Title	Measurement of a Grinding Wheel Surface by an Optical Fourier Transform Method
Author(s)	Miyoshi, Takashi; Saito, Katsumasa
Citation	北海道大學工學部研究報告, 120, 13-22
Issue Date	1984-03-30
Doc URL	https://hdl.handle.net/2115/41856
Type	departmental bulletin paper
File Information	120_13-22.pdf

北海道大学工学部研究報告
第120号（昭和59年）

Bulletin of the Faculty of Engineering,
Hokkaido University, No. 120 (1984)

Measurement of a Grinding Wheel Surface by an Optical Fourier Transform Method

Takashi MIYOSHI and Katsumasa SAITO

(Received November 30, 1983)

Abstract

An optical technique based on the optical Fourier transform with a lens system has been developed to estimate the statistical characteristics of the grinding wheel surface and can be applied to the in-process detection of grain wear.

The power spectrum patterns of the grinding wheel surface are observed directly by this optical technique. The grinding wheel surface rotating at 3000 rev/min is illuminated by parallel laser light (wavelength 632.8 nm). The light diffracted on the rotating wheel surface produces an average power spectrum pattern on a plate located at the principal focus of Fourier transform lens.

The relations between the average power spectrum patterns and the grain wear on the working surface of a grinding wheel are obtained and discussed.

From the measurements of average power spectrum patterns, the average width of grain wear flats can be estimated quantitatively on a rotating wheel surface and the critical grinding time, namely, the life time of the grinding wheel can be also determined.

1. Introduction

A common method of studying the grinding wheel surface is by taking microscopic photographs and traversing a stylus across the surafce. However, it is impossible to estimate quantitatively and directly the statistical characteristics of a grinding wheel surface by these methods.

The authors have been investigating the characteristics of the grinding wheel surface by an optical technique based on the optical Fourier transform with a lens system. Miyoshi and Saito (1) measured the power spectrum patterns of the grain distribution on a PVA sponge wheel surface by the optical Fourier transform, although these patterns were obtained from the film of the grain distribution transcribed on-to carbon paper.

The statistical data of the grain distribution, i. e., the orientation and periodicity of the grain distribution, the mean diameter of agglomerates of grains and the mean distance between the agglomerates were estimated in the power spectrum patterns.

This optical technique can also be applied to the in-process detection of the surface roughness. Kamei (2) and Inari (3) observed the power spectrum pattern produced by reflection from a rough surface without a lens system and suggested that this method could be used for the in-process detection of the surface roughness.

In this paper, the power spectrum patterns of the grinding wheel surface are observed

---

Department of Precision Engineering, Faculty of Engineering, Hokkaido University.

directly by the optical Fourier transform with a lens system. The relation between the power spectrum pattern of the stationary grinding wheel surface and the corresponding distribution of worn grains is primarily obtained. Moreover, the average power spectrum patterns around the different grinding wheel surfaces are obtained from the rotating wheel surfaces.

From the measurements of these average power spectrum patterns, the average width of grain wear flats can be estimated quantitatively on the grinding wheel surface rotating at 3000 rev/min, and the critical grinding time, namely, the life time of the grinding wheel can also be determined.

2. Measuring method and experimental procedure

2-1 Optical arrangement

The experimental arrangement for obtaining the average power spectrum pattern around the grinding wheel surface is shown in Fig. 1. The working surface of grinding wheel rotating at 3000 rev/min is illuminated by a parallel laser light (wavelength 632.8 nm) through an aperture (ϕ 10 mm). A cylindrical lens is located in front of the wheel to convert the plane wave into a cylindrical wave.

The light diffracted on the rotating wheel surface produces an intensity pattern called average power spectrum pattern on a plate located at the principal focus of lens L_3. A photograph of the average power spectrum pattern is taken on the plate. The intensity curve of the pattern is also measured through a pinhole (ϕ 1 mm) by a photomultiplier fixed on the table which can move in the direction of x or y within a range of 50 mm and at a traversing speed of 0.25 mm/sec.

Where x, y are two independent variables in rectangular coordinates on the plate. The x-axis is parallel to the direction of the wheel circumference and y-axis to the direction of the wheel axis. Frequency pair (μ, ν), which is called "spatial frequency", is given by

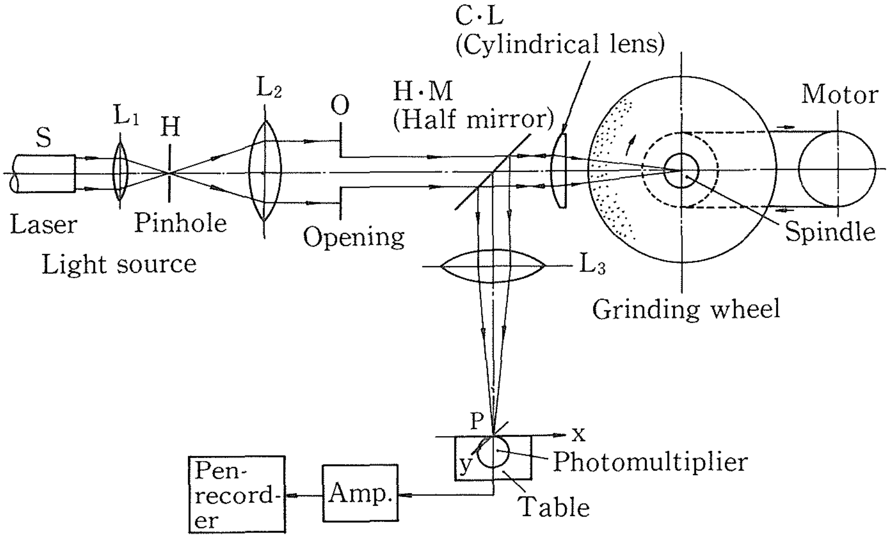


Fig. 1 Experimental arrangement for obtaining the power spectrum pattern of grinding wheel surface

$$\mu = k \cdot \frac{x}{\lambda f} \qquad \nu = \frac{y}{\lambda f} \tag{1}$$

where $k = \frac{f_0}{r}$ (f_0 : focus length of the cylindrical lens, r : radius of curvature of the wheel), λ is wavelength of the laser light and f is focus length of the Fourier transform lens.

2-2 Experimental procedure

The state of the grinding wheel surface changes with radial wheel wear during grinding. The wheel wear experiments are carried out under plunge grinding conditions to obtain different grinding wheel surfaces. The wheel profile is periodically checked by grinding a replica with an edge of a thin steel blade (S45C). The blade is examined on a stylus measuring instrument (Talysurf-4) to estimate the radial wheel wear.

The experimental conditions used are summarized as follows:

work material: S45C
wheel speed: 1700 m/min
table speed: 16 m/min
wheel infeed: 10 μm/stroke
wheel specification: WA46K (V_g : 46.5%, V_b : 9.6%)
ground surface: 120 mm length 12 mm width

where dressing is carried out by using a single diamond in the order of the infeed of 30, 20, 10 and 5μm.

3. Experimental results and discussions

3-1 Power spectrum pattern of a diffraction grating

A number of parallel equidistant strips are sculptured on the aluminum disk wheel surface finished by a diamond tool, with its long dimension perpendicular to the direction of the wheel circumference. The resultant wheel surface has a number of small rectangular reflection surfaces of the same width, which is called a diffraction grating of reflection type.

Assuming the width (b) of each reflection surface to be an average width of grain wear flats and the distance (d) between the reflection surfaces to be an average distance between the worn grains, the grating surface of aluminum disk wheel is considered to be a model of grinding wheel surface.

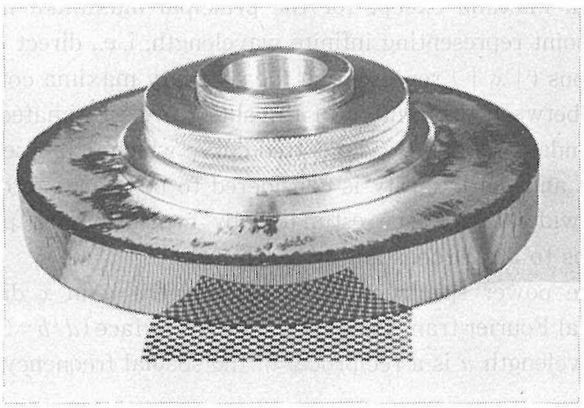


Fig. 2 Photograph of the grating surafce of aluminum disk wheel

Fig. 2 shows a photograph of a grating disk wheel and the wheel surface is seen to be finished like a mirror. The width (b) of each reflection surface is 0.2 mm and the distance (d) between these centers is 0.64 mm.

The power spectrum pattern of this model surface produced by the optical Fourier transform with a lens system is basically equal to the Fraunhofer pattern of an ideal grating for N slits. The intensity (I) in this pattern is generally expressed as

$$\mathrm{I} = \mathrm{A}_0^2 \frac{\sin^2\beta}{\beta^2} \cdot \frac{\sin^2 \mathrm{N}\gamma}{\sin^2\gamma} \tag{2}$$

where $\beta = \frac{\pi \mathrm{bx}}{\lambda \mathrm{f}}$, $\gamma = \frac{\pi \mathrm{dx}}{\lambda \mathrm{f}}$ and A_0 is constant. The factor ($\sin^2 \beta/\beta^2$) posseses minimum values 0 for $x = n\lambda f/b$ and the other factor ($\sin^2 \mathrm{N}\gamma/\sin^2\gamma$) posseses maximum values 1 for $x = m\lambda f/d$. The values of a n and m are both integers.

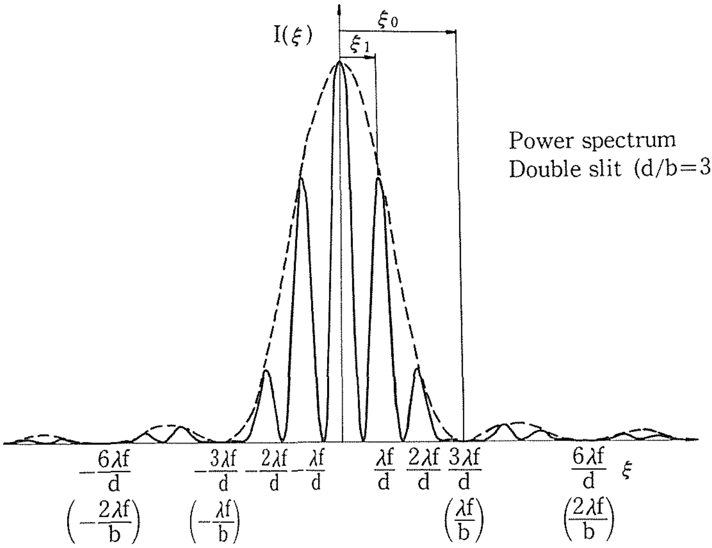


Fig. 3 Power spectrum of ideal grating for N = 2

Fig. 3 shows the power spectrum for a double slit (N = 2) where $d/b = 3$. The power spectrum has several maxima except for the principal maximum in the center which corresponds to the point representing infinite wavelength, i. e., direct current.

Since the positions (| x_1 |) representing the secodary maxima correspond to | $\lambda f/d$ |, the distance (d) between the centers of the slits can be estimated by measuring the positions of the secondary maxima. The dotted curve which expresses ($\sin^2\beta/\beta^2$) falls to zero at x = | λf/b | and the intensity is considered to be nearly zero for x ≦ | λf/b | . Therefore, the slit width (b) can be estimated by measuring the positions where the intensity curve begins to attain constant at nearly zero.

Fig. 4 shows the power spectrum vs. the wavelength u in x direction, which are obtained by the optical Fourier transform of the grating surface ($d/b = 3.16$) of the alminum disk wheel. The wavelength u is a reciprocal of the spacial freqnency u expressed in Eq. 1.

The spectrum is similar to that of the ideal grating shown in Fig. 3. The wavelength

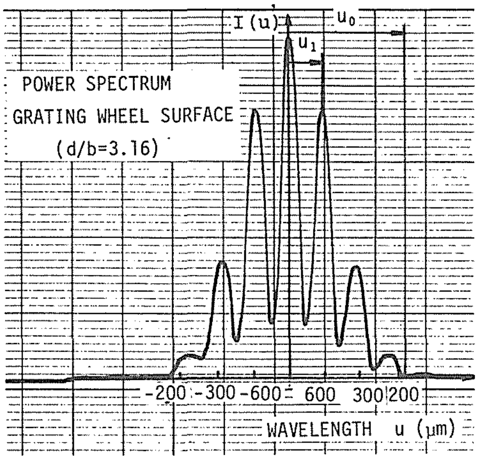


Fig. 4 Power spectrum obtained from the grating wheel surface

($u_1 = \lambda f/kx_1$) which represents the secondary maxima is 0.64 mm and the wavelength ($u_0 = \lambda f/kx_0$) where the power spectrum falls to nearly zero is 0.19 mm. These values u_0 and u_1 are in good agrrement with the distance ($d = 0.64$ mm) between the centers of the surfaces and the width ($b = 0.2$ mm) of eacth reflection surface respectively.

From the theoretical and experimental results, it is found that the proposed optical arrangement produces the correct power spectrum pattern, in which the characteristics of the grinding wheel surface can be estimated quantitatively.

3-2 Power spectrum pattern of a grinding wheel surface

Fig. 5 shows the relation between the grinding times and the radial wheel wear. Phase *A* is a short period of non-linear rapid wear, which is much influenced by the dressing technique. Phase *B* is a long period of 1000-4000 strokes in which the wheel wear occurs

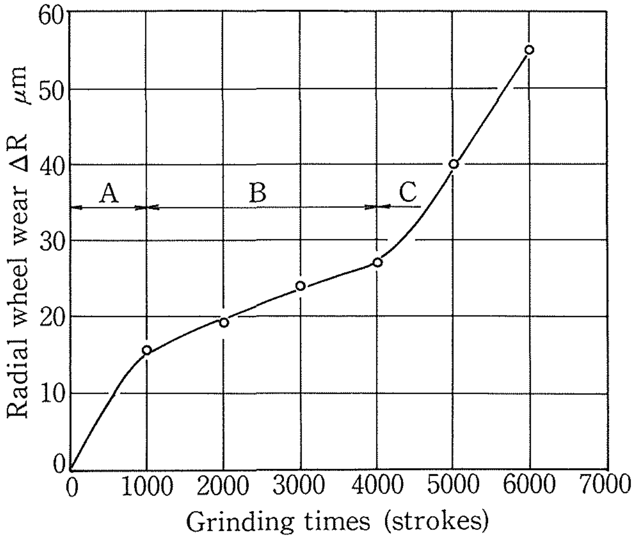


Fig. 5 Relations between grinding times and radial wheel wear

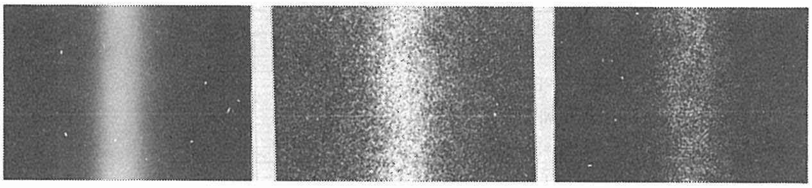


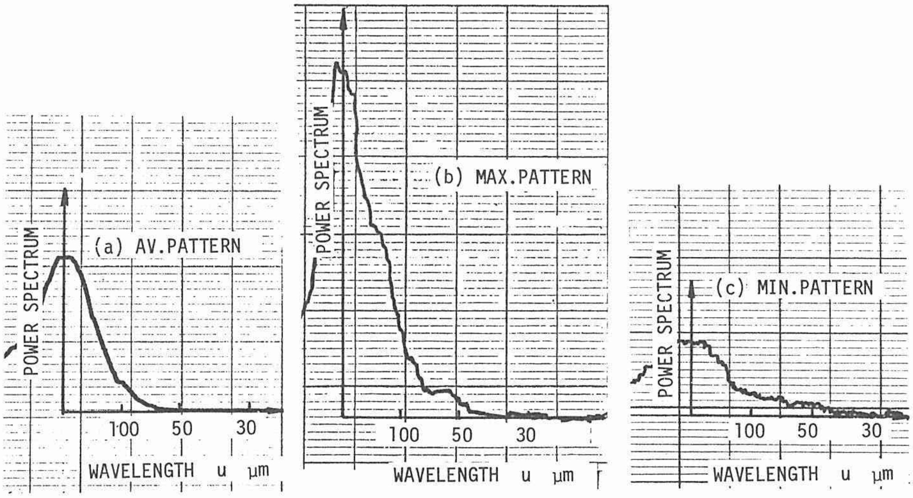
Fig. 6 Photographs of power spectrum patterns obtained from the grinding wheel surface

at a constant and relatively slow rate. Phase *C* is characterized by a rapid increase in wear rate and is generally found in poor grinding conditions.

Fig. 6 shows the power spectrum pattern at grinding times of 3000 strokes. Fig. 6 (a) is an average pattern obtained from the rotating wheel surface. While (b) and (c) of Fig. 7 are the strongest intensity pattern (maximum pattern) and the weakest intensity pattern (minimum pattern) obtained from a certain area on the surface of the stationary grinding wheel. The average pattern is clear compared with the stationary patterns in which numerous speckles can be seen.

The power spectrum pattern in each case is found to be short in *x* direction and long in *y* direction because the reflection is scattered toward *y* by many scratches existing in *x* direction, on the surface of the worn grains (Fig. 8).

The power spectra vs. the wavelength *u* in *x* direction are shown in Fig. 7 (a), (b) and (c), which correspond to the patterns shown above respectively. The curve of average spectrum is smooth and in approximately normal distribution, in comparison with the other curves. The power spectrum in each case has it maximum intensity in the center of spectrum pattern, namely, specular reflection from the grinding wheel surface is focused at the center of power spectrum pattern to produce maximum intensity. The intensity in the center is considered to be in proportion to the number of worn grains when the smear



(a) Av.pattern (b) Max.pattern (c) Min.pattern

Fig. 7 Power spectra in u direction obtained from the grinding wheel surface

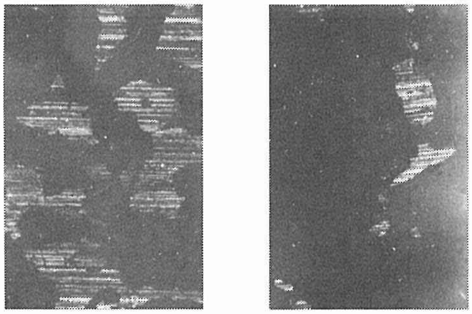

(a) Max. intensity (b) Min. intensity

Fig. 8 Photographs of worn grains on the grindng wheel surface

around the grinding wheel surface is uniform.

Fig. 8 shows the microscopic photographs on the wheel surfaces corresponding to the maximum and minimum patterns. From these photographs, it is found that there exists many worn grains on the wheel surface where the maximum pattern is produced, but only a few worn grains on that where the minimum pattern is produced.

Therefore, the variations of the number of worn grains around the grinding wheel surface can be observed from the center intensity of pattern which is continuously obtained by rotating the grinding wheel.

The grain wear flats appear to be complex features having many different widths as shown in Fig. 8, therefore, the grinding wheel surface is considered to be composed of a number of small rectangular reflection surfaces of many different widths.

By assuming the form of the sequential rectangular wave with a constant amplitude, as indicated schimatically in Fig. 9, the power spectrum in respect to the different widths of grain wear flats may be expressed as

$$\mathrm{I_F} = \mathrm{A}_0^2 \sum_{i=1}^{n} \mathrm{F_i} \cdot \mathrm{b_i}^2 \sin^2 \frac{\pi \mathrm{b_i}}{\mathrm{u}} \bigg/ \left(\frac{\pi \mathrm{b_i}}{\mathrm{u}}\right)^2 \cdot \tag{3}$$

where F_i is relative frequency distribution of grain wear flat widths (b_i) and u is $\lambda f/x$.

The histogram in Fig. 10 shows the relative frequency distribution of the grain wear flat widths obtained from microscopic photographs on the grinding wheel surface and the

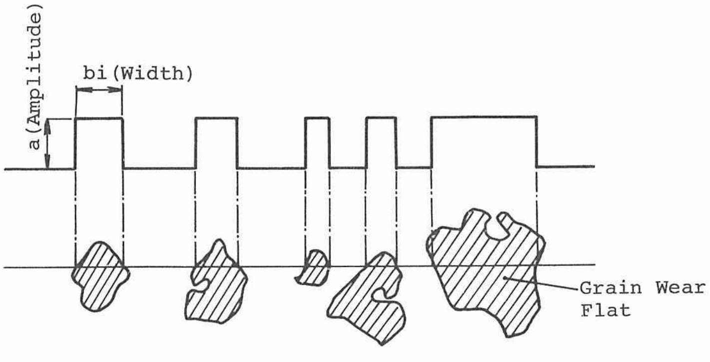


Fig. 9 Optical form of grain wear flat widths on the grindng wheel surafce

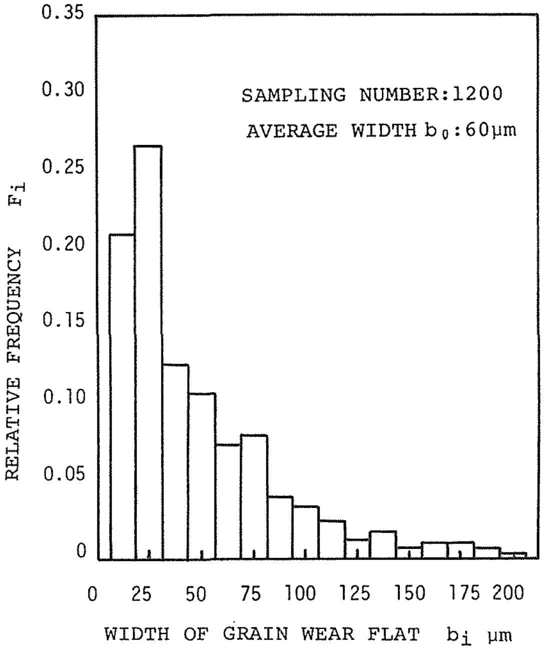


Fig. 10 Relative frequency distribution of the grain wear flat widths

average width is about 60 μm.

The intensity curve (Fig. 11) calculated by inserting the measured values of b_i and F_i into Eq. (3) is similar to the average power spectrum measured by the optical arrangement. The intensity indicating the average width (60 μm) is nearly zero, strictly speaking, the wavelength where the average spectrum falls to 4% of its maximum intensity corresponds to the average width.

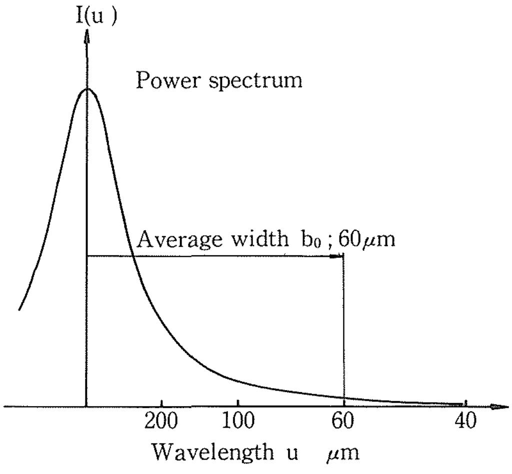
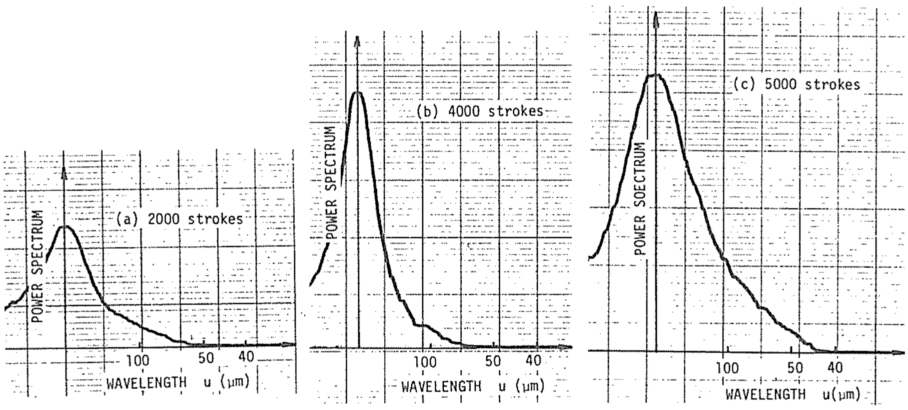


Fig. 11 Power spectrum obtained by calculating the intensity in Fraunhofer diffraction



(a) 2000 strokes (b) 4000strokes (c) 5000strokes

Fig. 12 Average power spectra in u direction obtained from the rotating wheel surface

Fig. 12 (a), (b) and (c) show the average power spectra obtained from the rotating wheel surface, at grinding times of 2000, 4000 and 5000 strokes respectively. The power spectrum at grinding times of 2000 strokes extends to the short wavelength region, while the power spectrum at 4000 strokes falls in the long wavelength region and intensity in the center of the spectrum at 4000 strokes becomes stronger than that at 2000 strokes.

This means that the grain wear rate on the working surface increases with the increase of grinding times until 4000 strokes. The power spectrum at 5000 strokes extends again and is similar to that at 2000 strokes, although the center intensity becomes stronger. This means that the worn grains begin to fall off and the new undressed grains appear on the working surface, namely, that the wheel wear rate increases rapidly beyond 4000 strokes as shown in Fig. 5 Terefore, re-dressing is necessary beyond 4000th stroke, which is considered to be the critical grinding time.

There is no remarkable peak for the average power spectra, in other words, each

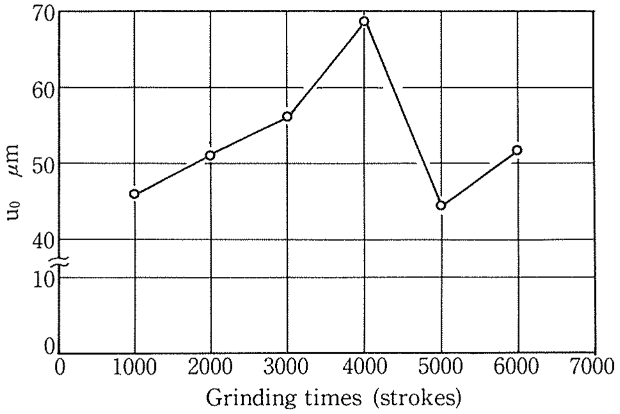


Fig. 13 Relations between grinding times and wavelengths u_0 where the average power spectrum falls to 4 % of its maximum intensity

spectrum is composed of many different wavelengths. This suggests that the worn grains are distributed at random on the working surface.

The position of nearly zero intensity which corresponds to the average width of grain wear flats can be seen clearly in these spectra.

Fig. 13 shows the relation between the grinding times and the wavelength u_0 where the average power spectrum falls to 4% of its maximum intensity. It is found that the curve of u_0 has a relatively sharp peak at 4000 strokes and decreases rapidly at 5000 strokes. Since the curve of u_0 varies remarkably at the critical grinding time of 4000th stroke, the opportunity of re-dressing can be determined by observing the curve of u_0. The average width of grain wear flats can be estimated to be 68μm (maximum value) at 4000 strokes and 44 μm at 5000 strokes by measuring the value of u_0.

width of grain wear flats can be estimated to be 68μm (maximum value) at 4000 strokes and 44 μm at 5000 strokes by measuring the value of u_0.

4. Conclusion

The average power spectrum patterns around the different grinding wheel surfaces are observed directly by the optical Fourier transfrom with a lens system.

From the wavelength where the average power spectrum falls to 4% of its maximum intensity,the average width of grain wear flats can be estimated quantitatively on the grinding wheel surface rotating at 3000 rev/min and the critical grinding time, namely, the life time of grinding wheel can be determined.

From the center intensity of pattern continuously obtained by rotating the grinding wheel, the variations of the number of worn grains around the grinding wheel surface can be detected.

Acknowledgement

The authors wish to acknowledge the support of the Ohkura Yorichika Memorial Foundation.

References

1) T. Miyoshi and K. Saito: "Distribution of Grains on an Elastic Wheel Used in Mirror-Finishing", Proc. of 3rd-ICPE, Kyoto (1977) 290.

2) M. Kamei and T. Inari: "Recognition and Inspection of Surface Roughness by Coherent Diffraction Pattern", Proc. of 3rd-ICPE, Kyoto (1977) 113.

3) T. Inari: "Automatic Detection and Control of Surface Roughness by Coherent Diffraction Patterns", Proc. of 16th-SPIE Annual Meeting, (1972) 47.