THE METHOD TO IDENTIFY MEASUREMENT PARAMETERS ON A BASIS OF MEASUREMENT DATA

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Abstract − Some measuring systems are characterized by parameters that are difficult to identify directly. The reason for this can be, for example, that some elements of the system are placed inside other ones and therefore it is difficult to reach them and to measure their dimensions. In such cases the parameters of the system can be evaluated with the use of measurement data. The paper presents the procedure of such evaluation and the example of its practical application.

Keywords: measurement, parameter, accuracy, measurement data

1. INTRODUCTION

The cylindrical elements belong to numerous group of machine parts [1, 2]. The measurement techniques used to measure and evaluate such elements become more and more sophisticated [3-7]. The mechanical properties of the surface of such components should be investigated accurately, too due to the fact that they influence robustness of mechanical devices [8-15].

Beside that the surface texture components of such parts should be controlled not only in laboratory but also under industrial conditions [16-18]. It is not always easy taking into account the fact that the question of measurements of cylindrical elements is a 3-dimensional problem. Correct conducting of measurements requires also developing of appropriate defining of measurement uncertainty [19] as well as application of correct procedures to process and to filter measurement data [20-23].

In some cases values of quantities to be measured are calculated as the function of certain measurement parameters [24]. The example of such measurement is the measurement of cylindricity deviations by the V-block method [25]. The theoretical aspects of such measurements as well as results of the experimental study have been presented for example in work [26]. Shortly, the idea of such measurement is shown in Fig. 1 [26]. The proposed concept assumes that the measured cylinder 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 also functions as a slideway for the measuring sensor. The angle of rotation of the cylinder and the sensor's displacement are controlled by the computer. The cylindricity measurement of an object involves appropriate scanning of the cylinder's surface with a measuring sensor, along a suitably-designed trajectory, by steering the cylinder's angle of rotation and the sensor's displacement. The developed concept requires a mathematical transformation of the sensor readings. The mathematical model of the transformation has been presented in [1]. The values α and β shown in Fig. 1 are the angular parameters, which are responsible for detecting particular harmonic components of the measured cylindricity profile. Therefore, it is of great importance to identify and measure real values of the angles α and β, as well as to investigate the difference between the real and nominal values and their influence on measurement results.
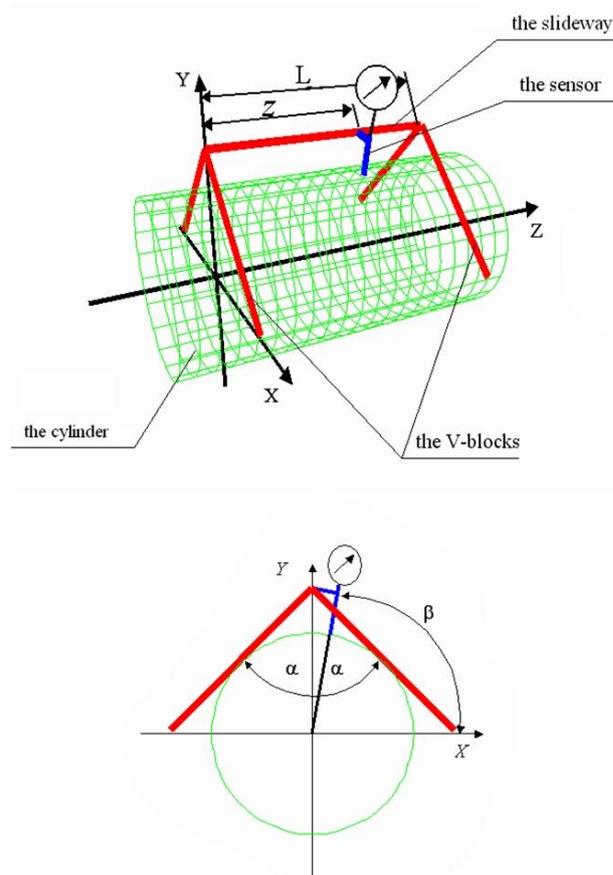

Fig. 1. Concept for cylindricity measurements by the V-block method (values α, β and L are the method parameters) [26].

2. FUNDAMENTALS OF THE METHOD

The angles of the base prisms can be measured directly using measuring devices of different types. However, we can

identify their real value also with the aid of the optimization method basing on the measurement data. Generally, if the real values of α is unknown, the real value of β needs to be identified, too. Thus, it is necessary to develop a procedure for simultaneous identification of the angles α_0, α_L and β.

It bases on the profiles of the same cylindrical element obtained with two methods:
- − a method of high accuracy– in this way we obtain a datum profile $R(\varphi,z)$ that will be regarded as a real cylindricity profile of the workpiece,
- − a reference method – this measurement will be performed using a device for which the real values of α_0, α_L and β need to be identified. In this way we obtain the profile $F(\varphi,z)$.

Then, on the basis of the profile $F(\varphi,z)$, a processed profile $R_{\alpha_0\alpha_L\beta}(\varphi,z)$ as a function of α_0, α_L and β, is calculated according to the equation (1)

$$R_{\alpha_0\alpha_L\beta}(\varphi+\beta,z)=F(\varphi,z)-G(\varphi,z,\alpha_0,\alpha_L)\cos\beta$$
$$-\left(H(\varphi,z,\alpha_0,\alpha_L)+I(\alpha_0,\alpha_L,R_0,z)\right)\sin\beta$$

(1)

where:

$$G(\varphi,z,\alpha_0,\alpha_L)=\left(-\frac{R(\alpha_0+\varphi,0)-R(\pi-\alpha_0+\varphi,0)}{2\cos\alpha_0}\right)\left(1-\frac{z}{L}\right)$$
$$+\left(-\frac{R(\alpha_L+\varphi,L)-R(\pi-\alpha_L+\varphi,L)}{2\cos\alpha_L}\right)\frac{z}{L}$$

(2)

$$H(\varphi,z,\alpha_0,\alpha_L)=\left(-\frac{R(\alpha_0+\varphi,0)-R(\pi-\alpha_0+\varphi,0)}{2\sin\alpha_0}\right)\left(1-\frac{z}{L}\right)$$
$$+\left(-\frac{R(\alpha_L+\varphi,L)-R(\pi-\alpha_L+\varphi,L)}{2\sin\alpha_L}\right)\frac{z}{L}$$

(3)

$$I(R_0,\alpha_0,\alpha_L,z)=R_0\left(\frac{1}{\sin\alpha_n}-\frac{1}{\sin\alpha_0}\right)\left(1-\frac{z}{L}\right)$$
$$+R_0\left(\frac{1}{\sin\alpha_n}-\frac{1}{\sin\alpha_L}\right)\frac{z}{L}$$

(4)

Among the values affecting the profile $R_{\alpha_0\alpha_L\beta}(\varphi,z)$, only the real values of α_0, α_L and β are unknown. Having two profiles: the datum $R(\varphi,z)$ and $R_{\alpha_0\alpha_L\beta}(\varphi,z)$, we can write the formula describing the quality indicator $J(\alpha_0,\alpha_L,\beta)$:

$$J(\alpha_0,\alpha_L,\beta)=\sum_{i=1}^{N}(R_i-R_{\alpha_0\alpha_L\beta_i})^2 \qquad (5)$$

where:

R_i – the sample of the datum profile $R(\varphi,z)$ for co-ordinates (φ_i,z_i),

$R_{\alpha_0\alpha_L\beta_i}$ – the sample of the profile $R_{\alpha_0\alpha_L\beta}(\varphi,z)$ for co-ordinates (φ_i,z_i).

The real values of α_0, α_L and β are determined by finding such values for which $J(\alpha_0,\alpha_L,\beta)$ reaches a minimum. The MATLAB function fmins is employed for this purpose. To apply this function, it was necessary to develop the next function that would enable us to determine the quality indicator $J(\alpha_0,\alpha_L,\beta)$ according to formula (5).

The source code of the function min_alfa1_alfa2_beta, whose minimization makes it possible to calculate the optimum values of α_0, α_L and β on the basis of the measurement data, is given below

```
function
[y]=min_alfa1_alfa2_beta(x,R,F,z,bet,Rn,alpha_n);
    [N K]=size(R);
    R0=[R(:,1);R(:,1)];
    RL=[R(:,K);R(:,K)];
    L=max(z)-min(z);
    for j=1:N
    Ex0(j)=-(R0(round(x(1)*N/360)+j)-R0((N/2)-
round(x(1)*N/360)+j))/(2*cos(x(1)*pi/180));
    ExL(j)=-(RL(round(x(2)*N/360)+j)-RL((N/2)-
round(x(2)*N/360)+j))/(2*cos(x(2)*pi/180));
    Ey0(j)=-(R0(round(x(1)*N/360)+j)+R0((N/2)-
round(x(1)*N/360)+j))/(2*sin(x(1)*pi/180));
    EyL(j)=-(RL(round(x(2)*N/360)+j)+RL((N/2)-
round(x(2)*N/360)+j))/(2*sin(x(2)*pi/180));
    end
    for j=1:K
      Ex(:,j)=(Ex0'*(L-z(j))+ExL'*z(j))/L;
      Ey(:,j)=(Ey0'*(L-z(j))+EyL'*z(j))/L;
    end
    for j=1:K
    dz(j)=(Rn*(sin(alpha_n*pi/180)^(-1)-sin(x(1)*pi/180)^(-
1))*(L-z(j))+Rn*(sin(alpha_n*pi/180)^(-1)-
sin(x(2)*pi/180)^(-1))*z(j))/L;
    end
    R_beta=ones(N,K);
    for j=1:K
    R_beta(:,j)=F(:,j)-Ex(:,j)*cos(x(3)*pi/180)-
Ey(:,j)*sin(x(3)*pi/180)-dz(j)*sin(x(3)*pi/180);
    end
    R_b=[R_beta;R_beta];
    Robr=R_b(N-bet+1:N-bet+N,:);
    tmp=(R-Robr).^2;
    y=sum(sum(tmp));
```

The above function min_alfa1_alfa2_beta, basing on the datum profile samples $R_i(\varphi_i,z_i)$ and the profile samples $F_i(\varphi_i,z_i)$, measured with a device for which the real values of α_0, α_L and β need to be determined, calculates the values of the processed profile samples $R_{\alpha_0\alpha_L\beta}(\varphi,z)$ (denoted in the code by R_beta), as a function of unknown angles. In the text of the function these values are denoted by respective co-ordinates of the vector x. The first co-ordinate of the vector corresponds to α_0 (in the text denoted by x(1)), the second one to α_L (in the text denoted by x(2)) and the third one to β (in the text denoted by x(3)). Then, the value of the quality indicator $J(\alpha_0,\alpha_L,\beta)$, is calculated from formula (5). In the source code of the function, the quality indicator $J(\alpha_0,\alpha_L,\beta)$ is denoted by the parameter y, which is the output value of the function. By applying the function fmins in relation to the function min_alfa1_alfa2_beta , we will be able to find the values

x(1), x(2) and x(3) for which the indicator y reaches its minimum. In a similar way we find the values of the angles α_0, α_L and β for which the quality indicator $J(\alpha_0,\alpha_L,\beta)$ reaches its minimum [27].

In order to verify the developed function, a computer simulation was performed. The simulation involved determining the real values of α_0, α_L and β on the basis of the measurement data. The simulation required:

- generating a datum profile $R(\varphi,z)$,
- generating the measured profile $F(\varphi,z)$ for the values of α_{0_r}, α_{L_r} and β_r different from the nominal values,
- calculating the quality indicator $J(\alpha_0,\alpha_L,\beta)$ using the developed function, from relationship (5),
- calculating the values of $\alpha_{0_{opt}}$, $\alpha_{L_{opt}}$ and β_{opt} for which the quality indicator $J(\alpha_0,\alpha_L,\beta)$ reaches its minimum, using the function fmins.

After performing the above operations, we calculated the values of $\alpha_{0_{opt}}$, $\alpha_{L_{opt}}$ and β_{opt}. The obtained values were equal to the real input values of α_{0_r}, α_{L_r} and β_r. This proves that the developed function min_alfa1_alfa2_beta was correct. Thus, this function can be applied to determine the real values of α_0, α_L and β on the basis of the measurements data.

3. PRACTICAL APPLICATION OF THE METHOD

Real values of the angles of the V-blocks α are quite easy to determine through direct measurements. However, in case of the angle β, the problem is more complex. Due to the fact, that β is the angle between the direction of the sensor movement and the X axis of the co-ordinate system related to the workpiece (see Fig. 1), its precise direct measurement is very difficult. Therefore, a calculation procedure for the real value of β was developed. The concept bases on the measurement data and employs the optimization methods.

The source code of the function min_beta, whose minimization enables calculation of the value β_{opt}, is given below

```
function [y]=min_beta(x,R,F,z,betha);
[N K]=size(R);
R0=[R(:,1);R(:,1)];
RL=[R(:,K);R(:,K)];
L=max(z)-min(z);
alfa_0=60;
alfa_L=60;
for j=1:N
Ex0(j)=-(R0(round(alfa_0*1024/360)+j)-R0(512-
round(alfa_0*1024/360)+j))/(2*cos(alfa_0*pi/180));
ExL(j)=-(RL(round(alfa_L*1024/360)+j)-RL(512-
round(alfa_L*1024/360)+j))/(2*cos(alfa_L*pi/180));
Ey0(j)=-(R0(round(alfa_0*1024/360)+j)+R0(512-
round(alfa_0*1024/360)+j))/(2*sin(alfa_0*pi/180));
EyL(j)=-(RL(round(alfa_L*1024/360)+j)+RL(512-
round(alfa_L*1024/360)+j))/(2*sin(alfa_L*pi/180));
end
for j=1:K
  Ex(:,j)=(Ex0'*(L-z(j))+ExL'*z(j))/L;
```

```
  Ey(:,j)=(Ey0'*(L-z(j))+EyL'*z(j))/L;
end
R_beta=ones(N,K);
for j=1:K
R_beta(:,j)=F(:,j)-Ex(:,j)*cos(x*pi/180)-
Ey(:,j)*sin(x*pi/180);
end
R_b=[R_beta;R_beta];
R_betha=R_b(1024-betha+1:1024-betha+1024,:);
tmp=(R-R_betha).^2;
y=sum(sum(tmp));
```

This function, basing on the datum profile samples $R_i(\varphi_i,z_i)$ and the profile samples $F_i(\varphi_i,z_i)$ measured with a device for which a real value of β is to be determined, is used to calculate the values of the processed profile samples $R_{\beta_i}(\varphi_i,z_i)$ (denoted in the code by R_betha), as a function of unknown β (in the code denoted by x). Then, the value of the quality indicator $J(\beta)$ is calculated from formula (4). In the source code of the function, the quality indicator $J(\beta)$ is denoted by the parameter y, which is the output value of the function. If the function fmin is applied in relation to the function min_beta, it is possible to calculate the value x, for which the indicator y reaches its minimum. In a similar way the value of the angle β, for which the quality indicator $J(\beta)$ reaches its minimum is found.

4. EXPERIMENTAL RESULTS

The procedure presented in the previous section 2 has been practically applied to increase the accuracy of the cylindricity measurement by the V-block method. In the framework of this research work real values of the V-blocks (denoted by α_0 and α_L, respectively) were established and the value of the angle β was calculated with use of the optimization method. Measurements of the angles of the V-blocks were carried out by the coordinate measuring machine Eclipse 550 and the measurement results were following:

- the angle of the immovable prism:
$$\alpha_0 = 59°51'27'',$$
- the angle of the movable prism:
$$\alpha_L = 59°51'58''.$$

Accordingly, the value of the angle β was estimated with use of the procedure described in the section 2 for the sample of seven cylindrical elements and the results are presented in Table 1.

Table 1. Values of the angle β obtained by the optimization method

Workpiece no.	Angle β
1	89.5005
2	89.9762
3	90.0102
4	89.8371
5	90.1919
6	89.9841
7	89.9603
Mean value	**89.9229**
Range	0.6914
Standard deviation	0.2136

4. CONCLUSIONS

Sometimes it is difficult to estimate real values of parameters of the measuring system through its direct measurements. Such case is the evaluation of the real value of the angle β of the system for cylindricity measurements by the V-block method. This is the angle between the measuring sensor axis and the horizontal plane of the system (see Fig. 1) and its value influences detection of individual harmonic components of measured profile. Therefore, identification of its real value is a matter of great importance. Direct measurement of the angle β is not possible due to the construction and dimensions of the system. This is why the procedure allowing identification of this angle was developed. The procedure involves optimization methods and it is based on measurement data. The procedure requires two sets of measurement data: the first set are the values of the reference profile measured by the method of very high accuracy and the second one are the values of the profile measured with the V-block system. The procedure allows calculation of such value of the angle β for which the difference between both profiles reaches its minimum. The advantage of this concept is its universality, because the procedure can be applied to the estimation of parameters of different types and its efficiency. The disadvantage is that both data sets utilized by the procedure have some specific errors that can influence the results. Despite of that the method described in the paper is sometimes the only solution of the problem of identification of real values of measurement parameters.

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