Measurement 82 (2016) 202–220

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Uncertainty estimation of an indexed metrology platform for the verification of portable coordinate measuring instruments

R. Acero [a,*], J. Santolaria [b], M. Pueo [a], J. Abad [c]

[a] Centro Universitario de la Defensa, Academia General Militar, Ctra. Huesca s/n, 50090 Zaragoza, Spain
[b] Department of Design and Manufacturing Engineering, University of Zaragoza, María de Luna 3, 50018 Zaragoza, Spain
[c] Department of Mechanical Engineering, University of Zaragoza, María de Luna 3, 50018 Zaragoza, Spain

ARTICLE INFO

Article history:
Received 8 June 2015
Received in revised form 21 November 2015
Accepted 19 December 2015
Available online 23 December 2015

Keywords:
Uncertainty
Indexed metrology platform
Monte Carlo

ABSTRACT

This work presents the development of an uncertainty estimation procedure for an indexed metrology platform. The use of an indexed metrology platform in calibration and verification procedures for portable coordinate measuring instruments, enables the evaluation of different working volumes of the instrument that rotates with the platform in six rotating positions without moving the gauge from a fixed location, reducing in this way the testing time and test setups in comparison with the tests included in the applicable standards. The platform is able to express points in a global reference coordinate system located in the lower platform through its mathematical model. Due to the platform model complexity and according to the GUM supplement 1, the propagation of distributions using the Monte Carlo method was applied to estimate the platform measurement uncertainty. The different error sources affecting the platform uncertainty were first identified. An analysis of the dynamic behavior of the platform by means of a computational and experimental modal test was done in this work. The capacitive sensors assembled in the platform determine the position and orientation of the upper platform with respect to the lower platform and were selected as input variables of the model with their related errors. The n-homogeneous transformation matrices obtained in the simulation as output variables will allow the coordinate reference system change from the upper platform to the lower platform. In this way, it is possible to estimate the influence of the indexed metrology platform position and orientation uncertainty in the generation of points in a global reference system and as a consequence, its influence in a distance measurement.

1. Introduction

According to the GUM supplement 1 [1], the measurement uncertainty estimation through distributions propagation using the Monte Carlo method gives a guidance for measurement uncertainty expression when the conditions for the GUM uncertainty framework [2] are not fulfilled or it is difficult to apply it due to the complexity of the model [3–5]. The approach is based on the n-iterations repetition of sampling from the probability distribution function of the input variables and the evaluation of the model in each event. The following stages are carried out in the uncertainty estimation procedure developed in this work:

– Selection of the output variable Y.
– Definition of the input variables X_i upon Y depends and their probability distribution functions.

* Corresponding author. Tel.: +34 976739831; fax: +34 976739824.
E-mail address: racero@unizar.es (R. Acero).

http://dx.doi.org/10.1016/j.measurement.2015.12.024
0263-2241/

– Development of the mathematical model liking the input variables X_i and the output variable Y.
– Propagation of the input variables probability distribution functions through the model to obtain the output variable probability distribution function.
– Estimation of the output variable Y most probable value, its uncertainty as a standard deviation and the confidence interval.

Extensive literature in regard to the use of the Monte Carlo method in measurement uncertainty estimation procedures have been identified [3,6], applied to coordinate measuring machines (CMMs) uncertainty analysis [4,5,7–9] or to articulated arm coordinate measuring machines (AACMM) as is Romdhani et al. [10] and in Ostrowska [11].

This work focus on the uncertainty estimation of an indexed metrology platform (IMP) using the Monte Carlo method due to the complex mathematical model of the platform. The indexed metrology platform is an auxiliary instrument to be used in calibration and verification procedures for portable coordinate measuring instruments (PCMMs) to evaluate their volumetric accuracy and repeatability [12]. Brau et al. [13] proposed the use of this platform whose main advantage resides in the reduction of the time and physical effort required to carry out these type of procedures. This is achieved by fixing the calibrated gauge object and placing the AACMM on the IMP's upper platform throughout the verification procedure, in comparison with the conventional procedures established in the standards ASME B89.4.22-2004 standard [14], VDI/VDE 2617-2009 part 9 guideline [15] and ISO/CD 10360 part 12-2014 draft [16]. It is the portable measuring instrument placed on the IMP the one that rotates jointly with the upper platform during the verification procedure, enabling a great coverage of the AACMM's working volume and the definition of a broad number of testing positions but avoiding the movement of the calibrated gauge object during the verification. Moreover, not only testing and set up times are reduced with the use of the IMP, but also the space needed in the data capturing process is diminished since the number of physical testing positions of the gauge are minimized. Each time the platform rotates to a new position allowing the AACMM to measure the same point in the gauge, the values of the AACMM's encoders change, and therefore a new working volume of the instrument is evaluated. The IMP is composed of two hexagonal platforms, one fixed lower platform and a mobile upper platform which rotates around the fixed one every 60° allowing the definition of six different positions, see Fig. 1. The mechanical repeatability of the platform is achieved by means of kinematic couplings configuration of spheres and cylinders. Three reference spheres located on each platform, allow the determination of the reference systems of both platforms and the possibility to express the coordinates of a captured point by the AACMM in the fixed lower platform global coordinate system during the verification procedure. By means of a mathematical model explained in Brau et al. [13] a homogenous transformation matrix (HTM) is found allowing the change of the coordinate reference systems required. The IMP has also a high mechanical position repeatability, being capable of measuring with high precision the orientation and position of the upper platform with respect to the lower platform. This feature is accomplished with the use of six capacitive sensors with nanometer resolution and measuring range of 100 μm for an output voltage from 10 to −10 V and an operational range from 100 to 200 μm with their sensors and targets assembled in the upper and lower platforms respectively.

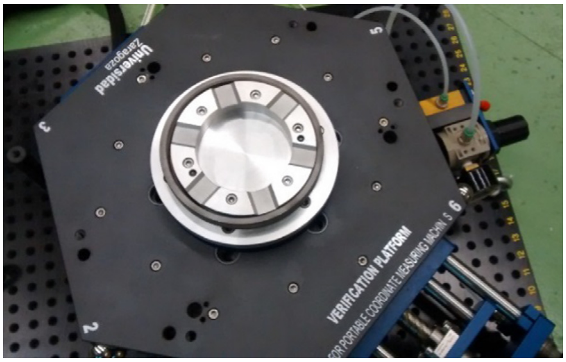

Fig. 1. Indexed metrology platform.

2. Model input variables definition

Prior to evaluate the uncertainty of the indexed metrology platform model, it is necessary to define and select the model input variables X_i which could affect the output variable Y. In this case, the possible error sources that may influence the uncertainty of the indexed metrology platform are the platform calibration uncertainty, the capacitive sensors assembled in the platform, the error of the portable measuring equipment that will be used with the platform, the temperature and the dynamic behavior of the platform during the measuring process.

The *calibration procedure* of the indexed metrology platform uses a geometric mathematical model based on the readings and the geometric features of the six capacitive sensors and their corresponding targets. In the calibration process of the platform, the readings of the capacitive sensors will be used as measurement values and the results obtained in the measurement with a coordinate measuring machine (CMM) will be considered as calibrated values, correcting the capacitive sensor ones. The final target of the indexed metrology platform calibration is to determine from the readings of the capacitive sensors a homogeneous transformation matrix that will allow a coordinate reference system change from the upper to the lower platform where the global coordinate reference system is located. The matrix obtained is a single matrix per point measured during the calibration or verification procedure of the portable coordinate measuring instrument. Once all the geometric features of the sensors and the corresponding targets are obtained and expressed in the global coordinate reference system, an identification procedure of the optimum geometric features is launched. These parameters will be the ones that will minimize the difference between the distance measured with the capacitive sensor and the