Comparison of Dimensional Measurements of Microparts Made Using Deep x-ray Lithography (LIGA): First Results

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Abstract

Deep x-ray lithography (x-ray LIGA) allows the production of high aspect ratio polymer structures with near perfect sidewall verticality and optical quality surface roughness. These structures can be used as templates for mass production of metal or ceramic micro-scale parts. Measuring such microstructures, for instance, 2 mm tall metal gears with external diameters of 1 mm or less, is difficult. To test different techniques and compare their results, a comparison has been initiated. A set of artefacts manufactured by x-ray LIGA will be sent to a number of organisations for 3D measurements. Different techniques (contact CMM, focus variation microscopy, confocal microscopy) will be used. The various artefacts cover a range of dimensions. The first results based on measurements from two contact CMMs of different design and specification are presented in this paper.

1 Introduction

Deep x-ray lithography is one of the most powerful processes used to produce high aspect ratio microstructures [1]. However, this key production technology lacks extensive quality and process control. The final 3D micro-scale parts require accurate and traceable metrology. Currently the best metrological solutions for high aspect ratio structures are those that use tactile probes, such as co-ordinate measuring machines (CMMs) [2]. The two CMMs used for this comparison are described in the following section.

1.1 The CMMs

At KIT/IMT, a Werth CMM (Video Check IP-400) incorporating a fibre probe was used to take a set of very repeatable measurements, however, the estimated expanded uncertainty of this machine is relatively high, $U = 2$ µm ($k = 2$) [3]. Furthermore, the 3D measurements on the Werth CMM using the fibre probe are limited in the vertical axis due to its reliance on an optical system to detect surface contact by the probe tip. The test structures were also measured on a Zeiss F25 micro-CMM at the National Physical Laboratory (NPL). The NPL micro-CMM has a similar repeatability as the Werth CMM at KIT/IMT, but has a higher specification: MPE = (0.25 + L/666) µm [4] (where L is the nominal measured length in mm). Also, NPL's micro-CMM is less limited when making measurements in the vertical axis, as its probing technology is based on piezoresistive strain gauges. Both CMMs are housed in temperature-controlled laboratories (20 °C ± 0.1 °C) and dust-free environments. The average diameter of the Werth probe tip is determined at KIT/IMT by probing a gauge block rotated through a series of angles. This diameter is verified once per year. Some discrepancies are observed between the KIT/IMT diameter results and the value given by the supplier [3]. The NPL F25 probe tip is qualified using a precision reference sphere. Qualifications are carried out before each measurement.

1.2 Best fit process and measurement procedure

The tested structures were holes and columns of various sizes, made by x-ray LIGA in poly-methyl-methacrylate (PMMA) and in metal. The best-fit calculations needed to match the measurement data to the theoretical geometry were tested. A set of algorithms (Levenberg-Marquardt, conjugate method with Polak and Ribière Factor [5]) was written in Borland C++ and was implemented to determine which fitting method is used by the measurement software of the two CMMs. By cross-referencing the outputs from the CMM software and the C++ algorithms, it was found that both best-fit processes are based on the Levenberg-Marquardt algorithm. For the roundness calculations, the least squares criterion was used. Similar measurement procedures were used on both CMMs. To measure the circular test structures, the Werth CMM was driven manually, whereas the NPL F25 was programmed to take points every 10º to 20º. Due to possible discrepancies between the position, diameter and form of the structure, calculated by the software of the two CMMs, all measurement data was output in raw format, (X, Y and Z positions of each measurement point), and processed in identical ways via numerical analysis. Due to time constraints, each measurement was completed on the NPL F25 only two times.

2 Preliminary results

Results from measurements of holes in two artefacts (an anchor watch part and a gear) in nickel (thickness 200 µm) are presented in Figures 1 and 2.

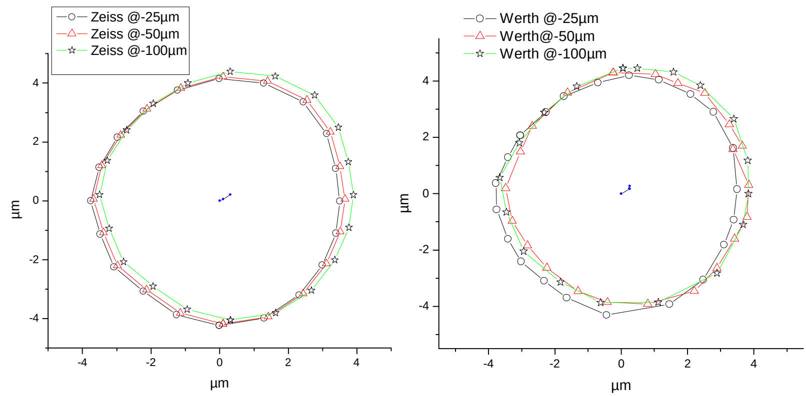

Fig. 1: Measurement results from a hole in a watch part taken at varying heights. On the left results from the NPL F25 - diameter: 299.77 µm, least squares circle (LSC) roundness: 0.96 µm, on the right results from the Werth CMM - diameter: 299.75 µm, LSC roundness: 1.05 µm.

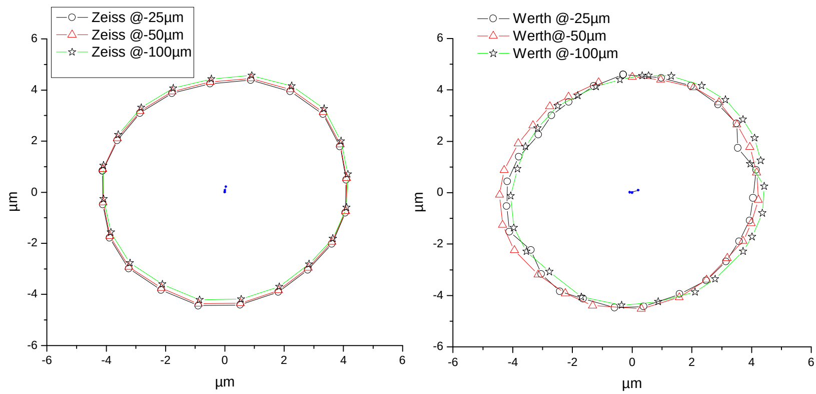

Fig. 2: Measurement results from a hole in a gear taken at varying heights. On the left results from the NPL F25 - diameter: 502.59 µm, LSC roundness: 0.56 µm, on the right results from the Werth CMM - diameter: 502.66 µm, LSC roundness: 0.83 µm.

It must be noted that the roundness evaluation of this data is inconsistent with the requirements of the relevant ISO standard [6], but is a reasonable indication of the comparability of the CMMs. The results using the Werth CMM are based on a tip diameter value of 82.0 µm [3], and are consistent with those obtained by the NPL F25 (tip diameter 125.0 µm). The diameter and LSC roundness measured by the two

CMMs over all the measurements taken differ by a maximum of 70 nm and 270 nm, respectively.

3 Discussion and future work

This comparison is the first ever of this type on such artefacts. The test compared results from two CMMs of different designs and specifications operated with similar measurement procedures in similar environments. These first measurements taken at NPL and KIT/IMT are comparable, but it is noted that careful consideration must be taken with the numerical analysis of the raw data. These preliminary results show firstly that the Werth CMM uncertainty is overestimated and secondly that such artefacts (holes and columns) could be used as reference structures for a more accurate determination of the tip diameter on the Werth CMMs fibre probe [4]. To continue this comparison, further measurements on other artefacts are needed and the results require further numerical analysis and a more rigorous uncertainty determination. As of yet, no uncertainty is calculated for the LSC roundness results. This uncertainty will be determined in future analysis using the algorithm suggested by Krystek *et al* [7].

4 Acknowledgments

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