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Evaluating a task-specific measurement uncertainty for gear measuring instruments via Monte Carlo simulation

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ABSTRACT

Evaluating the measurement uncertainty for gears with analytical or experimental methods is usually very time- and cost-consuming. In this paper we therefore present a Monte Carlo based method for evaluating the measurement uncertainty of gear measurements on gear measuring instruments, the VCMM-Gear, which is based on the method of the VCMM for coordinate measuring machines. Necessary extensions of the mathematical model of the measurement process in order to consider the significant uncertainty influences from rotary tables, workpiece clamping and scanning are described. Additionally the statistical reliability of the evaluated measurement uncertainty and the consideration of systematic error contributions to the measurement uncertainty are discussed. Finally the results of some first verification measurements are presented, giving a reliable impression of the capability and suitability of the VCMM-Gear.

1. Introduction

1.1. Motivation

Gears are rotationally symmetrically objects with a tooth system worked into the rim [1]. As parts of gear boxes they are of paramount importance in transmission industry. High demands are made on them regarding life expectancy, power transmission, running smoothness and noise emission. These demands are linked with high requirements for the geometric quality of the gears used, apparent in small manufacturing tolerances. Depending on size and field of use these often amount to a few micrometers only.

Compliance with these tolerances is often checked via measurements by coordinate measuring machines (CMM) or gear measuring instruments (GMI). This is only feasible if a proof of suitability of the instruments or measurement process is available [2]. Thus, a quantitative measure of the quality of the indication value is needed. This measure is the associated measurement uncertainty. A complete measurement result therefore consists besides the quantity value of a task-specific measurement uncertainty as a measure of the "reliability" of the quantity value [2]. Without a statement of the uncertainty a comparison of different measurement results or evaluation of the conformity to tolerances is not possible.

The more demanding the quality requirements of an object (i.e. the smaller the manufacturing tolerances) are, the more important is the unambiguous and traceable qualification of the measurement process used. An erroneously determined measurement uncertainty can cause follow-up costs as the decision on "go/no-go"parts may be compromised [3,4].

This leads to a great need for simple and universally applicable strategies for evaluating a task specific measurement uncertainty of gear measurements. As gears come in a large variety of geometries and the influence quantities are quite complex, common analytical and experimental methods of uncertainty evaluation are very time- and cost-consuming. Thus, a Monte Carlo based method for evaluating the uncertainty of gear measurements on GMIs was developed, the VCMM-Gear.

The versatility and applicability of uncertainty evaluation by Monte Carlo simulations was addressed for example in [5]. Apart from work performed at PTB concerning the Virtual Coordinate Measuring Machine [6], different groups adopted the concept of Monte Carlo simulation for calculating the task-specific uncertainty of measurements on CMMs and other 'multi-purpose measuring instruments' like articulating arms [7]. An approach for GMI was presented in [8]. The Virtual Gear Checker (VGC) is an offline computer program that considers the structures, motions and possible error factors of real gear measuring instruments. The VGC particularly focuses on analyzing effects of different error factors on

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laboratory basis which could be used by well educated gear scientists. In contrast, the VCMM-Gear can be seen as a traceable calibration technique which can be integrated in various CMMs or GMIs. As an online implementation it allows any user to determine the individual measurement uncertainty of each gear measurement automatically. Therefore, the VCMM-Gear considers all effects with significant influence on the measurement budget at the point of use. These are errors of the machine kinematics, actual measurement strategies, drift effects, environmental conditions and the important influence of the workpiece itself.

1.2. Outline of work

The VCMM-Gear is an extension of the Virtual Coordinate Measuring Machine (VCMM), which was developed at PTB in order to evaluate the task-specific measurement uncertainty on CMMs [6]. As a simulation software it allows the automatic determination of a task specific measurement uncertainty considering all significant error contributors. The basic principle is the replication of the entire measurement process. The randomly chosen error contributors lead to perturbations of the individual point coordinates. The simulation is equivalent to a sufficiently large set of real measurements, performed under varying measurement conditions. Similar to a classical uncertainty budget, the mathematical model of the measurement process and the influence quantities acting on the measurement process provide the basis for the calculation of the measurement uncertainty. The procedure thus meets the requirements of international directives, standards and guidelines [9,10].

The major objectives of transferring the VCMM approach to gear measurements were

- to set up the mathematical model of the gear measurement process on GMIs,
- to develop suitable methods for ascertaining the influencing parameters,
- to develop statistical evaluation methods suitable for taking into account uncorrected uncertainty influences and for ensuring the statistical significance of the resulting uncertainties, as well as
- to implement the developed models in an easy-to-use software and
- to define interfaces which allows the easy integration of the so called VCMM-driver into commercial gear evaluation software.

As modern GMIs and CMMs share a similar design, kinematic and probing system, the transfer of some mathematical models developed for CMMs to GMIs were possible. Nevertheless, additional models for additional significant influence quantities needed to be developed. These included models describing the uncertainty influence of the rotary table, the clamping of the workpiece and the scanning principle of modern probing systems, as the original VCMM was developed for single-point-probing only.

The new models were combined in a simulation software evaluating the measurement uncertainty following an adaptive Monte Carlo-procedure, allowing the provision of measurement uncertainty with a predefined statistical reliability.

This paper presents the new mathematical models implemented in the VCMM-Gear and discusses the results of a comparison of the VCMM-Gear to an experimental uncertainty evaluation performed in order to verify the simulation concept.

2. General steps of a gear measurement

The gear measurement process is composed of many single steps, including various simple measurement tasks, calculations and corrections as depicted in Fig. 1. As modern GMIs and CMMs are universally applicable, they can perform a multitude of measurement tasks. First step in gear measurement planning is the definition of measurands, necessary transformations and points to be measured. Many of these steps can be done automatically by the application software.

When performing the measurement, the workpiece is mounted to the instrument, the probing stylus needs to be verified by the instrument and the position of the workpiece needs to be "found" as well. Then, the measurement of the object may start. The measurement finally yields the measured points, which are composed of information about the position along the guideways, the rotary table position and the stylus deflection. The points are internally corrected for known systematic instrumentations errors, transformed to a convenient coordinate system and finally used to compute an indication value for the measurands such as profile and helix form deviations.

Each of these steps is subject to various error influences, which may result in deviations of the indication of the instrument from the correct value of the measurand. The main sources of influences are the measuring instrument, prevailing environmental conditions, the object to be measured, the measuring strategy and the operator. All these influence quantities need to be taken into account in the uncertainty budget.

As these quantities influence the measured points, their cumulative effect on the indication of measurement depends on the evaluated measurand since due to the calculation of the points (e.g. fitting and filtering algorithms) some influences may be negligible.

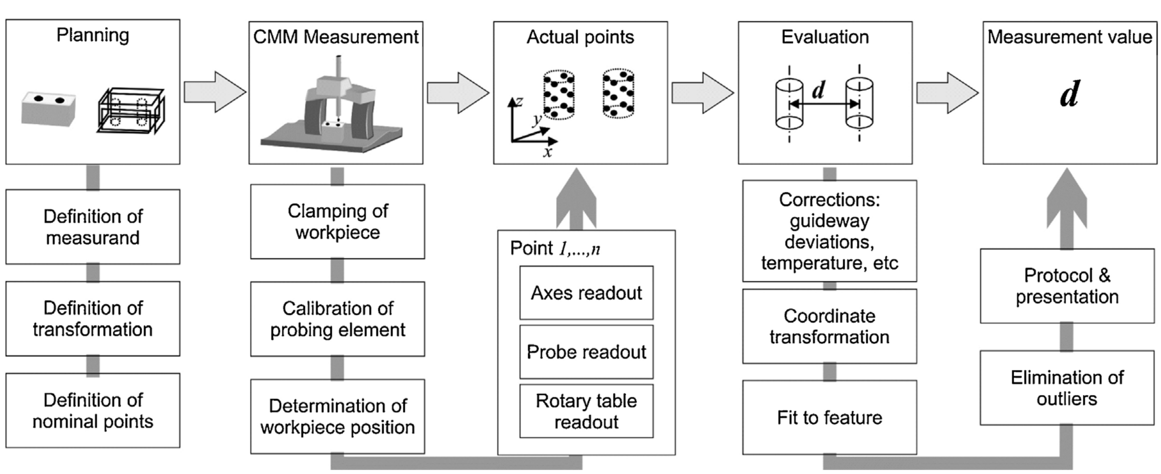

Fig. 1. Schematic steps of a measurement with CMMs and GMIs.