.

5. Summary

The FEA calculations have shown that, by introducing the internally cooled V-shaped inclined monochromator instead of the flat monochromator, a much better performance can be achieved in terms of low disturbance of the wavefront owing to low surface deformations and high reflectivity, which also results from low surface deformations. The technological tendency for the future is to increase the ring current in synchrotron facilities; for example, an increase from 200 mA to 400 mA at the ESRF. With our design of the internally cooled inclined monochromator, where the radiation power density is reduced by a factor of two, the twofold increase in the ring current would have no effect on the monochromator performance.

This study was supported by the GAAV of the Czech Republic, contract No. IAA100100716, the Institutional Research Plan AVCR, No. AVOZ10100522, and a VEGA grant from the Slovak Republic, No. 1/4134/07. We also thank Mr Lukáš from the company Polovodiče a.s. for fruitful discussions concerning the feasibility of producing the crystals discussed above.

References

Assoufid, L., Lee, W. K. & Mills, D. M. (1995). *Rev. Sci. Instrum.* **66**, 2713–2718.

Hrdý, J. (1990). Technical Note ST/S-TN-90/27. Sincrotrone Trieste, Italy.

Hrdý, J. (1992). *Rev. Sci. Instrum.* **63**, 459–460.

Hrdý, J. & Pacherová, O. (1993). *Nucl. Instrum. Methods*, A**327**, 605–611.

Hrdý, J. & Plešek, J. (1998). *J. Synchrotron Rad.* **5**, 667–669.

Kamiya, N. *et al.* (1995). *Rev. Sci. Instrum.* **66**, 1703–1705.

Khounsary, A. M. (1992). *Rev. Sci. Instrum.* **63**, 461–464.

Kushnir, V. (1994). *Rev. Sci. Instrum.* **65**, 3403–3407.

Lee, W. K., Macrander, A. T., Mills, D. M., Rogers, C. S., Smither, R. K. & Khounsary, A. M. (1992). *Nucl. Instrum. Methods*, A**320**, 381–387.

Macrander, A. T., Lee, W. K., Smither, R. K., Mills, D. M., Rogers, C. S. & Khounsary, A. M. (1992). *Nucl. Instrum. Methods*, A**319**, 188–196.

Rogers, C. S. & Macrander, A. T. (1993). *Nucl. Instrum. Methods*, A**335**, 561–568.

Smither, R. K. & Fernandez, P. B. (1994). *Nucl. Instrum. Methods*, A**347**, 313–319.

Sparks, C. J. & Ice, Gene, E. (1993). *Proc. SPIE*, **1740**, 11–17.