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A Calculation Method for Dressing Amount of Monolayer Electroplated Grinding Wheel Based on Zernike Moment

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A Calculation Method for Dressing Amount of Monolayer Electroplated Grinding Wheel Based on Zernike Moment

Li Bin[1, 2, a], Wang Shuai[1,2], Bao Hua[1,2], Chen Xiaoqiang[2]

[1] State Key Laboratory of Superabrasives, China
[2] Zhengzhou Research Institute for Abrasive & Grinding Co., Ltd., China

E-mail: [a]zhifeng920920@126.com

Abstract. Aiming at the difficulties in accurate prediction of the dressing amount of monolayer electroplated grinding wheel, a new calculation method based on image processing was proposed. For the purpose of increasing the measurement precision, all images were captured by CCD camera and a sub-pixel level accuracy edge detection approach based on Zernike moment was used. Two dressing amount of electroplated grinding wheel were calculated by protrusion height and run-out respectively, and the larger number of them was chosen as the optimal dressing amount. Finally, this method is applied to calculate the optimal dressing amount of 30 gothic-arc profile electroplated grinding wheels, and they were dressed by optical contour grinder. The results showed that, form precision of grinding wheels and roughness of workpiece were fine.

1. Introduction
Electroplated grinding wheel is made of a single layer of abrasive which have 60 to 80% of the grit height are covered by the galvanic embedding layer for effective grit retention[1]. With more complex and more precise of profile of grinding wheel, dressing is an essential process after electroplate [2, 3]. Moreover, due to small protrusion height, the using life reduces sharply with excessive dressing amount, and if dressing amount is inadequate, the accuracy cannot meet the requirement. In order to dress the monolayer grinding wheel, many inadequate presented various methods, such as cup dresser dressing [4], electrical discharge dressing [5], laser dressing [6], however, the majority of them were contrast experiment, which did not provide a method for calculating the dressing amount of grinding wheel. In recent research, an image processing method was used to measure wheel wear in curve grinding, and the contour error was less than 2 μm [7, 8]. In this paper, a new calculation method for prediction of dressing amount of monolayer electroplated grinding wheel was proposed. The figure of the grinding wheel was captured by CCD camera and the edge of it is extracted with a sub-pixel level edge detection algorithm based on Zernike moment operator. The optimal dressing amount was determined by reasonable procedure, and then, a precision dressing experiment of gothic-arc profile grinding wheel was carried out.

2. Image processing and calculation

2.1. Zernike Moment and Sub-pixel Level Edge Detection
The kernel of Zernike moment is the set of orthogonal Zernike polynomials defined over polar coordinates inside a unit circle [9]. The Zernike basis function of order n repetition m is

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$$V_{nm}(\rho,\theta) = R_{nm}e^{im\theta} \quad (1)$$

where n is a positive integer or zero, and m is an integer subject to the following constraints: n-|m| is even and . Rnm is given by

$$R_{nm}(\rho) = \sum_{s=0}^{(n-|m|)/2} \frac{(-1)^s (n-s)!\rho^{n-2s}}{s!(\frac{n+|m|}{2}-s)!(\frac{n-|m|}{2}-s)!} \quad (2)$$

Let f be a complex-valued function on the unit disc. The Zernike moment for f of order n repetition m is

$$Z_{nm}^{(f)} = \frac{n+1}{\pi} \iint_{x^2+y^2=1} f(x,y)V_{nm}^*(\rho,\theta)dxdy \quad (3)$$

According to the rotational invariant property of Zernike moment, the Zernike moment of the original image Znm and that of the rotated image Z’nm has following relationship:

$$Z_{nm}^{'} = Z_{nm}e^{-im\phi} \quad (4)$$

It is clear that Zernike moment merely acquire a phase shift on rotation and their magnitudes remain constant. This rotational invariant property is useful for accuracy edge detection.

(a) original image (b) rotated image

Figure 1. Ideal model of the sub-pixel edge detection.

Figure 1 shows that the ideal model of the sub-pixel edge detection. There are four parameters of every edge point: h is the background gray level, k is the step height, l is the perpendicular distance from the center of the circular kernel to the edge, and φ is the angle between l and x-axis. Figure. 1 (b) is generated by rotating Figure 1 (a) with φ. The most important parameters can be calculated as

$$l = \frac{Z_{20}}{Z_{11}^{'}}; k = \frac{3Z_{11}^{'}}{2(1-l^2)^{\frac{3}{2}}} \quad (5)$$

According to the invariant properties of the Zernike moment, angle φ can be expressed as

$$\varphi = \arctan(\frac{\mathrm{Im}[Z_{11}]}{\mathrm{Re}[Z_{11}]}) . \quad (6)$$

Therefore, the sub-pixel level edge position of the image is,

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + l \begin{bmatrix} \cos\varphi \\ \sin\varphi \end{bmatrix} . \quad (7)$$

Moreover, in discrete form, the calculating of the Zernike moment can be simplified to the mask calculating. In this paper, the unit circle is divided into 7*7 homogeneous grids as shown in Figure. 2. Convolving these masks with image points can get Zernike moment Z_{00}, Z_{10}, Z_{20}, Z_{31}, Z_{40} [10].

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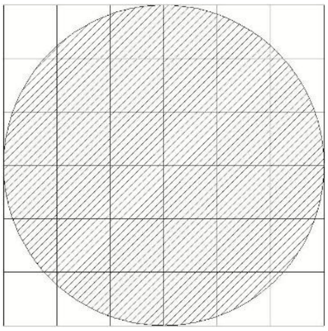


Figure 2. 7*7 mask.

Considering with the model effect, the sub-pixel level edge position of N*N mask can be improved as

$$\begin{bmatrix} x_s \\ y_s \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix} + \frac{Nl}{2} \begin{bmatrix} \cos\varphi \\ \sin\varphi \end{bmatrix}. \quad (8)$$

2.2. Calculate Dressing Amount Based on Protrusion Height

The protrusion height of electroplated grinding wheel is the distance between tip of abrasive and galvanic embedding layer. In theory, the grain size of abrasive follows the normal distribution, and the galvanic embedding layer has same level, as a result, the protrusion height follows normal distribution as well. However, such as 120/140 Cubic Boron Nitride, the extreme size of it is from 75 to 195 μm and range is 122 μm. Therefore, it is difficult to reduce the standard deviation by selecting grain. Chip space decreases with reduction of mean protrusion height, and amount of grains in the contact zone cuts down when standard deviation increases, which leads to increase of grinding force and surface roughness. As a result, one of the function of dressing is reducing the standard deviation while keeping the mean protrusion height.

Due to the random distribution of abrasive attached on abstract, the highest protrusion contacts the workpiece earlier than others. Figure 3 shows that the grinding wheel is divided to 8 homogeneous areas along the width direction, and the largest protrusion height of each area can represent the situation of this area. As a consequence, the mean protrusion height and standard deviation of grinding wheel can be calculated as long as superposing the largest protrusion height of each area into one image.

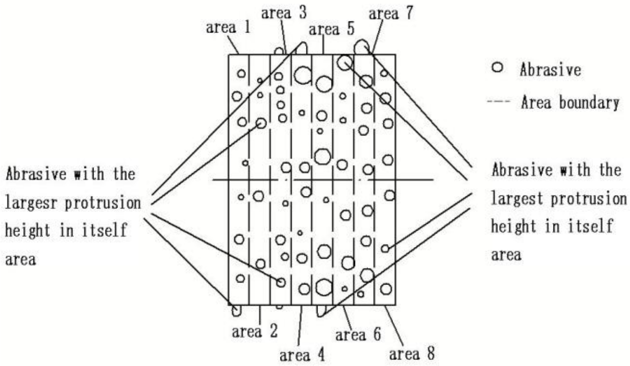


Figure 3. Largest protrusion height.

In this paper, optical contour grinder is chosen as dressing tool, and one of its properties is that the dresser can only feed along one direction while tool track is the nominal profile. The dressing amount, which means the reduction height of grains, of each area of complex profile grinding wheel contained line and arc is different, although the feed amount is same. According to the Figure 4, profile of grinding wheel is arc and dresser (not shown in the figure) feeds along X direction. The area painted black represents dressing amount and the volume of them shows that the dressing amount increases from area 1 to 5 and decreases from 5 to 8. Therefore, dressing amount can be calculated if a reasonable algorithm is proposed to process the superposition image, which can meet the function of dressing mentioned below.

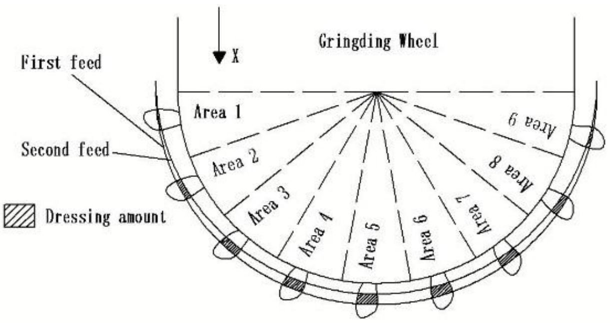


Figure 4. Reduction height of grains with same feed amount.

2.3. Calculate Dressing Amount Based on Run-out.

Another function of dressing is reducing the run-out of grinding wheel. Due to uneven surface, non-contact measurement is the most common method for measuring run-out of grinding wheel. For complex profile, such as the arc shown in the Figure 4, radius of fitting circle according to all grains of each section is different. Consequently, the range of those radius can be chosen as dressing amount.

3. Experimental set-up and step

3.1. Experimental Facilities

In this paper, gothic-arc chosen as experimental profile is a combined curve of two arcs with the same radius and shifted centers, and its fundamental requirements shown in the Table.1. Thereinto, contact angle is the angle between the line, which is connected between the tangent point of the gothic-arc and 3mm radius circle named A and center of A, and the vertical direction. In addition, the roughness Ra of workpiece grinded by grinding wheel after dressing is less than 0.6 μ m.

Table 1. Fundamental requirements of gothic-arc profile grinding wheel.

Size	Grit designation	Contact angle(Left)	Contact angle(right)
30*10*8-R3.118	120/140	42±3°	42±3°

Image measuring instrument with CCD camera and contourgraph contains function of measuring roughness were chosen as detecting instrument and optical contour grinder was used in dressing process. Table.2 shows the parameters of these facilities.

Table 2. Parameters of experimental facilities

CCD camera	Type	Port View 300
	Pixels in image output[pixel]	1280(h) x 1024(v)
	Vision field[mm]	5.69(h) x 4.55(v)
Optical contour grinder	Type	SPG-W
	Rotational accuracy[μm]	1
Dresser	Size[mm]	3F1 125*31.75*6
	Bonding	V
	Revolution[rpm]	6500
Contourgraph	Type	T8000RC200-400

3.2. Experimental Step

As shown in Figure 5, CCD camera captured a mass of images while the grinding wheel was rotated slowly by hand. After the edge position of each image shown in Figure 6 (a), of the grinding wheel is detected based on Zernike moment, which is shown in Figure 6 (b), and the threshold was subject to the following constraints:

$$l \le l_t = \bar{l} \bigcap k \ge k_t = \bar{k} \tag{9}$$

Considering pixels in image out and vision field in Table.2, the vertical and horizontal distance represented by each pixel could be calculated as

$$\begin{bmatrix} v \\ h \end{bmatrix} = \begin{bmatrix} 4.55/1024 \\ 5.69/1280 \end{bmatrix} = \begin{bmatrix} 0.0044 \\ 0.0044 \end{bmatrix} \tag{10}$$

Figure 6 (c) was the profile of one section of grinding wheel after translating sub-pixel edge position to actual size. And then, this profile was divided in two parts, named left arc and right arc, with the highest point as demarcation point. Furthermore, radius of right and left least-square circle of each image were denoted by set {R1，R2 …Rn} and set {L1，L2 …Ln}. After calculating the range of two sets, the larger number was chosen as the dressing amount, named V1.

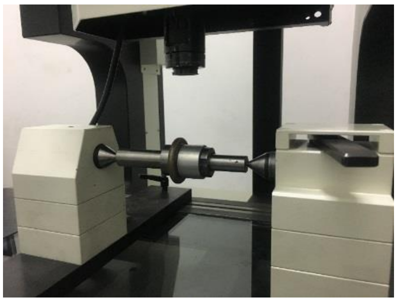
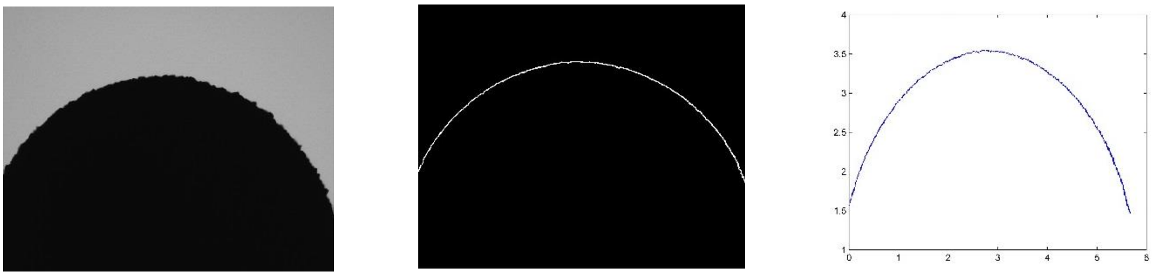


Figure 5. Appearance of image capture system.



(a)Original image （b）Edge position （c）Actual size

Figure 6. Image processing based on Zernike moment.

Moreover, superposing all images which were grayed before into one image, and edge position was calculated based on Zernike moment. Similarly, radius and center of left and right least-square circle were calculated, and the difference between data points and radius were calculated as the protrusion heights. After that, using the algorithm to calculate mean protrusion height and standard deviation under increased feed amount, and optimal feed amount was chosen as the dressing amount based on protrusion height, named V2. At last, larger number of V1 and V2 was chosen as optimal dressing amount, and carbon sample was grinded by the dressed grinding wheel, as shown in Figure 7.

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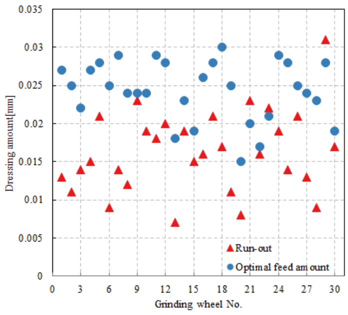
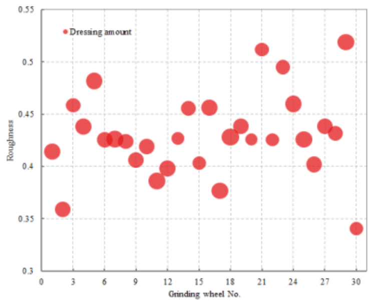
Figure 7. Carbon sample.

4. Experimental result

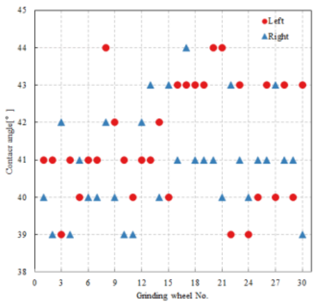
According to above-mentioned set-up and step, 30 gothic-arc were dressed in the experiment. Dressing amounts and measuring results of carbon sample were shown in Figure 8.



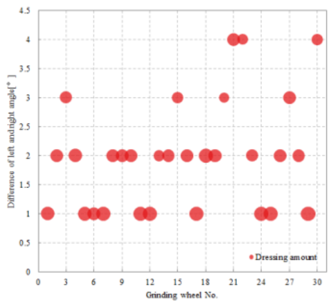
(a) Dressing amount



(b) Roughness vs dressing amount



(c) Contact angle vs grinding wheel No



(d) Contact angle vs dressing amount

Figure 8. Dressing amounts and measuring results.

Figure 8 (a) shows that the majority optimal dressing amount were calculated based on protrusion height, besides No.21， 23， 29 were in opposite, which meant radius of each section was similar. Moreover, the number of experimental grinding wheel which led to greater roughness value of workpiece were 5, 21, 23, 29, dressing amount of three of them were calculated based on run-out. In a word, surface roughness of workpiece was better if the dressing amount was calculated based on protrusion height than based on run-out, and roughness value increased while dressing amount was bigger than V2.

In addition, Figure 8 (c) shows that left and right contact angle could meet requirement shown in Table.1, and Figure 8 (d) shows that the volume of data point representing dressing amount when the difference of left and right angle was equal to 1 degree was less than that was equal to 4 degree. In other words, the difference of left and right contact angle decreased while dressing amount increased.

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5. Conclusion

Aiming at the difficulties in accurate prediction of the dressing amount of monolayer electroplated grinding wheel, a new calculation method based on image processing was proposed. Conclusions were drawn as follows:

1. With the sub-pixel level edge detector based on Zernike moment, the measurement accuracy is reached about 5 μm.
2. Two calculation method for dressing amount are proposed. One is calculated based on protrusion height, the other is calculated based on run-out. Surface roughness of workpiece is better if the former one is chosen as optimal dressing amount.
3. The proposed image processing system and calculation method are valid. The experimental results show dimensional accuracy of grinding wheel and roughness of workpiece can meet requirements.

6. References

[1] A. Chattopadhyay, L. Chollet and H. Hintermann 1990 On performance of chemically bonded single-layer CBN grinding wheel.*CIRP Annals* **39** 309-312

[2] A. Ghosh and A. Chattopadhyay 2007 Experimental investigation on performance of touch-dressed single-layer brazed cBN wheels. *International Journal of Machine Tools and Manufacture* **47** 1206-1213

[3] C. Dold, R. Transchel, M. Rabiey, P. Langenstein, C. Jaeger, F. Pude, F. Kuster and K. Wegener 2011 A study on laser touch dressing of electroplated diamond wheels using pulsed picosecond laser sources.*CIRP Annals-Manufacturing Technology* **60** 363-366

[4] X. Lin, Z. Wang, Y. Guo, Y. Peng and C. Hu 2014 Research on the error analysis and compensation for the precision grinding of large aspheric mirror surface.*The International Journal of Advanced Manufacturing Technology* **71** 233-239

[5] E. Weingärtner, R. Roth, F. Kuster, M. Boccadoro and F. Fiebelkorn 2012 Electrical discharge dressing and its influence on metal bonded diamond wheels.*CIRP annals* **61** 183-186

[6] E. Westkämper 1995 Grinding assisted by Nd: YAG lasers.*CIRP annals* **44** 317-320

[7] K.-C. Fan, M.-Z. Lee and J.-I. Mou 2002 On-line non-contact system for grinding wheel wear measurement.*The International Journal of Advanced Manufacturing Technology* **19** 14-22

[8] Y. M. Luo and D. J. Hu 2008 Real-Time Measurement and Compensation for Wheel Wear in Curve Grinding Based on Image Processing Method.*Key Engineering Materials* **359-360** 479-483

[9] M. R. Teague 1980 Image analysis via the general theory of moments.*JOSA* **70** 920-930

[10] J.-q. Li 2003 Improved algorithm of subpixel edge detection using Zernike orthogonal moments.*Optical Technique* **29** 500-503