BEAMLINES ON INDUS - 1

Indus-1 is a 450 MeV electron storage ring which will emit synchrotron radiation (SR) in the form of a quasi-continuous radiation spectrum with a critical wavelength of 61 Å. It provides usable radiation in the wavelength range of 20 Å and above. It has four bending magnets from which SR can be extracted through beamlines. In Indus-1, beamlines are drawn from only three bending magnets as the fourth magnet is close to the injection septum and transport line TL-2. From the vacuum chamber of each of these dipole bending magnets, two ports are taken out and from each port two beamlines can be extracted. Therefore many experiments, which may be quite diverse in nature, can be conducted simultaneously.

To make use of this radiation for any specific application, be it in the field of physics, chemistry or biology, the radiation has to be brought upto the target or sample under investigation in an experimental chamber. The specification of the beam at the target, in terms of size, divergence, and wavelength and its spread, depends upon the type of application and/or the experiment. This transport and refinement of the radiation is done by a beam line comprising of focussing and dispersing optical elements. The starting point for the design of any beamline is the requirements of beam quality and the photon flux at the target. Given these, and given the characteristics of the source (bending magnet, wiggler or undulator), the specifications of the various optical components comprising the beamline such as mirrors, monochromators, slits etc. are determined. While designing any beamline, the following points must be kept in mind :

- in the soft X-ray (20-300 Å) and vacuum ultra violet (300-3000 Å) range, the only optical elements which can be used are mirrors and gratings, used in reflection, or zone plates and self supporting transmission gratings. It is not possible to use conventional refractive optics because of the strong absorption of radiation by all materials in this wavelength region,
- to achieve high reflectivity from various optical elements at soft x-ray wavelengths (< 300 Å) it is necessary to work at near grazing incidence. At grazing incidence the aberrations are quite severe which thereby deteriorates the image quality enormously. Hence, aspherical optical elements which give less aberrations than spherical elements are generally preferred in the soft x-ray regime. However, for wavelengths > 300 Å normal incidence optics can be used.
- gratings with high groove densities are needed in order to obtain high angular dispersion and thus high resolution. Such gratings, however, are relatively inefficient.
- higher order contributions of lower wavelengths may be present due to continuous nature of SR spectrum.
- to avoid the contamination and consequent degradation of optical elements the beamline has to be in ultra high vacuum environment.
- the first optical element should be placed at such a distance from the SR source that the heat load does not cause any thermal damage to this element. For Indus-1 this heat load is insignificant at distances beyond 2 to 3 metres from the source.

It is proposed to construct seven beamlines and experimental stations on Indus-1 bending magnets. Out of these, five beamlines are being built by CAT/BARC and two beamlines are being built by Inter University Consortium for DAE facilities, Indore. Three beamlines use toroidal grating monochromators which have been procured (see cover photograph). These are the angle resolved photoelectron spectroscopy (PES) beamline, the angle integrated PES beamline and the metrology beamline. PES beamlines will be used for surface physics and for determination of band structure. The photophysics beamline, which will be used for time resolved spectroscopy, uses a Seya-Namiyoka monochromator. The high resolution spectroscopy beamline will have a 6.6 m off-axis eagle mount spectrograph. This beamline will be used for atomic and molecular spectroscopy. Two L-edge spectroscopy beamlines will use plane grating monochromators.

We will consider here the design of the metrology beamline on Indus-1 which will be used for calibration and reflectometry in the wavelength range 40-1000 Å. This beamline will also serve as a general purpose beamline for testing optics. Therefore the general requirement in the wavelength range mentioned above is a good throughput and a moderate energy resolution. This beamline is being installed on one of the bending magnet ports of Indus-1. In general, the optical components of a typical beamline consist of a premirror to focus the incident synchrotron radiation, a monochromator to select a wavelength of interest, and a post-mirror to focus the monochromatic radiation on to a target. Though a large choice exists for the selection of mirrors for use as pre and post focussing optics, toroidal shape has been selected for this beamline from the point of view of good image quality and also it being less expensive compared to other aspheric mirrors e.g. ellipsoidal. Moreover, a single mirror is able to focus in both meridional and sagittal directions thereby reducing the loss in intensity associated with every reflection.

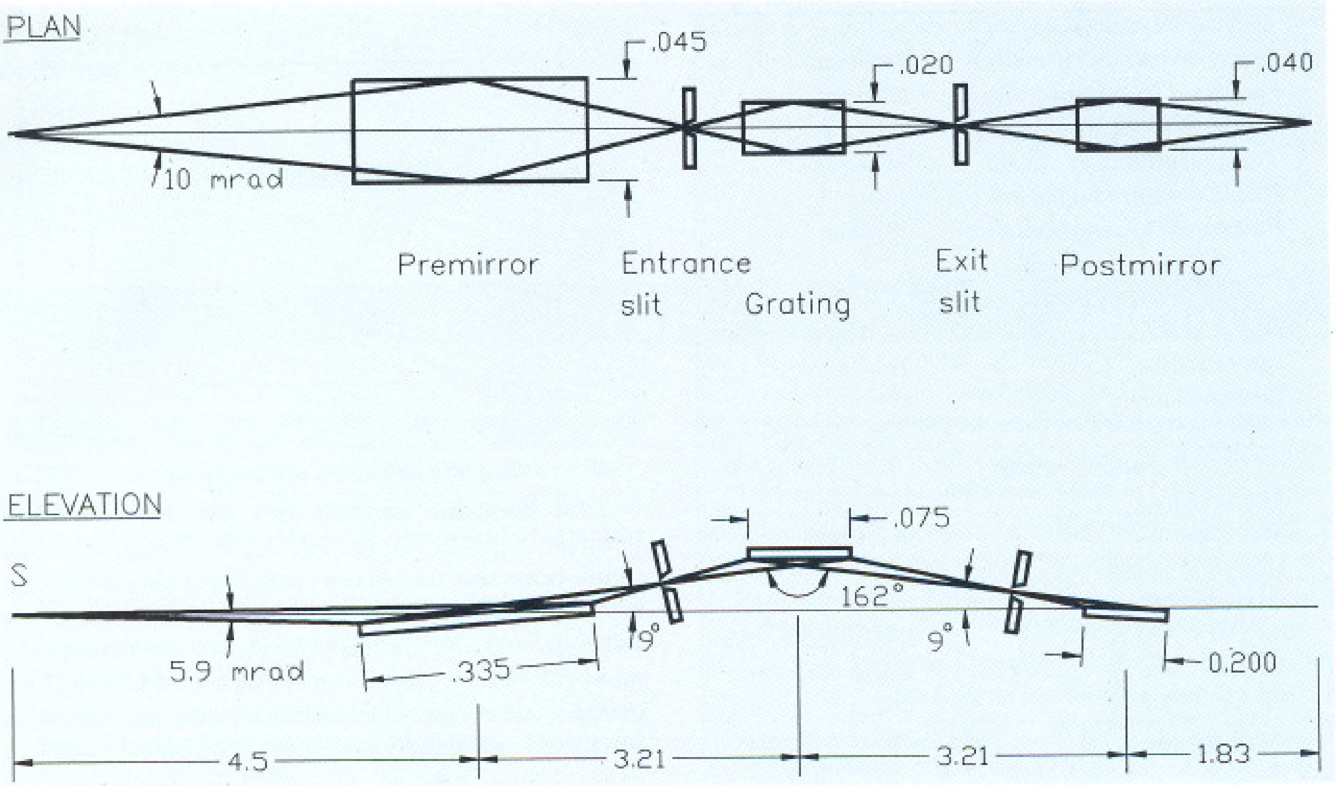

Fig. 1: Optical layout of the metrology beamline

The most critical component of a beamline is the monochromator. Any monochromator represents a compromise in the acceptance, resolution, spectral range, photon flux and the complexity of the design. Again for < 300 Å, conventional normal incidence monochromators cannot be used and one has to resort to grazing incidence geometry. A toroidal grating monochromator (TGM) is chosen for use in this beamline. The toroidal grating combines the dispersion and focussing in one element, thus minimizing the reflection losses in the system. The focal length of the toroidal grating is 1414 mm. To improve the resolution characteristics of the monochromator the aberration corrected holographically ruled gratings rather than the conventional straight groove, constant spacing gratings are being used. This monochromator utilizes three toroidal gratings for use in different wave length range and are interchangeable in situ in vacuum.

The optical layout of the beamline is shown in fig. 1. It comprises of a premirror M1, an entrance slit S1, a toroidal grating T, an exit slit S2, and a post mirror M2. Various physical constrains such as the length of the front end, shielding wall etc. restricts the placement of the first optical element to not before 4000 mm from the tangent point of the storage ring. The first optical element, i.e. the prefocussing toroidal mirror is therefore kept at a distance of 4500 mm from the source. This mirror is inclined at 4.5° to the horizontal plane and it illuminates the entrance slit by a 2:1 demagnification of the SR source. The grating in the TGM is vertically dispersing at a constant deviation of 162°. After diffraction by the grating, the monochromatic light passing through the exit slit is deflected back to the horizontal plane (plane of the electron orbit in the storage ring) by a second toroidal mirror at 1:1 magnification which focuses the monochromatised light onto the sample placed at a distance of 1836 mm from the mirror. Various parameters of mirrors and the monochromator are given in the table. This table also gives the source parameters for Indus-1.

It is extremely difficult to apply analytical expressions to analyze these type of optical systems comprising of several mirrors and gratings operating at grazing incidence. Therefore to analyze and evaluate the performance of such systems ray tracing simulation studies have to be carried out. Ray tracing can readily handle complex aspheric surfaces and holographic diffraction gratings, and by using a general purpose ray-trace program, it is possible to obtain detailed information about the overall performance of the beamline optical system, to visualize actual intensity distribution on all optical elements and on the image planes, and to determine the sensitivity of misalignment and the shape variations of the optical elements. For this purpose the raytracing program RAY from BESSY synchrotron has been adopted on the unix based Magnum mini computer in CAT. The program simulates the SR emitted from a bending magnet of a SR source and traces a set of pseudo random rays that are generated statistically taking into consideration various storage ring parameters such as

Distances

Source to toroidal premirror	4500 mm
Premirror to entrance slit	2250 mm
Entrance slit to toroidal grating	1000 mm
Toroidal grating to exit slit	1414 mm
Exit slit to toroidal postmirror	1836 mm
Postmirror to sample position	1836mm

Toroidal premirror

Major radius	38236 mm
Minor radius	235.4 mm
Deviation angle	171°

Toroidal grating

Major radius	7977 mm
Minor radius	182.3 mm
Deviation angle	162°
Grating density	
for 40 - 120 Å	1800 grooves/ mm
for 120 - 360 Å	600 grooves/ mm
for 360 - 1000 Å	200 grooves/ mm
Grating size	75 mm x 20 mm

Toroidal postmirror

Major radius	144.1 mm
Minor radius	23400 mm
Deviation angle	171°

Indus-1 source parameters

Source type	Dipole
Bending magnet radius	1000 mm
Critical wavelength	61 Å
Source size (σ - value)	0.8 mm x 0.1 mm
Horizontal divergence	10 mrad
Vertical divergence	2 - 9 mrad

bending magnet radius, energy of the stored electrons, and vertical and horizontal divergences of the photon beam. Beamline optical layout is also specified as an input to this program. This layout includes the object and image distances for the mirrors and the grating, the surface shape and sizes, incident and reflection angles, and the slit sizes, etc. The ray trace output consists of points on a plot where each ray intersecting a given plane is plotted. Ray trace output of the complete beamline using toroidal mirrors as pre and post focussing optics, and toroidal grating monochromator as the dispersing element, is shown in figure 2. This figure shows the spot diagram at the image plane as well as the intensity profiles in the horizontal and vertical directions. The calculation is done at the critical wavelength of Indus-1 viz. 61 Å.

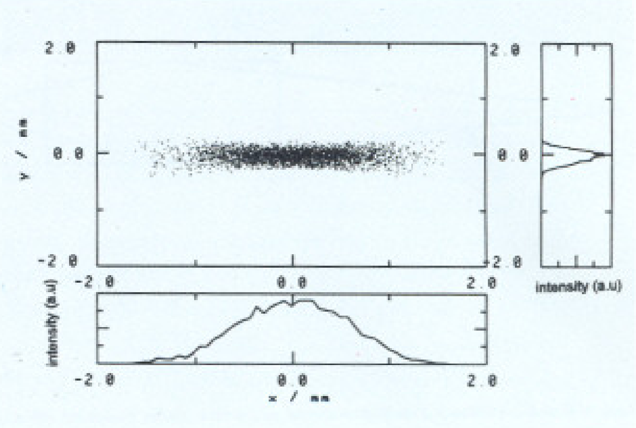

Fig. 2 : Spot diagram at the image plane.

The resolution achieved by a monochromator in a beamline depends on several factors including the SR source beam size, the photon beam size at the entrance slit in the dispersive direction, the exit slit size in the dispersive direction and the geometrical aberration limit of the monochromator. Since our design of TGM utilizes entrance and exit slits at fixed locations, the best resolution is achieved only at two wavelengths at which the TGM is at exact focus, and at all other wavelengths the monochromator is only approximately focused thereby giving a wavelength dependent resolution. The attainable resolution of the monochromator has been determined by ray tracing and it is expected to give a resolution ($\lambda/\Delta\lambda$) in the range of 200 to 800.

Another parameter of interest for experiments using monochromatic light is the maximum photon flux on the sample for a given slit size (or resolution). The radiation flux emitted by the SR source gets attenuated by the beamline because of its nonunity transmission. The transmission is determined by the focussing mirrors through their reflectivities and dimensions, by the grating through its reflectivity and diffraction efficiency, and by the slit sizes. By using analytical expressions for determining grazing incidence reflectivities and grating efficiency; and by using ray tracing to determine the geometrical throughput and the wavelength bandpass of the beamline the photon flux available at the target has been determined. A photon flux of 10^{11} - 10^{12} photons/sec is expected at the target for a current of 100 mA in the storage ring Indus-1.

The beamline performance can get severely degraded due to incorrect adjustment of optical elements and/or variation in their shapes. The imperfections in optical elements like micro-roughness and slope errors can also limit the performance of the optical elements. While the slope errors deteriorates the achievable resolution, the micro-roughness leads to diffused scattering thereby limiting the specular reflectivity. These contributions have been determined using ray tracing and from these calculations limits on the tolerances of the optical elements and of the mechanical assemblies were determined.

By performing all these design calculations a reasonable idea has been obtained about the characteristics of the beam, in respect of resolution, photon flux and spot size, which will be available for the users from this beamline. Such studies enable experimenters to plan their experiments in detail.

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