AUTOMATIC MICROBEAM FOCUSING FOR X-RAY MICROBEAM EXPERIMENTS AT THE 4B BEAMLINE OF POHANG LIGHT SOURCE-II*

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Abstract

The 4B beamline of the Pohang Light Source-II performs X-ray microdiffraction and microfluorescence experiments using X-ray microbeams. When performing X-ray micro-experiments, an X-ray microbeam should first be prepared. Up to recently, the microbeams with vertical and horizontal sizes (full width at half maximum) of less than 3 µm have been achieved, by manually adjusting the translations and pitch angles of the vertically and horizontally focusing mirrors, in a Kirkpatrick–Baez (K-B) mirror system. In this research, we developed a program that automates the complex and cumbersome process of microbeam focusing, divided into half-cutting and focusing phases. The developed program was applied to the 4B beamline and enabled the focusing of an X-ray beam to a minimum size within one hour. This paper introduces the algorithms of the program and also examines its performance.

HARDWARE RECONFIGURATION

The main equipments for the X-ray microbeam experiments of the 4B beamline consist of two slits (optics and experiment slits), an ionization chamber (IC), a shutter, a monochromator, a Kirkpatrick–Baez (K-B) mirror system at the rear, a sample stage used to move a sample, and detectors.

The front vertically focusing mirror (VFM) and rear horizontally focusing mirror (HFM) are arranged to configure a K-B optic system [1]. Each 102 mm long mirror translates in a direction perpendicular to the mirror surface or pitches with respect to the beam by two picomotors. The displacement of each picomotor is detected by a linear variable differential transformer (LVDT) mounted around the adjustment screw of the picomotor and displayed on an LVDT controller. Each mirror, of which the surface is plated with 30 nm-thick platinum, is adjusted into the required elliptical curvature by using a manual mirror bender.

An acrylic plate bolted to the sample holder is shown in Fig. 1. A 4 mm-diameter hole is machined at the central part of the acrylic plate, and two (vertical and horizontal) 250 µm-diameter tungsten wires are attached using Blutack across the hole. Thus, the hole is divided into four quadrants.

In this research, the IC outputs electric current values as negative numbers, and the beam intensity is the absolute value of the IC current.

The existing picomotor drivers and control pad used to drive the picomotors, as well as the existing LVDT display used to measure and display the displacements of the picomotors of the K-B mirror system, have no communication function. Thus, we replaced these components with a new picomotor controller and two new LVDT controllers with serial communication capability.
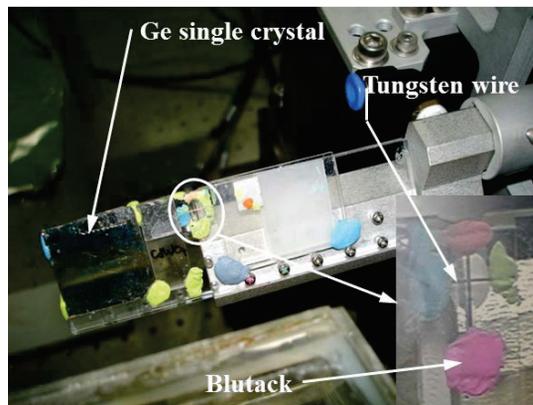

Figure 1: Sample holder and close-up view of the tungsten wires.

PROGRAMMING

After configuring a control routine (i.e., Picomotor-LVDT Closed-Loop Control routine), which controls the picomotors through proportional closed-loop control [2] by inputting pulses into the picomotors through the picomotor controller and reading the displacements of the picomotors from the LVDT controllers by the control computer, we developed a Microbeam Focusing Automation (MiFA) program using LabVIEW, which performs every step of the existing microbeam-focusing process.

In the MiFA program, algorithms that achieve a specific value of IC output while translating a mirror or a maximum of beam intensity or a minimum of beam size while rotating a mirror are required. In this research, the golden section search algorithm [3] that is very effective for this purpose was used but modified for practical reason in its application.

Picomotor-LVDT Closed-Loop Control Routine

Since the picomotors do not drive a uniform displacement for applied fixed pulses unlike a stepping motor [4], the actual displacement can be confirmed only by the LVDT output. The relation between the picomotor displacement and LVDT output also varies based on the calibration of LVDT. In this research, a LabVIEW routine using proportional closed-loop control [2] was coded to move a picomotor to a target LVDT position by directly treating the output of the LVDT as displacement of the picomotor. In this proportional control, the gain was set to 4000 pulses/V.

Half-Cutting Algorithm

The K-B mirror is in a half-cut state when each of the VFM and HFM blocks exactly half of the beam in a posture parallel to the beam. The half-cut states of the K-B mirrors are imposed to minimize the beam size while adjusting only the picomotor for the pitch angle of each mirror in the focusing phase using the fact that mirror rotation in the K-B mirror system is realized on the pivot axis, which is the transverse axis passing through the center of a mirror surface. The steps of the half-cutting phase used in the program are shown in Fig. 2.

1) The mirror is translated from a position away from the beam to a position where the front end of the mirror barely breaks through the beam centerline, in a state in which the front end is nearer to the beam than the rear end [Refer to Fig. 2(a).].

2) The mirror is rotated in a direction in which it can accept more of the beam, and whether or not the current pitch angle maximizes the beam intensity is checked using the IC output [Refer to Figs. 2(b) and 2(d).]. If the beam intensity is the maximum, we proceed to step 5); otherwise, we proceed to step 3).

3) Whether or not further rotation causes the front end of the mirror to move out of the beam is checked [Refer to Fig. 2(b).]. If yes, we proceed to step 4); otherwise, we proceed to step 2).

4) The mirror is again translated so that the front end of the mirror, which descended below the beam centerline by the prior mirror rotations, breaks through the beam centerline [Refer to Fig. 2(c).].

5) The mirror is again translated so that a straight line connecting the front and rear ends of the mirror coincides with the beam centerline [Refer to Fig. 2(e).].

Given that the mirror pitched on the pivot axis as in steps (b) and (d) in Fig. 2, more beam transmits to the rear of the mirror as the mirror pitches, and the beam intensity of the IC increases. However, in a state that the mirror exceeded the pitch angle parallel to the beam, the counterclockwise pitching of the mirror decreases the IC beam intensity. Thus, the parallelized pitch angle of the mirror can be achieved by searching the position at which the beam intensity is at a maximum, as in step (d).

The front end of the mirror should be prevented from moving outside the beam in steps 3) and 4) because meaningful changes in the IC output by mirror pitching do not occur in that case.

Steps 1), 4), and 5) are executed by Mirror for I routine, whereas steps 2) and 3) are executed by Mirror for Max I routine.

Since repetitive operations of combined Mirror for I and Mirror for Max I routines are required to complete the half-cutting, a while loop was configured. Inside the while loop, a segment that calls the Mirror for I routine, another that calls the Mirror for Max I routine, and an escape criterion segment exist.
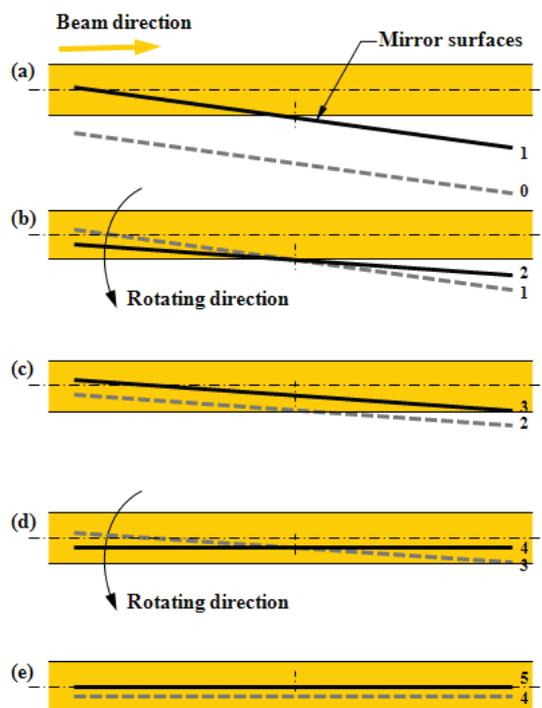

Figure 2: Process for achieving the half-cut state of a mirror.

Microbeam Focusing Routine

The Microbeam Focusing routine pitches a mirror to the pitch angle that yields the minimum beam size by repeating the measurement of beam size while changing the pitch angle. For every pitching, the routine translates the tungsten wires to predetermined offsets away from the beam by executing Cross-Wire Reposition routine and measures the beam size by executing Beam Size Scan routine.

Once the interval containing the pitch angle corresponding to the minimum beam size is captured, the routine subsequently measures the beam size at each equally partitioned position after dividing the length of the interval by ten. After fitting the 11 measured beam sizes to a third-order polynomial function, the routine pitches the mirror again to the pitch position corresponding to the minimum value of the function, measures the final minimum beam size, and outputs it to the parent routine. The golden section search algorithm is modified in the step of searching for the minimum value within the captured interval because the algorithm is rather prone to error due to low actual stability of beam size measurements within a relatively narrow pitch angle interval. A graph of beam sizes measured at the equally partitioned positions within the captured interval is shown in Fig. 3.

Main Routine

The main routine fulfills the whole microbeam-focusing process by achieving the half-cut states and

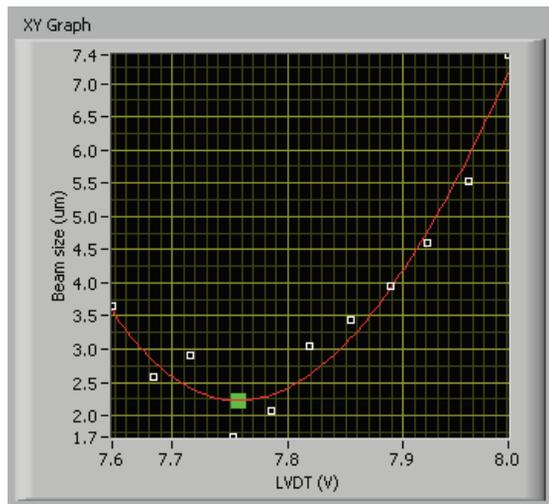performing the focusing phase of both mirrors using the subroutines.

Figure 3: Graph of the beam sizes measured at equally partitioned positions within the interval containing the pitch angle corresponding to the minimum beam size.

EXECUTION RESULTS

In parallelizing the pitch angle of each mirror to the beam to obtain the half-cut state, we believed at the initial stage of programming that a pitch angle where the beam intensity is at a maximum may be found while pitching the mirror by a fixed quantity of pitch angles in a direction that lowers the front end of the mirror from a state in which the front end is nearer to the beam than the rear end. We also believed that the mirror is parallelized to the beam at the pitch angle. However, the preliminary Mirror for Max I routine often could not capture the pitch angle of the maximum beam intensity. Thus, we inquired into the variations in beam intensities according to the pitch angles of the VFM and HFM. Figure 4 shows the beam intensity measured from the IC with respect to the pitch angles of the VFM. Figure 4 was measured while adjusting only the pitch angle of the VFM with the half-cut HFM.

The IC output decreases from the left up to point A and then increases up to point B in Fig. 4 for the VFM. The output presents the second minimum value at point C then increases continuously. This tendency also appears for the HFM. We found that point A corresponds to the pitch angle of the half-cut state by comparing with another half-cut state, which had been manually achieved.

Point A emerges because the mirrors have curvature. If a mirror has no curvature, the local minimum of the IC output is not formed because of the instant starting of beam reflection while the front end of the mirror is lowered, passing the parallel pitch angle. Conversely, if a mirror has curvature, the local minimum of the IC output, such as point A of Fig. 4 emerges while the front end is lowered. This is because the region used for reflection on the whole mirror surface is a little portion in the rear end of the mirror, and the beam reflected from the region is

partly blocked by the rear tip of the mirror. Thus, the entire amount of reflection drops, and the beam intensity decreases from point A up to point B, even if the pitching continues.
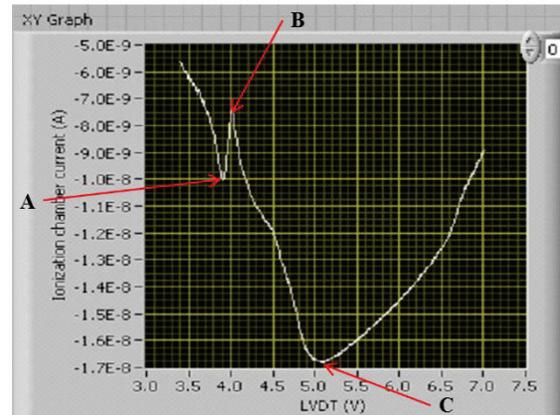

Figure 4: Variations in IC outputs with respect to the pitch angles of the VFM.

CONCLUSIONS

To automate the focusing of X-ray microbeams, we developed the MiFA program to perform the microbeam-focusing process.

A vertical beam size of 2.2 μm and a horizontal beam size of 2.0 μm resulted from the experimental operation of the developed program. These beam sizes are either equal to or smaller than those obtained from the existing manual microbeam-focusing process. The total duration of microbeam focusing using the program was about 50 min. Thus, the program is both labor- and time-saving, considering that an entire day is needed for executing the manual microbeam-focusing process.

The MiFA program was immediately applied to the 4B beamline of Pohang Light Source-II. The program enhances convenience of beamline users and shortens experimental periods.

ACKNOWLEDGMENT

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