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# PERFORMANCE VERIFICATION OF 3D PRINTERS

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## INTRODUCTION

During the last decade additive manufacturing processes have multiplied and evolved from mere prototyping towards true production. Furthermore, the last five years have shown an exponential growth in small table-top machines that can be acquired for a limited cost. One of the challenges of this development is to make sure that the 3D printers actually produce parts according to specifications. This is a big issue when producing complex parts with internal features as illustrated in [1]. However, a basic requirement for making all sorts of parts within specifications is that the machine tool as such (i.e. the 3D printer) is calibrated. This paper proposes a method to verify and possibly optimize the performance of a 3D printer by printing an artefact which is then subsequently analyzed. Based on these findings a possible correction of positioning errors and squareness errors can be applied, see Figure 1.

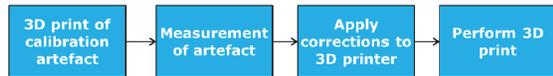


FIGURE 1. Illustration of proposed approach.

## APPROACH

The approach is based on the application of a calibration artefact for coordinate measuring machines (CMMs) called the optomechanical hole plate, see Figure 2. The hole plate was developed to create a connection between the traditional calibration method of mechanical CMMs and CMMs equipped with optical probes. The hole plate can be calibrated using a reversal method [2] and subsequently used to verify the performance of other CMMs [3,4].

In this context the design of the hole plate has been used because it is possible to measure this geometry with an acceptable accuracy on standard CMMs. 3D printed hole plates were produced with 25 holes (5x5) with a nominal diameter of 5,5 mm and a nominal center

distance of 20 mm in both X and Y directions. The thickness of the printed 3D hole plate is selected to 5 mm making the plate rigid.

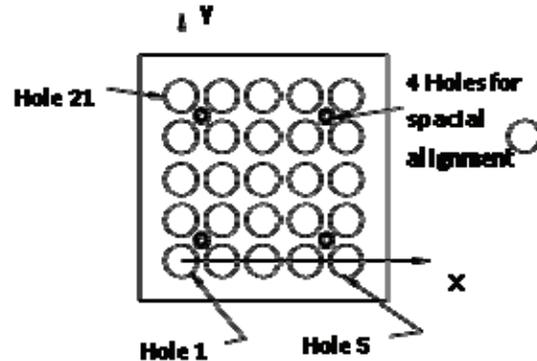


FIGURE 2. Illustration of principle of hole plate layout.

In this investigation a FDM based commercially available 3D printer was used and the material was ABS: The ABS filament is extruded through a nozzle at 260 °C. The diameter of the raw filament is Ø1.75 mm and the extruded filament is approximately Ø0.5 mm. The nozzle is moved using a CNC control in a Cartesian coordinate system.

## INITIAL RESULTS

The 3D printed hole plates were measured using a mechanical CMM and the data analyzed. Centre coordinates of the 25 holes were determined and the length between these calculated. Deviations from nominal (and expected) lengths were plotted (Figure 3 – X and Y directions only). Based on this correction values can be estimated and applied. It can be seen from the bottom part of Figure 3 that the perpendicularity error is almost negligible compared to the scaling errors.

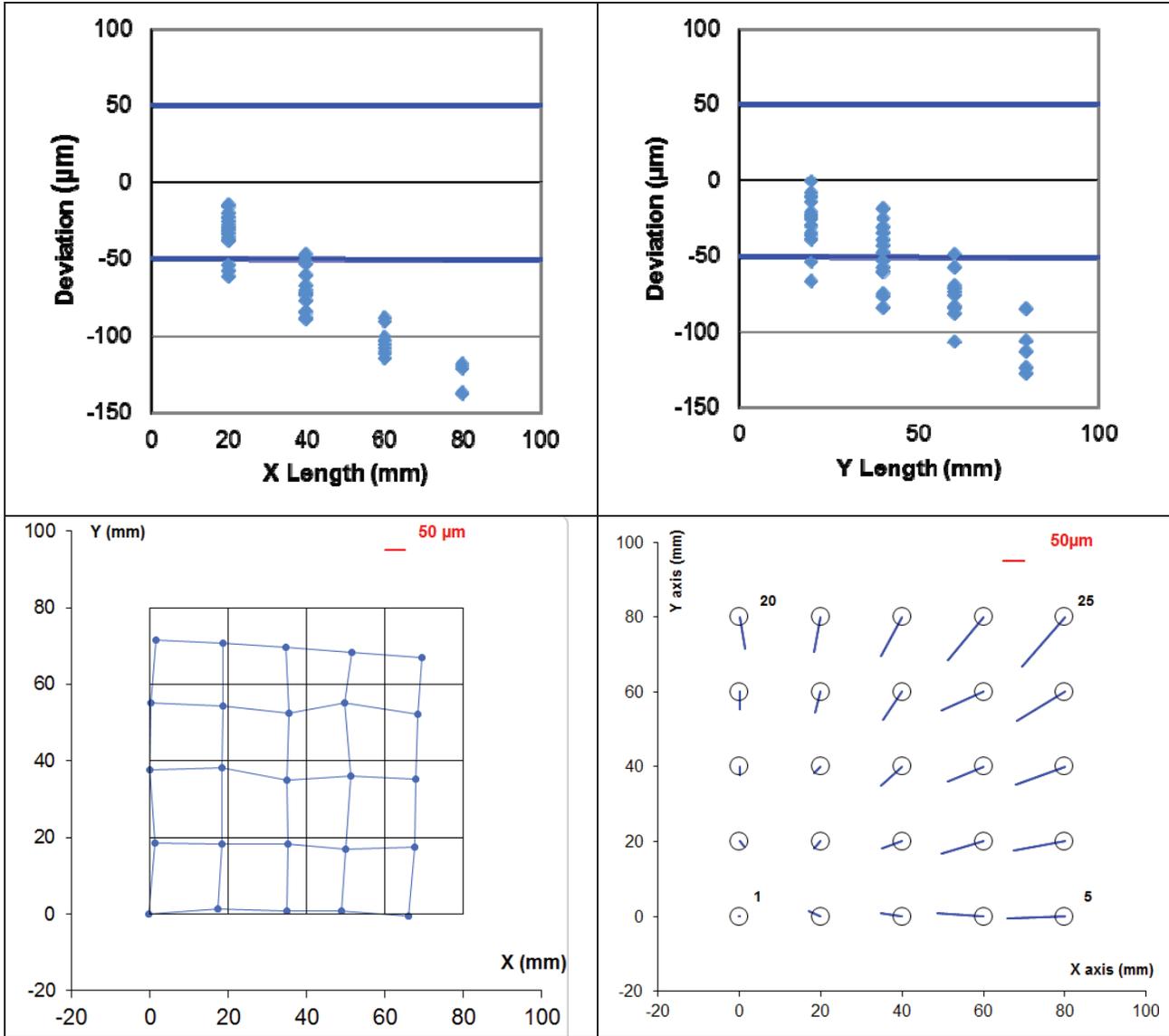


FIGURE 3. Analysis of 3D printed hole plate. Deviations from nominal position (bottom) and deviations from nominal length (top).

**ANALYSIS OF MEASUREMENT UNCERTAINTY**

It is clear from Figure 3 that there are scale errors that should be corrected. Also dispersions of points on length between center coordinates indicate variability in the determination of the center coordinates. This is due to the fact that the FDM process will create a layer-based component and this is also the case in the holes. An analysis of this phenomenon and its implications on the approach was performed.

Roundness of the printed holes was analyzed by means of a mechanical CMM. A standard approach to the measurement of a high quality hole plate in steel is based on determination of center coordinates by means of a 4 point measurement [3,4]. Figure 4 shows the progression of roundness of one printed hole as a function of measurement points. It is clear that the printed holes are not optimal for measurement purposes. A 4 point measurement clearly underestimates the roundness error by approximately 40 µm. It seems plausible that the roundness error of a single hole is of the order of

60  $\mu\text{m}$  with variations up to 100  $\mu\text{m}$ . The roundness error also is depending on the Z-height at which the measurement is performed. The large variation is an indication of this phenomenon. Figure 5 illustrates roundness deviations of selected holes.

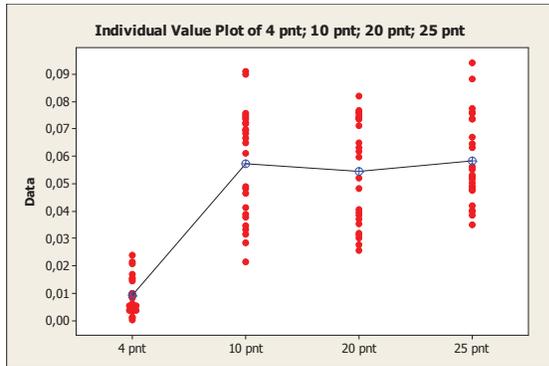


FIGURE 4. Roundness of printed hole as a function of measurement points. Vertical scale shows roundness error in [mm]. Measurements performed using a mechanical CMM with a probe of  $\varnothing 2\text{mm}$ .

The layered nature of the printed part is illustrated in Figure 6. Here mechanical roughness measurements were performed along a generating line of the inside of the hole. It is seen from Figure 6 that the layer thickness is of the order of 250  $\mu\text{m}$ . It can also be seen that the stylus is not able to reach the bottom of the profile. However, the variation of the top position of the profile varies, and this will affect the roundness measurement as well as the center point determination.

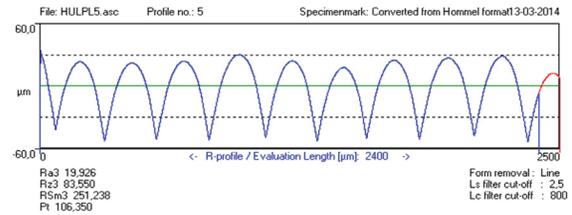


FIGURE 6. Roughness measurement of inside of printed hole.

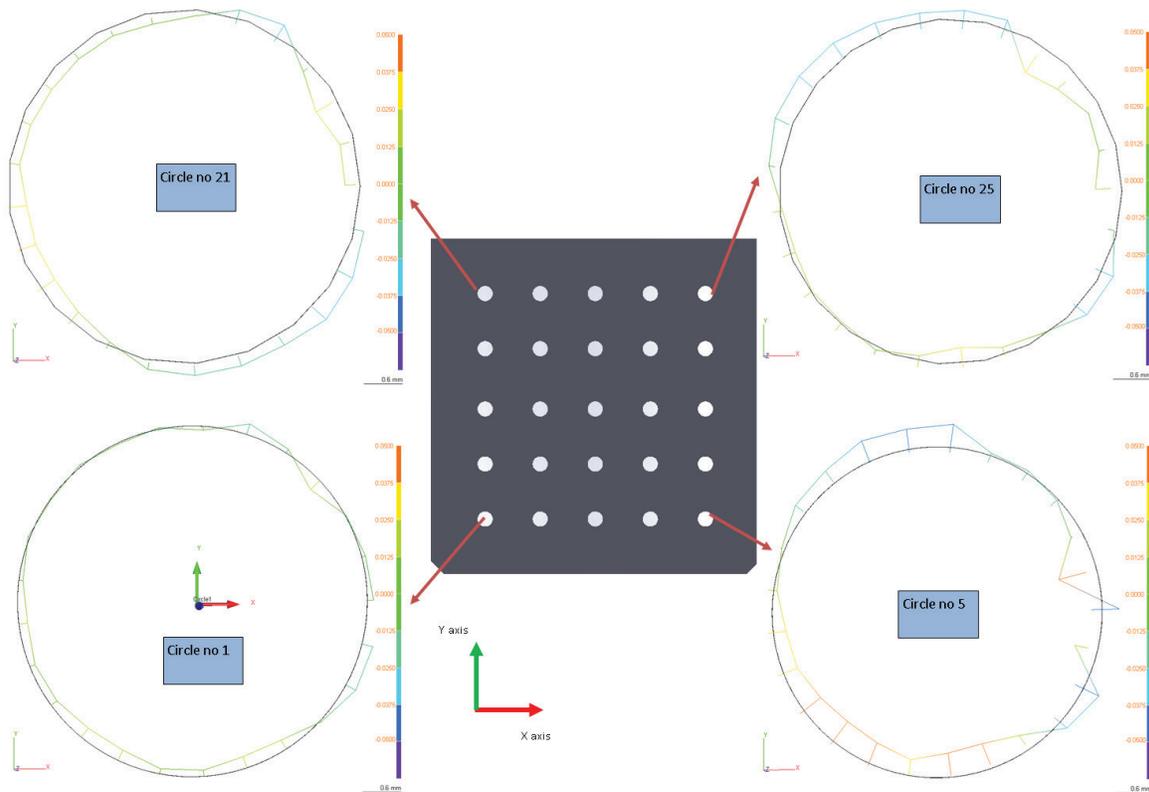


FIGURE 5. Roundness plots of selected holes. Roundness based on 25 measurement points.

Based on the above analysis an uncertainty estimation of length measurements was performed. The measurand was the length between center coordinates of holes. The CMM was calibrated using a high precision hole plate as described in [3,4]. Repeatability of center coordinates on the printed hole plate was assessed to be of the order of 6-7  $\mu\text{m}$  (1s level) and temperature influences of the same order of magnitude. In total, uncertainties of the order of  $\pm 20 \mu\text{m}$  on length measurements between center coordinates was estimated.

**CORRECTION OF 3D PRINTER**

The approach enables the determination of correction factors for scale errors both in X- and Y-directions based on the results presented in Figure 3. For the current paper three hole plates were printed, and the corresponding correction factors determined (Table 1).

TABLE 1. Correction factors for X- and Y-directions determined from 3 different printed hole plates.

	Correction factor	
	X	Y
Plate I	1,0017	1,0013
Plate II	1,0013	1,0008
Plate III	1,0014	1,0007
Average	1,0015	1,0009
Standard deviation	0,0002	0,0003

The correct application of these corrections factors would be to correct the FDM machine in its control software. As expected this turned out to be impossible due to a closed software. Recommendations from the machine vendor on different zero-setting procedures for the machines were followed, but without any visible results (Figure 6).

**CONCLUSION AND OUTLOOK**

The method described in this paper has been applied FDM based 3D printers. The hole plate enables correction of scaling errors, if the software of the machine allows such a correction. The total error encountered includes both axes errors and errors related to the process itself (in this case extrusion). The hole plate reflects a combination of these errors. In the future a separation of errors will be attempted.

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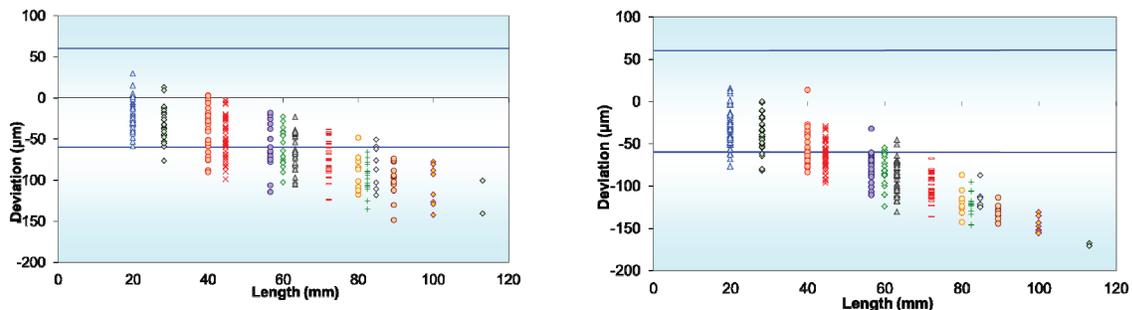


FIGURE 6. Example of length deviation plots for all lengths of hole plate. Left: Plate printed October 2013. Right: Plate printed January 2014. Full lines at  $\pm 60 \mu\text{m}$  indicate rough specification of machine producer.