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ANALYSIS AND DESIGN OF A NEW KIRKPATRICK-BAEZ MIRROR SYSTEM FOR MICROBEAMS*

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Abstract

The 4B beamline of Pohang Accelerator Laboratory is used for microdiffraction and microfluorescence experiments using an X-ray microbeam. The X-ray microbeam has been focused down to 3 μm × 3 μm using a Kirkpatrick-Baez (K-B) mirror system with vertically and horizontally focusing mirrors arranged in series.

In this research, a new K-B mirror system was developed for focusing a microbeam to 1 μm × 1 μm at the 4B beamline of the Pohang Light Source-II. The new K-B mirror system consists of a pair of assemblage having three mechanisms that adjust the position, pitch, and curvature of each vertically and horizontally focusing mirrors and stages that support both the assemblages to enable translations along two orthogonal axes and rotation on the horizontal plane. Both the pitch- and curvature-adjusting mechanisms were designed as flexural mechanisms driven by their respective single actuators to minimize the movement of the mirror center even when the pitch or the curvature of each mirror was adjusted. The K-B mirror system with these features will be robust against possible disturbances and will help promote easy and simple mirror adjustment.

This paper describes the whole design of the new K-B mirror system in detail and the structural analysis results of the pitch- and the curvature-adjusting mechanisms, and reports the operation principle of the curvature-adjusting mechanism.

DESIGN OF THE K-B MIRROR SYSTEM

The translation of each K-B mirror [1-2] is performed by driving a linear stage through a picomotor in the new K-B mirror system. The pitching of each mirror around the mirror center should be vitally stable; however, the range is small. Thus, pitching is performed by a pitch-adjusting mechanism designed as a flexural mechanism. The pitch-adjusting mechanism is attached on a linear stage for translation.

Support stages independent of the mirror manipulating apparatus of the K-B mirror system are installed under the mirror manipulating apparatus to enable translations along two horizontal orthogonal directions and azimuthal rotation of the mirror manipulating apparatus. Support stages are needed to make incident X-rays parallel to the long axis of the vertically focusing mirror and translate the reflection area in the transverse direction of the vertically focusing mirror when the reflectivity of the narrow reflection area of the mirror deteriorated because of long-term heat load.

The stability of the curvature-adjusting mechanism is especially important like the pitch-adjusting mechanism; thus, it was also designed as a flexural mechanism. In this research, the curvature-adjusting mechanism of the K-B mirror system was designed to satisfy the following design requirements:

- The mirror center must not move in any direction during curvature adjustment. In particular, the displacement must be fixed in the direction normal to the mirror surface.
- The ratio of the bending moment to deform the mirror to the displacement of the linear actuator has to be small. In other words, the resolution becomes higher when a larger displacement of the linear actuator is required to generate the same bending moment.
- The displacement of the linear actuator has to be linear with the mirror curvature or the bending moment to deform the mirror.
- The hysteresis of the mirror curvature to the displacement of the linear actuator has to be minimized.
- The number of linear actuators to drive the curvature-adjusting mechanism has to be minimized to perform in-situ curvature adjustment.

In this research, similar to the translation and pitching of each mirror, a motorized curvature-adjusting mechanism was designed for the in-situ curvature adjustment of the K-B mirrors on the beamline. Although this curvature-adjusting mechanism increases the number of adjustment parameters of the K-B mirror system and makes beam focusing difficult, a mechanism that can adjust the curvature by a single actuator was devised to alleviate the increase of the number of adjustment parameters for beam focusing.

STRUCTURAL ANALYSES

Analyses of the Pitch-Adjusting Mechanism

Figure 1 shows the structural analysis result of the pitch-adjusting mechanism. The vertical displacement of the mirror center moved downward by 1.64 μm when the picomotor tip of the pitch-adjusting mechanism advanced by 1.55 mm. Given that the picomotor displacement corresponding to the approximate pitch value for the focused beam is at a level of 0.8 mm, and the size of the raw beam incident on the mirror is at least 100 μm × 100 μm, the displacement of the mirror center because of the pitch adjustment of this K-B mirror system is not at a level to hinder beam focusing process.

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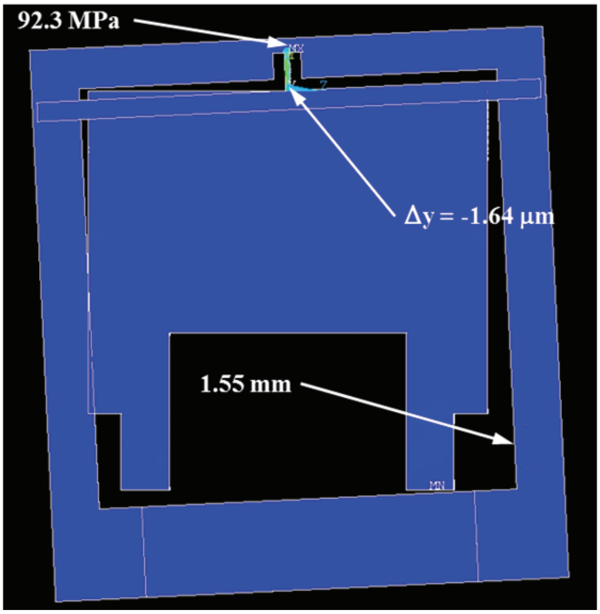

Figure 1: Deformed shape of the pitch-adjusting mechanism viewed from the front.

Analyses of the Curvature-Adjusting Mechanism

In this research, major design parameters were determined through structural analysis using the ANSYS code after conceptually designing a flexural mechanism for curvature adjustment, satisfying the requirements described above.

Based on the idea that the positions of the pivot points of the angular displacements that bring the bending moments may have an effect upon the size and direction of the displacement of the mirror center at a curvature-adjusting mechanism that adjusts the mirror curvature by applying angular displacements to support blocks supporting both ends of a mirror, structural analyses were repeated for a preliminarily designed flexural mechanism while varying the position of the pivot point to find the position of the pivot point where the displacement of the mirror center after curvature adjustment is minimized.

Figure 2 shows the general deformation and stress contour of the curvature-adjusting mechanism designed as a flexural mechanism. The figure in the lower part of Fig. 2 separately presents the displacement of the mirror of the mechanism. The left end of the mirror moved upward by 46.8 μm from the original height, whereas the right end moved upward by 58.1 μm. The center of the coordinate system on the mirror center before the deformation coincided with the mirror center after the deformation. Thus, almost no vertical displacement and displacements in different directions on the mirror center were observed.

STRUCTURE AND OPERATION PRINCIPLE OF THE CURVATURE-ADJUSTING MECHANISM

The curvature-adjusting mechanism (1) of this research was designed to adjust the curvature of a mirror (10) by applying bending moments to both ends of the mirror (10) or releasing the bending moments. Figure 3 shows the designed curvature-adjusting mechanism.

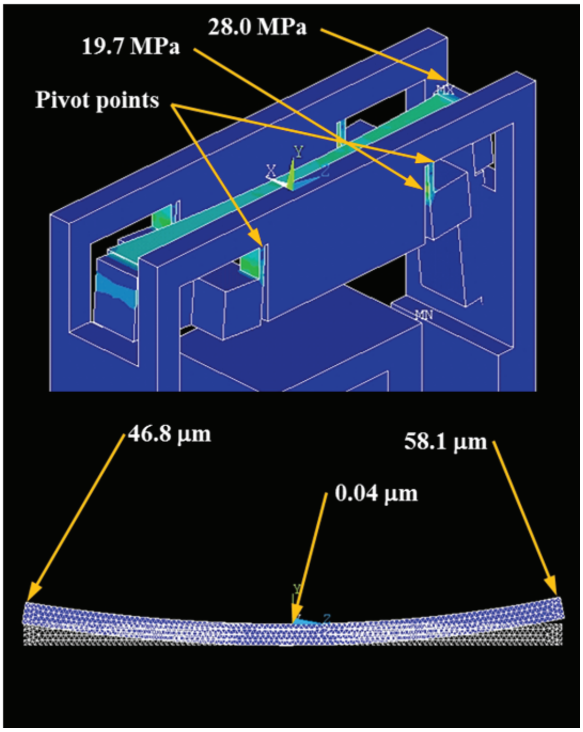

Figure 2: Deformation and stress contour of the curvature-adjusting mechanism.

The curvature-adjusting mechanism (1) consists of a base block (20); a pair of rotating blocks (30 and 30') connected to the base block (20) through their respective first leaf springs (31 and 31'), where each of the pair of rotating blocks (30 and 30') is rotated around a connection portion (PP1 or PP1') between the base block (20) and its first leaf spring (31 or 31') or elastically returning to its original position according to the application or release of an external force; a pair of support blocks (40 and 40') respectively disposed on the pair of rotating blocks (30 and 30') to support both ends of the mirror (10), where the pair of support blocks (40 and 40') apply bending moments to both ends of the mirror (10) by the rotation of the pair of rotating blocks (30 and 30'); and a driving part (50).

The driving part (50) includes a transfer member (51) that is transferred forward or backward in one direction; a single actuator (52) that transfers the transfer member (51); and a pair of transmission parts (53 and 53') respectively disposed below both sides of the transfer member (51) to transmit the transfer force of the transfer member (51) by the actuator (52) to the pair of rotating blocks (30 and 30'), thereby rotating each of the pair of rotating blocks (30 and 30'), wherein the first leaf springs (31 and 31') connect the rotating blocks (30 and 30’) to the base block (20) so that the support points (SP and SP') of the support blocks (40 and 40') of the mirror (10) are movable in a direction opposite to the moving direction of the central point (MC) of the mirror (10) by a change in the curvature, as the rotating blocks (30 and 30') are rotated.

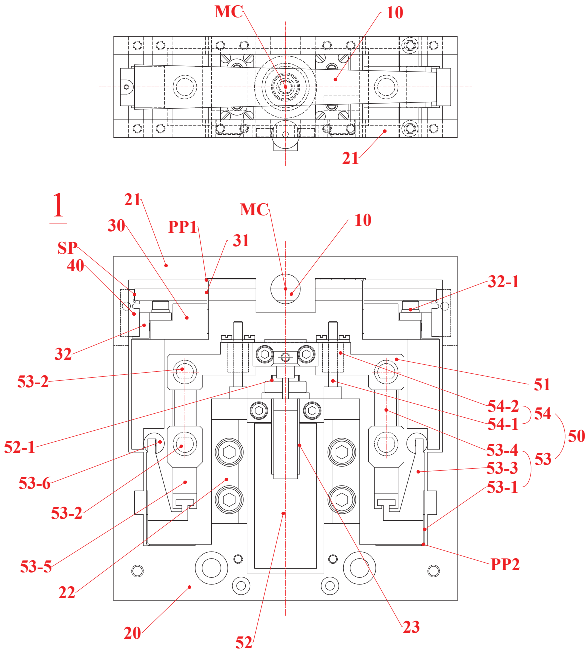

Figure. 3: Design of the curvature-adjusting mechanism.

Hereinafter, the operation principle of the curvature-adjusting mechanism (1) in this research will be described in detail based on the process for adjusting the curvature along the direction that the curvature of the mirror (10) is gradually increased.

First, to adjust the curvature of the mirror (10), the actuator (52) of the driving part (50) is operated to press the transfer member (51) contacting the driving shaft (52-1) upward when viewed in Fig. 3. Thus, the transfer member (51) may be stably guided by the guide part (54) constituted by four guide shafts (54-1) and four guide bodies (54-2), and then transferred upward.

As a result, the springs (53-4 and 53-4') connected to each side of the transfer member (51) may be elastically extended by the tensile force, and the transfer displacement of the transfer member (51) may be transmitted into the transmission blocks (53-3 and 53-3') in a state where the transfer displacement is reduced. Thus, the second leaf springs (53-1 and 53-1') may be elastically deformed to rotate the transmission blocks (53-3 and 53-3') around their respective second pivot points (PP2 and PP2').

Next, as the transmission blocks (53-3 and 53-3') are respectively rotated around the second pivot points (PP2 and PP2'), the extending ends of the rotating blocks (30 and 30') are pressed through the sliding members (53-6 and 53-6'). Thus, the first leaf springs (31 and 31') are elastically deformed by the pressing force to rotate the rotating blocks (30 and 30') around the first pivot points (PP1 and PP1'), respectively. Accordingly, the support blocks (40 and 40') fixedly disposed on the rotating blocks (30 and 30') may also be rotated. Then, the curvature of the mirror (10) is concavely increased when the support blocks (40 and 40') are rotated to apply bending moments to both ends of the mirror (10).

The support points (SP and SP') of the support blocks (40 and 40') move upward when the rotating blocks (30 and 30‘) are respectively rotated around the first rotating points (PP1 and PP1'). On the other hand, the rotating blocks (30 and 30') are rotated to apply bending moments to the mirror (10), thereby deforming the mirror (10) so that the curvature of the mirror (10) is concavely increased. Here, the central point (MC) of the mirror (10) is moved downward with respect to the support points (SP and SP'). Resultingly, the movement of the central point (MC) of the mirror (10) may be offset by the movement of the support points (SP and SP') in an opposite direction thereof. Thus, the absolute displacement of the central point (MC) of the mirror (10) is barely changed with respect to the base block (20).

CONCLUSIONS

Analysis and design of the new K-B mirror system were carried out in this research to stably focus a microbeam with a size of 1 μm × 1 μm at the 4B beamline of the Pohang Light Source-II.

Both mirror pitch-adjusting mechanism and curvature-adjusting mechanism that adopted flexural mechanisms operated by a single actuator were designed to maintain the position of the mirror center during operation. The displacement of the mirror center was verified to be negligible through structural analysis using the ANSYS code during mirror pitch and curvature adjustment. This stable K-B mirror system enables the adjustment of the curvatures of the K-B mirrors on the beamline, thereby reducing beam sizes more than before. Figure 4 shows the K-B mirror system being assembled.

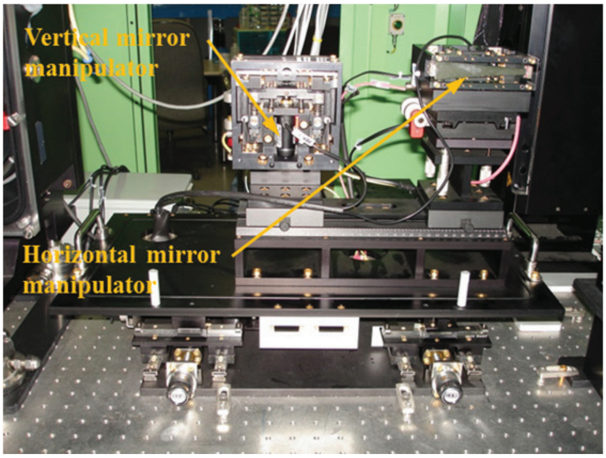

Figure 4: New K-B mirror system.

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