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Traceability issues for contact probe and stylus instrument measurements

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Abstract

Surface texture and form of products are important features to be examined and numerically characterised as parameters for engineering and scientific purposes. Form and surface measurement devices with contact probes and stylus are used to characterise such surfaces. Additionally, new generation Coordinate Measuring Machines (CMMs) can measure dimension and form simultaneously in scanning mode and also may employ surface roughness testers to perform measurements when the part is on the CMM machine. Use of probes for form measurements in scanning mode with a fast scanning speed might be problematic due to required high data acquisition rates, therefore the dynamic performance of the probe including the electronics of the instrument should be well calibrated. For the surface roughness devices, there is a need for new traceable standards due to a recent increase in the required measurement ranges (e.g. 1000 µm). Although there are documentation and methods for calibration of contact stylus instruments (ISO 12179; ISO 25178-701:2010 and DKD-R 4-2), there is no documentation for alternative routes or detailed investigations for calibration of reference stylus instruments used for calibration of reference standards of secondary level labs. The project, "Probe Trace" supported by the European Metrology Programme (EMPIR) has been started to respond to the above given demands. It aims to improve the scientific knowledge, instruments, methods and research capability in metrology for contact measurement probes and stylus instruments and enable calibration labs to develop new capabilities for self-provision of traceability to the SI unit of length, the metre. Update on the project results will be given in the paper including, investigation of new traceability routes with displacement generators, software tools for use of spheres for calibration of the devices and noise reductions, and calibration of groove standards using various state of the art devices.

Traceability, piezo actuators, form and surface testers, stylus devices, inductive probes, displacement interferometers

1. Introduction

An accurate measurement of surface roughness and form is vital to quality control of the machining of a workpiece. The contact measurement probes are one of the main physical sensors that are widely used in surface and form testers and Coordinate Measuring Machines (CMMs). In order to achieve traceable measurement that can be related to the meter, these sensors must be calibrated against a reference standard that is more accurate than the sensor under test. The calibration also provides corrections/adjustments and better performance for the measuring devices in addition to the traceability.

The probes used for form and surface roughness measurements can be basically static in its sensing direction, but are displaced lateral to this direction to track the form and surface deviations of the parts. E.g., the contact measurement probes are used in CMMs with the scanning mode, in other words, dimension and form of the parts are measured simultaneously by the probes. This requires further evaluations and checks for the dynamic performance of the probes in addition to calibration done under static conditions. Use of the probes for form measurements in scanning mode with a fast scanning speed might be problematic due to required high data acquisition rates, therefore the dynamic performance of the probe including the electronics of the instrument should be well calibrated. For the surface roughness devices, there is a need for new traceable standards due to a recent increase in the required measurement ranges (e.g. 1000 µm) [1].

Although there are documentation and methods for calibration of contact stylus instruments / contact measurement probes (ISO 12179; ISO 25178-701:2010 and DKD-R 4-2), there is no documentation for alternative routes or detailed investigations for calibration of reference stylus instruments used for calibration of reference standards of secondary level labs. This issue was also outlined by Haitjema [2] discussing the issues, methods and problems for traceable calibration of the contact probes up to 10-300 µm range.

The project, ProbeTrace-18RPT01 supported under European Metrology Programme (EMPIR) has been started to investigate portable traceable displacement generators and their use to establish new direct routes to SI unit metre definition, considering the emerging demands of industry in terms of dynamic properties, precision and larger measurement ranges in regard to contact probes used in form and surface roughness measurements [3]. The main of the project is to improve the scientific knowledge, instruments, methods and research capability in metrology for contact measurement probes and stylus instruments and enable calibration labs (particularly new National Metrology Institutes) to develop new capabilities for assurance of traceability to the SI unit of length, the metre.

The issues for surface and form tester probes will be outlined in section 2 with widely used calibration methods in industry and proposed alternative routes. Section 3 gives information about calibration of displacement actuators/generators and discuss the issues regarding to the related standards for performance of single axis linear positioning systems and task specific calibration. Noise problems in the surface roughness and form measurements are discussed in section 4 and developed software tools with experimental results are presented.

2. Roughness and form tester probes/styluses

The form and surface roughness testers mostly use inductive sensors also called linear variable differential transformers (LVDT) [4]. Depending on the amplification factor, resolutions at the sub-nm level can be achieved but the range may be limited to ±10 µm. Most of the inductive sensors used in the roughness and roundness testers have a range of up to ± 500 µm with a resolution from 1 nm to 10 nm. These sensors are calibrated using traceable artefacts calibrated by National Metrology Institutes (NMIs). Detailed information for this is given in below sub-sections.

2.1. Calibration of roughness tester probes

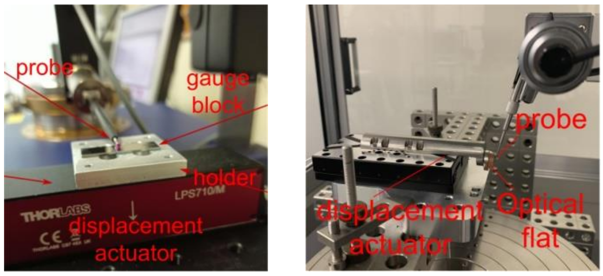
Artefacts having only specific nominal values (e.g. depth setting standards) are used for calibration of surface roughness testers. There is a need to calibrate these artefacts (ISO 5436-1:2000) by the NMIs with uncertainties of (10-100) nm up to 1000 µm range for industry. For this purpose, investigations for calibration of surface tester probes (to be used as reference device) were carried out using traceable displacement actuators/generators in the project. Such approach also provides continuous sampling with better knowledge for error mapping of the reference stylus instruments/surface testers as well as reaching larger calibration ranges e.g. 1000 µm. Figure 1 shows the calibration of surface tester probes using displacement actuators in TUBITAK UME and IPQ.

Figure 1. Calibration of surface tester using a displacement actuator (in TUBITAK UME-Turkey, left, in IPQ-Portugal, right)

2.2. Calibration of form tester probes

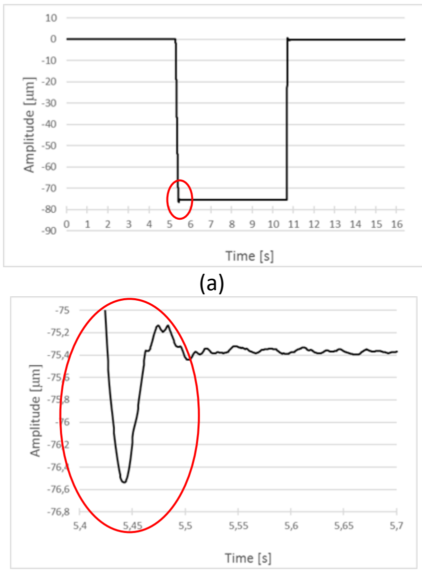
Form tester probes are calibrated in static mode mostly using gauge blocks and then in dynamic mode using flick standards (precise cylinders machined one side in flat with depths of 10 to 300 µm). Alternatively so called multiwavelength standards [5] are used for better performance check of the form measuring tester probes. All these artefacts are supposed to be calibrated by NMIs for the industry. In order to do that, there is need for a reference form tester calibrated in advance being traceable to SI unit metre.

For this, different form tester probes were calibrated using different traceable displacement actuators in static and in dynamic mode. For example, Figure 2 shows the set-up in (a) GUM-Poland and (b) in TUBITAK UME-Turkey. Figure 3 shows the results taken by GUM. The displacement actuators were driven to simulate grooves of the required depth repeatedly using a square excitation. Resulting signal recorded is shown in Figure 3 with the example of ringing oscillations observed in the simulated groove of 75 µm. Figure 4 illustrates the schematic view for calculation of the groove's depth according to the ISO 5436-1:2000 which is used for mitigation of the ringing oscillations during calibration of the contact probes. Detailed information can be taken from ref. [6].



(a) (b)

Figure 2. Calibration form tester probe using a displacement actuator, set-up (a) at GUM, Poland (b) at TUBITAK UME, Turkey.



(a)

(b)

Figure 3. (a) Example of ringing oscillations observed in the simulated groove of 75 µm (b) Zoomed-in oscillations at the falling edge of the groove [6].

Some of the manufacturers propose use of precise sphere with known diameter for calibration of surface roughness testers. Openly accessible software was developed to enable the calibration of any manufacturer's device without the need for proprietary software. Testing of the software by project partners is in progress as well as analysis of the results taken by displacement actuators and comparison of the different methods to each other.

The approach of the project for calibration of form and surface tester probes is illustrated in figure 5. The aim here is to provide new routes and novel methods for achieving direct traceability to the metre, instead of using artefacts and also create reference measuring devices for traceable calibration of these artefacts.

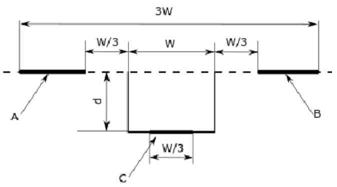


Figure 4. Typical schematic view for calculation of the groove's depth according to the ISO 5436-1:2000 standard.

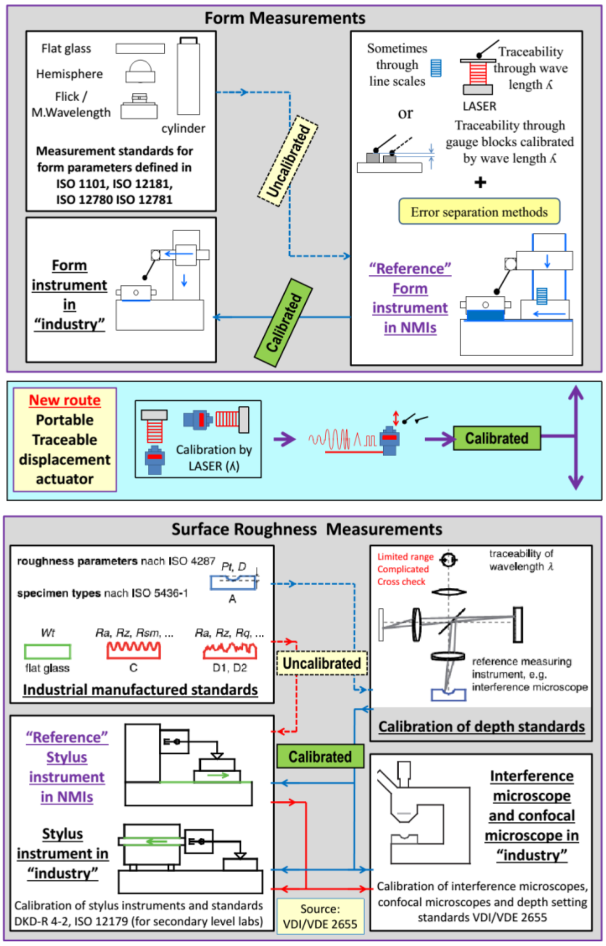


Figure 5. Calibration of form and surface tester devices [3]

3. Calibration of displacement actuators

The displacement actuators employing piezo driving mechanisms and precise sensors/scales are able to measure/generate very precise displacement steps. They can be used for calibration of form and surface tester probes in static and dynamic mode. These actuators can be integrated with laser displacement interferometers to provide direct traceability to the metre. However, this is complex and difficult besides such approach cannot cope with inherent errors of the displacement interferometers such as non-linearity / interpolation errors. However, they can be used as a stand-alone device after its calibration by the laser interferometers considering these error sources. In this case, it may be possible to reach better uncertainty values than those used together with the laser interferometers. This is also stated by Haitjema while discussing the calibration issues of these sensors [2].

The detailed investigation on how to use the displacement actuators as portable displacement generators for calibration of roundness and roughness tester probes are being carried out considering task specific calibration of displacement actuators. The reason for this is that these actuators considered as new linear positioning systems exist with ranges of motion as long as several centimetres and positioning resolutions as low as several nanometres. The ability to meet the demands for calibration of the contact probes requires accurate knowledge of the positioning performance of these systems, yet a dedicated standard for evaluating the performance of high-precision single axis linear positioning systems does not exist. Existing standards for the performance of single axis linear positioning systems within machine tools (ASME B5.54-2005, ASME B5.57-2012, ISO 230-1:2012) can be difficult to apply for the performance of high-precision positioning systems that can approach the required measurement uncertainty. A new standard with measurement methods specific to characterization of these stages is in preparation as ASME B5.64 ("Methods for the Performance Evaluation of Single Axis Linear Positioning Systems"), for performance evaluation of single axis linear positioning systems.

Considering the requirements for calibration of roundness and surface tester probes, different types of displacement generators (e.g. LPS 65 1" PM LS-072 by PI, LPS710M by Thorlabs, QNP60Z-500 by Aerotech) as a linear positioning system were investigated by the project partners. During the investigations, angular rotational errors (e.g. pitch, yaw) were measured using precise autocollimators and positioning performance of individual displacement actuators were checked using various displacement interferometers such as (DI-SIOS) by SIOS, XL-80 int. by Renishaw and also performing an intercomparison measurements between the participants.

Figure 5 illustrates the set-ups for calibration of two different displacement actuators using two different displacement laser interferometer systems, (a) using SIOS differential laser interferometer at TUBITAK UME (Turkey) in vertical orientation, (b) using Renishaw XL-80 laser interferometer at GUM (Poland). It is possible to achieve uncertainty values ranging from 5 nm to 20 nm using such systems.

(a) (b)

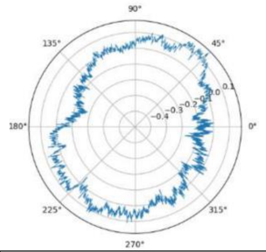
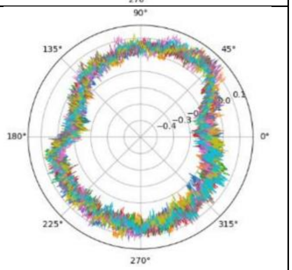
Figure 5. Set-ups for calibration of different displacement actuators using different displacement laser interferometer systems (a) at TUBITAK UME, Turkey (b) at GUM, Poland.

4. Noise reduction

During surface roughness and form measurement of precise parts, noise influences the accuracy of the measurement. This is because the measurement signal obtained by conversion of displacement values to electrical signal can contain undesirable noise due to mechanical, electrical, thermal, and other influences that can lead to an error in the measurement result. In order to achieve targeted uncertainties of 10 nm to 100 nm during development of the traceable and cost-effective measurement capabilities for the calibration of form and surface roughness standards, noise problem has to be solved. Besides, noise reduction is also important particularly for precise measurements of roundness standards and it is also required to be used for precise measurement of spindle error of the reference form tester by applying the error separation method. Some algorithms and software for noise reduction have been developed by the project partners to be used to pre-process roughness and form profile data.

The novel method for noise reduction investigated in the project is based on Random Noise Bias Removal [7,8] where only a few repeated measurements are needed to obtain unbiased results. TUBITAK UME-Turkey has worked on synthetic signals and developed some soft tools. FSB-Croatia has developed software toolset written in Python program language with functions for Fourier reduction and random component exclusion methods and functions for calculation of *RONt* and *RONq* roundness parameters [9]. Upload of measurements data can be done from the txt files. Application of the software has been performed using the experimental data sets taken from the form tester in FSB by measuring the roundness of a precise sphere [9]. Table 1 shows set of measurement results taken at 3600 sampling points in one revolution. 10 repeated measurements were taken and the results of *RONt* values are given individually starting from 1 to 10 with corresponding roundness profiles in Table 1.

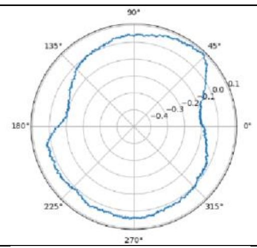
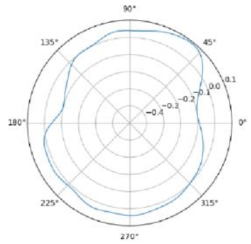
Table 1 *RONt* values on a precise sphere and roundness profiles

Measurement No	*RONt* nm	Roundness Profiles
1	344	
1 2 3 4 5 6 7 8 9 10	344 308 288 335 324 303 317 333 340 338	

The results of the *RONt* after processing the data in the developed software using Fourier reduction and Random component exclusion methods are presented in Table 2 with the roundness profiles. Considering the certified value (*RONt*) of the sphere being 14 nm, the measured *RONt* of 323 nm is mostly the result of a spindle rotation error and electrical noise in the measurement signal. This was also verified by performing the roundness measurement on the precise sphere when it is located with different angular orientation (90° shifted) on the spindle and observing the similar dominated error graph [9].

After noise reduction using the Fourier reduction method, the *RONt* value has been reduced to 211 nm. A similar level of noise reduction was found using Random component exclusion where the RONt value has been reduced to 191 nm. The roundness profiles given in Table 2 show this improvement. This can be considered as a positive step for calibration of precise roundness standards and determination of spindle error of the reference form testers using the error separation technique (multistep, reversal method) which will be the continuation of this research.

Table 2 *RONt* values on a precise sphere after noise reduction

Filteration method	*RONt* nm	Roundness Profiles
Fourier reduction method	211	
Random component exclusion	191	

5. Summary

Investigation of new routes for calibration of form and surface tester probes were presented using the results taken under the ProbeTrace (18RPT01) project. Use of recently developed and commercially available different piezo systems as portable displacement actuators shows very promising results. Their performance investigations and task specific calibration for provision of the traceability using different laser interferometers shows that they can be used for calibration surface and form tester probes in static and dynamic operation in order to calibrate such testers as a reference for calibration of well known artefacts. However, there is a need for development of new guides and standards about the use of these devices for this purpose. Use of software tools for the random noise reductions based on different approaches is also presented. It is shown that these tools are important and compliment the proposed routes to achieve uncertainties of 10-100 nm for calibration artefacts up to the measurement ranges of 1000 µm.

Acknowledgements

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