# Measuring the roundness deviation in the V-block measurement method

*Pavlina* Toteva *, *Dimka* Vasileva and *Krasimira* Koleva

Technical University of Varna, Department of Manufacturing Technologies and Machine Tools, 1 Studentska str., Varna 9000, Bulgaria

**Abstract.** In this paper the measurement capabilities of form deviation of cylindrical surfaces using V-Block method are studied. The paper presents the influence of the V – Block angle to the ratio coefficient of dimension, and the ratio coefficient of form deviation on the *k*-harmonic. The equations for the dimension ratio coefficient and the form ratio coefficient of *k*-harmonic are obtained. These equations give the opportunity to choose the most appropriate combination for the V-block angle and the measurement direction, angle $\beta$. Studies have been made using V-Blocks with the most common angles by symmetrical and non-symmetrical measurement schemes. Using V-Blocks for measurement is rational and appropriate in cases where for all measured details the number of harmonics are known in advance.

## 1 Introduction

The task in measuring the deviation of the form of parts is to get information for the real geometrical element, and to assess the form deviation according to requirements in the standards [1, 2, 3]. Over the measurement form deviation of cylindrical surface with TCMM (Three Coordinate Measuring Machine) and devices for measuring form deviation these measurements can be done using two or three point measurement [4, 5, 6].

These methods provide approximate measurements. In three point measurements of form deviation the V – block angle and the measurement angle reflect on the result.

## 2 Theoretical research

In measuring details with V-block there are two main tasks: to measure the diameter, and to measure the form deviation. In measuring diameter of details the influence of form deviation on the results have to be cut to a minimum. If the form deviation is measured, the V-block should have an angle, so that the ratio coefficient of the form deviation harmonics reaches its maximum. In both cases it is about an optimal V-block angle.

The choice of the V-block angle α for the diameter measurement is discussed in Kondshavskii *et al.* [7]. In Ribikov *et al.* [8] calculation of the ratio coefficient in diameter's

* Corresponding author: pavlina_toteva@abv.bg

measurement of part in the V-block by asymmetrical position of the measuring tip relative to the angle of the V-block (angle $\beta$) is outlined.

Ratio coefficient of dimension is:

$$k = \frac{\Delta h}{\Delta r} = 1 - \frac{cos\beta}{sin\alpha} \quad (1)$$

$\Delta h$ – indication change of measuring instrument;
$\Delta r$ – dimension change of measuring part;
$\alpha$ – half of the V-Block angle;
$\beta$ – measuring angle to V-Block bisector;
$k$ – ratio coefficient of dimension [7].
By changing the angle $\beta$ in (1) we can obtain the relationships for most popular measuring schemes shown in Table 1.

In V-Block measuring of dimensions using the shown schemes the roundness deviation strongly influences the measurement result. Most often the roundness deviation consists of several harmonics. The measurement errors are caused by the fact that different harmonics have different ratio coefficients depending on the angles α and $\beta$. The V-Block scheme of measurement is shown in Figure 1.

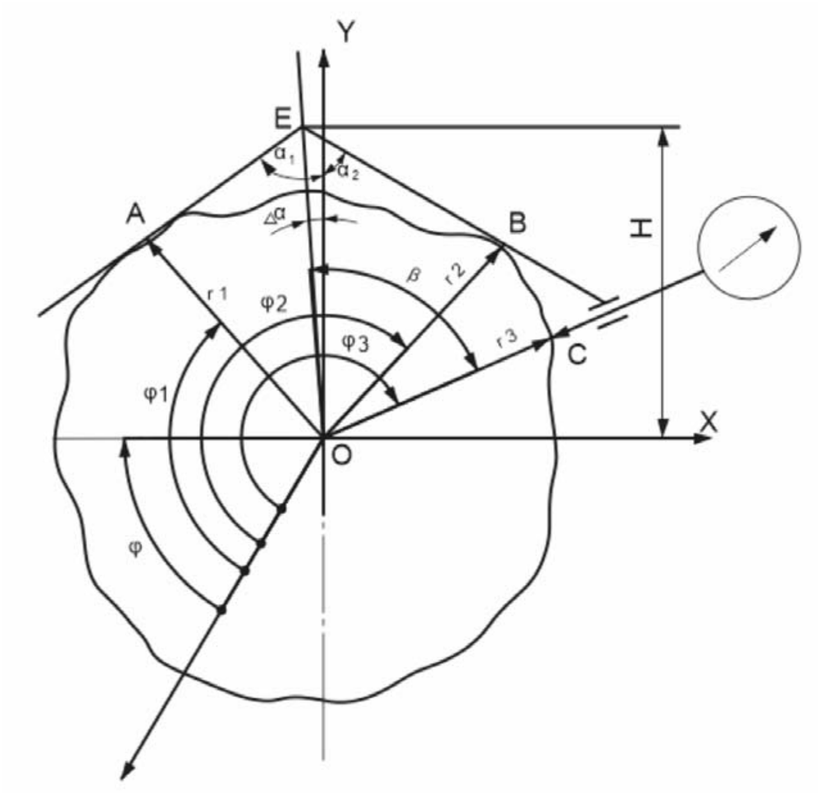
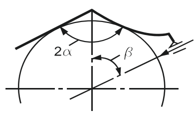
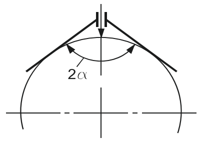
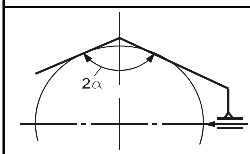
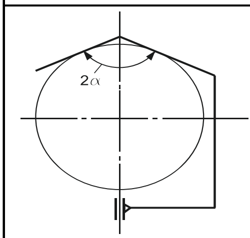
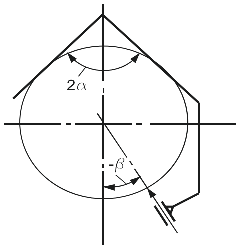



**Fig. 1.**V-Block scheme of measurement.

The presence of errors in the form leads to deferent values of the radiuses *r1, r2* and *r3* through the centre of detail (O) to the touch points with the V-block surfaces A and B, and with the measuring tip C. The top of the V-Block E will translate in rectangular coordinate system XOY when some of the radiuses changes.

**Table 1.** Measurement schemes using V-Blocks.

| Measurement Scheme | Value | Ratio Coefficient of Dimension | Ratio Coefficient of Form Deviation on the k-harmonic |
|---|---|---|---|
|  | $\beta=\alpha$ | $k=1-cos\beta/sin\alpha$ | $a_{kx} = -cos\beta. cosk\beta$ <br> $a_{ky} = cos\beta. cosk\beta\text{-}\frac{cosk(\alpha-\frac{\pi}{2})}{sin\alpha}$ <br> $a_k = \sqrt{a^2{}_{kx}+a^2{}_{ky}}$ |
|  | $\beta=0$ | $k=1-1/sin\alpha$ | $a_k = \frac{cosk(\alpha-\frac{\pi}{2})}{sin\alpha} - 1$ |
|  | $\beta=\pi/2$ | $k=1$ | $a_k = cos\frac{k\pi}{2} - \frac{cosk(\alpha-\frac{\pi}{2})}{sin\alpha}$ |
|  | $\beta=\pi$ | $k=1+1/sin\alpha$ | $a_k = 1 + (-1)^k\frac{cosk(\alpha-\frac{\pi}{2})}{sin\alpha}$ |
|  | $\beta=-\alpha$ | $k=1+sin\beta/sin\alpha$ | $a_{kx} = -sin\beta. cosk(\frac{\pi}{2}\text{-}\beta)$ <br> $a_{ky} = sin\beta. cosk(\frac{\pi}{2}\text{-}\beta). \frac{cosk(\alpha-\frac{\pi}{2})}{sin\alpha}$ <br> $a_k = \sqrt{a^2{}_{kx}+a^2{}_{ky}}$ |

The change of convertor indication will be defined by the V-Block bias on X and Y axes.

$$h_x = X_C = H. sin\frac{\alpha_1 - \alpha_2}{2} + r_3. sin\beta$$

$$h_y = Y_B - Y_C = H. cos\frac{\alpha_1-\alpha_2}{2} - r_3. cos\beta \quad (2)$$

Where *H* is the distance from the top of the V- Block to the centre of the detail O.
$h_x$, $h_y$ are the projections of the radius *r3* on the coordinate axes X and Y.

When the magnitude *α1*, *α2* and H from (2) are terminated the result is:

$$h_x = \frac{r_1 - r_2}{2cos_\alpha} + r_3. sin\beta$$

$$h_y = \frac{r_1+r_2}{2sin_\alpha} - r_3. cos\beta \quad (3)$$

Where *r1, r2* and *r3* are the current radiuses determined from the beginning of the coordinate system to the points A, B and C.

The current radiuses of the shaft are:

$$r_1 = r_0 + \sum_{k=2}^{n} A_k . sin(k\varphi_1 + \varphi_k)$$

$$r_2 = r_0 + \sum_{k=2}^{n} A_k . sin(k\varphi_2 + \varphi_k) \tag{4}$$

$$r_3 = r_0 + \sum_{k=2}^{n} A_k . sin(k\varphi_3 + \varphi_k)$$

Where $r_o$ is the radius of least squares (Gaussian) reference circle;
$A_k$ – amplitude of $k$-harmonic;
$\varphi 1$, $\varphi 2$, $\varphi 3$ – phase angles determining the location of radiuses $r1$, $r2$ and $r3$;
$\varphi k$ – initial phase of $k$-harmonic;
$k$ – number of the harmonic.

By replacing (4) in (3), the following is obtained:

$$h_x = r_0 . sin\beta + \frac{\sum_{k=1}^{n} Ak . cos(k\frac{\varphi_1 + \varphi_2}{2} + \varphi_k) . sink\frac{\varphi_1 - \varphi_2}{2}}{cos\alpha} + \sum_{k=1}^{n} Ak . sin(k\varphi_3 + \varphi_k) . sin\beta$$

$$h_y = r_0 . sin\beta + \frac{\sum_{k=1}^{n} Ak . cos(k\frac{\varphi_1 + \varphi_2}{2} + \varphi_k) . sink\frac{\varphi_1 - \varphi_2}{2}}{cos\alpha} + \sum_{k=1}^{n} Ak . sin(k\varphi_3 + \varphi_k) . sin\beta \tag{5}$$

After replacing the values for the phase angles in equations (5) which are:

$$\varphi_1 = \varphi + \alpha$$

$$\varphi_2 = \varphi + \pi - \alpha \tag{6}$$

$$\varphi_3 = \varphi + \frac{\pi}{2} + \beta$$

We obtain the change of the projections $\Delta h_x$ and $\Delta h_y$ of the radius $r3$ on the coordinate axes X and Y:

$$\Delta h_x = h_x - r_o . sin\beta = \sum_{k=1}^{n} Ak \left\{ \left[ \frac{sink(\alpha - \frac{\pi}{2})}{cos\alpha} + sin\beta . sink\beta \right] . cos\left[ k\left(\varphi + \frac{\pi}{2}\right) + \varphi_k \right] + cos\beta . cosk\beta . sin\left[ k\left(\varphi + \frac{\pi}{2}\right) + \varphi_k \right] \right\}$$

$$\Delta h_y = h_y - r_o\left(\frac{1}{sin\alpha} - cos\beta\right) = \sum_{k=1}^{n} Ak \left\{ \left[ \frac{cosk(\alpha - \frac{\pi}{2})}{sin\alpha} - cos\beta . cosk\beta \right] . sin\left[ k\left(\varphi + \frac{\pi}{2}\right) + \varphi_k \right] - sin\beta . sink\beta . cos\left[ k\left(\varphi + \frac{\pi}{2}\right) + \varphi_k \right] \right\} \tag{7}$$

The phases of all harmonics match when $\varphi_k = 3/2p$

$$\Delta h_x = \sum_{k=1}^{n} Ak \left\{ \left[ \frac{sink\left(\alpha - \frac{\pi}{2}\right)}{cos\alpha} + sin\beta . sink\beta \right] . sink\left(\varphi + \frac{\pi}{2}\right) - cos\beta . cosk\beta . cosk\left(\varphi + \frac{\pi}{2}\right) \right\}$$

$$\Delta h_y = \sum_{k=1}^{n} Ak \left\{ \left[ cos\beta . cosk\beta - \frac{cosk\left(\alpha - \frac{\pi}{2}\right)}{sin\alpha} \right] . cosk\left(\varphi + \frac{\pi}{2}\right) - sin\beta . sink\beta . sink\left(\varphi + \frac{\pi}{2}\right) \right\} \tag{8}$$

The whole deviation of indication of indicator is as follows:

$$\Delta h = \sqrt{\Delta h_x^2 + \Delta h_y^2} \tag{9}$$

The maximum value of the ratio coefficient on the harmonic components over the coordinate axis projections is defined by the following equation:

$$cosk\left(\varphi + \frac{\pi}{2}\right) = 1$$

then,

$$sink\left(\varphi + \frac{\pi}{2}\right) = 0 \tag{10}$$

From the equation it is visible that the most significant impact on the indication of indicator is the translation of the V-Block on the Y axis. For the *k*-harmonic single amplitude we have the following equation:

$$a_{kx} = cos\beta . cosk\beta - \frac{cosk(\alpha - \frac{\pi}{2})}{sin\alpha}$$

$$a_{ky} = -cos\beta . cosk\beta \tag{11}$$

$$a_k = \sqrt{a_{kx}^2 + a_{ky}^2}$$

The ratio coefficient values of the *k*-harmonic of the form deviations $a_k$ for the rest of the measurement schemes in Table 1 are defined in (5) depending on the value of the phase angle $\varphi$.

These calculations for different measurement schemes allows the choice of the best combination of V-Block angle $2\alpha$ and the measurement direction $\beta$.

## 3 Experimental research

Based on the displayed dependencies studies on V-Blocks with the most common angles by symmetrical and non-symmetrical schemes of measurement were made.
The results are depicted in Tables 2, 3 and 4.

**Table 2**. Ratio coefficient of form $a_k$ using symmetrical scheme of measurement when the harmonic is known.

| Harmonic | Angle of V-block $2\alpha$ | Ratio coefficient of form $a_k$ |
|---|---|---|
| 3 | 60°<br>120° | 3<br>1 |
| 5 | 120° and 90°<br>72° | 2<br>1 |
| 7 | 120°<br>103° | 2<br>1 |
| 9 | 60°<br>120° | 3<br>1 |

**Table 3**. Ratio coefficient of form $a_k$ using asymmetrical scheme of measurement when the harmonic is known.

| Harmonic | Angle of V-block $2\alpha$ | Angle of measurement $\beta$ | Ratio coefficient of form $a_k$ |
|---|---|---|---|
| 3 | 60°<br>120° | 60°<br>30° | 2 |
| 5 | 60°<br>120° | 60°<br>30° | 2 |
| 7 | 60°<br>120° | 60°<br>30° | 2 |
| 9 | 60°<br>120° | 60°<br>30° | 2 |

Application of three-point schemes of measurement is rational and appropriate in cases where all measured details are fixed, and harmonics are known in advance. It is recommended symmetrical schemes measurement in V-Blocks and the angle $\alpha$ depending on the number of harmonics given in Table 2. These angles are determined by the condition that the coefficient $a_k$ is equal to the largest integer or 1;

**Table 4.** Ratio coefficient of form $a_k$ using symmetrical scheme of measurement when the number of harmonics is known.

| Harmonics | Angle of V-bloc $2\alpha$ | Ratio coefficient of form $a_k$ |
|---|---|---|
| 2, 5, 9 | 130º | ~1,7 |
| 5, 7<br>3, 9 | 120º | 2<br>1 |
| 2, 3, 7, 8 | 108º | ~1,4 |
| 3, 5 | 90º | 2 |
| 3, 9 | 60º | 3 |
| 7, 9 | 45º | 2 |

To avoid determining the number of harmonics to every detail before measurement, parameters of three point measurement scheme in which the ratio coefficients $a_k$ are the same for all possible combinations in a sample should be selected.

The symmetrical measurement scheme is applicable only for some combinations shown in Table 4.

These angles of V-Blocks are suitable for measuring the form deviation including harmonics equal to *n*.

## 4 Conclusion

In this paper the opportunities for measuring the roundness deviation using V-Block method are given. The equations for the dimension ratio coefficient and the form ratio coefficient of *k*-harmonic are obtained. These equations give the opportunity to choose the most appropriate combination for the V-Block angle and the measurement direction. Studies have shown that non-asymmetrical measurement schemes are more universal.

## References

1. ISO 1101:2017(E) Geometrical product specifications (GPS) – Geometrical tolerancing – Tolerances of form, orientation, location and run - out
2. ISO/TS 12181-1:2003 Geometrical Product Specifications (GPS) – Roundness – Part 1: Terms, definitions and parameters of roundness
3. ISO/TS 12181-2:2003 Geometrical Product Specifications (GPS) – Roundness – Part 2: Specification operators
4. T. Pfeifer, R. Schmidt, *Fertigungsmesstechnik*, (Oldenbourgverlag Munchenq, 2010)
5. K. Stepien, D. Janecki, S. Adamczak, DAAAM International scientific book, 027 (2012)
6. O. A. Yalovoy, O. V. Zakharov, A. V. Kochetkov, IOP Conf. Series: Materials Science and Engineering, **93** (2015)
7. V. Kondshavskii, N. N. Ribikov, Metallurgical equipment (RIIHE), **21**, 6 (1973)
8. N. Ribikov, *Automatization of technical quality inspection in mechanical engineering*, Interuniversity collection of scientific papers, Omsk, 92 (1980)