Differentiating between serial, hybrid and parallel dimensional metrology

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Abstract

This article deals with the definition of the terms “serial metrology” and “parallel metrology” and the necessity to revise the existing definition to lay the basis of a clear and comprehensible classification of the metrology of multidimensional position or coordinate measuring systems (CMSs). The need for the revision is exemplarily shown with the classification of different CMSs according to the existing definition and the discussion of the results of it. Subsequently the revised definition for the given terms is proposed and the definition of the term “hybrid metrology” is added. Finally the re-classification of the chosen CMSs according to the revised definition is shown.

1 Introduction

The terms “serial” and “parallel” are widely used in the field of computing [1], medical testing [2] and kinematics [3]. However, they can also be used for describing the metrology of a multidimensional position or coordinate measuring device [4]. This concept considers the arrangement of different measuring systems and it is applied especially in micro- and nanometrology [5].
According to [4] serial metrology exists, when a “position sensor is assigned to each servo-controlled motion axis”. This definition also implies, that crosstalk or guiding errors are unnoticed and uncorrected in serial metrology. [4]
In parallel metrology, “each sensor measures the position of the same motion platform in the respective degree of freedom.” [4]. The crosstalk of the axes are kept inside the servo loop and can be corrected automatically according to the definition of parallel metrology in [4].
Although these definitions given in [4] of serial and parallel metrology exist, these terms are marginally used. However, the implementation of specific design aspects in parallel metrology offers the possibility to reduce the measurement uncertainty, which has already been used for high precision measuring systems [5], [6]. Due to the fact that a lot of conventional coordinate measuring systems (CMSs) (see [7]) have stacked x-, y- and z-stages (serial kinematic) as a positioning system, the definition of serial and parallel metrology in [4] works for those systems to a certain extent. However, a system, where each sensor measures the position of the same motion platform and, at the same time, is assigned to each servo-controlled motion axis (e.g. Stewart platform), can only be classified due to the crosstalk. Nevertheless, the definition of serial and parallel metrology should only be based on the setup of the sensors. Further design aspects, which need a certain setup of the metrology as a precondition, and their impact on the uncertainty are possible consequences of this arrangement and should not be included in the definition. Therefore a revision of the terms “parallel” and “serial” metrology is needed to provide a basis to clearly categorize the metrology of a system and to provide the possibility to establish these terms in the field of dimensional metrology. To clarify the need for the revision, different CMSs were exemplarily chosen and differentiated according to the definition given in [4]. Subsequently, we propose a revised formulation of the definition of the terms serial and parallel metrology to provide the basis for a comprehensible classification of measurement devices. Aditionally, a definition of the term “hybrid metrology” is added. To validate the revised definition, the exemplary CMSs are differentiated again according to the proposed definition.

2 Differentiation of different CMSs regarding their metrology according to [4]

In the following, different CMSs are exemplarily classified according to their metrology using the given definition in [4]. To simplify the classification, the probe system of every device is assumed a passive (micro) tactile probe system.

2.1 XENOS

The XENOS from ZEISS offers a length measuring error of 0.3 µm and a positioning accuracy clearly below 100 nm in a measuring range of 900 mm x 1500 mm x 700 mm. The XENOS uses stacked x-, y- and z-stages to move the probe (serial kinematic). The movement is detected by an incremental measuring system using encoders with temperature-stable high-resolution Zerodur scales. [8]
Regarding the definition in [4], the XENOS, like most conventional CMS, is a serial metrological system. A sensor is assigned to each of the stacked servo-controlled motion axis (see **Figure 1**) and in spite of the fact, that the guiding errors are being reduced and systematic errors are corrected by Computer-Aided Accuracy, random

guiding errors can neither be noticed nor corrected with the given measurement setup. Translational and rotational guiding errors as well as the non-orthogonality of the guides effects the axes of the machine coordinate system in terms of straightness and orthogonally.

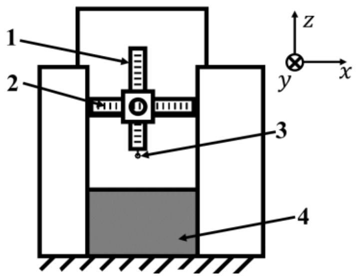

Figure 1 The XENOS from Zeiss: (1) z-scale, (2) x-scale, (3) tactile probe, (4) granite plate

2.2 Nanopositioning and Nanomeasuring Machine NMM-1

The well-known Nanopositioning and Nanomeasuring Machine NMM-1 provides a resolution of less than 0.1 nm in a range of 25 mm x 25 mm x 5 mm and a positioning accuracy below 10 nm. In [5] and [6] the NMM-1 is referred to as a parallel metrological system.

The positioning system of the NMM-1 is realized with stacked x-, y- and z- stages (serial kinematics) that move a corner mirror, on which the measuring object is located.

Flatness deviations and non-orthogonality of the corner mirror surfaces effects the axes of the machine coordinate system in terms of straightness and orthogonally

The three interferometers that are used as position sensors are attached to a common metrology frame and, therefore, have a fixed position to one another (see **Figure *2***). [5]

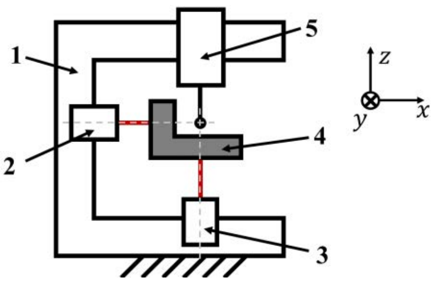

Figure 2 The NMM-1 according to [5]:
(1) Zerodur®metrology frame, (2) y-interferometer,
(3) z-interferometer, (4) corner mirror, (5) probe system

According to the definition in [4], the NMM-1 can be classified as a parallel metrological system. If the positioning system is moving the stages, the interferometers measure independently the resulting displacement of the same motion platform, the corner mirror. Due to this setup, the crosstalk of the positioning stages is measured with the interferometers and this information can be used for the control of the stage positions, so the crosstalk is kept inside the servo loop.

As a conclusion, the authors can confirm the classification of the NMM-1 as a parallel metrological system according to [4].

2.3 TriNano N100

The TriNano N100 enables a three-dimensional measurement in a measuring range of 200 cm^3. A measuring uncertainty of 100 nm was stated for the system. During the development of this machine attention was paid to obtain nanometre uncertainty and at the same time, reduce manufacturing costs greatly. Three identical translation axes, on which linear encoders are mounted, are located orthogonally to one another and in parallel and is therefore a parallel kinematics (see **Figure 3**). [9, 10]

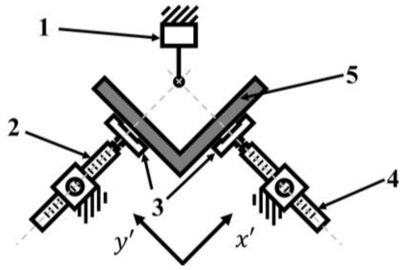

Figure 3 Schematic working principle (2D) of the TriNano N100 according to [10]: (1) probe system, (2) x'-bearing and scale, (3) vacuum preloaded air bearings, (4) y'-bearing and scale, (5) measurement table

In the case of the TriNano N100, a sensor is assigned to each servo-controlled motion axis and guiding errors of the individual axis are unnoticed and uncorrected, which would comply with the first part of the definition of serial metrology in [4]. At the same time, each sensor measures the position of the same motion platform in the respective degree of freedom, which is part of the definition of parallel metrology.

Flatness deviations and non-orthogonality of the measurement table surfaces as well as the constancy of the air gaps of the preloaded air bearings effects the axes of the machine coordinate system in terms of straightness and orthogonally.

The only way to differentiate between the metrologies is to look at the crosstalk. Since the crosstalk resulting from flatness deviations and non-orthogonality of the table surfaces cannot be measured with the given encoders and, therefore, cannot be corrected, the TriNano N100 is a serial metrological system according to the definition in [4].

2.4 NanoCMM

The NanoCMM is a CMS with low moving mass for fast three-dimensional measurement in the measuring volume of 50 mm x 50 mm x 4 mm. A volumetric uncertainty of 25 nm was stated for the system. The two x- and y-scale beams and two intermediate bodies with optical measuring heads are located on the horizontal air bearing system of the machine (see **Figure 4).** The z-mechanism, that carries the probe, provides the vertical motion and is connected to the

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x- and y-scale beams via a mounting face (see **Figure 5**). [11]

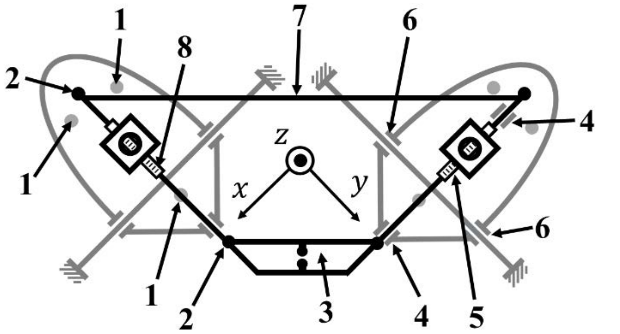

Figure 4 The horizontal plane of the NanoCMM according to [11]: (1) Three bearings between the intermediate body and the machine base, (2) two bearings between scale beam and the machine base, (3) plate with an elastic hinge, (4) two bearings between scale beam and intermediate body (asymmetrical), (5) x-scale, (6) two bearings between guiding beam and intermediate body, (7) rod, (8) y-scale

In the case of the NanoCMM, a sensor is assigned to each servo-controlled motion axis. The x- and y-scale beams measure the position of the same motion platform.

Since the z-mechanism is stacked onto the x- and y-scale beams, the measurement system of the z-axis is located on the motion platform and measures the movement of the probe in the z-axis therefrom. [11]

Translational and rotational guiding errors as well as the non-orthogonality of the guides effects the axes of the machine coordinate system in terms of straightness and orthogonally.

Due to this composition, crosstalk of the z-axis is unnoticed and uncorrected. For this reason, the authors would classify the NanoCMM as a serial metrological system according to [4].

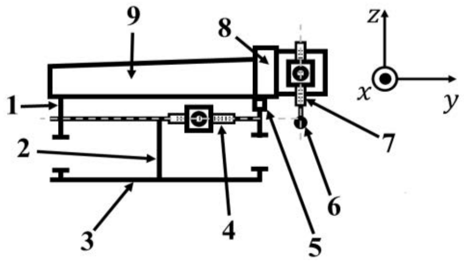

Figure 5 The vertical plane of the NanoCMM: (1) rod, (2) stress frame, (3) holder with preload bearings, (4) y-scale, (5) cross beam on rods, (6) probe system, (7) z-scale, (8) mounting face, (9) strip-on-edge plate

3 Discussion of the differentiation according to [4]

The abovementioned classification shows, that it is ocassionally difficult to differentiate between serial and parallel metrology according to the given definition in [4]. A conventional CMS with stacked x-, y- and z-stages and position sensors in every axis, like the XENOS, can be classified as a serial metrological system with the given definition in [4]. The NMM-1, where the x-, y- and z-interferometers measure the position of the moving platform in parallel, can less clearly be classified as a parallel metrological system, since a position sensor is assigned to each servo-controlled motion axis. However, the second part of the definition of serial metrology cannot be applied to the system and, therefore, it can be classified as a parallel metrological system. Regarding the classification of a CMS, it becomes more challenging as soon as the arrangement diverges from this common system setup with stacked x-, y- and z-axis (serial kinematic), since the formulation of the definition is based on different aspects.

For the TriNano N100 the definitions for serial as well as for parallel metrology is largely applicable. Since the definition of parallel metrology does not give any information about guiding errors, information about those cannot be used for the differentiation. Therefore, only the unnoticed and uncorrected crosstalk leads to the conclusion, that the system is serial metrological. However, the setup of this metrology system is very different to that of a common CMS with serial metrology, like the XENOS. If we only look at the setup of the sensors of the TriNano N100, we can state, that they are arranged in parallel. For this reason and in contrast to the classification according to [4], the authors of this paper would classify the TriNano N100 as a parallel metrological system.

Further, the authors do not agree with the classification of the NanoCMM as a serial metrological system. Regarding the horizontal set-up of the NanoCMM, the x- and y-position sensors do measure the position of the same element in parallel. However, the z-sensor is attached to this element and measures the displacement in z-direction therefrom, so the whole NanoCMM cannot be classified as a parallel metrological system. Instead of a classification of the whole system as a serial metrological system, the authors of this paper propose the classification as a hybrid metrology, since, to their understanding, elements of parallel metrology and serial metrology both exist.

4 Revised definition

The aforementioned examples and the discussion show the necessity for a revised formulation of the definition of serial and parallel metrology and the introduction of hybrid metrology.

If there is only one position sensor, the metrology or rather the mutual set-up of measurement systems can not be classified. This is why the precondition for the differentiation is, that there are at least two position sensors. Another precondition is that we only take the position sensors into account, which are not measuring on the same axis and, therefore, provide further information on the orientation or the position of the moving element.

The authors of this paper propose the following definition:

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“In serial metrology, the position sensors are not arranged in order to measure the position change in between the same moving stage and a common (fixed) reference system directly.”

“In parallel metrology, every position sensor is arranged in order to measure the position change in between the same moving stage and a common (fixed) reference system directly.”

“In hybrid metrology, only parts of the metrological system (at least two sensors) but not the whole system can be classified as parallel metrological while the other part of the metrological system (at least two sensors) can be classified as serial metrological.”

Additional to this revised definition, it also can be useful to take a look at the measurement loops [12] of each sensor. Normally, a parallel metrological system only should have an overlap of the measurement loops in parts of the probe, the measurement table and the measuring object.
This property helps to differentiate between serial and parallel metrology, but it is not part of the definition. The revised definition is only based on clearly identify aspects of the physical sensor set-up.

5 Differentiation of different CMSs regarding their metrology according to the revised definition

To validate the revised definition and to show its application, the different coordinate measuring machines, which have already been classified regarding their metrology according to the definition in [4], are going to be differentiated according to the revised definition proposed in this paper.

5.1 XENOS

In case of the Zeiss XENOS, the y-position sensor measures the position change between the machine frame and the upper cross bar (y-axis). The x-position sensor and the z-position sensor measure the horizontal position change of the vertical bar and the vertical position change of the measuring probe, respectively. Therefore, every position sensor measures the position change in between different stages and different reference systems. As a result, the XENOS can be classified as a serial metrological system.

5.2 NMM-1

Every interferometer of the NMM-1 measures the position change of the corner mirror. The interferometers are attached to the metrology frame, which functions as a common fixed reference system. For this reason, the NMM-1 itself can be classified as a parallel metrological system.

However, since the NMM-1 is used as a development platform for different probe systems, additional axes are sometimes added to the system [13, 14, 15]. Adding these additional axes with its own positioning sensors to the corner mirror (as in [13]) or to the probe system (as in [14]) makes the metrology of the whole system a hybrid metrology.

5.3 TriNano N100

Every linear encoder of the TriNano N100 measures the position change of the measurement table, which can be considered as the moving stage, with respect to the fixed machine basis. If this probe is not exchanged, the TriNano N100 can be classified as a parallel metrological system according to the definition proposed in this paper.

5.4 NanoCMM

Regarding the horizontal plane of the NanoCMM, the x- and y-position sensors measure the position of the same moving stage directly. Thus, this part of the measuring device is parallel metrological. However, the z-stage is attached to this stage, which functions as the reference system for the z-measurement. The Sensor does not measure the position of the same stage as the x- and y-position sensor. Therefore, the z-position sensor is not measuring in a direct way with regards to the reference system of the x- or y- position sensors. Since part of the system can be classified as a parallel metrological system and part of the system can be classified as a serial metrological system, the whole metrology of the NanoCMM is a hybrid metrology.

6 Conclusion

A revised definition of the terms “serial” and “parallel” metrology and the introduction of the term “hybrid” metrology has been proposed in this paper.
The differentiation of the selected coordinate measuring machines according to the existing definition in [4] was not quite clear and comprehensible and deviated from the expected classification.
Since the revised formulation is only based on the setup of the position sensors and not on any further design aspects, the NMM-1 and the TriNano N100 could be classified as parallel metrological systems. In addition, the term “hybrid metrology” offers the possibility to classify systems, in which some of the position sensors are measuring in parallel, but also some of the position sensors do not, like in the NanoCMM.
The proposed definitions of the terms “serial metrology”, “hybrid metrology” and “parallel metrology” are supposed to lay the basis for the classification of metrological devices and to establish the given terms in the field of dimensional metrology.

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7 Literature

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