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Feature Extraction from Sensor Data Streams for Optimizing Grinding Condition

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Abstract. A visualization method for time-series sensing data was designed to optimize grinding condition. The fluctuation pattern of time-series data streams can be visualized as a white and black pattern by utilizing the spindle power change rate average. The designed visualization method was applied to a condition monitoring in lapping operation. The relation between the fallout abrasive grain content and lapping behaviour was experimentally examined. In the lapping with grinding fluid containing no fallout abrasive, the spindle power decreased in a monotone manner with lapping time, while in the lapping with fallout abrasive, the spindle power decreased with lapping time up to 20s of lapping and then tended to converge on a constant value. The spindle power change rate average displayed as a white and black pattern reproduced the changes of spindle power very well. The appearance probability of white or black pattern has a strong relation with the fallout abrasive content and the designed data processing scheme could make possible to predict the grinding fluid condition from the easy-handling grinding test.

1. Introduction

The condition monitoring is one of the most important requirements for the automated and unattended manufacturing systems. The typical monitoring technique operates according to the vibrations, force, power consumption and acoustic emission because these are influenced by the cutting tool state and the material removal process conditions [1],[2]. Most of the promising methods have low detection sensitivity without a variety of statistical processing because the sensing data often show the large dispersion even in the data obtained from the machining under the same condition.

The authors have been studying tool condition monitoring using spindle power consumption [3]. The spindle power consumption is a fairly accurate measure of the deterioration of tool condition and its evolution is a picture of the evolution of cutting force. However, the motor current always fluctuates 1 to 30% due to the temperature rise, magnetic loss and so on [4]. This means that an alternative feature extraction method is required to monitor the tool condition with a high precision from the time-series sensing data of spindle power consumption.

In this study, we will design a visualization method for spindle power consumption change in grinding operation to understandably display the fluctuation pattern of time-series sensing data. The applicability of designed visualization method to the condition monitoring in grinding operations was experimentally examined through the lapping test of SUS304.

2. Feature extraction from time-series data streams

Figure 1 shows the condition monitoring algorithm for grinding and lapping operations. For example, 4 time-series sensing data were supposed to be collected during grinding operations. Series 1 & 2 and series 3 & 4 show the very similar fluctuation pattern but have a different absolute value with each other. The similarity of fluctuation pattern of time-series data was selected as the feature of time-series data stream for detecting the state of grinding and lapping operation, because the motor current always fluctuates 1 to 30% due to the temperature rise, magnetic loss and so on.

To discuss the similarity of fluctuation pattern, spindle power change rate average was utilized. At 1st, the time series data was segmented at fixed time intervals and the spindle power change rate average, which represents the magnitude and the changing direction of spindle power, was calculated for each segment. The calculated spindle power change rate average would have so much uncertainty since the most time-series sensing data consists of long-term data (trend component) and period data (noise component). To eliminate the noise component, the spindle power change rate average with the absolute value less than the predefined threshold α was removed. The residual spindle power change rate average is displayed as a white and black pattern in which the black pattern shows the segment with the absolute value more than α and the white pattern shows the segment with the absolute value less than α. The completed white and black pattern corresponds to a simplified expression of time-series sensing data, spindle power consumption, in grinding and lapping operations.
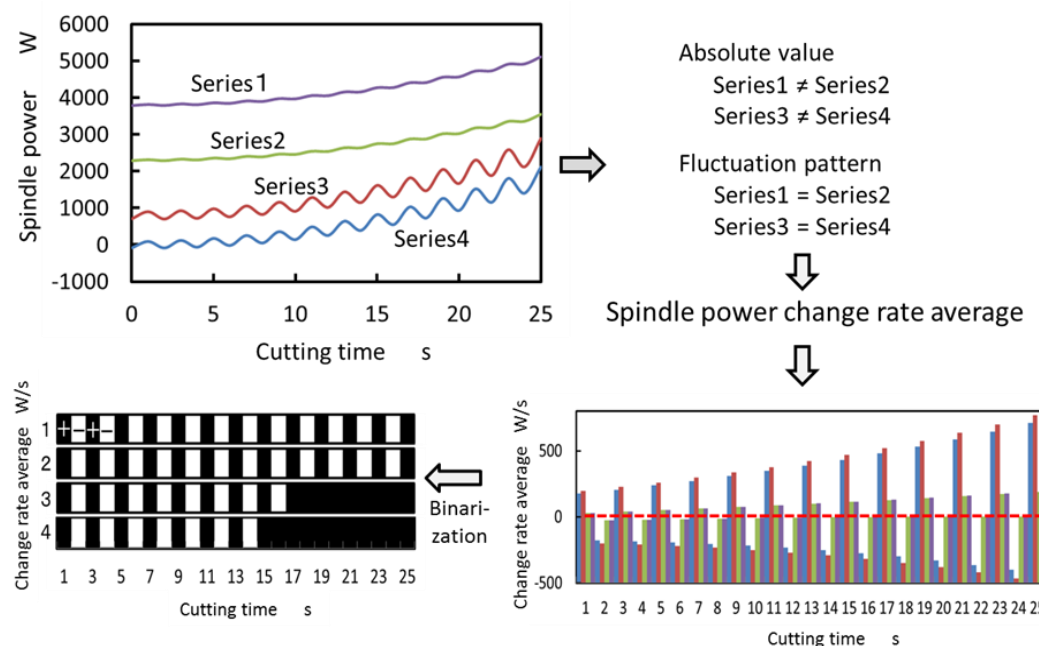

Figure 1. Condition monitoring algorithm for grinding and lapping operations

3. Experimental method

We examined the applicability of designed method to predict the contamination condition of grinding fluid, through the lapping operation of AISI304. Figure 2 shows the schematic drawing of lapping apparatus. Three pieces of work materials (AISI304) are lapped at a time with #1000 SiC abrasive paper under the condition of 2.1 [m/s] of peripheral speed of lapping disk (φ200mm). During the lapping operation, the coolant is supplied on the abrasive paper at 20 cm^3/min of pouring rate. A simulated grinding fluid, which is 5% water-soluble grinding fluid containing 0, 0.001, 0.005, 0.01 or 0.05 wt% of #800 GC abrasive grain, was prepared. The GC abrasive grain is simulating the fallout abrasive grains released from a grinding wheel into coolant. The power consumed P [kW] by the

electric motor of automatic polisher was measured at 0.2s interval using a power meter (HIOKI 3330). As the rule, the power consumed is given by

$$F\text{t} \cdot V = 1000 \times P \tag{1}$$

where $F\text{t}$ [N] is the tangential force on abrasive and V [m/s] is the peripheral speed of abrasive [5]. Once the power consumed by electrical motor had been measured, the tangential force $F\text{t}$ can be calculated easily.
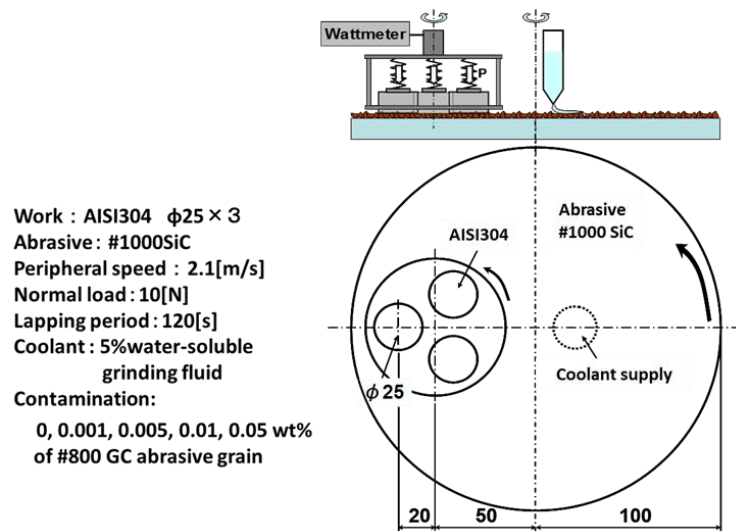

Figure 2. Schematic drawing of lapping apparatus and lapping conditions

4. Results and discussions

4.1 Spindle power change in lapping operation
Figure 3 summarizes the spindle power changes when the SUS304 was lapped for 120s using a simulated grinding fluid containing 0, 0.001, 0.005, 0.01 or 0.05 wt% of #800 GC abrasive. In the lapping with grinding fluid containing no #800 GC abrasive (virgin fluid), the spindle power decreased in a monotone manner with lapping time. While in the lapping with grinding fluid containing #800 GC abrasive, the spindle power decreased with lapping time up to 20s of lapping and then tended to converge on a constant value. When looking at the period (noise) component, the amplitudes of noise component tends to increase with the #800 abrasive grain content. This indicates that the long-term (trend) component in spindle power change has a stronger relation with the abrasive grain content rather than the short-term (noise) component.

4.2 Feature extraction based on power change rate average
The time-series spindle power data was divided into small segment at interval of 0.6s and then the spindle power change rate average was calculated for each segment. The interval of 0.6s was determined from the preliminary experiments. Figure 4 summarizes the change of spindle power change rate average when the SUS304 was lapped for 120s using a simulated grinding fluid containing 0, 0.001, 0.005, 0.01 or 0.05 wt% of #800 GC abrasive. Positive and negative values alternately appear in the spindle power change rate average stream, independent of the abrasive content. This means that it is difficult to define the feature of time-series spindle power data from the change rate average stream because the fluctuation width of period (noise) component is equal or larger than that of long-term (trend) component in spindle power change.
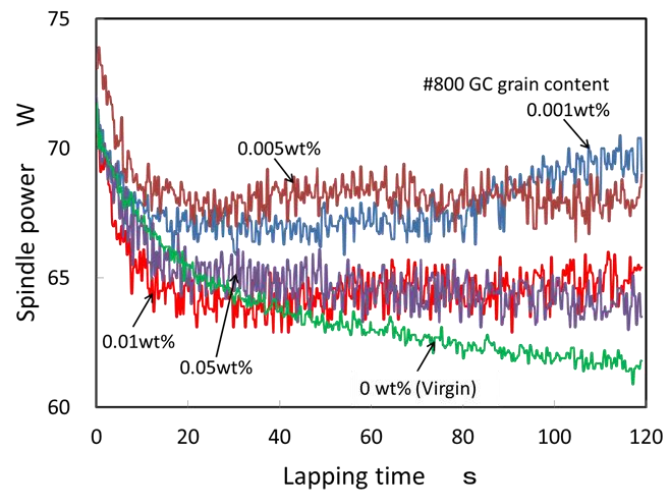
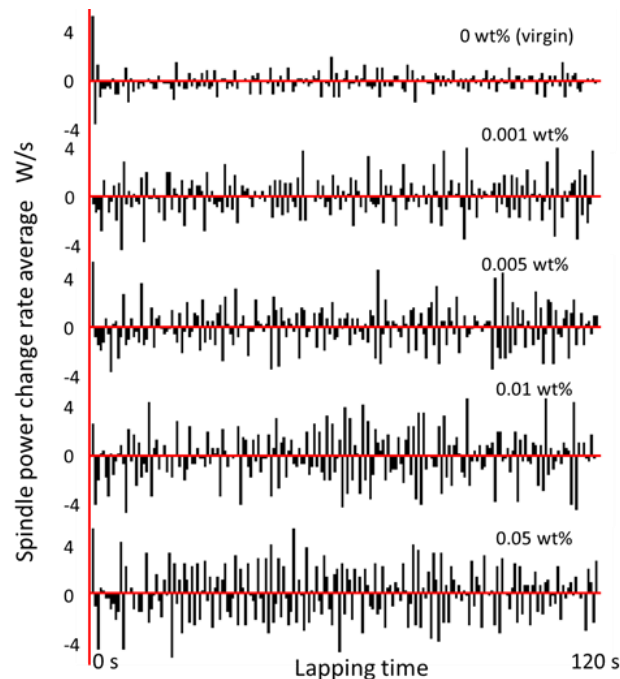**Figure 3.** Spindle power change in lapping operation

Figure 4. Change of spindle power change rate average

To extract the trend component from spindle power change, elimination of period component was attempted. Figure 5 shows the distribution curve of spindle power change rate average in the lapping with virgin fluid. The distribution has a normal distribution with the standard deviation of $\sigma = 0.63$. If the predefined threshold α sets the standard deviation $\sigma = 0.63$, the spindle power change rate average with the absolute value more or less than σ is the top 15.87% or the lower 15.87%. In this study, we defined that the top 15.87%, the middle 15.87 ~ 84.13% and the lower 15.87% of spindle power change rate average have a certainly rising spindle power slope interval, the slope interval with a large cumulative error and a certainly falling spindle power slope interval, respectively.

Figure 6 shows the spindle power change rate average displayed as a white and black pattern in which the black pattern shows the segment with the certainly rising spindle power slope interval and the white pattern shows the segment with a large cumulative error or a certainly falling spindle power slope interval. The completed white and black pattern reproduces the changes of spindle power

showed in Fig.4. This shows that the fluctuation pattern of spindle power can be visualized by processing the time-series data according to the processing scheme of Table 1.
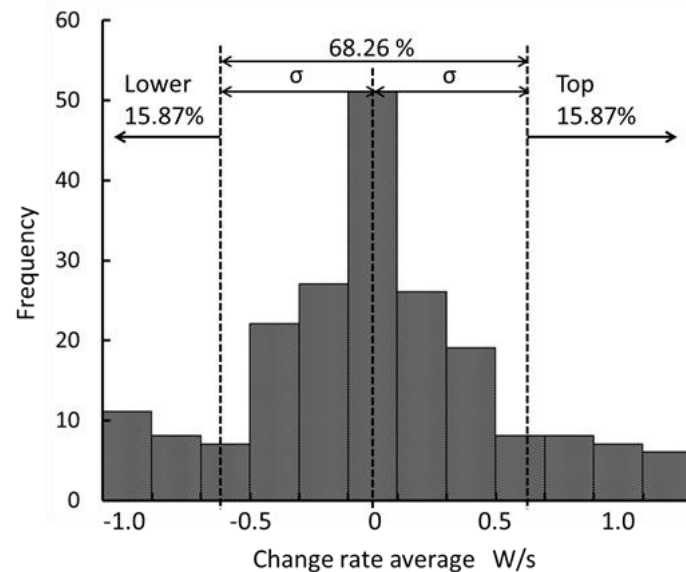

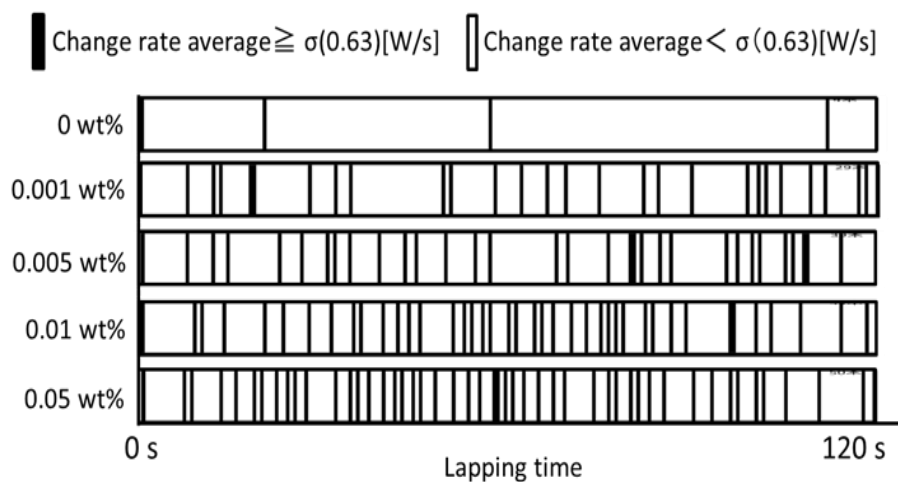**Figure 5**. Distribution curve of spindle power change rate average

Figure 6. Spindle power change rate average displayed as a white and black pattern.

5. Conclusion

We designed a visualization method for spindle power consumption change in grinding operation to understandably display the fluctuation pattern of time-series sensing data. The fluctuation pattern of time-series data streams can be visualized as a white and black pattern by utilizing the spindle power change rate average. The designed visualization method was applied to a condition monitoring in lapping operation. The spindle power change rate average displayed as a white and black pattern reproduced the changes of spindle power very well. The appearance probability of white or black pattern has a strong relation with the fallout abrasive content and the designed data processing scheme could make possible to predict the grinding fluid condition from the easy-handling grinding test.

Table 1. Data processing scheme
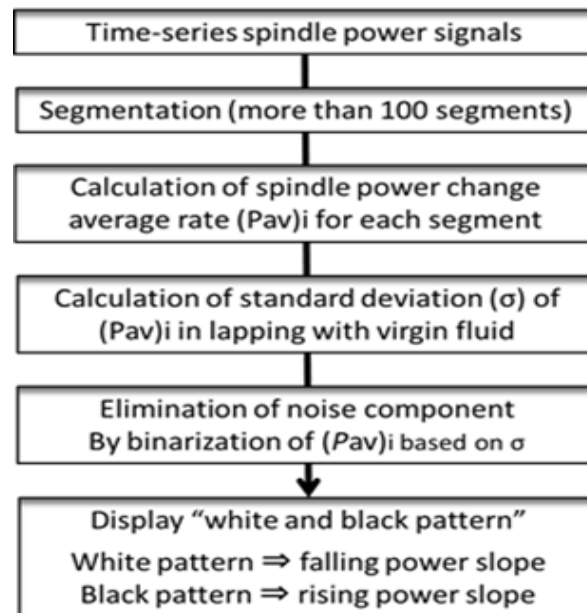
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