Transport Channel and Optics

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1. Introduction

Sudden increase in budget in May 1995 forced the optics group to reschedule everything. The number of public beamlines to be contracted in '95 fiscal year was raised from initial four to eleven which is the full number of the 1st phase scheduled beamlines. In addition, several contract beamlines are being planned to be in operation at the initial stage, so that more than quarter of total 61 available beamlines should be ready from the beginning. To our knowledge, no other SR facilities have experienced such a huge number of simultaneous beamline construction.

For managing the above situation, we analyzed the beamline structures which individual users groups had proposed, and found most x-ray transport channels and optics would be designed on the basis of two standard structures which correspond to undulator and bending magnet light sources. Exceptions are the wiggler and two soft-x-ray beamlines, for which detailed designs were made individually both for transport channels and optics [1,2]. During the design process of the standard beamlines, we extracted commonly used components, and then finalized their specifications. In addition, we compiled them in a "Beamline Component Catalog" which will be published in a near future.

Design of the standard monochromator mechanism was finalized in the previous year. The first two sets, one for undulator and the other for bending magnet will be delivered soon. Eight more monochromators were ordered under the same specification, which will be delivered early in 1997. Design of the standard mirror supports/benders was finalized this year and the orders of total 13 sets of various beamlines were placed.

2. Standard Transport Channel Structure

2.1 General Design Principle

Design study of each transport channel was commenced by locating optical components such as mirror support and monochromator at an appropriate position. Since we have not yet found the way to manage high heat-load on the total reflection mirrors in an undulator beamline, we adopted the crystal monochromator as the first optics of the undulator beamline. The front-end slit is placed fairly close to the monochromator, so that no slits are placed between the front-end Be window and the monochromator. Heat-load problem in bending magnet beamline is not so serious that we can make the total reflection mirror as the first optics. We placed a gamma-ray stopper just downstream of the monochromator tank to remove the gas-brems gamma-rays. A downstream shutter for the monochromatized x-rays was placed after the gamma-ray stopper followed by a 4-jaw slit. At the end of each x-ray beamline, we placed a beryllium window coupled with a helium substitution chamber when necessary. As a vacuum system, each transport channel is divided into 3 to 6 sections by gate valves, each of which have one exhaustion and one monitoring gauge unit. We adopted turbo-molecular pumps with backside oil-free scroll pumps to keep the oil-free environment both inside and outside of the beam duct.

2.2 Standard Component Kit

Standard component kits have been so designed that those having the same purpose should have the similar structure in spite of the differences in the light sources. The following items have been designed according to this principle:

(a) Downstream Shutters
(b) 4-jaw Slits for Monochromatic X-Rays
(c) 4-jaw Slits for White X-Rays
(d) Fixed Masks
(e) View Ports
(f) Bellows
(g) Beryllium Windows
(h) Gamma-Ray Stoppers
(i) Helium Chambers
(j) End Stoppers
(k) Exhaustion Units
(l) Vacuum Gauge Units

Most of the items have ICF70 (for undulator beamlines), ICF114 and ICF152 (for bending magnet beamlines) versions.

2.3 Standard X-Ray Undulator Beamline

Figure 1 shows the layouts of the first four public beamlines for x-ray undulators. These are practically identical up to the first slit after the standard fixed-exit monochromator where the diffraction occur in the rotated-inclined geometry. Only the mirror layout is different.

In BL41XU for protein crystallography, two bent mirrors are placed in Kirkpatric-Baez geometry to get a point focus. The use of supermirrors enables two-dimensional focusing at 40 keV.

BL09XU for nuclear resonant scattering involves one bent mirror which deflect the beam horizontally. Since the mirror is removable and the glancing angle is variable, the components after the mirror are set on a rotation stage to align the beam axis. The same layout is employed for BL39XU which is used for physicochemical analysis.

BL10XU for diffraction under high pressure has a set of parallel double-mirrors to reduce the throughput of higher harmonics. This is because the beamline will be shared with XAFS experiments.

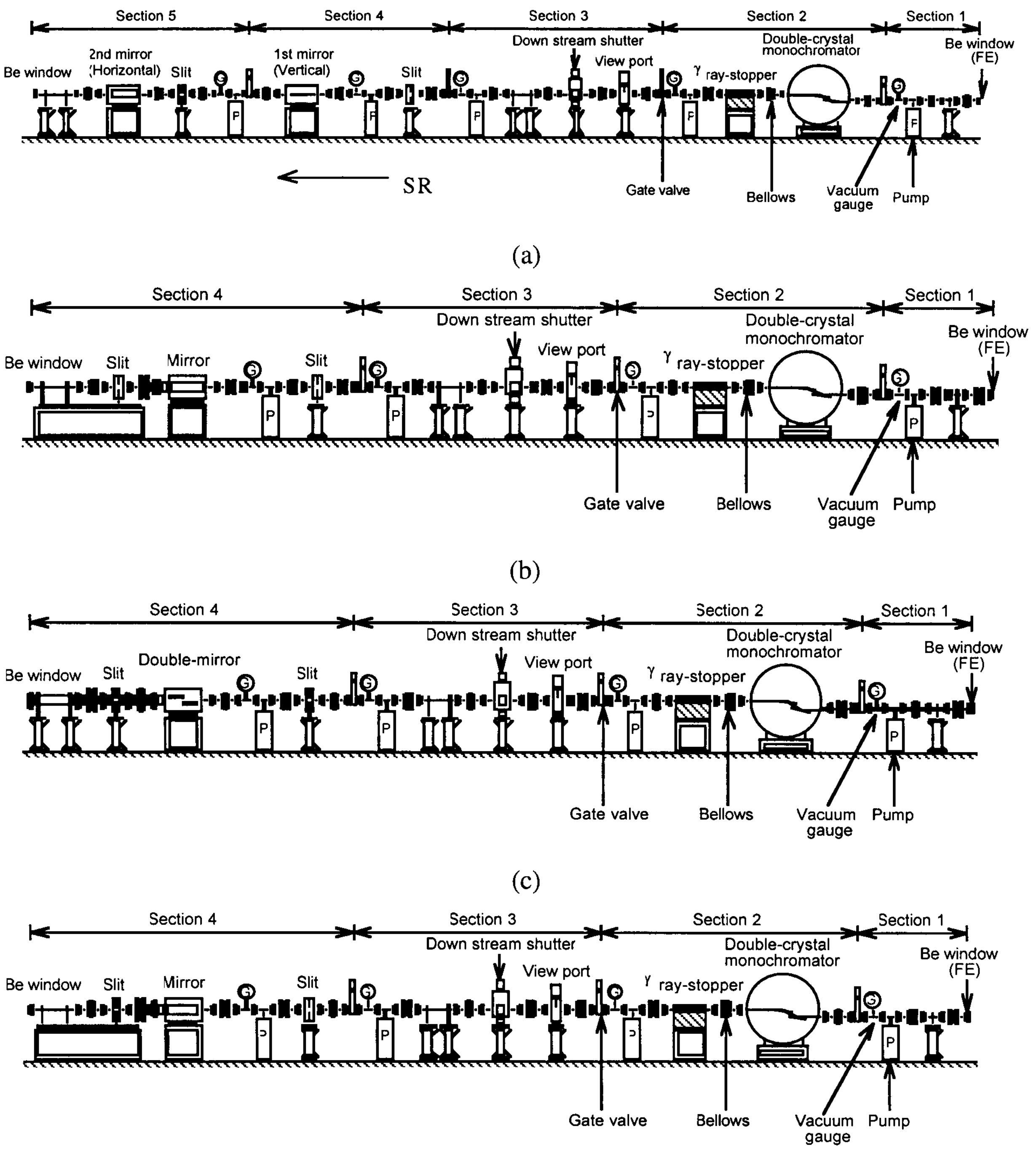

Fig. 1. Structures of x-ray undulator beamlines: (a) 41XU, (b) 09XU, (c) 39XU and (d) 10XU

2.4 Standard X-Ray Bending Magnet Beamline

There are two practically identical monochromatic x-ray beamlines for bending magnet sources(BL02B1 for crystal structure analysis and BL01B1 for XAFS) as shown in Fig. 2. The first optical element for these beamlines is water-cooled collimating mirror which reduces the vertical angular divergence of the beam. The deflected beam is introduced into the standard monochromator which is capable of sagittal focusing. Monochromatized beam is reflected by the second mirror which vertically converges the beam onto the sample position. Beamline components after the first mirror and before the second mirror are mounted on a common inclination stage which accords the axis of the components to the deflected beam. Those after the second mirror are mounted on an elevation stage.

BL04B1 is the only one public beamline that delivers white x-ray to the experimental station (Fig. 3). This beamline will be used for various energy-dispersive diffraction studies.

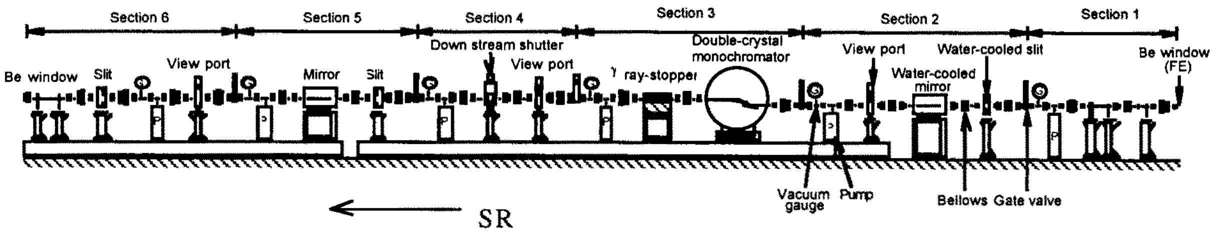

Fig. 2. Structure of standard bending magnet beamlines (01B1, 02B1)

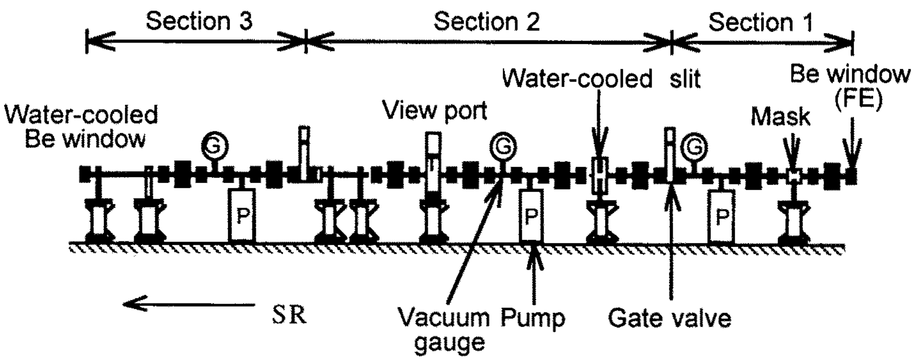

Fig.3 Structure of white bending magnet beamlines (04B1)

3. Optical Components

3.1 Standard X-Ray Monochromators

The design of standard x-ray monochromator for the SPring-8 is based on the so-called "modular concept", that is, to use common driving mechanism to both those for undulator and for bending magnet beamlines[3]. Two types would be replaced each other by only changing the crystal mounts and vacuum chambers.

Design target has been a fixed-exit monochromator with smallest possible numbers of axis for energy tuning, compatible with rotated-inclined double crystal geometry of silicon for undulator beamlines, as well as adjustable-inclined geometry of silicon for bending magnet beamlines. Compatibility is kept also for the diamond double crystal geometry.

The monochromator can cover the Bragg angle range from 3 to 25 degree by a rotation along only one axis, with one translation to change the first crystal position. Bragg angle resolution is designed to be 0.1 arcsec. The offset of the beam height will be kept at 30 mm by translating the first crystal normal to its diffraction vector using a mechanical-cam on the translation stage. The second crystal is fixed to the rotation axis so as to be used as an energy reference. A rotary encoder is directly attached to the rotation axis.

3.2 Standard Mirror Supports/Benders

Standard mirror supports consist of (a) alignment mechanisms and (b) vacuum chambers with optional (c) cooling systems and (d) benders. There exist several different types of mirror supports according to the mirror size, shape, materials, and beam deflection. However, all types were designed under the unified principle.

The alignment mechanism has four degrees of freedom of motion which are horizontal and vertical translations as well as rotations in horizontal and vertical plane. Stroke of two translations exceeds 20 mm with the positioning reproducibility of less than 5 µm. Range of two rotations exceeds 2.4 degree with the positioning accuracy less than 0.01 degree. All motions are driven by stepping motors outside of the vacuum chamber to keep the oil-free environment of the mirrors.

Cylindrical bend of the mirror is made only one translation using a sine-bar mechanism combined with a elastic torsion bar. Indirect water cooling is employed for those mirror which accept white beam from the bending magnet.

Details of the standard mirror supports will be reported elsewhere [4].

3.3 Other Monochromators

Besides the standard x-ray monochromators, three special purpose ones have been designed. Two of them are for high energy x-rays to be used for "high-energy x-ray inelastic scattering" experiments [1]. The remaining one is a grating monochromator to be used in a soft x-ray beamline [2].

4. Optical Elements

4.1 Pin-Post Water Cooling of Si

Thermal analysis for silicon crystals with the pin-post structure revealed that they work as an effective monochromator when the power density on the crystal surface is less than $5W/mm^2$ [5]. One realistic way to manufacture pin-post crystal is to fabricate the pin-post pattern by sand-blasting technique and to stick it to a flat crystal with water inlet and outlet. For sticking process, we have tested Au-diffusive bonding. We have not yet found out the appropriate condition for this process. Up to now, the best stuck crystals have 1.3 times wider rocking curve width than that of the perfect crystal, although the topographs of these crystals show the slightly strained pattern according to the bonding [6]. Some other techniques for crystal bonding are now being tested, including electro-static bonding, direct bonding, and glue bonding.

A computer code for evaluating the diffraction properties of the pin-post crystals has been developed by incorporating the strain field estimated from ANSYS into the Takagi-Taupin equation [7]. Evaluation of the rocking curve profiles of the pin-post crystal in the rotated-inclined geometry was made by using this code for the standard x-ray undulator beamline [8]. The result is promising that the total throughput decreases only slightly even if we use water as a coolant.

4.2 Rotated-Inclined Geometry

Diffraction properties of rotated-inclined geometry were studied both theoretically and experimentally. Ray-tracing calculation involving dynamical diffraction effect shows that the diffracted wavevector does not lie on the plane defined by the incident wavevector and reciprocal lattice vector concerning to the diffraction [9]. Accordingly, we can not realize fixed-exit monochromator in a strict sense by using a simple rotated-inclined double crystal geometry. However, positional deviation is very small for a relatively narrow range of energy, say a few keV for Si 111, so that this will hardly cause serious problems.

Rocking curve measurements for the rotated- inclined geometry were performed at the Photon Factory at various x-ray energy [6]. The analysis of the observed curves under the various condition was quite useful to establish the alignment strategy for the standard monochromator for x-ray undulator beamline.

4.3 Diamond Crystal

Diamond crystal has high thermal conductivity as well as small thermal expansion coefficient so that it is considered as one of the best available candidates for the monochromator of high heat-load beamlines. However, the perfection of the natural diamond crystals fluctuates enormously and it is hopeless to get sufficient number of good natural crystals having x-ray monochromator quality. On the other hand, at the beginning of 1994, some synthetic (001) diamond plate from Sumitomo Electric Industries (SEI) showed high perfection, but the crystal size was small ($5{\times}5mm^2$).

SEI and the SPring-8 started a joint R&D program aiming to synthesize big and highly perfect crystals from 1994 fiscal year. Our tentative target was to get highly-perfect crystals with less than 1 arcsec diffraction broadening caused by imperfections, more than 10×10 mm^2 in size and, if possible, (111) orientation.

In the first one and half years, we concentrated on the improvement of the crystal quality. Most of the diffraction broadening was found to be originated from the bulk defects, which were suppressed by selecting an appropriate growth condition. Now we can get good crystal with less than 1 arcsec broadening at a high rate. Some improvements for growth process were also made to suppress inclusions and defect nucleation.

4.4 Cryogenic Cooling

An APS-type cryo-cooler was introduced to make various tests for the cryogenic cooling of the monochromator crystals which are to be used for higher ring current operation being planned.

4.5 Bragg-Fresnel Zone Plates

Both linear and circular Bragg-Fresnel zone plates (BFZP) were fabricated in collaboration with NTT-AT[10]. Focusing properties of these BFZP's were characterized by using both laboratory x-ray source and the Photon Factory. Point focusing properties of the bent linear BFZP were also characterized. Conceptual design study has been proceeded for an optical arrangement using BFZP which does not change the position of the focal point in a wide energy range.

The real zones never have ideal rectangular shape but trapezoids. A computer code for calculating the focusing properties of such a BFZP is being developed [11].

4.6 Mirrors/Supermirrors [12]

The specifications of various x-ray total reflection mirrors to be used in the initial beamlines were finalized in 1995. For those mirrors accepting white radiation from bending magnets, Pt-coated silicon single crystal ones are selected from the consideration of cooling efficiency. The mirrors to be placed downstream of the crystal monochromator are made of quartz, because they do not suffer high heat load.

Design study of supermirrors which are non-periodic multilayers was made for the possible focusing elements for high energy x-rays. Fabrication of these mirrors was done by Osmic Co. Glancing angle and energy dependencies of reflectivity of the flat supermirrors were measured at laboratory x-ray source. Energy dependence of the reflectivity of the bent supermirrors is also being measured.

4.7 Sagittal Focusing [13]

Compatibility of the usual sagittal focusing technique with the adjustable-inclined double crystal geometry was examined by ray-tracing. The results were satisfactory so that we decided to use this scheme for the horizontal focusing of the bending magnet beamline.

Conceptual design was made for a crystal bender for the sagittal focusing which does not change the position where the center of the incident beam hit the crystal when the bending radius was changed according with the energy. An acrylic model was fabricated for the bending test. The results are just what we expected so that we proceeded the final design of the bender which is to be mounted on the standard monochromator .

4.8 Strained Silicon Crystal [14]

For getting higher integrated intensity from a high energy monochromator, the use of the strained silicon crystal is being considered. Triple-crystal diffractometry for the thermally and mechanically strained samples was reexamined using high-energy x-rays at the Photon Factory, which reproduced a similar intensity map as reported for lower energy x-rays.

4.9 Inclined Analyzer Interferometer [15]

X-ray interferometers for the determination of the spatial coherence length were surveyed. One candidate found is a modified Bonse-Hart type LLL-interferometer where the spacing between splitter and mirror crystal slabs is different from that between mirror and analyzer slabs. In such an interferometer, two x-ray beam paths to be superposed at the analyzer crystal have spatial separation in the incident beam for the initial splitter crystal.

Actual interferometer was fabricated so that diffraction at the analyzer crystal occurs in symmetric inclined geometry. The continuous change in separations between splitter-mirror and mirror-analyzer crystals enables direct observation of the absolute value of the mutual coherence function as the visibility of interference fringes.

Test of the interferometer was performed at the Photon Factory. Interference fringes were observed with the visibility modulation caused by the finite spatial coherence length. Estimated source size using van Cittert-Zernike theorem [16] agrees fairly well with the nominal source size.

5. Control and Safety

5.1 Beamline Control [17]

Design concept for the beamline control system was fixed and the detailed specification was finalized. The VMEbus (VME) are used as the front-end control system with a UNIX workstation (WS) as an operator console. CPU boards on the VME are RISC processor based board computer operated by LynxOS based HP-RT real-time operating system. The WS's (HP 9000/700 series with HP-UX) and the VME's (HP 9000/743rt with HP-RT), being linked each other by network, construct a distributed system.

The system is responsible for the control of the insertion devices (ID), front-ends (FE), and transport channels including optics. Any station control systems can be linked to the beamline control system, which insures the users' access to the ID, FE and optics operation.

Whole system for the initial beamlines has been contracted and will be delivered in 1996. Details will be reported elsewhere.

5.2 Interlock System [18]

The beamline interlock system was designed to obviate those accidents as radiation exposure, damages of equippments caused by irradiation of high power beam as well as vacuum breakdown which may happen in the beamlines.

Each beamline has one sequence controller for the interlock system, the logic of which is programmable. All sequence controllers are connected to FDDI for the storage ring control system through the ethernet, enabling remote sensing of the beamline status. Besides this, the sequence controllers construct an independent network system to ensure faster response to the abnormal status with higher reliability. Hardwire logic is adopted for such signals for emergency operation as beam dump.

Hardwares for the system have already been contracted toward the delivery in 1996-1997, while softwares including operation procedure are being prepared. Details will be reported elsewhere.

5.3 Radiation Shield

All transport channels and experimental station apparatuses in x-ray beamlines are to be covered with radiation shielding hutches which are designed after those used in APS.

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