Design of a new soft X-ray double crystal monochromator beamline, BL-13

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Abstract

A new soft X-ray double crystal monochromator beamline is designed and will be constructed at BL-13. Special care is paid for the degree of parallelism of the beam and the beam size at the focal point. We propose to use two toroidal mirrors, one for producing a parallel beam and another for focusing the beam at the sample position. Although a toroidal mirror is not ideal to produce a parallel beam, the ray-tracing simulation clearly indicates that the quasi-parabolic mirror (1:∞ focusing) produces a nearly parallel beam comparable with a parabolic mirror. Another quasi-parabolic mirror (∞:1) focuses the beam at the sample position in a size of 1 mm^H x 1 mm^V. The designed beamline will be constructed by the end of 2013 and be open to users in the next fiscal year.

1. Introduction

In the SR center, the soft X-ray double crystal monochromator beamline, BL-10 is in full use especially for characterization of secondary batteries. To satisfy further demands of users for a beamline covering the energy range from 1,000 to 4,000 eV, another soft X-ray double crystal beamline should be constructed.

BL-13 used to be a LIGA beamline, but has not been actively used for several years. Since there are still two other LIGA beamlines, we decided to scrap the LIGA apparatus in BL-13 and build a new double crystal beamline in the soft X-ray region. Fortunately, we succeeded in getting the fund from the secondary battery project, "RISING" of NEDO.

2. Design concept

(1) BL-13 is located just in front of the main gate and the total available distance is limited to ~8 m from the source point. Thus, all of the beamline and XAFS instrument should be set between 2.2 m and 8 m from the source point.
(2) New beamline should have better performance than the similar beamline, BL-10.
(3) The monochromatized beam should be focused into a spot of 1 mm^H x 1 mm^V at the sample position.
(4) It should be possible to measure XAFS spectra of liquid samples.

3. Optics of the beamline

In most of soft X-ray double crystal beamlines, the SR beam is 1:1 focused by using a toroidal mirror at the sample position and a double crystal monochromator is located in-between the mirror and the sample chamber [1,2]. For the crystal diffraction, it is an ideal condition to use a parallel incident beam, since any converged and/or diverged beam causes a low energy resolution. If the beamline is sufficiently long, the converged/diverged beam can be regarded as a parallel beam to the crystal monochromator. However, if the beamline is short as in the present case and if we want to use a wide acceptance angle of the SR beam, the degree of convergence and/or divergence is not negligible. We would not obtain high resolution and high through-put with the 1:1 toroidal mirror focusing. One possible way to overcome this problem is to use two parabolic mirrors; one for producing a parallel beam and another for focusing the beam at the sample position [3]. This idea works well, but a parabolic mirror is two or three times as expensive as a toroidal mirror, and we have to purchase two mirrors instead of one. Thus, we have given up adopting this idea. However, there exists another idea to overcome this problem. It is to manufacture a toroidal mirror producing a quasi-parabolic beam. Here, instead of 1:1 focusing, 1:∞ focusing optics is adopted, although the focusing property is not ideal.

Figure 1 shows the phase space diagrams of three kinds of optics; parabolic mirror, 1:1 focusing toroidal mirror and 1:∞ quasi-parabolic toroidal mirror. In the phase space, x and x' denote position and dispersion in the horizontal direction, respectively, while z and z' denote them in the vertical direction. The degree of parallelism of the 1:∞ toroidal mirror is much more improved than the 1:1 toroidal one. It is rather surprising that the degree of parallelism is apparently even better than that of the parabolic mirror.

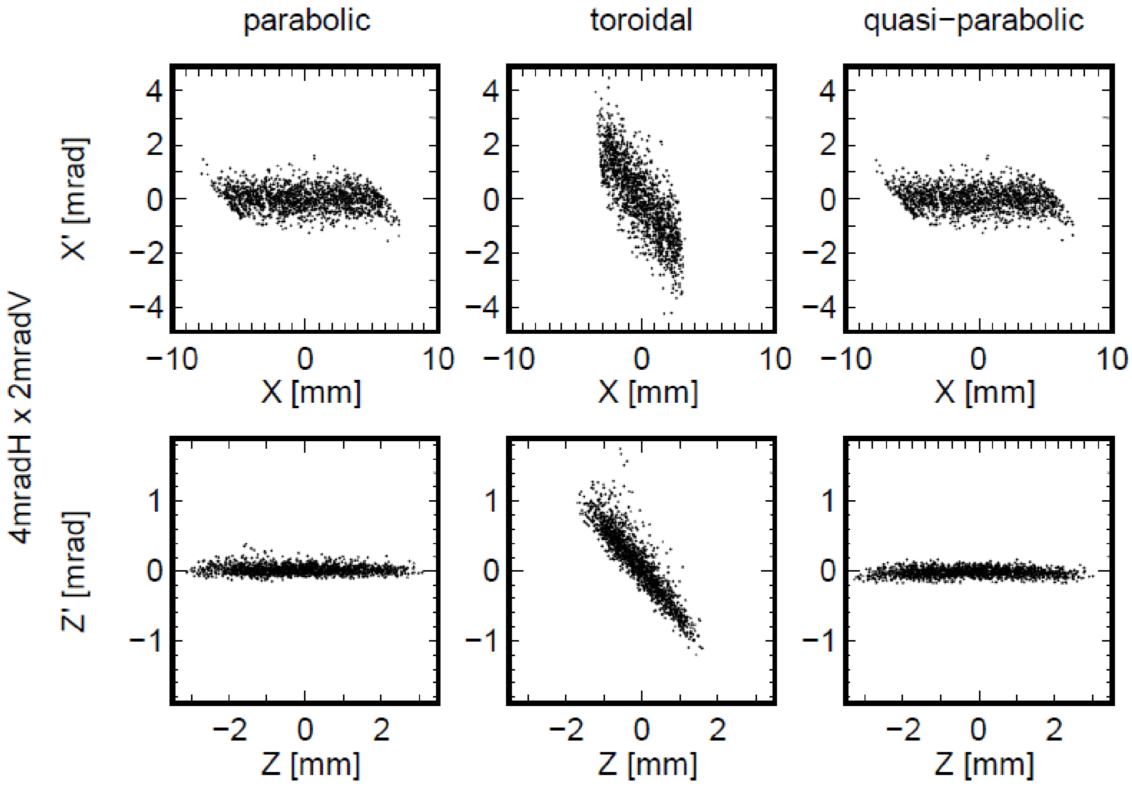

Fig. 1(a) Phase space diagrams of the SR beam at the monochromator position for parabolic mirror, 1:1 toroidal mirror and quasi-parabolic toroidal mirror from left to right. The SR beam divergence is 4 mrad^{H} x 2 mrad^{V}.

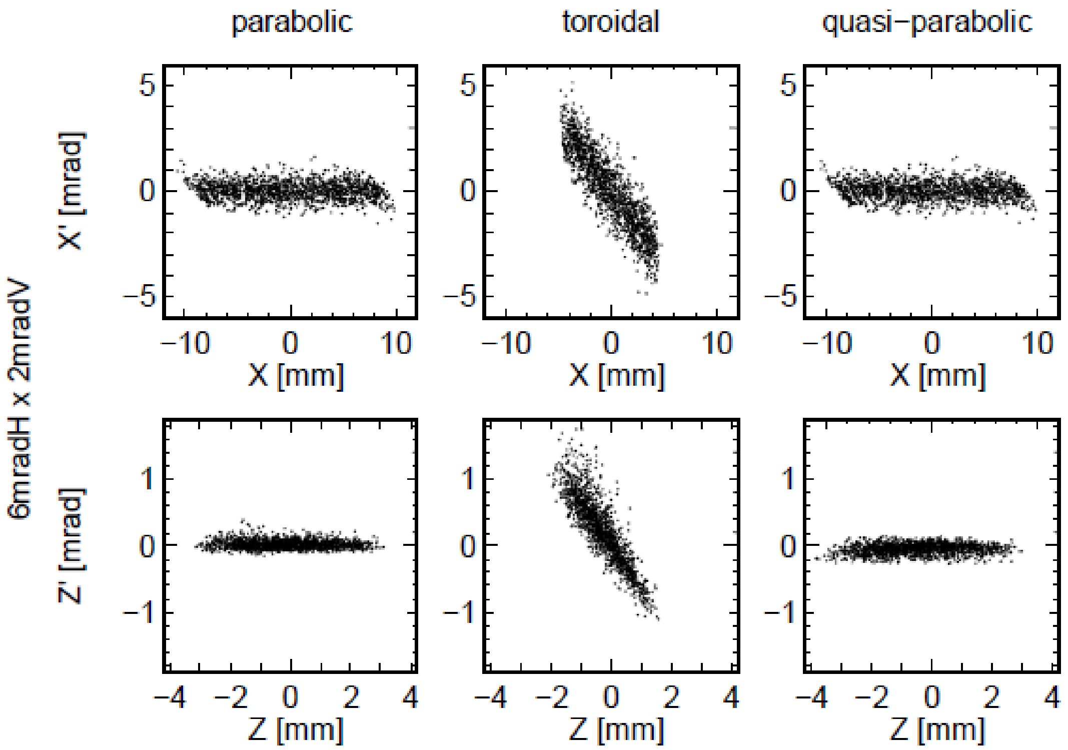

Fig.1 (b) Phase space diagrams of the SR beam at the monochromator position for parabolic mirror, 1:1 toroidal mirror and quasi-parabolic toroidal mirror from left to right. The SR beam divergence is 6 mrad^{H} x 2 mrad^{V}.

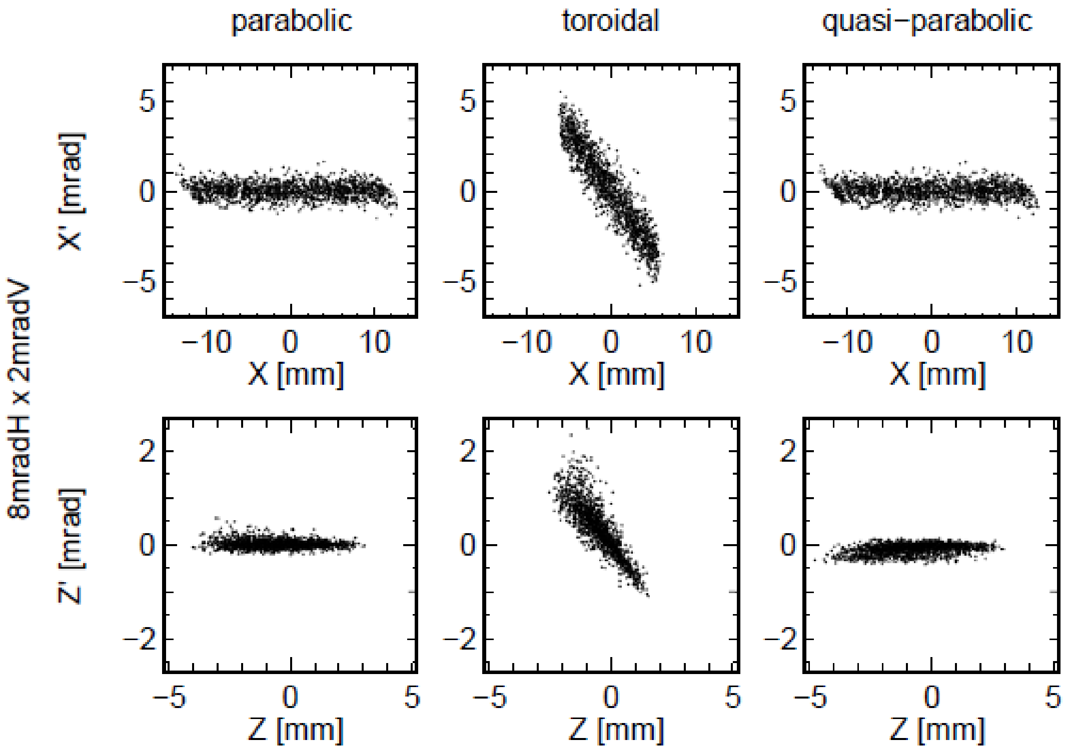

Fig.1 (c) Phase space diagrams of the SR beam at the monochromator position for parabolic mirror, 1:1 toroidal mirror and quasi-parabolic toroidal mirror from left to right. The SR beam divergence is 8 mrad^{H} x 2 mrad^{V}.

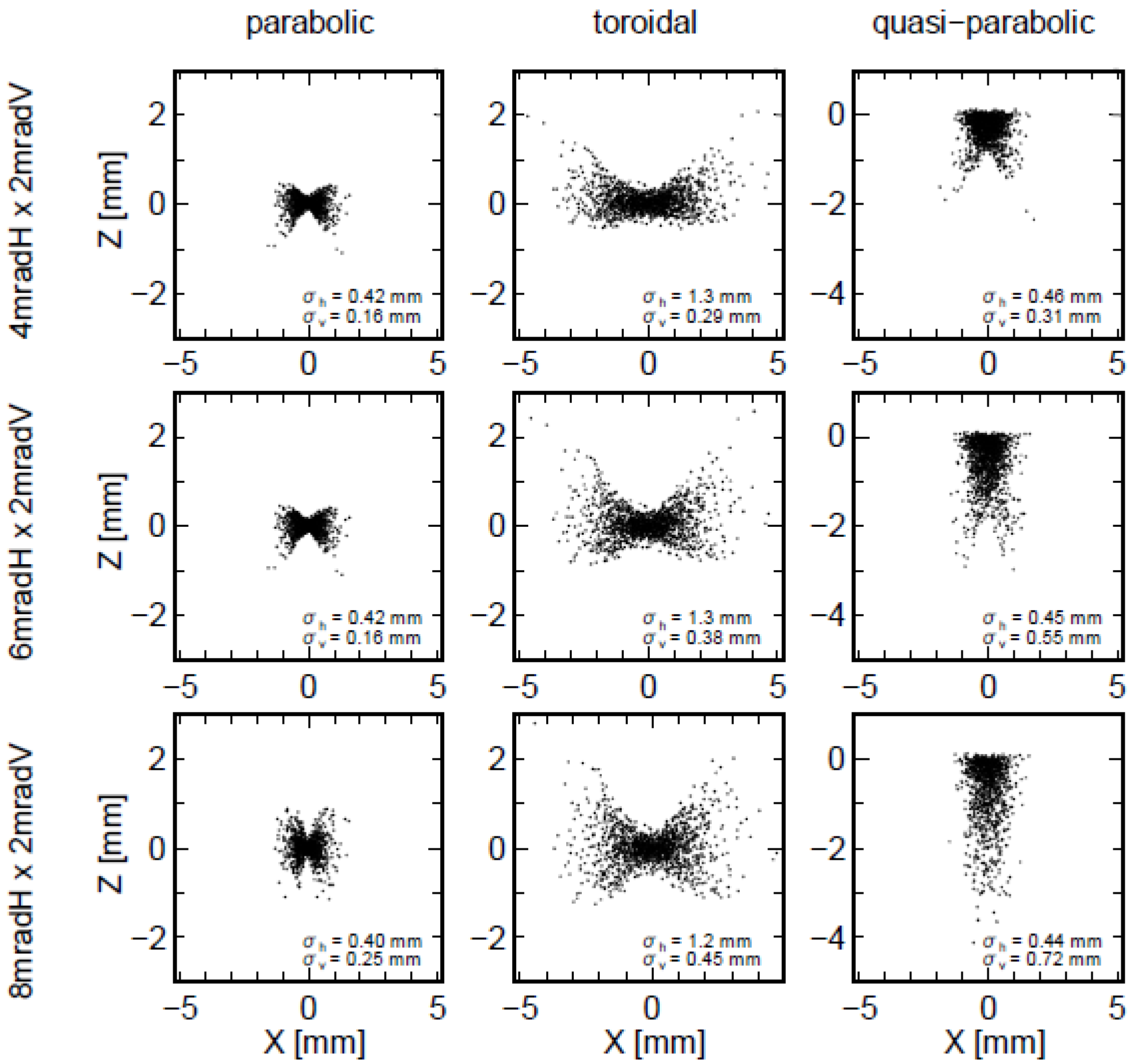

Fig. 2 The beam profiles at the focal point for different horizontal divergences.

Another important parameter is the beam size at the focal point. Figure 2 shows how the beam profile changes by increasing the horizontal divergence. As clearly seen, the set of parabolic mirrors gives the smallest beam spot almost indifferent of the beam divergence. 1:1 toroidal mirror also gives the largest beam profiles for three different divergences, while the set of the quasi-parabolic mirrors gives a comparable beam spot with that of parabolic mirrors, but its focusing condition gets worse drastically by increasing the horizontal divergence. This is because the quasi-parabolic mirror is best adjusted to the parabolic mirror at the zero horizontal divergence. However, the beam size at the focal point by using the 1:∞ toroidal mirror is smaller than that by using the 1:1 toroidal mirror at least till 8 mrad^{H}.

Above results encourage us to build a new high performance double crystal monochromator beamline.

4. Specification of the beamline

The layout of the beamline is shown in Fig. 3 and the specifications of the two toroidal mirrors are listed in Table 1. A water cooled 4 quadrant slits and Be filter is located at 2.4 m from the source point. Note that the main gate valve of the SR ring is located at 2 m from the source point. The first Ni coated Si toroidal mirror, whose effective size is 500 mm^{L} x 40 mm^{W}, is located at 3 m and deflects the SR beam downward by 1.5°. This mirror can accept an SR beam of as large as 10 mrad^{H} x 2.5 mrad^{V}. The deflected beam profile and intensity is monitored at 3.5 m. The parallel beam (σ_h=3.5mm, σ_v=1.3 mm) is introduced to the Golovchenko-type double crystal monochromator (made by TOYAMA Co. Ltd.).

As monochromatizing crystal pairs, we plan to prepare KTP (110), Beryl (10$\bar{1}$0), α-Quartz(10$\bar{1}$0), InSb(111), Si(111) and Ge(111). The monochromatized beam is deflected upwards by 1.5° and focused by the second Ni coated SiO$_2$ toroidal mirror, whose effective size is just same as the first one. The horizontally directed monochromatized beam is monitored at 5.8 m and focused at the sample position (6.5 m). When we use the horizontal divergence of 4 mrad, the beam spot size at the sample position, σ_h=0.46 mm, σ_v=0.33 mm is a little bit larger than that of the case of using the parabolic mirrors (σ_h=0.42 mm, σ_v =0.16 mm), but is sufficiently small.

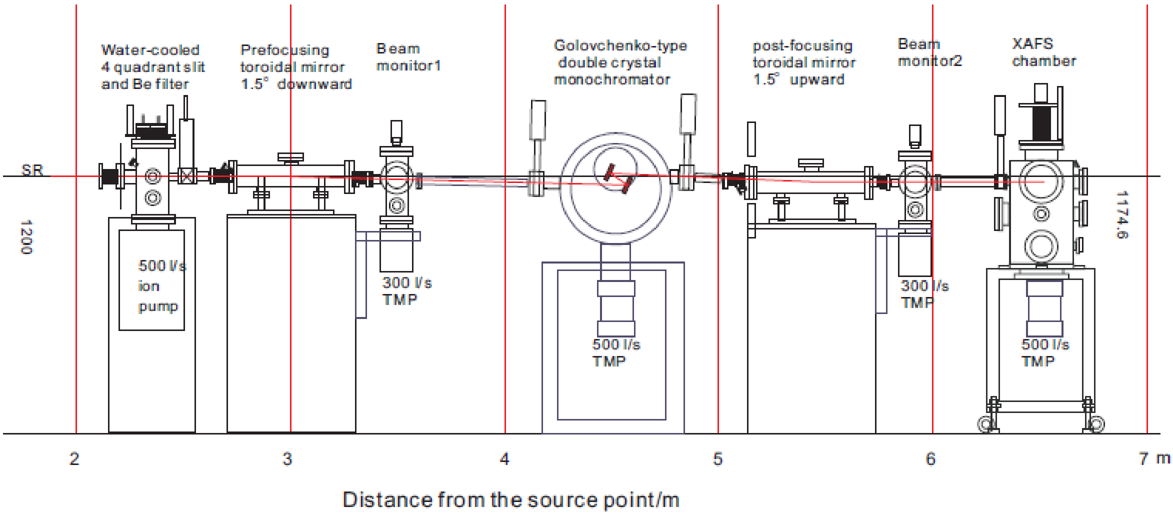

Fig. 3 The layout of the new soft X-ray double crystal beamline, BL-13

Table 1 Specifications of the two toroidal mirrors

	Pre-focusing mirror	Post-focusing mirror
Mirror size	500 mm^L x 50 mm^W x 30 mm^D	500 mm^L x 50 mm^W x 30 mm^D
Effective area	500 mm^L x 40 mm^W	500 mm^L x 40 mm^W
Tangential radius	458380 mm	152790 mm
Sagittal radius	78.538 mm	26.179 mm
Material	Si	SiO_2
Distance from the source point	3000 mm	5500 mm
Focal point	∞	6500 mm

5. **Features of the beamline**

The present design of the optics has several advantages.

(1) By using two 1:∞ toroidal mirrors, whose total cost is about 5 MY, we can produce a nearly parallel beam, allowing us to use perfect crystals, such as α-quartz and Si as the monochromatizing crystals. We can expect higher resolution by using such crystals.

(2) By setting the first mirror at 3m from the source point, we can make use of a wide acceptance angle by using relatively narrow mirrors. Furthermore, thanks to the parallel beam, we can make the whole beamline as short as 7 m.

(3) In the present layout, shown in Fig. 3, the second mirror is set to deflect upwards producing a horizontally directed monochromatic beam. However, the mirror chamber can be easily changed upside down and the second mirror deflects the beam downwards further by 3°, making possible to apply for XAFS measurement of liquid or fluid samples.

The whole beamline will be constructed by December, 2013 and will be open to users by the next fiscal year. The financial support by NEDO is highly appreciated.

References

[1] J.A.Howell and P.Holowitz, *Nucl. Instrum. and Methods* **125** (1975) 225

[2] T.Ohta, P.M.Stefan, M.Nomura, H.Sekiyama, *Nucl. Instrum. and Methods* **A246** (1986) 373

[3] M.Nomura and A.Koyama, *Nucl. Instr. and Methods* **A467-468** (2001) 733