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ROUNDNESS MEASUREMENT CAPABILITY AND TRACEABILITY AT NIMT

Samana Piengbangyang, *Thammarat Somthong*, *Jariya Buajarern, Anusorn Tonmueanwai*

Dimensional Metrology Department, National Institute of Metrology (Thailand), Pathumthani, Thailand,
jariya@nimt.or.th

Abstract − Roundness measurement capability and traceability at the National Institute of Metrology (Thailand), NIMT, is discussed here. RTH Talyrond 73 HPR is used to measure various roundness parameters of the specimen. The modifications of the measurement system and analysis software were employed in order to perform roundness measurement based on multi-step method. This technique enables us to separate roundness error of the workpiece from the spindle error of the instrument. The measurement uncertainty for the glass hemisphere calibration using multi-step method is Q[8, 8*R*] nm where *R* is the measured roundness error of the glass hemisphere in µm. The spindle error of the RTH Talyrond 73 HPR at NIMT up to 53 nm was observed.

Keywords: roundness, calibration, traceability

1. INTRODUCTION

Roundness measurements are essential in mechanical production control. Every rotating part will function properly only when the correct degree of roundness is achieved according to the specification. Out of roundness can produce numbers of problem, vibration, wear and noise for instances.

Roundness measurements contain measurement of a collection of points. For product inspection in the production line, measurement of deviations of diameter by caliper or dial test indicator can be used. These measurement methods are simple and low cost but have limitations. For more accurate measurement, 360° traces of the workpiece using a turntable-type instrument or a rotating stylus-type instrument is required. A least squares fit of measuring points to a perfect circle defines the non-circularity of the workpiece.

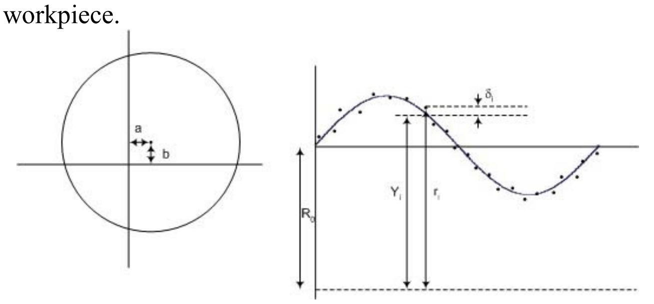

Fig. 1. (Left) Raw data from roundness measurement. (Right) Least square circle fitting.

Terms, definitions, parameters, filtering, measurement procedure and assessment of roundness are defined in the ISO 4291, ISO 4292, and ISO 12181-1 and -2 [1-4]. There are 4 types of roundness assessment procedures based on how the reference circle is constructed. There are Least Square Circle (LSC), Minimum Zone Circle (MZC), Minimum Circumscribed Circle (MCC), and Maximum Inscribed Circle (MIC) [5]. LSC is the most widely used especially among the national metrology institutes.

Fig. 1 shows raw data where centering error is at point (a, b). Using such data points to create a straight line, R_o became the center of LSC. r_i is radius of measured circle at each angle, within 360^o, and Y_i is the LSC.

$$y = \sum_{i=1}^{n} r_i \qquad (1)$$

$$Y = R_0 + a\sum_{i=1}^{n}\cos\theta_i + b\sum_{i=1}^{n}\sin\theta_i \qquad (2)$$

The minimum difference between LSC and measured traced points can be defined by

$$\delta_i = \sum_{i=1}^{n} r_i - (R_0 + a\sum_{i-1}^{n}\cos\theta_i + b\sum_{i=1}^{n}\sin\theta_i) \qquad (3)$$

Thus, deviation from least square circle, ΔZ_q is

$$\Delta Z_q = \delta_{i\max} - \delta_{i\min} \qquad (4)$$

where i is an integer number and n is number of traced points in the measured profile.

Roundness parameters include cylindricity parameters, angle plane parameters such as coaxiality and concentricity. Flatness, parallelism and squareness can be measured using circular contour tracing instrument. Numbers of assessment of roundness condition enable us to investigate regularity of form of the any workpieces.

In the following, a roundness measuring instrument used at NIMT is described in detail where all relevant influence quantities are investigated. Capability in roundness measurement of roundness workpieces, roundness standard and error separation techniques are discussed. Experimental results are reported and a measurement uncertainty budget is discussed.

2. MEASUREMENTS

At NIMT, RTH Talyrond 73 HPR which is a rotating-spindle type as shown in Fig. 2 is used. The spindle rotates at speed of 6 revolutions per minute. The measuring force is approximately 50 mN. Each revolution of spindle, 2000 data points are recorded. Stylus tip is made of tungsten carbide. For roundness measurement of spheres, tungsten carbide stylus length 63.5 mm, 0.79 mm ball radius is used. While stylus with 63.5 mm effective arm length with tip protrudes 1.5mm and hatchet radius 6.4 mm is suitable for cylinders, cones and bores.

Fig. 2. RTH Talyrond 73 HPR at the NIMT.

Workpieces of diameter up to 355 mm are capable of being measured with this instrument. Workpiece must not exceed height of 406 mm and not weight more than 68 kg.

2.1. Roundness Measurement

For roundness measurements that do not require a high level of precision, such as measurements of cylinders, plug gauges, and ring gages, a single trace is carried out using a normal mode. The magnification of the normal mode is up to 50 times. For higher precision roundness measurement such as spheres, high precision mode with magnification up to 500 times is selected. Gaussian function with cut-off wave number of 1-50 UPR (Undulation Per Revolution) were employed in order to analyse measured data points. LSC method was used to assess roundness parameters.

To measure cylindricity of workpieces, tilting stage was used to adjust axis of the workpiece to be perpendicular with the trace axis. The minimum tilting angle can be checked by monitoring the second harmonic of the roundness profile.

The weakness of the single trace method is that the deviations contain both the spindle error and the workpiece error. However, since the spindle error is rather small and within known limits, its effect can be neglected for low precision measurement. The measurement uncertainty for roundness measurement is Q[11.1, 11R] nm where R is the measured roundness error in μm and the measurement was performed in the high precision mode.

2.2. Calibration of Roundness Measuring Instrument

Flatness of the measuring stage is needed to be measured using flatness measurement menu before each calibration of the roundness measuring machine. If flatness exceeds 1 μm, tilting knob at the bottom of the measuring stage must be adjusted. Calibration of the roundness measuring machine is performed routinely using two flick standards (magnification setting standards), 19.53 μm and 283.2 μm, and a glass hemisphere.

Fifty one points of the roundness error obtained from the calibrated glass hemisphere are inputted to the calibration database of the Talyrond software before performing the spindle calibration. During this process, calibrated glass hemisphere is used as a roundness standard to compare roundness error from the database with the measured results. The difference is considered as the spindle error which is stored in the software as the spindle error database. Whenever perform roundness measurements, measured roundness profile will be subtracted with the spindle error profile yielding true roundness error of the workpieces under tested. Sensitivity of the measuring probe is also required to be calibrated to guarantee correct reading. By using two flick standards, linearity of the stylus probe can be obtained.

2.3. Roundness Standard Calibration

When perform high precision measurements such as a measurement of the standard glass hemisphere which is used as a primary standard of roundness, it is crucial to separate the spindle error from the roundness error of the standard. The measurement involves making multiple traces of the roundness standard which is rotated at known angle between each trace. Least-squares analysis of the measurement results enables the non-circularity of the spindle to be separated from the profile of the roundness standard [6-7].

In order to performed multi-step method calibration, indexing table manufactured by Issoku, model SPID-720A, was used to rotate the glass hemisphere at the 36 degrees increment. Spindle error database was removed by carrying out spindle error calibration with output cable unplugged. Thus roundness measurement data contain both roundness error of the glass hemisphere and the spindle error of the roundness measuring machine. Fig. 3 illustrates geometry of the glass hemisphere situated on the indexing table. Indexing table was rotated counter clockwise with interval of 36^o until complete a revolution. Ten measurements were employed at each rotation of the indexing table. The stylus probe is aligned perpendicular to the measuring surface of the glass hemisphere and situated at 3$\pm$0.5 mm above the supporting base of the glass hemisphere. The calibration procedure was reproduced 3 times.

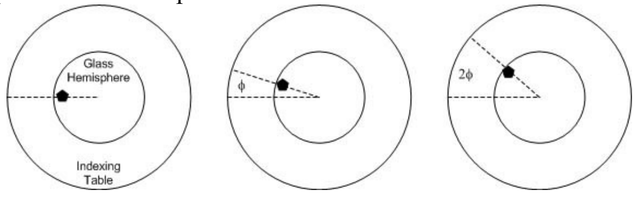

Fig. 3. Glass hemisphere was rotated by indexing table 36^o interval during multi-step measurement.

Measurement results from all orientation of the glass hemisphere are then converted to the .txt format and analysed by our own developed software. Firstly, the centering error due to alignment of the glass hemisphere was removed. Then the spindle error was calculated by averaging data points from all rotation axes. The spindle error was then subtracted from the measured roundness error yielding true roundness deviation of the glass hemisphere. Same as any surface texture measurement, the primary profile contains information of roughness, waviness and form of the workpiece. Here, gaussian function is used in order to filter out roughness profile. Fig. 4 demonstrates a moving average method in combination with Gaussian functions. The filtered profile was then assessed according to ISO 4291 giving the true circularity of the glass hemisphere. We chose to use LSC because of its widely used and to be consistence with other NMIs' assessment method.

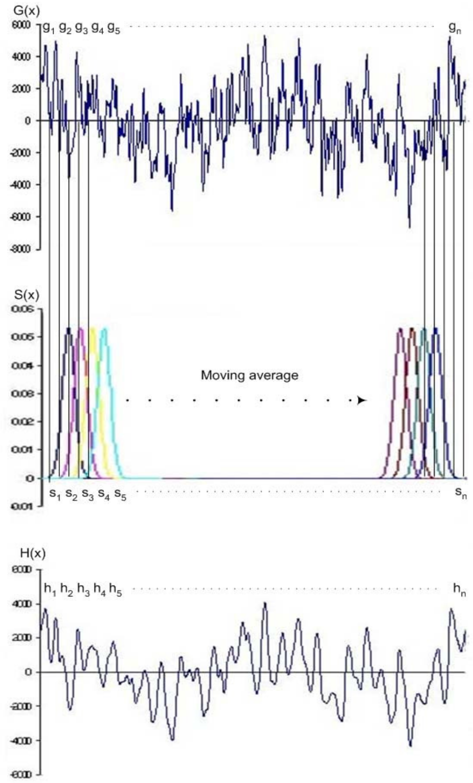

Fig. 4. Gaussian filter in the moving average method.

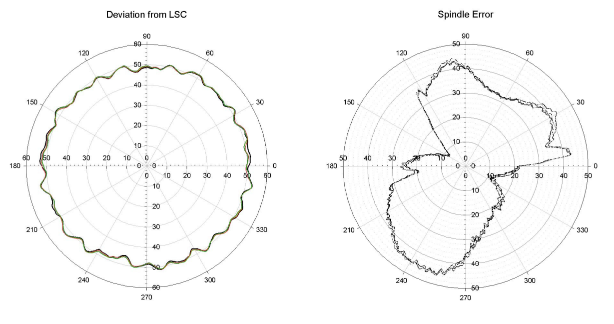

Fig. 5. Roundness deviation of the standard glass hemisphere and spindle error of the roundness measuring instrument obtained after performed calibration using multi-step method.

Fig. 5 shows three roundness measurement results of the same glass hemisphere and the spindle error profiles of the roundness measuring instrument. All three roundness measurement show very good repeatability.

Spindle error of the RTH Talyrond 73 HPR at NIMT is observed to be at 53 nm. Eventhough we can measure spindle error of the instrument, but due to limitation of the software, we cannot input this spindle error profile to the instrument software directly. Consequently, spindle calibration according to the software instruction must be performed against certified standard glass hemisphere.

2.4. Traceability

Traceability of roundness measurement at NIMT is summarized in Fig. 6. Magnification setting standards used for stylus sensitivity calibration were calibrated by the National Measuring Institute of Australia (NMIA) where the realization to Metre was achieved through the used of He-Ne laser. Standard glass hemisphere was self-calibrated at NIMT using combination of Talyrond 73 HPR and indexing table. However, standard glass hemisphere is neither traceable to the Talyrond 73 HPR nor indexing because error from both instruments can readily eliminated by mathematic used in multi-step method. Nevertheless, sensitivity of the stylus affects accuracy of the roundness error of the glass hemisphere. Thus, it can be said that multi-step calibration method is traceable to magnification setting standard.

Both flick standard and glass hemisphere are used for Talyrond 73 HPR calibration. Thus, the traceability chain to the roundness workpiece such as spheres, ring gauges, plug gauges and other roundness measuring instruments can be retained.

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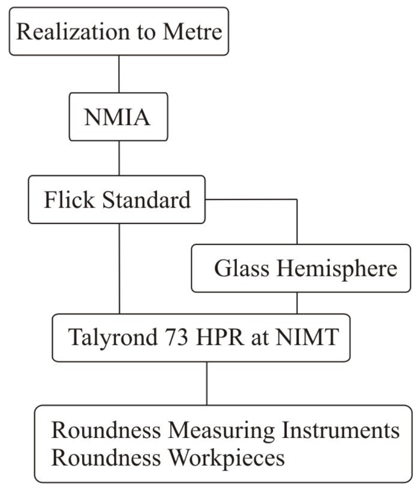

Fig. 6. Realization to the SI unit of the roundness measurement at NIMT through NMIA.

3. MEASUREMENT UNCERTAINTY

The measurement uncertainty was evaluated according to "Guide to the expression of the uncertainty in measurement" (GUM) [8]. The uncertainties of glass hemisphere calibration using multi-step method are summarized in Table 1.

Table 1. Measurement uncertainties.

Uncertainties	Contribution (nm)
Type A	0.29
Form deviation of the hemisphere	1.30
Probe calibration	0.19
Drift of the spindle error	1.15
Squareness of the instrument	2.89
Resolution	0.35
Thermal Drift	1.73
$U_{95\%}$	**8.01**

Measurement uncertainties include measurement reproducibility, form deviation of the hemisphere, stylus probe calibration, drift of the spindle error during calibration process, squareness of the measuring stage, digital resolution of the instrument and drift of the workpieces and stylus probe affected by the temperature variation. The combined measurement uncertainty at 95% certainty is appeared to be just over 8 nm.

4. CONCLUSIONS

We had explained the measurement procedure for roundness measurements at NIMT. By using the combination of indexing table and the RTH Talyrond 73 HPR, multi-step method can be done. Spindle error of the RTH Talyrond 73 and roundness error of the standard glass hemisphere were determined by our own developed software. Measurement uncertainty was observed to be within 9 nm with roundness error of 5 nm. The spindle error of the instrument is 55 nm.

Currently, we are working on developing the semi-automatic measuring system for the multi-step method calibration. The replacement of the indexing table with the rotary encoder is believed to improve the measurement uncertainty and reduce the calibration time. Not only that, the correlation between roundness measurements obtained from the rotating table and the rotating stylus will be investigated thoroughly by using this system.

ACKNOWLEDGMENTS

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