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Wear amount measuring method using red lead paint to innovate sensory inspection for female taper socket of machine tools

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Abstract: Machine tools are machines that manufacture different machines and parts. Therefore, the machine tools support all types of manufacturing. And they are known as "mother machines". When machining by a machine tool, a cutting tool is mounted into a female taper socket. Wear on the inner surface of the female taper which occur when changing tools or during heavy cutting have an influence on the run-out of tool. Therefore, female tapers require periodic maintenance. In the maintenance for female tapers of machine tools, sensory inspection has been standardized in JIS and ISO standards. However, this inspection is impossible to evaluate quantitatively and requires a lot of time. Additionally, this sensory method produces varying accuracies depending on the operators. Therefore, a new method of wear amount measurement was proposed in a previous study to solve these problems. The proposed method is a quantitative measurement method independent of the skill level of the operators. Then, this paper reports an improved method to reduce the error of measurement results using the proposed method. If this proposed method is established, it will contribute to improving production efficiency at the production site. In this previous method, the red lead paint mixed with red lead powder and oil is used to estimate the amount of wear based on the luminance value of the red lead paint. The red lead concentration has a significant influence on the results. In this study, we investigate the influence of red lead concentration through experiments and report the results.

Keywords: wear amount measurement; female taper surface; red lead paint; film thickness; image processing

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1. Introduction

Machine tools support the industrial fields because these are the machines that manufacture different machines and parts. Recently, the machine tools that can automatically change their tools have increased. Automatic tool changes and heavy cutting incur inner surface wear of female tapers. Machining with worn inner surfaces of female tapers lowers quality of machined products and production efficiency. Therefore, female tapers require periodic maintenance. In the maintenance for female tapers of machine tools, sensory inspection has been standardized in JIS and ISO standards [1-3]. This method is time-consuming and may not be compatible with increasingly automated production sites. Additionally, the method cannot evaluate the amount of wear quantitatively, and its accuracy varies from operator to operator. Therefore, in a previous study [4], a measurement method using fast Fourier transform was proposed to solve these problems. However, this method was not able to obtain highly valid results. Therefore, a method was proposed

to measure the amount of wear based on differences in paint color [5,6]. This proposed method [5,6] enabled the execution of a quantitative evaluation. To make this proposed method [5,6] more practical, we aim to achieve quantification, skillessness, and automation. We would also like to further improve our proposal method [5,6] and contribute to strengthen production capacity and international competitiveness in industry.

2. Proposed method

The proposed measurement method in previous studies [5,6] uses the color intensity of the paint. Paint is applied onto the measurement surface and spread thinly and evenly. As worn areas are usually grooved, the amount of paint therein is greater than that in unworn areas. As the amount of paint increases, the paint film thickness increases, and thus the color of the paint is dark [9–11]. By photographing the paint area with an infrared camera, the wear area in the photographed image becomes higher brightness values. Figure 1 shows an example of a photographed image. The luminance value is calculated from the centerline area of the photographed image. Figure 2 shows a graph of luminance values. Figure 3 shows a smoothed waveform of a graph of the luminance values. The difference between the maximum and minimum values in the smoothed waveform in Figure 3 is the maximum luminance difference.

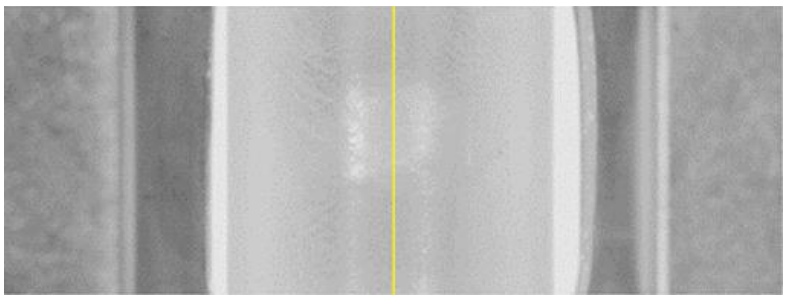

Figure 1. Paint area photographed with an infrared camera.

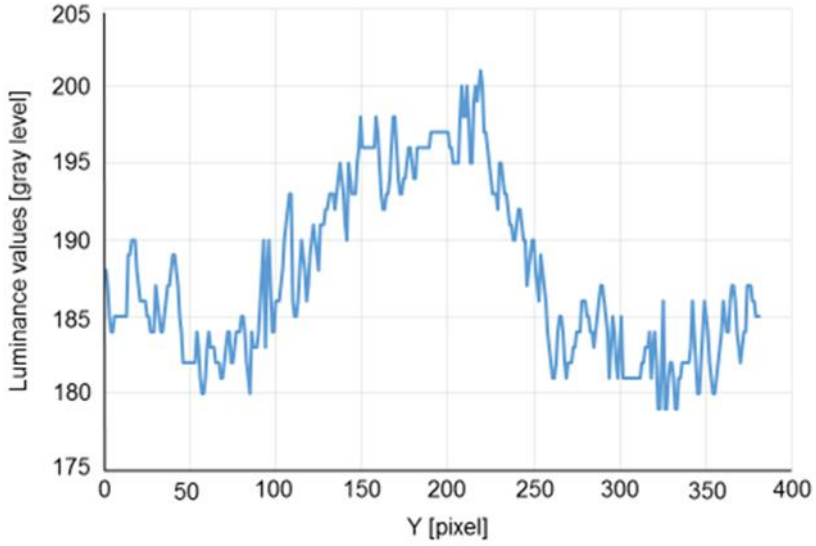

Figure 2. Line plot of luminance values extracted from Figure 1.

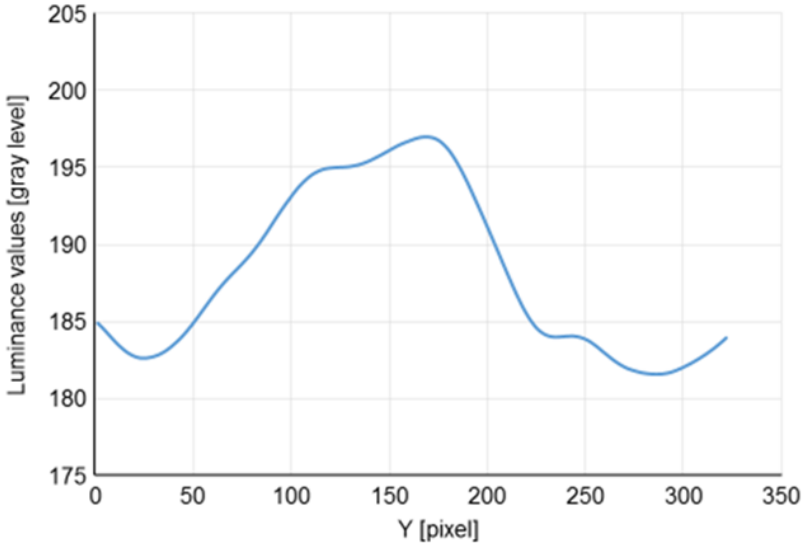

Figure 3. A smoothed waveform of a graph of the luminance values.

3. Experiment

3.1. Experiment equipment

In this proposed method, the red lead paint mixed with red lead powder (Figure 4) and oil is used. Figure 5 shows the female taper, which is the object of measurement in this study. The amount of wear of female tapers is difficult to measure quantitatively. Therefore, comparison of experiment results is impossible. Thus, a ring gauge (Niigata Seiki Co., Ltd.), as shown in Figure 6, is used as the experimental specimen instead of the female taper in this study. Figure 7 shows the imaging device used in the experiment. The camera is an infrared CMOS camera (L-834, HOZAN TOOL IND.CO., LTD.), which is mounted on the magnetic base on an optical table (TT-D8040, CHUO PRECISION INDUSTRIAL CO., LTD.). The light source is an infrared LED light (peak wavelength 950 nm, L-709, HOZAN TOOL IND.CO., LTD.). Figure 8 shows the cylindrical plano-convex lens (SIGMAKOKI CO., LTD., radius of curvature: 7.79 mm) used in the experiment. The cylindrical plano-convex lenses are also used to spread the paint thinly and evenly.

3.2. Experimental method

The previous method [5,6] has the problem of introducing errors because the measurement conditions are not defined. In particular, the red lead concentration has a significant influence on the results. Therefore, a suitable concentration of red lead paint for the measurement was estimated to reduce the error of measurement results [7,8]. However, previous studies [5,6] were conducted with a small number of experiments, and there was room for improvement in the experimental methods. Therefore, in this study, we improve the experimental method and increase the number of experiments, which fix the wear area to be measured and reduce the error. Then, we estimate the concentration of red lead paint suitable for more accurate wear amount measurement.

In this study, experiments are conducted at five different red lead paint concentrations to decide the concentration of red lead paint necessary for accurately measuring the amount of wear [7,8]. The five concentrations of red lead paint used in this study are 2:1, 1.5:1, 1:1, 1:1.5, and 1:2. This experiment is conducted ten times for each concentration of the red lead paint, and the maximum difference in luminance is calculated. From these

results, the appropriate concentration of red lead paint to measure the amount of wear is inferred.

3.3. Experimental results

The results of the experiment, conducted ten times for each concentration of red lead paint, are shown below. Table 1 lists the maximum differences in the luminance obtained in the experiments.

Figure 4. Red lead powder.

Figure 5. Female taper.

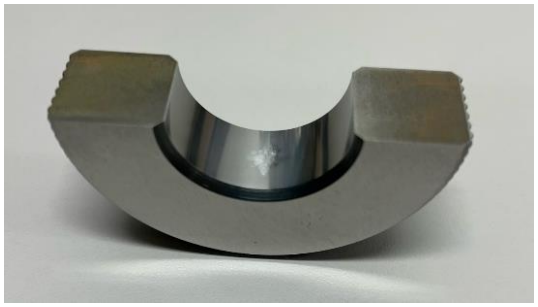

Figure 6. Ring gauge.

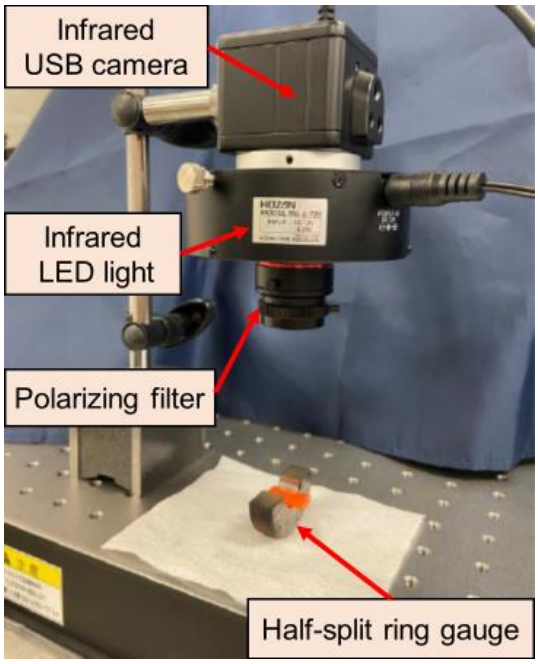

Figure 7. Imaging device.

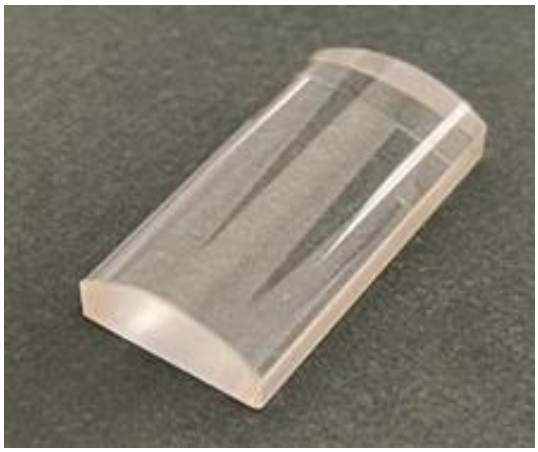

Figure 8. Cylindrical plano-convex lens.

4. Conclusions

In this study, we estimated the appropriate concentration of red lead paint for the wear volume measurement method for female tapers proposed in a previous study. The main conclusions are as follows.

This study fixed the wear area to be measured to improve the measurement method and accuracy. By increasing the number of experiments from the previous study, the error in the measurement results was reduced. As a result, we estimated a more appropriate concentration of red lead paint than in previous studies. The suitable conditions for measuring the amount of wear are that standard deviation and range of the maximum luminance difference are small. Therefore, we estimated that the most suitable concentration

Table 1. Maximum differences in the luminance obtained in the experiments.

		Concentrations of red lead paint (red lead powder : oil)				
		2:1	1.5:1	1:1	1:1.5	1:2
Luminance values [gray level]	1st	25.22	21.05	17.21	23.77	21.15
	2nd	26.95	18.10	14.12	14.38	15.89
	3rd	27.51	21.85	15.37	14.83	14.86
	4th	22.64	15.93	15.76	14.44	17.50
	5th	16.98	15.94	15.46	11.12	14.82
	6th	19.37	22.84	12.02	15.65	13.03
	7th	21.45	20.50	15.79	20.99	18.67
	8th	19.91	21.47	19.60	19.13	11.06
	9th	19.62	18.78	16.85	16.33	17.61
	10th	19.07	18.79	16.24	10.65	14.50
	Average	21.87	19.53	15.84	16.13	15.91
	Range	10.53	6.91	7.58	13.12	10.09
	Standard deviation	3.41	2.29	1.87	3.92	2.77

of red lead paint for measuring the amount of wear is that when the ratio of red lead powder to oil is 1:1. When the concentration of red lead paint was high, spreading the paint evenly was difficult. When the concentration of red lead paint was low, the luminance values of the photographed image were more affected by light. 3 The error in the results for the same concentration red lead paint suggests that the paint was not evenly applied. Therefore, the most important key of the proposed method is to spread the paint thinly and evenly. In the future, we will aim to solve this problem.

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