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Monte Carlo method to machine tool uncertainty evaluation

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Abstract

Currently machine tools are not only a way to make different parts based on material removal processes. These ones can be used as a measurement system too. In this way, overall inspection time is reduced and equipment productivity is increased.
Nevertheless, the use of machine tool probes as measurement tool in manufacturing parts required previous works. Firstly, the machine tool accuracy should be improved, in order to reduce the influence of its geometric errors. This way, volumetric verification based on laser tracker measurement has increased strongly in the last few years, especially in long range machine tools. Secondly, calibration uncertainty should be calculated to provide measurement uncertainty.
This way, the paper presents a new tool able to analyze the effect of different influence verification parameters in calibration uncertainty based on Monte Carlo method. Using real tests carried out on a milling machine and its geometric errors, the influence or laser tracker measurement noise in calibration uncertainty is studied using Monte Carlo method.

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Keywords: Volumetric verification; laser tracker; machine tool; uncertainty; Monte Carlo.

1. Introduction

Machine tool calibration (MT) is defined as the process from which the influence MT geometric errors is obtained. This way, the MT accuracy is increased reducing the influence of these systematic behavior through software compensation.

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Currently there are two different ways to obtain MT geometric errors. First one, determines the influence of each error from each axis in a particular position of the workspace of the MT [1]. Second one, indirect measurement method, obtain the joint influence of MT geometric errors based on multi-axis movement and MT kinematic model [2]. Meanwhile direct measurement provides the real physical behaviour of each error, indirect one provides a join optimum values. However, the relationship between geometric errors obtained using direct measurement is not studied and approximation functions obtained are directly extrapolated to all MT workspace. Similarly, each error needs an own assembly measurement procedure and data treatment; increasing substantially verification time. These are the principal reasons why volumetric verification (VV) based on indirect measurement errors using laser tracer, laser tracker or ball bar as measurement systems, are daily more popular than geometric verification, based on indirect measurement using laser interferometer, levels, etc.

Calibration process result is associated with calibration uncertainty value. It characterizes results dispersion in relation with geometric errors obtained and sources of errors that affect it. This one is considered especially relevant in different manufacturing and quality assurance processes. It is required when the MT is used as measurement system; providing metrological characteristic required to obtain a traceable measurement system.

The International Organization for Standardization (ISO) has developed and published different guidelines for the representation of measurement uncertainty (GUM), such as the UNE-ISO / TR 230-9 [3] standard for measurement uncertainty estimation for machine tool test, or ISO / TS 14253-2 [4], widely accepted. It combines the estimation of the different sources of error and their associated typical uncertainties, to determine the typical uncertainty associated with the overall process. This way, accuracy and metrological characteristic of a MT as measurement system are related to measurement system used, machine tool and calibration conditions. The GUM provides the basic framework for evaluating uncertainty in measurement, but it does not work properly in non-lineal process such as MT calibration based on VV. As errors that affect to VV have a random and probabilistic behavior, Monte Carlo method is recommended to obtain its uncertainty.

This paper presents a new simulation software developed to study how different factors with influence in volumetric verification affect to calibration uncertainty. The software allows the use of different probabilistic error functions (PDFs) to characterize the behaviour of each error source. Within different sources of uncertainty, this paper is focused on the study of laser tracker measurement noise influence. So, using a real milling machine with XFYZ configuration, a LT Leica LT 600 and a probe as measurement system and our own developed software, real tests have been carried out.

2. Comparison of the GUM and Monte Carlo Method to determine the uncertainty of a machine tool volumetric verification process

2.1. Volumetric verification and influence factors

Volumetric verification is based on an intensive process of parameters identification through the kinematic model of the MT. Minimizing the difference between theoretical and real pair of points, through the MT kinematic model, the joint influence of MT geometric errors are obtained. Their behavior are modeled minimizing the mean square volumetric error of the machine (Ev) using non-lineal optimization techniques [2].

As shows Fig. 1, principals' uncertainty sources with influence on machine tool verification are divided in three groups: machine tool, measurement and verification, and measurement system uncertainties.