Pramana - J. Phys., Vol. 39, No. 2, August 1992, pp. 177–180. © Printed in India.

Imaging characteristics of toroidal and ellipsoidal mirrors for synchrotron radiation source Indus-1

K J S SAWHNEY and R V NANDEDKAR
Accelerator Programme, Centre for Advanced Technology, Indore 452013, India

MS received 9 March 1992; revised 8 May 1992

Abstract. We discuss and compare the imaging characteristics of toroidal and ellipsoidal mirrors for different horizontal acceptances of synchrotron radiation source Indus-1; using a ray tracing method. It has been shown that the toroidal and ellipsoidal mirrors have similar focussing behaviour at small horizontal acceptances. For large horizontal acceptances, toroidal mirror shows an asymmetry in the focussed image. Though the data used here are for Indus-1, the results are generally valid for any bending magnet synchrotron radiation source incident at grazing angles on these mirrors.

Keywords. Synchrotron radiation; imaging characteristics.

PACS No. 42·10

For focussing synchrotron radiation, there exists a large choice of mirrors. The simplest option of using spherical mirrors introduces large spherical aberrations at grazing incidences. To reduce this aberration, aspheric surfaces have to be used for mirrors and gratings. An ellipsoid is an ideal surface to get a stigmatic image of a point source. However, it is rather difficult to fabricate ellipsoidal surfaces and hence are expensive. An aspheric surface which is simpler to fabricate than an ellipsoid is a toroid. We have therefore considered both types of mirrors in our beam line design (Nandedkar *et al* 1992a) and a comparison of their image characteristics has been performed.

An ellipse has a property that rays emanating from one point focus perfectly converge on to the second point focus. For rays to be focussed in both vertical and horizontal directions, an ellipsoidal surface has to be used. This surface can be generated by rotating an ellipse about its major axis. The principal radii of curvature of the ellipsoid are given by

$$R = \frac{1}{ab}[rr']^{3/2}$$

and

$$S = \frac{b}{a}(rr')^{1/2}$$

where r and r' are the object and image distances from the mirror surface and a and b are the semi major and semi minor axes of the ellipse.

Similarly a toroid is generated by rotating a circle of radius ρ in an arc of radius R (for details: West and Padmore 1987).

These mirrors are very commonly used as prefocussing mirrors. Indus-1 is a 450 MeV electron storage ring. The spectrum of radiation has a critical wavelength of 61 Å (Bhawalkar *et al* 1991). It has four bending magnets from where beam lines will be taken out for experimental work (Nandedkar 1992 and Sawhney and Nandedkar 1992). The first focussing mirror is kept at a distance of at least 3 m away from the tangent point because of front end and shielding wall.

We have carried out simulation studies using a general purpose ray tracing program RAY (Feldhaus and Schafers 1987). This programme is originally written to run under VMS operating system on a VAX computer. Extensive changes were made to adopt this program on UNIX based Magnum mini computer. Of the various options available for source e.g. matrix, point line, dipole etc. the dipole type source simulates the synchrotron radiation emitted from a bending dipole magnet of the storage ring and is used for present ray tracing calculations. In this program, a set of pseudo random rays is traced through the optical system to find out the reflected intensity. The rays are generated statistically taking into consideration various parameters such as the spatial and angular distribution and the probability distribution of the rays. In the present calculations, 20,000 rays have been generated for the ray tracing.

The ray tracing calculations have been performed using various values for the horizontal angular divergences of the SR beam. The intensity distribution in the image, in the meridian plane is shown in figure 1 for ellipsoidal and toroidal mirrors for two extreme divergence values. Figure 2 shows similar intensity distribution in the orthogonal (sagittal plane). The horizontal acceptance has been changed from 1 mrad to 10 mrad. Mirrors are considered ideal and hence the image distributions as obtained for ellipsoidal and toroidal mirrors are ideal. Radiations are incident at a grazing angle

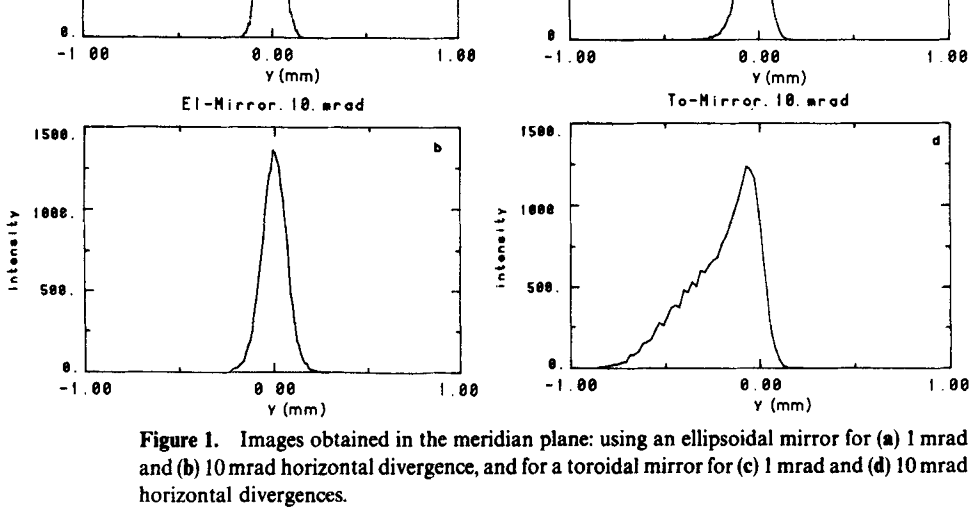

Figure 1. Images obtained in the meridian plane: using an ellipsoidal mirror for (**a**) 1 mrad and (**b**) 10 mrad horizontal divergence, and for a toroidal mirror for (**c**) 1 mrad and (**d**) 10 mrad horizontal divergences.

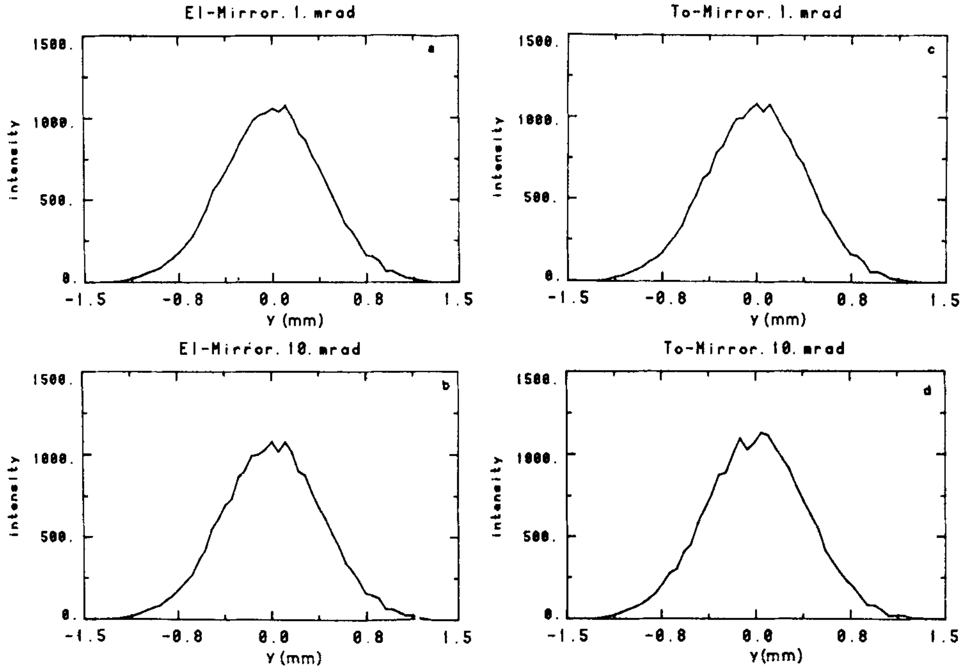

Figure 2. Images obtained in the sagittal plane: using an ellipsoidal mirror for (**a**) 1 mrad and (**b**) 10 mrad horizontal divergence, and for a toroidal mirror for (**c**) 1 mrad and (**d**) 10 mrad horizontal divergences.

Table 1. Input parameters for ray tracing.

Source Size	: 0·8 mm × 0·1 mm
Source type	: Bending magnet of INDUS-1
Critical wavelength	: 61 Å
Vertical divergence	: 2–5 mrad (wavelength dependent)
Electron Energy	: 450 MeV
Distance between tangent point and the optical element	: 4500 mm
Misalignment of mirrors	: 0
Tangent errors of mirrors	: 0
No. of rays	: 20,000
Demagnification	: 2:1
Size of the mirrors	: 50 × 340 (mm^2)
Angle of incidence	: 4·5° w.r.t. mirror surface

of 4.5° i.e. the included angle between the incident ray and reflected ray is 171°. Other input parameters are given in table 1.

For grazing incidence, all cartesian surfaces suffer from third order spherical aberration, and the first and third order coma. For grazing incidence optics the image quality is given more exactly by detailed ray tracing than by mathematical equations unlike normal incidence optics (Korsch 1991). It is clear from figure 1 that for a given source size and source divergence, toroidal mirrors give an asymmetric image due to coma. There is no coma in the sagittal plane as shown in figure 2. This coma in the image from the toroidal mirror in the meridian plane increases with the increase in the demagnification ratio (DMR), defined as the ratio of the object distance to the image distance from the optical element. We have presented results for DMR of 2, as this ratio is used in our Indus-1 beam line design. This coma is minimum for DMR equal to 1. The image of the source from an ellipsoidal mirror does not show any drastic change whereas the image of the source from a toroidal mirror changes as the source size and divergence are varied. The image from a toroidal mirror is almost symmetric for a small source size and source divergence. Increase in either of these two leads to an increase in the asymmetry, and a strong coma is observed. Therefore, if a toroidal mirror is to be used as a focussing element, one has to use small acceptance angle, as the source size cannot be changed in Indus-1 for a given configuration. The asymmetric part of the image for toroidal mirror can however be cut off at higher angular divergence by using appropriate apertures, but this will lead to decrease in the flux.

In summary the image quality of the bending magnet source of given dimensions from an ellipsoidal mirror is very good for all horizontal divergences whereas at higher angular divergence an asymmetry in focussed image results from a toroidal mirror. The results presented here are for ideal mirrors without any tangent errors. However, the image quality also gets affected by the figure of merit of mirror surfaces. Calculations are in progress to evaluate this and will be published elsewhere.

Acknowledgements

We express our sincere thanks to Dr F Schafers of BESSY Berlin for providing source code of RAY. Thanks are also due to Dr G S Lodha for many useful discussions. Encouragement from Dr D D Bhawalkar and Dr S S Ramamurthy is acknowledged.

References

Bhawalkar D D, Ramamurthy S S and Singh G 1991 *Proc. medium scale synchrotron radiation facilities in Asia* (eds) K Kohra and T Kasung (Singapore: World Scientific) 16

Feldhaus J and Schafers F 1987 Technical report BESSY TB–XX-87

Korsch D 1919 *Reflective optics* (Boston: Academic Press) Ch. 7

Nandedkar R V 1992 in *Int. Conf. on synchrotron radiation sources.* Indore Feb. 1992 (Proc. to be published)

Nandedkar R V, Sawhney K J S and Lodha G S 1992a CAT report CAT/I/92–01

Sawhney K J S and Nandedkar R V 1992 in *Int. Conf. on synchrotron radiation sources*, Indore, Feb. 1992 (Proc. to be published)

West J B and Padmore H A 1987 *Optical Engineering* in *Handbook of synchrotron radiation* (ed.) G V Marr (Amsterdam: North Holland) vol. 2, p. 21