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Evaluation of a high-speed air turbine microspindle for monitoring machining processes using audible sound and pressure measurements

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Abstract
In this study, we develop a high-speed air turbine microspindle with a built-in microphone and pressure sensor, to detect the breakage and wear of a micro tool and to detect anomalies in the bearing and other spindle components. The pressure sensor is employed to detect torque nonuniformity during machining, by using the frequency analysis of signals measured by the pressure sensor. The microphone is employed to detect anomalies in the bearing and other spindle components. The results show that the high-speed air turbine microspindle with a built-in microphone and pressure sensor can detect variations in the microtorque and the frequency components of rotation of the balls of the ball bearing; using the frequency analysis of signals measured by the pressure sensor and microphone.

Keywords: High-speed microspindle, Monitoring, Micro drill, Pressure sensor, Microphone

1. Introduction

In recent years, there has been increasing demand for a method that can precisely machine mechanical microstructures, microelectromechanical systems, micro molds, optical devices, microholes in various nozzles, etc. A micro drill is mainly employed to machine a microhole. However, the breakage of the microdrill creates problems because of the low rigidity of the small-diameter drill. When the drill breaks, the workpiece cannot be used because the broken drill jams the hole of the workpiece. In addition, removing the broken drill from the hole is time consuming. Many methods have been proposed to detect drill breakage, but they cannot be used for small-diameter drills (diameter less than 0.1 mm). Therefore, the commercialization of these methods have so far been unsuccessful. In this study, we develop a high-speed air turbine microspindle with a built-in microphone and pressure sensor, to detect the breakage and wear of a micro tool and to detect anomalies in the bearing and other spindle components. The pressure sensor is employed to detect torque nonuniformity during machining; the frequency analysis of signals measured by the pressure sensor is used to avoid tool breakage and monitor the wear of the microtool. The microphone is employed to detect anomalies in the bearing and other spindle components. The study results show that the high-speed air turbine spindle with a built-in microphone and pressure sensor can detect variations in the microtorque and the frequency components of rotation of the balls of the ball bearing by using the frequency analysis of signals measured by the pressure sensor and microphone.

2. Spindle design and components

Because the spindle being developed is driven by an air turbine, the rotational speed of the spindle will decrease when the torque is applied to the spindle during machining. Therefore, it is possible to detect torque variation by monitoring the change in the rotational speed caused by the onset of breakage or wear of the microtool. The pressure sensor is employed to detect the rotational speed of the spindle. Figure 1 shows a photograph of the air turbine microspindle with a built-in microphone and pressure sensor. The pressure sensor is installed to measure the pressure around the turbine blade. The measured signals of the pressure sensor include a frequency component representing the product of the rotational speed and the number of turbine blades. Therefore, the rotational speed of the spindle can be calculated by dividing the peak frequency by the number of blades after the frequency analysis of the measured signals. The amplitude of the pressure also varies with torque variation.

In addition, as shown in Figure 1, the microphone is installed near the air outlet of the spindle and records the exhaust sound of air. As in the case of the pressure sensor, the sound includes a frequency component representing the product of the rotational speed and the number of turbine blades. Furthermore, the sound includes a frequency component representing the anomalies in the bearing and other spindle components. Therefore, anomalies in the bearing and other spindle components can be detected.

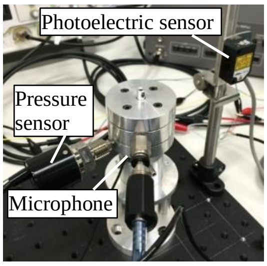

Figure 1. Photograph of the air turbine spindle

3. Rotational speed measurement and torque variation detection

Basic experiments were conducted using the method introduced in section 2 to confirm the possibility of detecting rotational speed variation when torque is applied to the spindle. For verifying the rotational speed calculated by the above-mentioned method, a photoelectric sensor is installed near the spindle, as shown in Figure 1. Figure 2 shows the results of the frequency analysis of signals measured by the pressure sensor at a rotational speed of 19531 rpm. First, the peak frequency is obtained by the frequency analysis of signals measured by the pressure sensor. Then, the peak frequency is divided by the number of blades, and thus, the rotational speed is calculated. It is confirmed that the calculated rotational speed corresponds well to the measured value of the photoelectric sensor (19598rpm). The measurement error can be reduced by narrowing the frequency interval. Figure 3 shows the results of the frequency analysis of signals measured by the pressure sensor at a rotational speed of 24618 rpm. With an increase in the rotational speed, the pressure amplitude also increases from 0.129 to 0.157, which can be seen by comparing Figures 2 and 3. Therefore, it is confirmed that the amplitude of the pressure around the turbine blade increases with an increase in the rotational speed of the spindle. Figure 4 shows the results of the frequency analysis of signals measured by the microphone at a rotational speed of 24618 rpm. Figure 5 shows the results of the frequency analysis of the recorded exhaust sound of air using the microphone when the spindle is not rotated. By comparing Figures 4 and 5, it is confirmed that most of the frequency components around the peak frequency represent the exhaust sound of air. Figure 6 shows the results of the frequency analysis after the frequency components of the exhaust sound (Figure 5) are removed from figure 4. Figure 6 shows another peak frequency at 11047Hz. This frequency matches the frequency component of rotation of the balls of the ball bearing. Therefore, it is considered that the condition of the ball bearing can be monitored by measuring the variation in this peak frequency. Figure 7 shows the measurement results of the rotational speed of the spindle using the measured signals of the pressure sensor when a microtorque (0.1 N·cm) is applied to the spindle. The maximum torque is 0.4 N·cm when a 40-μm-diameter microdrill is used to machine a stainless steel[1]. From Figure 7, it is confirmed that the high-speed air turbine microspindle with a built-in microphone and pressure sensor can detect variations in the microtorque using the frequency analysis of signals measured by the pressure sensor.

4. Conclusion

In this study, we develop a high-speed air turbine microspindle with a built-in microphone and pressure sensor to detect the breakage and wear of microtool and to detect anomalies in the bearing and other spindle components. The results show that the high-speed air turbine spindle with a built-in microphone and pressure sensor can detect variations in the microtorque (0.1 N·cm) and the frequency components of rotation of the balls of the ball bearing using the frequency analysis of signals measured by the pressure sensor and microphone.

References

[1] Ono M, Sugawara A and Yano H 1992 Study on Micro Drill Machining (1st report) – On the Measurement of Cutting Force – *Journal of the Japan Society for Precision Engineering*. **58** **8** 79-84

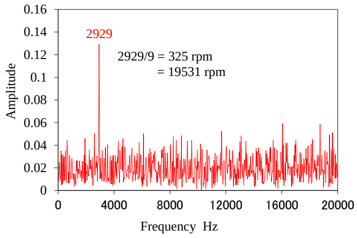

Figure 2. Results of the frequency analysis of signals measured by the pressure sensor at a rotational speed of 19531 rpm

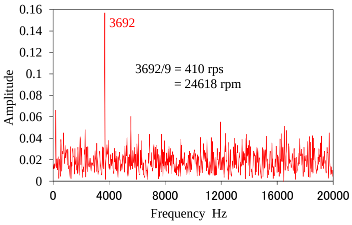

Figure 3. Results of the frequency analysis of signals measured by the pressure sensor at a rotational speed of 24618 rpm

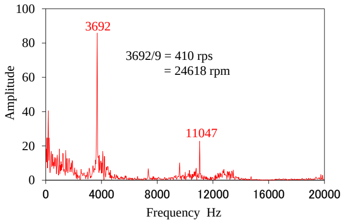

Figure 4. Results of the frequency analysis of signals measured by the microphone at a rotational speed of 24618 rpm

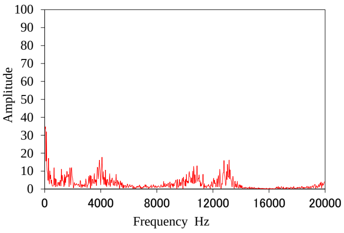

Figure 5. Results of the frequency analysis of the recorded exhaust sound of air using the microphone when the spindle is not rotated

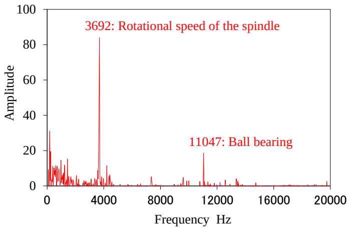

Figure 6. Results of the frequency analysis after the frequency components of the exhaust sound (Figure 5) are removed from Figure4

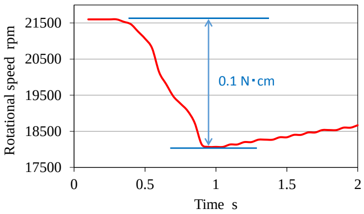

Figure 7. Measurement results of the rotational speed of the spindle using signals measured by the pressure sensor when a microtorque (0.1 N·cm) is applied to the spindle