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Verification of an articulated arm coordinate measuring machine using a laser tracker as reference equipment and an indexed metrology platform

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ABSTRACT

In this work the analysis of the use of a laser tracker as a reference instrument in calibration and verification procedures for articulated arm coordinate measuring machines (AACMM) with an indexed metrology platform is presented. In the case of AACMM verification procedures, where it is necessary to evaluate its maximum working volume, this technique represents an alternative to conventional one-dimensional gauges and avoids the need of materializing the lengths required for a conventional gauge by increasing the flexibility for defining test positions and broadening the definition of reference test lengths depending on equipment calibration or verification requirements. First a procedure for the AACMM verification with the indexed metrology platform (IMP) and the laser tracker (LT) used as a reference instrument was defined and the required accuracy of the equipment was assessed. The experimental testing to validate its proper application was carried out by means of laser tracker measurements of six retroreflector targets located in a mesh that simulated the AACMM working volume. Finally, the results obtained with both equipment, laser tracker and AACMM with indexed metrology platform, showed that the procedure presented is suitable and that the laser tracker could be considered as a reference instrument for AACMM verification processes when the nominal accuracy of the laser tracker is assured.

1. Introduction

Calibration and verification processes for portable measuring instruments require calibrated gauges to establish the reference dimensions which will be used to calculate the errors of the measuring process. In regard to articulated arm coordinate measuring machines (AACMMs), its usage comes from the verification processes of coordinate measuring machines (CMMs) where the verification is carried out by measuring gauges which materialize the dimensions to be quantified. One-dimensional, two-dimensional or three-dimensional gauges are commonly employed in these types of procedures. Gauges that could materialize more than one dimension allow reducing the number of positions of the gauge within the CMM verification procedures which results in the reduction of testing time and cost.

In regard to AACMM it is required to evaluate most of its working volume throughout the verification process, which makes one-dimensional gauges appropriate for this type of procedures, mostly due to its easy movement

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around the measuring equipment that allows to settle the testing positions according to the applicable evaluation norms [1–3]. Examples of this type of gauges are ball bars which materialize distances between spheres. They are extensively used in AACMM calibration and verification procedures due to its flexibility, high precision, low cost and easy use concept in comparison with other gauge types [4,5]. Verification standards [1–3] used this type of gauges in their specified testing protocols. Kovac and Frank [6] developed a new high precision measuring device for AACMM testing and calibration based on laser interferometer measurements along a line gauge beam. Santolaria et al. [5,7–10] reported a method to calibrate an AACMM based on the Denavit–Hartenberg kinematic model parameters [11]. These parameters are optimized measuring a calibrated ball bar gauge located at different orientations and positions of the AACMM working volume. In [12] the authors developed a metrological model to identify the kinematical parameters of a measuring arm as well as the errors associated with its measurements and in [13] was established an online simulation system called virtual articulated arm coordinate measuring machine, which allows the evaluation of measurements' accuracy as well as the determination of the compensation matrix using ball bar gauges. Regarding tridimensional gauges, Shimojima et al. [14] presented a method to estimate the uncertainty of an AACMM, involving the use of a three dimensional ball plate gauge with nine balls which is oriented in five different positions. As a result the kinematical parameters of each joint were determined. A similar approach for tridimensional gauges is shown in [15].

The use of kinematic seats in AACMM's calibration procedures is extended and shows advantages in comparison with other gauges as presented in [16], where kinematic seats are used for estimating the repeatability of the arm. In [17] it is proposed a solid plate composed of kinematic seats as gauge for AACMM's calibration. Piratelli [18] introduces the development of virtual geometry gauges, virtual ball bar, to evaluate the performance of AACMMs. The proposed gauge has two groups of four holes each that are used to determine points of the spherical surfaces. These points are fitted to spheres using computational algorithms and the distances between spheres centers are calculated and compared to the calibrated length. In further works of the same author [19], a virtual sphere plate gauge is developed defining 16 groups of four conic holes placed on aluminum pyramidal blocks. These groups determine 16 virtual spheres by taking points in each conic hole with a CMM rigid probe and a spherical stylus on the arm extremity. Performance test according to ASME B89.4.22, 2004 are carried out and the uncertainty of the virtual sphere plate is calculated. As mentioned in [18] the virtual sphere concept is applied in order to reduce the number of test positions specified in the standards [1–3] and increase the efficiency of the verification procedure for AACMM. Another approach to this concept using a virtual circle instead of virtual spheres as proposed in [18] for AACMMs evaluation, is done by Gonzalez et al. [20,21]. They present a virtual circle gauge method composed of two aluminium alloy bar gauges of 1000 mm length with four groups of three conic holes which determine the four virtual circles. The same author in [22] analyzes the influence of the contact force applied by the operator on the performance of AACMMs by means of a contact force sensor and a ring gauge, proposing a probe deflection model to reduce the diameter error. AACMMs are manually operated, fact that allows that a same point could be measured from multiple arm's poses. This is a big advantage but it consequently makes AACMM's repeatability and accuracy to be lower than in CMMs. In relation to this point and in order to identified accurately the metrological characteristics of an AACMM, Cuesta et al. [23], develop a novel gauge for AACMM's verification and calibration which includes multiple geometries in the same gauge, manufactured conic holes on each gauge sides that will allow the measurement of distances between centers and diameters of the virtual spheres defined by the conic holes.

Nevertheless, the physical nature of the gauge itself imposes limitations on the number of distances to be materialized within the tests, due to the reason that the number of test lengths is restricted to the gauge length or to the distance combinations between gauge sphere centers. On these grounds, sometimes several gauges should be used in the same testing procedure to increase the number of test lengths.

In order to develop new gauges and alternative calibration and verification techniques applied to AACMM, in this work the analysis of the use of a laser tracker as a reference instrument in the calibration and verification procedures of AACMM replacing the conventional one-dimensional gauges as ball bars is presented. This technique avoids the need of materializing the length required in a conventional gauge, increasing the flexibility for defining test positions and broadens the definition of reference lengths depending on equipment calibration or verification requirements.

The first developments of measurement based on laser tracker applied to accuracy analysis for robots dates back to the 1980s [24–26]. But recently the dimensional verification for large range structures in automation or aeronautic sectors [27] has pushed forward and laser tracker technology has grown substantially over the last 20 years. The need for improving current dimensional verification techniques available for large volume parts and for machine tool calibration and verification [28] has led to the evolution of large scale non-contact measuring equipment as laser trackers or lacer tracers. The laser tracker is a large scale portable measuring instrument with high accuracy that measures the position of an object in spherical coordinates. It uses interferometry for measuring relative distances and optical encoders for azimuth and elevation angles of a beam steering mirror. A laser tracker is composed of the following components: laser source, a beam steering mechanism with angular encoders, interferometer, position sensor detector (PSD), beam splitting optics, a retroreflector and a control unit. These components are used to track the target, typically an spherically mounted retroreflector (SMR) and measure its center x, y and z coordinates. Its working principle [29,30] is based on a source beam emitted by the interferometer which is divided into two by the beam splitting optics. The measurement beam travels from this beam splitter to the