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Testing Technology

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Ion microtomography offers new nondestructive testing technique

Microscopic resolution detects invisible defects

An artificial heart valve from Carbon Implants, Inc., made of the same material supplied to Sandia for IMT analysis.

A research team from Sandia and Lawrence Livermore national laboratories, sponsored by DOE's Defense Programs, is developing a nondestructive, high-energy nuclear microprobe technique for materials characterization. The new ion microtomography technique produces high-resolution images of slices through objects much like medical X-ray computer-aided tomography (CAT scans), but IMT images are approximately 1,000 times more detailed.

A unique feature of IMT is its usefulness for samples with low total density or where small density variations make X-ray analysis difficult. Its high resolution allows it to "see" constituent parts as small as one micron (the diameter of a human hair is about 100 microns) and material density variations on the order of 1 percent.

MASTER

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Testing news in brief

SMARTS collects high sample rate data in missile tests

The Sandia Modular Advanced Reconfigurable Telemetry System is being used to transmit shock and vibration data from third-stage Minute Man rocket motors. These motors will be launching defense research payloads, and the shock/vibration environment must be clearly defined before such launches. SMARTS carries two data channels at 80 thousand samples per second, four channels at 40 kbps, and 14 channels at six kbps, downlinked through a PCM link at 1.4 megabits per second. The system's capabilities are also useful in other shock and vibration environments.

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New method detects heat flux from cryogenic objects

Researchers at Sandia have patented a new quantitative method for determining the total heat flux from cryogenic objects. The implementing device detects the temperature change created by heat transport across a microscopically thin boundary layer of supercooled normal liquid helium which exists between a solid surface and the bulk superfluid helium. The technique has already determined the very small amount of total power dissipated in an array of superconducting junctions. The technique may also be applied in tritium assays in weapons programs and in space image-plane array applications.

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Multiple battery tester comes on line

A new battery test facility at Sandia can evaluate up to 10 battery systems simultaneously. The system can perform life-cycle tests at constant current or power levels, peak power tests, frequency regulation tests, and electric vehicle driving profile tests. Testing temperatures can range from ambient to 400°C. The facility features VXI controllers, DC power supplies, field-effect transistor load units, high-temperature box ovens, and a Unix work station.

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Focal Point handbook guides testing to generic requirements

Sandia's new Focal Point Ground Test Handbook provides information on the "Design for Testability" concept as part of the weapons development process. The Focal Point program's philosophy and test requirements support the concept of qualifying a weapon system to a set of broadly applicable requirements that reflect the anticipated stockpile-to-target test requirements for future systems. The book describes Sandia's Development Test Center and shows system and component design engineers how to map test requirements and ES&H considerations to facilities, capabilities, and cost.

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Acoustic and vibration analyses support the National Machine Tool Partnership

Analysts from Sandia's Development Testing Center are working with the National Machine Tool Partnership (funded by the Departments of Energy and Commerce) to help U.S. machine tool makers improve their products in this critical industry. Cincinnati Milacron Corp. asked for an acoustic analysis of a computer-controlled lathe, while Boston Digital Corp. has requested vibration and modal analysis of their numerically controlled multi-axis milling machine. Other work includes the study of bearing packs for Boston Digital.

Danny Gregory, Org. 2741, (505) 844-9743 (for Boston Digital work), or
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The IMT data for a cross-sectional slice through a sample are obtained using a beam of high-energy ions (usually 3-20 MeV protons) focused to micron-scale dimensions with a magnetic quadrupole lens system. The beam is scanned across the object in small steps; the sample is turned slightly at the end of each scan until it has rotated through 360°. The density data for each slice are reconstructed on a computer to yield a spatial density map of that slice through the specimen. Many slices can be assembled to produce a full, three-dimensional rendering of the object. The three-dimensional images can also be manipulated to produce different perspectives and cross-sectional views.

Recently, researchers used IMT to analyze the stock material for 1-mm-thick artificial heart valves. The valves, made by Carbon Implants, Inc., may cycle 38 million times in a year, and Carbon Implants wanted to study the effect of intentional defects in the valve material to improve the quality and durability of the miniature devices. For instance, the valve material may experience delamination under pressure, or a flaw in one part of the material may cause residual flaws elsewhere. Carbon Implants vice president John Ely sees useful applications for IMT: "This is not a quality assurance tool, but is a research tool that may lead to structural improvements in our product."

In working with the heart valve material, researchers extended the standard IMT technique to analyze samples too thick for the ion beam to penetrate at all angles. The concept behind the new technique, called limited-data IMT reconstruction, is to collect as much IMT data over as large an angular range as possible and then generate a three-dimensional density map based on the limited data set.

IMT (in both full-data and limited-data applications) shows promise for many other important industrial uses in nondestructive materials evaluation and fabrication process control. For example, IMT has been used to produce three-dimensional images of the junction between nearly identical welded glasses in order to investigate weld integrity. Researchers have also studied the metal-matrix composite materials used in airplane engine parts and turbine blades. IMT can be used for inspecting small manufactured parts because of its high sensitivity to light elements (such as carbon), even in the presence of heavier elements. With its current and potential applications, IMT will be an important tool for nondestructive evaluation for many materials and components. ■

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Dan Morse and Mark Hildner check test results at the ion accelerator that generates the proton beam for ion microtomography analyses.

Thin-film gauge checks detonators on centrifuge

Inexpensive device measures detonator performance

Until now, it's been hard to get good data on the functioning of explosive detonators while they're spinning on a centrifuge (to simulate the reentry acceleration loads a ballistic weapon system might experience). Now, shock-induced polarization, a new method for measuring detonator function in this test, has begun to replace the fiber-optic sensors used earlier.

A shock-induced polarization gauge (enlarged view) made of thin polysulfone film, showing the copper electrodes deposited on both sides of the film. When a flyer plate impacts the gauge, the current generated is carried by wire to recording instruments.

The shock-induced polarization gauge uses the electrochemical function of a specialized material to produce an electrical signal in response to impact from a high-velocity disk. The SIP gauge is constructed from polysulfone film, generally 250 to 330 nanometers thick, with copper or gold electrodes deposited on either side of the film. The polysulfone film is readily polarized by shock, and when it is struck at a stress level above its polarization threshold, the film polarizes and releases electrical energy to the electrodes. The amplitude of the resulting waveform is proportional to the transit time, through the gauge, of the initial shock pulse. Recording the waveform allows the researcher to determine the shock wave transit time through the thickness of the gauge. The transit time is then used with an accurate value for the thickness of the film to calculate the shock velocity.

Because the material of the impacting disk is known, equations-of-state can be used to determine the flyer velocity and the impact pressure. Both of these parameters are very important in determining the behavior of the weapon system. (Neither parameter could be determined using fiber-optic instruments, which only provided the time of arrival of the shock.)

Early designs of the SIP gauge used simple electrode designs on either side of the polysulfone film. Researchers soon discovered that placing additional conducting material (a guard ring) around the rear electrode and connecting it to the front electrode reduced spurious electrical signals. In addition to the front and rear electrodes and the guard ring, additional circuit paths can allow the operator to determine if the gauge is correctly connected to the recording device. The SIP gauge is part of the weapons testing research sponsored by DOE's Defense Programs office.

The main advantages of the SIP gauge over other techniques are that the device is inexpensive (approximately \$25 to \$50); the thickness and configuration of the active area can be tailored to the specific application; the gauge is passive and needs no external power or monitoring; all materials are stable with long shelf-life; the gauge is unaffected by most environments (high/low temperature, humidity, etc.); and it can be encapsulated in many media. The gauge has potential applications in other situations where detection of a rapidly applied stress is needed, such as reactive armor, impact guardrails, and time-of-arrival detectors. ☐

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Laser trackers ride the range

Helicopters are the latest targets at Coyote Canyon

For aerial or suspended target tracking, what is more accurate than radar, more efficient than multiple camera stations, and capable of traveling all around the country? The answer—Sandia's mobile laser tracking systems. Sandia has operated laser tracking systems for over 20 years and now has three mobile tracking units utilizing state-of-the-art tracking and control equipment. The three systems can operate individually or in concert and can also control a separate slaved system providing photometric coverage.

In 1991 and again in 1993, the laser trackers have supported the Anti-Helicopter Mine program, a program sponsored by ARPA to meet the increasing helicopter threat in conventional warfare. Sandia's trackers covered over 1,400 helicopter flights at the Coyote Canyon Test Complex in 1991, providing data on dozens of flights a day as various sizes and models of helicopters made low-level flights that could not have been tracked by radar. The trackers

supplied position data to within 1/2 meter to allow comparison of various anti-helicopter mine systems as the unarmed mines responded to approaching helicopters.

"One of the data items desired for the AHM systems was repeatability," recalls Gary Phipps, the photometrics engineer who designed the system's optics. "The fast turnaround on our trackers, with their inherent accuracy, permitted hundreds of tests on each of the three companies' systems in '91." The AHM competition is narrowed to two contractors, with hundreds of tests again this year.

Sandia's laser trackers have supported many other test projects, ranging from smart munitions to parachute systems, at locations such as the Coyote Canyon Test Complex's cable facilities at Sandia, Sandia's Tonopah Test Range, and the Army's White Sands Missile Range, as well as other locations. Targets beyond 10,000 meters, with velocities to 2,000 meters per second, have been successfully tracked. The system slew rate (angular turn rate) is capable of tracking much higher velocities; the upper limit has so far been determined by target speed, not by the tracker. "The laser trackers are also much more accurate than radar," according to Duane Patrick, lead operator for the trackers. "We can provide location or trajectory data to within a foot on cable tests, and we can get closer than that with repeated tests."

Each tracking system uses a flat mirror in an azimuth-over-elevation gimbal to direct a laser beam to the test vehicle. Since the low-mass, gimbaled mirror is the only moving part, this design is capable of significantly higher slew rates than traditional tracking mounts, which have to move much greater masses. Modulated continuous-wave laser light, bounced back from the cooperative, reflective target, is picked up by an image position sensor and a range measuring system. The tracker then provides real-time, three-dimensional position data. The range, azimuth, elevation, and precise time can be stored to computer disk every millisecond. These raw data can be desampled, filtered, and used to produce trajectory data in a variety of numerical and graphic forms within an hour after the test. A portion of the visible light from the mirror is shared between video and 16-mm film cameras to provide standard photometric coverage to 500 frames per second.

In the two newest, upgraded tracker systems, data storage, camera control, and closed-loop servo control are performed by a real-time control system comprised of eight parallel microprocessors. This system, using appropriate software, gives the trackers unique capabilities, such as unaided acquisition of test vehicles on the fly, trajectory prediction through obstructions in the flight path, the ability to send command and control signals by an RF link to a test vehicle in flight, and (in the case of long flights) hand-off tracking to another laser tracker farther down range. It can also acquire targets using data from the target vector translation system currently in use at Tonopah Test Range.

The laser trackers have proven to be reliable, high performance, state-of-the-art systems capable of supporting a wide range of test

One of Sandia's laser trackers in operation. The beam is directed by a gimbaled mirror, whose low mass makes rapid tracking (high slew rates) possible.

requirements. Recent test programs have supported the development of hardware for Sadarm and SFW antitank submunitions, the Stinger missile, Desert Shield, and Sandia's magnetic rail launcher, as well as the AHM program. As Duane Patrick notes, "The tracker is a single-station solution for accurate time, space, and position information. And for the AHM program, the tracker video provided data on helicopter attitude." For either high- or low-slew-rate tracking of rocket sleds, missiles, and airborne test vehicles, as well as visual information, Sandia's laser trackers can cut costs and data reduction time and improve data quality compared to more conventional methods.

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Cascade simulations bear fruit for industry

Radiation transport software predicts electron/photon effects

When photons or electrons smash into some material, further waves of photons and electrons are generated. This cascade can have either useful or harmful effects, but simulating the cascade in complex geometries is a difficult task requiring sophisticated computational tools. Sandia has been developing such simulation tools since the 1970s, and this effort, supported by the Defense Programs office of DOE, has culminated in the Integrated TIGER Series.

The ITS system is a powerful and user-friendly software system that solves linear, time-independent, coupled electron/photon radiation transport problems. Using sophisticated Monte Carlo analyses, the system maximizes operational simplicity without sacrificing physical accuracy, giving both experimentalists and theorists a tool for the routine, rigorous simulation of complex engineering applications. The codes are integrated into a single system that runs on platforms ranging from supercomputers to PCs.

"ITS is one of the top programs for simulating an electron/photon cascade," says John Halbleib, of Sandia's Simulation Technology Research Department. "It's been used extensively for applications involving nuclear, space, and accelerator sources." The nuclear industry has benefited from the application of ITS to reactor safety and to transportation and cleanup problems associated with radioactive waste. The ITS system has also helped solve problems encountered with space radiation in astrophysical, satellite, and spacecraft research and applications.

The most active commercial applications of the ITS system are in electron accelerator research. Leading the way are applications in medical physics, including radiation treatment planning and research, and diagnostic imaging. ITS codes have also been employed to investigate using accelerators to sterilize hospital waste as an alternative to hazardous chemicals.

The ITS codes have contributed significantly to research in the use of electron accelerators for sterilization and preservation. Eradicating insects and microorganisms in foodstuffs could reduce quarantine times for fruits and vegetables, retard spoilage, and increase the shelf life of a number of foods. Effective irradiation, however, depends upon knowing the effects of exposures (to radiation) for many different foods at various intensities and for various durations. ITS can simulate the effects of irradiation and provide some of the answers for food processing companies.

The ITS source code is available from the Radiation Shielding Information Center at Oak Ridge National Laboratory, DOE's center for distributing radiation transport software. "We help here at Sandia by supporting specialized

Ron Kensek (upper left), John Halbleib (lower left), and Greg Valdez examine the on-screen graphics from an Integrated TIGER Series analysis.

applications and modifications of the software," Halbleib says. "In almost all of its applications," he continues, "the ITS software can also be used to investigate related issues, such as shielding requirements to minimize personnel hazards and radiation effects in system electronics."

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Getting up to speed with transit technology

Acoustic research for BART will lead to quieter commuting

For Bay Area Rapid Transit commuters in the San Francisco area, normal conversation in the older "B" rail cars at 80 mph is nearly impossible; at 50 mph, conversation is still pretty difficult. Sandia National Laboratories is working with BART's own R&D group to study noise abatement in the commuter cars. This research is especially timely as BART plans to start refurbishing all of its passenger cars, some already over 20 years old, over the next few years.

One of the BART initiatives involves active noise cancellation to increase passenger comfort. Active noise cancellation refers to an acoustic technique that silences noise, not by conventional methods such as insulation, but by "cancelling out" noise with devices that generate identical sound waves 180° out of phase with the specified sound waves. (Passive technologies will also be considered as part of the noise abatement effort.)

On a complex noise generator, such as a rapid transit rail car, the first order of research is a comprehensive measurement of the environment and an assessment of the data to identify noise sources and their characteristics. In February 1993, Bill Sullivan, project leader, and Scott Gray collected preliminary data suggesting that most of the noise is low frequency (below 1,000 Hertz). Sullivan and Gray applied measurement techniques and experience developed at Sandia in working with submarine acoustics for the U.S. Navy and ARPA.

In May 1993, a Sandia team instrumented two BART cars with calibrated microphones and accelerometers throughout the interior to collect high-fidelity acoustic data under operating conditions on the route from Fremont through the transbay tube to San Francisco and Daly City. After collecting the basic data, they will analyze the information and advise BART officials of the likelihood of active noise cancellation as a way to increase passenger comfort, or recommend other appropriate ways to reduce noise levels.

Other Sandia projects with BART are in the definition phase, including one to provide a safety analysis for BART's design for a new control system to reduce the "headway" between trains. (Headway is the elapsed time between two trains passing a common point while traveling in the same direction.) BART designers are hoping to reduce the headway from four minutes to two minutes.

Sandia researchers are also studying BART's station car concept (to transport commuters to and from the station, probably in electric cars), an emergency notification system for accidents, and preventive maintenance monitoring. Bill Wilson, manager of the Transportation Programs Office at Sandia's California site, says that all of these efforts show how Labs-wide expertise, from California to New Mexico, can be applied to local problems. "We've brought together a team from many areas and disciplines to help a major transit operation as it moves into the future," Wilson says. "We're working with BART, CALTRANS, the Energy Commission, and the Air Resources Board to understand

Anthony Gomez (pointing) and Bill Sullivan checking BART routes in the Bay area. They are selecting annotation points for the data tapes of the Fremont to Daly City run.

A BART train in the assembly yard at Fremont. The number of cars in each train varies with the passenger load throughout the day. Acoustic data were collected in cars on the Fremont to Daly City route.

and solve problems that could become major headaches if they are not addressed in time. The expertise we've developed in defense work in acoustics and weapons safety can be useful to these civilian projects." ■

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