Lay-out of ultrahigh-vacuum DC-monochromator

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Abstract. Features and design advantages of the ultra-high vacuum double-crystal monochromator with (practically) fixed exit and the opportunity of sagittal focussing are discussed.

Monochromator is projected and is under construction for 6-th synchrotron radiation beamline at VEPP-3 storage ring of Siberian SR center. The first results of testing of monochromator's kinematics are presented as well.

INTRODUCTION

At present the Siberian synchrotron radiation center has about ten beamlines with 2T wiggler as a source of radiation; energy of electrons in storage ring VEPP-3 at working in SR-mode is 2 GeV. For monochromatization of x-rays, single-crystal monochromators are installed at 4-th and 5-th beamlines, and channel-cut monochromators are used at some other beamlines; while 6-th and zero beamlines use only white radiation.

A double-crystal monochromator with fixed exit and sagittal focussing is a necessary element of x-ray optics of modern beamline as it raises beamline performance significantly. Our center needs for such an equipment. However its purchase is some difficult because of high cost, and, besides because of large sizes of commercially available monochromators. High density of beamlines (ten beamlines on a wiggler) in our case makes that space in horizontal direction is limited very much.

Therefore we have suggested the variant of the kinematics layout of the double-crystal monochromator (with *practically* fixed exit) which uses mainly the space along the beamline: instead of traditional goniometer, the main source of movement hear is precision (not vacuum) linear positioner, see Figure 1.

We believe that similar approach (but with two linear positioners — one for every crystal) could be used for DC-monochromator *of general position* (or *skew* monochromator suitable for side beamlines) [1] that means that input and output lines do not lie in one plane. It is interesting to note that skew double-crystal monochromator with fixed exit does not in general case require that crystals to be equal.

DESIGN FEATURES OF THIS MONOCHROMATOR

General view of DC-monochromator and nearest beamlines can be seen in Figure 1a. More detailed layout drawing is shown in Figure 1b. This layout is development of our earlier project [2]. In that early scheme, the important elements of a design were the copying rulers having a complex profile line, which would set the turn of levers and crystals (a sort of cam mechanics). In the new variant of kinematics, the crystal's levers are supported by rollers; each roller is fixed concerning the axis of rotation of the corresponding crystal. It is possible to find such a variant of configuration, i.e. position parameters of rollers and levers, when the working surface of levers is *very simple*, merely plane, while the relative precision of *fixed exit* condition, $\Delta h/h$, is about $3 \cdot 10^{-4}$ (for Bragg-angle range $5^\circ < \theta < 18.5^\circ$). Thus, the overall objective achieved in this variant is that the most crucial surfaces of parts of a construction are *very simple*, i.e. plane or cylinder surface, which allows us to ensure higher manufacturing accuracy and kinematics precision.

The movement of the first crystal C_1 (and all unit of crystal C_1) is made by horizontal positioner 3 (Huber, with a working range of ~ 180 mm) through bellows 4 with the help of plunger-rod 5, see Figure 1b. Inside the rod the two tubes are provided for water cooling of the first crystal. The change of beam height which is set by vertical position of the second crystal, is $h = 40$ mm, and the range of energy at work with crystals Si 111 makes 6–22 keV. The axis of rotation of second crystal C_2 is fixed, and the turning of this crystal consists of two parts. The first is a fast turn with the lever L_2 clamped to roller R_1. The accuracy of manufacturing and assembly of parts of mechanics should to guarantee correct absolute orientation of crystals with an error $\sim 10''$ in all the working range.

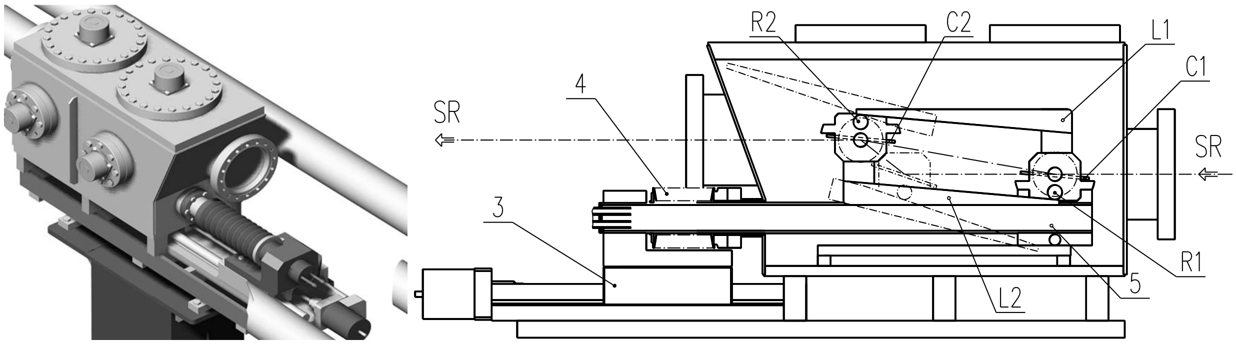

FIGURE 1. (a) Sketch view of monochromator and nearest beamlines; (b) Layout drawing of DC-monochromator.

The precise tuning of θ-angle of the second crystal will be provided with the help of the mechanism using tense wave friction transfer with high transmission factor [3], which could change the angle between the lever and the crystal, φ_2, with a step $\sim 0.2''$. The same unit of angle control will be used also for the first crystal, but it is used only for initial adjustment of the angle φ_1 required after replacement of crystals. The prototype of this unit has been well tested.

CALCULATION OF OPTIMUM PARAMETERS OF KINEMATICS

Let us calculate at first the true lever profile (necessary for *fixed exit* condition) in a dot roller approximation – correction on roller's radius is simple. The origin in Figure 2a is the axis of rotation of the first crystal, A_1; the axis u is parallel to crystal planes. The axis of the second crystal, A_2, is visible under angle θ to the axis u and is away from A_1 on distance $L = h/\sin 2\theta$.

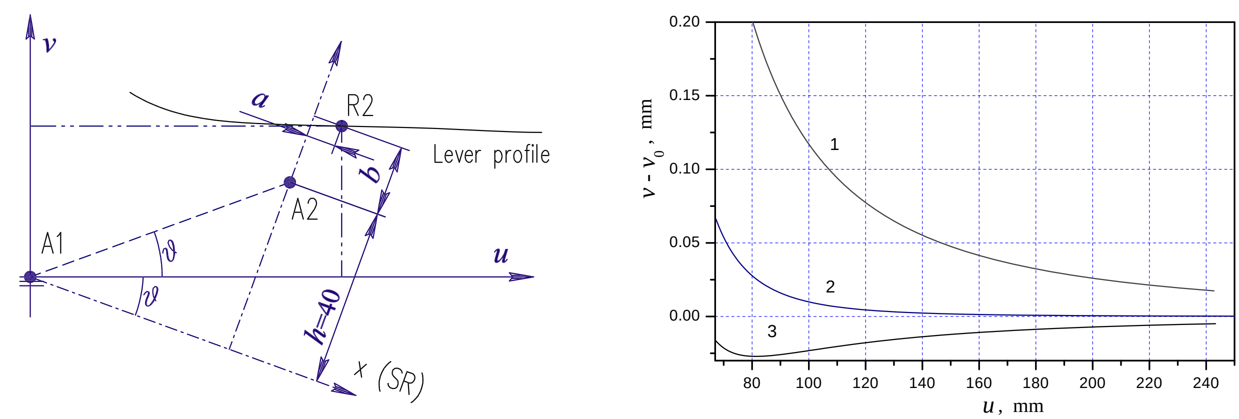

FIGURE 2. (a) Derivation of true profile; (b) Lever profiles from Eq. (1) [$h = 40,\ a = 0$]: (1) $b = 15$; (2) $b = 20$; (3) $b = 21.5$.

The parameters a and b adjust position of roller R_2. From Fig. 2a we find co-ordinates (u, v)

$$u(\theta) = (L + a)\cos\theta + b\sin\theta; \quad v(\theta) = (L - a)\sin\theta + b\cos\theta \quad (L = h/\sin 2\theta). \tag{1}$$

Figure 2b shows the profiles of the lever, $v(u) - v_0$ ($v_0 = h/2 + b$) calculated for a number of different values b (angle θ varies in the range 5°–19°). For the case $b = 21.5$, profile with high accuracy is approximated by the straight line.

Now let us consider the case with plane lever, to find the deviations of the output beam height

$$\Delta h(x) = h^* - h, \quad \text{where} \quad x = x_{A2} - x_{A1} = -x_{A1} \quad \text{– "control" parameter.}$$

Parameters of the lever are: B – offset of lever plane from axis A_1, φ – angle between lever and crystal, see Figure 3a.

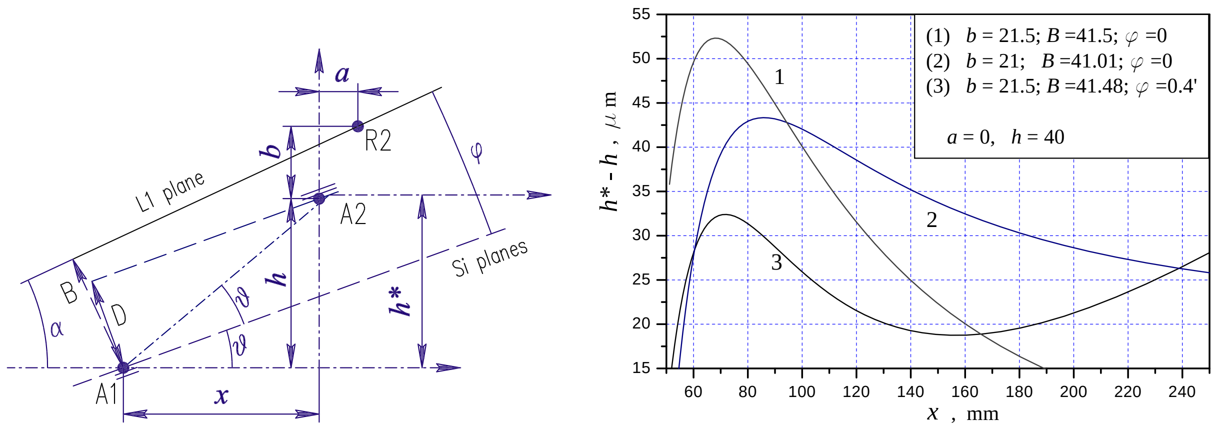

FIGURE 3. (a) Derivation of beam height $h^*(x)$ for plane lever; (b) Deviations of output beam height $\Delta h(x)$.

For the angle α it is easy to write:

$$(x+a)\sin\alpha + B = (h+b)\cos\alpha, \quad \alpha = \theta + \varphi. \tag{2}$$

That is, the function $x(\theta)$ is found. Now we find distance between planes of two crystals, D, and also h^*:

$$D = h\cos\theta - x\sin\theta, \quad h^* = 2D\cos\theta. \tag{3}$$

In a result from Eqs. (2), (3) we obtain function $h^*(x)$ in a parametric form:

$$x(\theta) = (h+b)/\tan(\theta+\varphi) - B/\sin(\theta+\varphi) - a, \tag{4}$$

$$h^*(\theta) = (h\cos\theta - x\sin\theta)\cos\theta. \tag{5}$$

Figure 3b shows $\Delta h(x)$ calculated for several variants; the best choice of parameters, we think, is the following:

$$a = 0;\ b = 21.5;\ B = 41.48;\ \varphi = 0.4'\ (h = 40). \tag{6}$$

This set of parameters is used in real mechanics of monochromator which is under construction now.

It is possible to generalize this result taking into account the deflection of the second crystal at sagittal focusing.

ASSEMBLING ACCURACY AND KINEMATICS TESTING

For the purpose of verification of kinematics accuracy and the precision of the linear stage, we have used Heidenhain+Burleigh-measuring system which has 0.1 μm accuracy of measurement. The positioner in half-step mode has the (half)step, δx, of 5 μm (and 2×200 h-steps per rotation). The corresponding step of θ-angle, $\delta\theta$, depends on a current position x (or current θ-angle), see Figure 4a. It would be desirable to increase the positioner's precision (and to decrease vibration) using either wave reducer or micro-stepping.

Using the same measuring system we have found that bearing units of both crystals do provide rotation with such a small step as $0.3''$ (at large x, see Fig. 4a). Deviations of θ-angles (from a smooth interpolating curve, or one scan from another) of "crystals" or their levers are about $4''$; these deviations are mostly because of residual slackness of ball bearings (rollers R_i) and we plan to eliminate this defect.

The assembling of details of kinematics has to be very accurate to provide parallelism of levers and crystals. The differences of parameters of first and second crystal units,

$$\Delta B = B_1 - B_2,\ \Delta b = b_1 - b_2,\ \Delta a = a_1 - a_2,$$

should be as small as possible, at least less than 10 μm. Differentiating Eq. (4) one can obtain the following expression for the off-orientation angle, $\Delta\theta = \theta_1 - \theta_2$,

$$\Delta\theta = (\Delta b\cos\alpha - \Delta B - \Delta a\sin\alpha)/(x\cos\alpha + (h+b)\sin\alpha) \tag{7}$$

Figure 4b shows $\Delta\theta(x)$ for differences of parameters equal to 10 μm. Using thing metal foils for fine adjustment of Δb we have reduced the variation of the total difference up to 70 μrad (or 14$''$).

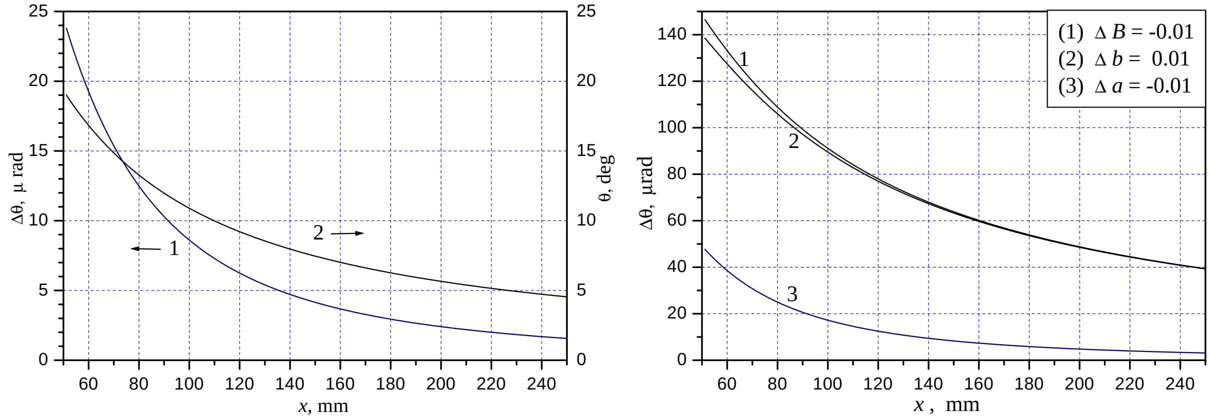

FIGURE 4. (a) The angle step (1) and θ-angle as functions of *x*; (b) Off-orientations of crystals [terms of Eq. (7)].

The first optical testing of monochromator's kinematics both in air and in low vacuum, has been carried out, see Figure 5. Relative off-orientation of "crystals" (at this stage we have used either mirrors or polished metal plates, end measures, instead of crystals) was estimated using laser level with ruler placed 10 m away from the second crystal. Light spots on insets 1 and 2 of Figure 5b relate to low- and high-end of *x*-range, respectively. Their height difference of 1.4 mm corresponds to $\Delta\theta$-variation of 14$''$.

We are going to improve the precision of monochromator's kinematics when the next development stage will be completed. This last stage includes crystal holders (with fine adjustment of a crystal on a separate stand) and units of θ-angle fine adjustment as well.

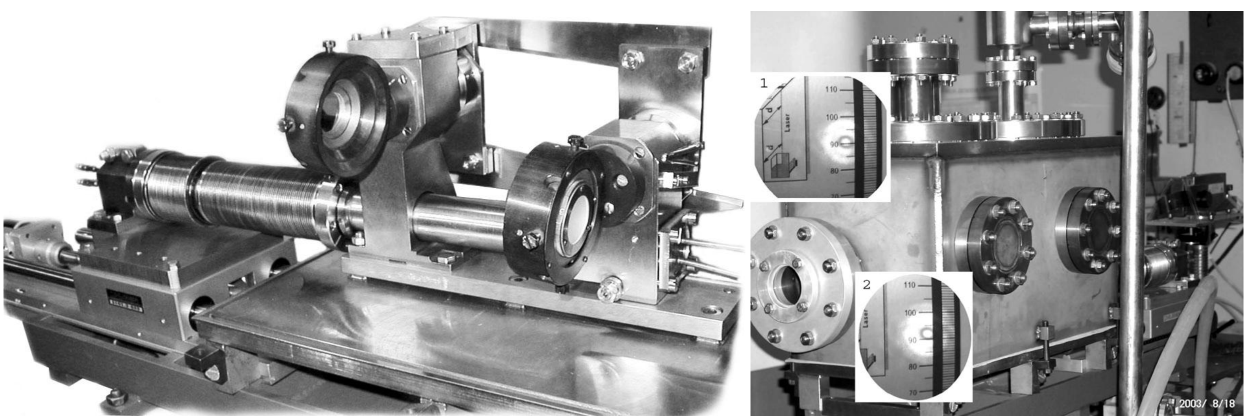

FIGURE 5. Optical testing (a) in air and (b) in low vacuum.

This double-crystal monochromator will allow to have a minimum of tunings when it works; the high accuracy of manufacturing of the most important monochromator elements reduces the time necessary for the energy adjustment. All elements of monochromator sustain warming up at 300°C and can work in ultrahigh vacuum; very small width of monochromator, $\sim$ 250 mm, allows to install it on 6-th SR beamline in a very limited space.

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