Metrologia
Fortaleza - CE 2017

Planejamento da medição baseado no método de substituição para controle de elementos em microescala

Substitution method-based measurement design for dimensional control of micro-scale features

C R Baldo [1], J Mewis [2], M O Tamborlin [3], L W S L Ramos [4], E Uhlmann [2]

[1] Centre for Engineering, Modeling and Applied Social Sciences - CECS/UFABC, Brazil; [2] Institute for Machine Tools and Manufacturing Systems - IWF/TUB, Germany; [3] Laboratory of Computer Application in Design and Manufacturing - SCPM/UNIMEP, Brazil; [4] Laboratory of Micromanufacturing - LMI, Institute for Technological Research - IPT, Brazil

E-mail: crhistian.baldo@ufabc.edu.br

Resumo: A microusinagem tem experimentado grandes avanços recentemente devido à necessidade crescente por produtos microestruturados. No laço de desenvolvimento de peças em microescala, a metrologia tem um papel crucial, por prover informações para melhoria da fabricação. A implementação de técnicas para verificar elementos de tamanho de moldes microfluídicos define o tópico maior deste trabalho. Considerando o modelo de integração da incerteza, o método de substituição é adotado para avaliar a incerteza. O plano da medição e os principais resultados são apresentados e discutidos.

Palavras-chave: microdimensões, incerteza de medição, método de substituição.

Abstract: Micro-milling operations have faced enormous advances in recent years due to the increasing demand for micro-structured parts. Focusing specifically on micro-scale product development loop, metrology plays a crucial role as it gives information for manufacturing optimization. The definition of appropriate strategies for measuring microfluidic mould features of size is addressed in this work. Using the integrative framework proposed in previous studies, the substitution method is applied to evaluate the uncertainty. The measurement setup and results are presented and discussed.

Keywords: micro-scale FOS, measurement uncertainty, substitution method.

1. INTRODUCTION

The growing need for micro-structured parts with optical functional surfaces has boosted enormous developments in manufacturing-based techniques and machine tools. The realization of micro-scale parts, features and specifications can be attained by implementing conventional cutting processes under proper conditions with regard to equipment, cutting tools and thermal behavior. Dimensional accuracy and surface quality are critical factors in parts with micro features regarding functionality. Therefore, metrology plays a fundamental role in the micro-scale product development loop, since it provides useful and necessary information for manufacturing optimization.

The matter of defining suitable techniques for measuring microfluidic mould datum-dependent features (step height, line distance) is addressed in this work. Multisensor Coordinate Measuring Machines (CMM) was selected and substitution method employed to determine the task-specific measurement uncertainty and enhance metrology knowledge. The integrative framework proposed by Baldo and Donatelli [1] has been used to drive that choice. The measurement setup and the main findings are outlined and discussed in this paper.

2. MICRO-SCALE TEST SAMPLE

Micro-structured products have been described in published literature as components whose feature has at least one functional-determining dimension that is significantly smaller than 0.1 mm, with a tolerance range of a few micrometers, while the whole component may feature larger dimensions [2], or components with at least one critical size in the micrometer range [3]. For this work, both definitions are acknowledged.

Exemplary moulds for microfluidic devices have been designed and experimentally machined using appropriate machining conditions [4]. The manufacturing process realization is exhibited in figure 1, from the technical drawing to the virtual and physical machined mould. The dimensional content of the mould is composed of features of size (*i.e.* inlet hole diameter and channel width) and channel heights.

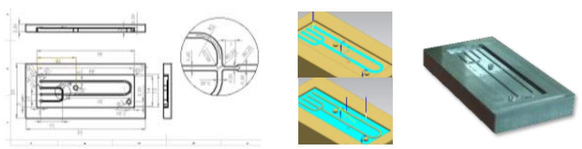


Figure 1. Manufacturing process realization: (a) technical drawing of a mould with micro features; (b) CAM tool path generation of operations; (c) machined exemplary mould.

3. MEASUREMENT PLAN

Considering the measurement requirements for the micro-milled test sample just described, this section describes the measurement setup planned for checking the micro-scale dimensional content. The microfluidic device features were intended to be inspected on a multisensor CMM (WERTH VIDEOCHECK IP 400 3D CNC) using an inbuilt image processing unit, as exhibited in Fig. 2. The CMM is installed in a room kept at (20 ± 1) °C. In this condition, the supplier states a maximum permissible error at stage level of (1.4 + L/250) µm for measurements parallel to the CMM axes.

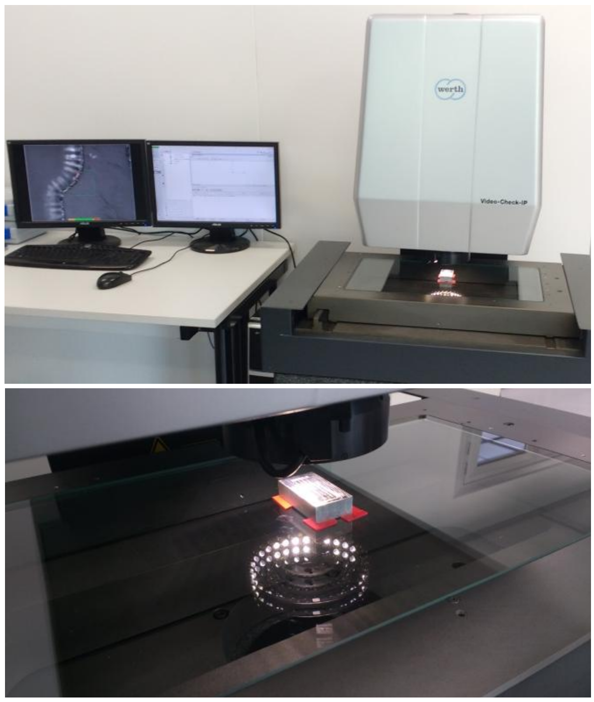


Figure 2. Multisensor CMM (top) selected for checking the dimensional content of microfluidic moulds (bottom).

3.1 Inspection of features of size

Regarding the evaluation of the mould features, diameters/radii were realized by associating ideal features of type circle to the optically scanned points using the least-squares association method; channel widths were realized by associating ideal features of type straight line to the scanned points on both opposite sides of a given channel section using the least-squares association method.

In order to estimate the uncertainty associated with the measurement results and hence validate the measurement setup, the substitution method was selected. For example, the channel width was experimentally simulated by an arrangement of gauge blocks that resembles the actual mould feature of size. With this arrangement an average error of (0.0008 ± 0.0011) mm was estimated for nominal distances (*i.e.* gauge block arrangement lengths) of 0.5 mm and 1 mm. That average error can be extended to channel width measurements as an (instrumental) uncertainty of 0.0018 mm.

3.2 Inspection of channel height

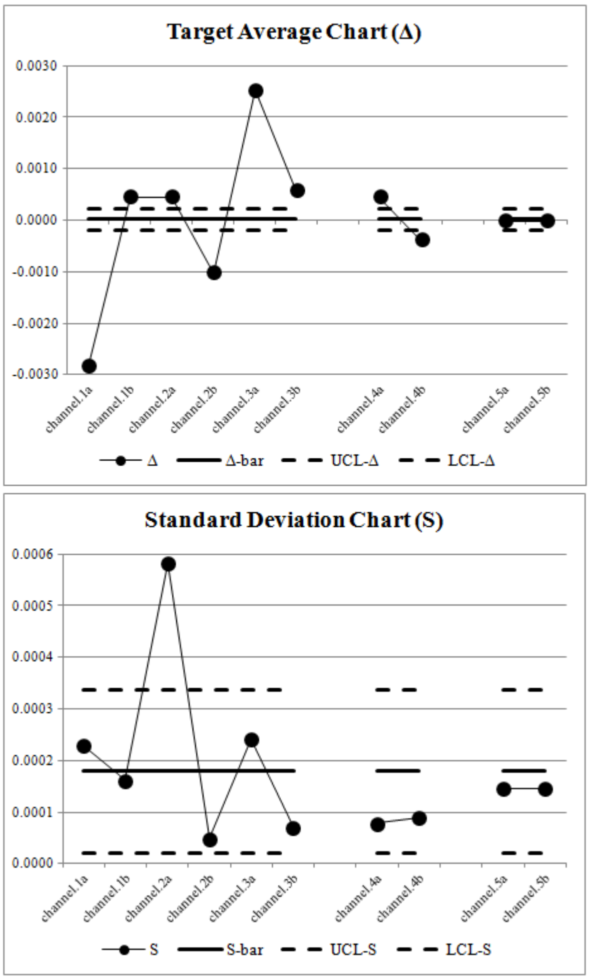
Regarding the mould channel height, preliminary tests using another arrangement of gauge blocks were performed on the same multisensor CMM, but using the autofocus feature of the camera unit. Ideal features of type plane were associated to the points optically sampled on the channel floor and the channel top, and the projected distance was used to calculate the channel height. Using this approach an average error of (0.004 ± 0.003) mm was found, which was unacceptable for the task due to the both intrinsic measurement bias and measurement variability. In fact, the experimental results confirmed the note made by Fleischer and Behrens [5]; they expressed the autofocus feature of optical sensors offers lower accuracy owing to strong reliance on the optical properties of the material. Being unable to probe the mould floor with a conventional CMM touch probe, a stylus surface profiler was chosen to measure the mould channel height, with measurement uncertainty in the sub-micrometer range. More details on these evaluations are given by Baldo et al. [6].

4. MEASUREMENT RESULTS

4.1 Results for mould channel width

The width of each mould channel, represented in the technical drawing of figure 1, was determined with a similar measurement strategy as described in subsection 3.1. The specified width for channel 1 to 3 was 0.45 mm; for channel 4, 0.60 mm; for channel 5, 0.30 mm. A tolerance range of 30 µm was assigned for all channel widths.

The experimental results were evaluated using target average [7] (*i.e.* normalized by subtracting a target value from the actual value) and standard deviation control charts. They allow verifying the statistical consistency of differences and variation, taken from seven replicates on each channel. The charts will evidence causal differences among the estimates, reducing the risk of wrong statements about the measurement accuracy.



UCL: Upper Control Limit. LCL: Lower Control Limit.

Figure 3. Control charts of the exemplary mould channel widths exhibiting out-of-control points (values in millimeters).

Figure 3 shows the standard deviation control chart at the lower part, which exhibits one point beyond the upper limit. This exceeding point was a consequence of an abnormal sidewall variation on the respective channel. The average standard deviation was lower than 0.15 µm after removing that outlier. For the target averages shown at the upper part, they are clearly out of control, as the between-channel variation cannot be reasonably explained by the measurement repeatability. In fact, those points outside the control limits can be attributed to the micro-milling process.

The resulting expanded uncertainty associated with the channel width measurement results was assessed considering the instrumental uncertainty (see subsection 3.1), measurement procedure (*i.e.* standard deviation control chart centerline shown in figure 3) and further thermal effects. It resulted in an expanded uncertainty U = 0.002 mm (k = 2), regarded as reasonable for the specific task.

4.2 Results for mould inlet radius

The inlet radius of the four channels, represented in the drawing of figure 1, was assessed using the strategy outlined in subsection 3.1. The nominal radius as per drawing was 0.50 mm (tolerance of ± 15 µm). The statistical analysis using the target average and standard deviation charts resulted in similar remarks as those pointed out in subsection 4.1, *e.g.* target averages clearly out of control, as the between-inlet differences cannot be explained by the measurement dispersion. Consequently an expanded uncertainty U = 0.002 mm (k = 2) also was determined for the inlet radius measurement results.

5. CONCLUSIONS

This paper outlined the design and validation of measurement methods for evaluating features on micro-scale parts. Features of size such as mould channel widths and inlet radii could be optically checked on a multisensor CMM with satisfactory uncertainty, when using the substitution method for assessing some task-specific measurement errors. For measuring the mould channel height using the autofocus feature of the camera unit, measurement results were not reliable enough. Consequently, future researches will involve tests with another multisensor CMM outfitted with an optical sensor unit and a fiber probe 3D.

6. REFERENCES

[1] Baldo C R and Donatelli G D Measurement uncertainty integrated with the model of product / measurement realization in 3D metrology 2013 *International Symposium of Measurement Tech and Intelligent Instruments* Aachen GER

[2] Petz M, Tutsch R, Christoph R, Andraes M and Hopp B Tactile–optical probes for three-dimensional microparts 2012 *Measurement* **45**(10) 2288-98

[3] Hansen N H Dimensional metrology in micro manufacturing 2007 *International Conference on Multi-Material Micro Manufacturing - Keynote Paper* Borovets BUL

[4] Uhlmann E, Mewis J, Baldo C, Ramos L, Peukert B, Schützer K, Conte E and Tamborlin M Virtual machining of micro-milling processes for prediction of cutting forces and surface quality 2017 *International Conference on Virtual Machining Process Technology* Montréal CAN

[5] Fleischer J and Behrens I Quality assurance and dimensional measurement technology 2005 *Microengineering of Metals and Ceramics: Part II: Special Replication Techniques, Automation and Properties* Wiley-VCH Verlag GmbH GER

[6] Baldo C, Ramos L, Mewis J, Uhlmann E, Conte E and Schützer K Measurement design for dimensional control of functional micro-scale features on microfluidic moulds 2017 *Brazilian Congress on Manuf. Engineering* Joinville BRA

[7] Griffith G K SPC methods for long and short runs 1996 *ASQC Quality Press* Milwaukee USA