CASE STUDY IN INVESTIGATION OF ACCURACY OF HOLE DRILLING

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Abstract
The determination of the machine capability index is an appropriate method to assess the accuracy of the machining devices in a real production situation. It can help to determine the right tolerance zone from the viewpoint of production and develop and compare the manufacturing technologies. The article presents a case study related to the investigation of hole drilling.

Keywords: *Hole drilling; Machine capability index*

INTRODUCTION

The aim of the tolerances is to define the allowed manufacturing errors, which depends on the work of the machine part; the details of manufacturing technology, like tool, machining parameters, machine tool, fixture; and the measuring technology. During the manufacturing process planning two demands have to be harmonized: the required value of the tolerances and the capability of the manufacturing equipments. The machine capability indexes (C_m, C_{mk}) are the tool for solve this problem.
Hong [1] use this method to evaluate machining properties of a vertical machining centre. The investigated part was a complex specimen according to ISO 10797-7A standard and 25 pieces were produced. Wanare and Gudadhe [2] classify a vertical machining centre based machine capability index calculated on hole distance of 40 pieces of swing lever. It was concluded that the C_m and C_{mk} indexes are suitable for complex investigation of accuracy of the machining equipments and technology.
The aim of the machine capability index is to assess the state of the manufacturing device and technology. The index is derived from short term continuous, uninterrupted production. The index is calculated based on investigation of 50...100 products.
The index is:

$$C_m = \frac{USL - LSL}{6 \cdot \sigma} \tag{1}$$

$$C_{mk} = MIN\left\{\frac{FTH - \mu}{3 \cdot \sigma}; \frac{\mu - ATH}{3 \cdot \sigma}\right\} \tag{2}$$

where USL is the upper specification limit, LSL is the lower specification limit, σ is the theoretical standard deviation, μ is the theoretical expected value [3]. The C_m index shows how the manufacturing process satisfies the tolerance zone, and the C_{mk} shows where takes places the mean value within the specification zone.

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The theoretical standard deviation and expected value can be estimated in various ways [4]. The expected mean value can be estimated by

- the mean value of all measured data ($\hat{\mu}_1 = \bar{x} = \frac{1}{N}\sum x_i$) (*N:* total number of samples*)*,
- the median value of the set ($\hat{\mu}_2 = \tilde{x}$). The median is the middle number in a sequence of units,
- the calculated value from the distribution ($\hat{\mu}_3 = X_{50\%}$),
- mathematically the next expression, the mean values of the 5 elements' (*n*=5) averages (*m* is the number of small groups) is equal with the first one ($\hat{\mu}_4 = \bar{\bar{x}} = \frac{1}{m}\sum \bar{x}_i$),
- the mean value of the 5 elements' medians ($\hat{\mu}_5 = \bar{\tilde{x}}$).

The expected deviation can be estimated by

- the mean value of the subsets' standard deviations ($\hat{\sigma}_2 = \bar{s} / c_4$), the c_4 coefficients depend on the number of subset's elements (Table 1),
- the mean value of the subsets' ranges. The range is the difference between the highest and lowest values ($\hat{\sigma}_3 = \bar{R} / d_2$), the d_2 coefficients depend on the number of subset's elements (Table 1),
- the value of the standard deviation for all data:

$$\hat{\sigma}_4 = s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \tag{3}$$

- the calculated value from the distribution.

Table 1

d_2 and c_4 coefficients

n	2	3	4	5	6	7	8	9	10
d_2	1.128	1.693	2.059	2.326	2.534	2.704	2.847	2.970	3.078
c_4	0.798	0.886	0.921	0.940	0.952	0.959	0.965	0.969	0.973

Based on the value of the index the machine capability can be evaluated:

Criterion	Grade
C_m, C_{mk}<1.00	Not capable
1.00< C_m, C_{mk}<1.33	Barelly capable
1.33< C_m, C_{mk} <1.50	Satisfactory
1.50< C_m, C_{mk} <2.00	Good
2.00< C_m, C_{mk}	Excellent

In this project a twist drilling process was investigated in order to collect information about the capability of a CNC machining centre and the twist drilling technology. This case study presents the differences between the different estimation methods which is used in determination of machine capability index.

MATERIALS AND METHODS

The manufacturing of the test parts were performed in a MAZAK 410A-II CNC machining centre. The test parts were made of 42CrMo4 steel (1.7225; 300 HB, $R_m \approx 1000$ MPa). 50 holes were drilled to two 12 mm thick test parts. The holes were drilled by a 6 mm diameter HSSCo twist drill with TiAlN coating from Gühring. The cutting conditions were:

- cutting speed: $v_c = 30$ m/min,
- revolution: $n = 1590$ 1/min,
- feed: $f = 0.08$ mm,
- feed speed: $v_f = 127$ mm/min.

Two tests were performed (signed by *A* and *B*), the cutting conditions were same, but in the first case (*A*) centre drilling and cooling were not applied.
The diameter of the holes was measured by a Mitutoyo PJ-H3000F profile projector at the entrance (Side 1) and the exit (Side 2) level with four points by least squares method (Gaussian regression). The specification for the diameter of the drilled hole is as follows: LSL=6.00 mm; USL=6.15 mm.
The surface roughness and the profile of the holes were measured by a Mahr-Perthen Concept 2D/3D surface roughness measurement equipment.

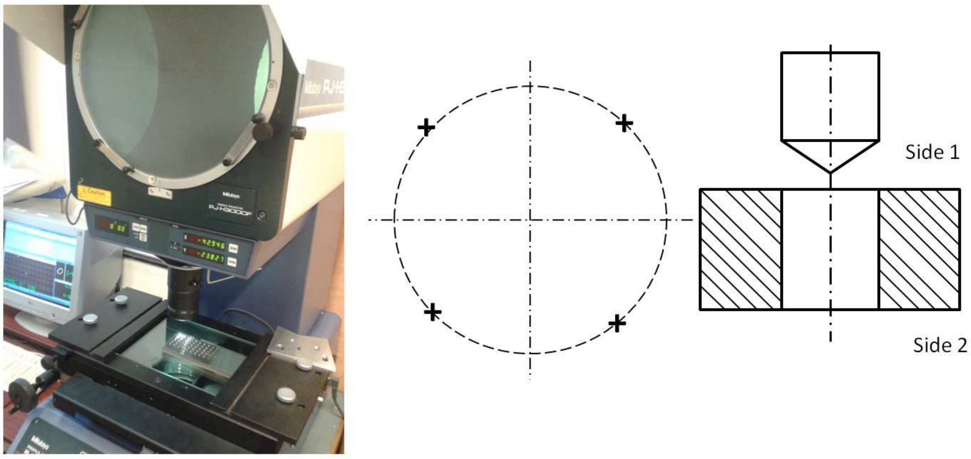

Figure 1
Profile projector and measuring method

RESULTS

The measured data are shown in Figure 2. It can be seen that there are differences between the measured diameter values being in the entrance of the hole (Side 1) related to the diameters which are in the exit side (Side 2). The diameters are much smaller in case of Test B, where centre drilling and cooling also have been applied. The measured diameters in case of the first test (A), in side 1 do not fulfil the criteria.

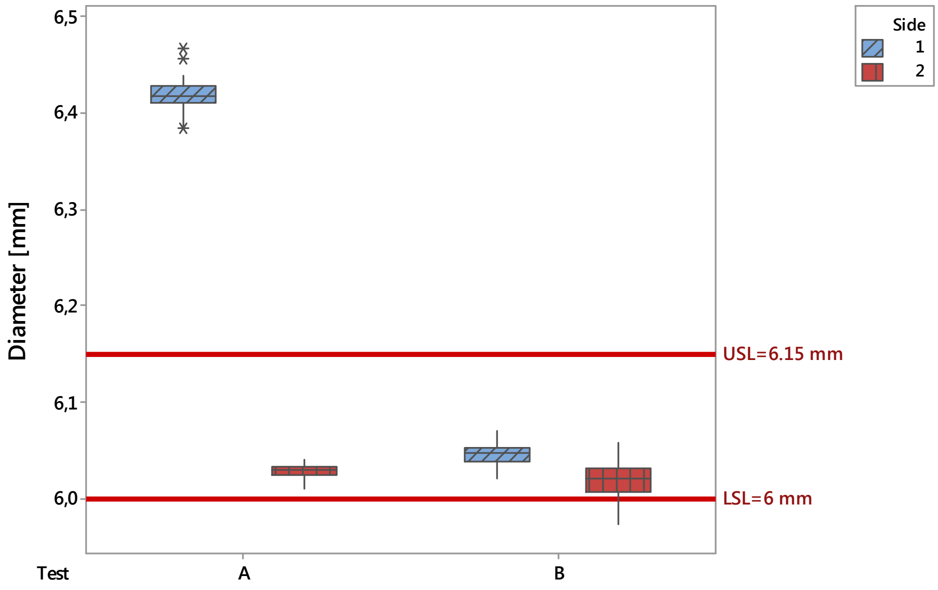

Figure 2
Box plot of the measured values

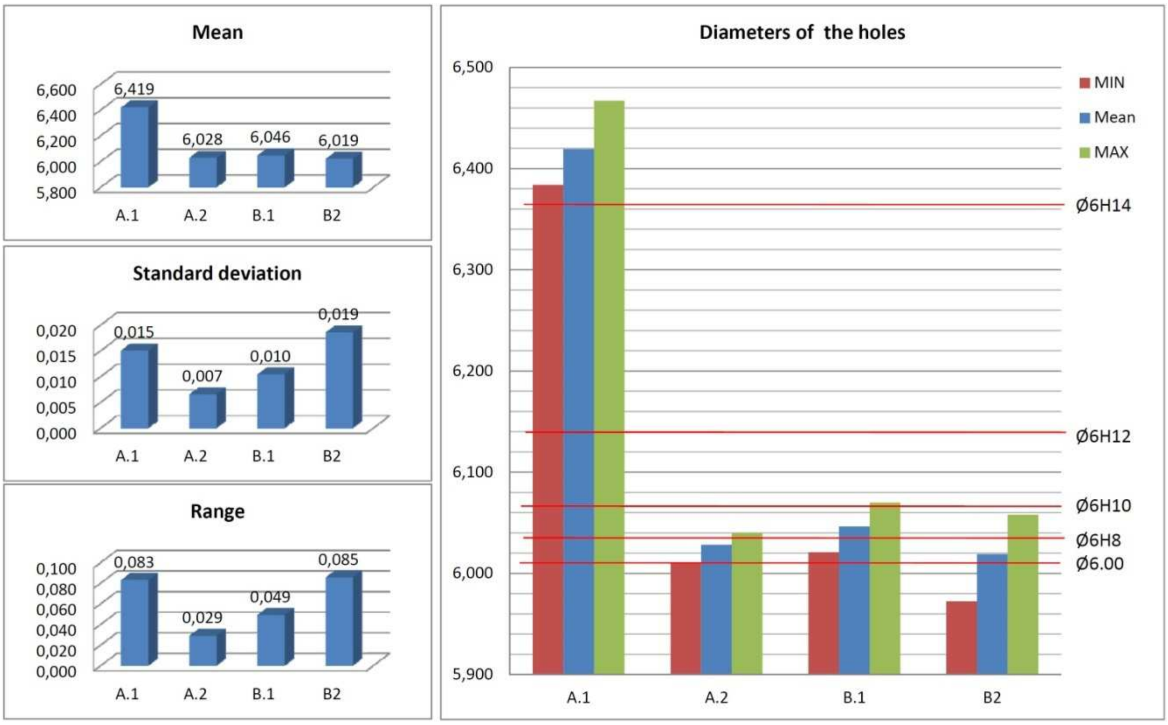

Figure 3
The values of mean, standart deviation and the range

The effect of the centre drilling is well discernible in Figure 3. The mean diameter of the first set is 6.419 mm in the entrance side (A.1). The mean value of the second set, where centre drilling was applied, is 6.046 mm. The diameters become smaller through the hole, at the exit surface the mean diameters are smaller in both tests. The standard deviation and the range show similar tendencies, in case of first set the deviation and the range are larger at the start level, cause of the uncertain drive of the twist drill. At the second set (*B*), the uncertainty is smaller, thanks to the centre drilling, the diameter is more accurate, but the deviation increases at the exit surface. These differences are shown in the Figure 4. This difference is well shown in the Figure 5 too, which contains the results of profile scanning. The range of the profile in case of Test A is about 250 µm, which matches to the measured diameter. In case of Test B the profile range is only 25 µm.

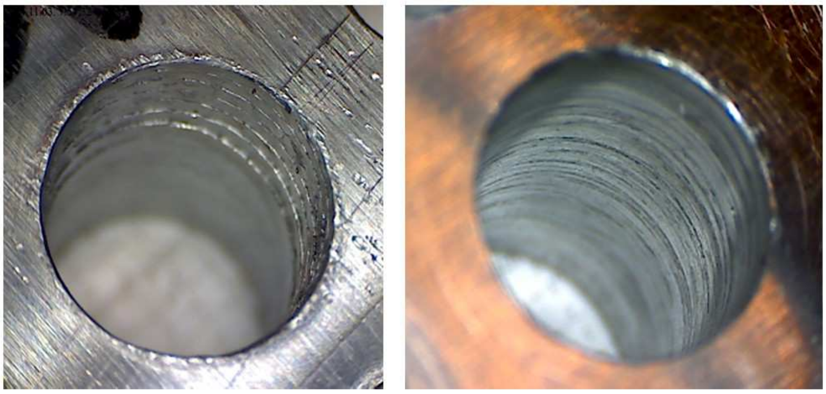

Figure 4
Photos of a hole from Test A and Test B

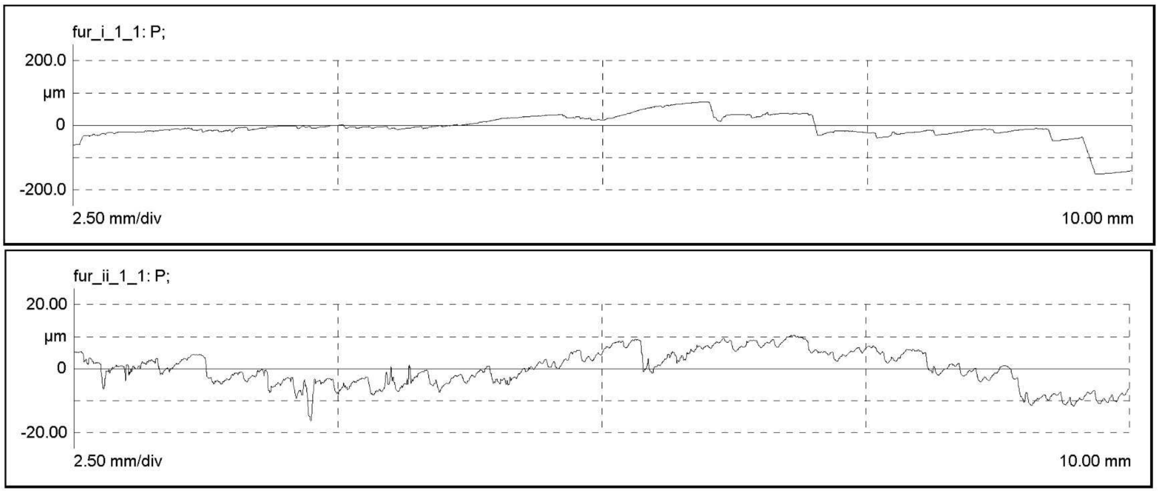

Figure 5
The profile section of the holes

MACHINE CAPABILITY INDEX

The Figure 3 shows the minimum, maximum and mean values of diameters compare with different tolerance zones. As it can be seen the target tolerance zone can be between IT10 and IT12. In the current calculation Ø6H12 (+0.15/0) tolerance was selected.
The machine capability index can indicate our possibilities in define the tolerance zone consider the production. In order to calculate machine capability index, the expected value and the standard deviation are estimated. Table 2 shows the calculated values. The different estimation methods result in different, but close values.

Table 2
The different values of mean and deviation

	Mean value			Deviation		
	$\hat{\mu}_1$	$\hat{\mu}_2$	$\hat{\mu}_5$	$\hat{\sigma}_2$	$\hat{\sigma}_3$	$\hat{\sigma}_4$
A.1	6.4193	6.4180	6.4175	0.0142	0.0145	0.0151
A.2	6.0284	6.0295	6.0285	0.0059	0.0062	0.0065
B.1	6.0463	6.0480	6.0472	0.0080	0.0083	0.0104
B.2	6.0191	6.0214	6.0202	0.0173	0.0171	0.0185

In case of Test A (A.1, A.2) based on C_m indexes show (Table 3), than the tolerance range can be satisfied, the values are larger than 1.50, but the C_{mk} indicates the large mean value at A.1.

Table 3
The values of C_m and C_{mk} indexes

A.1		$\hat{\sigma}_2$	$\hat{\sigma}_3$	$\hat{\sigma}_4$
C_m		1.77	1.73	1.66
C_{mk1}	$\hat{\mu}_1$	-6.34	-6.21	-5.96
	$\hat{\mu}_2$	-6.31	-6.18	-5.93
	$\hat{\mu}_5$	-6.30	-6.17	-5.92
C_{mk2}	$\hat{\mu}_1$	9.87	9.68	9.28
	$\hat{\mu}_2$	9.84	9.65	9.25
	$\hat{\mu}_5$	9.83	9.63	9.24
C_{mk}	$\hat{\mu}_1$	-6.34	-6.21	-5.96
	$\hat{\mu}_2$	-6.31	-6.18	-5.93
	$\hat{\mu}_5$	-6.30	-6.17	-5.92

A.2		$\hat{\sigma}_2$	$\hat{\sigma}_3$	$\hat{\sigma}_4$
C_m		4.23	4.07	3.83
C_{mk1}	$\hat{\mu}_1$	6.85	6.59	6.21
	$\hat{\mu}_2$	6.79	6.53	6.16
	$\hat{\mu}_5$	6.84	6.59	6.21
C_{mk2}	$\hat{\mu}_1$	1.60	1.54	1.45
	$\hat{\mu}_2$	1.66	1.60	1.51
	$\hat{\mu}_5$	1.61	1.55	1.46
C_{mk}	$\hat{\mu}_1$	1.60	1.54	1.45
	$\hat{\mu}_2$	1.66	1.60	1.51
	$\hat{\mu}_5$	1.61	1.55	1.46

B.1		$\hat{\sigma}_2$	$\hat{\sigma}_3$	$\hat{\sigma}_4$
C_m		3.13	3.01	2.40
C_{mk1}	$\hat{\mu}_1$	4.32	4.16	3.32
	$\hat{\mu}_2$	4.26	4.10	3.27
	$\hat{\mu}_5$	4.29	4.13	3.29
C_{mk2}	$\hat{\mu}_1$	1.93	1.86	1.49
	$\hat{\mu}_2$	2.00	1.93	1.54
	$\hat{\mu}_5$	1.97	1.90	1.51
C_{mk}	$\hat{\mu}_1$	1.93	1.86	1.49
	$\hat{\mu}_2$	2.00	1.93	1.54
	$\hat{\mu}_5$	1.97	1.90	1.51

B.2		$\hat{\sigma}_2$	$\hat{\sigma}_3$	$\hat{\sigma}_4$
C_m		1.45	1.46	1.35
C_{mk1}	$\hat{\mu}_1$	2.53	2.56	2.36
	$\hat{\mu}_2$	2.48	2.51	2.32
	$\hat{\mu}_5$	2.51	2.53	2.34
C_{mk2}	$\hat{\mu}_1$	0.37	0.37	0.34
	$\hat{\mu}_2$	0.41	0.42	0.39
	$\hat{\mu}_5$	0.39	0.39	0.36
C_{mk}	$\hat{\mu}_1$	0.37	0.37	0.34
	$\hat{\mu}_2$	0.41	0.42	0.39
	$\hat{\mu}_5$	0.39	0.39	0.36

The results of Test B are better thanks to the centre drilling and cooling. The tolerance zone can be satisfied, the C_m indexes larger than 2 at the entrance side, but there are between 1.33 and 1.50 at the exit surface. The C_{mk} at the exit surface shows poor result, thanks to the worst standard deviation and range.

CONCLUSION

The different estimation methods result different C_m and C_{mk} values. In order to clear comparison the appropriate method has to be defined during the process planning. The method can help to determine the right tolerance zone from the viewpoint of production and develop and compare the manufacturing technologies. By means of them the results of the development of the manufacturing technology can be measured.

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