Gear Measurement Traceability and Uncertainty

Bruce L. Cox

Introduction

Until recently, there was a void in the quality control of gear manufacturing in this country (Ref. 1). Gear measurements were not traceable to the international standard of length through the National Institute of Standards and Technology (NIST). The U.S. military requirement for traceability was clearly specified in the military standard MIL-STD-45662A (Ref. 2). This standard has now been replaced by commercial sector standards including ISO 9001:1994 (Ref. 3), ISO/IEC Guide 25 (Ref. 4), and the U.S. equivalent of ISO/IEC Guide 25 - ANSI/NCSL Z540-2-1997 (Ref. 5). The draft replacement to ISO/IEC Guide 25 - ISO 17025 states that measurements must either be traceable to SI units or reference to a natural constant. The implications of traceability to the U.S. gear industry are significant. In order to meet the standards, gear manufacturers must either have calibrated artifacts or establish their own traceability to SI units.

Metrology and Traceability-Related Workshops. NIST hosted and co-sponsored two industrial workshops that addressed metrology issues in U.S. manufacturing. In August, 1992, NIST hosted "Metrological Issues in Precision Tolerance Manufacturing," in Gaithersburg, Maryland. This workshop revealed a concern among a wide cross-section of American industry that the quality control practices in the production of gears are not sufficiently traceable to NIST standards (Ref. 6).

In response to this finding, NIST teamed with the Department of Energy Oak Ridge Y-12 Plant in Oak Ridge, Tennessee, to conduct an "Advanced Gear Metrology Workshop" at the Y-12 Plant in April, 1993. Significant planning assistance for the workshop was also provided by the Defense Logistics Agency, which is responsible for the procurement of gears for U.S. military weapon systems. The most important findings from the workshops were that the gear industry most often uses involute or tooth alignment artifacts that were often not traceable to NIST; and that there were no nationally accepted standard artifacts or standard measurement systems to use in measurement comparisons.

Committee on Gear Metrology. As a result of the workshops, a partnership was formed between the American Gear Manufacturers Association (AGMA), the American Society of Mechanical Engineers (ASME), NIST, Pennsylvania State University, and the Y-12 Plant. ASME formed an industrial advisory committee known as the Committee on Gear Metrology (COGM). This committee was established to give industry's priorities on reestablishment of gear measurement traceability to NIST and the Y-12 Plant.

National Gear Metrology Center. In October 1994, a $3-million stipend was awarded through the Department of Defense's Technology Reinvestment Program. The first item on the agenda was the reestablishment of involute profile artifact calibration with a stated uncertainty and direct traceability to the SI unit of length through NIST. Next, a facility—the National Gear Metrology Center (NGMC)—was constructed at the Y-12 Plant. This facility was equipped with state-of-the-art coordinate measuring machines (CMMs) for the calibration of all types of gear artifacts. A computer controlled generative gear checking instrument was loaned to the Y-12 Plant for several years by M&M Precision Systems Corporation to help correlate data from the CMMs to the gear checking instrument.

Fig. 1—Involute profile artifact.

Gear Artifact Measurement Uncertainty

The measurement uncertainty method used at NIST and the Y-12 Plant is known as measurement decomposition. In this method, which was developed by Dr. Howard Harary at NIST, the complex measurement task is broken down into a series of simple subtasks, which can be represented with reference artifacts such as gage blocks, angle blocks, or spheres. The uncertainties of the reference artifacts and the repeatability of the measurements are combined to reach a final uncertainty for the gear artifact.

The measurement decomposition for involute profile artifacts consists of measuring the centers of two circles on spheres and calculating a line between the circle centers, translating a distance from the line using a gage block, and measuring a series of points in a direction normal to an involute curve on a sphere (see Fig. 1). A multiplier ($k=2$) is used to allow the uncertainty to

Bruce L. Cox

is an engineering specialist at the Oak Ridge Metrology Center, located at the Department of Energy Oak Ridge Y-12 Plant, which is managed by Lockheed Martin Energy Systems, Inc. He serves on the AGMA Inspection Handbook Committee and is the vice chairman of the AGMA Calibration Committee.

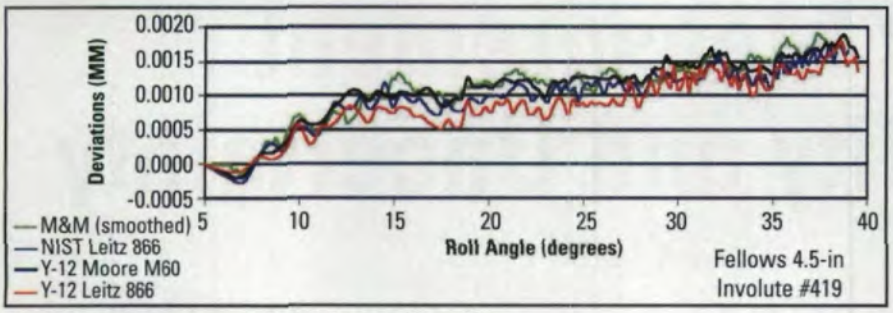

Fig. 2—Intercomparison of the involute profile artifact.

represent approximately a 95% confidence level of uncertainty for involute profile artifacts of ±0.9 micrometers. To check the uncertainty, an intercomparison was done between NIST, Y-12, and M&M Precision Systems Corporation. The results are shown in Fig. 2.

The measurement decomposition for pin artifacts consists of measuring the centers of two circles on spheres and calculating a line between the circle centers, translating a distance from the line using a gage block, and measuring the diameter of a sphere (see Fig. 3). The stated uncertainty at approximately 95% confidence level for pin artifacts is ±0.7 micrometers for offset, ±0.5 micrometers for diameter, and ±0.3 micrometers for roundness.

The measurement decomposition for tooth alignment artifacts consists of measuring the centers of two circles on spheres and calculating a line between the circle centers, translating a distance from the line using a gage block, and measuring a series of points at an angle to the line using an angle block (see Fig. 4). The stated uncertainty at approximately 95% confidence level for tooth alignment artifacts is ±0.8 micrometers for infinite leads, ±0.9 micrometers for 100-inch leads, ±1.1 micrometers for 32-inch

Fig. 3—Pin artifact.

Fig. 4—Tooth alignment artifact.

leads, ±1.2 micrometers for 16-inch leads, and ±1.3 micrometers for 11-inch leads. Intercomparison data between NIST and Y-12 for tooth alignment artifacts is shown in Fig. 5.

The measurement decomposition for index artifacts utilizes a rotary table and the principle of circle closure to subtract rotary table errors. In circle closure, all angular measurements must add to 360°; therefore any error can be subtracted from the measurement (Ref. 7). The decomposition consists of measuring the radial and axial runout of the rotary table, the repeatability of measuring an angle between three spheres on the rotary table, and the repeatability of an index artifact on the rotary table (see Fig. 6). The stated uncertainty at approximately 95% confidence level for index artifacts is ±1.6 arcseconds or ±0.6 micrometers for index artifacts up to 6 inches in diameter. Intercomparison data between NIST, Y-12, and The Gleason Works is shown in Fig. 7.

In addition to the intercomparison measurements above, Y-12 has been involved in a round-robin of involute profile artifacts that is sponsored by the AGMA Calibration Committee and an international round-robin of gear artifacts that is sponsored by the University of Newcastle, UK. The results of the AGMA round-robin were published in the proceedings of the 1998 AGMA Fall Technical Meeting. The results of the international round-robin have not been published yet.

National Voluntary Laboratory Accreditation Program

The NGMC was accredited by the NIST National Voluntary Laboratory Accreditation Program (NVLAP) for measurement of involute profile artifacts, pin artifacts, and tooth alignment artifacts on July 8, 1999. This is the first laboratory accredited by NVLAP to calibrate gears.

Future Plans

During the 1999 AGMA Fall Technical Meeting, the COGM met to discuss the future of gear metrology. The committee decided that the NGMC should begin offering calibrations that meet the ISO 1328-1 and ISO 1328-2 standards, and their corresponding tech-

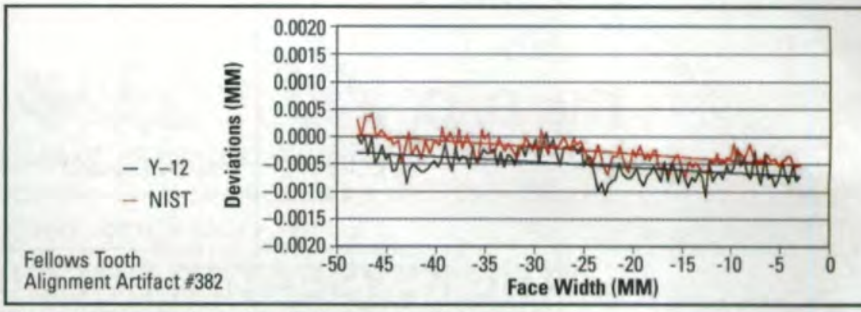

Fig. 5—Intercomparison of tooth alignment artifact.