Flatness measurement primary measurement information processing

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Abstract. A methodology for measuring and processing the primary measurement information when estimating the deviation from flatness of significant large-scaled objects is considered. The laser measurement system used and the algorithms used to process the measurement information are described.

1. Introduction
In order to evaluate the accuracy of the shape of the planar surfaces, additional information on their topography is needed. This information is obtained during the measurement process, as a result of which the position of points from the measured surface is determined relative to some datum (surface, profile, axis, trajectory, etc.).
At large-scaled objects, the measurement of flatness deviation is usually performed by measuring the deviation from straightness in a system of longitudinal, transverse and diagonal sections of the measured surface.
The results of mutually independent measurements of the deviations from the straightness of a given system of longitudinal, transverse and diagonal profiles of the surface are used. The values of the deviation from straightness obtained in the measurement are calculated by certain algorithms to a common datum line (reference plane), after which the deviations from the plane are compared with the associated plane of the minimum zone or the mean associated plane.
The processing of primary measurement information (the results of measurement of deviations from straightness) is covered in this paper.

2. Measurement scheme
Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented.
In the evaluation of the form of the flat surfaces of large-scaled objects and facilities, laser measuring systems are widely used. A schematic diagram for measuring such a system is shown in Fig. 1. The stabilized laser source 1 is positioned at one end of the test surface 5 in the direction of the X axis. In order to provide complete coverage of the normalized area from the test surface, the laser beam is deflected in the corresponding directions by means of the flat mirrors 3 and 4.
Figure 1. Principal scheme of measurement of deviations from flatness.

The position-sensitive photocell determines the position of a certain number of points from the measured surface profiles relative to the energy axis of the laser beam acting as an output reference line.

A major problem with such schemes is to bring this primary measurement information to a common coordinate system for estimating the deviation from flatness of the investigated surface.

3. Measurement methodology

At the beginning of the proposed methodology is the idea that if defines a virtual reference plane (VRP) related to the measured surface for the purposes of the study, we can, following a certain sequence, describe the form of the surface by aligning the measured Z coordinates of the selected points to a virtual reference coordinate system (VRCS) defined by the VRP (Fig. 2).

Figure 2. Schematic diagram for define the virtual reference datum plane.
Processing of the primary measurement information for the points to the VRCS is reduced to the determination of correction parameters by which the errors in the measured coordinates compensate for the repositioning of elements of the measuring system involved in the process. A mathematical model is used to determine, after re-measuring points, the coordinates of which are already known, from another measurement position, the mathematical relationships between the measured and known values for the corresponding point. On the basis of these calculations, adjustments are made for all points along the measurement line, to bring them to the VRCS.

For the purposes of this study, the VRP is considered to be the plane constructed through three of the four points limiting the normalized section in which the deviation from flatness is determined. The measured points are located on a grid constructed within the normalized section and bounded by the points defining the VRP (Fig. 2).

Where:

\( n \) – number of the intervals at \( X \) axis;

\( i \) – moment point on \( X \) axis, where \( i = 0,1,2,3 \ldots n \);

\( L_X \) – length of the normalized section at \( X \) axis (length of the grid at \( X \) axis);

\( l_i = L_X/n – X \) axis step length;

\( l_i = iL_X/n – x \)-coordinate of the \( i \)-th points (the length between the beginning of the coordinate system to \( i \)-th points on \( X \) axis);

\( m \) – number of intervals at axis \( Y \);

\( j \) – moment point at \( Y \) axis, where \( j = 0,1,2,3 \ldots m \);

\( L_Y \) – length of the normalized section at \( Y \) axis (length of the grid at \( Y \) axis at common case);

\( l_j = L_Y/m – Y \) axis step length;

\( l_j = jL_Y/m – y \)-coordinate of the \( j \)-th point (the length between the beginning of the coordinate system to \( j \)-th points on \( Y \) axis);

\( ij \) – moment point of the grid;

\( z_{ij} \) – coordinate \( z \) of the moment point \( ij \) of the grid, according to VRP;

\( z_{ij}^0 \) – \( z \) coordinate of the moment point \( ij \) of the grid, measured from position \( i0 \) (Fig. 3);

\( \Delta z_{ij}^0 \) – correction value equals to the difference between the values from the moment measure of \( Z \) coordinate of point \( ij \), measured from \( i0 \) position and the value of the coordinate of the point according to VRP.

![Figure 3. Value of coordinates according to VRP.](image-url)
For the computational part, what matters is the type of grid that will be built when exploring the site. This circumstance comes from considerations for minimizing the number of repositioning of items of measurement equipment, which is important both for the complexity of the measurement and the duration of the process and for the accuracy of the measurement.

Most suitable is the case where the number of intervals along the $X$ and $Y$ axes are equal and even ($n = m = 2k$). Then, regardless of the number of points along the axes, the diagonals intersect at a point in the grid and pass through such points along their entire length.

Measurements can be made with the least number of repositions of items of measurement equipment and with the least number of measurements. In addition, this option allows the control (multiple) measurement of points from each line.

By using different axis steps $l_x = L_x / n \neq l_y = L_y / m$ this grid can easily be applied to differently shaped objects.

4. **Algorithms for conducting measurement and processing of primary measurement information**

![Diagram](image-url)

**Figure 4.** Measurement of the diagonal $n0 - 0m$.

The test is carried out in the following order:
1. Determination of the normalized area on which the measurement will be carried out;
2. Determination and construction of the grid of the normalized section;
3. Positioning of the measuring system with respect to the grid (Fig. 1);
4. Measurement of the coordinates $z_{00}, z_{10} ... z_{n0}$ at all points of the grid lying along the $X$ axis – 00, 10 ... $n0$;
5. Measurement of the coordinates \( z_01, z_02 \ldots z_0m \) at all points of the grid lying along the Y axis – item 00, 01 \ldots 0m;
6. Determination of VBP at the points 00, n0 and 0m with Z coordinates \( z_{00}, z_{n0}, z_{0m} \) (Fig. 2);
7. Measuring \( p, 0m \) from position \( n0 \) – determining \( z_{0n0}^{\text{p}\text{m}} \) and calculating the correction \( \Delta z_{0n0}^{\text{p}\text{m}} \) and the correction \( \Delta z_{p\text{q}0}^{n\text{m}} \) for the intersection point of the diagonals \( (p = n/2, q = m/2) \) (Fig. 4).

\[
\Delta z_{0n0}^{\text{p}\text{m}} = z_{0n0}^{\text{p}\text{m}} - z_{0m} 
\]

\[
\Delta z_{p\text{q}0}^{n\text{m}} = \frac{1}{2} \cdot \Delta z_{0n0}^{\text{p}\text{m}} 
\]

8. Measuring the Z coordinate \( z_{p\text{q}0}^{n\text{m}} \) at the intersection of the diagonals from position \( n0 \) (Fig. 4) and bringing it to the VBP by \( \Delta z_{p\text{q}0}^{n\text{m}} \) – determining \( z_{p\text{q}} \);
9. Measure \( z_{p\text{q}0}^{n\text{m}} \) – the coordinate of the intersection of the diagonals of position 00 and determine the correction \( \Delta z_{p\text{q}0}^{n\text{m}} \). Calculation of the corrections \( \Delta z_{nm}^{n\text{m}} \) for the points on the diagonal \( 00 - nm \) (Fig.5);

\[
z_{nm} = z_{n0}^{\text{p}\text{m}} - \Delta z_{nm}^{\text{p}\text{m}} 
\]

\[
\Delta z_{nm}^{n\text{m}} = z_{nm}^{0\text{m}} - z_{nm} 
\]

**Figure 5.** Measurement of the diagonal 00 - nm.

10. Determination of the VBP-aligned Z coordinate of the point \( nm \) from the \( 00 - nm \) diagonal by \( \Delta z_{nm}^{n\text{m}} \) – determination of points \( z_{il} \), incl. \( z_{nm} \) – analogously to p. 8 (Fig. 4);
11. Measurement of \( z_{nm}^{0\text{m}} \) – measurement of the point \( z_{nm} \) from position \( 0m \) and calculation of the corrections \( \Delta z_{nm}^{0\text{m}} \) for the points along the line \( 0n - nm \) (Fig. 6);

\[
\Delta z_{nm}^{0\text{m}} = z_{nm}^{0\text{m}} - z_{nm} 
\]
6

\[ \Delta z_{im}^0 = \frac{i}{m} \Delta z_{nm}^0 \]  

(5)

**Figure 6.** Measurement of the line 0m - nm.

12. Measuring the \( z_{im}^0 \) - Z coordinates of the points along the line 0m - nm from position 0m and bringing their values to the VBP:

\[ z_{im} = z_{im}^0 - \Delta z_{tm}^0 \]  

(6)

13. Measuring consecutively the points along the lines 10 - 1m, 20 - 2m ... i0 - im ... n0 - nm. The points 1m, 2m ... im ... nm of the positions at the points 10, 20 ... i0 ... n0 are respectively measured and the determination of \( \Delta z_{im}^{i0} \) (Fig. 7).

\[ \Delta z_{im}^{i0} = z_{im}^{i0} - z_{im} \]  

(7)

\[ \Delta z_{ij}^{i0} = \frac{f}{m} \Delta z_{im}^{i0} \]  

(8)

14. Alignment of all measured points to the VBP by the calculated correction coefficients for each position in the network:

\[ z_{ij} = z_{ij}^{i0} - \Delta z_{ij}^{i0} \]  

(9)

15. Construction of the mean associated plane to the surface defined by the coordinates \( x_{ij}, y_{ij} \) and \( z_{ij} \).
Figure 7. Measurement of the points on lines 10 – 1m … i0 – im … n0 – nm.

16. Determinating deviation from flatness.

5. Conclusion
Measurement methodology, algorithms for processing of primary measurement information and corresponding software have been developed, which allows measuring the deviations from the flatness of surfaces of significant large-scaled objects.

References
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