Integrating Measuring Uncertainty of Tactile and Optical Coordinate Measuring Machines in the Process Capability Assessment of Micro Injection Moulding

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Abstract

Process capability of micro injection moulding was investigated in this paper by calculating the Cp and Cpk statistics. Uncertainty of both optical and tactile measuring systems employed in the quality control of micro injection moulded products was assessed and compared with the specified tolerances. Limits in terms of manufacturing process capability as well as of suitability of such measuring systems when employed for micro production inspection were quantitatively determined.

1 Dimensional quality control micro injection moulded product

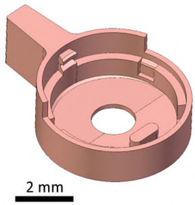
Compliance with tolerances is described in ISO 14253 [1], though a downscaling below the defined lower limit of ISO-GPS standards may present issues [2][3]. In case of quality control of micro manufacturing processes it must be ensured that the measurement uncertainty is sufficiently small to: (a) actually be able to verify the specified tolerances; (b) not introduce a too large spread and bias in the quality control of the employed micro manufacturing process, invalidating its capability.

Micro injection moulding enables the mass production of precision polymer micro components. For this research, a micro moulded component for medical application (weight of 35 mg, material = liquid crystal polymer) was selected. Four different measurands were chosen for the investigation: outer diameter (D), inner diameter of the hole in the middle of the part (d), concentricity of the two circles (C), and height (H) of the pillar at the bottom of the component (see Figure 1a). Nominal dimensions and tolerances are: D = 5.400 ± 0.030 mm, d = 1.550 ± 0.020 mm, C = 0.020 mm, H = 0.380 ± 0.030 mm. In case of geometrical and dimensional tolerances, high accuracy tactile (TCMM) and also faster but less accurate optical (OCMM) coordinate measuring machines are suitable instruments for dimensional quality control of precision micro moulded products. For this study case, expanded measuring uncertainties U were calculated for both CMMs (see Table1) [4].

Table1: Uncertainty of dimensional CMM measurements on polymer μ-components.

[μm]	U(TCMM)	U(OCMM)	[μm]	U(TCMM)	U(OCMM)
D	1.5	8.7	C	1.7	3.3
d	3.4	5.4	H	4.7	25

(a)



(b)

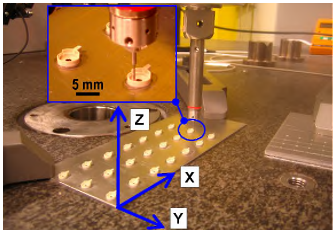


Figure 1: Micro moulded part 3D model (a) and actual products measured with a tactile coordinate measuring machine (b).

2 Process capability assessment

The process capability coefficients Cp and Cpk were considered: Cp is related to the standard deviation of the process and Cpk is related to the mean [5]. The Cp and Cpk statistics assume that the population of data have a Gaussian distribution. Assuming a two-sided specification, if σ and $\underline{x}$ are the standard deviation and the mean of the normal data, USL and LSL are the upper and lower specification limits, respectively, then the population capability indices are defined as follows:

- $Cp = (USL - LSL) / 6\sigma$
- $Cpk = \min [(USL - \underline{x}) / 3\sigma ; (\underline{x} - LSL) / 3\sigma]$

Cp shows whether the distribution can potentially fit inside the specification: Cp < 1 means the system is not capable (specification cannot be achieved consistently) and vice versa. Cpk shows whether the overall average is centrally located: the larger difference between the two terms $USL - \underline{x}$ and $\underline{x} - LSL$, the more off the centre is the process (Cpk < 1 means process is off centre, reflecting a capability issue). Frequently a Cpk>1 is required when parts are being assembled (in fact, often the minimum is 1.33). Reduced variation at the centre of the specification gives considerable benefit, namely quicker and more accurate parts assembly. By pushing for higher Cpk values, the improvement effort is focused on shrinking variation around the centre of the specifications. It is also possible to have a repeatable process (Cp > 1) and not be making any product within specification (Cpk<1).

3 Micro moulding process capability and measuring uncertainty

Cp and Cpk of μIM were calculated for all the measurands, implementing the uncertainty of both measuring instruments (TCMM and OCMM) and also considering different scenarios of uncertainty to tolerance ratio U/T% (from 0%, i.e. ideal measuring instruments, up to 20%, i.e. upper limit of the Golden Rule of Metrology, according to [5][6]).

When an actual process is assessed, the resulting standard deviation is composed by the process standard deviation σ itself and the standard uncertainty of the measuring instrument u. Therefore, a σ_{tot} standard deviation (including both measurement and production spread) is calculated ($\sigma_{tot} = \sqrt{\sigma^2 + u^2}$). The larger is u, the lower the process capability will appear. Cp and Cpk for the considered production of micro moulded parts have been calculated as function of the expanded combined measuring uncertainty U ($U = k \cdot u$, with k=2 for a confidence level of 95%) in 5 different situations: U=0 (i.e. perfect/ideal measurement), U=10%T, U=20%T, U=U(TCMM), U=U(OCMM) (see Table 2).

Table2: Cp and Cpk for 4 measurands (D, d, C, H) and 5 uncertainty scenarios.

Cp	U=0%T	U=10%T	U=20%T	U=U(TCMM)	U=U(OCMM)
D	3.28	2.34	1.49	2.94	1.08
d	1.89	1.64	1.25	1.36	1.03
C	5.41	2.84	1.59	3.17	1.89
H	1.01	0.96	0.86	0.91	0.37
Cpk	U=0%T	U=10%T	U=20%T	U=U(TCMM)	U=U(OCMM)
D	3.28	2.34	1.49	2.94	1.08
d	0.38	0.33	0.25	0.27	0.21
C	4.57	2.40	1.35	2.68	1.60
H	0.44	0.42	0.37	0.39	0.16

Depending on the considered measuring uncertainty, the assessed process capability can be of different results. Regarding Cp, the following observations can be made: when U is not considered (Cp>1), the process is capable of producing D,d,C,H; the tactile CMM is a suitable measuring system for the quality control of D,d,C,H (even though Cp(H,TCMM)=0.91≈1); U/T=10% is recommendable for all measurand, but U/T=20% would be sufficient for most measurands (exept H, where Cp(H,U=20%T)=0.86); the optical CMM is not capable of checking this process because it makes the process appearing not robust (i.e. OCMM introduces too large variability on the measurements).

Regarding Cpk, it can be seen that the process is capable of producing D and C centred within specifications also when U/T=20% (including both TCMM and OCMM systems) is considered (Cpk > 1 and in most cases Cpk > 1.33); on the other hand, the process is not capable to produce d and H as required.

4 Conclusion

The process capability of micro injection moulding was investigated, also taking into account the uncertainty of two measuring systems (tactile and optical CMM). The paper demonstrates that depending on the considered measurand, measuring instruments with uncertainty-to-tolerance ratios up to 20% could be employed and allow an effective µIM process capability assessment. In particular, for the larger diameter and the concentricity, a Cpk(D,C) > 1.33 was found using both CMMs. On the other hand, it was found that the process was not capable of producing the height (H) and the smaller diameter (d) within the specifications: the process was repeatable within the tolerances (Cp>1) but the centring should be improved.

Acknowledgements

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