Manufacturing Metrology Programs

Mechanical Metrology Program

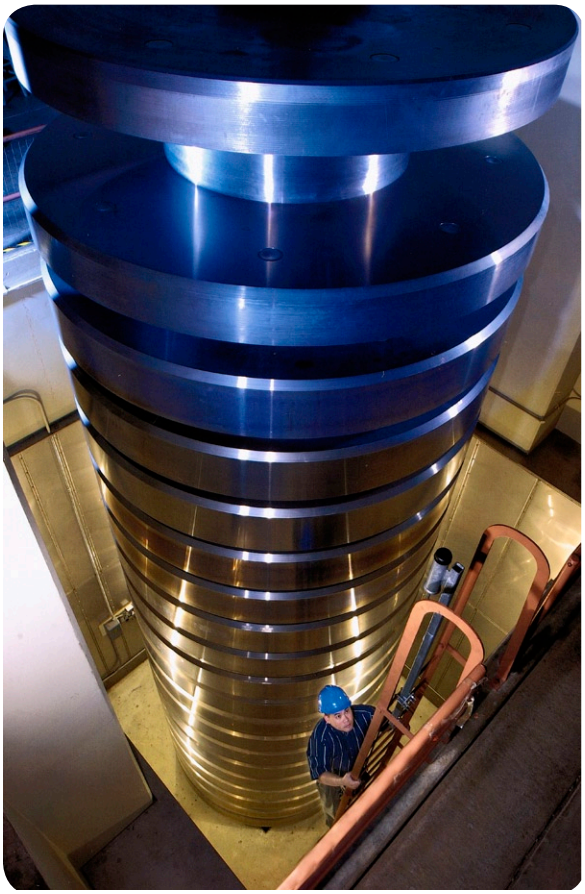
Annual FTEs: 19.0 NIST staff
5.5 guest researchers
24.5 total FTEs

Challenge

Develop and deliver timely measurements and standards to address critical U.S. industry needs for traceable mechanical metrology in the areas of acoustics, force, mass, and vibration, particularly for the support of trade and innovation, process-control, and manufacturing quality.

Overview

Mechanical metrology plays a critical role in nearly all sectors of the U.S. economy and in everyday life. Accurate and traceable measurements of mechanical quantities and standardized metrology methods are crucial to domestic and international trade, to cost-effective manufacture of innovative new products, to distributed and global manufacturing, and to ensuring compliance with regulatory requirements. This program provides the metrology infrastructure to satisfy the current and future needs of the U.S. government and industry for SI-traceable measurements of acoustics, force, mass, and vibration. The program realizes, maintains, and disseminates the basic SI unit of mass and the quantities of acoustics, force, and vibration for a broad customer base. To ensure U.S. competitiveness in world markets, the program represents the U.S. through active participation in international metrology organizations and associated international comparisons of measurement capabilities. NIST-developed measurement and uncertainty evaluation techniques are transferred to U.S. industry and other government agencies through leadership in national and international standards activities, partnerships and collaborations, and other direct outreach activities.



The 4.448 MN (1,000,000 lbf) deadweight machine

This program addresses the mechanical metrology challenges and needs faced by U.S. industry and government through:

1. Research and development to anticipate long-term, short-term, and current needs of fundamental SI metrology, government, and industry, and to drive future advancements in the areas of mass, acoustics, force, and vibration;
2. Contacts with customers from U.S. industry, government agencies, and academia to evaluate and assess future research and development needs in mechanical metrology;

3. Measurement services in conformance with an ISO 17025 compliant quality system to meet the needs of U.S. government and industry in acoustics, force, mass, and vibration;
4. International comparisons to ensure U.S. compliance with the Mutual Recognition Arrangement (MRA) and the competitiveness of U.S. industry in world markets;
5. High-level technical expertise for acoustics, force, mass, and vibration standards to ensure traceability and comparability of U.S. physical and documentary standards in mechanical metrology to those of other nations, and to represent and protect the interests of U.S. industry in global markets.

Key Accomplishments and Impacts:

- Successfully completed crucial initial steps towards the redefinition of the Kilogram:
  - Demonstrated ability to magnetically levitate and weigh a 1 kg mass. Completed design and began construction of system to directly relate, for the first time, air to vacuum weighing using magnetic levitation principles. This will provide the link between the existing artifact-based definition realized in air and the future realization of mass based on fundamental constants in vacuum. This link is essential to guarantee continuity and equivalency of mass measurements.
  - Completed manufacturing of first prototype stable 1 kg mass standard. Chemically inert and resistant to wear, this standard will eliminate most sources of instability in the dissemination of the unit of mass.
  - Provided major contributions and direction to activities and decisions of the Consultative Committee on Mass and Related Quantities (CCM) to establish proper guidelines and methodologies for a timely and successful redefinition of the Kilogram.
- Established technical foundation and leadership in the metrology of small forces ranging from micronewtons to piconewtons:
  - Established NIST Electrostatic Force Balance as an SI-traceable tool for the measurement and dissemination of accurate values of atomic force microscope cantilever stiffness.
  - Collaborated with other NIST laboratories to produce a prototype standard reference material consisting of an array of precisely machined microcantilevers with accurately known stiffness values that are traceable to the NIST Electrostatic Force Balance.
- Completed the research and development foundation for the establishment of new measurement capabilities in low-frequency vibration and next-generation microphones, in accordance with customer demands for extension of the low-frequency vibration calibration range and for reduction in measurement uncertainty for new types of microphones.
- Provided critical and state-of-the-art measurement services to the U.S. government and industry through nearly 3000 tests performed annually for over 100 customers.

Future Directions and Plans:

This program will continue to emphasize practical access to state-of-the-art measurement accuracy for high-impact SI mechanical metrology and the advancement of measurement science to meet future and unmet present needs. Specific emphasis will be on U.S. contributions for redefinition of the Kilogram, development of intrinsic force standards based on fundamental nanoscale forces, establishment of new measurement services in low-frequency vibration, next-generation microphones, and robotic mass measurements, and representation of U.S. interests in international metrology communities and in national and international standards to ensure open markets for U.S. industry. Awards and Recognition

- Dave Evans, Victor Nedzelnitsky, and Randy Wagner received the 2007 NIST Edward Bennett Rosa Award for outstanding achievements in development of standards and measurement practices to assure the quality and performance of acoustical devices and measuring instruments used by the public and laboratories worldwide.
- Jon Pratt received the 2006 *Measurement Science and Technology* Outstanding Paper Award in the Precision Measurement category for his article "Prototype Cantilevers for SI-traceable Nanonewton Force Calibration" [Meas. Sci. Tech., Vol. 17, Issue 10, pp. 2852-2860].
- The Director of NIST selected the following projects for FY2006 NIST Innovation in Measurement Science (IMS) funding (formerly known as NIST Competence projects):
  - An Alternative Approach to Mass Metrology (Zeina Jabbour)
  - Intrinsic Force Standards Based on Atomic and Molecular Interactions (Jon Pratt)
- Zeina Jabbour was chosen to represent the U.S. mass metrology community as invited member of the CIPM Consultative Committee on Mass and Related Quantities (CCM) ad hoc working group on redefinition of the SI units. [2005-2008]
- David Evans was recognized by the Acoustical Society of America (ASA) for outstanding contributions to standards activities, including service as Chair of the ANSI-accredited standards committee S2 on Mechanical Vibration and Shock from 1993-2000 and as Vice-Chair from 2000-2006. [October 2006]

Projects

Mechanical Metrology Program

Research and Development for Next-Generation Mechanical Metrology

(Status: to be completed in FY2011)

Challenge/Problem Addressed:

NIST metrology programs strive constantly to pioneer technology that will improve upon the state-of-the-art in order to provide the peak of the measurement traceability chain. NIST customers continually need new measurement capabilities, lower measurement uncertainties, and expanded ranges for measured quantities to meet their technical demands for innovative and more complex products and scientific applications. NIST measurements must undergo rigorous uncertainty assessments to ensure customer confidence in measurement results. The challenges in the Mechanical Metrology Program are no exception, and advancement of NIST mechanical metrology capabilities in response to identified and anticipated needs requires cutting edge research and development. As the country's National Measurement Institute, NIST must represent U.S. mass metrology interests in the current international effort to prepare for a redefinition of the unit of mass – the Kilogram – away from a physical artifact. NIST's expertise will be essential in developing the necessary technical advancements to allow the U.S. (and the world) to adopt the Kilogram redefinition.

Objective

Conduct research and development to anticipate long-term, short-term, and current needs of fundamental SI metrology, government, and industry, and to drive future advancements in the areas of mass, acoustics, force, and vibration.

Accomplishments:

- Successfully completed crucial initial steps towards the redefinition of the Kilogram:
  - Demonstrated ability to magnetically levitate and weigh a 1 kg mass. Completed design and began construction of system to directly relate, for the first time, air to vacuum weighing using magnetic levitation principles. This will provide the link between the existing artifact-based definition realized in air and the future realization of mass based on fundamental constants in vacuum. This link is essential to guarantee continuity and equivalency of mass measurements.
  - Completed manufacturing of first prototype stable 1 kg mass standard. Chemically inert and resistant to wear, this standard will eliminate most sources of instability in the dissemination of the unit of mass. Began studies of long-term stability.
  - Provided major contributions and direction to activities and decisions of the Consultative Committee on Mass and Related Quantities (CCM) to establish proper guidelines and methodologies for a timely and successful redefinition of the Kilogram.

- Established technical foundation and leadership in metrology of small forces ranging from micronewtons to piconewtons:
  - Established NIST Electrostatic Force Balance as an SI-traceable tool for the measurement and dissemination of accurate values of atomic force microscope cantilever stiffness.
  - Collaborated with other NIST laboratories to produce a prototype standard reference material consisting of an array of precisely machined microcantilevers with accurately known stiffness values that are traceable to the NIST Electrostatic Force Balance.
- Completed the research and development foundation for the establishment of new measurement capabilities in low-frequency vibration and next-generation microphones, in accordance with customer demands for extension of the low-frequency vibration calibration range and for reduction in measurement uncertainty for new types of microphones.
- Developed, integrated, and delivered to the U.S. Air Force Metrology Calibration Laboratories (AFMETCAL) a new vibration exciter and primary calibration system to calibrate accelerometers. The new system uses a quadrature laser interferometer and a new measurement approach to calibrate accelerometers over a wide frequency range, enabling AFMETCAL to carry out their own primary accelerometer calibrations with uncertainties similar to NIST measurement capabilities.

Planned Future Accomplishments:

- Establish the first direct link between the current SI Kilogram defined in air and the future vacuum-based definition of mass.
- Establish a mass metrology dissemination mechanism based on the new realization and the stable artifacts.
- Establish intrinsic force standards based on fundamental nanoscale forces that can supplant artifact-based force metrology to affix SI-traceable values to atomic and molecular force interactions.
- Complete research and development required to establish new calibration services and standard operating procedures in infrasonic metrology.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp.
- U.S. Army; U.S. Air Force; U.S. Navy
- U.S. Department of Veterans Affairs (VA)
- NASA
- Los Alamos National Laboratory
- Amgen
- Morehouse Instruments
- Asylum Research
- Veeco Products
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- University of Illinois at Urbana-Champaign
- University of Florida
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Mechanical Metrology Program

Measurement Services

(Status: to be completed in FY2011)

Challenge/Problem Addressed:

This project provides high-accuracy measurement services and special tests for NIST customers in the areas of acoustics, force, mass, and vibration, with traceability to the International System of Units (SI) and with measurement uncertainties equal to or better than those specified in NIST Special Publication (SP) 250. NIST measurement services must maintain and adhere to a quality system that is in compliance with the ISO 17025 standard for all administrative and technical aspects of the measurement services. Quality system requirements include maintenance of control charts, regular calibration of NIST reference and working standards, and calibration of all calibration equipment or associated instrumentation, with direct traceability to NIST. An ongoing project emphasis is to continually monitor and improve the delivery of measurement services for NIST customers. The goal is to provide 90% or better on-time delivery of reports of calibrations and special tests to all customers.

Objective

Provide high-accuracy measurement services in conformance with an ISO 17025-compliant quality system to calibrate devices submitted by NIST customers in the areas of acoustics, force, mass, and vibration.

Accomplishments:

- Provided critical and state-of-the-art measurement services to the U.S. government and industry through nearly 3000 tests performed annually for over 100 customers.
- Developed new measurement methodology and new weighing designs to establish robotic mass calibrations that will improve the delivery of mass calibrations, minimize human error, reduce statistical uncertainty, eliminate temperature effects caused by operators, and reduce the turn-around time for customer calibrations.
- Automated and upgraded several force deadweight machines to improve the delivery of force calibrations, reduce the risk of equipment failure, minimize human error, and reduce the turn-around time for customer calibrations.

Planned Future Accomplishments:

- Provide critical and state-of-the-art measurement services to NIST customers in the mechanical metrology areas of mass, force, acoustics, and vibration.
- Develop quality system documentation and implement new measurement capabilities to provide new measurement services in low-frequency vibration, next-generation microphones, and robotic mass measurements.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp.
- U.S. Army, U.S. Air Force, & U.S. Navy
- U.S. Department of Veterans Affairs (VA)
- NASA
- Los Alamos National Laboratory
- Amgen
- Morehouse Instruments
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Mechanical Metrology Program

International Comparisons and Standards (Status: to be completed in FY2011)

Challenge/Problem Addressed:

An elaborate system of international comparisons, performed in accordance with the international Mutual Recognition Arrangement (MRA), allows measurement capabilities among different countries to be recognized and accepted as the foundation for international trade. Some comparisons are on a global scale, such as those conducted through committees of the International Committee on Weights and Measures (CIPM), while others are regional, such as those done through the Interamerican Metrology System (SIM), which coordinates metrology activities within the Americas. NIST represents and defends U.S. interests in these international metrology communities, particularly through the CIPM consultative committees and SIM working groups. The Mechanical Metrology Program interacts primarily with the CIPM Consultative Committee on Mass and Related Quantities (CCM) and the Consultative Committee on Acoustics, Ultrasound, and Vibration (CCAUV), and the corresponding working groups of SIM. The program's challenges are (1) to determine the appropriate level of U.S. representation and participation in the planning and execution of international comparisons necessary to meet U.S. requirements and (2) to develop and implement effective comparisons that evaluate high-priority measurement capabilities and obtain reliable results that promote U.S. competitiveness. In addition, expert-level representation and technical contributions to national and international standards are necessary to ensure traceability of U.S. physical and documentary standards in mechanical metrology and comparability of U.S. standards to those of other nations.

Objective

Ensure the competitiveness of U.S. industry in world markets and U.S. compliance with the international Mutual Recognition Arrangement (MRA) by conducting international comparisons of measurement capability and providing high-level technical expertise for national and international standards in acoustics, force, mass, and vibration.

Accomplishments:

- Piloted international comparison in force (CCM, 2MN to 4 MN), analyzed results, and published initial report. Provided participating countries a direct link to the highest precision force measurements available worldwide above 2 MN, thereby establishing greater confidence and reliability in the equivalence of the measurements.
- Piloted international (regional) comparison in vibration (SIM, 50 Hz to 50 kHz), analyzed results, and published initial report. Provided SIM participants, through NIST, a link to other countries that participated in CCAUV comparisons with NIST. This guarantees the recognition and validity of the calibration and measurement capabilities of the participating countries under the mutual recognition arrangement (MRA), thereby supporting international trade.
- Completed measurements for CCM key comparisons in force metrology (1 MN, PTB pilot and 100 kN, NPL pilot) to guarantee mutual recognition of measurement capabilities and to facilitate international trade.
- Completed analysis of CCAUV key comparison for microphones in 31.5 Hz to 25 kHz range and published results in Metrologia.

- Provided technical expert knowledge to numerous national (ANSI, ASTM) and international (ISO, IEC, CIPM, OIML, SIM) standards in the mechanical metrology areas of acoustics, force, mass, and vibration to ensure traceability of U.S. physical and documentary standards in mechanical metrology and comparability of U.S. standards to those of other nations. (See attached table: *Standards Leadership and Participation*)

Planned Future Accomplishments:

- Represent U.S. interests in the Consultative Committee on Mass and Related Quantities (CCM) related to the redefinition of the Kilogram.
- Define the measurement protocol and conduct measurements as part of the U.S. participation in the regional comparison for low frequency vibration metrology.
- Represent U.S. interests in international metrology communities, international comparisons of measurement capability, and national and international standards activities in the mechanical metrology areas of mass, force, acoustics, and vibration to ensure open markets for U.S. industry.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp.
- U.S. Army, U.S. Air Force, U.S. Navy and U.S. Department of Veterans Affairs (VA)
- NASA
- Los Alamos National Laboratory
- Amgen
- Morehouse Instruments
- Asylum Research
- Veeco Products
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- Universities of Illinois at Urbana-Champaign and Florida
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Mechanical Metrology Program

Customer Outreach and Interactions (Status: targeted activity completed in FY2007)

Challenge/Problem Addressed:

The Mechanical Metrology Program must establish and maintain the appropriate level of technical contacts within our customer organizations. The primary contact with NIST's measurement services is frequently in the customer's calibration or procurement office. This contact understands the calibration to be performed, but most often does not know the intended end-use or application of the device being calibrated. At times there is no insight into how NIST metrology services impact the company's bottom line or their next innovative product or application. This deeper level of technical information is very important for NIST planning, for understanding customer needs, and for determining how best to represent U.S. interests in the international community. For these reasons, this project must perform targeted customer outreach activities and interactions to reach the necessary technical contacts within our customer base.

Objective

Establish and maintain contacts with NIST customers from U.S. industry, government agencies, and academia to identify and assess future research and development needs in mechanical metrology.

Accomplishments:

- Organized and conducted an industry workshop on U.S. torque metrology requirements. The workshop uncovered major discrepancies in torque measurements and pointed to the need for establishing uniformity in the realization and dissemination of the SI unit of torque.
- Received direct feedback from customers about their current and future needs in mechanical metrology through several site visits and other interactions. Received information about how measurements services performed at NIST are used by the customers and about the crucial role of NIST measurement services in manufacturing and in satisfying regulatory requirements.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp
- U.S. Army
- U.S. Air Force
- U.S. Navy
- NASA
- Amgen
- Morehouse Instruments
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- University of Illinois at Urbana-Champaign
- Southern California Edison
- Duke Power
- Bruel & Kjaer