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Traceability of optical length measurements on sand surfaces

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Abstract

This work concerns traceable measurements on moulds used in automatic casting lines made of green sand, which has a very low strength against the force of a contact probe. A metrological set-up was made based on the use of calibrated workpieces following ISO 15530-3 to determine the uncertainty of optical measurements on a sand surface. A new customised sand sample was developed using a hard binder to withstand the contact force of a touch probe, while keeping optical cooperativeness similar to that of green sand. The length of the sample was calibrated using a dial gauge set-up. An optical 3D scanner with fringe pattern projection was used to measure the length of a green sand sample (soft sample) with traceability transfer through the hard sample. Results confirm that the uncertainty of the optical scanner on the substituted hard sample is similar to that of the soft sample, so the hard sample can successfully represent the soft sample in the ISO 15530-3 procedure. The expanded uncertainty (k=2) of length measurements on sand was estimated to 10 µm.

Keywords: metrology, traceability, optical 3D scanning, sand

1. Introduction

Mould sand for automatic casting lines, called green sand, is soft and not suitable for a tactile coordinate measuring machine (CMM). The tactile systems are well-known and traceable to the meter unit and have been used for decades to measure three-dimensional engineering components. Development of new optical dimensional measurement instruments has a great advantage of measuring in a short time complex geometries without any contact. A cylindrical green sand sample (soft sample) was designed for verifying the length measurement capability of an optical 3D scanner against a calibrated dial gauge. To overcome the low strength of the soft sample, a sample with a hard binder (hard sample) was developed and substituted. The uncertainty of measurement was obtained following the GUM [1]. The traceability of optical measurements was established through utilization of calibrated workpieces according to ISO 15530-3 [2]. This requires calibrating a workpiece by comparing the optical results with traceable results obtained from a reference measuring system [3], e.g. length measurements using a dial gauge. The key concept behind the substitution method described here is the transfer of the uncertainty in measurement to other workpieces. Similarity requirements specified in ISO 15530-3 are followed so that the soft sample in this work is replaced by the hard sample featuring the same colour and surface structure.

2. Uncertainty estimation

The expanded uncertainty related to dial gauge measurement U_{cal} is calculated following the approach in ISO 14253-2 [4], with uncertainty components due to the reference standard (u_{RS}), the resolution of instrument (u_{RA}), the repeatability (u_{RE}), the temperature difference (u_{TD}), the effects due to difference in coefficients of thermal expansion (CTE) of a reference gauge block and the hard sample (u_{TA}) and the measurement process (u_P). The largest component is chosen between u_{RA} and u_{RE} (k = 2 for 95 % confidence level).

$$U_{cal} = k\sqrt{u_{RS}^2 + (\max(u_{RA}, u_{RE}))^2 + u_{TD}^2 + u_{TA}^2 + u_P^2} \quad \textbf{(1)}$$

The measurement uncertainty for the optical scanner U_{opt} is estimated following ISO 15530-3. Four uncertainty contributors are taken into account, similar to estimation of the uncertainty for tactile CMM measurements. These contributors are related to calibration (u_{cal}), measurement procedure (u_p), bias (u_b), influence of the soft sample (u_w)(k = 2).

$$U_{opt} = k\sqrt{u_{cal}^2 + u_p^2 + u_b^2 + u_w^2} \quad \textbf{(2)}$$

3. Experiments and discussion

The soft and hard samples were cylindrical with Ø50 mm with length in the range of 60 mm to 65 mm. The sand used for both samples had an average grain size of 0.230 mm. To compare the similarity of hard and soft samples, the surfaces were visualized for colour and reflex using optical microscope and quantified for the roughness using focus variation 3D microscope (*Ra* = 60 µm).

Length calibration of the hard sample was performed by a digital dial gauge with a measuring range 0-25 mm and resolution 0.001 mm using 10 mm diameter disc probe (Fig. 1-left).

The optical experiments have been performed with ATOS III Rev.02 optical 3D scanner with blue light fringe projection using GOM-Inspect professional SR1 software for analysis of the point clouds (Fig. 1 right). The system had two 8 mega pixel CCD cameras with measurement volume (320 x 240 x 240) mm providing minimum 0.104 mm distance between points. The experimental set-up was designed so that both instruments could measure the workpiece simultaneously without interfering each other, so there was no need to move the workpiece between instruments, which would involve relocation error, time and temperature effects.

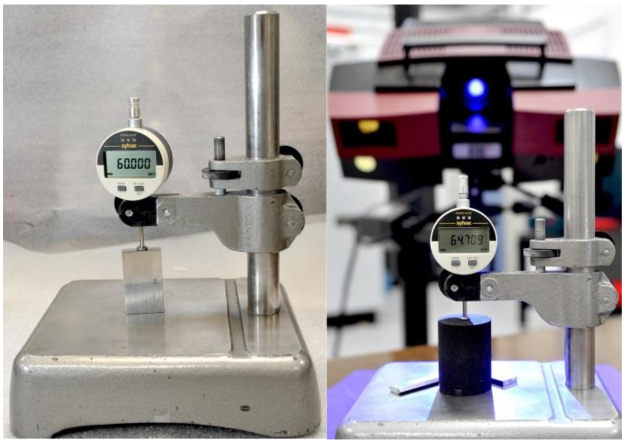

Figure 1. Left: Calibration of the dial gauge, Right: Simultaneous measurements by dial gauge and optical scanner.

Table 1 presents the uncertainty contributors for calibration of the dial gauge on hard sample according to Eqn. 1.

Table1. Uncertainty of dial gauge measurement [µm].

	u_{RS}	u_{RA}	u_{RE}	u_{TD}	u_{TA}	u_P	U_{cal}
Dial gauge [µm]	0.07	0.3	0.2	0.2	0.4	0.5	1.4

The hard sample was located in a defined position constrained by two edges and a rotation reference (Fig. 1 right). Optical scanning was performed by moving the scanner around the dial gauge set-up in 6 positions. The whole measurement was repeated 6 times. The point clouds were polygonised and the resulting meshes were aligned using the software. A disc probe was simulated in the same direction of contact and the local contact point with each mesh was calculated. Interaction of measurement instruments and the sand surface under the probe is illustrated in figure 2.

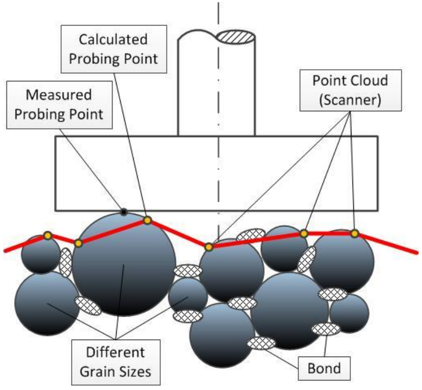

Figure 2. Interaction between disc probe and the sand surface.

The dial gauge touches the peak point. The optical scanner, which is limited to its resolution (0.104 mm), can roughly take one or two measurement points per grain (average grain size 0.230 mm) to produce a point cloud. Due to this effect, the unique local peak in the interest area can hardly be captured by the scanner. Therefore the point cloud is made using the neighbourhood points and it is expected that the simulated length measurement by the scanner will be lower than dial gauge probing. Figure 3 shows the results of repeated measurements. Since the measurement process was repeated with the same positioning constraints on the hard sample it is highly probable that the dial gauge touched the same grain repeatedly. This is confirmed by length change of 3 µm in repeated measurements compared to the average grain size (230 µm). Results of scanning are lower than contact probing.

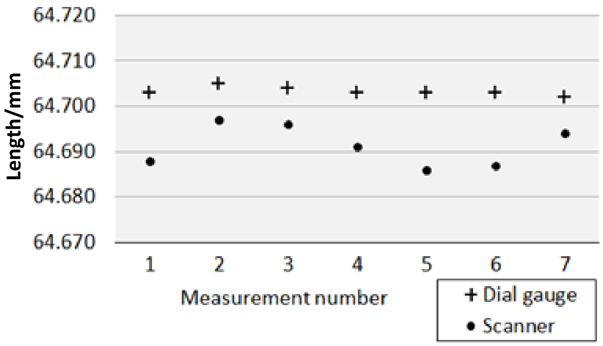

Figure 3. Optical and dial gauge measurements on the hard sample.

Finally a soft sample was subjected to measure by the optical scanner with 7 repetitions, which resulted in a standard deviation STD of 0.005 mm.

The complete measurement result is given by:

$$Y = \bar{y} - b \pm U_{opt} \tag{3}$$

Where $\bar{y}$ is the mean value obtained by optical scanner on soft sample, b is the bias value (0.012 mm) and U_{opt} is the expanded uncertainty of measurement (0.01 mm according to table 2). The bias is given by:

$$b = \bar{y}_{ref} - y_{cal} \tag{4}$$

Where $\bar{y}_{ref}$ is the length measured on hard sample by optical scanner and y_{cal} is the calibrated value obtained by dial gauge on hard sample.

Table2. Uncertainty of optical measurement based on Eqn. 2.

	u_{cal}	u_b	u_w	u_p	U_{opt}
Optical scanner [µm]	0.7	1.1	3.8	3.0	10

4. Conclusion

In this paper a metrological approach is presented to measure the length of a soft green sand sample by an optical scanner. Using the concept behind the substitution method (ISO 15530-3), a hard sample was replaced the soft sample. The substituted sample was used as a traceability element between an optical scanner - with unknown uncertainty - and a calibrated dial gauge with a disc probe with 2 µm expanded uncertainty. The measurement bias of the optical scanner was 12 µm. The estimated expanded uncertainty for the length measurement using optical scanner was 10 µm.

References

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