HARTMANN SCREEN AND WAVEFRONT SENSOR SYSTEM FOR EXTRACTING MIRROR AT SSRF*

J. Chen, K.R. Ye, Y.B. Leng, SINAP, Shanghai, China

Abstract

A Be mirror was used to extract visible synchrotron radiation light from bending magnet at SSRF. The surface of mirror was deformed because of X-ray heat. A set of Hartmann Screen Test was used to measure the surface of the mirror. Another equipment named The Shack-Hartmann wavefront sensor system was introduced to get more precision data. The result of two kind of test match each other well.

GENERAL OVERVIEW

There are two diagnostic beam lines in the storage ring of Shanghai Synchrotron Radiation Facility, one of them adopt interferometer to measure the transverse electron beam size of storage ring using visible light. The visible light was extract from synchrotron radiation by a Be mirror. The Be mirror was special designed to reflect visible light from vacuum and let x-ray pass through. Part of the energy of x-ray was absorbed by the Be mirror and the heat cause deformation of the mirror. The impact of mirror deformation to measurement of interferometer was analyst and the deformation was measured by Hartmann Screen and Shack-Hartmann wavefront sensor. The result of deformation measurement was used to correct the measurement of beam size by interferometer.

DESIGN OF THE Be MIRROR

Beryllium is the best metal to conduct x-ray with high melting point (1287°C) and high specific heat (1925 J·kg−1·K−1) and with low absorption of x-ray.[1] As shown in Fig. 1(a), the shape of mirror back is paraboloid with equation y=0.05x2+2. Center of the mirror is thin to absorb less energy of x-ray. Water flow across two hole to take heat away. Although these method are implemented to reduce the heat deformation, it can't be avoided. In simulation, the distribution of temperature is displayed in Fig. 1(b), the highest temperature is 65°C locate in the center of the mirror and the lowest temperature is 35.3°C. The deformation of mirror is shown in Fig. 1(c), height of the peak is 5.16μm, height of the bottom is 2.68μm, peak to valley is 7.84μm.[2]

A thermal-mechanical analysis with electron beams show: the thermal distortion values for metals between 0°C to 400°C, these effects were especially good in Beryllium mirrors .The deformation of Be mirror is simulated by ANSYS and XOP for varying the shape, size, and diameter of cooling tube. We fixed outer-dimension of beryllium mirror is 80mm(wide), 60mm(high), 12mm(thickness). With the diameter of water-cooling tube will 8mm, the centric deformation of mirror surface results 3.9μm with inlet water temperature 26°C. The highest temperature of mirror will be 56°C.

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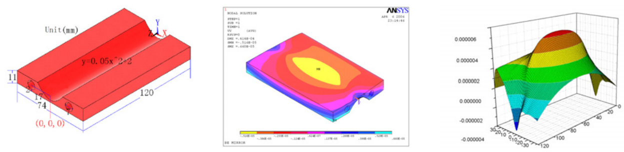


(a)Shape of Be mirror (b)Temperature distribution (c)Deformation distribution

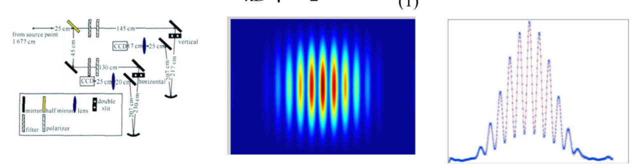
Figure 1: Design and simulation of the Be mirror.

INFECT TO BEAM SIZE MEASUREMENT

Beam size is measured by interferometer[3], the optics layout is shown in Fig. 2(a), the optical system include some relay mirrors to transport and split light, one double slits to split the wavefront and a focus mirror to make two light beam from two slits intersect at the surface of CCD sensor. [4]

The formula to calculate beam size is shown as Eq. 1, in which σ means the size of beam, λ is wave length of light, D is preparation of double slits, and γ is spatial coherence. The coherence is measured by Levenberg–Marquardt fitting of intensity distribution of interference fringe(shown in Fig. 2(b), Fig. 2(c)), and the other parameters can be measured by simple way.

$$\sigma = \frac{\lambda R}{\pi D}\sqrt{-\frac{\ln\gamma}{2}} \qquad (1)$$



(a)Optics layout of interferometer (b)interference fringe (c)L-M fitting to calculate spatial coherence

Figure 2: Measurement of beam size.

As design shape of the Be mirror, it tend to bend in vertical direction and the deformation in horizontal can be ignored. As shown in Fig. 3, the distance from source point to Be mirror A and the distance from Be mirror two double slits B and the separation of double slits D_{real} are known. Assuming the deformation lead mirror shift angle is b, D_{ideal} is the ideal separation of double slits which means the separation of double slits should be used without deformation. In Eq.1, the parameter D should be D_{ideal} instead of D_{real}. In Eq.2, A, B, D_{real} are known, if we measure the mirror deformation to get shift angle b, the ideal separation of double slits can be calculate like this:

$$h = \frac{D_{real}}{2} - B * \tan(2b) \Rightarrow a = \arctan\left(\frac{h}{A}\right) \qquad (2)$$
$$\Rightarrow D_{real} = 2(A+B)\tan(a)$$

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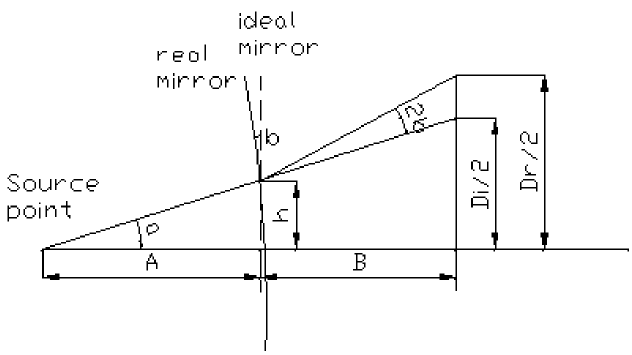

Figure 3: Deformation of mirror influence to D(separation of double slits).

HARTMANN SCREEN TEST

The principle of Hartmann screen test is shown in Fig. 4, the device Hartmann screen is a plate with 10×10 holes array, the diameter of each holes is 1mm, and the distance to center of adjacent holes is 5mm. If the mirror is flat, in projection of holes array, the distance to center of adjacent spots should be same. The deformation of the mirror can be measured by analysis the arrangement of holes array projection. The projection of hole array was received by a screen, the image of projection on the screen was taken by a CCD camera. [5]

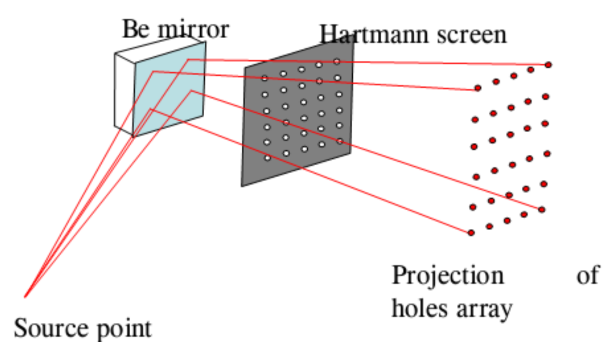

Figure 4: Hartmann screen to measure mirror deformation.

The image of size known grid in paper at the place of project screen was taken to calibrate magnification of imaging system. The image of holes array projection is shown in Fig. 5. A MATLAB script was written to figure out the separations of holes' projection by analyzing the image and calculate the distortion of the mirror surface and rebuilding the model of mirror surface. The data process flow is shown in Fig. 5.

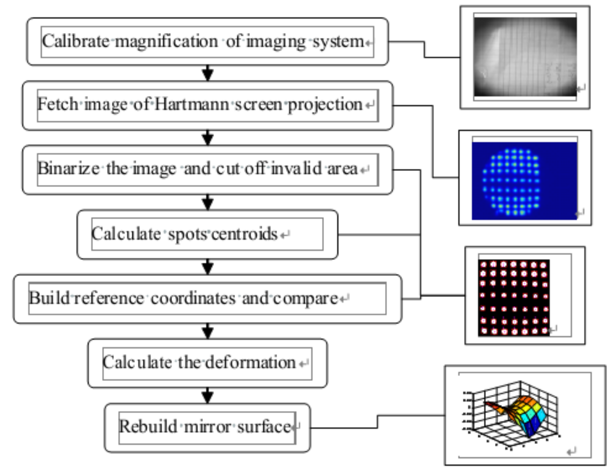

Figure 5: Data process flow of Hartmann screen test.

SHACK-HARTMANN SCREEN TEST

A Shack-Hartmann wavefront sensor is an optical instrument used to characterize an imaging system. It is a wavefront sensor commonly used in adaptive optics systems. It consists of an array of lenses (called lenslets) of the same focal length. Each is focused onto a photon sensor (typically a CCD array or quad-cell). The local tilt of the wavefront across each lens can then be calculated from the position of the focal spot on the sensor. Any phase aberration can be approximated to a set of discrete tilts. By sampling an array of lenslets all of these tilts can be measured and the whole wavefront approximated. [6]

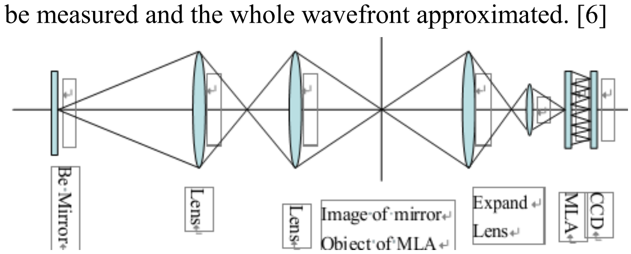

Figure 6: Optical layout of Shack-Hartmann screen test.

Optical layout is shown in Figure 6, four lens imaging Be mirror at lenslets, the CCD is on the focal point of lenslets. There are three basic steps to the analysis process: determination of the spot positions, conversion to wavefront slopes, and wavefront reconstruction, as shown in Figure 7. In the reconstruction step, the wavefront is described in terms of Zernike polynomials which have analytic derivatives. The measured slope data is then fit to the derivative of these functions, allowing a direct determination of the wavefront from the fit coefficients.[7]

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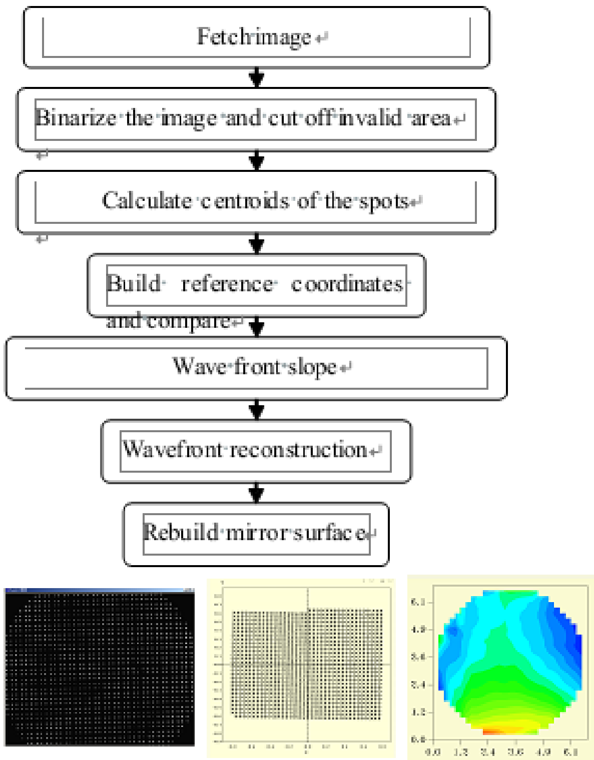

Figure 7: Data process flow of Shack-Hartmann screen test.

CONCLUSION

The parameter $k=D_{ideal}/D_{real}$ was introduced to characterize the degree of mirror deformation, it has been measured under beam current from 1mA to 190mA, the result is shown in Figure 8. The mirror is not flat, there are two kinds of deformation, one kind of deformation is fixed and don't change with beam current changed. The other kind of deformation change linearily with beam current changed, but it has much less infect to measurement of beamsize than the fixed deformation. The result of deformation measurement was used to correct the measurement of beam size by interferometer.

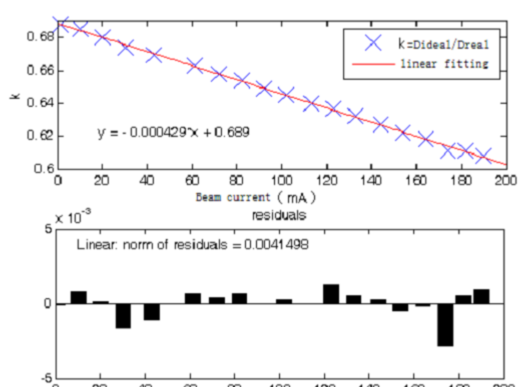

Figure 8: Data process flow of Shack-Hartmann screen test.

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REFERENCES

[1] http://en.wikipedia.org/wiki/Beryllium

[2] W. Maoyuan, "The research of measueing synchrotron radiation with interferometer," Master's degree thesis, 2006, 5.

[3] T. Mitsuhashi. "Measurement of Small Transverse Beam Size Using Interferometry," Proceeding of DIPAC 2001 – ESRF, Grenoble, France.

[4] J. Chen, K. R. Ye, Y.B. Leng. "Development of Shanghai Synchrotron Radiation Facility synchrotron radiation interferometer[J]," High Power Laser and Particle Beams, 2011, 23(1): 179 ~184.

[5] T. Mitsuhashi, M. Tadano. "Measurement of Wavefront Distortion Caused By Thermal Deformation Of Sr Extraction Mirror Based on Hartmann Screen Test And Its Application For Calibration Of SR Interferomterter," Proceeding of 2nd APAC2001, Beijing, China.

[6] N. Takeuchi, T. Mitsuhashi, etc. "Wavefront Distortion Measurement of a Sr Extraction Mirror For The Beam Profile Monitor Using Shackhartmann Method," 0-7803-4376-X/98 Ó 1998 IEEE 859~861.

[7] D. R. Neal, J. Copland, D. Neal. "Shack-Hartmann wavefront sensor precision and accuracy," Proceedings of SPIE Vol. 4779 (2002) © 2002 SPIE 0277-786X/02.

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