# Recent progress in CMM based form measurement

O. Jusko[1], M. Neugebauer[1], H. Reimann[1], R. Bernhardt[2]
[1]*Physikalisch-Technische Bundesanstalt, Braunschweig, Germany*
[2]*Carl Zeiss IMT GmbH, Oberkochen, Germany*
otto.jusko@ptb.de

## Abstract

Form standards with different profile geometries were measured on a 3D CMM prototype with a precision rotary table by three and four axis scanning. Physical boundary conditions like probing force, probe diameter, probe geometry, probe material, and scanning speed were varied and the results were analyzed. Some results were found to be equivalent to those gained by form measuring machines. Limitations of the current implementation of this technique are discussed.

## Introduction

In many industrial applications users wish to measure form measurands with coordinate measuring machines (CMM), because such the time and effort for a second setup and measurement of the work-piece on a specialized form measuring machine (FMM) could be prevented. However, until scanning was implemented into the CMM control the limited speed and data density of the data acquisition prevented productive measurement processes. Now, since more than a decade scanning has been optimized with respect to speed and accuracy by the CMM manufacturers, but still there is doubt about the achievable accuracy, maybe because early work achieved only mediocre results [1, 2]. Furthermore CMM [3-5] and FMM standardisation [6, 7] have been developed in parallel and were not harmonized. Especially, the use of a rotary table for scanning roundness measurements alike the working principle of FMMs is not reflected in the standardisation.

Therefore is was decided to determine the current state of the art in CMM form measurement by conducting measurements tasks which are typically for FMM. These include roundness straightness measurements at simple geometry artefacts like spheres, cylinders, and rings as well as magnification standards (e.g. flicks) and multi-wave standards (MWS) [8]. The resulting data should also deal as input to coming CMM standards which reflect the role of CMM in FMM mode.

## 1. Probe Material and probing force

An important pre-requisite for reliable tactile form scanning measurements with a CMM is the stability of the contacting sphere. Many FMM users already know about rapid probe wear during contacting of some work-piece materials and surface textures. This even happened during measurements with probing forces between 5 mN and 35 mN. It is reasonable, that the wear would be even larger at the typical scanning forces of modern CMM, like 50 mN to 400 mN. It was shown that the use of contact spheres made from crystalline diamond and diamond-coated spheres leads to highly reproducible measurement scanning results [9]. Therefore probes like these with diameters of 1 mm and 3 mm were also utilized for the measurements of this measurement campaign

## 2. Measurement equipment for calibration and testing

All utilized form standards were calibrated by FMM, which are also used for the realisation of PTB’s form measurands CMCs (calibration and measurement capabilities) [10]. These were a Talyrond 73 [11], a MarForm MFU 110WP [12] and a modified MarForm MFU 8/800 [13].

The CMM measurements were performed with a prototype of a Zeiss PRISMO 7 ultra with the probe system “VAST Gold” and an additional fourth axis realized by a rotary table ”RT-AB 300”. The three Cartesian axes (3A) scanning specification of the PRISMO is $MPE_{RONt} = 0.5$ µm. The four axes scanning with rotary table (4A) is not explicitly specified.

## 3. Measurements and Results

The parameter space for the test is very large. If all combinations of the variables scanning speed, contacting force, clamping, probe material, probe geometry, initial angle of measurement, form standards, number of repeats, and 3A and 4A scanning would have been realized there would have been 3.3 million measurements to conduct. Therefore, only a meaningful subset of approx 10,000 profiles was acquired and analysed. Only two key results of these will be reported. A more comprehensive analysis can be found at [14].

### 3.1 Roundness measurement at a glass hemisphere

A hemisphere with roundness deviation RONt = 0.010 µm (U = 0.006 µm) was selected. The main purpose for a roundness measurement of such a standard was to check the resolution of the CMM probe system and the vibration contribution from the motion control. With 3A scanning a roundness value of RONt (LSCI) = 0.383 µm (std.dev. $\sigma$ = 0.034 µm, 15 repeats, 50 UPR) could be achieved. In 4A mode a result of RONt (LSCI) = 0.101 µm (std.dev. $\sigma$ = 0.009 µm) could be achieved. This shows that the FMM alike scanning with the rotary table yielded to a great improvement of both measurement result and reproducibility. The selected scanning speed amounted to approx. 1 $\text{min}^{-1}$ or 3 mm/s.

### 3.2 Roundness measurement at multi-wave standards

The most interesting measurands of MWS are the amplitude heights of the lines in the spectrum profile. There were already attempts to solve this measurement task by scanning in 3A mode [15]. But there were occasional problems with low data density and non equidistant sampling resulting in spectral artefacts [16]. With the PRISMO two MWS were measured and their profiles were analysed. No spectral artefacts were observed. The deviations of the amplitude heights to the calibrated values (U = 0,050 µm) were found to be less than 0.020 µm (5 UPR - 150 UPR), and 0.170 µm (500 UPR), where the uncertainty of the calibration amounted to U = 0.050 µm. The scanning speed was adjusted to approx. 0.5 $\text{min}^{-1}$ or 8 mm/s.

## 4. Conclusion and outlook

The results show that modern CMM are able to achieve form measurement results with high reproducibility and low deviations from FMM calibration values even at challenging work-pieces. Coming tasks will include the definition of suitable specifications, filling the gaps in the standardization, and the calculation of the uncertainty of measurements like these.

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