Measuring of Thermal Expansion of Grinding Wheel by Means of Laser Displacement Sensor

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Abstract. Machining accuracy decreases depending on a thermal deformation of grinding wheel caused by the influence of heat occurred in grinding point. A control of thermal deformation of grinding wheel is difficult so that the workpiece is too much grounded by expanded grinding wheel. From such a viewpoint, this study aims to measure the thermal expansion of grinding wheel by means of a laser displacement sensor. This paper describes about the appropriateness of measuring method by means of the laser displacement sensor.

Introduction

In grinding operations, grinding heat is generated at the grinding point where a grinding wheel contacts with a workpiece. Therefore, grinding wheel induces thermal deformation, which leads to degradation of machining accuracy. In some recent grinding machines, the thermal deflections of grinding machine are sometimes controlled by monitoring the temperature of the spindle and the motor. However, the thermal deformation of the grinding wheel cannot be controlled at present. If the grinding wheel deformation can be measured quantitatively in the grinding process, the machining accuracy is improved by control of a feed rate of wheel spindle stock taking into account the grinding wheel deformation.

In the recent studies about thermal expansion of grinding wheel, measuring method of grinding wheel surface position using an air micrometer is proposed by Nakajima [1], however, it has not been well used in the machining site recently. On the other hand, a laser displacement sensor is one of the practical noncontact measuring devices which is able to measure the thermal expansion of grinding wheel.

From such a viewpoint, this study aims to measure the thermal expansion of grinding wheel by means of a laser displacement sensor.

Measurement of thermal expansion of grinding wheel in dry grinding

In case of measurement of the grinding wheel surface by means of the laser displacement sensor, the influence of coolant during grinding operation is concerned. Therefore, in first step, it is confirmed whether the thermal expansion of grinding wheel can be measured using the laser displacement sensor in dry grinding without coolant.

Figure 1 shows schematic diagram of cylindrical grinding machine equipped with measuring devices. A laser displacement sensor is attached to the wheel spindle stock of the cylindrical grinding machine on the opposite side of the grinding point of grinding wheel in order to measure the grinding wheel surface position. The cylindrical grinding machine is GOP10-30 manufactured by Toyoda Machine Works Ltd., and the laser displacement sensor is LK-H055 manufactured by KEYENCE Corporation. An in-process measurement device

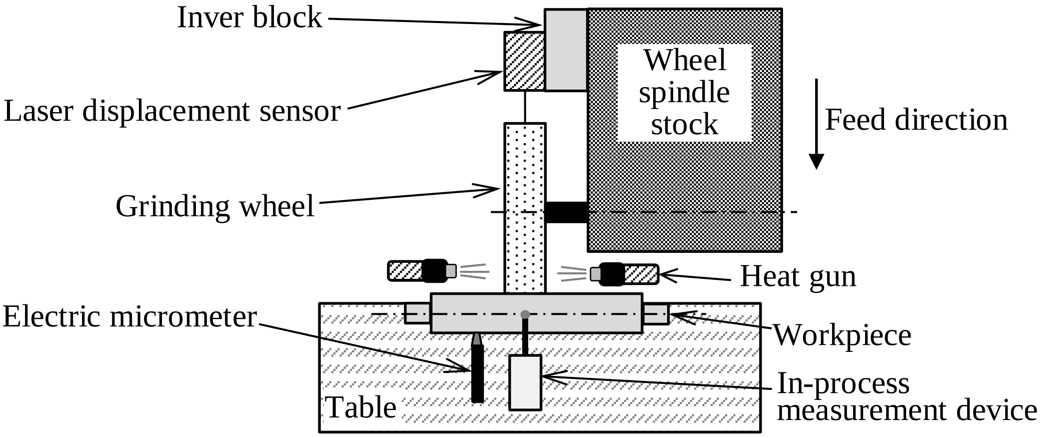

Fig.1 Schematic diagram of cylindrical grinding machine equipped with measuring devices

attaches on the table in order to measure volume of material removed of workpiece. An electric micrometer also attaches on the table in order to measure thermal deformation of workpiece.

The experiment method is as follows. Spark-out grinding is carried out after plunge grinding so that the grinding wheel and the workpiece contact with each other on the same tangent line. Using two heat guns, the grinding wheel is heated from both side surfaces of the grinding wheel. After heating, the grinding wheel starts to expand. The amount of thermal expansion of the grinding wheel at this time is measured with the laser displacement sensor.

On the other hand, the volume of material removed of workpiece is measured with the in-process measurement device. Since the amount of thermal expansion of the grinding wheel is copied to the workpiece, if the two measured results of thermal expansion of grinding wheel and volume of material removed agree with each other, it can be confirmed that the amount of thermal expansion of the grinding wheel can be measured using the laser displacement sensor.

Grinding wheel is WA60J6V (ϕ355), workpiece is S55C (ϕ26), and each revolution speed is $2435 min^{-1}$ and $183 min^{-1}$.

Figure 2 shows measured results of the amount of thermal expansion of the grinding wheel, the volume of material removed of the workpiece and the amount of thermal deformation of workpiece. In this figure, the heating of grinding wheel is carried out from 8 minutes to 14 minutes, and positive direction of the vertical axis shows the amount expansion of the grinding wheel, the removal amount of the workpiece, and the contraction amount of the workpiece.

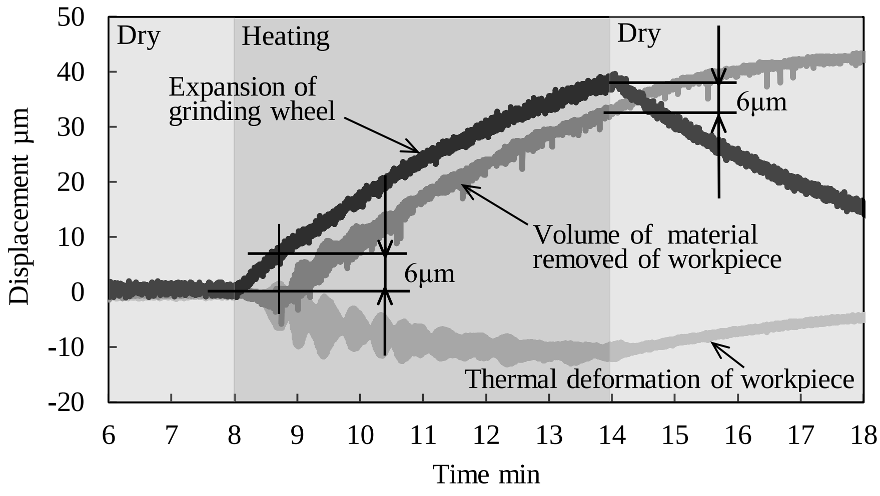

Fig.2 Thermal expansion of grinding wheel in dry grinding

Comparing measured results of the grinding wheel and the workpiece in heating, it can be seen that the inclination of the amount of expansion of the grinding wheel agrees with one of the volume of material removed of the workpiece. From this result, it is known that the amount of thermal expansion of the grinding wheel is well copied to the workpiece as the removal amount.

On the other hand, although the grinding wheel is contracting from 14 minutes after stopping the heating of the grinding wheel, the removal amount of the workpiece is increasing with the increase of the time. From measured result of the thermal deformation of workpiece, it is seen that the workpiece is expanding while the grinding wheel is heated, however is contracting after stopping the heating. Comparing measured results of the removal amount of workpiece and the thermal deformation of workpiece, it is known that, after stopping the heating in 14 minutes, the tendency of the removal amount of the workpiece coincides with the contraction tendency of workpiece. From this result, it is found that the removal amount of workpiece which is increased after stopping the heating of the grinding wheel is due to the thermal contraction of the workpiece.

Comparing measured results of the amount of thermal expansion of the grinding wheel and the removal amount of workpiece in heating the grinding wheel, these increasing inclinations are similar, while as described above. However, although the grinding wheel is expanding immediately after heating, the workpiece is not removed by the grinding wheel at this time. The amount of expansion of the grinding wheel until the workpiece is removed by the grinding wheel is 6μm in this experiment. This amount is the same as the residual stock removal of the workpiece at the end of heating.

From observing the grinding point immediately after heating the grinding wheel, it is seen that sparks is generated at the grinding point from immediately after heating the grinding wheel. So, it is found that the grinding wheel immediately after the expansion is in contact with the workpiece. Nevertheless, the reason why the workpiece is not removed immediately after the start of the expansion of grinding wheel is that the grinding wheel occurs the loading, so it may be measured as if the grinding wheel is expanded.

From this reason, next experiment is carried out in wet grinding in order to avoid the loading.

Measurement of thermal expansion of grinding wheel in wet grinding

Next experiment is to confirm whether thermal expansion of the grinding wheel can be measured also in wet grinding condition with coolant. This experiment is same condition with the above experiment of dry grinding, although air is blown to the grinding wheel surface in order to remove the coolant around the grinding wheel surface.

Figure 3 shows measured results of the amount of thermal expansion of the grinding wheel and the volume of material removed of the workpiece. From this figure, comparing measured results of the grinding wheel and the workpiece in heating, it is seen that the inclination of the amount of expansion of the grinding wheel agrees with of the volume of material removed of the workpiece. And, it is also seen that the workpiece is removed after the grinding wheel has the expansion of some microns as same as the experiment results of dry grinding. This amount of expansion agrees with the residual stock removal of the workpiece at the end of heating. From this experiment, it is confirmed that thermal expansion of the grinding wheel in wet grinding can be measured using the laser displacement sensor as same as dry grinding. And, it is found that the residual stock removal of the workpiece at the end of heating is not caused by the loading of grinding wheel.

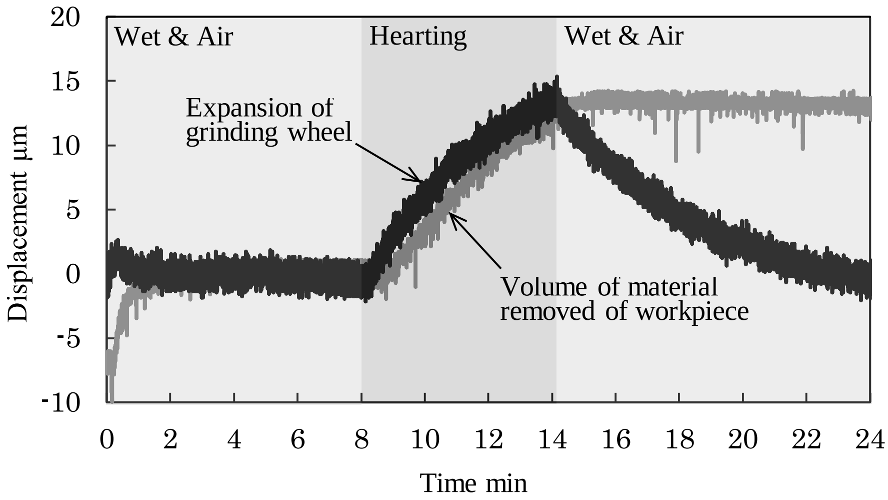

Fig.3 Thermal expansion of grinding wheel in wet grinding

This expansion amount of the grinding wheel until workpiece is removed may be influence of rubbing and ploughing which shows elastic deformation and plastic deformation of the workpiece [2].

Verification of rubbing and ploughing

In order to verify whether the expansion amount of the grinding wheel until workpiece is removed is caused by rubbing and ploughing, experiment is carried out in dry grinding.

Figure 4 shows schematic diagram of rubbing, ploughing and cutting. (a) is rubbing, and the workpiece occurs elastic deformation. (b) is ploughing, and the workpiece occurs plastic deformation and ridges. (c) is cutting, and chips are produced and material is rapidly removed. From these three stages, in rubbing and ploughing, it is considered that the workpiece is not removed, and the surface roughness becomes worse due to generate ridges in ploughing. So, in next experiment, the surface roughness of ground surface is measured at certain time intervals after heating.

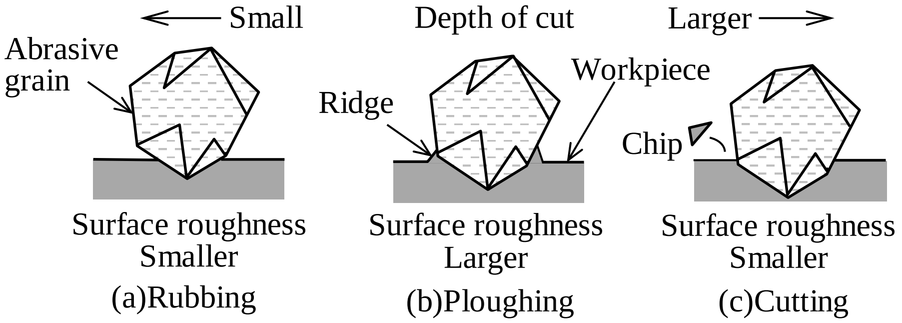

Fig.4 Schematic diagram of rubbing, ploughing and cutting

Figure 5 shows measured results of surface roughness of maximum height h_z. In immediately after heating and/or at the initial point of contact between the grinding wheel and the workpiece, the surface roughness is small because only elastic deformation occurs in the workpiece. After a little while after heating, the surface roughness becomes larger due to the influence of ridges. And, after the start of the workpiece removal, the surface roughness becomes smaller again because material is removed as chips. These results show that rubbing occurs in immediately after heating, ploughing occurs after a little while, and cutting starts with the increase of the wheel diameter.

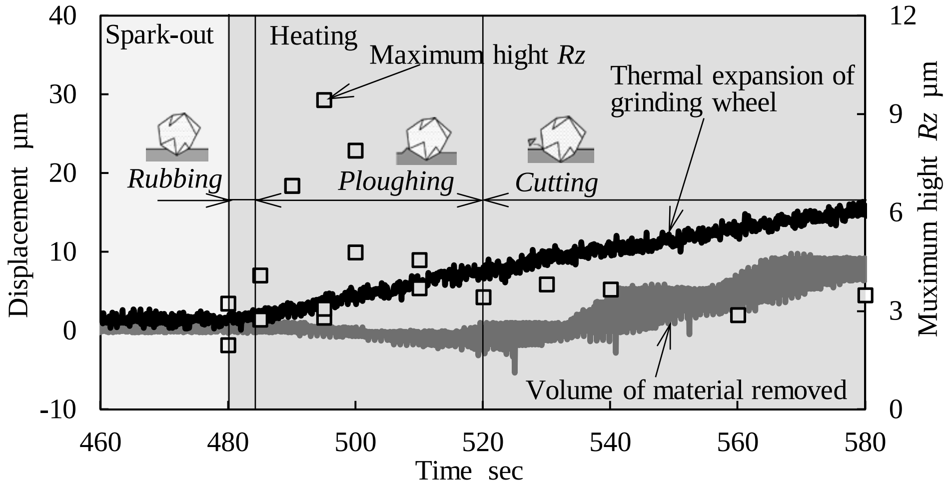

Fig. 5 Measured results of surface roughness

From above, it is found that the difference between the amount of thermal expansion of the grinding wheel and the amount of removal of the workpiece at the beginning of heating as shown in figures 2 and 3 is a non-ground state in which the workpiece is not removed. Taking into account these results, it is confirmed that the grinding wheel surface can be measured using the laser displacement sensor.

Relationship between thermal expansion of grinding wheel and feed rate of wheel spindle stock

In plunge grinding, the actual amount of thermal expansion of the grinding wheel is measured by changing the feed rate of the wheel spindle stock. This experiment is carried out in wet grinding. Air is blown to the measuring point of grinding wheel surface irradiated the laser. After spark-out grinding is carried out after plunge grinding, the wheel spindle stock is fed at various speeds from 0.01 to 1.8 μm/rev. Supply quantity of coolant is about 1.0 L/min.

Figure 6 shows measured result of the amount of thermal expansion of the grinding wheel when feed rate of wheel spindle stock is 0.77 μm/rev. From this figure, it is known that the grinding wheel is expanded as 7.5 μm by grinding heat generated in the grinding point.

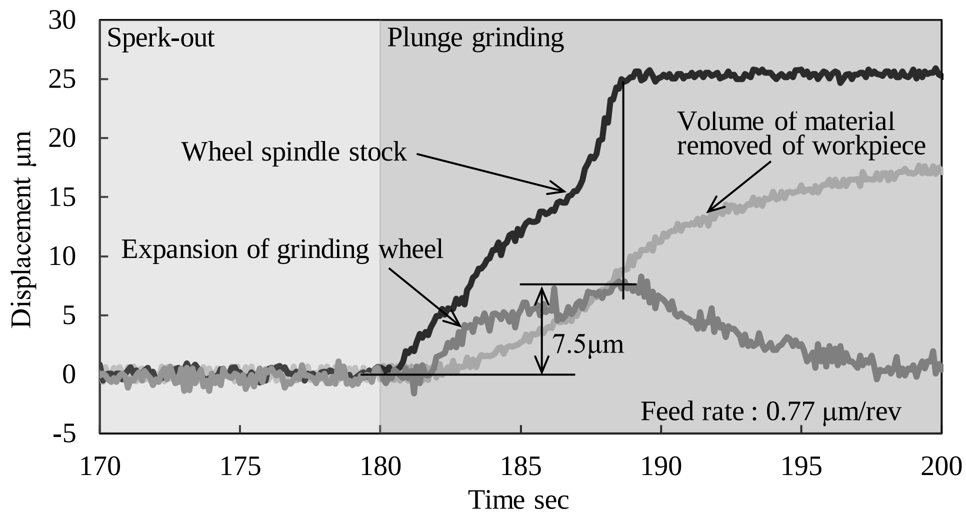

Fig.6 Relation between feed rate and volume of material removed of workpiece

Figure 7 shows measured results of relationship between feed rate of wheel spindle stock and the amount of thermal expansion of grinding wheel. From this figure, it is known that the amount of thermal expansion increases with the increase of the feed rate of wheel spindle stock. This reason is that grinding heat increases with the increase the feed rate, so that grinding wheel expands depending on the increasing feed rate of wheel spindle stock.

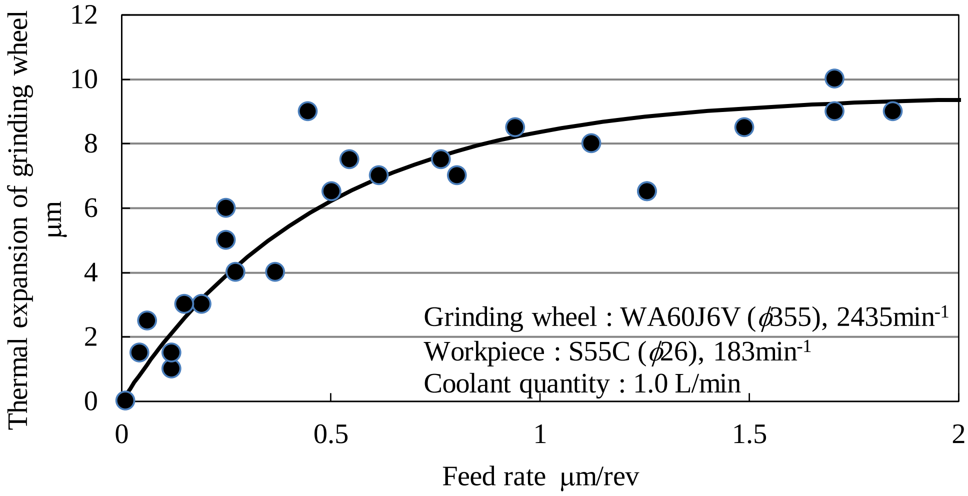

Fig. 7 Relation between feed rate and thermal expansion of grinding wheel

Summary

In order to measure the amount of thermal expansion of the grinding wheel, measuring method using the laser displacement sensor was proposed in this study. From experiment results, it was known that the amount of thermal expansion of the grinding wheel could be measured using the laser displacement sensor in both grinding of dry and wet. It was found that the difference between the amount of thermal expansion of the grinding wheel and the amount of removal of the workpiece at the beginning of heating was caused by influence of rubbing and ploughing. It was confirmed that the amount of thermal expansion of the grinding wheel increased with the increase of feed rate of wheel spindle stock.

References

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