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Paper:

Evaluation of Grinding Wheel Surface Shape on Difference Multiple Helical Dressing Condition

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In the grinding process, a grinding wheel surface is a tool that is directly applied to the workpiece. As the condition of the grinding wheel surface is determined by its dressing conditions, the ability to accurately measure the grinding wheel surface with an applied dressing would enable the prediction of the ground surface characteristics of the workpiece as well as the determination of optimum dressing conditions. Recently, a new dressing method called the multiple helical dressing was proposed, which has led to improvements in the grinding performance. However, there is still no method to quantitatively evaluate the changes in the grinding wheel surface condition caused by multiple helical dressings. In this study, we measured the grinding wheel surface applied with multiple helical dressings using a so-called measured focus position recalculation method to determine whether we can quantitatively evaluate the measured dressing grooves generated on the grinding wheel surface by multiple helical dressings, and the resultant undulated grinding wheel surface shapes. We ground an actual workpiece to demonstrate the effects of changes in the grinding wheel surface shape due to multiple helical dressings on the ground surface of the workpiece. The experimental results show that our proposed measuring method can accurately measure the changes in the grinding wheel surface condition due to multiple helical dressings. We also proposed a method to evaluate the dressing grooves to prove that we can quantitatively evaluate the measurement results of dressing grooves generated by multiple helical dressings. In addition, we evaluated undulated grinding wheel surface shapes as its cylindricities by extracting only the undulation shapes generated by multiple helical dressings. Finally, we performed groove grinding with a grinding wheel applied with multiple helical dressings to reveal the relationship between the ground surface of the workpiece and the grinding wheel surface condition, which demonstrated the effectiveness of multiple helical dressings.

Keywords: grinding wheel, multiple helical dressing, dressing groove, cylindricity of grinding wheel, measured focus position recalculation method

1. Introduction

In the grinding process, the shape of the grinding wheel surface is known to significantly affect its performance as well as the ground surface characteristics of the workpiece [1, 2]. In particular, changes in truing or dressing conditions have significant effects on the ground surface characteristics of a workpiece [3]. If we can measure the grinding wheel surface with high accuracy the optimum truing and dressing conditions can be effectively evaluated with no prestige machining, thereby contributing to a high efficiency in the grinding.

Several methods have been proposed to measure a grinding wheel: a stylus method [4], an image method [5–10], and a laser sensor method [11–13]. The disadvantages of these methods include the abrasion of the stylus in the stylus method, and difficulty in quantitatively evaluating changes in the height direction of the grinding wheel surface in the image method. Although many measurement methods using a laser sensor have been proposed, none have been put into practice owing to issues such as measurement duration and accuracy. Therefore, we propose the measured focus position recalculation method [14, 15] by applying the point autofocus profiling method [16–19], which uses a laser sensor. Our proposed method has been proven to measure the grinding wheel surface condition with high accuracy.

Recent studies have proposed a new dressing method called the multiple helical dressing [20]. In dressing a grinding wheel with a diamond dresser, the diamond dresser is often provided with some cuts passing one way or both ways on the grinding wheel. In contrast, with multiple helical dressings, the dresser approaches the grinding wheel at a controlled angle and moves forward and backward a few times, as shown in **Fig. 1**. In dressing the grinding wheel, the dresser approaches it at the same an-

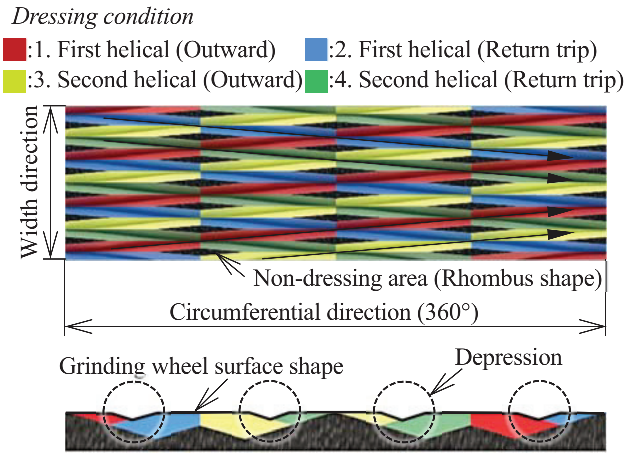


Fig. 1. Schematic of multiple helical dressing (example of double helical dressing).

gle as in machining a multiple-thread screw, shifting the phase by the angle obtained by dividing 360° by the number of times it passes forward and backward (the number of threads). The abovementioned dressing leaves parts of the grinding wheel surface that the dresser did not pass as rhombus-shaped at constant intervals. In other words, the grinding wheel surface was not dressed regularly in its circumferential direction, making it undulated. Such irregularly dressed parts are twice as many as the number of threads. Considering the grinding wheel's rhombus-shaped part as a cutter, the more threads the dresser has, the more cutters are created; hence, the grinding wheel surface dressed by such a dresser should be able to produce an excellent ground surface for a workpiece. In multiple helical dressings, the geometrical patterns that appear on the grinding wheel surface affect the grinding. To quantitatively evaluate the effects of multiple helical dressings, it is essential to measure the changes in the grinding wheel surface condition due to different multiple helical dressing conditions. It is also necessary to develop a method to quantitatively evaluate the dressing grooves and resultant undulated grinding wheel surface shapes.

In this study, multiple helical dressings were applied to a grinding wheel, which was then measured with our proposed measured focus position recalculation method. We also proposed a method to evaluate the dressing grooves generated by the multiple helical dressings and the resultant undulated grinding wheel surface shapes to quantitatively evaluate the grinding wheel surface condition. In addition, we experimentally evaluated the effects of changes in the dressing conditions on the ground surface of a workpiece.

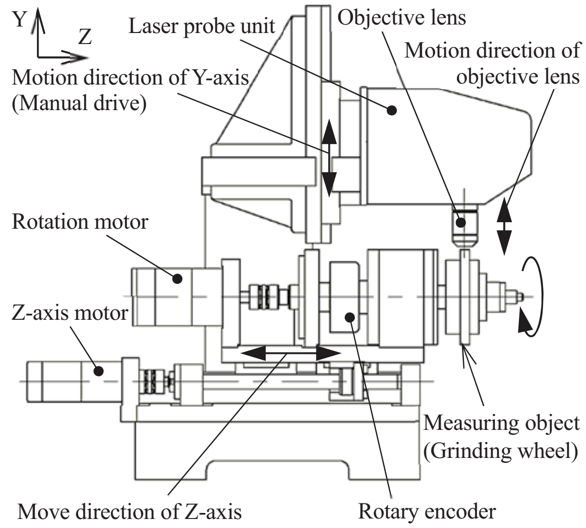


Fig. 2. Schematic of the surface shape measuring device.

2. Measuring Device and Experimental Method

2.1. Measuring Device by Measured Focus Position Recalculation Method

Our proposed measured focus position recalculation method applies a point autofocus profiling method, in which the laser beam is irradiated to the surface of a measured object via an objective lens, and the reflected light is received by a photodiode sensor. The autofocus is achieved by moving the objective lens in such a way that the reflected light is always received by the photodiode sensor at the same position. The surface shape of the measured object is then measured from the autofocus position of the objective lens.

In contrast, in the measured focus position recalculation method, the grinding wheel surface is measured with high efficiency without using the autofocus; the measured object is rotated at a constant speed and the output voltage of the sensor is sampled in the circumferential direction with the objective lens fixed at a certain height. Afterward, the same point is resampled by increasing the height of the objective lens by the measurement interval. These sampling procedures are repeated until the objective lens is raised to a specific height. After measuring all points, the focus position is calculated from the relationships between the output voltage and objective lens height at each circumferential position.

Figure 2 shows a schematic of the prototype grinding wheel surface measuring device. **Table 1** lists the specifications of the measuring device. For the point autofocus unit in the measuring part, we used the MP-3N by Mitaka Kohki Co., Ltd., which was modified to obtain the output voltage of the Si photodiode sensor. The measurement starting point is always in the same phase by setting the Z-phase of the rotary encoder installed on the rotation axis as a trigger. When measuring the grinding wheel surface, voltages in the A- and B-phases were recorded along with

Table 1. Specifications of the surface shape measuring device.

Laser probe unit	Wavelength of laser-beam	635 nm (Semiconductor laser)
	Laser power	1.25 mW
	Light receiving element	Si photodiode sensor
	Spot diameter of laser	ϕ1 μm (when 100 x)
	Magnification of objective lens	100 x
	Movement range of objective lens	10 mm
	Resolution of objective lens	0.01 μm
Resolution of rotary encoder		0.01°
Resolution of z-axial direction		0.5 μm

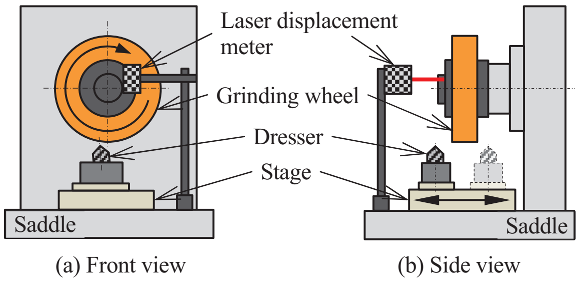


Fig. 3. Schematic of the multiple helical dressing device.

Table 2. Dressing conditions.

	Type	Dressing lead L_d	Dressing pitch P	Dressing depth of cut	Dresser
I	One-way	0.6 mm/rev	0.6 mm	20 μm	Prismatic dresser (□0.3 mm)
II	Single helical				
III	Double helical	1.2 mm/rev			
IV	Triple helical	1.8 mm/rev			

the output voltage of the Si photodiode sensor. To calculate the focus position in each circumferential direction, positional displacements in the circumferential direction were prevented by placing in the position that changes the pulse of the rotary encoder.

2.2. Experimental Method

In the experiments, we used a surface grinding machine to apply four types of dressing to a vitrified grinding wheel WA60J6V (178 mm in diameter × 19 mm) and measured the surface condition after groove grinding.

Table 2 lists the dressing conditions: I for an ordinary one-way dressing where the dresser is fed in one direction; II for another ordinary dressing where the dresser passes forward and backward (single helical dressing); III and IV for multiple helical dressings, i.e., double and triple helical dressings applied in the experiments. We used a prismatic dresser with a side length of 0.3 mm. The dressing pitch P was fixed at 0.6 mm, the dressing depth of cut was 20 μm, and the wheel peripheral speed was 1800 m/min. As in the case of a general multiple-thread screw, the product of the dressing pitch P and number of threads is the dressing lead L_d. Therefore, we only varied the number of threads and the dressing lead L_d in the experiments.

Figure 3 shows the schematic of the device for multiple helical dressings. When applying multiple helical dressings to a grinding wheel, the phase in which the dresser approaches the grinding wheel is very important. Thus, we installed a multiple helical dressing device in the surface grinding machine equipped with a laser displacement meter and dresser-mounted stage. The multiple helical dressing device has its starting point in the phase where the laser displacement meter detects the grinding wheel flange block irradiated with a laser beam. The device also has a mechanism to simultaneously calculate the grinding wheel revolutions. The initial forward and backward dressings were applied by moving the stage in the starting point phase, where the laser displacement meter detected the laser-beam-irradiated grinding wheel flange block. In the second and subsequent forward and backward dressings, multiple helical dressings were applied by moving the stage when the angle of the grinding wheel – calculated from the number of revolutions and time – reached the phase where it matches the number of threads.

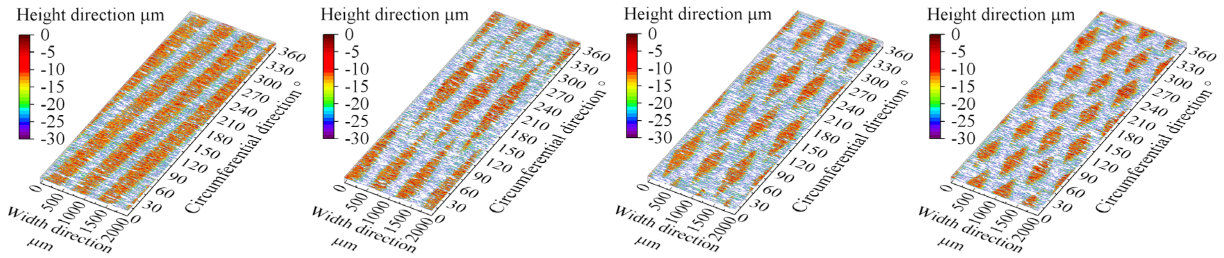
The grinding wheel was measured under the following conditions: wheel peripheral speed of 14 m/min (25 min^{-1}); measurement range of the grinding wheel surface is 360° in the circumferential direction, 2 mm in the width direction, and 50 μm in the height direction; the measurement interval is 0.01° (15.5 μm) in the grinding wheel's circumferential direction, 15 μm in the width direction, and 1 μm in the height direction.

Next, we performed groove grinding on the grinding wheel surface to evaluate the effects of changes in the dressing conditions on the ground surface of a workpiece. During the groove grinding, we cut one pass of grooves on a plastic mold steel NAK55 by plunge grinding. The setting depth of cut was set at 5 μm, the wheel peripheral speed was 1800 m/min, and the table feed rate was 6 m/min. We measured the ground surface shape of the workpiece using a laser displacement meter (LJ-V20), which used a line laser to measure the cross-sectional shape of the object at a rate of 10 μm. We measured the three-dimensional ground surface shape of the workpiece by feeding the laser beam irradiated to it at a rate of 10 μm.

3. Experimental Results

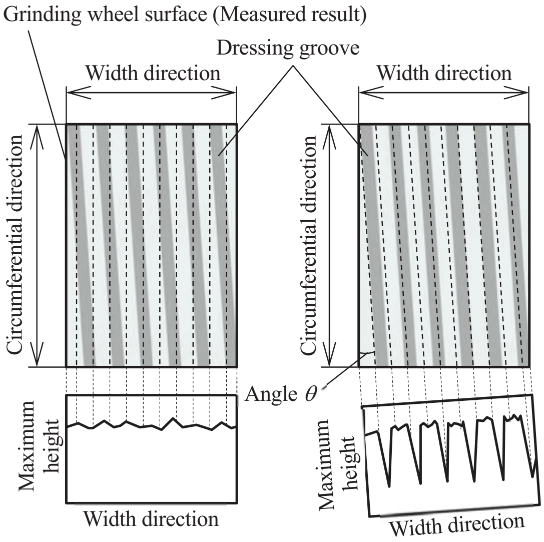
3.1. Comparison of Grinding Wheel's Three-Dimensional Distribution Diagrams

Figure 4 shows the measured three-dimensional distribution diagrams of the grinding wheel surface. The outermost peripheral part is indicated by 0 μm, while the inner parts toward the grinding wheel center are indicated by incremental negative values. We can see from the figure that



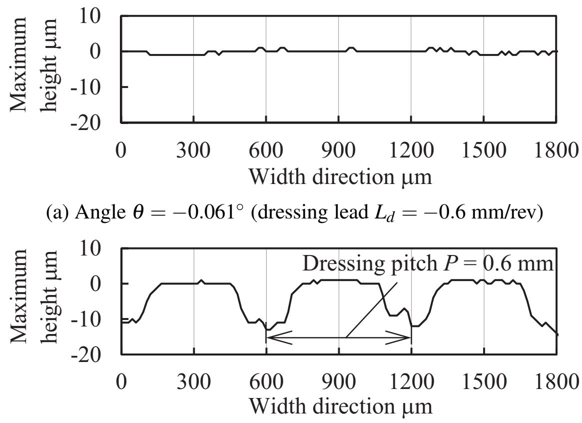
(a) One-way dressing (b) Single helical dressing (c) Double helical dressing (d) Triple helical dressing

Fig. 4. Measured result of three-dimensional surface shape of grinding wheel.



(a) No tilting (b) Tilting angle θ

Fig. 5. Evaluation method of dressing by projected grinding wheel surface shape.



(a) Angle $\theta = -0.061°$ (dressing lead $L_d = -0.6$ mm/rev)

(b) Angle $\theta = 0.061°$ (dressing lead $L_d = 0.6$ mm/rev)

Fig. 6. Evaluation result of dressing groove (one-way dressing).

the grinding wheel surface condition varied greatly at different dressing conditions. In other words, the proposed measuring device measured the grinding wheel surface condition with high accuracy. **Figs. 4(b)–(d)** show the rhombic patterns generated on the grinding wheel surface by the dressings. The arrangement of the rhombic shapes and their number agree with the theory of multiple helical dressings. The measurement results prove that the proposed measuring device can accurately measure changes in the grinding wheel surface condition due to different dressing conditions.

Although the dressings were properly applied, the measurement results in **Fig. 4** do not indicate whether the dressing grooves were created by the corresponding dressing conditions. Thus, we propose a method to quantitatively evaluate the dressing grooves in the following subsection.

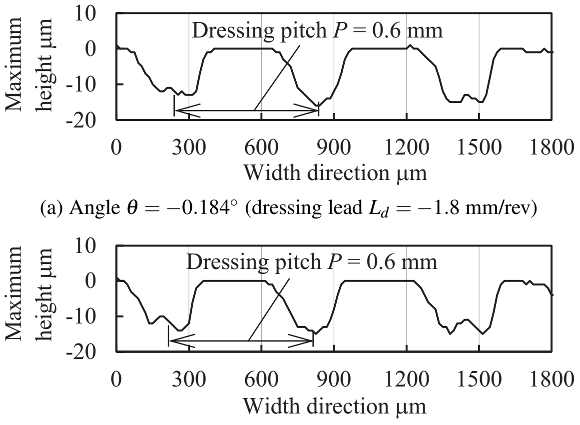
3.2. Proposed Method to Evaluate Dressing Grooves

Figure 5 shows the proposed method for evaluating the dressing grooves. **Fig. 5(a)** shows the schematic of the grinding wheel's cross-sectional shape in the width direction, projecting its measurement results over each other for its full circumference. As every row contains the grinding wheel surface areas that the dresser did not pass, the projected results are expected to provide almost the same values. However, **Fig. 5(b)** shows the schematic of the grinding wheel's cross-sectional shape projected at tilt angle θ; hence, it should be at right angle to the dressing grooves, in which case the dressing groove shapes are transcribed onto the projected measurement results. The transcribed dressing groove shapes enable us to not only evaluate their depths and shapes, but also calculate the dressing pitches from their intervals. The dressing lead L_d can also be calculated from the tilt angle θ and from the grinding wheel diameter D using the following equation:

$$L_d = \pi D \tan\theta. \quad (1)$$

When applying dressings forward and backward, we can recognize the dressing grooves from the projection plane even when the tilt angle θ is negative. The proposed evaluation method enables us to evaluate ordinary dressing conditions as well as multiple helical dressings.

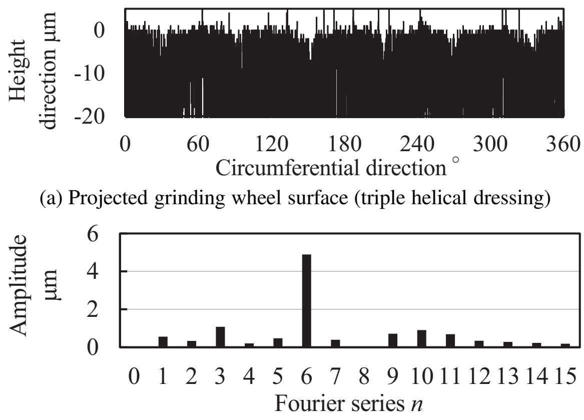
For example, **Fig. 6** shows the evaluation results for the dressing grooves generated by the one-way dressing, while **Fig. 7** shows those by the triple helical dressing. **Fig. 6(a)** shows the evaluation results for the dressing grooves generated when $\theta = -0.061°$ ($L_d =$



(a) Angle $\theta = -0.184°$ (dressing lead $L_d = -1.8$ mm/rev)

(b) Angle $\theta = 0.184°$ (dressing lead $L_d = 1.8$ mm/rev)

Fig. 7. Evaluation result of dressing groove (triple helical dressing).



(a) Projected grinding wheel surface (triple helical dressing)

(b) Result of Fourier series expansion (triple helical dressing)

Fig. 8. Calculation method of undulation shape of grinding wheel.

-0.6 mm/rev), where the dressing grooves generated by the one-way dressing cannot be recognized. **Fig. 6(b)** shows that the dressing grooves are deepest when $\theta = 0.061°$ ($L_d = 0.6$ mm/rev). **Figs. 7(a)** and **(b)** show that the dressing grooves are deepest at $\theta = \pm 0.184°$ ($L_d = \pm 1.8$ mm/rev). In **Figs. 6(b)**, **7(a)**, and **7(b)**, we calculated the dressing pitch P from the distance between the dressing groove centers to obtain $P = 0.6$ mm in each of them. The dressing lead and dressing pitch, as calculated from the tilt angles in both figures, agree with the dressing conditions in **Table 2**. However, the dressing groove depth tends to be slightly shallower than the dressing depth of cut of 20 μm. The elastic deformation of the abrasive grains seems to have made the groove depth shallower than the setting depth of cut. These measurement results prove that the proposed evaluation method can quantitatively evaluate the dressing grooves. The grinding wheel we measured was applied with dressings under similar conditions as in the experiment.

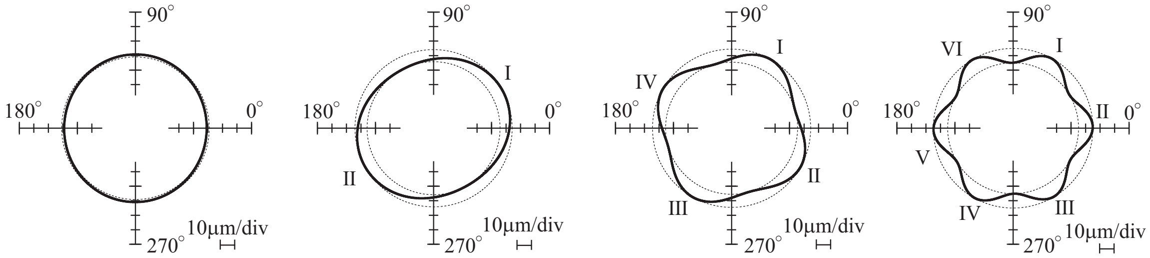
3.3. Evaluation of Undulated Grinding Wheel Shapes

Next, we evaluated whether the multiple helical dressings created undulated grinding wheel surface shapes. **Fig. 8** shows how to calculate the undulated grinding wheel surface. **Fig. 8(a)** shows the cross-sectional shape in the circumferential direction of the grinding wheel surface, projecting the measurement results of the three-dimensional surface shape of the grinding wheel applied with triple dressings, as shown in **Fig. 4(d)**. Despite projecting the grinding wheel surface with numerous irregularities, we cannot determine from **Fig. 8(a)** whether undulated surface shapes were generated because of the large variations in their values. **Fig. 8(b)** shows the Fourier series expanded measurement results, which indicate the highest amplitude at the sixth member in the series. As multiple helical dressings generate an undulation twice as large as the number of threads, in the case of triple helical dressing, the sixth member in the series represents the undulation component generated by the multiple helical dressing. In other words, we can quantitatively evaluate the undulated grinding wheel surface shapes by extracting just the said undulation component.

Figure 9 shows the undulated grinding wheel shapes due to different dressing conditions. It also shows the differences in the height of the grinding wheel's undulations, calculated as its cylindricities. Although no undulations were observed on the grinding wheel surface in **Fig. 9(a)** for the one-way dressing, **Figs. 9(b)–(d)** show an undulation of approximately 10 μm. We counted the number of grinding wheel surface undulations and found that these were twice as many as the number of threads in each multiple helical dressing, in agreement with the theory of multiple helical dressing. These results demonstrate that some undulations were generated on the grinding wheel surface when multiple helical dressings were applied, and that we can quantitatively evaluate the grinding wheel's degree of undulation by calculating its cylindricities.

3.4. Effects of Multiple Helical Dressings on Actual Grinding

Figure 10 shows the measurement results for the ground surface shapes of a workpiece. **Figs. 10(a)** and **(b)** show that for the ordinary dressing conditions, the grinding wheel areas were slightly removed, left striped, or lattice-shaped, which agrees with the tendency of the dressing grooves depicted in **Fig. 4**. This suggests that the dressing groove shapes were transcribed onto the ground surface of the workpiece. On the contrary, **Figs. 10(c)** and **(d)** show that the dressing grooves were very less transcribed onto the ground surface of the workpiece, which can be attributed to the fact that the number of times the grinding wheel came into contact with the workpiece per rotation increased with the increase in the number of threads. In other words, as the number of threads increased, there was an increase in the number of rhombic-shaped cutters that were created, which ground the workpiece surface so well that the dressing groove shapes could not be identified. We may regard the undulated



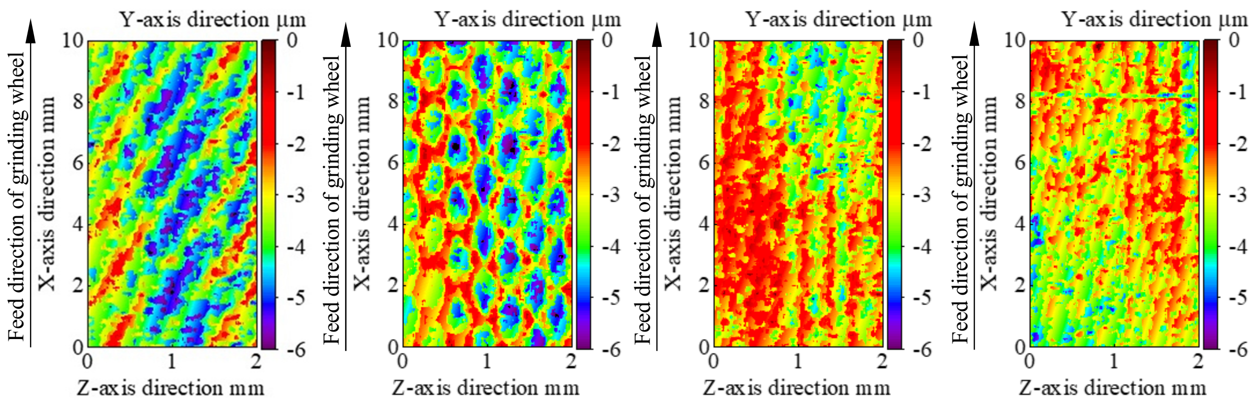
Cylindricity = 1.8 μm
(a) One-way dressing

Cylindricity = 8.3 μm
(b) Single helical dressing

Cylindricity = 9.0 μm
(c) Double helical dressing

Cylindricity = 9.9 μm
(d) Triple helical dressing

Fig. 9. Comparison of undulation shape and cylindricity of grinding wheel due to changes in dressing conditions.



(a) One-way dressing
(b) Single helical dressing
(c) Double helical dressing
(d) Triple helical dressing

Fig. 10. Three-dimensional surface shape of the workpiece after grinding.

grinding wheel shape with the smallest cylindricity in **Fig. 9(a)** as an excellent ground surface for one-way dressing. However, the one-way dressing increased the grinding wheel area that came into contact with the workpiece, which in turn led to the creation of fewer cutters on the grinding wheel surface than those in the multiple helical dressings; this resulted in a low quality ground surface.

These measurement results show that we can quantitatively evaluate the effects of multiple helical dressings on actual grinding by quantitatively evaluating the grinding wheel surface as well as prove the effectiveness of multiple helical dressings through the grinding wheel surface measurement results.

4. Conclusions

To quantitatively evaluate the changes in the grinding wheel surface due to multiple helical dressings, we measured the grinding wheel surface condition using the measured focus position recalculation method proposed in this study. We also quantitatively evaluated the dressing grooves and undulated grinding wheel shapes. We experimentally demonstrated the effects of changes in the grinding wheel surface condition on actual grinding. Our findings are summarized as follows.

(1) The measured focus position recalculation method can accurately measure changes in the grinding wheel surface conditions caused by different dressing conditions.

(2) The proposed dressing groove evaluation method enabled us to quantitatively evaluate the dressing leads, pitches, and dressing groove depths.

(3) We proved via the grinding wheel measurement results that the degree of undulation of the grinding wheel can be quantitatively evaluated as its cylindricities by extracting the undulation components from the Fourier series expansion.

(4) We demonstrated that we can quantitatively evaluate the ground surface shapes of a workpiece based on the changes in the measured grinding wheel surface condition, thereby demonstrating the effectiveness of multiple helical dressings.

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References:

[1] M. Fujimoto, S. Ohishi, R. Hinaga, and Y. Kubo, "Wheel Working Surface Topography and Grinding Force Distributions in Creep Feed Grinding," Int. J. Automation Technol., Vol.12, No.2, pp. 223-229, 2018.

[2] T. Orioka, "Theory of Probability on Generating Process of Finished Surface in Grinding Operation," J. Jpn. Soc. Mech. Eng., Vol.63, No.499, pp. 1185-1193, 1960 (in Japanese).

[3] K. Suzuki and K. Takahashi, "Studies on the Dressing of Grinding Wheel (1st Report) – Measurement on the Number of Grains per Unit Area by the Point Counting Method, and Variation of Dressed Surfaces –," J. Jpn. Soc. Precis. Eng., Vol.30, No.350, pp. 246-252, 1964 (in Japanese).

[4] S. Matsui and J. Tamaki, "Studies on Measuring Method of Wheel Surface Topography (4th Report) – Stylus Method –," J. Jpn. Soc. Precis. Eng., Vol.50, No.4, pp. 672-678, 1984 (in Japanese).

[5] K. Syoji, L. Zhou, and S. Matsui, "Studies on truing and dressing of diamond wheels (1st Report) – The measurement of protrusion height of abrasive grains by using a stereo pair and the influence of protrusion height on grinding performance –," J. Jpn. Soc. Precis. Eng., Vol.55, No.5, pp. 865-870, 1989 (in Japanese).

[6] E. Goto, M. Touge, and Y. Ohbuchi, "In-process Measurement of Wear of Abrasive Grain (4th Report) – High-Speed Visualization for Wheel Working Face –," J. Jpn. Soc. Precis. Eng., Vol.65, No.12, pp. 1804-1808, 1999 (in Japanese).

[7] A. Hosokawa, H. Yasui, M. Nagase, and K. Sato, "Characterization of the Grinding Wheel Surface by Means of Image Processing (2nd Report) – Tracking Measurement of Surface Topography of Grinding Wheel in Grinding Process –," J. Jpn. Soc. Precis. Eng., Vol.65, No.10, pp. 1440-1444, 1999 (in Japanese).

[8] T. Kawashita, A. Sakaguchi, T. Kawaguchi, S. Matui, J. Maeda, and S. Matsuo, "Three-dimensional measurement of wheel surface topography with image processing (4th Report) – High-speed image acquisition by the line camera and analysis of cutting edge distribution using a Voronoi diagram –," J. Jpn. Soc. Abras. Technol., Vol.60, No.8, pp. 442-447, 2016 (in Japanese).

[9] T. Suto, T. Waida, and T. Sata, "In-Process Measurement of Working Wheel Surface in Grinding Operations," J. Jpn. Soc. Precis. Eng., Vol.36, No.429, pp. 676-682, 1970 (in Japanese).

[10] M. Fujimoto, Y. Wu, M. Nomura, H. Kanai, and M. Jin, "Surface Topography of Mini-Size Diamond Wheel in Ultrasonic Assisted Grinding (UAG)," Int. J. Automation Technol., Vol.8, No.4, pp. 569-575, 2014.

[11] H. Sakamoto and S. Shimizu, "On-machine measurement method of grinding wheel cutting edge density considering grain holding stiffness," J. Jpn. Soc. Abras. Technol., Vol.54, No.7, pp. 431-436, 2010 (in Japanese).

[12] H. S. Lee, T. Yamada, and M. Kobayashi, "Development of a 3-D Measuring Equipment for Surface Geometries of Grinding Wheel Surfaces," Proc. of the ASPE 2006 Annual Meeting, pp. 10-13, 2006.

[13] Y. Kakino, A. Matubara, I. Yamaji, K. Matuda, H. Nakagawa, T. Hirogaki, and Y. Kita, "A Study on Measuring Surface Topography of Grinding wheel on the Machine (1st Report) – Development of Measuring System using a Laser Stylus –," J. Jpn. Soc. Precis. Eng., Vol.63, No.2, pp. 228-232, 1997 (in Japanese).

[14] G. Uchida, T. Yamada, and K. Miura, "Evaluation of Grinding Wheel Surface Shape by Different Dressing Condition," Proc. of the 8th Int. Conf. of Asian Society for Precision Engineering and Nanotechnology, C03, 2019.

[15] G. Uchida, T. Yamada, K. Miura, and H. S. Lee, "Measurement of grinding wheel surface shape by measured focus position recalculation method," J. Jpn. Soc. Abras. Technol., Vol.64, No.3, pp. 140-145, 2020 (in Japanese).

[16] ISO 25178-6:2010, "Geometrical product specifications (GPS) – Surface texture: Areal – Part 6: Classification of methods for measuring surface texture," 2010.

[17] A. Sato, "Non-contact Measuring Methods for Areal Surface Texture," J. Jpn. Soc. Precis. Eng., Vol.81, No.10, pp. 922-925, 2015 (in Japanese).

[18] K. Miura, T. Matsuba, T. Tsukamoto, H. Hirose, and H. Kotajima, "Development and Practicality of a Point Autofocus Probe Ultra-precision 3D Whole Circumference Measuring Instrument (MLP-2SP)," J. Jpn. Soc. Precis. Eng., Vol.81, No.2, pp. 113-116, 2015 (in Japanese).

[19] K. Miura and A. Nose, "Accuracy verification of a point autofocus instrument for freeform 3D measurement," Proc. of the 20th Int. Symp. on Advances in Abrasive Technology, pp. 1080-1084, 2017.

[20] K. Ichihara, "Dress mark effect on roundness of grinding wheel and principle of multiple helical dressing and its grinding effect," J. Jpn. Soc. Abras. Technol., Vol.63, No.7, pp. 365-371, 2019 (in Japanese).

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• "Study on the generation of micro shafts by turning operation – 3rd report: Empirical formula for estimation of thrust force on turning process –," J. Jpn. Soc. Abras. Technol., Vol.54, No.12, pp. 737-742, 2010.

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• "On the method to determine the stiffness of grinding machines," J. of the JSPE, Vol.48, No.7, pp. 913-918, 1982.

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• Japan Society for Precision Engineering (JSPE)
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