Influence of scanning speed on measurement process capability on CMMs

Artur Savinov*

CTU in Prague, Faculty of Mechanical Engineering, Department of Machining, Process Planning and Metrology, Technická 4, 166 07 Prague 6, Czech Republic

Abstract

Paper presents experimental procedure to investigate influence of scanning speed on measurement process capability on coordinate measuring machines. Concepts of process capability and measurement system capability are explained. The measurement system capability indices are implemented to evaluate dependence of dimensional and geometric characteristics on scanning speed. The particular dependencies of characteristics are graphically represented. In the future, results can be used to consistently optimize measurement process to acquire adequate measurements.

Keywords: CMM; scanning speed; measuring system capability

1. Introduction

The coordinate measuring machines are used for a wide range of application in automotive, aerospace and electronics industries. CMMs have become an integral part of manufacturing, and the demand for them continues increasing gradually.

Geometrical and dimensional precision of manufactured parts is essential in terms of functionality and reliability. Measuring with precision is determined by the need to manufacture products within tolerances. Such as precision, the productivity of measurements is also important since each minute of measurement costs money. Reducing the measurement time of single characteristic in serial production at least for a few seconds while maintaining the required precision means saving a lot of money. CMM manufacturers have been constantly trying to improve productivity and quality capabilities of measuring technique. For instance, the contact scanning is one of the productivity improvement steps. Certainly, it is also necessary to develop methods of using measuring equipment.

Apparently, CMM scanning speed has significant influence on achievable accuracy of the measurement results. Aim of this paper to propose possible approach to optimizing quality control on CMMs with scanning capability in terms of productivity. The concept of method is based on the approach to optimal scanning speed while maintaining required measurement system capability.

2. Process capability and measurement system capability

2.1. Process capability

Process capability is the ability of the process to consistently provide products that meet the specification requirements [1]. Capability indices C_p and C_{pk} are being used to evaluate process capability. These indices assess potential and actual capability of process. C_p is defined as follows.

$$C_p = \frac{\mathrm{USL}-\mathrm{LSL}}{6\sigma} \quad (1)$$

where σ is standard deviation. USL and LSL are upper specification limit and lower specification limit respectively. C_p index is expressed as the ratio of the allowable variability and the “natural” variability of the process [2]. Normal distribution is assumed. This index does not take the position of the expected value relatively to the target value into account. This means that the process with compliant index may lie outside the tolerance. The C_{pk} index solves the problem of centering.

$$C_{pk} = min\left\{\frac{\mathrm{USL}-\mu}{3\sigma}; \frac{\mu-LSL}{3\sigma}\right\} \quad (2)$$

where μ is expected value. Normal distribution is also assumed. The C_{pk} index takes expected value into account and it is always less than or equal to C_p index [2].

2.2. Measurement system capability

Evaluating of measuring system capability using C_g and C_{gk} indices has similar principle as evaluating of process capability. The indices compare the variability of repeated measurements and a part of their tolerance. C_g index considers only the precision of measurement, while C_{gk} index considers the precision and the trueness of measurement [3].

According to [4] measurement precision is closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions. Measurement precision can be expressed by standard deviation, variance or coefficient of variation. In addition, measurement trueness is closeness of agreement between the average of

* Corresponding author: Arturmarseljevic.savinov@fs.cvut.cz

an infinite number of replicate measured quantity values and a reference quantity value.

Capability of measurement system is stricter than process capability. There are Bosch and Ford methods of C_g and C_{gk} indices calculation. Both methods considering that variance of measuring system can be only a part of measured parameter variance. Measurement system capability can be related to the standard deviation of process or to the width of tolerance. In the first case, better results can be obtained when the "natural" variability of process fills the greater part of tolerance. In the second case, better results can be obtained when the "natural" variability of process fills a smaller part of tolerance. This means that measured results are not spread in tolerance zone. The difference between the methods is based on width of tolerance that measurement system can retain. Usually, it is 15% or 20% of tolerance. [3]

The Bosch method was implemented in this study. The C_g index is defined as follows.

$$C_g = \frac{0.2\mathrm{T}}{S_a} \tag{3}$$

where S_a is a sample standard deviation of measured results. The C_{gk} is defined as follows.

$$C_{gk} = min\left\{\frac{((X_r + 0.1T) - \bar{X})}{3S_a}; \frac{(\bar{X} - (X_r - 0.1T))}{3S_a}\right\} \tag{4}$$

where X_r is reference value, $\bar{x}$ is average of measured values. Currently, if C_g and C_{gk} are greater than or equal to 1.33 then the measurement system is capable.

3. Experimental procedure

CMMs are generally used for dimensional and geometric tolerances inspection. To study influence of scanning speed were selected a few typical parameters: diameter dimension, roundness and perpendicularity. For measurements, a precise part was used (Fig. 1).

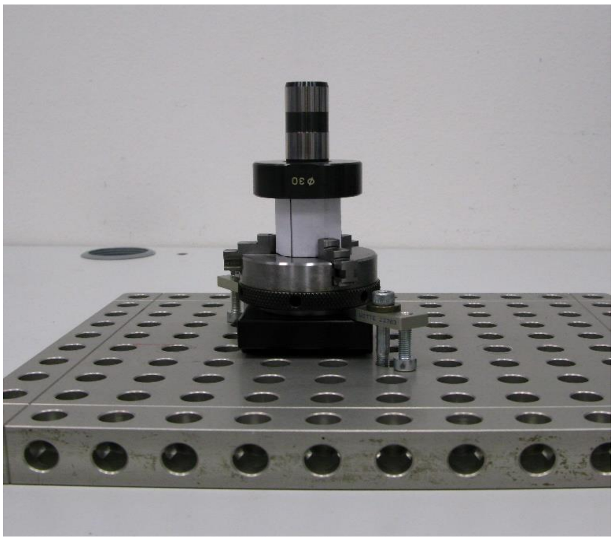

***Figure 1.** Measured part.*

In order to evaluate scanning speed, measured part has to have small actual form error.

The measurements were carried on a Zeiss PRISMO CMM with an active VAST Gold scanning probe with a 3 mm stylus ball diameter and 47 mm length. Single stylus configuration was used. Reference values of characteristics were measured on the same machine with 2 mm/s scanning speed (Tab. 1).

***Table 1.** Reference values.*

Characteristic	[mm]
Diameter	19,999904
Roundness	0,000466
Perpendicularity	0,001098

The measuring system is influenced by the random and systematic sources of variability. These sources are caused by random or specific factors. Possible sources of variability are identified and monitored or eliminated. Specific factors are usually dependent on the specific application [3]. Variability of measuring system is mainly affected by the environment, operator, measured part, machine and measurement method. Since aim of paper to study influence of scanning speed, all parameters except scanning speed are constant for all measurements.

Experiment was conducted at a scanning speed of 5, 10, 15, 20, 30, and 50 mm/s. 10 replication for each speed. Measurement plan was created in Calypso software from Carl Zeiss. Measured part is a combination of cylindrical component and plane. Circle feature is defined with circular path with 0.1 mm width step. Number of sampling points for circle feature is 786 and angle range is set to 450º. For circle feature low-pass spline filter is used. Minimum feature method is used for calculation of geometric elements. Circle feature was measured on bottom of cylinder near the plane. Perpendicularity is evaluated between plane and cylinder axis. 3D line is defined by 4 circles. To create 3D line 3 additional circles were measured along the cylinder with the same strategy. Plane is defined with circular path with 0.1 mm width step, 1571 points in total. For plane low-pass spline filter is used. Outlier elimination is disabled.

4. Results evaluation

From measured values, averages and standard deviations were calculated for each characteristic (Tab. 2, 3).

***Table 2.** Averages of measured values.*

Scanning speed [mm/s]	Diameter [mm]	Roundness [mm]	Perpendicularity [mm]
5	19,9998026	0,0004040	0,0011760
10	19,9996606	0,0004387	0,0015636
15	19,9994365	0,0006668	0,0019324
20	19,9991156	0,0011249	0,0029742
30	19,9982019	0,0023017	0,0038816
50	19,9960346	0,0046856	0,0057466

Table 3. *Sample standard deviations of measured values.*

Scanning speed [mm/s]	Diameter	Roundness	Perpendicularity
5	0,0000104	0,0000397	0,0001320
10	0,0000098	0,0000189	0,0001893
15	0,0000063	0,0000421	0,0002909
25	0,0000062	0,0000812	0,0004170
30	0,0000059	0,0000985	0,0006567
50	0,0000096	0,0001958	0,0007012

Tolerance for all characteristics was 0.01 mm. Sample standard deviations are in the range of one micron for all characteristics. The C_g and C_{gk} capability indices were used to evaluate measuring system capability. Capability indices were calculated by Bosch method (Tab. 4).

Table 4. *C_g and C_{gk} indices.*

Scanning speed [mm/s]	Diameter		Roundness		Perpendicularity	
	C_g	C_{gk}	C_g	C_{gk}	C_g	C_{gk}
5	192.13	28.77	50.38	7.88	15.16	2.33
10	204.69	25.81	105.67	17.14	10.57	0.94
15	316.33	28.07	47.46	6.32	6.87	0.19
20	324.26	11.43	24.62	1.40	4.80	-0.70
30	336.36	-39.97	20.30	-2.83	3.05	-0.91
50	209.35	-100.12	10.21	-5.48	2.85	-1.73

The dependences of capability indices on scanning speed are represented in Fig.2, 3.

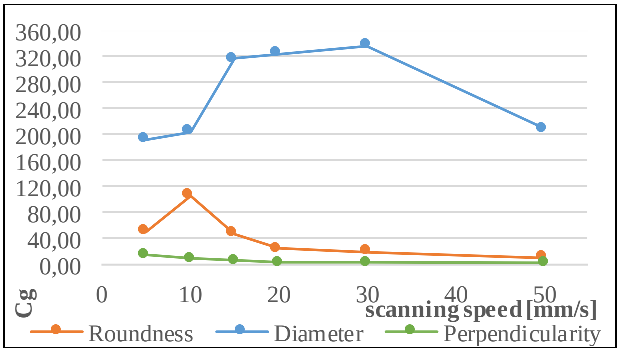

Figure 2. *Influence of scanning speed on C_g indices.*

From calculated results appears that measurement process capability in case of diameter characteristic measurement is less affected by scanning speed. The measurement process appears capable in terms of measurement precision for each scanning speed. Nevertheless, major deterioration occurred in terms of measurement trueness. The C_{gk} index for diameter is acceptable up to 20 mm/s scanning speed. The C_{gk} index for roundness is acceptable up to 20 mm/s speed. The C_{gk} index for perpendicularity is acceptable only for 5 mm/s scanning speed.

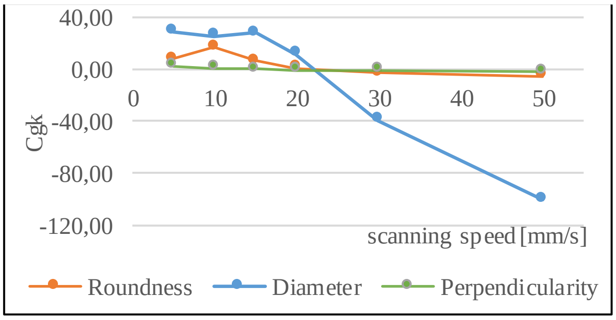

Figure 3. *Influence of scanning speed on C_{gk} indices.*

It is supposed that capability indices outlier for roundness at 10 mm/s speed is produced by dynamic compensation. See overall measurement time for each speed in Tab. 5.

Table 5. *Measurement process time.*

Scanning speed [mm/s]	5	10	15	20	30	50
Time [min]	2:30	1:36	1:16	1:06	0:58	0:51

The rough optimal scanning speed for diameter, roundness and perpendicularity would be 20, 20 and 5 mm/s respectively.

4. Conclusion

Experimental procedure for determining the influence of scanning speed on capability of geometric and dimensional characteristics measurement was presented. Scanning speed is reflected in evaluated characteristics. Measurements are capable to a certain point. Dimensional characteristic are less sensitive to scanning speed changes.

Capability functions can be linearly approximated in order to get consistent optimal scanning speed, but more replicates are needed. Then optimal combinations will be verified. Main goal is to measure as accurate as necessary and not accurate as possible.

Acknowledgement

This paper follows up habilitation thesis of Ing, Libor Beranek Ph.D.

References

[1] NENADÁL, Jaroslav. *Moderní management jakosti: principy, postupy, metody.* Praha: Management Press, 2008. ISBN 978-80-7261-186-7.

[2] MONTGOMERY, Douglas C. *Introduction to statistical quality control.* 6th ed. Hoboken, N.J.: Wiley, c2009. ISBN 978-0-470-16992-6.

[3] *FABIAN, František. Statistické metody řízení jakosti. Praha: Česká společnost pro jakost, 2007. ISBN 978-80-02-01897-1.*

[4] JCGM 200:2008 International vocabulary of Metrology – Basic and general concepts and associated terms (VIM).