High Precision Technique of Laser Interferometer for Warhead Roundness Measurement

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***Abstract*—This research present high precision technique by apply the measuring roundness instrument using laser interferometer. This measurement composes of laser interferometer, a single-axis rotary table, a glass hemisphere and a testing warhead. The measurement has a high precision turntable which rotates the workpiece against a probe which is held stationary. This paper is broken into 2 cases 1) calibrating the application measuring roundness instrument using laser interferometer and compare the results 2) measuring roundness of the testing warhead. Roundness measurement capability and traceability is discussed here. Considering the experiments where the uncertainties can be described.The experimental results demonstrate the effectiveness of this method, whereby the measuring precision has been improved considerably.**

***Index Terms*—laser interferometer, roundness measurement, uncertainties, warhead roundness**

I. INTRODUCTION

From the past to the present the measurement process is very importance for industrials and militaries such as the roundness measurement. The measurement of roundness deviation of workpiece is essential in mechanical production control. Most roundness measurements are carried out with rotating spindle instruments. For the traceable calibration of roundness standards primary roundness measuring machines are used, offering lowest possible measurement uncertainty [1]. High precision measurements of roundness are appropriate where an object, such as a glass hemisphere, is intended to be used primarily as a roundness standard. So this paper used the glass hemisphere to be certified reference material for calibrate the application measuring roundness instrument using laser interferometer.

Measurements of roundness require 360 ° traces of the testing warhead make with a turntable and application the measuring roundness instrument. A least squares fit of points on the trace to a circle define the parameters of noncircularity of the testing warhead. This paper use at each roundness sampling angles 10 degrees.

Laser interferometer is the high precision length measurement in the resolution of one nanometer so it is used for measurement and calibration other instruments such as calibrate grade 2 gauges block for lengths 70 to 100 mm [2] and measure the roundness of the reference workpiece compare the results [3].

In the context of this paper, defining accuracy characteristic of the application measuring roundness instrument using laser interferometer and considering the uncertainties where the sources be.

II. KINEMATIC DESCRIPTION

For simplicity this case is divided into two categories.

A. The Application Measuring Roundness Instrument Calibration

The aim of this case is the calibration of the application measuring roundness instrument and compare the results between the reference results and the experiment measurement results. The uncertainty of this system shows in the Fig. 2 and Table I.

For the application measuring roundness instrument set up, the reflector mirror is placed on moving slide which can move along the glass hemisphere surface. The displacement of reflector along the glass hemisphere results to the radius of it at each sampling angle show in Fig. 1. The glass hemisphere is calibrated by National Institute of Metrology (Thailand) or NIMT. The comparison of the results between NIMT and the experiments use the E_n ratio show in Eq. (1) and number of replications show in Eq. (2). After that, finding the correction of all sampling angle used to adjust in the measurement software.

$$E_n = \frac{Lab - Ref}{\sqrt{U_{Lab}^2 + U_{Ref}^2}} \tag{1}$$

$$n' = \left(\frac{z\alpha_{/2} S}{e}\right)^2 \tag{2}$$

$$e = \frac{\left(t\alpha_{/2,n-1}\right) S}{\sqrt{n}} \tag{3}$$

where E_n is ratio of the average difference of experimental result (Lab) and reference result (Ref) divide square root of difference totality of both deviations. n' is the numbers of replications. S is the standard deviation. e is the system tolerances. n is the start numbers of replications and α is the significant levels [4].

In the present work, the glass hemisphere is the certified reference material for calibrate the application measuring roundness instrument.

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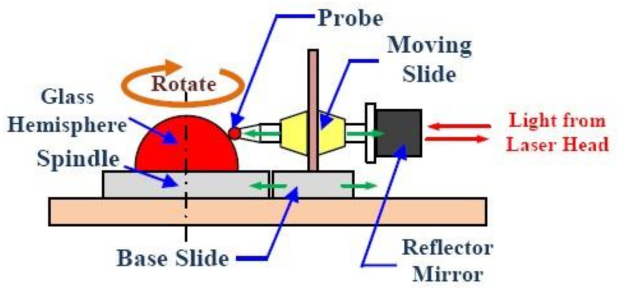

Figure 1. The application measuring roundness instrument calibration diagram

From Fig. 1 shows the application measuring roundness instrument diagram. The calibration procedures are described here. The first, set up the laser interferometer adjust all moving slides, set up the highly accurate spindle and set up the temperature be constant at 20 to 30 ± 0.2 ℃. The Second, put the glass hemisphere on the spindle. The component is rotated on a highly accurate spindle which provides a circular datum. The glass hemisphere axis is aligned with the axis of the spindle by means of a centering and leveling table. The third, measure the glass hemisphere. The sampling angles (A_k) are 10 degrees. The start number of replications (n) are defined in 3 replications at the significant levels (α) are 5%.

Considering where are the uncertainties from Fig. 2, type A and type B uncertainties can calculate the standard total uncertainty from Eq. (9) and Eq. (10) and the results show in Table I [5], [6].

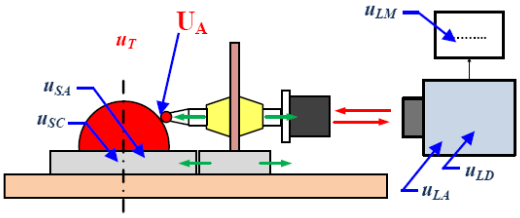

Figure 2. The application measuring roundness instrument calibration uncertainties

where:

U_A is the type A uncertainty

u_{LA} is the uncertainty from the accuracy of the laser interferometer.

u_{LD} is the uncertainty from deviation of the laser interferometer.

u_{LM} is the uncertainty from a monitor resolution error of the laser interferometer.

u_T is the uncertainty from the thermal expansion.

u_{SA} is the uncertainty from the accuracy of spindle rotating

u_{SC} is the uncertainty of spindle at coverage factor 95% confidence interval.

u_c is the total uncertainty.

B. Roundness Measurement

In this paper, using Least Square Method for the roundness and find the reference cycle and the reference center of cycle shows in Fig. 3.

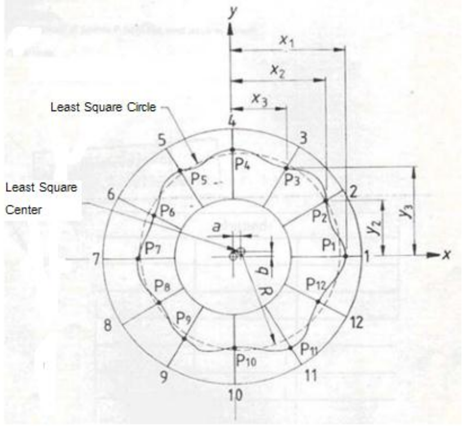

Figure 3. Determination of Least Squares Circle (LSC)

From Fig. 3, the distance from the center of the chart to the coordinate (a, b) are the center of the reference circle [7].

$$a = \frac{2}{n}\sum_{i=1}^{n} x_i \tag{4}$$

$$b = \frac{2}{n}\sum_{i=1}^{n} y_i \tag{5}$$

where:

x_i are the distance between the radius each sampling angle in x axis.

y_i are the distance between the radius each sampling angle in y axis.

n are the number of the sampling radius.

After finding the center of reference circle, the roundness of the workpiece can calculate.

$$R_i = \sqrt{(x_i - a)^2 + (y_i - b)^2} \tag{6}$$

$$\Delta R = R_{MAX} - R_{MIN} \tag{7}$$

where:

R_i are the distance from the reference center of the circle to the circumference in each experiment.

(x_i, y_i) is the intersection coordinate of the circumference in each sampling radius.

(a, b) is the reference center coordinate.

ΔR is the roundness of the workpiece

R_{MAX} is the maximum radius (max R_i)

R_{MIN} is the maximum radius (min R_i)

The roundness measurement processes are broken into 2 cases.

1. Finding the numbers of replications (n') from the start number of replications (n) are defined in 3 replications. From the experiment at the sampling angle (A_k) are 10 degrees. The standard deviations (S) are 0.0018 µm. So, the numbers of replications (n') are 3.44 ≈ 4 replications from Eq. (2).

2. Measuring the roundness of the glass hemisphere for 4 replications. The total horizontal axis of coordinates (Σx, Σy) are calculated for the center of reference cycle refer to Eq. (4) and Eq. (5) when Σx = 0.017 µm, Σy = -0.020 µm and n = 36. So, the center of reference cycle in coordinates is (0.001, -0.001). The radius of the center of reference cycle can calculate from Eq. (6) are 30,000.003

μm. The roundness of the hemisphere from the experiment is the different of maximum radius 30,000.035 μm and minimum radius 29,999.965 μm. equal 0.070 μm and the uncertainty are ±0.082 μm show in Table I. The measurement results from NIMS are 0.066 ±0.007 μm.

TABLE I. THE UNCERTAINTIES OF THE APPLICATION MEASURING ROUNDNESS INSTRUMENT

Type	Standard Uncertainty	Probability Distribution	Divisor	Uncertainty Contribution
U_A	0.002	normal	$\sqrt{4}$	0.001
u_{LA}	0.001	normal	$\sqrt{3}$	0.000577
u_{LD}	0.025	normal	2	0.0125
u_{LM}	0.001	rectangular	$2\sqrt{3}$	0.000289
u_T	$0.07 \times 11.5 \times 10^{-3} \times 0.2$	rectangular	$2\sqrt{3}$	0.000047
u_{SA}	0.03×0.07	rectangular	$\sqrt{3}$	0.00123
u_{SC}	0.08	normal	2	0.04
u_c	0.041			
U/ u_{AI}	0.082			

From Fig. 4 show the polar coordinate and Fig. 5 show the coordinate plane from the experiments.

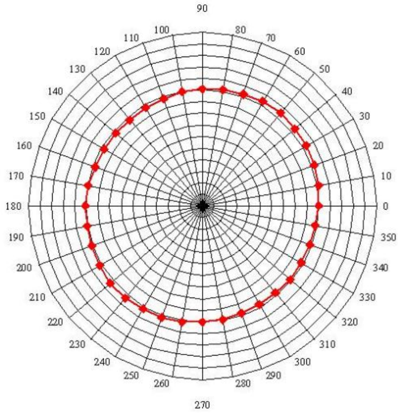

Figure 4. The polar coordinate

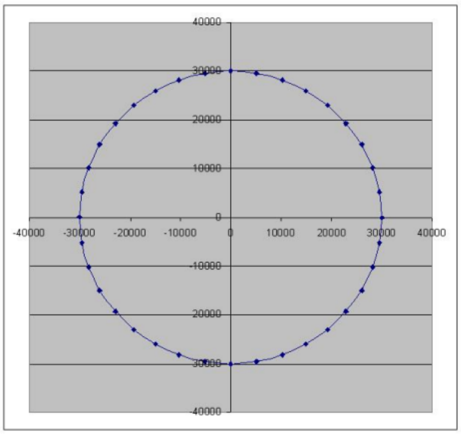

Figure 5. The coordinate plane

In this case, show the application measuring roundness instrument using hemisphere to be the reference. The application measuring roundness instrument uncertainty (u_{AI}) is ±0.082 μm.

Finally, compare the both results *Lab* and *Ref* using E_n ratio in Eq. (1).

$$E_n = \frac{0.070 - 0.066}{\sqrt{0.082^2 + 0.007^2}} = 0.043$$

From the comparison using E_n ratio the result is 0.043 shows the application measuring roundness instrument can be used at the uncertainty (u_{AI}) is ±0.082 μm.

C. The Warhead Roundness Measurement

In this process shows an application of laser interferometer for warhead roundness measurement. After the application measuring roundness instrument calibration process, the measurement system is ready to measure roundness of the warhead.

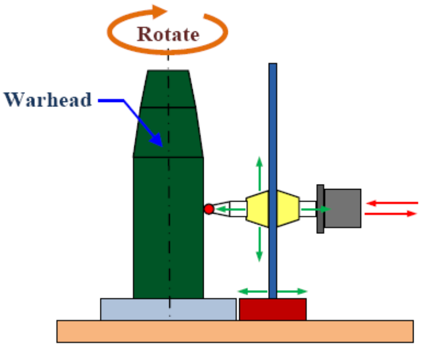

Figure 6. The testing warhead measurement diagram

From Fig. 6 show the testing warhead measurement system diagram. This process is described here.

1) The system set up

After the application measuring roundness instrument calibration process, a glass hemisphere was taken a place of the testing warhead. The testing warhead axis is aligned with the axis of the spindle by means of a centering and leveling table.

The probe is touched at the testing warhead surface at the start point by moved the base slide. The forces of probe proceed to the testing warhead surface are 1.8 N or less. In this paper, the moving slide used dial indicator by fix the reflector mirror at the tail of the probe. Set up the laser interferometer and set monitor to zero, the system is ready.

2) The measuring testing warhead

In this process would start after the measuring set up by not move the all system and not change environment.

This step, the testing warhead replaced the glass hemisphere. The testing warhead was set up like a glass hemisphere in the step before.

In the Fig. 7 (A) shows the sampling high, $\mathbf{H_i}$ is the high of cone section and $\mathbf{H_j}$ is the high of cylinder section where $\mathbf{H_i} = [h_{i1}, h_{i2}, h_{i3},\ldots, h_{im}]^T$ and $\mathbf{H_j} = [h_{j1}, h_{j2}, h_{j3},\ldots, h_{jn}]^T$. The Fig. 7 (B) shows the sampling angle $\mathbf{A_k} = [a_1, a_2, a_3,\ldots, a_{36}]$

The measuring process using the sampling angles (A_k) are 10 degrees from Fig. 7 (B). The start numbers of replications (n) are defined in 3 replications at the significant levels (α) are 5%. From Eq. (2), the numbers of replications are 2.276 ≈ 3 replications.

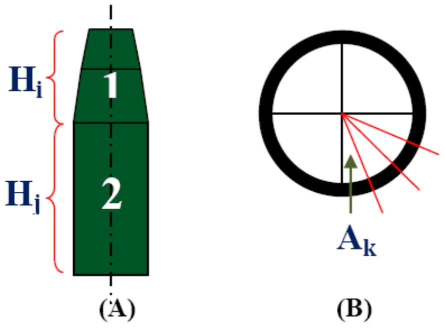

Figure 7. The sampling high and the sampling angle

Considering where are the uncertainties from Fig. 8, type A and type B uncertainties could calculate the standard total uncertainty from Eq. (8) and Eq. (9) [8].

$$u_c^2(y)=\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)+2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i,x_j) \quad (8)$$

$$u_c=\sqrt{u_A^2+\sum_{i=1}^{10}u_i^2} \quad (9)$$

$$\mathrm{U}=k.u_c \quad (10)$$

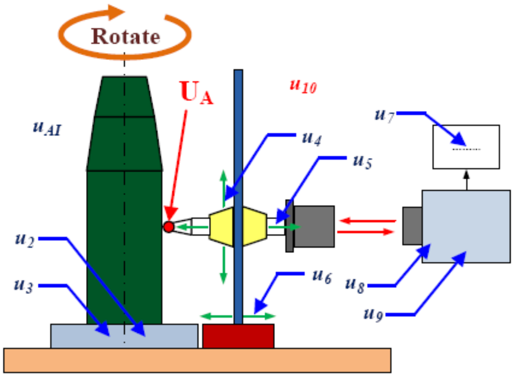

Figure 8. The uncertainties of the system

TABLE II. THE UNCERTAINTIES OF THE SYSTEM

Type	Standard Uncertainty	Probability Distribution	Divisor	Uncertainty Contribution
U_A	σ	normal	$\sqrt{3}$	0.5773 σ
u_{AI}	0.082	normal	2	0.041
u_2	0.08	normal	2	0.04
u_3	0.03 $E[\Delta R_i]$	Rectangular	$\sqrt{3}$	0.01732 $E[\Delta R_i]$
u_4	0.01	normal	2	0.005
u_5	0.01	normal	2	0.005
u_6	0.01	normal	2	0.005
u_7	0.001	Rectangular	$2\sqrt{3}$	0.000289
u_8	0.01	Rectangular	$\sqrt{3}$	0.00577
u_9	0.025	normal	2	0.0125
u_{10}	0.00575 $E[\Delta R_i]$	Rectangular	$2\sqrt{3}$	0.004979 $E[\Delta R_i]$
u_c	$\sqrt{0.33327\sigma^2+0.000325E[\Delta R_i]^2+0.003541}$			
U	$2\sqrt{0.33327\sigma^2+0.000325E[\Delta R_i]^2+0.003541}$			

$$U=2\sqrt{0.33327\sigma^2+0.000325E[\Delta R_i]^2+0.003541}$$

where:

u_c is the total uncertainty.

U_A is the type A uncertainty.

u_{AI} is the uncertainty from the applied machine.

u_2 is the uncertainty of spindle at coverage factor 95% confidence interval.

u_3 is the uncertainty from the accuracy of spindle rotating..

u_4 is the uncertainty of probe moving in vertical.

u_5 is the uncertainty of probe moving in horizontal.

u_6 is the uncertainty of base slide in horizontal.

u_7 is the uncertainty from a monitor resolution error of the laser interferometer.

u_8 is the uncertainty from the accuracy of the laser interferometer.

u_9 is the uncertainty from deviation of the laser interferometer.

u_{10} is the uncertainty from the thermal expansion.

From the Table II. shows all uncertainties of the measurement system. The expand uncerainty (U) show that in Eq. (10) where σ is the standard diviation of repeated measurement at the 3 replications. $E[\Delta R_i]$ is the average of roundness in the experiments.

III. CONCLUSIONS

Based on the results, we can summarize as follows:

A. The Application Measuring Roundness Instrument Calibration

From the experiment at the sampling angle (A_k) are 10 degrees. The standard deviations (S) are 0.0018 µm. So, the numbers of replications (n′) are 3.44 ≈ 4 replications at the start numbers of replications are 3 replications.

From measuring the roundness of the glass hemisphere for 4 replications using LSC method, the center of reference cycle in coordinates is (0.001, -0.001). The radius of the center of reference cycle is 30,000.003 µm. The roundness of the hemisphere from the experiment is the different of maximum radius 30,000.035 µm and minimum radius 29,999.965 µm. equal 0.070 µm and the uncertainty are ±0.082 µm. The measurement results from NIMS are 0.066 ±0.007 µm. From the comparison using E_n ratio the result is 0.043 shows the application measuring roundness instrument can be used at the uncertainty (u_{AI}) is ±0.082 µm.

B. The Warhead Roundness Measurement

From the experiment at the sampling angle (A_k) are 10 degrees. The numbers of replications (n′) are 2.276 ≈ 3 replications at the start numbers of replications are 3 replications.

The uncertainties of this measurement, the expand unceraintry (U) are in equation where σ is the standard diviation of repeated measurement at the 3 replications. E[ΔR_i] is the average of roundness in the experiments.

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