

Calibration of Master Gears on Coordinate Measurement Machines

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American Gear Manufacturers Association



TECHNICAL PAPER

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and Dr. Earnest Walker, NC A&T State University**

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Primary-level calibration of master gears requires quantifying the measurement uncertainty on the artifact being calibrated by a method that does not rely on a transfer comparison. The measurement decomposition method, developed jointly by National Institute of Standards and Technology (NIST) and Oak Ridge Metrology Center (ORMC) personnel, is used to determine the uncertainty of each component of the measurement task. Once quantified, these components are added in quadrature according to NIST Technical Note 1297, 1994 Edition. Verification of this method can be accomplished by inter-comparisons with other methods and laboratories. The techniques developed at NIST and ORMC utilize a CMM with a rotary table, a FORTRAN program for involute data generation, and a ProEngineer solid model for gear visualization.

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American Gear Manufacturers Association
1500 King Street, Suite 201
Alexandria, Virginia, 22314

October, 1998

ISBN: 1-55589-724-X

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Introduction

There is no standard for uncertainty determination; however, there are at least five approaches used in industry. The Global approach uses ANSI/ASME B89.1.12M-1990² or similar performance tests to form a basis for uncertainty estimates. The Virtual Coordinate Measuring Machine (CMM) method requires a detailed model of all the machine and probing errors. Once this model is created the predicted machine errors can be combined appropriately with the artifact geometry to predict the measurement errors for specific measurement tasks. The Comparator method involves measuring

a master artifact and a test artifact one after the other in the same position on the measuring machine. A calibrated artifact nearly identical to the workpiece is required but very low uncertainties can be achieved. The Surrogate artifact method approximates a measurement task on a spatial arrangement of reference (simple geometry, low uncertainty) artifacts. The Decomposition method breaks down the measurement task into its basic components. The method uses reference artifacts to characterize measurement errors and their effect on the final measurement task.

This paper describes the general concept of measurement decomposition for a master gear. A more detailed discussion of each uncertainty method is provided in Y-12 Technical Report Y/AMT-328³.

Master Gear Measurement Decomposition

In the case of a master gear, the uncertainty determination consists of measuring an involute profile artifact, a tooth alignment artifact, and an index artifact in the same orientation as a gear. The uncertainty of each artifact has been previously determined measurement decomposition and repeatability measurements are made in the new orientation to determine the uncertainty of each feature (involute profile, tooth alignment, and index). For the involute profile artifact and the tooth alignment artifact, the reference surfaces are a plane and one shaft center, when orientated on the rotary table. The artifacts are shown in figures 1-3.

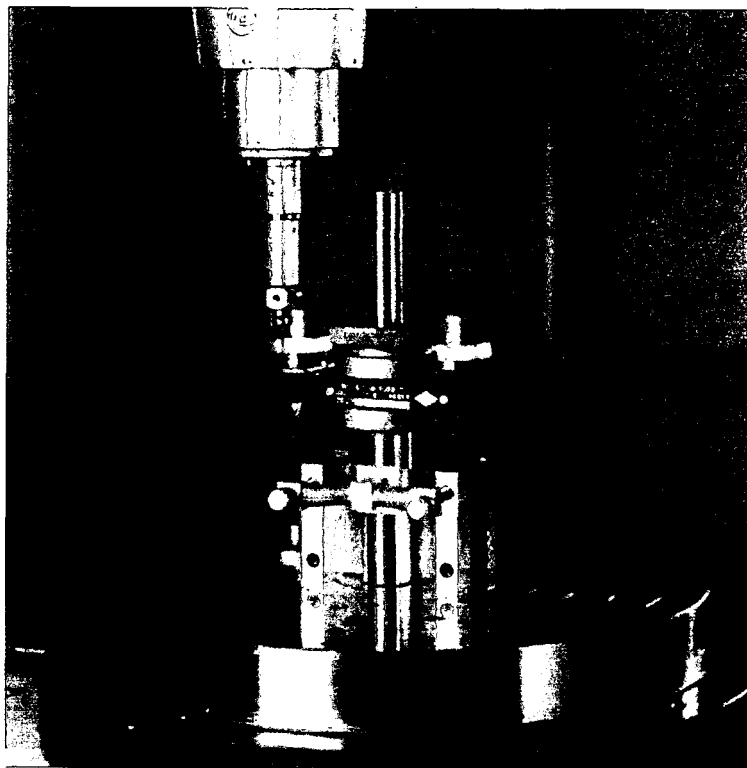


Figure 1. Involute profile artifact positioned for master gear uncertainty test

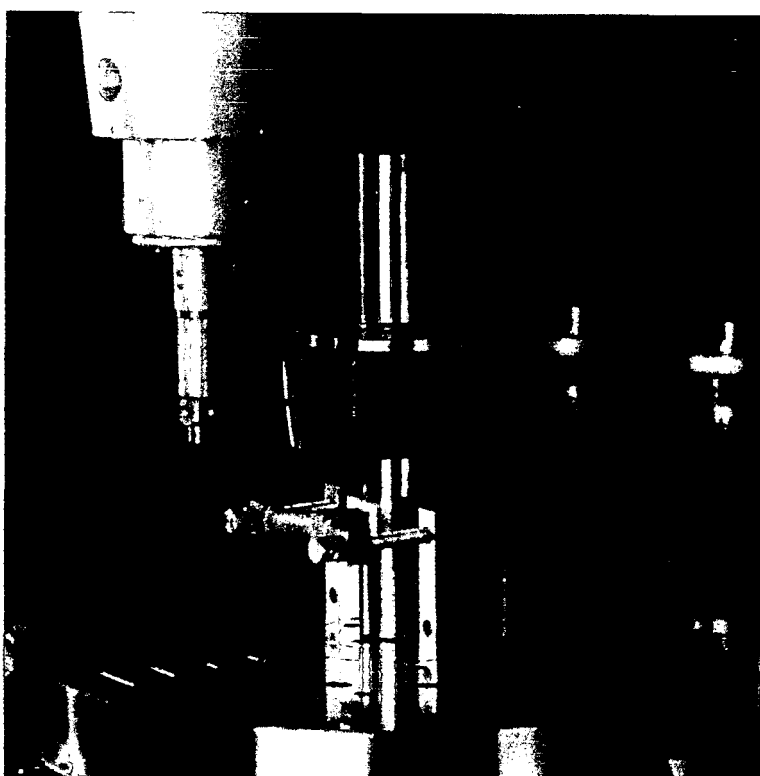


Figure 2. Tooth alignment artifact positioned for master gear uncertainty test

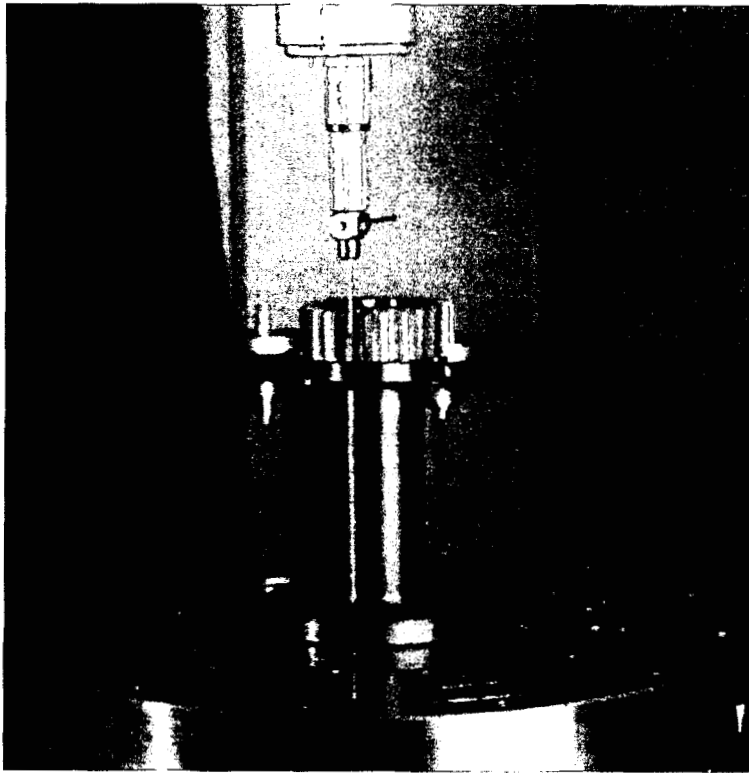


Figure 3. Index artifact positioned for master gear uncertainty test

A spur master gear will also be used for internal process control purposes and inter-comparison measurements are being conducted with NIST.

The measurement decompositions for the involute profile artifact and the tooth alignment artifact are discussed in AGMA 97FTM1⁴. Inter-comparison results are presented below.

In order to verify the uncertainty estimate, three independent measurements were made for inter-comparison. A surrogate artifact was available from a previous experiment. This artifact is a spatial arrangement of three precision spheres that closely simulates the basic elements of a gear profile artifact (figure 4).

Previous measurements provided an informal 2-sigma estimated uncertainty of $\pm 0.2 \mu\text{m}$ on the spherical section that approximates the gear profile. CMM profile measurements on this artifact and subsequent calculations resulted in a 2-sigma uncertainty of $\pm 0.8 \mu\text{m}$.

Measurements on two involute artifacts were also made at NIST. Although NIST equipment is similar,

the analysis application software was developed independently, different personnel operate the equipment, and holding fixtures are different. One of the two involute artifacts was measured on two different CMMs at ORMC, NIST, and M&M Precision Systems Corporation. All ORMC, NIST, and M&M Precision Systems Corporation measurements (on the total mean rise of the profile) were within $0.5 \mu\text{m}$ (see figure 5).

Using a third method based on traditional manual metrology methods gave the final affirmation to the uncertainty estimate. This method essentially duplicated the NIST method developed and reported in the 1980s. The NIST method uses a precision rotary stage and linear slide to trace the involute profile (unwound string). Comparison of $0.6 \mu\text{m}$ between the CMM method and the traditional method is shown in figures 6 and 7.

The consistency of all the inter-comparisons indicated that the uncertainty estimate was valid and perhaps a bit conservative. After a review of our data and methods, we published a 95 % confidence level uncertainty of $0.9 \mu\text{m}$.



Figure 4. Three-ball surrogate involve artifact

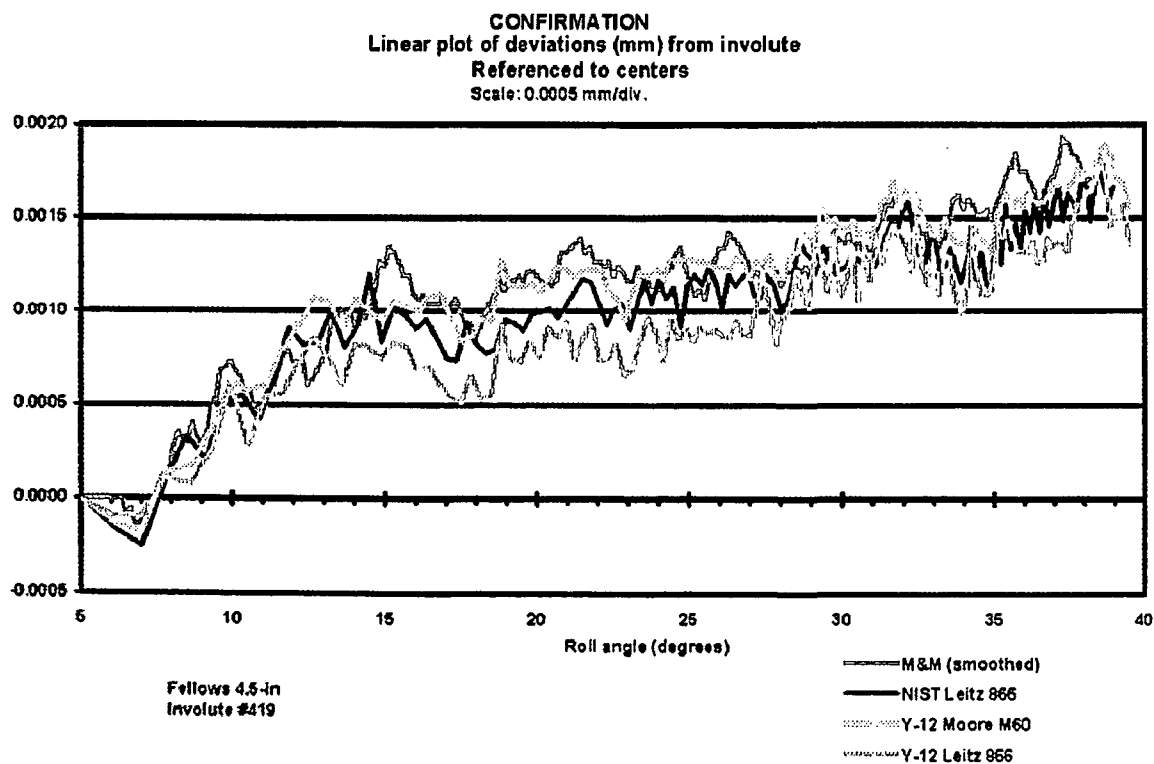


Figure 5. Comparison between ORMC Moore M60, ORMC Leitz 866, NIST Leitz 866 and M&M gear checker for involute prone artifact