J. Synchrotron Rad. (1999). **6**, 176–178

Performance of the ESRF ID26 beamline reflective optics

Riccardo Signorato*, V. Armando Solé, Christophe Gauthier

European Synchrotron Radiation Facility (ESRF), B.P. 220, F-38043 GRENOBLE Cedex, FRANCE
Email: signorato@esrf.fr

This paper presents the experimental results obtained during the commissioning of the X-ray mirrors installed on the ESRF beamline ID26. The ID26 spectrometer is dedicated to XAFS studies on ultra-diluted samples in the energy range 2.3 - 25 KeV using the excitation of X-ray fluorescence. The beamline has been open to external users since January 1998 and all the main optical elements are fully commissioned. The reflective optics layout consists of three devices: a high heat load deflecting mirror installed in the white beam section and a classical Kirkpatrick-Baez couple installed downstream the monochromator. The focusing mirrors are based on the multi-segmented piezoelectric mirror technology and allow for a continuos and very precise adjustment of the curvature. Spot sizes as small as 170 x 7 (hor. x vert) μm^2 FWHM can be easily achieved, with a total flux well in excess of 10^{13} photons s^{-1} when using Si 220 monochromator crystals.

Keywords: X-ray, beamline, mirror, focusing, bimorph, EXAFS

1. Introduction

The ESRF beamline ID26 is dedicated to XAFS studies on ultra-diluted samples. Typically, the concentration of the absorbing element varies from a few ppm up to 10000 ppm. Its operational energy range was defined to span from 2.3 up to 25 KeV and it is accessible to the ESRF users community since January 1998. The main figures of merit for the reflective optics design were set as:

(i) highest possible flux at the sample
(ii) spectral purity of the excitation beam
(iii) minimisation of background, scattered, radiation
(iv) possibility to focus the beam in both planes for mapping, μ-XANES experiments, use of a high resolution fluorescence analyser or high pressure cells
(v) maximisation of the polarisation transfer function of each individual optical component
(vi) stability during energy scans
(vii) easy alignment and operation.

These requirements led to a design (Signorato & *al.*, 1997) that makes use of total reflection mirrors for beam deflection, focusing and high energy photons cut-off.
The beamline consists of two lead hutches (optics and experimental hutch) followed by two unshielded control cabins. This article will focus on the source characteristics and on the first (optics) lead hutch, describing mainly the reflective optics scheme which was adopted to preserve as much as possible the source brilliance down to the sample location.

2. Source Characteristics

As one of the main figure of merit is the photon flux at the sample, the source is a powerful multisegment undulator inserted in an high β (β_{hor} = 35.6 m rad^{-1}, β_{vert} = 2.5 m rad^{-1}) section of the storage ring. The insertion device (ID) consists of three 1.6 m long independent, phasable, segments (U42d, U42m & U42u) whose magnetic period is 42 mm (38 periods per segment). Fig. 1 shows the measured monochromatic photon flux increase obtained by phasing two undulator segments.
Nowadays, the minimum authorised ID gap (for a maximum of 2 segments) is 16 mm, but lower values are foreseen. At minimum gap the first harmonic peak is at *ca.* 2.3 KeV. The measured B_0 values vs. gap opening are reported in Table 1, together with the corresponding deflection parameter (k) values.

Table 1

Undulator gap (mm)	B_0 (T)	k
14	0.64	2.51
16	0.55	2.16
18	0.48	1.88
20	0.41	1.61
25	0.28	1.10
30	0.19	0.745

The theoretical source size for a magnetic lattice horizontal emittance of 4 nm rad and 1% coupling is ca. 875 x 23 (hor x vert) μm^2 FWHM and its divergence 26 x 16 (hor x vert) μrad^2 FWHM. Assuming 3 ideally phased segments and 200 mA stored current, the total emitted power could be as high as 6.5 kWatt, but on the central cone one is left with ca. 250 W/mm^2 impinging onto the first optical element (OE).

3. First mirror: HDM1

The first upstream component installed in the ID26 optics hutch (whose layout is shown in Fig. 2) is a set of standard ESRF vertical & horizontal primary slits. They are used to define the undulator emission axis and to tailor the heat load on the following OE's.
The first OE is a Horizontally Deflecting Mirror (HDM1). It withstands the direct white beam from the ID and accomplishes two main functions:

- heat Sink - to reduce heat load on the following OE's
- beam horizontal deflection - to steer the beam out of the storage ring Bremsstrahlung emission cone.

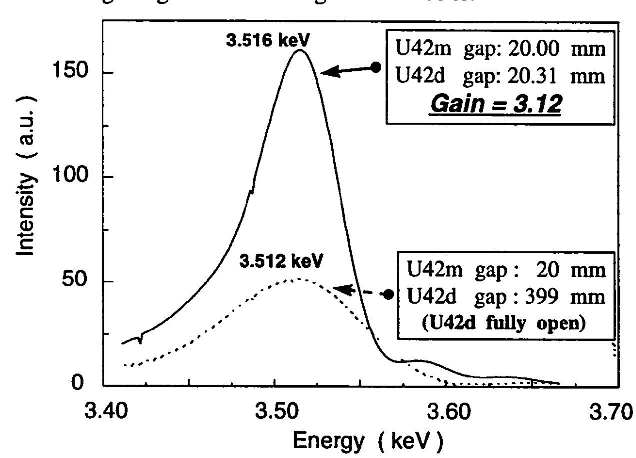


Figure 1
Measured monochromatic flux gain on the first harmonic obtained by phasing two 1.6 m long undulator segments at ID26

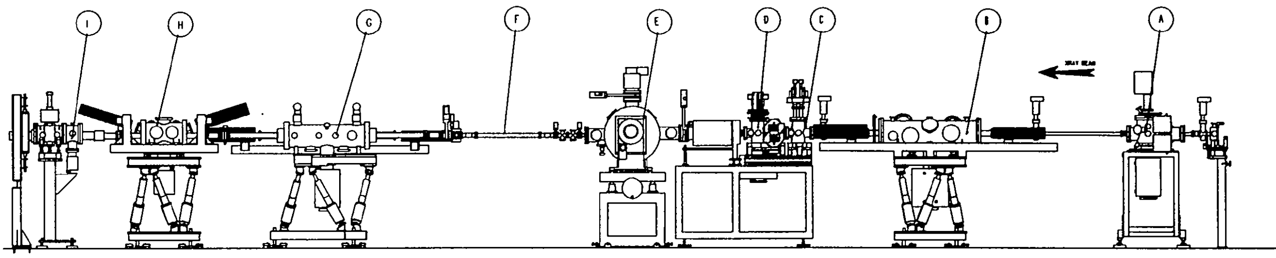


Figure 2
Layout of the ESRF beamline ID26 optics hutch. Side view. A) Horizontal and vertical primary slits B) HDM1 C) Attenuators chamber D) Horizontal and vertical secondary slits E) KoHzu double crystal monochromator F) Beam chopper (not represented) G) HFM2 H) VFM3 I) Safety photon shutter.

As it is not possible to act on its surface shape when exposed to the white beam, it has been designed to be the less critical OE of the beamline. It was preferred to split between different mirrors focusing and heat dumping functions, associating the latter to an horizontal deflection which does not affect the monochromator energy resolution.
HDM1 was cut from a monolithic Si ingot and polished to a flat surface by SESO Ltd (France). Its geometrical dimensions are: L= 520 mm, W= 60 mm, T= 130 mm. The white beam grazing angle can vary from 1.5 to 5 mrad. In order to enhance the energy cut-off range, two metallic strips (each 20 mm wide) were deposited on each side of the central 20 mm section, which was left with bare Si. The metallic coatings chosen were Cr and Pt; their thickness is *ca.* 500 Å. After manufacturer's delivery, the technical acceptance tests were carried out in the ESRF metrology laboratory (Hignette & Rommeveaux, 1996) by means of a Long Trace Profiler (LTP). Results are reported in Table 2.

Table 2
HDM1 characteristics

STRIP	Bending radius (Km)	Slope error (μrad rms)	Roughness (Å rms)
Pt	> 70	4.6	4.8
Bare Si	> 70	5.3	7.5
Cr	> 70	2.6	6.8

Water cooled tungsten Bremsstrahlung stoppers were integrated on the downstream and upstream side of the mirror. The upstream one is designed to protect the mirror edge from accidental, almost normal incidence hits with the white beam during beamline alignment. Positioning of the mirror is achieved by means of a six-legs manipulator robot (hexapod) which translates/rotates the whole vacuum chamber.
The estimated heat load impinging on HDM1 is *ca.* 800 W at minimum ID gap (16 mm) and 200 mA stored current. Therefore the mirror is side water-cooled by means of two copper radiators. The thermal contact between copper and silicon has been enhanced by inserting a thin Indium film and the radiators are clamped on each side very close to the reflecting surface. Their width is limited to 20 out of the total 130 mm thickness. This cooling geometry achieves maximum performances in reducing heat load induced deformations when the mirror is systematically overfilled with the white beam. No drifts associated with heat load induced thermal bumps were ever detected during routine beamline operation.
ID26 is a windowless beamline, directly connected to the storage ring vacuum, so extreme care was taken during HDM1 installation not to contaminate the mirror or the mechanics. After bake-out, pressure in the 1~3 10^{-9} mbar range is routinely achieved. No outgassing from the mirror is detected under white beam exposure.

4. Focusing optics section

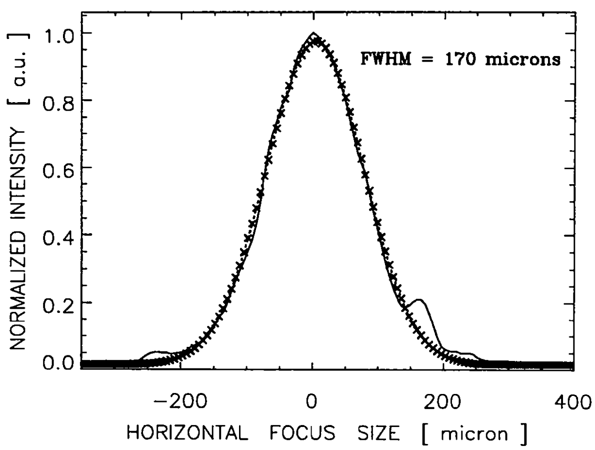
An absorbers chamber is installed immediately downstream HDM1. Thin Cu, Al or graphite foils can be inserted in the photon beam to modulate its intensity and/or to dump the low energy photons. Then, a set of horizontal and vertical standard ESRF secondary slits cleans up the beam from the scattered photons coming from HDM1 and defines the angular acceptance for the following OE: a fixed exit double crystal monochromator (manufactured by KoHzu Seiki Co. - Japan). The direction of the exit beam is kept unchanged during energy scans and a fixed downward offset of 25 mm is achieved after the double Bragg reflection. Two sets of crystals can be simultaneously installed: we opted for Si 111 and Si 220. The monochromatized beam is then temporally modulated (typically at 67 Hz) by a chopper before impinging on the focusing optics.
Beam focusing is achieved by means of a couple of mirrors set in the classical Kirkpatrick-Baez (K-B) configuration. This setup is extremely flexible, as it allows to independently vary the horizontal or vertical beam width at the sample. The first OE in the K-B setup is an Horizontally Focusing Mirror (HFM2; L= 750 mm, W= 45 mm, T= 30 mm), followed by a Vertically Focusing Mirror (VFM3; L= 450 mm, W= 45 mm, T= 28 mm). Both of them are active, bendable devices, and they can be shaped to either spherical or aspherical shapes. They are based on the multi-segmented piezoelectric bimorph mirror technology recently developed at the ESRF (Susini & *al.*, 1995; Signorato & *al.*, 1998*a*; Signorato, 1998*b*). They both have a fused silica reflecting surface, with two metallic strips (Cr and Pt) to enhance reflectivity at medium/high energy, respectively.

4.1 Horizontally focusing mirror.

The reflecting surface of HFM2 lies in the vertical plane and the beam deflection (in the horizontal plane) is towards the storage ring. Typical grazing angles vary from 2 to 10 mrad, p (source-to-mirror distance) is 37 m and q (mirror-to-focus distance) can vary from *ca.* 4.5 to 8 m. If HDM1 and HFM2 are set at the same grazing angle, the beam direction after the second mirror will be strictly parallel to the undulator emission axis. However, by adjusting the angle on HFM2, it is possible to sweep the monochromatic beam in the horizontal plane at the sample position, or to independently change the energy cut-off with respect to HDM1. Also HFM2 is positioned by an hexapod robot that translates/rotates the whole vacuum vessel assembly.

4.2 Vertically focusing mirror.

VFM3 lies in the horizontal plane and deflects the beam upwards. It is designed to operate in the 2 to 10 mrad grazing angle range, p is set to 39 m and q can vary between *ca.* 2.5 and 6 m.



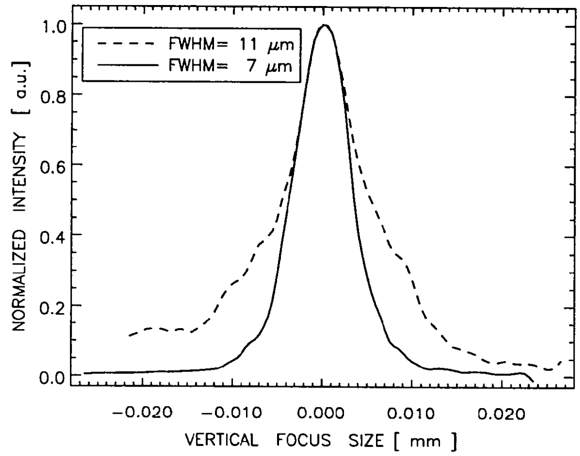


Figure 3

Measured focused beam profiles. *Left*: Horizontal plane focusing (solid line) with superimposed gaussian fit; HFM2 set at θ= 2.5 mrad, p= 37 m and q= 5.2 m. *Right*: Vertical plane focusing; VFM3 set at p= 39 m, q= 2.8 m and θ=2.3 mrad (dashed) or 6.5 mrad (solid)

Optically, it is the most critical mirror of the beamline and its surface finish quality must be *state-of-the-art* in order to reach vertical focus sizes as small as ~10 μm FWHM several meters away. It was assembled (by CILAS Ltd -France), polished (by SESO Ltd -France) and finally delivered at the ESRF by end 1997 and was installed and commissioned at ID26 during the first half of 1998. The results of its LTP characterisation in the ESRF metrology lab are reported in table 3. Its supporting mechanics are identical to the HDM1 one (hexapod).

Table 3

VFM3 characteristics

LTP Scan length	Bending radius (m)	Slope error (μrad rms)	Roughness (Å rms)
whole mirror (420/450 mm)	1135	1.9	1.1
central portion (130/450 mm)	1077	0.69	1.0

5. Beamline results

The first focusing mirror commissioned was HFM2. All the measurements were carried out at the third harmonic of the undulator emission spectrum and the gap was set to fix the peak energy at 8 KeV. The focus size was measured by horizontally scanning a 20 μm wide slit 5.2 m downstream the OE. The tests were carried out at a grazing angle θ of 2.5 mrad and an horizontal acceptance of 2.1 mm, as this setup gives a beam footprint of about the same length of the mirror itself (overfilling). The optimized focal spot is shown in Fig. 3: its FWHM is 170 μm and the shape is gaussian. No effect due to the segmentation of the mirror can be seen. θ was then increased and different [θ, spherical radius (R)] couples were checked. The shape of the focused beam profile did not change, thus demonstrating that varying R does not spoil the HFM2 performances.

The VFM3 commissioning was carried out at a fixed energy of 6 KeV on the first harmonic of the undulator emission spectrum. The vertical beam size at the focus was determined by derivation of a knife edge scan obtained by translating a thick Al mask situated 2.8 m downstream the mirror by steps of 0.5 μm. The mirror vertical acceptance was fixed by a set of slits to 0.9 mm. Several configurations [θ, R] were tested and two of the measured focused beam profiles are reported in Fig. 3. The first (dashed line) was taken at θ= 2.3 mrad (beam footprint *ca.* 390 mm); the second profile (solid line) was measured at θ= 6.5 mrad (beam footprint *ca.* 140 mm). At 2.5 mrad the beam profile shows a relatively small asymmetric tail on the left side due to spherical aberrations that totally disappears at 6.5 mrad. Again, no effect due to the segmentation of the mirror can be detected.

The performances reported in Fig. 3 are remarkable, due to the quality of the ESRF source (extremely small source size and divergence) and the rather long optical lever arm q that amplifies the figure errors of the mirrors. Moreover, even at the small θ value of ~2.5 mrad the mirrors acceptance allows focusing of the whole undulator central cone, thus ensuring the maximization of the flux at the sample. This last parameter has been characterized, and it is well over 10^{13} photons s^{-1} for a single undulator segment when Si 220 crystals are in use and the ESRF storage ring is run at 200 mA.

6. Conclusion

An optical scheme relying on a water-cooled Si deflecting mirror + a K-B dynamically focusing couple (based on the multi-segmented piezoelectric bimorph mirror technology) has been experimentally tested at the ESRF ID26 beamline. This setup routinely delivers a very high flux at the sample (> 10^{13} ph s^{-1}) on a rather small, stable spot size (170 x 7 μm^2 FWHM) with a very efficient harmonic rejection (more than 4 orders of magnitude) in the range 2.3-25 KeV. It has also been shown to withstand the heat load associated with the 5 m long undulator.

References

Hignette, O. & Rommeveaux, A. (1996). Proceedings SPIE **2856,** 314-322.

Signorato, R., Susini, J., Goulon, J., Gauthier, C. & Marion, P. (1997). J. Phys IV France **7**, C2 / 331-332.

Signorato, R., Hignette, O. and Goulon, J. (1998*a*). Journal of Synchrotron Radiation **5**, 797 - 800.

Signorato, R. (1998*b*). Proceedings SPIE **3447,** in the press.

Susini, J., Labergerie, D., Zhang, L. (1995). Rev. Sci. Instrum. **66** (2), 2229-2231.

(*Received 10 August 1998; accepted 26 October 1998*)