In-situ Measuring Method and Experimental Research on Grinding Wheel Global Surface Roughness

Zhu Jianhui[1, 2, a *], Shi Chaoyu[1, 2, b], Yan Ning[1, 2, c], Zhao Yanjun[1, 2, d], Yang Wei [1, 2, e], Bao Hua[1, 2, f]

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

[a]zjh@zzsm.com, [b]scy@zzsm.com, [c]yn@zzsm.com, [d]zyj@zzsm.com, [e]yw@zzsm.com, [f]bh@zzsm.com

Keywords: In-situ measuring method；Grinding wheel；Wheel global surface roughness；Prediction

Abstract: Aiming at the problem of difficulties in quantitatively evaluating the surface topography due to the complex condition of the abrasive grain in the grinding wheel surface, an in-situ measuring method for the grinding wheel global surface roughness was proposed. Firstly, the grinding wheel global surface topography data was measured through a laser displacement sensor. Secondly, the measured data was analyzed and processed. Finally, the wheel global surface roughness was calculated. The results show that detecting the wheel global surface roughness provides a new idea for the quantitative evaluation of the grinding wheel geomorphology. It is of great significance for the grinding wheel state recognition, grinding performance prediction and grinding process optimization.

1 Introduction

The distributions, geometric shapes and exposed heights of abrasive grains in the grinding wheel surface constitute the wheel micro topography. The differences of abrasive type, bond and manufacturing process lead to a very big gap in grinding performance. However, the grinding performance not only depends on structures and material properties, and more depends on the micro surface topography characteristics of the grinding wheel [1].

Grinding wheel surface roughness could reflect the exposed situation of grains in the surface, and then it becomes available that we can quantitatively evaluate grinding wheel topography, and predict grinding force, grinding temperature and grinding performance.

It is almost blank in the field of grinding wheel surface roughness detection. Common methods for measurement of grinding wheel topography consist of stylus method [2], microscopic method [3,4,5], duplicating method [6], laser cross section method [7], optical scanning method [8], binocular vision method [9], the white-light interferometer method [10], etc. Those methods have a variety of problems such as low efficiency, high cost, big subjectivity, complex operation and difficult quantification, which cannot satisfy the request of in-situ measurement and quantitative analysis for wheel surface roughness.

Laser displacement measurement principle was applied in this paper. First of all, the grinding wheel surface morphology was continuously scanned in a spiral way. Secondly, grinding wheel surface measuring spiral path matrix model was set up. Thirdly, the analysis of measurement data was processed, and the median line of the surface microscopic features was fitted. Finally, the grinding wheel surface roughness quantitative value was calculated.

2 Principle of in-situ measuring

Trigonometric function method [11] was employed for the measurement of grinding wheel topography by a laser displacement sensor. The wheel surface was irradiated by laser emission light, and scattered the light in all directions. Afterwards, some of the scattered light was focused by a lens, which led to an imaging result in the photoelectric detector. And then, the relative displacement, code name y, could be figured out through a contrast with related dimensions in the standard imaging, as shown in the dotted line in Fig.1. The calculation formula base on trigonometric function is as follows:

$$\cos\alpha = \sqrt{(a^2 - n^2)}/a, \qquad \cos\beta = n/y$$

$$\cos\beta = \sin\theta \cdot \cos\alpha - \cos\theta \cdot \sin\alpha$$

$$\frac{m}{n} = \frac{b}{\sqrt{(a^2 - n^2)}}$$

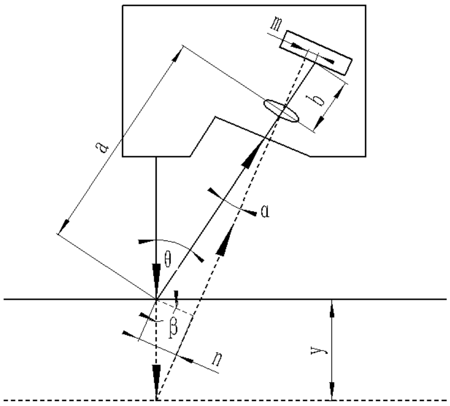


Fig.1 Laser displacement measurement principle

Form formula (1),(2),(3), the calculation formula of the relative displacement is as follows:

$$y = \frac{a \cdot m}{b\sin\theta - m\cos\theta}$$

Laser displacement sensor could realize the dynamic continuous in-situ measurement of grinding wheel surface, as shown in Fig.2. First of all, the grinding wheel in the machine rotated at a constant speed. Secondly, the emission light from laser displacement sensor irradiated through spindle center line, and grinding wheel moved along the axial direction (Z direction in Fig.2) at a constant velocity, code name *v*. Thirdly, laser displacement sensor continuously scanned the wheel's cylindrical surface and collected its topography displacement data, thus finishing the wheel surface non-contact measurement. Finally, effective data was extracted and original topography data of grinding wheel was obtained.

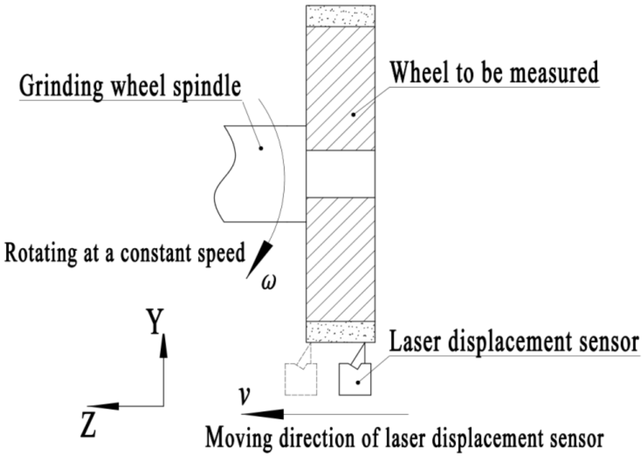


Fig.2 In-situ measuring system of wheel global surface roughness

3 Data processing and quantitative evaluation

Measured topography displacement data was processed and technically analyzed, which made it available that the index parameters of grinding wheel global surface roughness could be figured out.

3.1 Amplitude-limited filter with sliding window

Sensor's singular point data mostly appears with anomaly amplitude, thus amplitude-limited filtering methods can solve the problem of singular noise. Filtering window slid along the collected data point one by one, and the data beyond window threshold was deleted. After filtering window traversed and analyzed all the data, all the singular point data was filtered and eliminated. A set of data, for example, comparison between before and after filtering is shown in Fig.3.

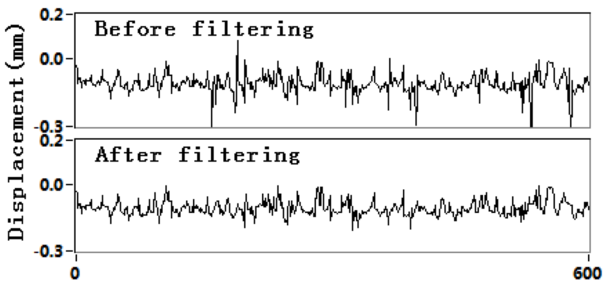


Fig.3 Comparison between before and after filtering

3.2 Grinding wheel surface measuring path matrix construction and regional segmentation

Grinding wheel surface topography displacement data is a one-dimensional scalar array. The measured path information should be incorporated into the array. Therefore, grinding wheel surface measuring spiral path matrix model was built, and point cloud coordinate (c, z, y) system was established. The mathematical expression was shown in formula (5).

$$\begin{cases} c = 6\omega \cdot dt \cdot i - 360(k-1) \\ z = \dfrac{v/\omega}{60/\omega \cdot dt} \cdot i = \dfrac{v \cdot dt \cdot i}{60} \\ y = y_i \end{cases}$$

Where: c is the angular coordinate of the sampling point in the circumferential direction of the grinding wheel, the unit is (°). z is the coordinate of the sampling point in the axial position of the grinding wheel, the unit is (mm). k is the periodic cycle number of the current sampling point. i is the current sampling point number. ω is the rotation speed of the tested grinding wheel, the unit is (r/min). dt is the sampling interval time of the laser displacement sensor, the unit is (s). v is the moving speed of the laser displacement sensor(Z direction), the unit is (mm/min). y_i is the measured displacement data of the current sampling point.

For the constructed matrix model, the data points whose c-axis coordinate values were within (0~2π), were selected in turn, which divided the entire circumference area.

3.3 Topography median line generation

The y-values with different amplitudes were assigned different weighting coefficients in the segmented matrix data. The data points with small amplitude and high confidence probability had large weighting coefficients. The weighted moving average method was used to obtain the median line feature points.

The median line feature points were fitted to the least-squares curve, namely, minimizing the sum of the squared deviations of the approximate curves at each feature point, thereby generating a geomorphologic median line. That is, looking for an approximate curve whose expression was $\varphi(x) = e_0 + e_1 x + \cdots + e_n x^n$.

3.4 Grinding wheel global surface roughness calculation

According to the formula (6), (7), and (8), the RS_a, RS_{ap}, RS_{am}, and their average values in each segmentation matrix were calculated based on the topography median line. The average values were quantitative evaluation indicators for the wheel global surface roughness.

$$RS_a = \frac{1}{m}\sum_{i=1}^{m} |y_i - \tau_i|$$

$$RS_{ap} = \frac{1}{m_1}\sum_{i=1}^{m_1} [(y_i)_+ - \tau_i]$$

$$RS_{am} = \frac{1}{m_2}\sum_{i=1}^{m_2} |(y_i)_- - \tau_i|$$

Where: y_i is the y data in the sub-matrix. τ_i is the corresponding data in the topography median line. $(y_i)_+$ is the y data above the topography median line. $(y_i)_-$ is the y data below the topography median line. m is the number of all y data points in the sub-matrix. m_1 is the number of y data above the topography median line. m_2 is the number of y data below the topography median line.

4 Test and analysis on grinding wheel global surface roughness

The wheel surface roughness was tested through a laser displacement sensor manufactured by Keyence in this experiment. At the same time, specialized data processing and analysis software base on LabVIEW was developed, through which the automatic test and evaluation of wheel surface characteristics were realized. The main performance parameters of the laser displacement sensor are as shown in Tab.1.

Tab.1 Table of the laser displacement sensor parameters

Parameter name	Parameter value
Spot diameter	Φ25 [μm]
Measurement range	±3 [mm]
Resolution	0.01 [μm]
Repeatability	0.02 [μm]
Linearity	±0.02%F.S.

To make a contrastive analysis of the quantitative characteristics of wheel surface roughness, a vitrified bond CBN wheel (1A1-250×20×75mm, 120/140#) was selected and used in the experiment research, which was performed on the type MM7120 surface grinder. And then, the wheel surface roughness and grinding states were examined under different conditions of sharpness and dullness. The related experiment parameters are as shown in Tab. 2.

Tab.2 Table of the experiment parameters

Detecting parameter		Grinding parameter	
Parameter name	Parameter value	Parameter name	Parameter value
Sample interval	2.55 [μs]	Wheel speed	1500 [r/min]
Wheel speed	1500 [r/min]	Grinding depth	0.01 [mm]
Axial velocity	375 [mm/min]	Workpiece material	high-speed steel

4.1 Repeatability test accuracy assessment of wheel global surface roughness

The global surface roughness of the same grinding wheel under two different conditions, sharpness and dullness, were repeatedly detected 10 times. The detection results are as shown in Fig.4. The repeatability standard deviations of RS_a values under two different conditions of sharpness and dullness were 0.094μm and 0.063μm, respectively. Accordingly, the repeatability limits were 0.282μm and 0.189μm with a 95% confidence probability, which were far less than the deviation value of RS_a between sharpness state and dullness state of the same wheel. It follows that the repeatability test accuracy can meet the analysis requirement completely.

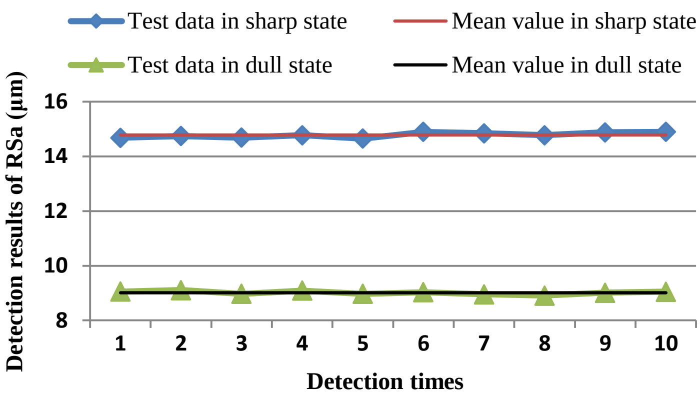
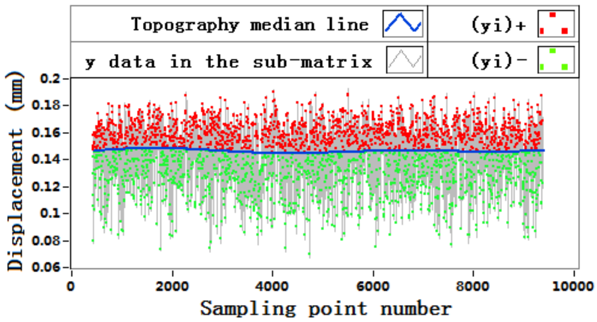


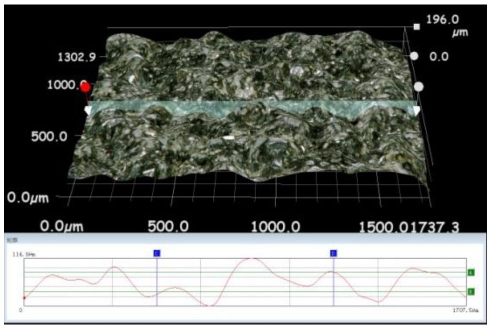
Fig.4 Repeated measurement results of wheel surface roughness

4.2 Quantitative analysis on wheel global surface roughness

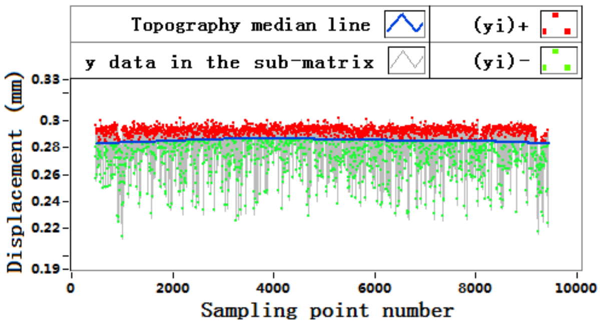
The test data curves of wheel surface roughness and photomicrograph of wheel topography under two different conditions, sharpness and dullness, are as shown in Fig.5. Correspondingly, the index values of wheel surface roughness are as shown in Tab.3.



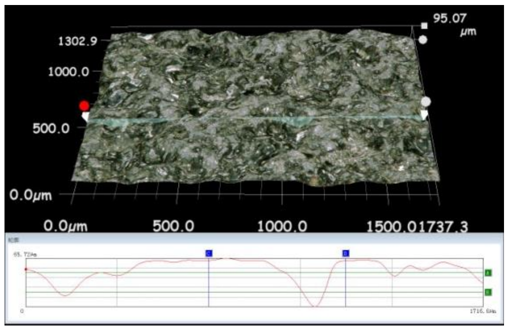
(a) Test data curves with sharpness



(b) photomicrograph with sharpness



(c) Test data curves with dullness



(d) photomicrograph with dullness

Fig.5 Test data curves of wheel surface roughness and photomicrograph of wheel topography

Tab.3 Index values of wheel surface roughness

Wheel state	RS_a [μm]	RS_{ap} [μm]	RS_{am} [μm]
sharpness	14.78	12.93	17.24
dullness	9.01	6.19	14.87

From the analysis results of Fig.5 and Tab.3, it could be seen that the wheel topography and global surface roughness were both different under different conditions of sharpness and dullness. Compared with sharpness state, there were abrasive wear and delamination wear at dullness state, which decreased the exposed height of grains and the depth of concave in the wheel surface. Correspondingly, the index values of global surface roughness were decreased. The RS_a value was comprehensive evaluation of wheel global surface roughness, and the RS_{ap} value was quantitative characterization of the exposed height of grains, at the same time, the RS_{am} value was quantitative characterization of the depth of concave. In conclusion, the index values of wheel surface roughness can quantitatively assess wheel topography, and identify different wheel states of sharpness and dullness.

4.3 Experimental verification of grinding

The curves of grinding power and acceleration RMS of vibration under the two different conditions of sharpness and dullness are as shown in Fig.6.

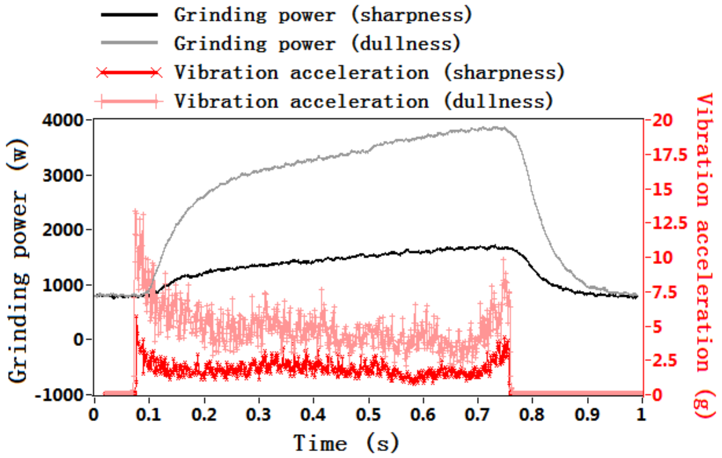


Fig.6 Curves of grinding power and acceleration RMS of vibration

At the sharpness state of wheel, the surface grains were sharp and had high exposed height, as a result, the index values of wheel surface roughness grew big. Accordingly, there were low grinding forces and grinding power in the grinding progress, what's more, the acceleration amplitude of vibration was small and stable. At the dullness state of wheel, the most surface grains were worn away and bond got worn seriously, the index values of wheel surface roughness grew small. There were high grinding forces and grinding power in the grinding progress correspondingly, at the same time, the acceleration amplitude of vibration was large and volatile. Hence one can see that there are great matching and consistency between the test results of wheel surface roughness and the grinding results.

5 Conclusions

(1) The parameters of the grinding wheel global surface roughness were figured out by in-situ measuring method proposed in this paper, which provided a novel idea for the quantitative evaluation of the wheel surface topography.

(2) Experiments were carried out on different conditions with the same grinding wheel. The results show that the repeatability test accuracy of the wheel global surface roughness satisfies the analysis requirements, and the detection results are in good consistency with the wheel characteristics and the grinding performance.

(3) The combination of the laser displacement sensor measuring device and the data

processing analysis software can realize high-efficiency on-machine detection of the wheel global surface roughness. In-situ measuring method is helpful for the identification of the grinding state, the prediction of the grinding performance and the optimization of the grinding process, which is of great significance for the engineering application.

References

[1] NGUYEN A T, BUTLER D L. Correlation of grinding wheel topography and grinding performance—a study from a viewpoint of three-dimensional surface characterization [J]. Journal of Materials Processing Technology, 2008, 208(1): 14-23.

[2] Huang Y L, Yu W. Experiment study on surface profile character of ultra-fine grits wheel after dressing [J]. Aviation Precision Manufacturing Technology, 2009, 3(45): 5-6.

[3] Su C, Shi Z H, Liu Y W. Topography modeling and grinding simulation of vitrified bonded CBN wheel [J]. China Mechanical Engineering, 2012, 23(14): 1742-1745.

[4] L.Blunt. S.Ebdon. The application of three-dimensional surface measurement techniques to characterizing grinding. Int.J.Mach. Tools Manufact, 1996, Vol.36(11): 1207-1226.

[5] MYSHKIN N K, GRIGORIEV A Y, CHIZKIK S A, et al. Surface roughness and texture analysis in microscale [J]. Wear, 2003, 254(10): 1001-1009.

[6] Wang D H, Chen J F, Qiao G Q. Research on the surface state evaluation of grinding wheel dressing quality [J]. Journal of Zhongyuan Institute of technology, 2006, 17(5): 53-57.

[7] Gong J F, Wu Y Y. Study of grinding wheel morphology measuring technology based on linear structured light[J]. Diamond & Abrasives Engineering, 2010, 30(1): 46-49.

[8] MCDONALD A, .BAUER R, WARKENTIN A. Design and validation of a grinding wheel scanner system to repeatedly measure and optical characterize wheel surface topography[J]. Measurement, 2016, 93: 541-551.

[9] Zhang X F. Fundamental research on the detection technology of grinding wheel topography based on binocular vision principle [D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2007.

[10] Yan L, Rong Y M, Jiang F. Quantitive evaluation and modeling of alumina grinding wheel surface topography [J]. Journal of Mechanical Engineering, 2011, 47(17): 179-186.

[11] Fan Y, Wu S J, Hao D J. Precision measurement of micro-displacement by direct laser triangulation [J]. Journal of Xi’an Technological University, 2018, 38(1): 69-73.