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

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Abstract

The wavefront distortion caused by a thermal deformation of SR extraction mirror in the SR monitor was measured by means of the Hartmann screen test. The stored beam was used as a primary light source. The Hartmann pattern was observed at 5m downstream from the Hartmann screen by a mat screen with a CCD camera. With this observation range, we reached a resolution of $\lambda/6$. The distortion of wavefront will have a influence to deform the effective separation of the double slit in the SR interferometer. A correction of effective separation of the double slit is also developped.

1 INTRODUCTION

So called SR monitor in that mainly aided to measure the beam size and the profile based on optical method is one of most fundamental monitor in the storage ring. Many apparatuses are adopted in the SR monitor such as imaging system to make an image of the beam, the SR interferometer to measure the beam size, and the streak camera to measure a longitudinal beam profile, etc. In this monitor, the visible SR beam is usually extracted from the storage ring by a mirror. Thermal deformation of the extraction mirror introduces a wavefront error, and it reduces a quality of the measurement. Therefore, to measure this wavefront distortion is very important for the precise measurement. There exist a number of quantitative-method to measure a wavefront distortion, such as the interferometory, the micro Shack-Hartmann sencer, and the Haltmann test etc [1]. Since latter two methods are incoherent measurement, and usually use for the large-scale optical system that has a few 10m optical path, as in a large telescope in the observatory. So called Hartmann test that consists of sampling the wavefront with a perforated screen is very simple and suitable to measure an absolute degree of wavefront distortion [1]. This method also has enough precision in our case of SR monitor that has a few 10m optical path. In this paper, it is described that the measurement of wavefront distortion caused by a thermal deformation of SR extraction mirror with Hartmann square-array screen. The distortion of wavefront will have a influence to deform the effective separation of the double slit in the SR interferometer [2]. A correction of effective separation of the double slit is also described.

2 THEORY

The basic concept behind screen test is that a wavefront can be sampled in a number of locations across it in a predetermined manner, and that the wavefront can be reconstructed when the sample points are related to each other. The premise is that a portion of a wavefront , when tilted relative to the ideal wavefront in this region, causes light come to the observation plane at a distance different from the ideal one. If the wavefront is sampled by a number of rays normal to it, ray deviation at observation plane can be obtained as shown in fig.1.

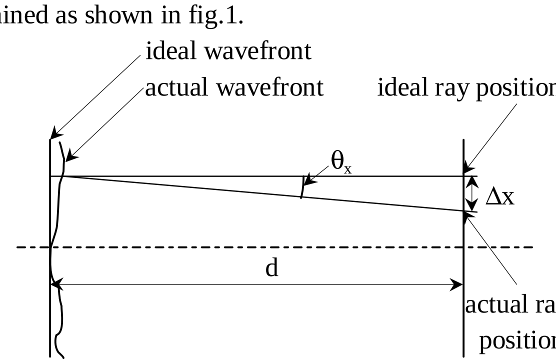


Fig. 1 Schemtics of rays and wavefronts in Hartmann test.

In Fig.1, Δx is the value of one of the components of the ray deviation, d is the distance between the extraction mirror and observation plane, and θ_x is the angular tilt of the portion of wavefraont. The relation between the wavefront aberration W (separation between ideal wavefront and actual wavefront) and x component Δx of the ray deviation in the observation plane is given by:

$$\frac{\partial W}{\partial x} = \frac{\Delta x}{d} \qquad (1).$$

Integrating this equation, we can obtain,

$$W = \frac{1}{d}\int_0^x \Delta x \, dx \qquad (2).$$

Since the Δx is sampled at discrete points by the holes in a sampling screen, the integration is performed by a summation.

3 SQUARE-ARRAY SCREEN

There exist sampling screens with a number of different hole patterns [1]. Since the optical system in the SR monitor has a square aperture, we applied so-called square array. As shown in Fig.2, such an array consists of points equidistantly at the intersection of lines parallel to the orthogonal axis of a Cartesian coordinate system. We used a 100-hole square-array screen. The hole diameter should be small but not so small that their diffraction pattern on the observation plane overlap each other and of sufficient small size to permit an accurate measurement of their positions. The interval of the holes should be also small having a sufficient number of the sampling points of wave front, but not so small that their interference fringe pattern between surrounding holes stands out.

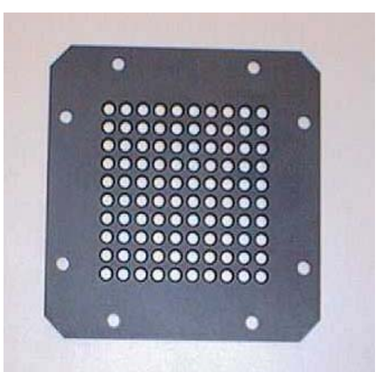


Fig.2. A 100-hole square-array screen.

The hole diameter is carefully optimized by diffraction analysis at the observation point. In figure 3, we show the results of diffraction analysis (simulation) with various hole diameters. From this figure, we can see the diffraction pattern beacomes Fraunhofer-like pattern to Fresnel-like pattern as the hole diameter becomes larger. Since, a hole smaller than 1mm gives a spread projection pattern, we adopt a hole diameter 1mm. This hole gives a Fraunhofer-like diffraction pattern and it has a sharp peak in the center. We apply the hole interval of 5mm.

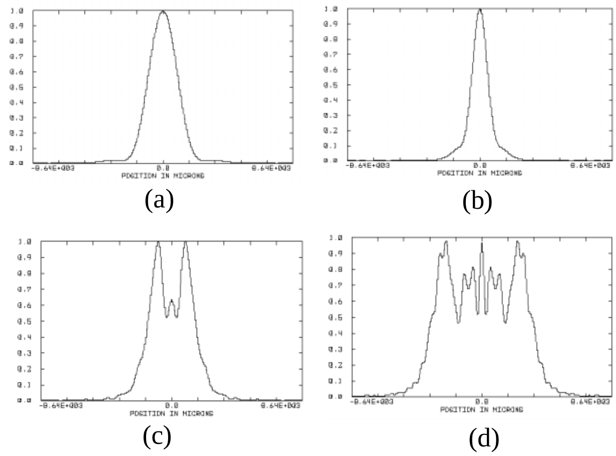


Fig.3. Results of diffraction analysis. The diameter of holes are; (a) 0.5mm, (b) 1 mm, (c) 1.5mm, (d) 2.5mm.

The square-array screen is fixed on a X-Y moving stage. So, we can increase the sampling point beyond the number of hole. Since this screen test is destructive method, the screen is removed from SR beam by this moving stage during the SR monitor is operated.

4 OBSERVATION OF HARTMANN PATTERN

The setup of the wavefront measurement is shown in Fig. 4. Since the dimension of stored beam is small enough, we use the beam as a primary light source. It is better to set the square-array screen at just front of the SR extraction mirror, but we have a vacuum chamber system for SR extraction mirror. Then we set the screen 1m downstream from the extraction mirror. Distances between the components are as follows, from the source point to SR extraction mirror : 2.79m, from SR extraction mirror to square-array screen : 1m, from screen to observation point : 5m. With this setup, if we measure the dot positions of the Hartmann pattern on the observation plane with 0.1mm resolution, we can measure the wavefront with λ/6 (in here, λ is 633nm) precision.

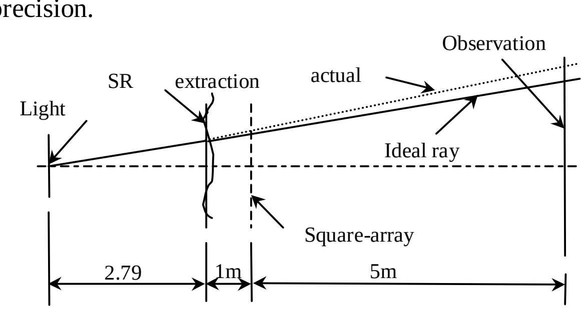
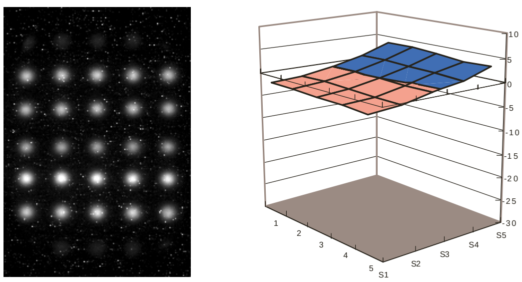
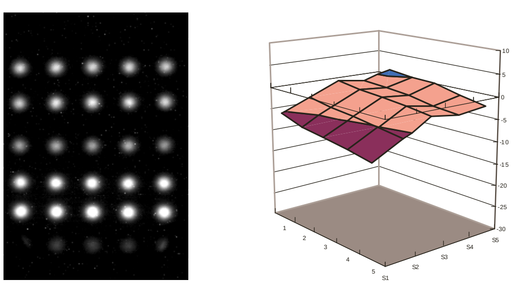


Fig. 4. Measurement setup

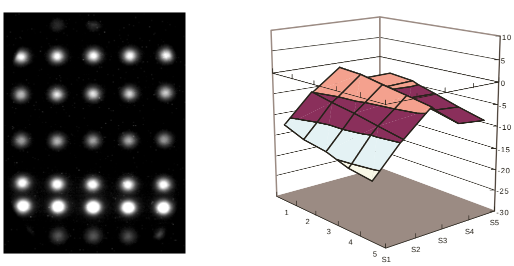
The Hartmann pattern is projected on a mat screen. The mat screen is put on the observation plane. This Hartmann pattern is observed with A digital CCD camera. The Hartmann patterns observed in the Photon Factory at various ring current is shown in Fig.5. The measurement area on the extraction mirror is 25mm(width) x 25mm(height). The intensities of Hartmann dots are modulated by the intensity distribution of the SR beam.



(a) 50mA



(b) 230mA



(c) 436mA

Fig.5. Hartmann patterns observed in the Photon Factory at three ring currents (left side). Reconstructed wavefronts are also shown in right side.

5 WAVEFRONT RECONSTRUCTION

From the measured shifts of Hartomann-dot positions, the wavefront can be reconstructed by the use of equations (1) and (2). The results of reconstructed wavefronts from the Hartmann patterns in Figure. 5 are also shown in Fig. 5. As mentioned in section 4, since we can easily measure the shifts of dot positions in the resolution better than 0.1mm, we can reconstruct the wavefront with $\lambda/6$ precision. From Fig. 5, we can see the wavefront was deformed by irradiation of strong power of X-ray component in SR beam.

6 CALIBRATION OF SR INTERFEROMETER BY USING A SINGLE-HOLE SCREEN

The SR interferometer [2] is used for beam size measurement. The actual separation of double slit of the interferometer is changed by deformation of the mirror. To find the ideal separation between the two rays at the location of double slit, we use a single-hole screen as shown in Fig. 6. We can probe the paths of two ideal rays by scanning the single-hole screen in the plane which perpendicular to the optical axis.

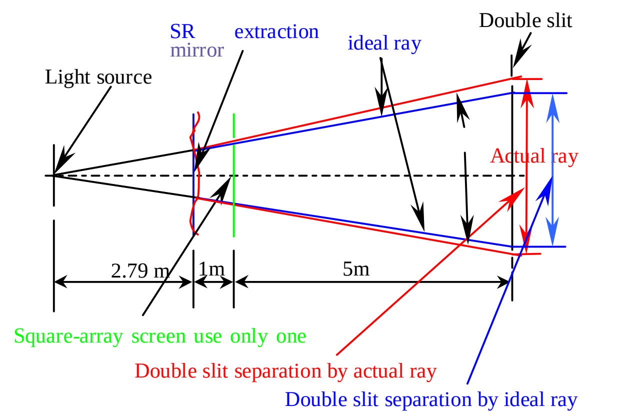


Fig. 6 Setup to find the ideal separation of double slit by scanning a single-hole screen.

7 CONCLUSIONS

The wavefront distortion caused by a thermal deformation of SR extraction mirror in the SR monitor was measured by means of the Hartmann screen test. The Hartmann pattern was observed at 5m downstream from the Hartmann screen by a mat screen with a CCD camera. With this observation range, we reached a resolution of $\lambda/6$. The deformation of wavefront will have an influence to change the actual separation of the double slit of the SR interferometer. A correction method to actual separation of the double slit is also developed.

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