THE DEPENDENCE OF THE MEASUREMENT ACCURACY OF MEASURED ITEM ORIENTATION ON THE CONTOUR MEASURING MACHINE

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ABSRACT
Contour measuring machines are not used as commonly as standard coordinate measurement equipment (CMM). The reason is their very specific application, for example thread contour measurement, gear tooth contour measurement, etc. Relatively small number of these machines and specific coordinates system make them quite unexplored concerning the accuracy of measurement and its dependence on measured item orientation. This paper presents the results of measurements of angle standards with different orientations on the contour measuring machine. Other measurement parameters such as speed, resolution, types of data collection, etc. have been tested. Conclusions also were presented.

Keywords: contour measuring machine, accuracy

1. INTRODUCTION

Contour measuring machines are another proposition in coordinate metrology, next to coordinate measuring machines, roundness measuring instruments, microscopes, etc. offered by manufacturers of measuring equipment. Their characteristic feature is that they can be applied to measure quantities defined by the contour of a surface, such as: contours of threads, toothed wheels, differences between diameters of stepped shafts and holes as well as hole diameters in the case where a contour measuring machine with the capability of measuring on both sides is used. Such a scope of applications has an impact on the design of these machines and on the specific coordinate system presented in fig. 1.

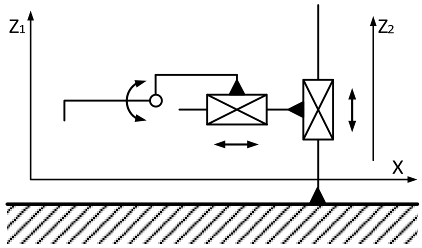

Figure 1. Kinematic system of contour measuring machine

The general concept of a contour measuring machine's kinematic system resembles the system used in profilometers intended for measurement of a surface's geometric structure, however the much greater range of measured quantities results in differences between both types of measuring instruments. Measurement on the Z axis performed by means of a rotating arm causes the measuring tip to be displaced on the X axis due to large displacements of the tip on the Z axis (due to the small height of measured unevennesses, this problem is not present in profilometers), which necessitates correction of this displacement. Manufacturers of contour measuring machines apply mechanical, electrical or programmed compensation of such displacements [1]. In the case of certain machines, the XZ coordinate system is supplemented by an additional Z axis which makes it possible to determine vertical displacements of the measuring tip, and this is applied e.g. during two-sided measurement. Two axes are then distinguished: Z_1 and Z_2 . The geometry of measuring tips is a fundamental factor determining a contour measuring machine's measuring capabilities. The measured contour is the track of the center of a measuring tip which most commonly has a spherical shape. The dimensions of measuring tips affect the maximum value of the angle of inclination at which measurement of a surface that rises in falls relative to the X axis is possible. Contour measuring machine manufacturers have noted this limitation, and the capability of combining several contours, measured separately, is usually provided in software.

2. MEASURIN CONDITIONS

Measured has been angle standard in form of class 1 angle gage with nominal size: $\alpha = 120°$, made by VIS Company, according to withdrawn now, Polish PN-81/M-53108 [2] standard. Gages, meets requirements listed in tab. 1.

Table 1. Requirements for angle stanards, according to PN-81/M-53108

Roughness of measuring surfaces	R_z*) ≤ 0,2 µm
Roughness of others surfaces	Ra ≤ 0,63 µm
Maximum flatness deviation of measuring surfaces	0,5 µm
Maximum deviation of angle between measuring surfaces	± 12”
Minimum hardness	62 HRC

*) Value for Rz parametr defined according to previously valid ISO 4287:1984 standard

A Contracer CV2100M4 contour measuring machine from Mitutoyo was used for measurements. The machine's technical specifications are presented in table 2 [3].

Table 2. Mitutoyo Contracer CV2100M4 technical specification

Quantity		Value
X-axis measuring range:		100 [mm]
Resolution	X-axis	0,1 [µm]
	Z_1-axis	0,1 [µm]
X-axis drive speed		0÷20 [mm/s]
Measuring speed		0,02÷5 [mm/s]
Measuring direction		forward / backward
Traverse linearity		2,5µm/100mm
Accuracy (at 20°C)	X-axis	±(2,5+2L/100)µm (L = drive length [mm])
	Z_1-axis	±(2,5+|0,1H|) µm (H = measurement height from horizontal position within ±25 [mm])
Inclining range		±45°
Z_2-axis (column)		
Column drive type		manual
Vertical travel		350 [mm]

During tests, the contour measuring machine was equipped with a measuring arm 155 mm in length, with a measuring solid carbide tip, unilaterally tapered at an angle of 12°, with a length of 20 mm and tip radius r_{tip} = 0.025 mm (fig. 2). The tip radius is compensated for by the software after the instrument is calibrated on a spherical standard. The arm and measuring tip are standard equipment. FormTracePak v4.1 software is included with the machine, making it possible to determine linear and angular dimensions, offsets, graduations for periodical quantities as well as geometrical deviations such as linearity, roundness, inclination. The software makes it possible to determine geometric elements using the Minimum Zone or Least Square method. Measurements were conducted using both methods. It is also possible to modify measuring parameters such as speed, resolution and the method of measuring points on measured surfaces, within a wide range. Measuring speed can be modified within the range of 0.02÷5 [mm/s]. Measurements were carried out at speed: v_m = 1, 2 and 5 [mm/s]. The resolution of measurement, or the distance between two points on a surface measured one after the other, can be modified within the range from 0.0001 mm upwards. The selection of this parameter's value is linked to selection of measuring speed – the software corrects the set speed value, if it is too high compared to the selected measuring resolution. Tests were conducted at resolutions d(x) = 0.005; 0.01 and 0.1 mm. The method of measuring points on measured surfaces makes it possible to choose between: determination of the distance between points, set in the resolution parameter, in the direction parallel to the contour of the surface (fig. 3a) or in the direction parallel to the X axis (fig. 3b).

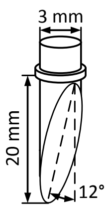

Figure 2. Measuring tip

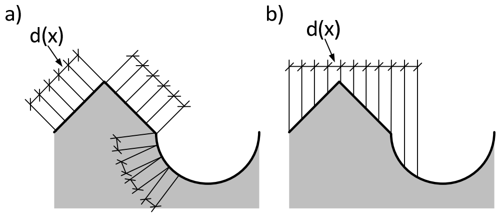

Figure 3. Method of measuring points on the surface

During preliminary tests, measurements were conducted according to both the former and latter method of acquiring points on the surface. The results proved to be very similar, which can be explained by low flatness deviation and low roughness of angle standard surfaces (tab. 2). The method of measurement in the direction parallel to the contour of the surface was selected for tests as providing a better representation of the measured contour.

3. MEASUREMENTS RESULTS

Figures 4 and 5 present measurement results for angle standard α = 120° in a position ensuring the same values of the ascent and descent angle of the surface, equal to 60°. The spacing of sample points (resolution) was equal to d(x) = 0.005 mm. Integral associated features were determined by the minimum zone (MZ) method and least square (LS) method, respectively. Measurements were carried out at different measuring speeds: v_m = 1, 2 and 5 [mm/s]. Measurement with such an angle standard configuration resulted in the smallest displacements of the arm's measuring tip on the X axis, and thus, the lowest expected error of the measured angle.

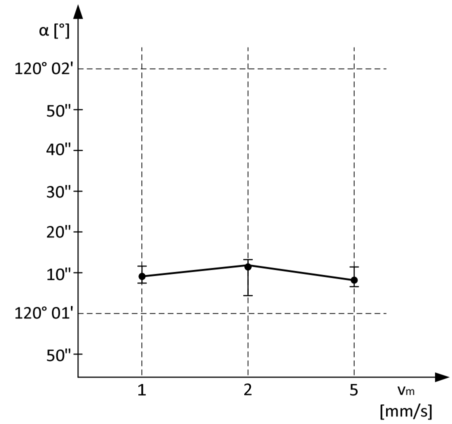

Figure 4. Measured angle dependence of measurement speed v_m. Angle gauge $\alpha = 120°$, ascent angle $\beta = 60°$, descent angle 60°, sample points spacing d(x) = 0,005 mm, minimum zone method.

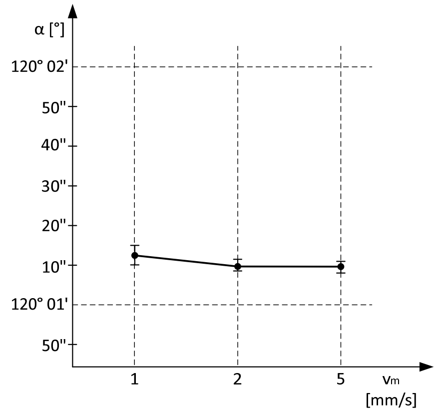

Figure 5. Measured angle dependence of measurement speed v_m. Angle gauge $\alpha = 120°$, ascent angle $\beta = 60°$, descent angle 60°, sample points spacing d(x) = 0,005 mm, least square method

It can be seen that a change of measuring speed has a small impact on the scatter of measurement results. All differences between measured angle values, regardless of the speed and the method of determining geometrical elements, fall within a range with an interval of 7". However, the average value of measured angles amounts to approx. 120° 01’ 10”, which is a value 01' greater than the nominal value, accounting for the error of standard manufacturing, equal to ±12”. Figures 6 and 7 present measurement results for angle standard $\alpha = 120°$ in a position ensuring the same values of the ascent and descent angle of the surface, equal to 60°. Measurements were performed at a speed of $v_m = 1$ mm/s. Integral associated features were determined by the minimum zone (MZ) method and least square (LS) method, respectively. Measurements were performed at different sample point spacings (resolutions) d(x) = 0.005, 0.01 and 0.1 mm.

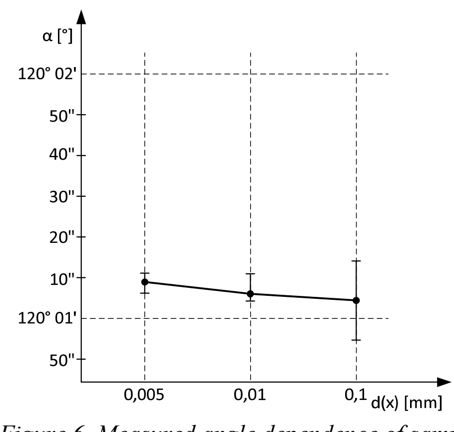

Figure 6. Measured angle dependence of sample points spacing d(x). Angle gauge $\alpha = 120°$, ascent angle $\beta = 60$, descent angle 60°, measure speed $v_m = 1$ mm/s, minimum zone method

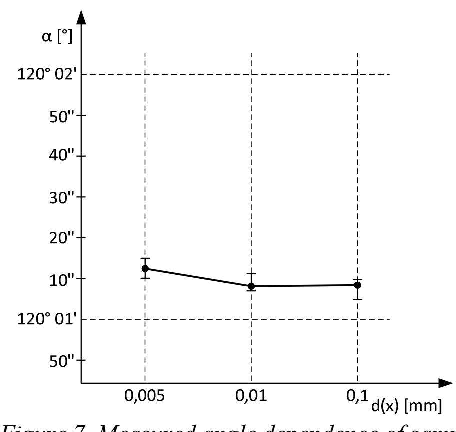

Figure 7. Measured angle dependence of sample points spacing d(x). Angle gauge $\alpha = 120°$, ascent angle $\beta = 60°$, descent angle 60°, measure speed $v_m = 1$ mm/s, least square method

It can be seen that a change of sample point spacing also has a small impact on the scatter of measurement results. All differences between measured angle values, regardless of the sample point spacing and the method of determining geometrical elements, fall within a range with an interval of 8" for values determined by the MZ method and 5" for values determined by the LS method. The average value of measured angles amounts to approx. 120° 01' 5", which is a value 01' greater than the nominal value for the MZ method and approx. 120° 01' 10" for the LS method. The noticeably greater scatter of angle measurement results for 0.1 mm sample point spacing in the MZ method should be noted. This is probably caused by the method of determining an integral associated feature in this method, where individual measured points may affect its position. Figures 8 and 9 present the results of measurements of angle standard α = 120°. Measurements were performed at a speed of v_m = 1 mm/s. Integral associated features were determined by the minimum zone (MZ) method and least square (LS) method, respectively. Measurements were performed for sample point spacing d(x) = 0.005 mm. The varying position of the angle standard made it possible to obtain ascent angles with values β = 15°, 60° and 115°. These values made it possible to measure the standard for maximum ascent angle values (for β = 15°) and maximum descent angle values (for β = 115°) of the machine, as specified in its documentation.

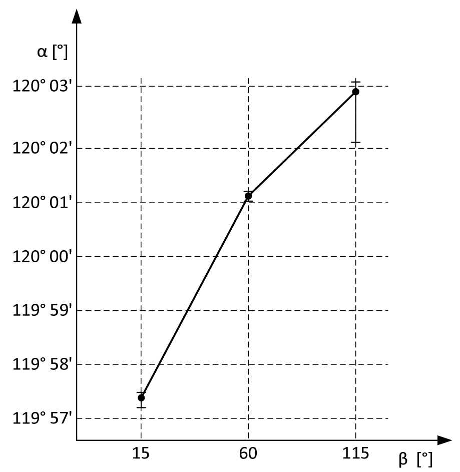

Figure 8. Measured angle dependence of ascent angle β. Angle gauge α = 120°, measuring speed v_m = 1 mm/s, sample points spacing d(x) = 0,005 mm, minimum zone method.

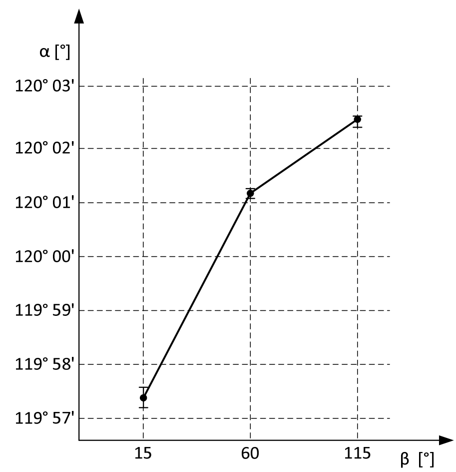

Figure 9. Measured angle dependence of ascent angle β. Angle gauge α = 120°, measuring speed v_m = 1 mm/s, sample points spacing d(x) = 0,005 mm, least square method.

It can be observed that a change in the orientation of the measured standard results in significant differences between obtained measurement results. For ascent angle β = 15°, the value of the measured angle is equal to 119° 57' 20" for the MZ method and 119° 57' 24" for the LS method. Increasing the ascent angle to β = 60° causes the value of the measured angle to rise to 120° 01' 10" for the MZ method and 120° 01' 13" for the LS method. Increasing the ascent angle further to β = 115° results in an increase of the value of the measured angle to 120° 02' 56" for the MZ method and 120° 02' 29" for the LS method. The differences between measured values are due to the fact that, for ascent angles β = 15° and β = 115°, measurements on the contour measuring machine are conducted near the technical limits of its measuring capabilities. When the measuring tip undergoes small displacement along the X axis, information about the coordinates of a relatively large number of points on the measured surface is collected. In addition, the measuring arm undergoes significant displacement on the Z axis, which is linked to displacement of the arm's tip on the X axis independently of the measuring tip's drive and the necessity of applying the correction mentioned above.

4. CONCLUSIONS

The orientation of the measured object relative to the measuring instrument's X axis has the greatest impact on accuracy of measurement on the contour measuring machine. A visible increase of measurement error can be observed at positions of the measured object where the angle of inclination of one of its surfaces approaches the limit value of ascent or descent angle of the measuring tip. This is caused by the kinematic system of contour measuring machines, which necessitates recalculation of the coordinates of points measured on the Z axis from the measuring arm's polar coordinate system to the Cartesian coordinate system of the machine's measuring system. Another factor that affects accuracy of measurement is unintended displacements of the measuring tip on the X axis during measurement of quantities on the Z axis, and the necessity of applying a correction to account for such displacements. Measuring speed and sample point spacing have a low impact on accuracy of measurement in the case of measurements of angle standards. This may be due to low flatness deviation of the surface, low shape errors and low roughness. It can be expected that in the case of measurement of machine parts with inferior surface geometry parameters, the impact of measuring speed and sample point spacing may be significantly greater.

6. REFERENCES

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[3] Mitutoyo Contracer CV2100M4 Instruction Manual. Mitutoyo Corporation 2016.