

Validation of the Non-Contact Roundness Measurement Method Based on V-Block and Laser Distance Sensor

Thanh-Trung Nguyen

School of Mechanical Engineering, Hanoi University of Science and Technology, Vietnam

Author's E-mail: trung.nguyenthanh2@hust.edu.vn

Abstract - In this study, a roundness measurement approach is proposed, which combines a V-block setup with a non-tactile distance sensor. The results obtained from this method are compared with those measured using a commercial CMM. The proposed method is not only cost-efficient but also enables high-frequency data acquisition, which facilitates a more detailed characterization of the actual surface profile. Furthermore, it features a straightforward hardware configuration and simplified data processing. Measurements were conducted on two cylindrical surfaces (denoted A and B) of a shaft specimen, with each measurement repeated 15 times to assess repeatability based on the standard deviation. The results indicate that the V-block method yielded lower standard deviations than the CMM method with varying numbers of measurement points. Notably, a significant discrepancy was observed for surface B. This suggests that the sparse sampling of discrete points by the CMM may be insufficient to capture the true surface profile. Overall, the proposed method demonstrates strong potential as a reliable and practical solution for roundness evaluation.

Keywords: Non-contact measurement, Roundness, V-block, laser sensor, Coordinate machine measuring.

I. INTRODUCTION

Roundness is a geometric parameter that quantifies the degree to which rotating cylindrical parts approximate a perfect circle, and it has a significant influence on the performance of mechanical components. For instance, the geometry of the valve seat directly affects the compression ratio of an internal combustion engine, especially affecting the compression and combustion phases [1]. Similarly, the roundness of the cylinder or piston seal influences the coefficient of friction; large roundness deviations increase the total frictional force and result in reduced engine efficiency [2]. Additionally, the distribution of contact stress between the metal seal and the sliding sleeve in an interval control valve (ICV) is also governed by the roundness deviation of the mating surfaces [3].

According to ISO 12181-1:2011(E) [4], roundness deviation (peak-to-valley roundness deviation) defined as “value of the largest positive local roundness deviation added to the absolute value of the largest negative local roundness deviation”. This leads to the concept of *local roundness deviation*, which refers to the “minimum distance from a point on a roundness profile to the reference circle”. This value is negative when the point lies inside the reference circle and positive when the point lies outside (as illustrated by distance *a* and *b* in Figure 1).

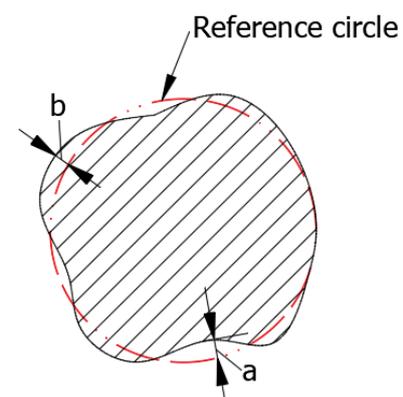


Figure 1: Local form deviation of an external roundness feature [4]

Consequently, determining the roundness deviation depends on how the reference circle is defined. The ISO 12181 standard outlines four methods for determining this reference circle: Minimum Zone Circle (MZC), Minimum Circumscribed Circle (MCC), Maximum Inscribed Circle (MIC), and Least Squares Circle (LSC). Among these, the MZC method is most widely recommended, as it consistently yields the smallest roundness deviation [5, 6]. The LSC method, although potentially less accurate in some cases, offers the advantage of fast data processing, making it suitable for applications involving large datasets such as optical surface scanning [7]. MCC is typically applied to hole-type parts, while MIC is more appropriate for shaft-type parts [8, 9].

Roundness deviation can be measured using a coordinate measuring machine (CMM) by acquiring the coordinates of discrete points along the surface of the measured part.

Alternatively, a super-precision rotary table combined with either a contact or non-contact sensor can be employed, following the operating principle of a dedicated form measuring system. However, a major limitation of the rotary table approach is the inevitable presence of eccentricity and tilt between the axis of rotation and the center of the workpiece [10–12]. To overcome this issue, form measuring machines must be equipped with a turntable that allows center adjustment relative to the axis of rotation.

A more cost-effective and widely used method for assessing the roundness of external cylindrical components is to use a V-block and a dial indicator while manually rotating the part. This method benefits from low equipment costs, and simple setup. When implemented correctly, it can still provide results with acceptable accuracy [13]. Nevertheless, as a contact-based technique, it remains subject to certain limitations such as stylus wear and force fluctuations caused by workpiece rotation, which can affect measurement reliability. To overcome these drawbacks, this study proposes a non-contact roundness measurement approach that combines a laser distance sensor with the V-block setup, facilitating contactless data acquisition, followed by post-processing and compared against measurements obtained from a Mitutoyo Crysta Apex S544 CMM. The primary objective of this study is to evaluate the feasibility, accuracy, and reliability of the proposed low-cost measurement method, with the aim of establishing its suitability for practical roundness evaluation tasks in industrial and research settings.

II. PRINCIPLE OF MEASURING ROUNDNESS ON V-BLOCK

Roundness measurement using a V-block is based on the variation in contact positions at three points: two contact points between the measured part and the angled surfaces of the V-block, and one point at the probe (or laser spot) position. As illustrated in Figure 2, when measuring the roundness of a lobed workpiece placed on a V-block with an appropriate angle α , there will be moments during one full rotation where the circumscribed and inscribed circles of the actual profile are in contact with the two edges of the V-block, respectively. At these points, the sensor (e.g., a laser distance sensor) captures the maximum and minimum displacement values, corresponding to the variation in the measured value L_c . The geometric relationship between L_c and the nominal radius R of the workpiece is:

$$L_c = \left(1 + \frac{1}{\sin(\frac{\alpha}{2})}\right) R \quad (1)$$

Therefore, the roundness deviation ΔR is calculated according to the formula:

$$\Delta_R = R_{max} - R_{min} = \frac{L_{cmax} - L_{cmin}}{1 + \frac{1}{\sin(\frac{\alpha}{2})}} = \frac{\Delta x}{1 + \frac{1}{\sin(\frac{\alpha}{2})}} \quad (2)$$

In which, Δx is the difference between the largest and smallest output values recorded by the sensor as seen in Figure 1. In addition, the V-block angle α should be selected based on the number of lobes n of the workpiece, and can be calculated using the following formula:

$$\alpha = 180^\circ - \frac{360^\circ}{n} \quad (3)$$

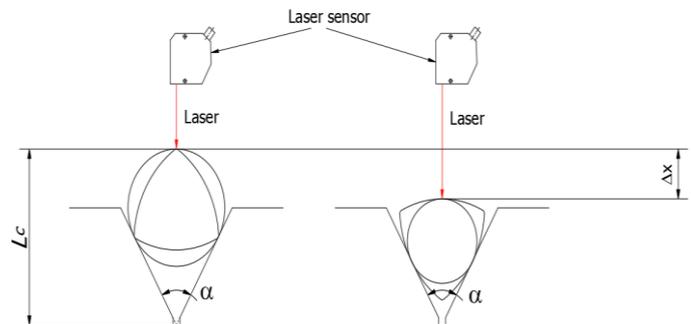


Figure 2: Schematic diagram illustrating the principle of roundness measurement using a V-block

III. RESULTS AND DISCUSSION

The roundness deviation experiments using a V-block and the Keyence LK-H055 laser distance sensor were conducted as illustrated in Figure 3. The angle between the two inclined faces of the V-block was 60 degrees, and the specifications of the LK-H055 sensor are presented in Table 1. To determine the displacement variation Δx , the measured part was rotated for at least one full revolution (additional revolutions produced repeatable results). During rotation, the sensor recorded distance fluctuations with a sampling cycle of 10 ms. The data were exported both as a graph (Figure 4) and as a .csv file. From the data file, Δx was calculated as the difference between the maximum and minimum values in the entire dataset. The roundness error Δ_R was then determined using the formula $\Delta_R = \Delta x / (1 + 1/\sin(\alpha/2)) \approx \Delta x / 3$, with $\alpha = 60^\circ$.

Each measurement was repeated 15 times at the same cross-section on surfaces A and B to calculate the standard deviation and to evaluate the Type A measurement uncertainty. The Type B measurement uncertainty was not evaluated in this study, as the effects of systematic errors arising from misalignment of the rotation axis and the positioning of the measured part on the V-block could not be quantified.

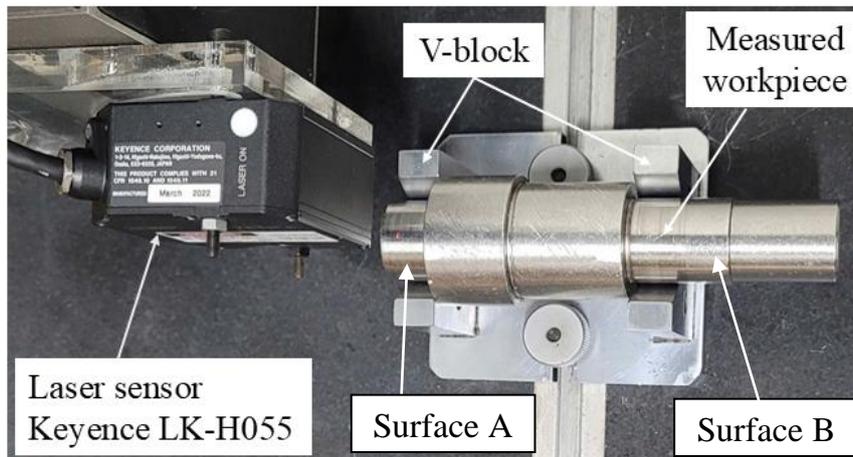


Figure 3: Experimental setup for roundness measurement using a V-block and a laser distance sensor

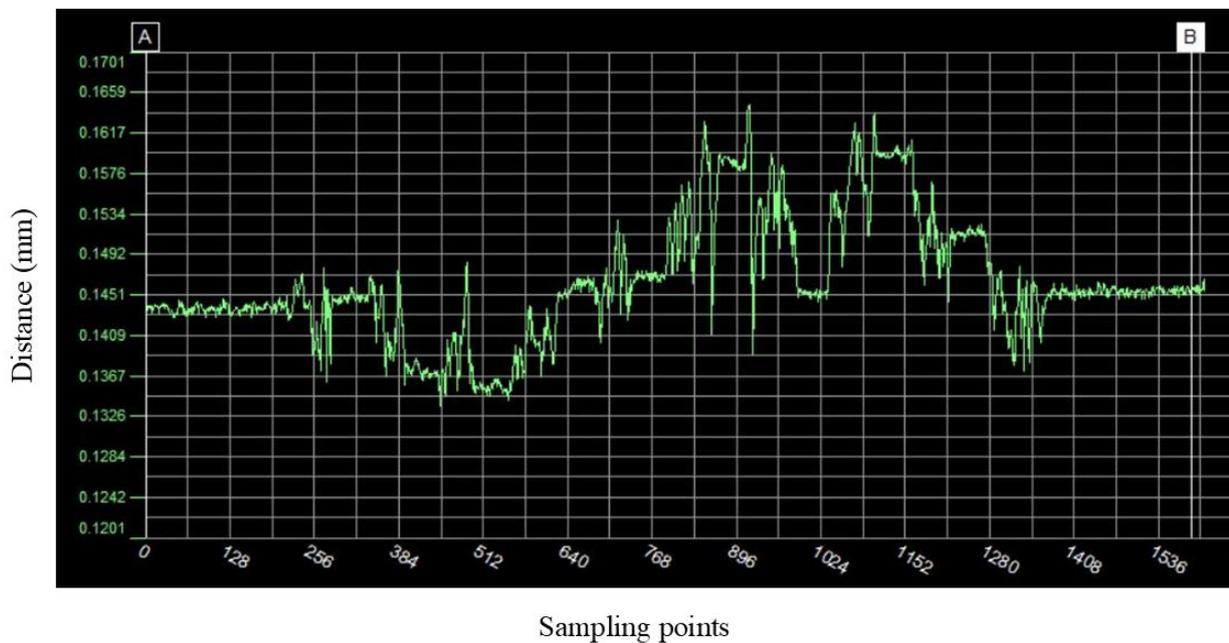


Figure 4: Distance data graph extracted from the LK-H055 laser distance sensor

Table 1: Specification of Keyence LK-H055 laser distance sensor

Specifications	Value
Reference distance	50 mm
Measuring range	±10 mm
Wavelength of laser source	655 nm
Laser spot	0.05 × 2 mm
Repeatability	0.025 μm

To compare the roundness measurement results between the V-block method and the CMM method, the shaft was re-measured using a Mitutoyo Crysta Apex S544 CMM equipped with a TP20 probe. The CMM has a maximum permissible

error ($E_{0, MPE}$) of $2.2 + 4L/1000$ (μm), where L is the measured length in millimeters. According to studies [14, 15], the accuracy of roundness measurement is significantly influenced by the number of sampling points and the distortion profile of the measured profile. Therefore, the number of measuring points should be selected to ensure sufficient accuracy without unnecessarily increasing time and cost. The authors also emphasize that using too few points (fewer than 12) can result in failure to detect roundness deviations in many cases. When the number of points exceeds 30, the measured values tend to stabilize and show minimal variation. Based on this, three measuring point levels: 30, 36, and 45, were selected for the experiment. The roundness results obtained using the two methods (V-block and CMM) are shown in Figure 5, while the standard deviations corresponding to each method and measurement surface are compared in Table 2.

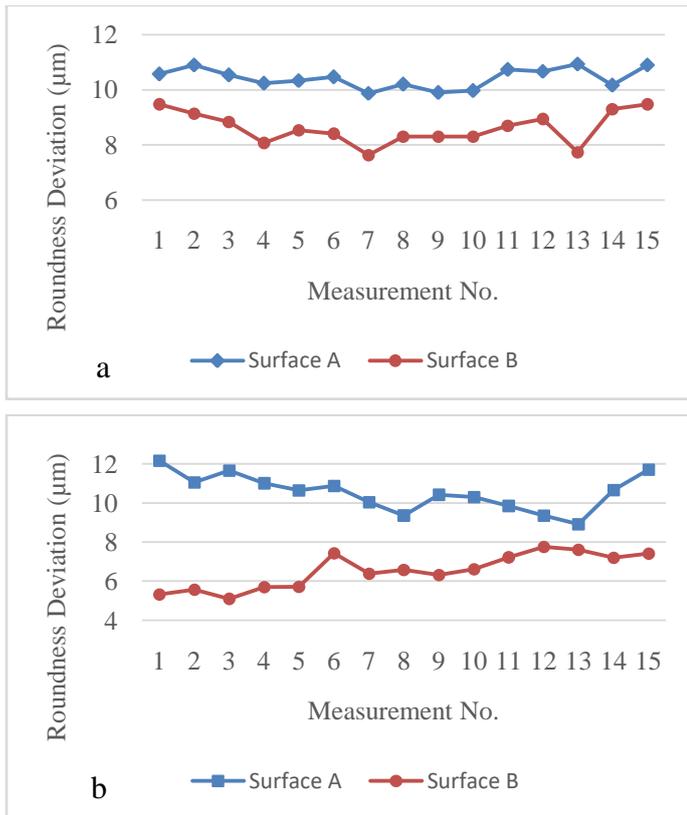


Figure 5: Roundness results obtained using two methods: (a) V-block; (b) CMM

Table 2: Average Roundness and Standard Deviation for each method and surface

Measurement method	Measured position	Average roundness value (µm)	Standard deviation (µm)
V-block and laser sensor	Surface A	10.42	0.36
	Surface B	8.61	0.58
CMM	Surface A	10.53	0.93
	Surface B	6.53	0.89

The standard deviations of roundness for both Surface A and B obtained using the V-block method (0.36 µm and 0.58 µm, respectively) were markedly lower than those recorded using the CMM (0.93 µm and 0.89 µm), indicating superior measurement repeatability of the former. In terms of average roundness values, results for Surface A were closely aligned between the two methods, 10.42 µm with the V-block setup and 10.53 µm with the CMM, suggesting strong consistency. However, a substantial discrepancy was observed for Surface B: 8.61 µm with the V-block method compared to 6.53 µm with the CMM. This divergence implies that the discrete sampling points of the CMM (a maximum of 45 points in this

study) may have inadequately represented the actual profile. In contrast, the laser displacement sensor integrated into the V-block setup enabled high-density data acquisition, on the order of thousands of points, and potentially up to hundreds of thousands per second using the Keyence LK-H055 providing a more granular and comprehensive characterization of the roundness profile.

IV. CONCLUSION

This study validates the feasibility of a non-contact roundness measurement method using a V-block combined with a laser displacement sensor. Experimental results demonstrate that this method provides higher repeatability compared to a commercial CMM. Specifically, the standard deviations for surfaces A and B using the V-block method were 0.36 µm and 0.58 µm, respectively, significantly lower than those obtained with the CMM method (0.93 µm and 0.89 µm).

Although CMMs are widely recognized for their high precision, the results indicate sensitivity to sampling density. When surfaces A and B were measured with 30 to 45 points, the roundness deviations changed by 27% and 34%, respectively. In contrast, the method of V-block and laser sensor enables dense and continuous data acquisition, enhancing the detection of subtle surface form deviations that may be missed by discrete-point measurement techniques. The maximum variation in roundness across 15 repeated measurements was only 10% for surface A and 19% for surface B. Therefore, this method presents a promising alternative for rapid, accurate, and cost-effective roundness evaluation of cylindrical components in practical metrology applications.

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AUTHOR'S BIOGRAPHY



Thanh-Trung Nguyen is a researcher at the School of Mechanical Engineering, HUST. He holds a Ph.D. in ultrasonic-assisted turning and has over 19 years of experience in metrology, fine mechanisms, and laser technologies, with active collaborations and peer-reviewed publications.

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