A PRELIMINARY STUDY TO EVALUATE THE TOPOGRAPHY OF NARROW SURFACE PLATE

STUDI AWAL UNTUK MENGEVALUASI TOPOGRAFI MEJA RATA BERPENAMPANG SEMPIT

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ABSTRACT

An approach method to evaluate the topography of narrow surface plate has been proposed. In some cases, the calibration of narrow surface plate would be very difficult to carry out when using the electronic level, the autocollimator, or the laser interferometer. Therefore, the mechanical probe and universal measuring machine can be used as an alternative standard since they can substitute the function of measurements that was performed by the third measuring instruments. In this research, the narrow surface plate is represented by rectangular granite blocks of 600 mm x 90 mm in dimension, while the measuring standard is a mechanical probe of 0.01 µm in resolution and a universal measuring machine. The readings from the mechanical probe and universal measuring machine were analyzed by numerical methods to obtain information about the topography of the surface. As per the result, this proposed method can be applied to evaluate the topography of narrow surface plate, but this method still requires to be compared with the other method to validate the measurement procedure.

Keywords: Surface flatness, Numerical analysis, Mechanical probe

ABSTRAK

Telah dikembangkan suatu metode pendekatan untuk mengevaluasi bentuk topografi meja rata berpenampang sempit. Pada beberapa kasus tertentu, kalibrasi meja rata berpenampang sempit akan sangat sulit dilakukan jika menggunakan level elektronik, autocollimator*, ataupun laser interferometer. Oleh karena itu,* probe *mekanik dan mesin ukur universal dapat digunakan sebagai alternatif standar karena mampu menyubstitusi fungsi pengukuran yang dilakukan oleh ketiga alat ukur tersebut. Pada penelitian ini* rectangular granite block *berdimensi 600 mm x 90 mm digunakan sebagai* unit under test *yang merepresentasikan meja rata berpenampang sempit, sedangkan* probe *mekanik yang mempunyai resolusi 0,01 µm dan mesin ukur universal digunakan sebagai standar. Hasil pembacaan dari* probe *mekanik dan mesin ukur universal dianalisis menggunakan metode numerik sehingga diperoleh informasi tentang topografi dan nilai kerataan dari permukaan tersebut. Metode pendekatan ini telah diuji untuk mengevaluasi topografi meja rata berpenampang sempit Meskipun demikian, metode ini masih membutuhkan perbandingan dengan metode lain sebagai validasi prosedur pengukurannya.*

Kata Kunci: *Kerataan permukaan, Analisis numerik, Probe mekanik*

1. INTRODUCTION

Measurement is the process to determine the value of a quantity. Measurement does not only involve the measuring object as unit under test and measuring equipment as reference standard, but also the other equipment as a supporter unit. One of them is surface plate. Surface plate is often used as the datum plane for performing dimensional, length, and angle measurements in the quality assurance and calibration laboratory.[1] According to its size of plate, surface plate can be classified into two (2) types, i.e. narrow surface plate and large surface plate. According to the document standard JIS B 7513, the union jack and rectangular grid are two types of measurement grids commonly used to calibrate surface plate. Both type of measurement grids can be applied to measure flatness of surface plate using electronic level, autocollimator, or laser inter-ferometer.[1–2] Those calibration methods are more suitable for large surface plate and it would be very difficult to carry out in the calibration of narrow surface plate, due to the limited width of this surface plate. Coordinate

Measuring Machines (CMM) have been used to generate measurement points for the surface.[2–4] The CMM has a function as close as the combination between universal measuring machine and mechanical probe. It means that if effective area of unit under test is limited, the mechanical probe and universal measuring machine can be used as an alternative standard. The mechanical probe and the universal measuring machine do not only substitute the function of measurements performed by the electronic level, the autocollimator, or the laser interferometer, but they also function as close as the CMM to generate measurement points. In addition, the mechanical probe and the universal measuring machine should use rectangular grid and manually analyzed by numerical methods to obtain information about the topography of the surface.

This paper discussed about flatness measurement of narrow surface plate and its uncertainty analysis. This measurement technique uses a universal measuring machine and a mechanical probe (i.e. lever type) as measuring standard. Meanwhile, a rectangular granite block with dimension of 600 mm x 90 mm is used as unit under test. The readings from the mechanical probe and universal measuring machine were analyzed by numerical methods to obtain the information about the topography of the surface. The flatness can be determined afterwards. In order to check the effect of operator calibrations quality, statistical test is conducted.

The purpose of this research is to provide an alternative solution to determine flatness. The result of this experiment is a preliminary study to evaluate the topography of narrow surface plate.

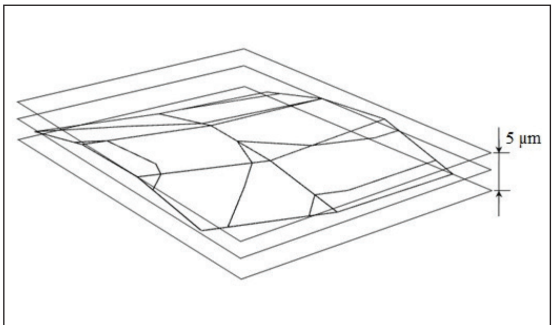

Figure 1. Ilustration of Surface Flatness, i.e. 5 µm.

2. THEORETICAL BACKGROUND

2.1 Surface Plate

A surface plate is solid, it has a flat plate used as the main horizontal reference plane for performing calibration, precision inspection, and tooling setup.[5] Surface plate is often used as the datum plane for most measurement in the quality assurance and calibration laboratory, also in shop inspection station. According to the size of plate, surface plate can be classified into two types, i.e. narrow surface plate and large surface plate. Meanwhile, in order to calibrate surface plate, the union jack and rectangular grid are two types of measurement grids commonly used.

2.2 Introduction of Flatness Measurement

Flatness measurement is closely related to the straightness measurement.[5] Straightness is visualized by lines, while the flatness is visualized by planes. The quality of surface flatness is measured by "the maximum allowable separation of two parallel ideal planes which entirely enclose the surface".[6] The ilustration of surface flatness is shown in Figure 1.

2.3 Fundamental of Flatness Evaluation

Surface flatness evaluation is performed by evaluating the straightness at every lines, i.e. all longitudinal and tranversal lines. Fundamental knowledge of straightness evaluation is the basis to evaluate surface flatness.[5] The straightness quality is measured by "the maximum allowable separation of two parallel ideal lines which entirely enclose the line". Ilustration of the straightness quality is shown in Figure 2.

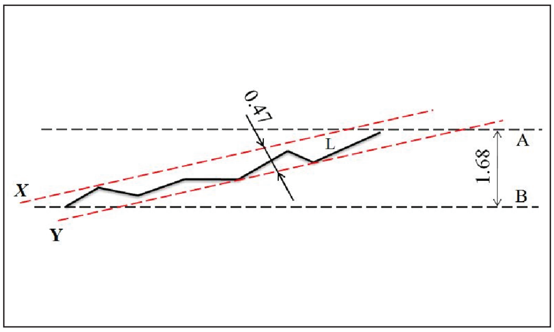

Figure 2. Example of Straightness Quality of a Line, i.e. 0,47 cm.

In order to obtain the optimal deviation value at each point to the reference line (δ'_i), it should be analyzed with these two steps. They are as follows.

a. Calculate the value of initial deviation at each point (δ'_i)

This value can be obtained by applied least square fit method to reduce the height reading.[6–7] The height reading is shown by display of mechanical probe. Mathematically it is formulated by:

$$\delta_i = h_i - Y_{slope}$$

$$\delta_i = h_i - (mX + b) \quad \text{..........................} \quad (1)$$

with :

δ_i is the value of initial deviation at each points

h_i is the value of height reading at each points

Y_{slope} is the value of the bias due to slope.

X is the position of mechanical probe along the axis travel

m is slope

b is intercept

b. Applied Normalization

Normalization can be done by "tilt" the end of line at x-axis or y-axis as a pivot. Mathematically it is formulated by:

$$c_i = \frac{i}{n} c_{\max} \quad \text{......................................} \quad (2)$$

So the optimal deviation value at each point to the reference line ($\delta_i^{'}$) can be obtained by:

$$\delta_i^{'} = \delta_i - c_i \quad \text{...} \quad (3)$$

with

δ'_i is the optimal deviation value at each point to the reference line (after correction)

δ_i is the value of initial deviation at each point the (before correction)

c_i is correction factor

n is number of points

i is stage points

c_{max} is the correction value at the furthest point

2.4 Measurement Instrument of Surface Flatness

Electronic level, autocollimator, and laser interferometer are common types of measuring instruments that can be used to measure surface flatness. In terms of practicality, electronic level is the most practice than laser interferometer and autocollimator.[1,5] The electronic level shows slope as a function of gradient, not as an angle unit although the unit of gradient can be converted into angle unit. In order to determine the height (h_i), level indication (G_i) is multiplied by base length of the electronic level (L).[5–7] The general objective of those series process is to determine the absolute height at each point of surface so its topography can be evaluated and created in the 3D image.

The other measurement instrument of surface flatness is Coordinate Measuring Machines (CMM). It can be used to generate measurement points for the surface. The universal measuring machine and the mechanical probe have a function as close as CMM to generate measurement points, but they should use rectangular grid and manually analyzed by numerical methods to obtain information about the topography of the surface.

2.5 Numerical Analysis

Measurement technique is closely related to the curve and the calculation. Some curves and calculations are not easy to understand, they required a further approach to obtain the true value. The numerical method is a method that uses analytical approach to obtain the true value. There are several kinds of numerical methods which are often used, i.e. least square fit, integration, interpolation, etc.

In order to evaluate some cases in dimensional measurement field, the numerical method can be applied.[8] The main consideration to use one kind of the numerical method is based on easy of graphics and engineering calculations. In this case, an algorithm that repeats the calculation process to obtain true value approximation is required. This concept is known as the iteration approach.

3. RESEARCH METHODOLOGY

3.1 Experimental Scheme

This research was performed on length metrology laboratory with room temperature (19.8 ± 0.5)°C and relative humidity (55 ± 3)%. The type of data in this research is quantitative, derived from reading of the universal measuring machine and mechanical probe. The measurement was performed using two operator calibrations with five number of samples per person (df = 8). The experimental scheme of this research is shown in Figure 3 in which each equipment was represented by symbol as follows.

A = rectangular granite block

B = mechanical probe

C = display of mechanical probe

D = display of universal measuring machine

E = universal measuring machine

This research conducted a universal measuring machine and a mechanical probe (i.e. lever type) as measuring standard. Meanwhile, a rectangular granite block with dimension of 600 mm x 90 mm was used as unit under test. This proposed method applied a mechanical probe with 0.01 μm resolution. This probe is made by different manufacturer with universal measuring machine. The pattern in this research is illustrated in Figure 4.

The points in Figure 4 represent the entire surface of the unit under test. The value of height (h_i) at the points were obtained from the reading of the mechanical probe,[9] while the universal measuring machine has function for positioning the points only.

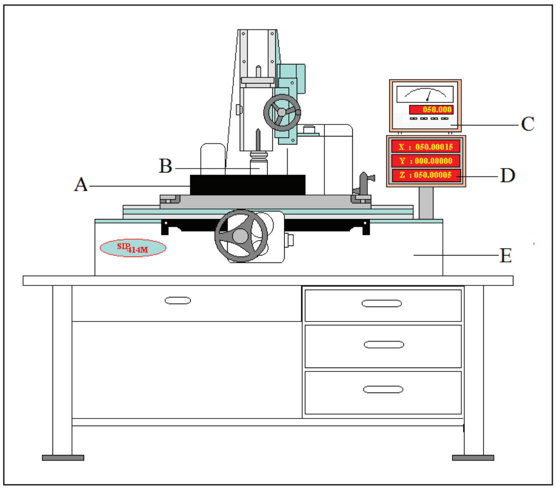

Figure 3. Experimental Scheme

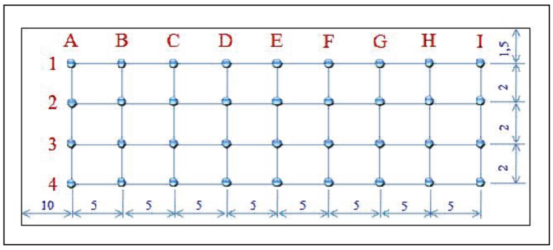

Figure 4. Pattern of Flatness Measurement (Distance in cm Unit)

3.2 Measurement Procedure

The measurement procedure in this research is shown in Figure 5.

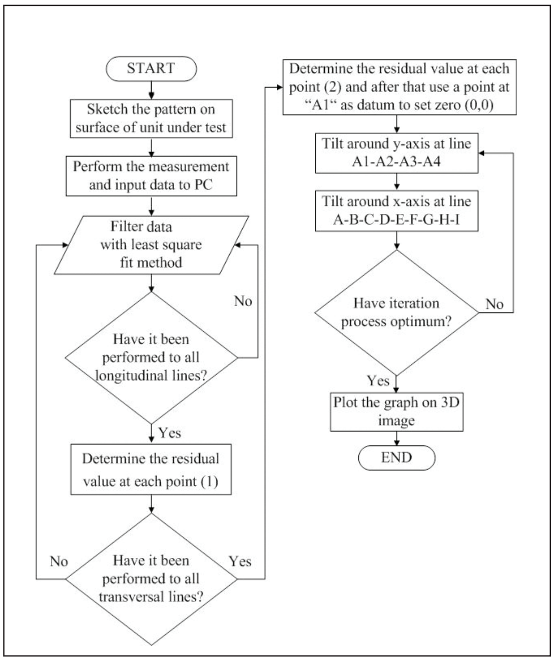

Figure 5. Measurement Procedure

4. RESULT AND DISCUSSION

4.1 Measurement Result

Figure 6 and Figure 7 were measurement results of narrow surface plate that were plotted by IGOR Pro software.

Figure 6 and Figure 7 had fews optimal deviation value (z-axis) at each points to the reference line of surface plate. Both measurement results were performed by two operator calibrations (A and B). Measurement surface flatness of 21 μm was obtained by operator calibration A, while the operator calibration B was 4 μm. According to ISO 8512-2, flatness over all of narrow surface plate grade 3 with dimension of 630 mm x 400 mm is 39 μm. If assumed that rectangular granite blocks in this research is within specification of those narrow surface plate, it means that both measurement results from operator calibration A and B are within range of these document standard.

In order to view over all surface, both measurement results were also plotted in Figure 8 and Figure 9.

Figure 8 and Figure 9 showed that topography from both of surface measurements were different. It means that there were discrepancy value of surface flatness due to “inconsistency” measurement result, however they were within range of ISO 8512-2 specification. It had possibility come from human factor because the other factors such as material, machine, method, and environment gave a less effect.

In order to statistically check the effect of operator calibration quality to the measurement result, it can be approached by hypothesis testing (t-test). The purpose of hypothesis testing (t-test) is to check the claim based on small samples and statistic test. The result of hypothesis testing (t-test) is to check the effect of operator calibration quality to the measurement result. The result is shown in Figure 10.

According to the results of statistical test conducted by Minitab software, p-value is 0.000. P-value is the probability of wrong judgment that the null hypothesis is not true. Since p-value is 0.000 or less than 0.05, null hypothesis can be rejected.[10] It can be said that both operator calibrations are different quality so they effected

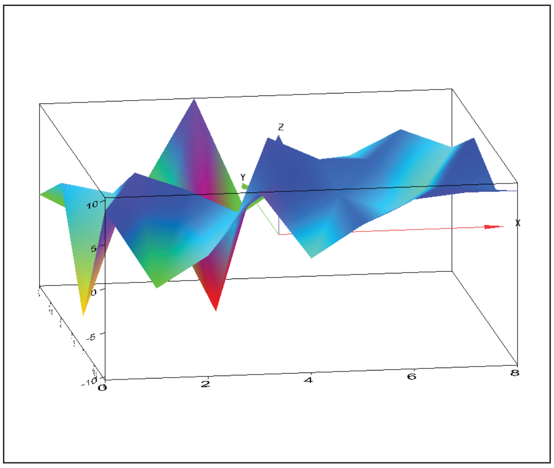

Figure 6. Measurement Result That Was Performed by Operator Calibration A

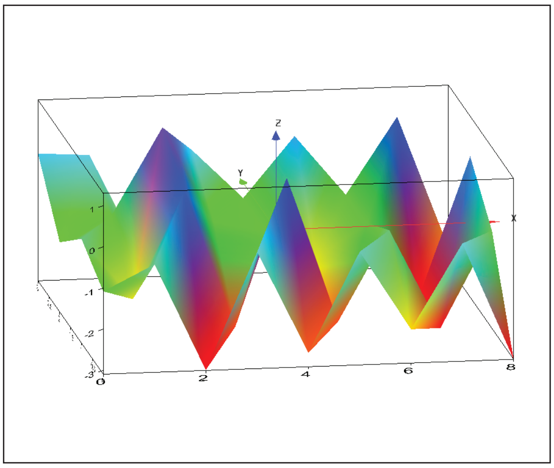

Figure 7. Measurement Result That Was Performed by Operator Calibration B

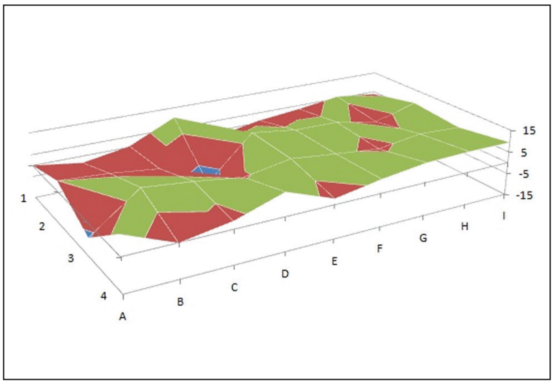

Figure 8. Over All Surface Measurement That Was Performed by Operator Calibration A

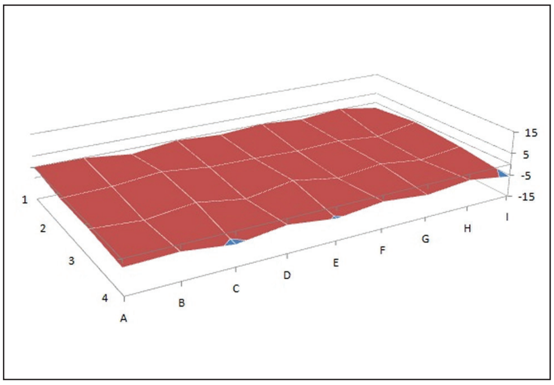

Figure 9. Over All Surface Measurement That Was Performed by Operator Calibration B

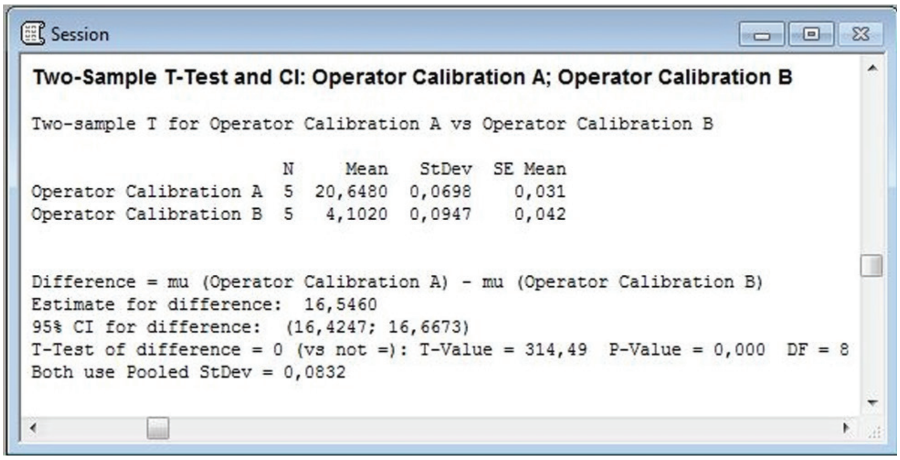

Figure 10. The Result of Hypothesis Testing (T-Test)

measurement result, however technically their measurement results are within range of ISO 8512-2 specification.

The measurement procedure has been reviewed. Refer to this review that both operator calibrations have different deflection value, it looks at the first step measurement. The deflection value at the first step measurement of operator calibration A was 106.26 µm, while the operator calibration B was 49.76 µm. It might cause the discrepancy value of surface flatness. In order to reduce discrepancy due to deflection value, setup measurement system with deflection value at the first step measurement should be less than 50 µm.

4.2 Uncertainty Evaluation

Mathematical models of this proposed method is formulated by equation (1). Therefore, the uncertainty formula of this proposed method can be expressed by:

$$u(\delta_i) = \sqrt{u^2(h_i) + u^2(Y_{slope})} \qquad \text{.........................(4)}$$

If assumed that the value of standard uncertainty to all height reading (h_i) is expressed by $u(h)$, it means that:

$$u(\delta_i) = \sqrt{\sum_i u^2(h_i) + u^2(Y_{slope})}$$

$$u(\delta_i) = \sqrt{i \times u^2(h) + u^2(Y_{slope})} \qquad \text{................ (5)}$$

If a plane has number of $(L \times W)$ measurement step, with L is number of measurement step on length direction and W is number of measurement step on width direction, then the furthest point from point (0.0) is located $(L+W)\times$ measuring step length from the origin point. It means that the largest uncertainty of $\delta_{1,w}$ is

$$u_c(\delta_{l,w}) = \sqrt{(L+W) \times u^2(h) + u^2(Y_{slope})}$$

$$u_c^2(\delta_{l,w}) = \left[(L+W) \times \left(u^2(h_1) + u^2(h_2) + u^2(h_3) + \ldots + u^2(h_6)\right)\right] + u^2(Y_{slope}) \qquad \text{..(6)}$$

with:

$u_c(\delta_{l,w})$ is combined uncertainty

$u(h_1)$ is repeatability

$u(h_2)$ is uncertainty from readability of the mechanical probe

$u(h_3)$ is uncertainty from calibration of the mechanical probe

$u(h_4)$ is uncertainty from readability of the universal measuring machine

$u(h_5)$ is uncertainty from calibration of the universal measuring machine

$u(h_6)$ is uncertainty from cosine error

$u(Y_{scope})$ is uncertainty from compensation error due to linier regression.

The table of measurement uncertainty budget of this proposed method is shown in Table 1.

Tabel 1. Estimated Uncertainty Budget of This Proposed Method

Source Uncertainty	Symbol	Unit	Dist.	Unc. Std. (u_i)	c_i	DOF	$(u_i \times c_i)^2$
repeatability	$u(h_1)$	µm	A	0.008	11	9	0.008
readability of the mechanical probe	$u(h_2)$	µm	Rect.	0.002	11	1000	0
calibration of the mechanical probe	$u(h_3)$	µm	N	0.090	11	1000	0.980
readability of the universal measuring machine	$u(h_4)$	µm	Rect.	0.144	11	1000	2,521
calibration of the universal measuring machine	$u(h_5)$	µm	N	0.300	11	1000	10,890
cosine error	$u(h_6)$	µm	Rect.	0.115	11	50	1,613
compensation error due to linier regression	$u(Y_{scope})$	µm	Rect.	3,464	1	50	12,000
				Combine uncertainty, u_c			5.29
				Effective degree of freedom, υ_{eff}			257
				Expanded uncertainty at k = 2, U_{95}			11 µm

From Table 1, it can be seen that the prominent uncertainty of surface flatness measurement using this proposed method is derived from compensation error due to linier regression and calibration of the universal measuring machine, i.e 43% and 39%. Meanwhile, the influence of other sources of uncertainties, such as repeatability, readability of the mechanical probe, etc. had less significant effect. Using this proposed method, the expanded uncertainty of 11 µm was obtained from calibration of narrow surface plate.

5. CONCLUSION

Analysis and discussion about proposed method to evaluate the topography of narrow surface plate by mechanical probe and universal measuring machine were done. Technically this proposed method can be expected to evaluate the topography of narrow surface plate due to the measurement results are within range of ISO 8512-2 specification. However, this method still needs to compare to the other methods to validate the measurement procedure.

In order to reduce discrepancy of measurement result, setup measurement system with deflection value at the first step measurement should be less than 50 µm. The prominent uncertainty of surface flatness measurement using this proposed method is derived from compensation error due to linier regression and calibration of the universal measuring machine, i.e 43% and 39%. Meanwhile, the influence of other source of uncertainties, such as repeatability, readability of the mechanical probe, etc. giving less significant effect. There will be a challenge in the future to reduce the contribution of regression error in the uncertainty budget.

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