PECULARITY OF METROLOGY ASSURANCE COORDINATE MEASUREMENTS OF GEOMETRICAL PARAMETERS OF THE SHAPED SURFACES.

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Abstract: This report outlines the basic principles for metrology assurance of the 3D coordinate measurements of geometric parameters (CM GP) of surface areas, taking into account in the complex all the factors identified as a result of scientific research that affect to the accuracy and reliability of 3D coordinate measurements. The main differences between 3D coordinate measurements of geometric parameters of arrangement of surfaces from 1D linear-angular measurements are considered.

Key words: metrology, surface, coordinate measuring machine

INTRODUCTION

Abstract: This report outlines the basic principles for metrology assurance coordinate measurements of geometric parameters (CM GP) surface areas, taking into account in the complex all the factors identified as a result of scientific research that affect to the accuracy and reliability of 3D coordinate measurements. The main differences between 3D coordinate measurements of geometric parameters of of surfaces from 1D linear-angular measurements are considered.

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The principles of CM GP treated surfaces have some significant differences from traditional linear measurements of length and cannot be unambiguously described and implemented by methods of the conventional one-dimensional (1D) measurements. A direct transfer unit length, by the traditional one-dimensional linear methods and measuring equipment (ME) in the measurement of GP surfaces of complex shape is not possible without significant loss of accuracy. It is therefore advisable to allocate spatial measurements, carried out by coordinate methods in an independent field of Metrology – dimensional (3D) Metrology. Accordingly, CM GP require a fundamentally new approach to its metrology assurance (MA).

In the coordinate measurement by universal coordinate measuring machine (CMM), in addition to calibration of scales of measuring equipment (ME) (which is a necessary and sufficient condition for one-dimensional length measurement) is necessary to define and maintain the orthogonal Cartesian system of coordinates (SC), in which coordinates of points on the controlled surface are measured.

In practice, the coordinate measurements are carried out in the mechanical implementation of SC, burdened by the geometric errors of manufacturing and alignment. Therefore, the definition and compensation of errors in measurement of coordinates of points in any region of the working volume of the CMM can be done by direct methods by measuring certified physical implementation of SC. The alternative is mathematical modeling of mechanical errors in the SC (for example, 21 parametric model of SC CMM) and the creation of tools for the calibration, clearly revealing these errors to compensate. [1]

Traceability of CMM to the primary standard of the length unit can be carried out by using laser interference systems (LIS), transmitted to CMM unit length of their scales, and measuring and compensating the remaining 18 geometric errors of SC CMM, or with a set of other measures, replaced LIS as the reference ME.

Traceability of CMM as ME of GP (for example, the deviation from the cylindricity, sphericity, flatness, evolventness, roundness, etc.) can be done in two ways – by the direct comparator method with the help of standard measures of cylindricity, roundness, flatness, etc., and also by an indirect method, through the attestation software that calculates the geometric parameters from the measured coordinates of the controlled finish surface and the definition (in certification process) of the error of indirect measurement GP of surfaces.

CM GP deviation of form (flatness, evolventness, roundness, e.t.c.) on special ME – devices for measuring flatness, evolventness, roundness, e.t.c. has common principles, consisting in setting and maintaining (during measurement) coordinating surface with nominal form of surface along the normal to it. Therefore, the binding ME to the original standard form requires the reproduction and transmission of unit length normal to the coordinate surface of nominal shape, which is provided by measures of deviations from flatness, and other coordinates of the surface of the nominal shape and maintaining it during the measurement process.

Significant difference of CM GP from the traditional linear measurements is the availability of software that implements the 3D indirect measurement of GP, as the functional of the primary measuring information about the coordinates of the investigated surface. Therefore, a significant component of MA is the certification of the algorithms and the software that implements CM GP.

Since direct transfer of length units from the State primary standard of length is not possible without significant loss of accuracy, for CM GP treated surfaces it needs to create a complex special standard unit of length, reproducing it in the special conditions in precision measurement of geometric parameters of the deviations from circularity, flatness, sphericity, evolventness, and other described complex analytical and algorithmic dependencies.

The mathematical model of coordinate measurement procedure

As a specific example, surfaces of complex shape, consider the involute surface (IS).

The measurement of GP IS on CMM has a number of inherent coordinate methods steps:

-select probes (the filtering of certain irregularities of the surface to be measured depends on the radius of the probe);

-calibration of the probes (the procedure of establishing a valid, geometrical ratios between the individual elements of the probe arm of the system);

-the choice of coordinate system of details (for error reducing dynamic range);

-the approach of the coordinate system details to the canonical (i.e., all calculations of the parameters of IS are produced in the canonical coordinate system);

-the determination of estimates of the actual values of the parameters IS and the parameters of the canonical coordinate system by the method of least squares;

-determination of the error of the measurement result.

To implement these stages of measurement, a mathematical model of the procedure of coordinate measurement on a CMM is considered. The model is implemented in the form of algorithms and programs. It is based on mathematical conversion of primary measuring information at various stages of measurement of parameters of IS. For the selection stage of the probe of the equation of the trajectory of the vertex of a spherical probe when generating evolvent is written:

$$h(x) = \sqrt{r^2 - x^2} \qquad (1)$$

$$Y_0'(X_{0i}) = h'(X_{0i} - X_i) \qquad (2)$$

$$h(X_{0i} - X_{1i}) - Y_0(X_{0i}) = \min \qquad (3)$$

$$\begin{cases} Y_1(X_1) = Y_0(X_{0i}) - r + \sqrt{r^2 + r^2\left[Y_0'(X_{0i})\right]^2 / \left[1 + (Y_0'(X_0)\ ^2\right]} \\ X_1 = X_{0i} + rY_0'(X_{0i}) / \sqrt{1 + \left[Y_0'(X_{0i})\right]^2} \end{cases} \qquad (4)$$

Where $h(x)$ – is the profile of a spherical probe in the coordinate system of the CMM;

-equation (2) defines the touch point probe IS;

-equation (3) is a condition of searching the minimum distance from IS to the probe;

-the relations (4) describe the trajectory of the vertex of the probe.

Based on the geometric dependencies, we can formulate requirements to the choice of the radius of the probe, providing a precise measurement of real evolvent. Because the radius of the probe is a function of the geometrical parameters IS (the minimum step of the bumps and their height), the radius of the probe should not exceed the value:

$$R_{\max} \le \frac{S_0^{\ 2}}{H 4\pi^2} \qquad (5)$$

where H is the height of the irregularities;

- a is the step of the irregularities on the midline.

Errors of calibration of a spherical probe ΔR in case of deviations from sphericity are functions of measurement errors of the coordinates of the probe (X_i, Y_i, Z_i), the center of a spherical probe (X_o, Y_o, Z_o) and errors of their measurement (ΔX_i, ΔY_i, ΔZ_i, ΔX_o, ΔY_o, ΔZ_o) and the number of measured points N:

$$\Delta R = f(X_i, Y_i, Z_i, X_0, Y_0, Z_0, \Delta X_i, \Delta Y_i, \Delta Z_i, \Delta X_0, \Delta Y_0, \Delta Z_0, N) \qquad (6)$$

The coordinates of the axis of IS are determined by the least-squares method on a cylindrical base surface. The accuracy of the algorithm discrete measurement axis in the coordinate system of CMM and the accuracy of their calculation is determined by the values of the measured coordinate axis IS and errors of their measurement ΔX_i, ΔY_i, ΔZ_i.

In the transition to a canonical coordinate system conversion algorithm of coordinate system to the canonical, corresponds to the following chain of transformations:

$$(X, Y, Z)\ cmm \Rightarrow (X, Y, Z)det. \Rightarrow$$

$$\Rightarrow (X(f)\ Y(f)\ Z(f), f, R)\ canonical \qquad (7)$$

The result of measurement of the coordinates of the IS is a set of discrete samples of the coordinates (X_i, Y_i) profile IS.

The step of determining estimates of the actual values of the parameters IS the theoretical equation of evolvent representing an element of IS in parametric form in canonical coordinate system are written as follows:

$$\left.\begin{aligned} X &= R\cos(\varphi) + R\varphi\sin(\varphi) \\ Y &= R\sin(\varphi) - R\varphi\cos(\varphi) \end{aligned}\right\} \qquad (8)$$

where: X and Y are the coordinates of the IS in the canonical coordinate system;

R is the radius of the base circle;

φ – is the angle of expansion.

In this case the real surface IS can have deviations from the theoretical, as well as the coordinates (X, Y) and the radius of base circle R and the angle of expansion φ. Taking into account these deviations and due to the errors of the parameters ΔX, ΔY, ΔR and $\Delta\varphi$, the above equation can be written as:

$$\left.\begin{aligned} X + \Delta X &= (R + \Delta R)\cos(\varphi + \Delta\varphi) + (R + \Delta R)(\ + \Delta\varphi)\sin(\varphi + \Delta\varphi) \\ Y + \Delta Y &= (R + \Delta R)\sin(\varphi + \Delta\varphi) - (R + \Delta R)(\varphi + \Delta\varphi)\cos(\varphi + \Delta\varphi) \end{aligned}\right\} \qquad (9)$$

In addition, due to the presence of errors of determination of the canonical system of coordinates of the theoretical involute deployed on the measured at some angle $\Delta\alpha$ for the respective axes $0X$ and $0Y$, there is an offset by ΔX_1 and ΔY_1.

Mathematically, the resulting transformation is equivalent to the displacement and rotation of the canonical coordinate system of the theoretical evolvent in relation to the real:

$$\left.\begin{aligned} X &= X'\cos(\Delta\alpha) - Y'\sin(\Delta\alpha) + \Delta X_1 \\ Y &= X'\sin(\Delta\alpha) + Y'\cos(\Delta\alpha) + \Delta Y_1 \end{aligned}\right\} \qquad (10)$$

where: are the X, Y the canonical coordinates;

coordinates in the expanded coordinate system;

ΔX_1, ΔY_1 – are the offset values along the axes $0X$ and $0Y$;

$\Delta\varphi$ – is the angle turn.

Further conversion of the measuring data represent the building normal to the theoretical surface IS defined by the system of parametric equations:

$$\Delta Xo / \Delta\varphi \bullet (X - Xo) + \Delta Yo / \Delta\varphi \bullet (Y - Yo) = 0$$

$$\Delta Xo / \Delta\varphi = \Delta X / \Delta\varphi\ (\varphi o); \qquad (11)$$

$$\Delta Yo / \Delta\varphi = \Delta Y / \Delta\varphi\ (\varphi o)$$

$$X = R \bullet \cos(\varphi) + R \bullet \varphi \bullet \sin(\varphi)$$

$$Y = R \bullet \sin(\varphi) - R \bullet \varphi \bullet \cos(\varphi)$$

and measuring the deviations normal to the real evolvent from the theoretical.

Conclusion

Analysis of the proposed mathematical model of measurement of parameters of IS allows to develop an algorithm procedure for the measurement of the parameters of the IS and to assess the influence of the relevant error components.

It follows from this that:

the accuracy of determining the coordinates of the center base circle leads to a parallel displacement of the profile evolvent by ΔX along the X-axis and ΔY along the Y-axis;

the error of the radius of the base circle ΔR leads to linear tilt profile evolvent proportional to the magnitude of error ΔR;

the error of the reference angle introduces a non-linear component, according to (9) in the mathematical model.

Non-excluded systematic components of errors, in General, determine the limits of accuracy of coordinate measurement techniques of the parameters of IS.

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