A method for calculating the center position of collimated light*

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It is a key problem to accurately calculate beam spots' center of measuring the warp by using a collimated laser. A new method, named double geometrical center method (DGCM), is put forward for the first time. In this method, a plane wave perpendicularly irradiates an aperture stop, and a charge couple device (CCD) is employed to receive the diffraction-beam spots, then the geometrical centers of the first and the second diffraction-beam spots are calculated respectively, and their mean value is regarded as the center of datum beam. In face of such adverse instances as laser intension distributing defectively, part of the image being saturated, this method can still work well. What's more, this method can detect whether an unacceptable error exits in the courses of image receiving, processing and calculating. The experimental results indicate the precision of this method is high.

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Collimated laser-based has been widely applied in machining, dam-detecting and railway-building.[1-8] How to receive the beam spots and calculate its center position has great influence to the measurement precision. To that end, symmetry method, curve-fit method, and barycenter method[9-11] are usually used when a charge coupled device (CCD) detector is used as the beam receiver. For these traditional methods, a minute change of the energy distribution of the laser beam spots must result in the shift of the result.[8,12] Commonly, such error can not be found out. Therefore, these methods can not be widely used on account of the employing locale condition often generates the change of the energy distribution.

In this paper, we propose a new method for calculating the center position, namely double geometrical center method (DGCM). In DGCM, we select two diffraction rings generated by the circular aperture diffraction of a plane wave, and calculate these two rings' geometrical centers. Thus, the average of these two centers is acted as the center position of the beam spots. Without question, the change of the energy distribution has little influence on DGCM.

For the unit-amplitude plane wave perpendicularly irradiating on the diffraction screen, its complex amplitude z_1 behind the diffraction screen can be expressed as[13]

$$E(x_0, y_0) = \frac{\mathrm{e}^{\mathrm{i}kz_1}}{\mathrm{i}\lambda z_1} \mathrm{e}^{\mathrm{i}\frac{\pi}{\lambda z_1}\left(x_1^2+y_1^2\right)} T(u,v) \tag{1}$$

where x_0 and y_0 are the coordinates in the observation spots, x_1 and y_1 are the coordinates in the aperture stop. In Eq.1, $\mathrm{e}^{\mathrm{i}kZ_1}/\mathrm{i}\lambda z_1$ is a constant, $e^{i\frac{\pi}{\lambda z_1}(x_0^2+y_0^2)}$ is a quadratic phase quantity, and $T(u,v)$ is the Fourier transform of the diffraction screen transmission coefficient. This formula indicates that the complex amplitude is proportional to the Fourier transform.

For an aperture stop with radius R, $T(u,v)$ can be calculated by

$$T(u,v) = \pi R^2 \left[\frac{J\left(2\pi R\sqrt{u^2+v^2}\right)}{2\pi R\sqrt{u^2+v^2}} \right] \tag{2}$$

where $J(\ )$ is zero Bessel function.

The distributing of the optical wave field can be viewed as the field of one dimension moving around the center. Therefore, Eq.2 can be simplified in one dimension coordinate as:

$$T(u) = \pi R^2 \left[\frac{\mathrm{J}(2\pi R u)}{2\pi R u} \right] \tag{3}$$

Since the intensity distribution, $I(u)$, is proportional to the module square of the Fourier transform, the intensity distribution of one dimension (shown in Fig. 1) can be obtained from Eq.3:

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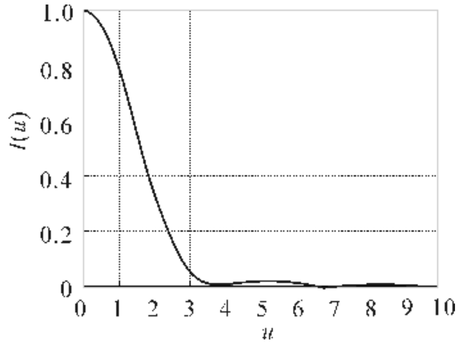


Fig.1 One-dimension intensity distribution

It is obvious that the diffraction rings of all levels (DRAL) are homocentric, which means that the geometrical centers of DRAL along the beam form a line. By the same token, the geometrical centers of DRAL can compose a datum line of warp measuring.

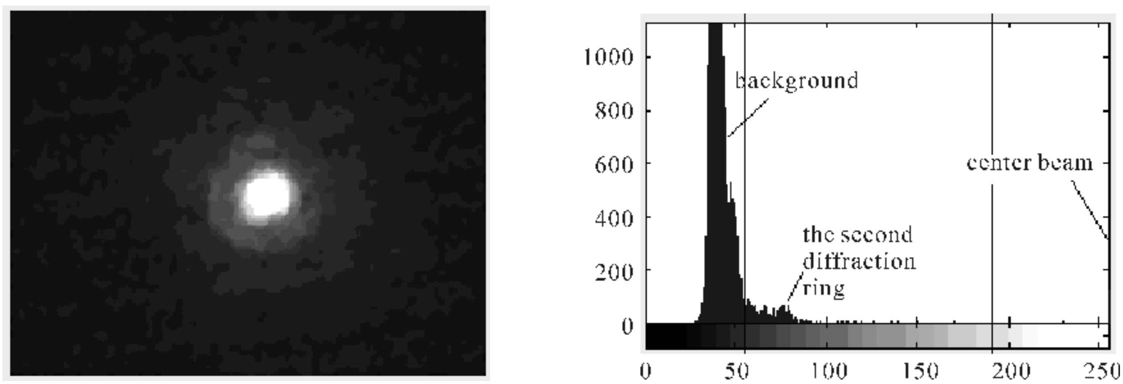
According to the theory described above, using the mean value of the geometrical centers of DRAL can effectively reduce the error of image collecting, processing and calculating. For example, if n diffraction rings are adopted arbitrarily, the error can be reduced by the factor of $\sqrt{n}$. Meanwhile, the threshold could be set to ensure acceptable mean value (here the threshold is 0.008 mm). Specifically, if the difference of any two centers is smaller than the threshold, the mean value is acceptable; otherwise, the mean value is unacceptable and the image must be recollected, reprocessed and recalculated.

In order to retain the definition of the center spot, light intensity should be attenuated properly, which in turn makes it difficult for the third diffraction ring to be distinguished from the background noise when a CCD is used to sense images. Therefore, only the center spot and the second diffraction ring will be selected for calculating the geometrical centers in DGCM, and the mean value of these two centers will be considered as the datum if they satisfy the threshold criteria.

According to the characteristic of the beam spots and the intention of the image processing, such methods are adopted as follow:

1) Adjusting the contrast

When the light intensity is attenuated, the gray value of the second diffraction ring is close to that of the background. The beam spot and its gray histogram are shown in Fig.2, respectively.



(a) (b)

Fig.2 Original beam spot (a) and its gray histogram(b)

Consequently, certain measures should be taken to increase the contrast between the second diffraction ring and the background. In this paper, a gray-changing function (Eq. 4) based on sine function is used to achieve this.

$$f(x)=\frac{D_m}{2}\left\{1+\frac{1}{\sin(a\frac{\pi}{2})}\sin\left[a\pi(\frac{x}{D_m}-\frac{1}{2})\right]\right\} \qquad (4)$$

where grayscale is between 0 and D_m, ‘α’ is between 0 and 1.

The modified beam spot and its gray histogram are shown in Fig.3, respectively.

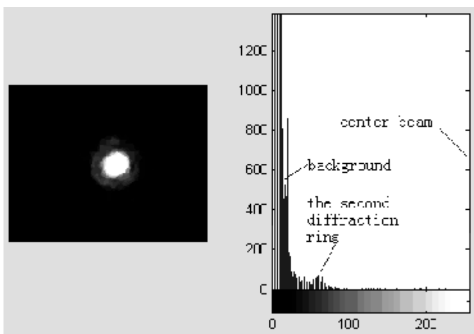
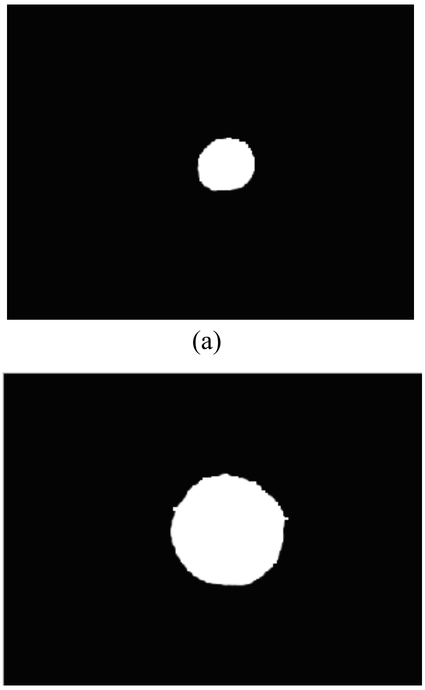


Fig.3 The modified beam spot (*Left*) and its gray histogram(*Right*)

2) Calculating the center

It needs to calculate two geometrical centers in DGCM.

By choosing two different threshold quantities, Fig.2 can be converted into two binary images, one of which contains only the central beam spot, while the other contains the central beam spot and the second diffraction ring. Then the interspace in the two images are filled respectively. After the image-processing is completed, the two new images in Fig.3 can be obtained.



(a)

(b)

Fig.4 Binary image. (a) central beam spot. (b) the second diffraction beam spot

The coordinates (X, Y) of the center position of the beam spot are calculated as

$$X = \left[\frac{\sum_{ij} I_{ij} * i}{\sum_{ij} I_{ij} - 256/2} \right] * c_x \qquad Y = \left[\frac{\sum_{ij} I_{ij} * i}{\sum_{ij} I_{ij} - 256/2} \right] * c_y \tag{5}$$

where I_{ij} is 1 (white) for a (i,j) pixel in Fig.1 with luminance greater than the threshold and 0 (black) for all other pixels; c_x and c_y are the length and width of a pixel respectively.

A lamp-house comprises a single mode fiber (SMF) pigtailed laser diode, a telescopic field-lens, and a circular aperture (Φ 1.0 mm). A CCD detector is used as the beam receiver, which is placed on an exact move-platform (whose precision is 0.005 mm). The walk way of the move platform is parallel to the sensitive surface of the CCD, and is vertical to the laser beam (as shown in Fig.5). The CCD and the laser are 5 meters apart.

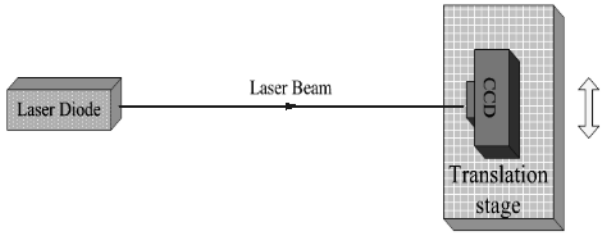


Fig.5 The experimental setup

The move platform goes in the changeless direction, and the CCD detector takes one picture per 0.1 mm. The calculation results of the center position are shown in Tab.1.

Tab.1 Experimental results (unit: mm)

Number	1	2	3	4	5	6	7	8	9
Actual displacement	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900
Calculated value	0.102	0.195	0.301	0.404	0.497	0.605	0.701	0.803	0.896
Difference of two centers	0.008	0.002	0.006	0.006	0.001	0.005	0.002	0.007	0.003

The maximum measurement error of DGCM is 0.01 mm (Tab.1). If the errors due to the translation-stage and the CCD detector can be eliminated, the measurement error would be smaller than the current result.

We proposed a new method, DGCM, for measuring the warp relative to the collimated light beam. The high precision is proved through experimental results. In addition, this method has the following advantages:

1) When calculating the geometrical center, an original grayscale image is converted into a binary image. Since the gray value of every pixel is useless and the holes in the binary image can be filled, small lacunas in the laser-beam spot do not affect the calculation precision.

2) If the first and second diffraction beam spot can be distinguished clearly, partly saturated image is acceptable.

3) An unacceptable error occurring during image collecting, processing, or calculating can be effectively and timely detected through setting the threshold about the difference of these two center positions.

References

[1] ZHU Yu, ZHU Ri-hong, and NIE Shou-ping, ACTA PHOTONICA SINICA, **27** (1998), 189.

[2] Evan D. H. Green, Kulwant S. Brar, Proc. SPIE, **4308** (2001), 25.

[3] JIAO Guo-hua, LI Yu-lin, and ZHANG Dong-bo, Journal of

Zhejiang University SCIENCE A, **7**(2006),1772.

[4] FANG Zhong-yan, YIN Chun-yong, and LIANG Ji-wen, Aviation Metrolrgy & Measurement Technology, **17** (1997), 3.

[5] LU Naiguang, DEN Wenyi, and YAN Bixi, Proc. SPIE, **4222** (2000), 383.

[6] LU Yi-qun, Journal of Beijing Institute of Civil Engineering and Architecture, **18** (2002), 13.

[7] Brommundt, E., Krämer, E., Forschung im Ingenieurwesen, **70**(2005), 25.

[8] LIU Li-hua, ZHANG Zuo, and ZHANG Shang-zhong,. Aviation Metrolgy & Measurement Technology, **18** (1998), 39.

[9] Luedeking, A., Http://www.rsesjoutnal.com.(2005).

[10] Studenberg, D., Http://www.mt-online.com/articles/index.cfm., (2002).

[11] ZENG Ai-jun, WANG Xiang-zhao, and BU Yang, Chinese Optics Letters, **2** (2004),520.

[12] CHEN Qing-shan, LU Nai-guang, and YAN Bi-xi, Computer Measurement & Control, **12** (2004), 486.

[13] Born M, Wolf E., 7th ed. Cambridge: Cambridge University Press.(1999).