Novel method for uncertainty evaluation of coordinate measurements

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A new method of uncertainty evaluation of coordinate measurement is presented. The models of particular geometrical characteristics (dimensions, geometrical deviations) are developed with taking into account the fact that coordinate measurement is an indirect measurement in which the measurands are <u>differences of coordinates</u> x_i of characteristic (eg. probing) points [1]. Assuming the minimal mathematical number of points and using formulae for point-point distance, point-straight line distance or point-plane distance allows deriving relatively simple measurement models.

Uncertainty of measurement can be evaluated by means of the formula for uncertainty of indirect measurement [2]:

$$u(l) = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial l}{\partial x_i}\right)^2 u_{xi}^2} \qquad (1)$$

Fig. 1 depicts an example of tolerance specification and modelling of flatness deviation measurement. The model refers to a simplified method of classical measurement of flatness. The point *S* is to lay near the gravity centre of points *A*, *B* and *C*.

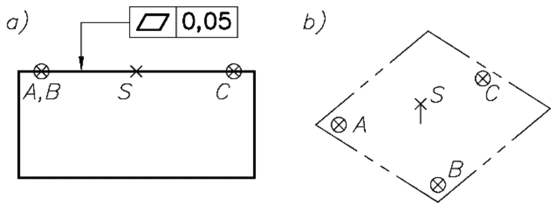

Fig. 1 Measurement model of deviation of flatness

The distance *l* of point *S* from the plane *p* given by any point *P* belonging to this plane and the unit normal vector *u* is calculated as follows:

$$l(S,p) = |(P - S) \cdot u| \qquad (2)$$

The uncertainty of measurement of flatness equals the uncertainty of measurement of distance between point *S* and plane *ABC* and is function of coordinate differences for pairs of points *AS*, *AB* and *AC*. Basing on this, measurement models of flatness can be defined:

$$l(AS, AB, AC) = \left| AS \cdot \frac{AB \times AC}{|AB \times AC|} \right| \qquad (3)$$

The input data on the CMM accuracy is just formula for maximum permissible error of CMM E_{MPE}. Standard uncertainties of measurement of particular differences of coordinates are evaluated by type B method assuming that biggest possible error is equal to maximum permissible error of length measurement of the CMM assuming normal distribution (k = 1/3) – therefore in uncertainty budgets is assumed:

$$u_{xi} = E_{MPE}/3 \quad (4)$$

Table 1 presents the uncertainty budget of flatness measurement on CMM with $E(MPE)$ = 2 + 4L µm. The measured surface is a square with side length 400 mm. The points A(5, 5), B(395, 5) and C(200, 395) define the reference plane. Point S can be located in any place near the plane but usually around the central point of the plane. The result do not differ significantly over the plane - the largest value of the measurement uncertainty is 0.74 µm.

Table 1. Uncertainty budget of the flatness measurement for S(200,150,0)

Component	x_i, mm	$\frac{\partial l}{\partial x_i}$	u_{xi} = MPE_E/3, µm	$\frac{\partial l}{\partial x_i} u_{xi}$, µm
as_1	150	0.00	0.87	0.00
as_2	100	0.00	0.80	0.00
as_3	0.01	1.00	0.67	0.67
ab_1	300	0.00	1.07	0.00
ab_2	0	0.00	0.67	0.00
ab_3	0	-0.33	0.67	0.22
ac_1	150	0.00	0.87	0.00
ac_2	300	0.00	1.07	0.00
ac_3	0	-0.33	0.67	0.22
			u =	0.74

For the workpiece aligned along the CMM axes the weights of many components in the uncertainty budget are equal 0 which makes the analyses easier. It should be noted that one of the uncertainty components occurs with a weight of 1 and two with a weight of 0.33, and all concern a small (zero or almost zero) measured value. The components related to large measured values and related to the size of the measured object occur in the budget with a weight equal to zero, which means that the size of the measured object does not affect the uncertainty of the flatness measurement.

[1] Jakubiec W, Płowucha W., Starczak M.: Analytical estimation of coordinate measurement uncertainty. Measurement 45 (2012), p. 2299–2308
[2] ISO 14253-2:2011 Geometrical product specifications (GPS). Inspection by measurement of workpieces and measuring equipment. Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification