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ACCELERATION OF QUALITY CONTROL ON COORDINATE MEASURING MACHINES WITH "NAVIGATOR SCANNING"

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Abstract
The tactile probing technology with coordinate measuring machines (CMMs) is today commonly used for measurement of workpieces in industrial production. The accuracy needed for the testing of components especially with form errors, is achieved by scanning technology, which is now standard. Coordinate measuring machines with tactile probes also with tactile scanning probes however, generally fail to achieve the through-put of modern processing equipment. They often become the bottle-neck in production. Therefore, it is important to increase the output of coordinate measuring machines with tactile sensors by accelerating the measuring process but without loosing accuracy. This objective was achieved with so called "Navigator Scanning Technology" from Carl Zeiss IMT (Industrial Metrology). It compensates for the variations caused by dynamic influences, thus enabling a significant increase in scanning speed.

1 Introduction: Dynamic influences on scanning CMMs

The continuously measurement point recording during the movement of the probe across the workpiece surface so called „scanning" is on the way to become a standard ability of a coordinate measuring machine (CMM). With scanning the number of measuring points being recorded during the measurement can be increased dramatically. Especially for workpieces with form errors the scanning technique improves the accuracy of coordinate measurements considerable [1, 2].

Nevertheless the measurement time on a CMM is still relatively high in comparison to the cycle time of a modern machining center. Although CMMs, with their modern drive designs, can achieve high travel speeds, it is often to see that a CMM slowly scans the surface of the workpiece or almost stops before contacting the workpiece and then probes it slowly. These speed reductions are necessary to maintain the dynamic forces arising from high speeds and rapid acceleration, so that they do not produce undesirable deformation of the geometry of the probe and equipment, (Figure 1) which lead to measurement deviations [3, 4].

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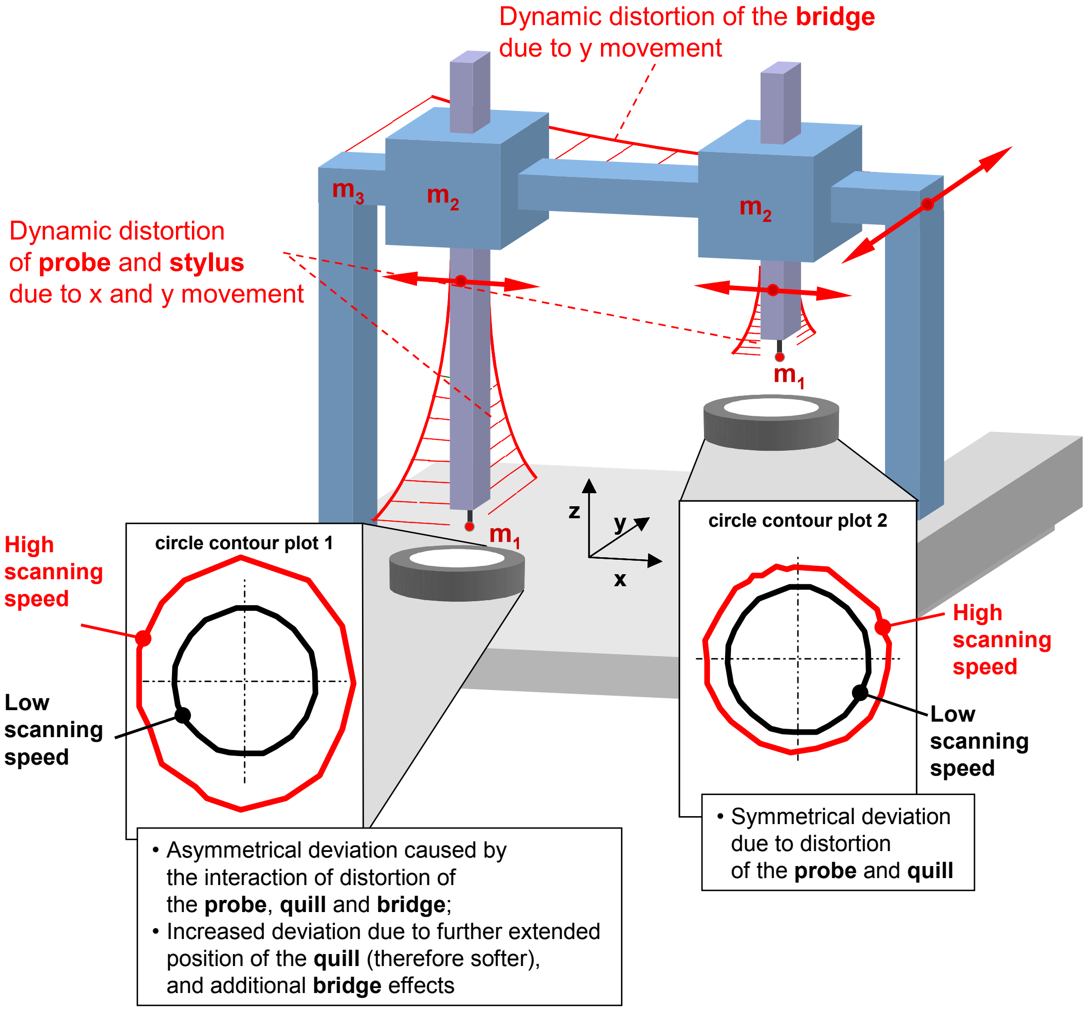


- Asymmetrical deviation caused by the interaction of distortion of the **probe**, **quill** and **bridge**;
- Increased deviation due to further extended position of the **quill** (therefore softer), and additional **bridge** effects

- Symmetrical deviation due to distortion of the **probe** and **quill**

Figure 1: Variations in the uncompensated measurement of a ring gauge in two different positions on the table caused by dynamic distortion (simplified, qualitative diagram) [8]

2 Relative Calibration for the Compensation of Dynamic Influences

For the compensation of the dynamic deflections are different methods applicable. The most simple one is the comparator principle [5]. It is also known as “gauge calibration”. In gauge calibration, the workpiece to be checked and an identical or similar object or measurement standard already calibrated are measured in the same location by the same probe. The difference between the measurement recorded on the measurement standard and the calibrated value is used to correct the corresponding measurement on the workpiece. This process produces a major improvement in the accuracy of coordinate measuring machines. It is therefore frequently used for the calibration of gauges in coordinate measuring machines. In this process, an extremely-accurately calibrated gauge represents the measurement standard and the corrections obtained from the measurement of this gauge are used to correct the measurements of other gauges.

The principle of gauge calibration is also suitable for increasing measuring speed, for example in scanning bored holes. In this process, the feature to be checked is scanned once at low speed and once at high speed. The obtained results are used to correct measurements taken at high speed. As no measurement standard is used, this process is more accurately called “relative calibration”.

As relative calibration assumes that the measurement taken at low speed is the correct value and is therefore considered to be the “calibration value”, the process is fully dependent on the measurement obtained at low speed. It is, therefore, advisable to repeat this procedure several times in order to be certain that the correction is accurate. However, safe use of this procedure is only possible if calibration values for the workpiece features to be measured are available.

3 Feature Independent Compensation with “Navigator”

The Navigator uses another approach: If the relationships between the dynamic forces and the deformation of the probe and the machine equipment are known, a measuring feature independent compensation for the deformation can be built into the measuring equipment controls.

Carl Zeiss IMT uses what is called “D-CAA” (dynamic bending CAA). D-CAA is derived from CAA (computer aided accuracy), an expression used to designate the recognized process of computer-aided correction of geometric error in the axes of CMMs [1, 6]. D-CAA describes the location-dependent, dynamic deformation behaviour of the machine’s geometry. It is designed individually for each type and size of measuring machine and is embedded in the equipment controls.

The probe as well as the machine deforms as a result of dynamic forces. As the probe is individually constructed by the user for his particular task, the probe’s dynamic deformation behaviour must be defined in the dynamic probe calibration, which is part of Navigator. The data obtained in this process is used to correct the speed-related probe deformation, just as the D-CAA data is used to correct the machine deformation.

Both compensation methods guarantee that the distortion due to dynamic forces does not exceed 1um.

Furthermore the use of the patented, active-scanning measuring heads in Carl Zeiss IMT machines enables the measuring force of the head to be directly influenced by electro-magnetic activators [7]. This ability to influence measuring force allows the measurement changes caused by centrifugal force to be actively corrected by Navigator’s patented centrifugal force clamp. Therefore the measuring force always corresponds to the required force, so that displacement from the workpiece surface at high scanning speeds is prevented to a very large degree.

The patented Navigator behaviour for the achievement of complete dynamic correction described above with

- D-CAA for compensating the dynamic distortion of machine geometry
- dynamic correction of probe distortion to compensate for dynamic distortion of the probe itself, and
- centrifugal force compensation to reduce dynamic changes in measuring force

allow scanning speed to be significantly increased without increasing measuring deviations (Figure 2).

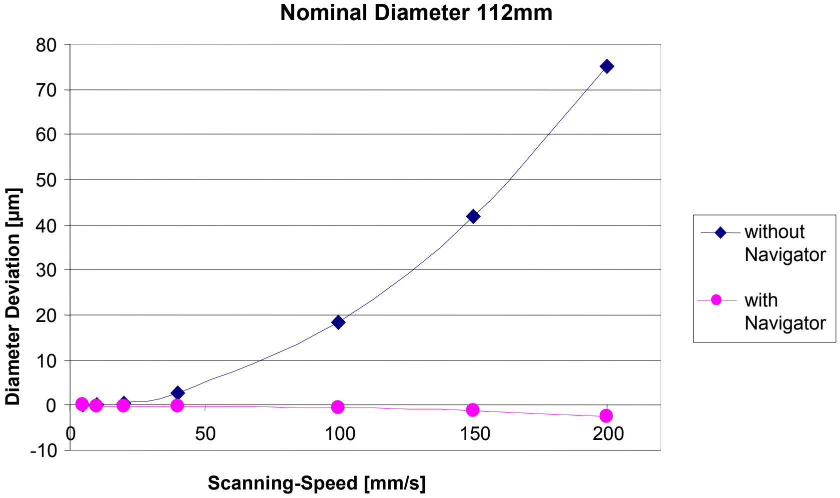
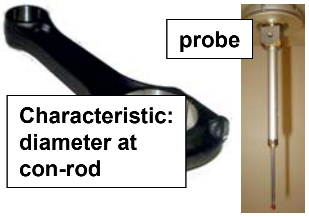


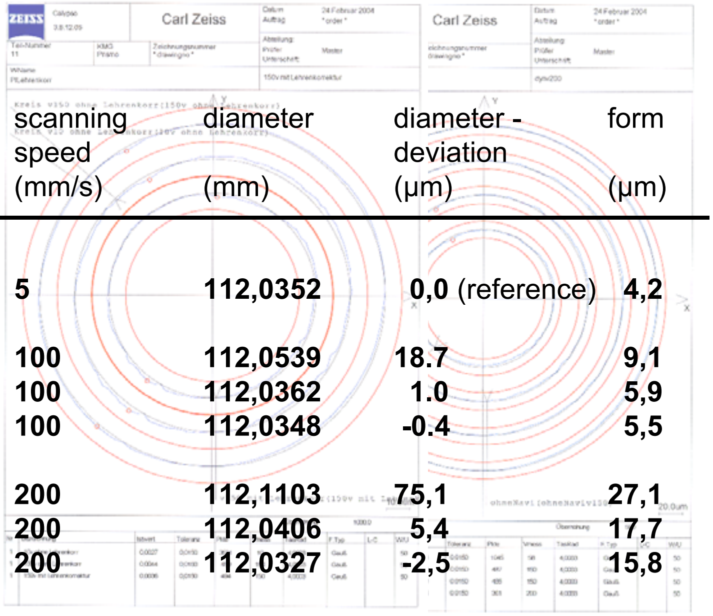
Figure 2: Scanning Speed and Deviation with and without Navigator (measurement of a 112mm diameter)

Investigations show that relative calibration and "Navigator Scanning" reach approximately the same accuracy at equal scanning speed (Table 1). But Navigator's compensation processes are effective in all measurement tasks across the entire range of the measuring machine. They do not require a specific calibration at every feature.

Furthermore the Navigator functionality comprises functions to optimize the moving speed and simplify the selection of the suitable scanning speed through software assistants [8].

Table 1: Comparison between relative calibration and Navigator





	scanning speed (mm/s)	diameter (mm)	diameter - deviation (µm)	form (µm)
Reference measurement	**5**	**112,0352**	**0,0** (reference)	**4,2**
without compensation	**100**	**112,0539**	**18.7**	**9,1**
relative calibration*	**100**	**112,0362**	**1.0**	**5,9**
Navigator	**100**	**112,0348**	**-0.4**	**5,5**
without compensation	**200**	**112,1103**	**75,1**	**27,1**
relative calibration*	**200**	**112,0406**	**5,4**	**17,7**
Navigator	**200**	**112,0327**	**-2,5**	**15,8**

*(gauge calibration)

4 A New Gauge for Evaluating of Scanning Performance

The standardized performance tests according to the ISO 10360 are focused on accuracy. Only the scanning performance specifications in part 4 of the ISO 10360 demands the definition of a accuracy value that has to be measured in a certain time [9]. But also this test demonstrates only roughly the scanning abilities at an artifact (small sphere, diameter 25mm). A real performance test should comprise more realistic measuring tasks. Furthermore the test should take account of additional effects that influences the measuring time and accuracy like the calibration procedure.

Therefore a new procedure based on a very simple test artifact (Figure 3) was defined [11]. It consists of three ring gauges. The artifact represents typical measuring tasks from the area of power train application. It is derived from the test procedure for the crank bore of an engine block. Beside the diameters the form and the concentricity has to be checked at the crank bore. The artifact represents all this characteristics.

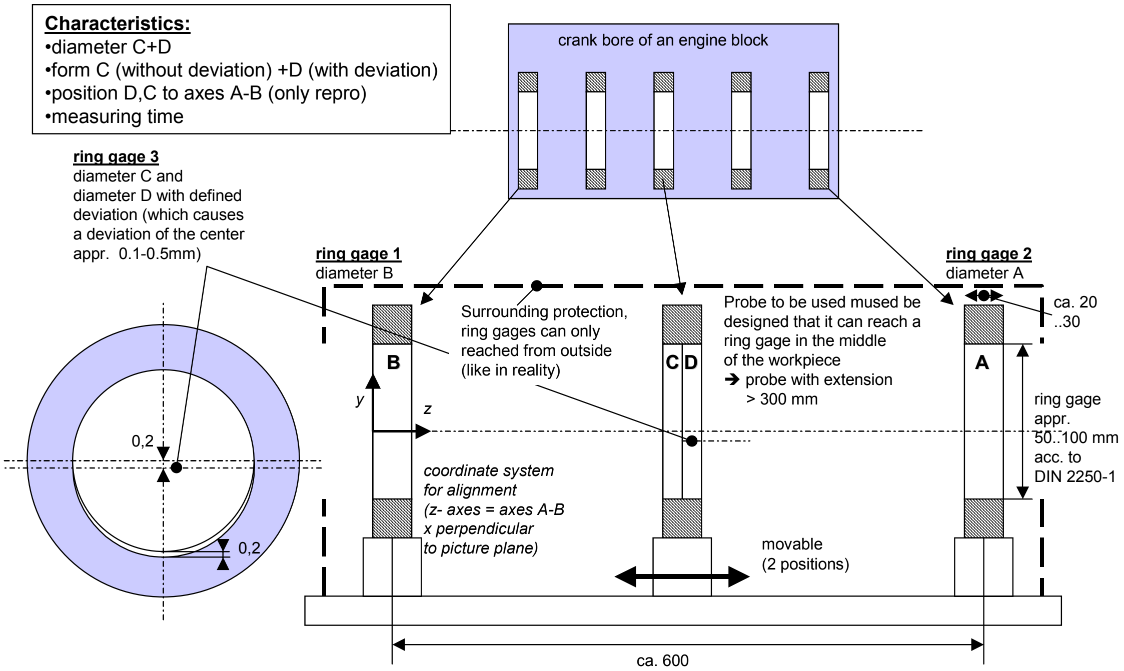


Figure 3: Artifact for scanning performance

The test procedure (Figure 4) offers the opportunity to evaluate a wide variety of CMM performance data. Beside accuracy and measuring time the smallest tolerance to fulfil typical measuring system analysis requirements (Capability Indexes, GR&R-Test [10]) can be determined (Figure 5).

5 Results with New Scanning Gage

A comparison between the fixed active scanning probe head VASTGold with Navigator and a passive scanning probe head mounted on an articulating probe holder demonstrates the advantage of the Navigator technology (Figure 6 and 7). The fixed probe head needs less than the half of time for the measurement.

Furthermore this examples shows that the articulating system is not able to fulfil the capability requirements (cg>1,33) for the form tolerances due to the limited repeatability of the articulating probe holder [12].

- **Preparation**:
  - Selection of a appropriate probe configuration
    Example: 1 long probe or 2 probes (T-probe) or articulating probe head
- **Full qualification of the probe**
- **Alignment**
  - z-axes defined
    by center points of circle A/B
  - Zero point (z) at the axial surface
    of the ring gage 1 (B)
- **3 test runs with**
  20 x measurement cycles of the ring gages;
  before and between the runs / cycles the probe must be full qualified
  => enables GR&R- and cg/cgk- evaluation
- **Measurement of the necessary cycle time**

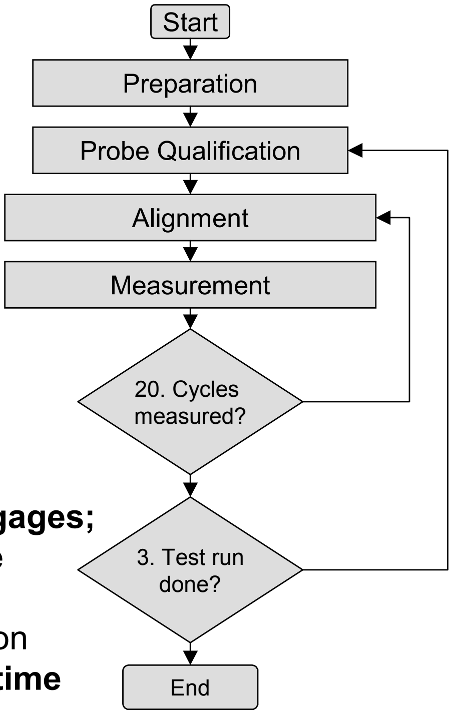


Figure 4: Test procedure for artifact for scanning performance

For 3*20 measurements
including 3 probe qualifications with

- c_g, c_{gk}>1,33 acc. to type 1 study with c_g=0,2T/4s (determined from 60 measurements)
- <u>Performance Data:</u>
  - **Gage dimensions:**
    - ring gage diameter: ***50mm***
    - ring gage distance: ***600mm***
  - **Measuring time:**
    - ***<60 minutes***
      (<45 minutes without form)
  - **Tolerances:**
    - ***diameter: +/-0,008mm***
    - ***position: 0,02mm***
    - ***form:0,007mm***

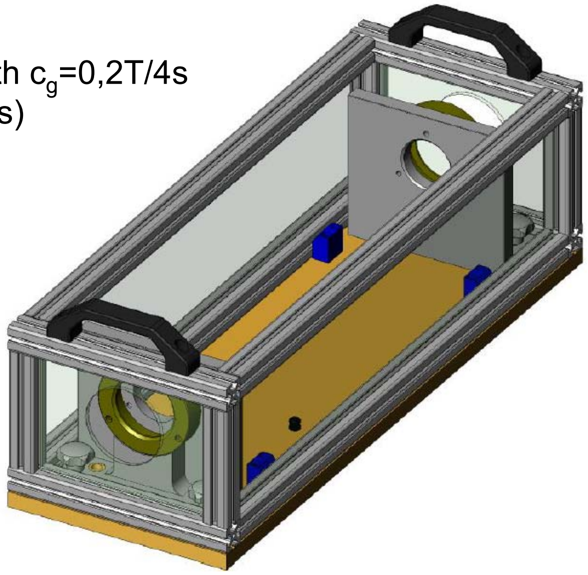
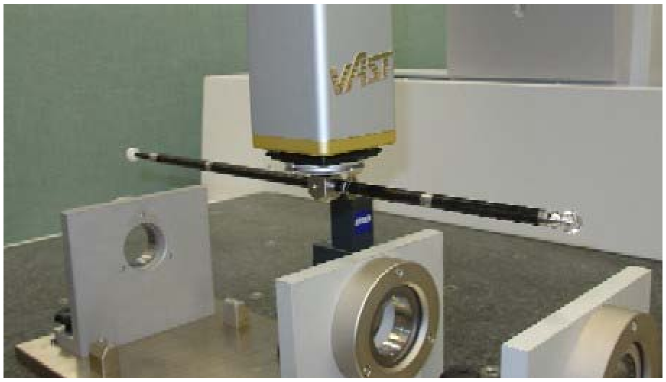


Figure 5: Specification for a Scanning CMM with Navigator Scanning (cg and cgk define a relation between standard deviation of the measuring machine: s and the tolerance: T [10])

Two short probes (300mm each)



Time for 20 runs: 11,5 Minutes
Time for qualification of probe: 8 Minutes
Total time: **59 Minutes**

Scanning parameters:
80mm/s for Ref. A & B
65mm/s for C
65mm/s for D

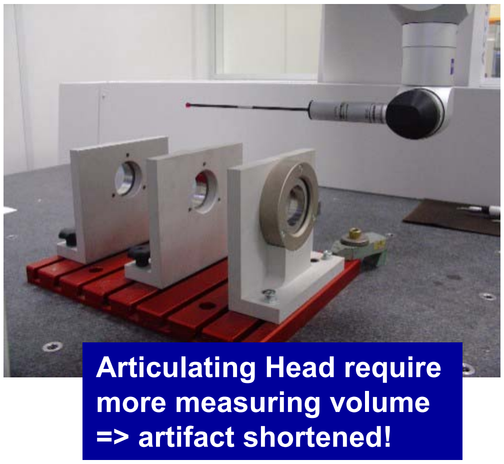
Capability values:
Position C (Tol 0,02mm): cg = 1,93
Position D (Tol 0,02mm) : cg = 3,48

Diameter D (Tol 0,016mm) cg = 37,5 cgk = 33,3

Roundness C (Tol 0,007mm): cg = 1,34
Roundness D (Tol 0,007mm): cg = 2,93

Figure 6:Result with Active Scanning, Navigator Technology and Fixed Probe Head

One short probe (250mm)



Articulating Head require more measuring volume => artifact shortened!

Time for 20 runs: 34 Minutes
Time for qualification of probe: 10 Minutes
Total time: **132 Minutes**

Scanning parameters:
50mm/s for Ref. A & B
10mm/s for C
10mm/s for D

Capability values:
Position C (Tol 0,02mm): cg = 0,73
Position D (Tol 0,02mm) : cg = 0,23

Diameter D (Tol 0,016mm) cg = 3,27 cgk = 3,02

Roundness C (Tol 0,007mm): cg = 3,07
Roundness D (Tol 0,007mm): cg = 2,19

Figure 7: Result with Passive Scanning and Articulating Probe Holder

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