

# Automation of Microbeam Focusing for X-Ray Micro-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  $\mu\text{m}$  have been achieved, by manually adjusting the positions and pitch angles of the vertically and horizontally focusing mirrors, in a Kirkpatrick-Baez mirror system. In this research, we developed a program that automates the complex and cumbersome process of microbeam focusing. Some part of the control the hardware of the K-B mirror system was replaced by corresponding components. A control routine to control the picomotors by means of proportional closed-loop control was also configured. Based on the control routine as well as the output of an ionization chamber arranged at the rear of the K-B mirror system, the whole Microbeam Focusing Automation program was completed using LabVIEW. 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 microbeam focusing automation program and also examines the performance of the program.

## HARDWARE RECONFIGURATION

### $\mu$ -beam Focusing Instruments

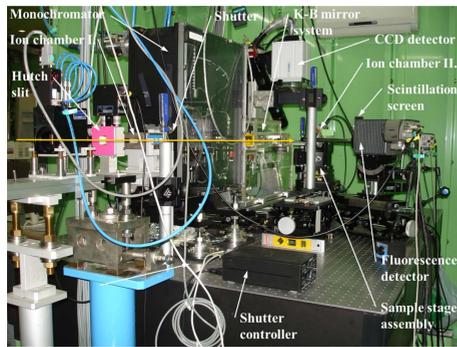


Fig. 1. Equipments for X-ray micro-experiments.

- The main equipments for the X-ray micro-experiments of the 4B beamline at the PLS-II consist of
  - two slits (optics and experiment slits), two ionization chambers (IC-I and IC-II), a shutter, a monochromator, a Kirkpatrick-Baez (K-B) mirror system, a sample stage, a charge-coupled device area detector, and a fluorescence detector.
  - K-B mirror system
    - The front vertically focusing mirror (VFM) and the 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.

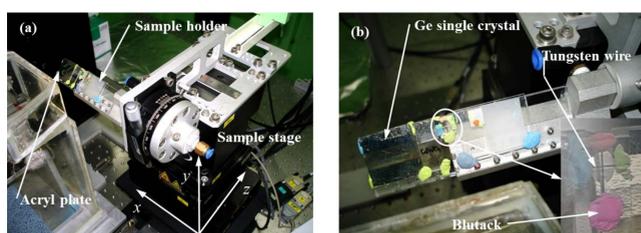


Fig. 3. The sample stage (a) and a close-up view of the sample holder (b). The close-up view in (b) shows the tungsten wires and the four-quadrant hole.

### Hardware Reconfiguration for $\mu$ -beam Focusing

- 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 as well as the existing linear variable differential transformer (LVDT) display of the K-B mirror system, have no communication function.  $\Rightarrow$  we replaced these components with a new picomotor controller and two new LVDT controllers with serial communication capability.

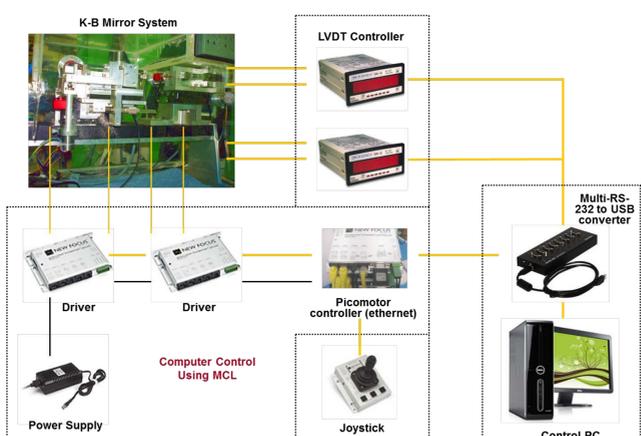


Fig. 4. Hardware configuration for the microbeam focusing automation system.

## MICROBEAM FOCUSING AUTOMATION PROGRAM

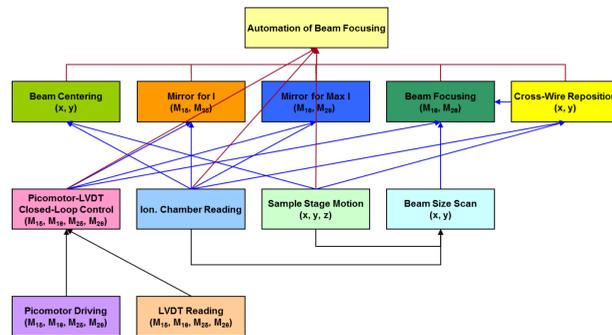


Fig. 5. Hierarchical structure of the Microbeam Focusing Automation program.

### Golden Section Search Algorithm [3]

- was used but modified for practical reason for 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.

### Subroutines

- Fundamental Subroutines
  - Ion Chamber Reading, Sample Stage Motion, Picomotor Driving, LVDT Reading, and Beam Size Scan routines
- Picomotor-LVDT Closed-Loop Control Routine
  - Picomotor: non-uniform displacement for applied fixed pulses [4]
  - LVDT output depends on the calibration of the LVDT.  $\Rightarrow$  a LabVIEW routine using proportional closed-loop control [2] to move a picomotor to a target LVDT position ( $K = 4000$  pulses/V).
- Beam Centering Routine
- Cross-Wire Reposition Routine

### Half-Cutting Algorithm

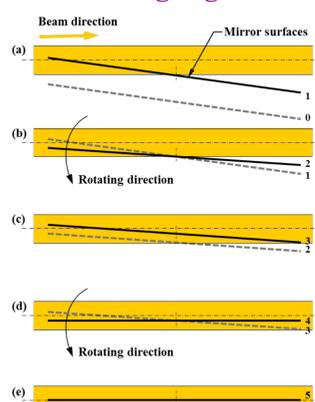


Fig. 7. Process of achieving the half-cut state of a mirror.

- 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 center line, in a state in which the front end is higher than the rear end [Refer to Fig. 7(a)].
- 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. 7(b) and 7(d)].

If the beam intensity is the maximum, we proceed to step 5); otherwise, we proceed to step 3).

- Whether or not further rotation causes the front end of the mirror to move out of the beam is checked [Refer to Fig. 7(b)]. If yes, we proceed to step 4); otherwise, we proceed to step 2).
- The mirror is again translated so that the front end of the mirror, which descended below the beam center line by the prior mirror rotations, breaks through the beam center line [Refer to Fig. 7(c)].
- The mirror is again translated so that a straight line connecting the front and rear ends of the mirror coincides with the beam center line [Refer to Fig. 7(e)].

Mirror for I routine: is used to translate the mirror for the ionization chamber output so as to reach or just exceed a set target value.

Mirror for Max I routine: is used to parallelize a mirror with respect to the beam.  $\Rightarrow$  configuring a while loop

### $\mu$ -beam Focusing Routine

- The Microbeam Focusing routine rotates a mirror to the pitch angle of the mirror that yields the minimum beam size.
- Bracketing the interval:  $\psi_u > \psi_m$
- Searching the minimum:
  - measures the beam size at each equally partitioned position after dividing the length of the interval by 10.
  - finds the final minimum beam size by fitting the 11 measured beam sizes to a 3<sup>rd</sup> order polynomial function.

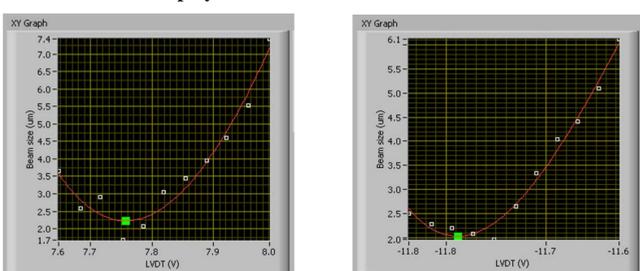


Fig. 9. Graph of the beam sizes measured at equally partitioned positions within the interval containing the pitch angle corresponding to the minimum beam size, captured by the Microbeam Focusing routine.

### $\mu$ -beam Focusing Automation Routine

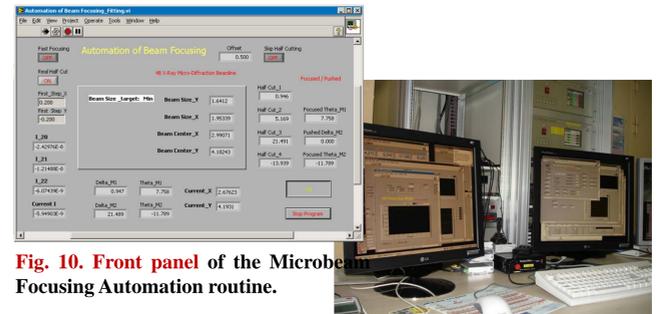


Fig. 10. Front panel of the Microbeam Focusing Automation routine.

Fig. 11. Image of the Microbeam Focusing Automation program being executed.

The Microbeam Focusing Automation routine (i.e., the main routine) fulfills the whole microbeam focusing process by achieving the half-cut states and performing the focusing phase of both the mirrors using the subroutines.

## EXECUTION RESULTS

### Beam Intensity w.r.t. the Pitch Angle

- Point A: the pitch angle of the half-cut state
- Point A ~ point B: The beam which starts to reflect cannot enter the IC because of the concave curvature of the mirror.
- Point C (2<sup>nd</sup> minimum value): can be deduced as the state in which the entire beam reflects on the mirror surface
- Point C ~: increasing reflection angle  $\Rightarrow$  decreasing beam intensity
- Conclusion: The conventional golden section search algorithm cannot be applied for finding point A, since the valley of the curve is too narrow.

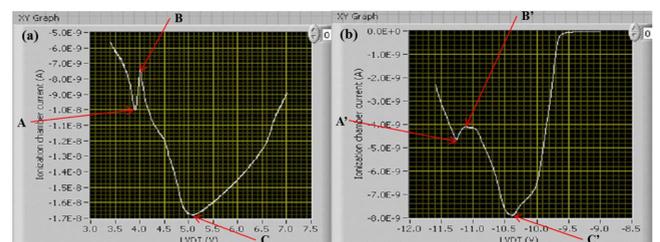


Fig. 12. Variations in the ionization chamber outputs with respect to the pitch angles of the VFM (a) and HFM (b).

### Examination of the Execution Results

- Raw beam size: 100  $\mu\text{m}$  (H)  $\times$  100  $\mu\text{m}$  (V) defined by the exp. slit
- 2 cycles of the half-cuttings of both the VFM and HFM
- 1 cycle of the half-cutting of the VFM
- 2 cycles of the half-cuttings of both the VFM and HFM
- Leftmost flat region of (a): a process where the VFM is advancing toward the beam

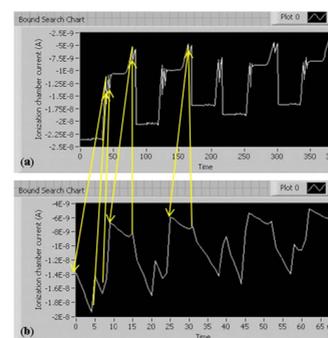


Fig. 13. Interval search charts of the Mirror for I (a) and Mirror for Max I (b) routines.

- Sawtooth waveforms of (a): The half-cutting of the VFM is being accomplished in tandem with the Mirror for Max I routine.
- Leftmost region of (b): is increasing beam intensity while lowering the front end of the VFM

## Conclusions

- In this research, in order to automate the focusing of X-ray microbeams, we
  - replaced some of the hardware of existing experimental equipments
  - developed Microbeam Focusing Automation program in LabVIEW
- Execution results
  - Vertical beam size: 2.2  $\mu\text{m}$
  - Horizontal beam size: 2.0  $\mu\text{m}$  < Manual beam sizes  $\Rightarrow$  adequate applicability
  - Total duration of microbeam focusing:  $\sim$  50 min
  - $\Rightarrow$  The developed program: both labor- and time-saving
  - $\Rightarrow$  The program enhances beamline users' convenience and shortens experiment periods.

## References

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