What's NIST

Robert B. Aronson
Senior Editor

The statement, "I'm from the government and I'm here to help" might be hard to believe. But in the case of our National Institute of Standards and Technology (NIST), it's true. This 100-year old government agency, formerly the National Bureau of Standards, has a number of programs that attack esoteric manufacturing problems, chiefly those that industry hesitates to take on alone. Their work is a combination of government-only and government-industry programs.

The main function of NIST, like its predecessor, continues to be measurements and standards. But, in addition, manufacturing research, with a focus on measurements and standards for manufacturing, is a big part of their work. Most of the manufacturing-related work takes place in the Manufacturing Engineering Laboratory (MEL).

They have a number of programs in place that are currently in various stages of development. One of the themes running through several programs is to improve productivity for various material removal processes, chiefly milling and turning. Many of the program results will ultimately influence manufacturing in America over the next few years.

According to one survey, manufacturers use the right tool only 50% of the time, the right cutting speed only 58%, and use the tools to full life only 38%. This is said to waste an estimated $10 billion per year, so NIST has its work cut out.

What's in it for you? How can anyone take advantage of a NIST program? There are several channels. The easiest way to get basic information is to log on to their site (http://www.mel.nist.gov), and read the program summaries. That gives some idea of what the programs are about, and how far along each is. Keep in mind, NIST does not sell books, or reports, or commercial products. But commercial products are often the result of their work, particularly when the project has industrial partners. Once experimental results show promise, an industrial participant may commercialize the work.

A more indirect benefit to industry is through new or modified standards. Often a

Tests of linear motor may help develop industry standards for this high-speed positioning device.

Doing for You?

Researching industry's high-tech problems

project goal is to systemize existing activities, for example standardizing machine tool performance parameters and associated test procedures, as in the ASME B5 and ISO standards work.

Metrology has long been NIST's basic reason for existence, but as one researcher put it. "Now we don't just generate reports that moulder on a shelf somewhere, we get useful information to industry."

MEL is one of the seven Measurement and Standards Laboratories of NIST. Its mission is to satisfy the measurement and standards needs of US discrete-parts manufacturers in the areas of dimensional and mechanical metrology, as well as advanced manufacturing technology.

According to David Stieren, MEL strategic relations manager, "MEL's goal is to promote a healthy US manufacturing economy by solving tomorrow's measurement and standards problems today." Ideally, if manufacturers can develop self-monitoring systems that ensure product quality, it will be possible to remove NIST and other national measurement institutes (such as Germany's PTB or the UK's National Physical Laboratory) as the "middle man" in establishing that product and process measurements descend directly from international standards. The products and services delivered by these projects will enable NIST-quality, task-specific measurements of parts on the shop floor without recourse to NIST-provided calibrations or related services.

Here is a sampling of the NIST activities.

The Mysterious Hexapod: The hexapod caused an uncharacteristic wave of excitement when Giddings & Lewis showed off a prototype during the 1994 IMTS. Interest grew for a couple of years as various prototypes were seen at trade shows. Despite high hopes, the concept has not caught on in a significant way. It survives in some "parallel linkage" workholding systems, and the technology has been applied to spindle head positioning, such as Cincinnati Machine's Z3 Head.

"We have the second hexapod machine produced by the Ingersoll Milling Machine Company," explains Al Wavering of NIST's Intelligent Systems Division. "With it, we

Grid encoder is used to test contouring performance of a machine tool. Device measures the errors of arbitrary toolpaths in two coordinate directions.

MELs Five Divisions

- Precision Engineering Division: Precision-engineered, length-metrology-intensive systems in measuring and production machines and instrumentation.
- Manufacturing Metrology Division: Realization and dissemination of SI mechanical quantities of mass, force, vibration, sound pressure level, and ultrasonic power. It also develops methods, models, sensors, and data to improve metrology, machines, and processes for manufacturing. MMD also helps develop national and international standards for mechanical metrology, machine metrology, process metrology, and sensor integration.
- Intelligent Systems Division : Works with industry, universities, and other government agencies to develop new measurement techniques and standards for intelligent machine systems, robots, and automated manufacturing systems. It also develops engineering guidelines for the design and implementation of intelligent control systems.
- Manufacturing Systems Integration Division: Promotes information-intensive manufacturing systems. Application areas include engineering design, process planning, production planning and control, and enterprise integration.
- Fabrication Technology Division: Provides fabrication support services for instruments and devices required by researchers from MEL and other NIST laboratories.

worked on performance characterization, error modeling and analysis, kinematic calibration and other ways to improve accuracy. We made a lot of progress, and believe the concept can deliver competitive performance, but cost competitiveness is another story."

Also, the limited spindle tilt range of hexapod machines is a problem. "We don't have a spherical joint that has a wide range of motion along with the necessary stiffness and accuracy. With the six-legged extensible strut design, it is tough to be competitive with existing five-axis machines. It may yet see use in some applications, but the market for these machines hasn't materialized to the extent many people thought it would. However, people are looking at other configurations, including hybrids of parallel and serial mechanisms, to get around the workspace limitations."

How good is the linear motor? The linear motor is another case of a technology with mixed reviews. They are being used in greater numbers by some machine tool manufacturers. But there are still a lot of questions about their performance, reliability, and cost. In an effort to clarify the situation, NIST has developed a test bed that is looking at key performance characteristics such as accuracy, acceleration, stiffness, and heat generation. "This project was motivated by the difficulties encountered by the machine tool industry in implementing linear motors," says Alkan Donmez, group leader for Machine Tool Metrology in the Manufacturing Metrology Division. "The project will also study the controller aspects of linear motors, failure modes, methods for predicting impending failure and remaining life, as well as estimating the mean time between failure."

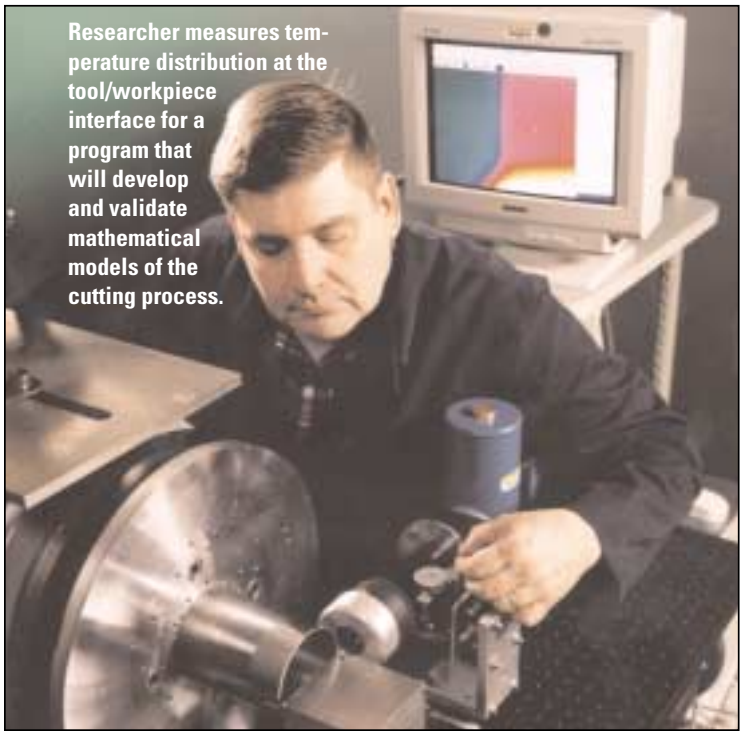
First part, good part. The classical feedback quality assurance technique is to make a part, check it, then modify the process and try again until the resulting part meets specifications. But there is a need to characterize and specify manufacturing processes and equipment to ensure that the first part is a good part. The concept of first part, good part (or first part correct) is to understand and design the product and process such that the right part is produced the first time and every time with no errors and limited need for physical prototyping. Several MEL programs are contributing various components that will contribute to this vision.

In particular, the Predictive Process Engineering (PPE) program investigates issues in process metrology, process modeling, process data representation, and integration with process-related applications. According to the PPE program manager, Kevin Jurrens of the Manufacturing Metrology Division, "this program will develop the process models, methods, measurements, and standards needed to fully use the capacities of manufacturing systems through complete use of manufacturing knowledge and process data throughout the product lifecycle." Feedback from process metrology improves the process model, the process specification, and the manufacturing process itself.

This program is addressing the typical ad-hoc nature of current manufacturing process development where parameters, such as machining speeds, feed rates, and tool selection, are chosen by costly, trial-and-error prototyping, with the resulting often less than optimal solutions. The vision is to gain a science-based understanding of the manufacturing processes, coupled with validated mathematical models of the process, to enable predictive capabilities for establishing optimum parameters.

How about HSM? High-speed machining (HSM) is certainly a major thrust in machine tool and machining process development, but it has different requirements in various applications. High spindle speed is not the only criteria. NIST is contributing to HSM studies through both the process metrology and the machine tool metrology. Understanding the process dynamics and such effects as cutting tool wear lead to optimum settings for speeds and feed rates. One specific application under study is HSM of large-scale, propulsion system components (propellers).

Similarly, the contouring performance of the machine has become more important as the higher feed rates put more demands on the coordinated motion of the machine axes. This has led to a NIST project that is investigating whether or not current standards sufficiently handle contouring errors. The current ASME B5 and ISO performance standards address contouring performance by evaluating the



Researcher measures temperature distribution at the tool/workpiece interface for a program that will develop and validate mathematical models of the cutting process.

errors of a circular path, typically measured using a ball bar or grid encoder. Although these are very powerful and effective tests, there is some question as to whether they can adequately assess a machine tool's ability to make very complex shapes at high speeds. In the current project, NIST researchers will make recommendations as to whether current tests are adequate, need to be amended, or new tests need to be developed. They are also studying the use of the test results to optimize the values for the many parameters in modern controllers.

Machine tool performance. Metrology and standards to characterize, monitor, and improve the performance and reliability of machine tools are a major theme of the "Smart Machine Tools" program managed by Hans Soons of the Manufacturing Metrology Division. NIST researchers are collaborating with industry to improve ASME and ISO standards for machine tool performance evaluation. The standards provide parameters and test methods to specify, validate, and monitor the performance of a machine tool, in particular its accuracy. The standards provide an alternative to purchasing machine tools based on expensive customized machining tests.

Once a machining tool is in operation, no matter how well it was set up, its accuracy will change over time due to environmental factors, wear, accidents, and maintenance. Currently we look for those errors by measuring the parts to keep track of performance with time. This is fine if you only make one part all the time, but when you make a variety of parts, it's difficult to follow trends. In that case it may be advantageous to monitor the machine performance instead. This also facilitates diagnosing and fixing problems at their source.

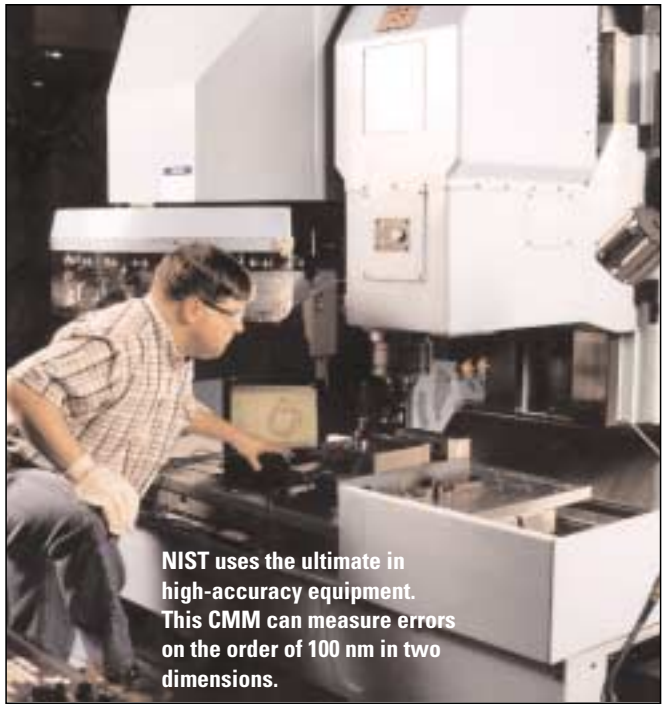
New tools and algorithms are being evaluated to reduce the time and expertise required for machine characterization and to obtain comprehensive, intuitive performance parameters. Error sources being investigated include: axis accuracy and alignment, thermal loads, static and dynamic compliance, and contouring errors. One of the challenges is how to translate generic performance parameters into the expected tolerances of specific parts. Such a translation is key to selecting the right machine tool for a job and to ensure that parts are machined to correct tolerances.

Other research includes the use of performance data and sensor information to improve machining accuracy. NIST researchers are also working with industry to develop standardized data formats for machine tool performance data and tools to facilitate the archiving of this data. They also ant to communication this data to applications that need it, such as e-commerce, machine programming, simulation, and maintenance. One such tool is an internal web site that allows a machine operator to archive and analyze the results of a performance test while providing immediate access to the results of previous tests.

Repair philosophy. There are three maintenance philosophies: fix it when it breaks, have scheduled preventive maintenance, and condition-based maintenance. The idea behind the latter method is to use information about the machine's condition to determine what to maintain and when.

A key challenge is what do you measure to get a clue as to the machine's condition: vibration, heat, motor current or what? The first step is to know why key machine tool components such as spindles and drive systems fail. Next, try to identify some measurand that indicates impending failure, or even better, that allows you to predict the remaining life. Finally you need smart signal processing algorithms to pick the critical data out of the often noisy and transient signals, and interpret the results. NIST researchers hope that research in these areas will reduce unexpected breakdowns and assist in the remote diagnosis of machine condition so that the correct maintenance can be performed at the right time.

Smart sensors. To enable machinery to monitor and improve its own performance, NIST researchers are working with industry to develop metrology and smart sensor interface standards. There is a strong need for reliable, inexpensive sensors and simplified wiring. One area of research is the development of standardized interfaces and communication protocols that enable "plug-and-play" capabilities of sensors into



NIST uses the ultimate in high-accuracy equipment. This CMM can measure errors on the order of 100 nm in two dimensions.

any of the 60-plus industrial networks and sensor buses on the market. This work is in support of the IEEE 1451 Standard on Smart Transducer Interface for Sensors and Actuators. This standard will ease the application of sensors and actuators across industries, including manufacturing. The standard provides sensors that can identify themselves over the network: who made the sensor, what does it measure, when was it last calibrated, and what are its calibration parameters. The user/operator can then identify and modify sensor operation on-line via the network or Internet.

Digging into CMMs. One complexity of CMMs is their versatility. They can measure numerous geometrical features such as flatness, concentricity, and parallelism. And each of these measurements can be made in many ways. How many points were used? What type of probe and stylus configuration were used? All these factors influence the measurement results and to evaluate these variables and determine their influence on the accuracy of a measurement is a daunting mathematical chore.

One answer is a software package being developed in cooperation some industrial partners based on research at NIST. This software greatly simplifies these calculations. When fully developed, the operator will install the program on an ordinarily PC computer or possibly in the CMM controller. When making a test, the user enters information on the type of measurement to be made and the CMM characteristics. The program then automatically estimates the accuracy of the measurement.

Decision rules. NIST's Precision Engineering Division is currently working on something called "decision rules" or: What governs the acceptance or rejection of a component? Technology's continued advance means ever tighter tolerances. "Things we used to sweep under the rug, like measurement uncertainty, are now a bigger part of the manufacturing metrology problem" according to Dr. Steven Phillips, manager of a metrology program in MEL

Decision rules provide the accept/reject criteria based on the specified tolerance, the evaluated measurement uncertainty, and the measurement result. If the measurement result is just inside the specification, the part may actually be unacceptable if the uncertainly, or potential error, of the instrument is high. Conversely, a part with a measurement result just outside the specification may be good.

As tolerances become tighter, the allowance for instrument uncertainty becomes smaller. In some cases where very high accuracy is required, the measurement uncertainly is equal to part tolerance.

Although this issue was initially only a consideration for very high precision equipment and optics, the requirements are now being applied in the automotive and aerospace areas.

"We are working to develop decision rules that help the user decide what to do in these difficult cases," explains Dr. Phillips. This is not a problem for every product. For example if you know your equipment can measure with an uncertainty of 10 micrometers and the part tolerance is 200 micrometer, you don't have to worry. Currently, there is an ISO standard (ISO 14253-1) that discusses decision rules and a related ANSI standard (B89.7.3.1) now in publication.

A related issue is laboratory accreditation. Some manufacturers may be stunned to learn that, thanks to new ISO standards, they are responsible for knowing how accurate their measuring instruments are. For those who want ISO 17025 (for a measurement lab) accreditation, you must produce measurement uncertainly statements for your measurement results.

Other projects include:

- **Systems integration**. Computer-controlled manufacturing processes and systems need to speak the same language. Computer-aided design (CAD) systems must receive and transmit product data accurately between and within shops. CAD systems must be able to communicate efficiently with other computer-aided systems used throughout product and process development, including computer-aided manufacturing (CAM) systems. Specifically, the program participates in industry efforts to standardize open architecture control for the machine tool, robot, and automated metrology equipment sectors.
- **Trouble with heat**. A major problem in many metrology operations is that people insist on mea-

suring workpieces that are not in thermal equilibrium. That is, the part to be measured has not been allowed to cool or warm to ambient conditions before a measurement is made. NIST researchers are trying to determine ways to estimate the measurement uncertainty in cases where thermal equilibrium conditions are not established.

- **Power reliability.** The "quality" of the current going to a machine tool may influence its performance. But in what ways and by how much? In the project called Power Quality Effects on Machine Tools, MEL researchers are investigating the need for power quality standards for machine tools. Together with industry they define parameters that allow for the specification of the level of power quality events a piece of equipment must be able to tolerate or ride-through, before its performance degrades significantly or it shuts down.
- **Flatness.** Although principally a concern of semiconductor manufacturers and makers of high-precision mirrors, flatness can be a critically important property in other industries. To do this type of evaluation, NIST has developed a one-of-a-kind machine dubbed XCALIBIR (X-Ray Optics Calibration Interferometer) to make state-of-the-art flatness measurements (and measurement references) of flatness. This instrument is housed in an enclosure with temperature control to within 0.05°C. To minimize the influence of unwanted vibration, it sits on a 16-ton granite table. The unit is designed to measure the dimensional error of flat and spherical surfaces up to 300 mm in diameter with a measurement uncertainty of 0.25 nanometer; equivalent to the diameter of one or two atoms.
- **Hardness.** Rockwell hardness tests are commonly used in industry. To ensure the testing accuracy, NIST provides highly precise calibration test blocks for the most frequently used hardness standard, the Rockwell C scale. The high quality of the agency's calibration artifacts results from two NIST-developed innovations: a precision "deadweight standardizing" machine for measuring Rockwell hardness and a method for measuring the shapes of the diamond tips used to make test indentations. Some nations use non-unified Rockwell hardness scales, which could result in technical barriers to trade. With the development of ISO 9000 quality standards, the pending European Union directive to "harmonize measurement instruments" and other factors, there is strong motivation to establish a worldwide unified Rockwell hardness scale.
- **Robotic control.** In the robotics area, NIST is attacking the issue of interface standards for interoperability. Industry now spends an estimated $2 billion to $4 billion annually to integrate robots into manufacturing systems. A substantial portion of this might be saved through the development and use of open architectures and standard interfaces for integrating robots and other automated manufacturing equipment.■