XVIII IMEKO WORLD CONGRESS
Metrology for a Sustainable Development
September, 17 – 22, 2006, Rio de Janeiro, Brazil

AN ANALYSIS OF ERRORS OF V-BLOCK CYLINDRICITY MEASUREMENT WITH REGARD TO THE METHOD PARAMETERS

Stanisław ADAMCZAK [1], *Dariusz JANECKI* [2], *Krzysztof STĘPIEŃ* [3]

[1] Kielce University of Technology, Kielce, Poland, adamczak@tu.kielce.pl
[2] Kielce University of Technology, Kielce, Poland, djanecki@tu.kielce.pl
[3] Kielce University of Technology, Kielce, Poland, kstepien@tu.kielce.pl

Abstract: At the Kielce University of Technology (PL) a new method of cylindricity measurements using V-blocks has been developed. Results of the statistical verification of the method show that its accuracy equals about 19% in relation to accurate radial method. The paper presents results of the research work covering the analysis of potential sources of errors of the method, related to the method parameters.

Keywords: cylindricity, measurement, V-block method.

1. INTRODUCTION

Cylindrical elements belong to a numerous and important group of machine parts. Although cylindricity measurement of small elements has reached a high metrological level, with instruments of high accuracy, the problem of large-size cylinders, encountered in shipbuilding, power industry, paper industry, metallurgical industry, etc., has not been solved so far [1]. As their size and mass make it impossible to take measurements at a measuring stand, cylindricity deviation of such elements has been evaluated in a simplified way, through the roundness profile measurement in a few selected cross-sections. Yet, such an approach is becoming unsatisfactory when we take into account the new standards set in the Geometrical Product Specification system. It requires that such cylindricity measurement methods be developed that enable an accurate cylindricity deviation measurement of elements on the production line, directly on a machine tool or a work-stand [2]. Responding to the need, the Kielce University of Technology made efforts to adapt the so called reference method (called also a V-block method) to accurate cylindricity measurements. It was assumed, as was in the case of roundness profile measurements before, that the reference method can be applied to accurate cylindricity measurements of machine parts directly on a machine tool or a work stand. Figure 1 presents the diagram for the measurement taken by means of the developed concept.

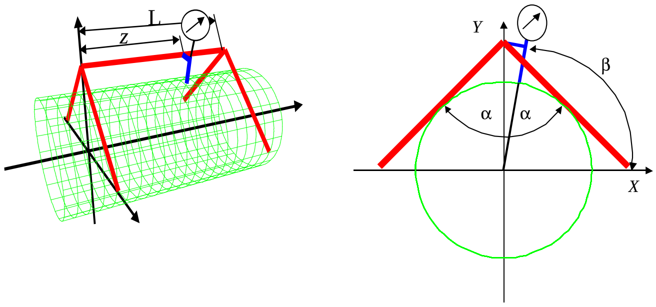


Fig. 1. Cylindricity measurement using V-block method

The proposed concept of cylindricity measurement by means of the V-block method assumes that the measured object is placed on a machine tool (in a centering device). Two interconnected V-blocks adhere to its surface. The connecting element of the V-block functions additionally as a guide, along which an induction sensor is shifted. The V-blocks are slightly pressed down to the measured object by means of a set of springs, which ensures their stable contact with the object in rotation. As the V-blocks are connected with the machine tool, they cannot move along the object. In the measuring device, both the object's angle of rotation and the sensor's displacement are controlled by means of a computer controller. The cylindricity measurement of an object implies appropriate scanning of the object's surface with a measuring sensor, along the suitably designed trajectory, through appropriate steering of the object's angle of rotation and sensor's displacement. Values α and β shown in fig.1 are the angular parameters of the V-block method for cylindricity measurement. They are responsible for detecting particular harmonic components of the measured cylindricity profile.

The developed concept has been presented in a number of publications, including [3]. It requires a mathematical transformation of the sensor-recorded profile into the real profile. The test measuring device, presented in fig.2., was constructed based on the concept assumptions.

Rys. 2. A model test measuring device for V-block measurement of cylindricity profiles PSA 6

The experimental verification of the developed V-block measurement of cylindricity concept was conducted by means of a model test measuring device PSA 6. It involved statistical comparison of cylindricity deviation measurement results for a number of cylindrical elements. The cylindricity deviation for each sample element was determined with two methods: the investigated V-block method and the highly accurate radial method. The conducted tests, the results of which were published in [4] and other works, showed that the accuracy of the cylindricity deviation measurement taken by means of the proposed method is about 19% compared to the highly accurate radial method (at the adopted probability level P=0,95). The obtained accuracy of the method makes it possible to use it for industrial measurements.

As the applicability of the V-block method to cylindricity measurements was proved, the next step was to look for its improvement and measurement accuracy enhancement. The work mainly involved the analysis of potential sources of measurement errors, and their elimination or compensation through specially developed procedures.

The theoretical analysis of potential sources of cylindricity deviations measurement errors for V-block method revealed the following two groups:

- Errors related to the fact that angular parameters values of the method are different from the nominal ones
- Other errors related to the measurement system (e.g. a rectilinearity error of the guide, its tilt relative to the object, etc.).

This article refers to the theoretical analysis of potential sources of measurement errors related to angular parameters of the method - angles α and β (see fig. 1).

2. ERRORS RELATED TO METHOD PARAMETERS

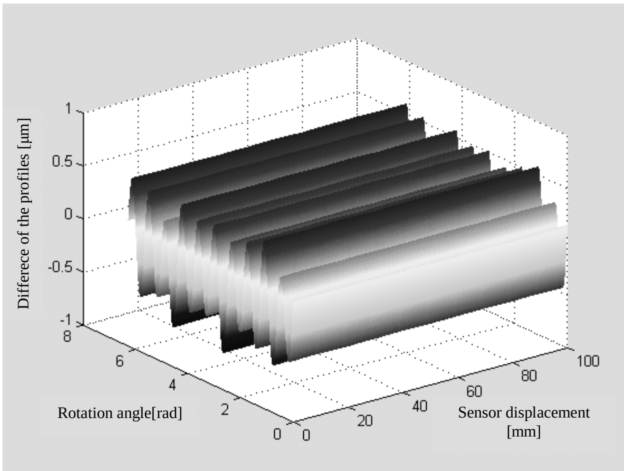
The results of the roundness measurements conducted by means of the V-block method prove that the method angular parameters values influence the recognition of particular harmonic components of the profile [5]. Changing them will then influence, to a certain degree, the obtained profile values. In order to investigate the influence of errors related to the method parameters on the obtained results, the theoretical analysis of the problem, further backed up with computer simulations, was carried out. The following sources of errors were considered:

a) a real value of β is different from its nominal value
b) a real value of α is different from its nominal value, and analyzed were the cases where:
   - angles of both V-blocks are equal,
   - angles of V-blocks are different from each other.

2.1. Difference between a real and nominal value of β

For the purpose of investigating the influence the difference between the real and nominal value of β has on the change in the measured profile value, a computer simulation was carried out. It helped generate the nominal profile and the profile recorded by the sensor, when the real value of β is different from its nominal value.

The simulation helped define the difference of the profiles values. Figure 3 presents the difference of profiles obtained for values $\beta = \beta_n$ and for $\beta = \beta_r$, where $\beta_n = 90°$ and $\beta_r = 89°$.



Rys. 3. Difference of profiles obtained through a simulation of the difference between a nominal and real value of β

The difference maximum value for the compared profiles is 0,63 μm, which is about 4,5 % of the cylindricity deviation value. As both profiles were defined for angles β_n and β_r, with a considerable difference ($\beta_n - \beta_r = 1°$), we can assume that the difference between the nominal and real value of β has an insignificant influence on the V-block cylindricity measurement result.

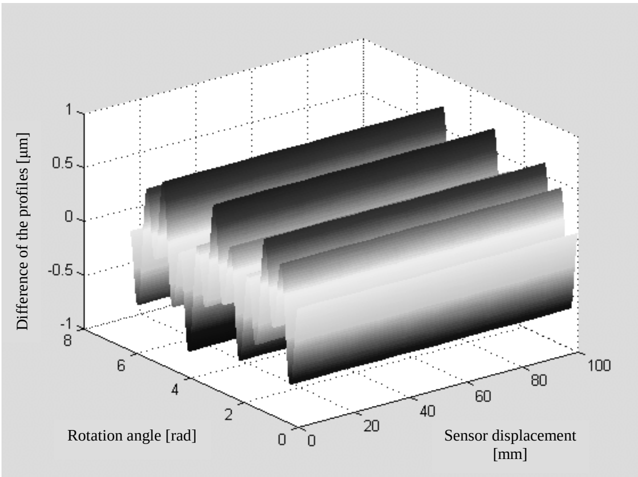
2.2. Difference between real and nominal value of α

In our discussion over the influence of the error of α on the measurement result, we will introduce new notation: α_0 will stand for half the angle of the initial base V-block, and α_L will stand for half the final base V-block. Also, the nominal value of α will be denoted by α_n, whereas α_r will stand for the real value of α. As we mentioned before, while analyzing the error of α we can deal with two cases:

- angles of both V-blocks are different from the nominal value, being equal to each other, that is $\alpha_0 \neq \alpha_n$ and $\alpha_L \neq \alpha_n$, but $\alpha_0 = \alpha_L$,
- angles of both V-blocks are different from the nominal value and different from each other, that is $\alpha_0 \neq \alpha_n$ and $\alpha_L \neq \alpha_n$, but $\alpha_0 \neq \alpha_L$.

a) case of equal angles of V-blocks

The case analysis of equal angles in the both V-blocks $\alpha_0 = \alpha_L$ was conducted analogically to the case of angle β error, described in 2.1. Appropriate computer procedures helped make a simulation of profiles obtained for the ideal case, which is when angles of both V-blocks are equal to the nominal value, and for the discussed case – that is when angles of both V-blocks are equal to each other but different from the nominal value. Figure 4 presents the difference in profiles obtained for $\alpha_0 = \alpha_L = \alpha_n$ and for $\alpha_0 = \alpha_L = \alpha_r$, where $\alpha_n = 90°$ and $\alpha_r = 89°$.



Rys. 4. The difference between the model profile and the profile obtained through the error simulation of α

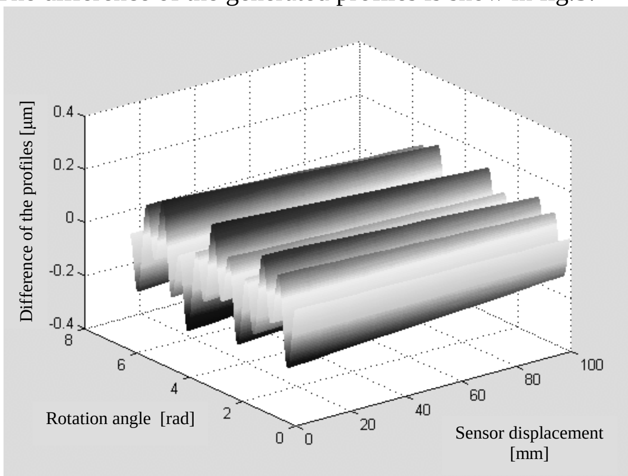
The difference maximum value for the compared profiles is 0,76 µm, which is about 5,2 % of the cylindricity deviation value. As both profiles were defined for angles α_n and α_r, the difference of which is considerable ($\alpha_n - \alpha_r = 1°$), we can assume that when the both V-blocks have equal angles, the influence of the difference between the nominal and real value of α on the cylindricity V-block measurement result is insignificant.

b) case of unequal angles of the V-blocks

While analyzing the case of unequal angles of the V-blocks, two kinds of errors are encountered:

- calculation error caused by failing to use calculation procedures in which the nominal value of α is present for transforming the profiles obtained by means of the V-blocks, whose Vee angles are equal to α_0 and α_L respectively,
- the error caused by the guide's axis tilt relative to the measured object, due to the fact that $\alpha_0 \neq \alpha_L$.

Computer simulations helped analyze the first case through the simulation of the profile obtained by means of the system with V-blocks angles equal to the nominal value and for the system with unequal V-block base angles (with the analysis of the guide's axis tilt to be conducted later). The difference of the generated profiles is show in fig.5.



Rys. 5. The difference of the model profile and the profile with the considered computational terror caused by the V-blocks angles difference

As shown in fig.5, the value of the profiles difference changes together with the sensor displacement along the element of the cylinder. The error results from the guide's axis tilt relative to the base cylinder's axis, which will be discussed later in the paper. The compared profiles difference maximum value is 0,23 µm, which is about 1,5 % of the cylindricity deviation value. We can thus assume that the computational error related to the mathematical transformation of the cylindricity profile, obtained with the V-blocks of unequal angles of Vee, has little influence on the result of V-block cylindricity measurement.

Let us discuss the guide's tilt relative to the measured object, caused by unequal V-blocks angles, and its influence on the measurement result. The conducted analysis showed that the influence can be described with the following dependences:

$$F_{\alpha 0 \alpha L}(\varphi, z) = F(\varphi, z) + d(z)\sin\beta , \quad (1)$$

where:

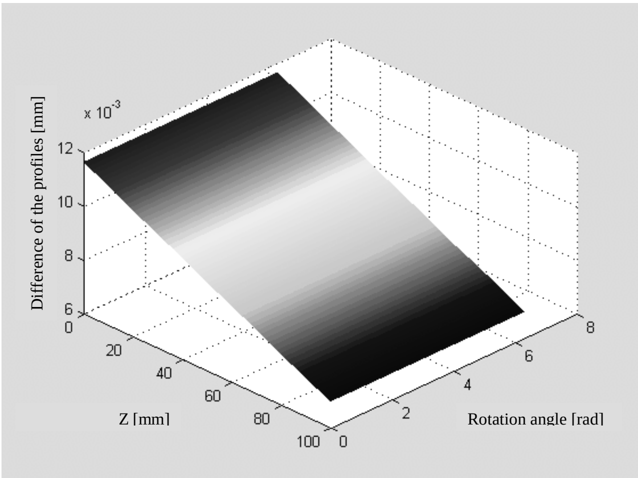
$$d(z) = \frac{d_0(L-z) + d_L z}{L}, \quad (2)$$

$$d_0 = R\left(\frac{1}{\sin\alpha_n} - \frac{1}{\sin\alpha_0}\right), \quad (3)$$

$$d_L = R\left(\frac{1}{\sin\alpha_n} - \frac{1}{\sin\alpha_L}\right). \quad (4)$$

In the above mentioned dependences, $F_{\alpha 0 \alpha L}(\varphi, z)$ is the profile recorded for the tilted axis of the guide, $F(\varphi, z)$ is the nominal cylinder profile, φ is a cylinder rotation angle, z is a measuring point coordinate, where axis Z coincides with the cylinder's axis, β is the previously defined method parametr (see fig.1.), R is a radius of the cylinder's nominal profile, α_0 is an angle of the initial base V-block, α_L is an angle of the final base V-block, and α_n is the nominal value of the angle of base V-blocks.

Dependences (1)-(4) helped carry out a computer simulation for the influence of the guide's axis tilt, caused by the difference of V-blocks angles, on the obtained signal value. For the purpose of the simulation, the following method parameters values were adopted: $\alpha_0 = 59{,}95°$, $\alpha_L = 59{,}97°$, $\alpha_n = 60°$, $\beta = 90°$. An ideal cylinder with a radius of $R_0 = 20$ mm was the nominal profile. The simulations showed that the difference of base V-blocks angles would bring about the recording of the profile's conicity virtual deviation. The diagram shown in fig.6, resulting from the simulations, features the difference of the nominal profile and the profile recorded by the sensor, caused by the tilt of the sensor's guide's axis.



Rys. 6. Difference of the model profile and the profile recorded by the sensor moving along the guide tilted relative to the object's axis.

Figure 6 illustrates the assumption that the difference between profiles changes linearly, together with the change in value of *z*, which corresponds to the sensor's displacement along the element of the measured cylinder. The profiles difference maximum value is about 11,7 μm. Such a considerable difference, obtained for a small difference of V-blocks angles, equal to $\alpha_L - \alpha_0 = 0{,}02°$, implies that the V-blocks angles difference will have a huge influence on the obtained measurement results.

3. CONCLUSIONS

The outcome of the tests we conducted proves that the V-block method can be used for cylindricity measurements in industrial environment, even directly on a machine tool or a work stand.

At the same time, there are high possibilities of increasing its accuracy through elimination or compensation of the errors related to the method angular parameters, and other possible sources of errors, e.g. rectilinearity deviation of a guide, etc.

The analysis of the effect of the method parameters angular values on the obtained measurement result shows that the accurate determination of angles α and β can contribute to a significant enhancement of measurement accuracy. Particular emphasis should be placed on ensuring that the angles of both base V-blocks are equal. A little difference causes a huge measurement error (in the analyzed case the difference of 0,02° caused an error of about 11,4 μm).

Other analyzed here cases did not cause such errors. However, in order to enhance the cylindricity V-block measurement accuracy, the impact of each potential errors source should be eliminated or compensated.

REFERENCES

[1] Nyberg T. R., Kotamäki M., "Cylindricity Measurement of Large Rollers by Combined 3-point-method and Sequential 2-point- method". 4th International Symposium on Dimensional Metrology in Production and Quality Control, ISMQC, 16 s. 1992, Tampere, 1992.

[2] Sonozaki S., Fujiwara H.: "Simultaneous Measurement of Cylindrical Parts Profile and Rotating Accuracy Using Multi-Three-Point- Method". Bull. Japan. Soc. of Prec. Engg. vol.23, n.4, pp.286-291, 1989.

[3] Adamczak S., Janecki D., Stępień K.: "Concept of Reference Measurements of Cylindricity Profiles of Machine Parts": XVII IMEKO World Congress „Metrology in the 3rd Millennium", s. 201., Dubrovnik 2003.

[4] Adamczak S., Janecki D., Stępień K.: "Investigation on Possibilities of Applying Reference Methods in Accurate Cylindricity Measurements". 8th International Symposium on „Measurement and Quality Control in Production". VDI-Berichte No. 1860, s. 719 – 726, Erlangen (Germany) 2004.

[5] Westkamper E., "Prozessnahe Rundheitsmesstechnik mit 3-Punktmessystemen". 6th International DAAAM Symposium, s. 363-364, Cracow 1995.