

INTERFEROMETER DATA ANALYZING USING THE PCA METHOD AT SSRF *

Y.B. Leng[#], H. J. Chen, J. Chen, Z. C. Chen, Y.B. Yan, SSRF, SINAP, Shanghai, China.

Abstract

An SR interferometer, which was used to monitor the transverse beam size in the SSRF ring, had been implemented and put into operation since 2009. The direct projection and curve fitting was adopted for raw image data processing. Any CCD alignment error could introduce some beam size measurement error in this case. Using primary component analyzing (PCA) method to process raw image data, the horizontal and vertical distribution information can be decoupled and the misalignment information of CCD can be derived. Beam experiment results will be discussed in this paper.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF) is the 3.5GeV third generation light source with the emittance of 3.9nm.rad. The typical transverse beam sizes are 53 μ m in horizontal plane and 22 μ m in vertical plane with 1% vertical coupling. To monitor such small transverse beam dimension and motion, a set of interferometer was implemented since 2009 [1].

The source point of SRM is inside the second bending magnet of the cell#2. The synchrotron light is extracted by a water-cooled beryllium mirror. Then three mirrors guide the light to the dark room.

Two Harsherman-type reflective SR interferometers are installed to measure the both of vertical and horizontal beam sizes. The double slit is set at 18 meter apart from source point. A focusing mirror, $f=2000$ mm, is used as an objective mirror. A small off axis diagonal mirror is set for the convenience of the observation. A band-pass filter, which has 50nm or 80nm bandwidth at 550nm, is used to limit the wavelength of input light. The σ -polarization of SR is selected by dichroic polarization filter.

The 800Mb/s interface enables full frame rate and even more cameras on the same bus. The IEEE-1394b cable with jack screws allows a more secure connection to the camera. 12-bit A/D converter, Via external trigger, software trigger (on same bus), This equipment has been tested and found to comply with the limits for a Class A digital device, have good linearity It provide reasonable protection against harmful interference when the equipment is operated in experimental environment. After all environments and system calibration, Interferometer is good enough for the measurement of a few μ m small beam size. [2]

Figure 1 shows a set of typical interference image data and corresponding data processing method. In order to minimize measurement uncertainty, CCD exposure time was set to a large number (for example 200ms) to get

strong visible light signal. Meantime the edge part of raw image with poor SNR was cut and only central part was reserved to get interference flange profile using direct projection method.

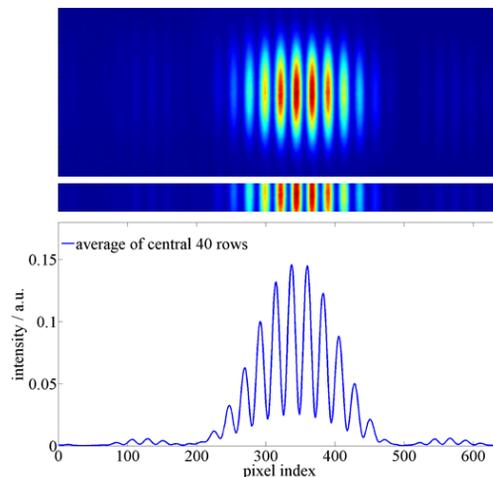


Figure 1: Typical interference image (top), central slice of 40 rows (middle) and projected interference flange (bottom).

The SNR of the final profile can be guaranteed with above CCD configuration and data processing method. But two disadvantages were introduced into the system at the same time. The first, not all information of the raw image was used. The second, any misalignment between the double slit and CCD will contribute measurement error and this contribution is hard to find and fix with direct projection method.

So we propose to use PCA method to process raw image data, reduce random noise, detect misalignment angle and decouple the horizontal and vertical profile.

IMAGE PROCESSING USING PCA

PCA method is originally used in image processing filed to reduce data dimensions and now widely used in accelerator field to do BPM turn-by-turn data analyse. [3]

The interference image matrix can be decomposed into three terms by using SVD:

$$IMG=USV \quad (1)$$

where U and V are unitary square matrices and S is a diagonal matrix. U is the matrix of the eigenvectors of the covariance matrix IMG and each column of U corresponds to the horizontal distribution pattern of a specified mode; V is the matrix of the eigenvectors of the covariance matrix IMG and each column of V corresponds to the vertical distribution of a specified mode; Each element of S is nonnegative and real, and it corresponds to the intensity of a specified mode.

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#lengyongbin@sinap.ac.cn

For 1D interferometer application, the horizontal and vertical distribution is totally independent with ideal configuration. In this case interference image can be fully decoupled using SVD method and interference flange can be retrieved from horizontal matrix U directly. Since the whole IMG matrix was used to do SVD analyse there is no information abandoned and the maxima SNR can be get with this method.

Figure 2 shows a typical SVD result of interference image acquired with almost perfect system configuration. Only the mode #1, which horizontal vector is interference flange, vertical vector is gaussian distribution and singular value is much larger than other modes, is true physical mode. The all rest modes stand for random noise which can be removed.

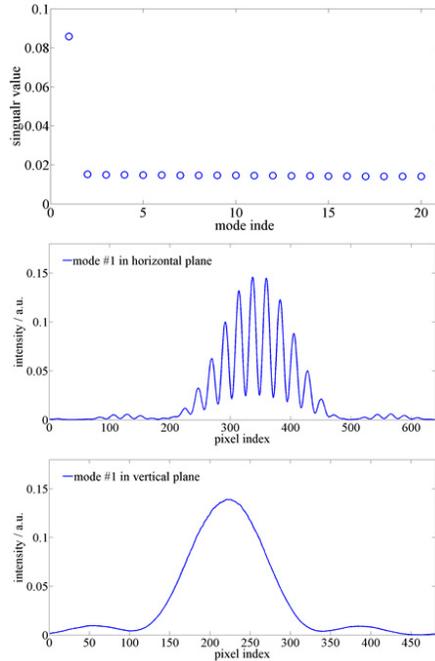


Figure 2: Raw image data processing result using PCA method: singular value (top), horizontal distribution of mode #1 (middle) and vertical distribution of mode #1.

If there is any misalignment between double slit and CCD the independency between horizontal and vertical distribution pattern will be crashed. Then SVD will give us more than one mode and the singular value of mode #2 will be large than noise floor. Let's define a new factor

$$\sigma_{12} = S_{11}/S_{22} \tag{2}$$

as normalized singular value of mode #2. This factor σ_{12} will be very sensitive to misalignment angle and can be used to detect and fix this misalignment.

BEAM EXPERIMENT

To verify the feasibility of PCA method two set of beam experiments were carried out in the SSRF ring. Low beam current (10mA) experiment was set to investigate random noise reduction effect. High beam current (240

mA) experiment was set to check the feasibility of misalignment angle detection and comprehension.

Random Noise Reduction

Usually we can get high quality data from interferometer during daily operation since visible light signal is strong enough due to high beam current (large than 200 mA), low CCD gain (minimal) and large exposure time (typical 0.2s). But if we want to increase data updating rate or measure beam size with very low beam current we have to decrease exposure time and increase CCD internal gain. In this case the SNR of raw image will be poor and pre-processing will be required.

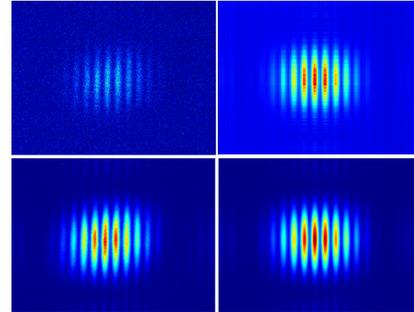


Figure 3: Interference image before and after noise reduction using PCA method: shutter speed 50ms before noise reduction (left-top); 50ms after noise reduction (right-top); 1s before noise reduction (left-bottom); and 1s after noise reduction (right-bottom).

To investigate the feasibility of random noise reduction of PCA method series of image data were taken with different shutter speed configuration under 10mA low beam current condition. Fig 3 shows the image pre-processing result, which indicates that PCA is very effective for poor SNR data (shutter speed 50ms) but not so effective for good SNR data (shutter speed 1s).

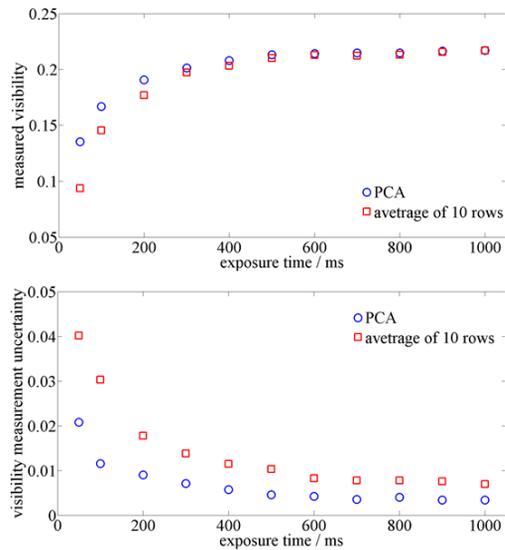


Figure 4: Investigation of shutter speed effect: measurement error (top) and measurement uncertainty (bottom).

Figure 4 shows the measurement error comparison of PCA method and old projection method. It is obvious that PCA method has better performance.

Misalignment Angle Detection

Another series of beam experiment was carried out to demonstrate the misalignment angle detection using PCA. By rotating CCD angle from 166 degree to 194 degree with step of 2 degree we can simulate misalignment between double slit and CCD from -14 degree to +14 degree.

Figure 5 shows the singular value variation depends on misalignment angle. It is easy to find that more independent modes show up with angle increasing from 0 degree to 14 degree just like expecting.

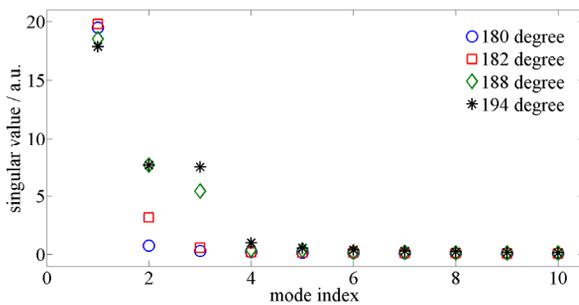


Figure 5: Singular value VS misalignment angle.

Figure 6 shows the dependency between rotation angle and normalized singular value of mode #2. The sharp peak at the zero degree (180 degree) indicates that we do find a very sensitive flag for misalignment angle detection.

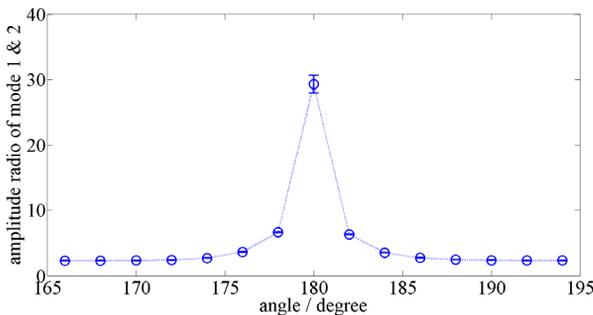


Figure 6: Normalized singular value of mode #2 VS misalignment angle.

For acquired image the following pre-processing can be used to check if there is misalignment angle or not: a) rotate digitized image in two direction (clockwise and anti-clockwise); b) do SVD for every rotated image and get the normalized singular value of mode #2; c) plot the normalized singular value of mode #2 VS rotating angle, the peak index indicates the misalignment angle; d) the corresponding rotated image is corrected data.

Figure 7 shows an example of misalignment angle detection. In this example a small angle of 3.75 degree was detected.

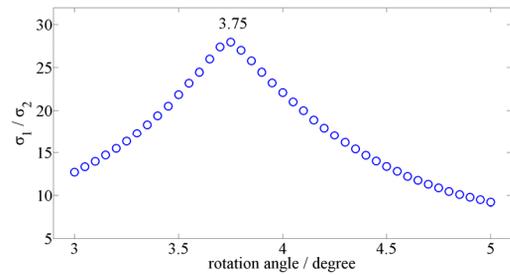


Figure 7: Misalignment angle detection using normalized singular value of mode2 as flag.

In order to find the relationship between mode #1 and mode #2, the horizontal and vertical vector of mode #2 and the differential curve of mode #1 were plotted together in Fig. 8. It is obvious that they match each other very good.

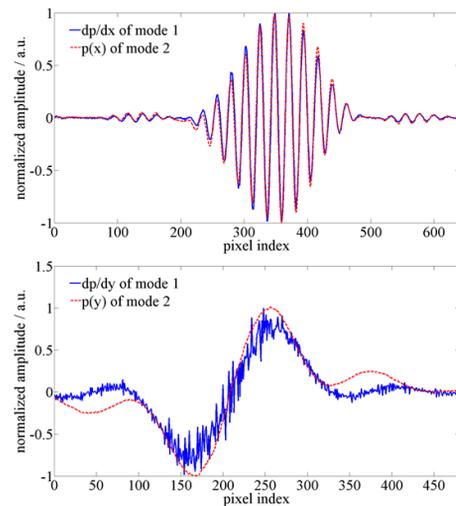


Figure 8: Horizontal vectors (top) and vertical vectors (bottom) using PCA in small misalignment angle case.

CONCLUSION

The PCA was applied in interferometer image data analysing. Compared with direct projection method PCA is better to retrieve more information and improve image data quality especially in poor SNR condition. The PCA has also been proved to be a very sensitive tool to detect the misalignment angle between double slit and CCD.

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