In-process Measurement of Topography of Grinding Wheel by Using Hydrodynamic Pressure

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1. Introduction

Wet grinding is one of the major ways of high-precision machining. An error factor in grinding is wear of a grinding wheel. In order to reduce machining error, in-process measurement of the grinding wheel wear is required.

Loading and dulling on a grinding wheel frequently occur under inappropriate grinding conditions. Eventually, the surface of a workpiece is burned. Therefore, it is very important to measure both wear amount and topography change of the grinding wheel during grinding process.

Grinding fluid, which causes the difficulty of the in-process measurement, is often used to cool a workpiece. Some in-process measurement methods of wear of a grinding wheel have been proposed for both dry and wet grinding [1][2].

Some methods to detect or measure loading, dulling and shedding of a grinding wheel have been also proposed by using a triangulation displacement sensor [3] for dry grinding. Because the grinding fluid disturbs light, it must be removed in wet grinding. Sensing acoustics [4] or vibration [5] has been also proposed for both dry and wet grinding. However, they are indirect methods.

Some measurement methods by measuring static pressure caused by applying fluid to a grinding wheel have been proposed [6]-[8]. Because these methods are similar to an air micrometer, superfluous grinding fluid must be removed for accurate measurement. The authors have proposed a measurement method using hydrodynamic pressure [9][10]. This method actively uses the grinding fluid to generate the pressure. The topography of the working surface of a grinding wheel affects the flow of the grinding fluid. Therefore, it is expected that the topography change can be measured by analyzing the pressure.

In this paper, the in-process measurement method of a grinding wheel in wet condition is introduced. Then the relationship between the topography and the pressure during grinding is discussed.

2. Principle of measurement

Fig. 1 shows the measurement principle in the case of applying to a surface grinding process [9][10]. A pressure sensor is set beside a grinding wheel. Additional grinding fluid is poured near the gap between the grinding wheel and a pressure sensor. Grinding fluid is dragged by the rotation of the grinding wheel into the gap. Hydrodynamic pressure is generated in the gap. Then the pressure change caused by the hydrodynamic pressure is measured with the sensor. The hydrodynamic pressure decreases with an increase of the gap distance between the sensor and the working surface of the grinding wheel. After a relationship between the gap and the pressure is calibrated, the gap can be predicted by measuring the pressure. The electromagnetic properties of the grinding wheel, a workpiece and grinding fluid do not affect the pressure. Viscosity of the grinding fluid seldom changes during grinding even if the temperature of the working fluid is slightly changed or debris is mixed. The diameter

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change by the wear seldom affects the peripheral speed of the grinding wheel because the ratio of the wear to the diameter is negligible. Therefore, the measurement process by this method becomes easier and more accurate than the measurement process with other noncontact sensors. Because the grinding fluid is actively used, no other additional device is needed.

A roughness of the working surface of a grinding wheel changes because of loading, dulling and shedding during grinding, and affects flow in the gap. As a surface becomes rougher, flow is separated earlier in general and becomes more turbulent. It is expected that its frequency components change. The influence of the roughness is investigated by frequency analysis.

3. Experimental setup

An external cylindrical grinding machine was used in the following experiments. Table 1 shows specifications of the grinding machine and a grinding wheel. The grinding wheel was composed of grains made from white fused alumina with an average diameter of 250 µm.

Fig. 2 shows an arrangement of a pressure sensor. The sensor was covered with a plate with a hole of 1 mm to avoid the direct contact with the grinding wheel. The surface roughness of the plate is 1.7 µmRz. Table 2 shows specifications of the pressure sensor. The sensor with a diaphragm of 6 mm in diameter was a strain gauge type. The sensitivity of the pressure sensor was 10 kPa/V at the output of the strain amplifier.

The sensor unit was mounted on the table of the grinding machine with a combination of an xyz and a rotational stages, which can be mounted and dismounted with a magnet chuck. The maximum pressure was at 5 mm above the contact point of the grinding wheel with a workpiece. Because the sensor unit was removed during grinding, the pressure sensor must be exactly put back after grinding process by adjusting the position with the stage. The gap was measured with an eddy current displacement sensor with a measurement range of 1 mm and a resolution of 0.4 µm.

Soluble-type grinding fluid containing surfactant was diluted 70 times with water. The grinding fluid was supplied at the maximum flow rate of $1.3 \times 10^{-4}$ m$^3$/s through a regulator.

4. Experiment

4.1 Adjustment of gap distance

The gap distance between the grinding wheel and the plate mounting the sensor must be adjusted before the experiments.

Fig. 3 shows the adjustment process of the gap distance. The sensor was arranged in parallel to the working surface of the grinding wheel. When the grinding wheel contacts with the plate detecting by a spark on the plate, this distance of the gap was defined as zero. Then, the spindle was moved backward to change the gap. The gap distance is measured as the displacement of the spindle. The removed depth in the zero detection procedure is measured with a

<table>
<thead>
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<th>Table 1</th>
<th>Specifications of grinding machine</th>
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<tr>
<td>Cylindrical grinding machine</td>
<td>Revolution of grinding wheel</td>
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<td>Maximum peripheral speed</td>
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<table>
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<tr>
<th>Grinding wheel</th>
<th>Type</th>
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<tbody>
<tr>
<td>Grain</td>
<td>White fused alumina</td>
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<tr>
<td>Average grain size</td>
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<tr>
<td>Bond</td>
<td>Vitrified</td>
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<tr>
<td>Diameter</td>
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<td>Width</td>
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<th>Table 2</th>
<th>Specifications of pressure sensor</th>
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<tr>
<td>Pressure sensor</td>
<td>Type</td>
</tr>
<tr>
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<tr>
<td></td>
<td>Diameter of diaphragm</td>
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<tr>
<td></td>
<td>Natural frequency</td>
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<td></td>
<td>Linearity</td>
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| Strain amplifier | Band width | DC-200 kHz |
| | Accuracy | ±0.1 % of FS |
| | Linearity | ±0.01 % of FS |

FS: full scale
4.2 Influence of supplying direction of grinding fluid for measurement

A flow rate of the grinding fluid and a nozzle position affect conditions in the gap [11]. Their influence on the pressure is investigated.

Fig. 4 shows two arrangements of a nozzle. The grinding fluid was supplied from the 20° or tangential directions. The pressure sensitively changed below a flow rate of 6×10⁻⁵ m³/s with the inclined nozzle. The grinding fluid was frothed with the rough surface of the grinding wheel. This trend grew as the flow rate was increased with the inclined nozzle. However, the pressure was almost flat with the tangential nozzle. The supply from the tangential direction makes the pressure robuster against the ripple of the grinding fluid. The grinding fluid was applied from the tangential direction in the following experiments.

4.3 Relationship between pressure and gap distance

The relationship between the pressure and the gap distance must be calibrated for each grinding wheel before actual measurement.

Fig. 5 shows a relationship between the pressure and the gap distance in the case of using the grinding wheel shown in Table 1. The spindle was driven to change the gap. The grinding fluid was applied at a flow rate of 4.2×10⁻⁵ m³/s. The peripheral speed of the grinding wheel was set to 26 m/s. The pressure was linearly decreased with a sensitivity of 150 Pa/µm from 5 to 30 µm in gap distance. The pressure changes in the same way in both the cases of changing the diameter of the grinding wheel by dressing and of adjusting the spindle position because the diameter change affects its peripheral speed little.

4.4 Pressure change caused by loading

Table 3 shows grinding conditions to accelerate loading of the working surface. Mild material, aluminum, was used for a workpiece. Against the general grinding conditions for aluminum, the structure of the grinding wheel was porous and the peripheral speed of the workpiece was slow to deposit debris on the grinding wheel by the accumulated heat.
Total amount of grinding was 208 mm² after grinding to a thickness of 50 µm. The wear of the grinding wheel was too small to measure it. Frequency components were observed with a Fast Fourier Transform (FFT) analyzer. Fig. 6 shows an example of spectra of the pressure, which is the average of 50 measurements to avoid random errors. The initial gap was set to 20 µm. As the gap between the sensor and the grinding wheel increased with the progress of grinding, total pressure becomes smaller. However, some components, a frequency of 350 Hz mainly in this case, were increased after grinding. The roughness of the working surface of the grinding wheel is decreased from 285 to 191 µmRz and from 13 to 9 µmRa because of loading. No diameter change was measured. This trend was clearly observed at higher flow rate.

Fig. 7 shows a change of the spectra of the pressure with a progress of grinding. The horizontal lines
indicate 0.1 kPa in each set of spectra. Table 4 shows grinding conditions. Bearing steel (JIS-SUJ2, ASTM-52100) is ground to a thickness of 10 \( \mu m \) to remove cracked part of grains just after dressing. Then the pressure was observed during grinding aluminum. Though the spectra from 400 to 500 Hz were observed very little after dressing and the initial wear by grinding bearing steel, they were increased with a progress of grinding. This band depends on the structure of the grinding wheel.

Fig. 8 shows a dependency of frequency components of the pressure on the gap distance. Higher components decreased with an increase of the gap distance. Smaller gap is preferable to detect the topography change.

4.5 Pressure change caused by dulling

The working surface becomes flatter also by dulling. In-process measurement of dulling was also tried. After grinding a tungsten carbide rod with a diameter of 40 mm to a thickness of 50 \( \mu m \) with a depth of cut less than 1 \( \mu m \), the working surface of the grinding wheel was dulled.

Fig. 9 shows examples of the spectra of the pressure before and after dulling under the grinding conditions shown in Table 5. The spectra in a higher frequency range are increased as well as loading. Therefore, dulling can be detected by this method.

The discrimination among loading, dulling and shedding should be considered for detail analysis of the topography of the grinding wheel. However, it is enough to detect the necessity of dressing.

5. Conclusions

In this paper, the topography change of a grinding wheel was observed using hydrodynamic pressure. The conclusions can be drawn as follows.
Spectra of the pressure in higher frequency were increased with the progress of loading and dulling.

Not only the flow rate but also turbulent flow of the grinding fluid and air affected the measured pressure.

The pressure was decreased with an increase of the gap distance in the case of a narrow gap.

A measured diameter of the grinding wheel by this method changes by the wear and topography changes caused by loading, dulling and shedding. Their influence should be discriminated in the measurement process in future.

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**References**


