FORM DEVIATIONS MEASUREMENT OF PLANAR SURFACES BY OVERLAPPING MEASURING POSITIONS USING REFERENCE PLANE METHOD

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Abstract: A multisensory system for form deviation measurements of planar surfaces of large-scaled details is considered. The form deviation measurement requires preliminary information on the topography of the extracted surface obtained by measurement according to some output datum. In the reference plane method, such reference datum is the plane defined by three reference points of the support platform of the system when initially set it in a measuring position. At each subsequent position the current reference plane changes its position in space. To restore it to the initial position, adjustments are made to the parameters that define it by corresponding algorithms. Determination of these adjustments is made by overlapping measurement positions.

The system has been successfully implemented in the control of the mechanical elements of the Buster and the Collider of NICA project, developed by JINR, Dubna

Key-Words: deviation from form, measurement, accuracy, large size details.

1. Introduction

Deviations from form measurement of planar surfaces, as well as any other deviation of form, comprises the following three steps:

Stage I: Getting information on the topography of the measured surface, by measuring according to reference datum, i.e. obtaining the extracted surface;

Stage II: Construction according to the extracted surface/profile of an associated plane / line by a certain criterion (e.g. the Chebychev or Gauss criterion);

Step III: Determination of the form deviation as a distance between two extremal points from the extracted surface to the associated plane by the normal to the associated plane/profile.

The choice and realization of the output datum is the basic element of any form deviation measurement.

The purpose of this report is deviations of form measurements of planar surfaces whereby the first step is performed by the reference plane method by overlapping the measuring positions.

2. Reference plane method

In this method, a datum plane is defined by three reference points on the carrier platform of the measuring device, the so-called reference plane when it is first set to the measuring position Q_1. At these three points, the measuring device contacts the measured surface F. In the measurement process at each subsequent measurement position, the position of the support plane Q_j in the space changes. Returning it to the initial (output) position Q'_j is accomplished by introducing corresponding corrections of the parameters that define it (Figure 1).

The position of the reference plane in space, i.e. in any selected coordinate system XYZ is determined by the coordinate z_m (at fixed x_m and y_m) of the characteristic point m of the considered reference plane and the position of the normal vector therein in the accepted coordinate system or by the three-point coordinates x, y and z of the reference plane (for example, the characteristic point m and the other two arbitrarily selected points n and k).

For measurements at each subsequent measuring position, corrections are made in the vertical and angular positions of the reference plane, respectively in the coordinates of the three selected points m, n and k, in order to bring the reference plane back to the original output position, i.e. in the position it had in the initial measuring position.

Then

$$z'_{m,j} = z_{m,j} + \Delta z_{m,j} \quad (1)$$

$$z'_{k,j} = z_{k,j} + \Delta z_{m,j} + \Delta z_{\alpha,k,j} \quad (2)$$

$$z'_{n,j} = z_{n,j} + \Delta z_{m,j} + \Delta z_{\beta,n,j}, \quad (3)$$

where:

j is measuring position number;

$\Delta z_{m,j}, \Delta z_{\alpha,k,j}, \Delta z_{\beta,n,j}$ are corrections at points m, n and k, taking into account the vertical and angular positions of the reference plane;

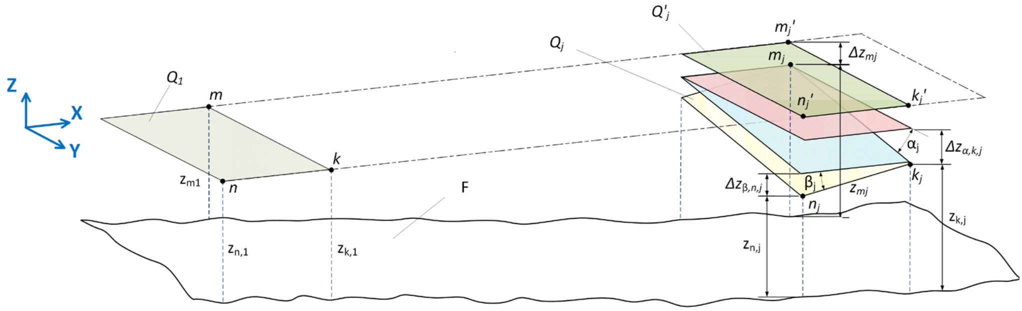

Fig.1 Reference plane method

α and β are angles between the subsequent position of reference plane have according to the initial position in planes XOZ and YOZ of the chosen coordinate system;

$z'_{m,j}, z'_{n,j}, z'_{k,j}$ - the coordinates of the points *m*, *n* and *k* in *j*-th measuring position according to the initial position of reference datum plane Q_1;

$z_{m,j}, z_{n,j}, z_{k,j}$ - the coordinates of the points *m*, *n* and *k* in *j*-th measuring position according to the current reference plane position Q_j.

The calculations of these adjustments are made according to the respective algorithms depending on the adopted measurement scheme.

3. Overlapping measuring positions measuring scheme

Two groups of measuring probes (MP) – measuring probes, position 3 and correcting probes (*A*, *B*, *C*, *D* and *E*), position 1 are located on the support platform 2 (Figure 2) of the measuring system. The MP receives information about the position of the measured points of the surface in relation to the current position of the reference plane and the corrections (*A*, *B*, *C*, *D* and *E*) readings of the correction heads determine the corresponding corrections in the readings of the measuring heads in order to bring them to the reference datum. MP *B* and *E* play the role of both correction and measuring, i.e. $G_1 \equiv B$ and $G_k \equiv E$.

It is assumed that the reference plane at the first measuring position Q_1 lies in the *XOY* plane of the output coordinate system. The *Z* axis is oriented along the line of measurement of the form deviations (deviation from flatness and deviation from straightness of the profiles).

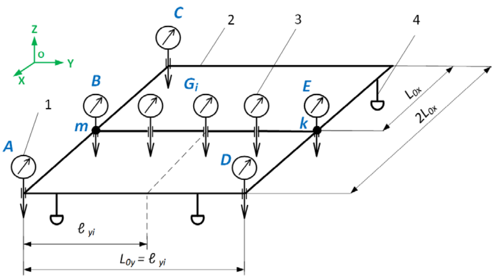

Fig.2 Measurement scheme: 1 – correcting measuring probes (A, B, C, D u E); 2 – support platform of the measuring system; 3 – measuring probes Gi; 4 – supports of the platform, determining the reference datum plane

The movement of the support platform 2 is on the *X* axis (discrete with step $t = L_{0x}$). Correcting MPs, position 1, are located in two lines in the direction of the *X* axis at a distance L_{0y} from one to another and the measuring MPs (G_i), position 3 - in the direction of the *Y* axis.

All measuring heads are set to zero by reference detail. The number and location of the points on the measured surface depends on the number of one-line measuring heads and the displacement step. The necessary corrections in the MP readings are obtained by indicating corrective MPs by overlapping the measurement positions.

When moving the support platform of the measuring system using *k*-number of measuring heads, they are scanned *k* parallel profiles of the measured surface. Measurement and processing of information from measuring and correcting measuring heads is performed in the following order.

The measuring system is set in the adjustment position (on the reference detail). Reset the measuring heads G_i ($i = 1 \dots k, k$ - number of measuring heads) and the correction heads *A, B, C, D* and *E*. After reset, the system is positioned in the initial measuring position ($j = 1$). The readings $z_{i,1}$ of the measuring heads and $z_{a,1}$, $z_{b,1}$, $z_{c,1}$, $z_{d,1}$ and $z_{e,1}$ of the corrective probes (*A, B, C, D* and *E*), corresponding to the distances from points of the measured surface to the reference plane are accounted. Consequently, the measuring system is moved in the direction of measurement (axis *X*) at step $t = L_{0x}$, where L_{0x} is the distance between the individual corrective MPs along the *X* axis. It is positioned in all measuring positions ($j = 1 \dots n$) and in analogy to the first position the readings $z_{i,j}$, $z_{a,j}$, $z_{b,j}$, $z_{c,j}$, $z_{d,j}$ и $z_{e,j}$ of all MPs are accounted (Fig. 2).

Based on these results, the distances $z'_{i,j}$ of the i,j-th points of the measured surface to the initial position of the reference plane can be determined:

$$z'_{i,j} = z_{i,j} + \Delta z_{i,j}, \quad (1)$$

where: $\Delta z_{i,j}$ is the result correction in i,j-th point;

Since the measuring heads *Gi* are arranged in a line (parallel to the *Y* axis) from a functional point of view, only the rotation about the *X* axis is of importance.

Then the correction of the result $\Delta z_{i,j}$ is determined by the formula:

$$\Delta z_{i,j} = \Delta z_{m,j} + \Delta z_{\alpha,i,j}, \quad (5)$$

$$\Delta z_{m,j} = \Delta z_{b,j} \quad (6)$$

$$\Delta z_{\alpha,i,j} = l_{y,i}.\mathrm{tg}\alpha_j = l_{y,i}.\frac{\Delta z_{k,j}}{l_{y,k}} \quad (7)$$

Depending on the $z'_{i,j}$ values obtained after correction, an average plane is constructed and the flatness deviation (Stage II and Stage III) is determined.

4. Measurement system

On the basis of the described method and measurement scheme is developed multi-sensor measurement system (Figure 3).

The system contains three basic modules - mechanical, measurement and software.

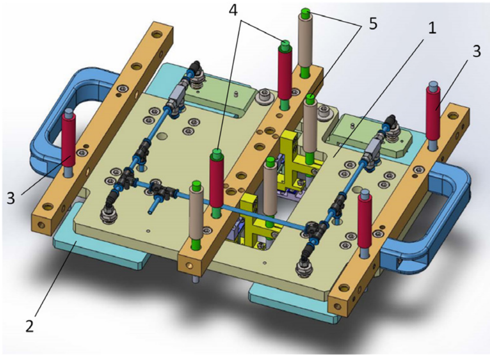

Fig.3 Measuring system: 1 - support platform; 2 – flat aerostatic supports; 3 - correcting probe; 4 – both measuring and correcting probe; 5 - measuring probes

The mechanical module includes a support platform 1 for mounting the measuring 2 and correcting 3 probes and the base elements. The platform is based on the measured surface on flat aerostatic supports, position 4, kinematically defined self-orientated. The role of the three reference points defining the reference datum plane play the centroids of the support surface points in contact with the measured surface.

The measurement module contains 6 pieces measuring probes, position 2 (two of which play a role of measuring and corrective) and three more, position 3, just corrective probes TESA GT21, connected to the computer via interface boxes TESA BPX-44.

The software module includes algorithms and programs for processing the primary measurement information and presenting the measurement result.

The system is designed for deviation from form measurements of responsible planar surfaces of units and details from the Buster and Collider of magnetic systems of the NICA complex, developed by the Joint Institute for Nuclear Research (JINR), the city of Dubna.

The system has been successfully implemented in the production process.

5. Conclusions

In the reference plane method for determining the extracted surface, a plane defined by three reference points of the support platform of the measuring system shall be used when it is set in the initial measuring position. Ensuring stability of the position of the reference plane in the initial measuring position in the space, i.e. in any selected XYZ coordinate system, each subsequent measurement position is provided by correcting the parameters that define the reference plane. Corrections are determined by appropriate algorithms on the readings of the corrected measurement probes located in a certain way when overlapping the measuring positions.

6. References

[1] ISO 1101:2017 Geometrical product specifications (GPS) - Geometrical tolerancing - Tolerances of form, orientation, location and run-out.

[2] ISO 17450-1:2011 Geometrical product specifications (GPS) - General concepts - Part 1: Model for geometrical specification and verification.

[3] ISO 17450-2:2012 Geometrical product specifications (GPS) - General concepts - Part 2: Basic tenets, specifications, operators, uncertainties and ambiguities.

[4] ISO 17450-3:2016 Geometrical product specifications (GPS) - General concepts - Part 3: Tolerance features.

[5] http://www.tesatechnology.com/en-gb/products/gt-21-hp-high-precision-probe-0-2-mm-4-3-mm-travel-p848.htm

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