LOS ALAMOS NATIONAL LABORATORY
WHERE SCIENCE MAKES A DIFFERENCE

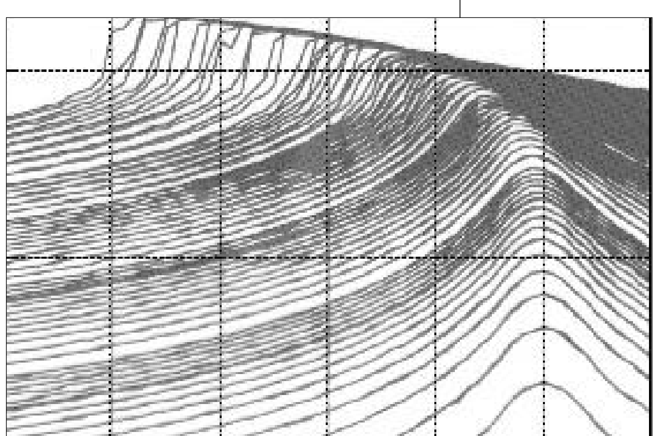
DATELINE LOS ALAMOS

U.S. DEPARTMENT OF ENERGY
UNIVERSITY OF CALIFORNIA

DETECTING MATERIAL DAMAGE

USING NONLINEAR WAVE SPECTROSCOPY TO INSPECT CONCRETE COULD EXPAND TO INCLUDE AGING AIRCRAFT AND NUCLEAR REACTORS

Scientists are measuring nonlinear properties of materials to demonstrate a difference between damaged and undamaged concrete. The research may have broad applications for detecting damage in many materials and could have enormous economic impact.



➔ A typical set of resonance curves of berea sandstone in air showing the shift in the resonant frequency as the volume is increased.

"To our knowledge, there is no other method as sensitive in characterizing damage in materials," said Los Alamos researcher Paul Johnson.

The potential uses of nonlinear techniques to reveal defects in materials include inspections of aging aircraft, quality control for assembly line applications, monitoring containment walls of nuclear reactors and applications to the national infrastructure such as examining bridge pillars and other structures.

Nonlinear materials research includes a technique called nonlinear resonant ultrasound spectroscopy, which is being used by graduate student Loren Byers to measure the difference in the response to an acoustic wave by damaged and undamaged concrete core samples.

"This is the first work to our knowledge that shows the difference between damaged and undamaged concrete using nonlinear methods," Johnson said.

In his research using NRUS, Byers imparts energy to a concrete sample through a speaker-like device that sends a sound wave through the sample. The speaker is set up to input tones over a range from below to above the sample's resonant frequency.

This is called a tonal or frequency sweep. At each tone in the range, he measures the volume and frequency of the wave at the other end of the sample. This procedure is used at progressively increasing volume levels.

In a sample that is undamaged, the volume output is directly related to the volume input, and therefore the resonant frequency remains the same as the applied volume is increased. In a sample that is damaged, the resonant frequency shifts as the applied volume increases, and the amount of the shift can be measured precisely.

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Graduate student Loren Byers checks data from testing samples for damage.

Byers likens it to playing a piano. “For a sample of undamaged material, it’s comparable to hitting a key harder and making the sound louder,” he said. “In a nonlinear sample, when you hit the key harder, the response is not only louder, it’s a different note.”

Moreover, the frequency shift is greater in samples that are more damaged, even with microscopic cracks. So, in a piece of plastic that contains no cracks, there will be no change in resonant frequency as the wave volume is increased. In a sample with a small crack, the resonant frequency will shift readily with amplitude.

Concrete is always slightly damaged in the curing process due to pressures from chemical reactions that build up inside and crack the sample. In a fresh concrete core, the resonant frequency shift is measurable, but becomes considerably larger for the damaged sample, with the same volume input.

This change makes it very obvious what is damaged and what is fresh concrete, because nonlinearity is extremely sensitive to damage.

Evidence of damage is not only provided by the amount of the frequency shift, but by other manifestations of nonlinearity. For example, Byers also tests samples in a “conditioning and recovery” mode in which a loud-volume tonal sweep is followed by several soft-volume tonal sweeps.

In damaged materials it takes some period of time for the sample to return to its original resonant frequency. Further, more damaged samples take longer to return to the original resonant frequency.

"Traditionally, nonlinear properties have been ignored in favor of studying the linear properties of the material to detect damage or flaws," he said. "Nonlinearity is a new frontier in damage diagnostics."

For the immediate future, the researchers would like to test more core samples so they will have a large set of data to study variations in concrete types and damage intensities. They're working toward a correlation between the size of the frequency shift and the amount of damage in a sample, and toward making the technique available to applications indoors and outdoors.

Another technique of elastic wave spectroscopy is nonlinear wave modulation spectroscopy, which involves applying two single-frequency waves to a sample simultaneously and measuring for nonlinear modulation effects that indicate damage.

Los Alamos is collaborating on research in this area with Russian scientists from the Institute of Applied Physics in Nizhny Novgorod, who were instrumental in developing methods to study nonlinear modulation effects for the study of damage.

Other Laboratory collaborations in nonlinear diagnostics are under way with the Catholic University of Belgium in Leuven and the University of Massachusetts at Amherst.

The results stem from research supported by the Department of Energy's Office of Basic Energy Sciences.

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HIGH-TEMPERATURE SUPERCONDUCTING TRANSFORMERS

LOS ALAMOS TO PROVIDE ELECTRICAL CHARACTERIZATION FOR NOVEL ENERGY PROJECT

As partners in a project that could improve the way electrical energy is delivered in America, Los Alamos scientists will be providing special electrical characterization of components used in the first high-temperature superconducting transformer installed in a U.S. electric utility network.

The Laboratory is teaming up with ABB, American Superconductor Corp., and Air Products and Chemicals Inc. to support the development, manufacture, installation and field testing of the HTS transformers.

Los Alamos will characterize certain wires and coils of various sizes used in the transformers to measure their superconducting properties as they relate to fluctuations of temperature and magnetic fields. Lab researchers also will provide cryogenic engineering support for the project.

“Los Alamos was designated 10 years ago as one of three Department of Energy national technology centers for the development and application of high-temperature superconductors,” said Dean Peterson, leader of the Laboratory’s Superconductivity Technology Center. “The expertise and facilities we have to offer to development of a HTS electrical transformer was recognized by ABB to be unique.”

The HTS transformers being tested will offer a number of improvements over conventional power transformers including higher electrical efficiency, smaller size and weight, which increases existing substation capacity and reduces the size of future substations, and a novel liquid nitrogen design that will greatly reduce the potential for transformer fires.

The development and manufacture of the transformer is under the auspices of the DOE’s Superconductivity Partnership Initiative.

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LOS ALAMOS RECEIVES DOE GRANTS

The Department of Energy has awarded grants totaling about $3.6 million to six innovative Los Alamos projects in advanced biological research and environmental cleanup.

The four biological research grants will build on the wealth of information from the Human Genome Project and other research activities to solve complex biological problems. This information will be valuable in a variety of areas, such as health, industry, environment and agriculture.

The two environmental cleanup research projects are targeted at some of the most difficult legacy problems facing the country — the millions of gallons of high-level radioactive waste stored in tank farms and the thousands of contaminated buildings that must be cleaned up and closed or torn down.

BIOLOGICAL RESEARCH

♦ A project aimed at reducing the time it takes to determine the structure of a protein from years to months, or even weeks, is designed to increase the rate of structural determination through techniques in X-ray crystallography and nuclear magnetic resonance. Cutting the time would be a significant advance since there are some 60,000 proteins in the human genome. It is a follow-on to the Human Genome Project to decode the genetic material of a human being.

♦ Another grant will be used to produce biological samples for structural studies. Researchers will grow bacteria that produce specific proteins, which are "labeled" with stable isotopes that don't occur naturally, making them useful for study with neutron scattering and nuclear magnetic resonance techniques. This research holds the promise of significantly reducing the cost of producing labeled samples for research.

♦ Research to improve the ability of the atomic force microscope to provide structural information about biological molecules will ultimately allow researchers to obtain three-dimensional images of proteins and protein DNA complexes rapidly with high resolution. Atomic force microscopy generates images by "feeling" the surface features of a sample. The resolution of the microscope can allow the visualization of materials at the atomic level.

♦ A grant for microbial genome research is for using DNA sequencing techniques to identify and study soil bacteria. This project will provide a survey of bacterial species that may include ecologically important organisms, then use their DNA "signatures" to separate them from the environment for further study. These novel bacteria may have potential uses in such areas as environmental cleanup, production of antibiotics and chemical manufacturing.

ENVIRONMENTAL CLEANUP

♦ A project focusing on actinide aluminate speciation in alkaline radioactive waste addresses high-level waste. Highly alkaline radioactive waste tanks contain a number of transuranic species, the exact forms of which currently are unknown. Studies have shown that the solubility of transuranic ions increases in the presence of aluminate ions under alkaline solution conditions. Researchers want to better understand the molecular nature of the soluble species to predict solubility and sorption behavior in tanks, determine whether revised chemical separations are needed for waste treatment and design separation processes.

♦ A second environmental cleanup project involves using environmentally benign supercritical carbon dioxide to develop a system for selectively removing metals from contaminated surfaces while also reducing the amount of transuranic waste and secondary waste streams generated. Currently, any solid object such as a contaminated glove must be disposed of entirely as radioactive waste. Researchers hope to use new polymers that form micelles — loosely bound aggregates of several molecules that form ultramicroscopic particles — in supercritical CO2 to remove contaminants from the surfaces of such materials. The micelles would interact with contaminated surfaces and dissolve the radioactive material into the micelle core, decontaminating the object and concentrating the radioactive materials for recovery or final disposal.

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ELECTRIC VEHICLES

FROM PIPE DREAM TO PRACTICALITY

The electric-vehicle scenario has always been attractive — autos, trucks and buses that are efficient, nonpolluting and free from dependence on imported petroleum — but it has faced major technical and economic obstacles. In recent years, however, the possibility of putting significant numbers of electric vehicles on the road appears to be more likely, thanks to advances at Los Alamos and elsewhere in the development of fuel cells for transportation.

Tommy Rockward, a graduate research assistant, runs a test at a fuel cell testing station. He is collecting data to help determine the effects of impurities in the fuel stream on fuel-cell performance.

Fuel cells are battery-like devices that convert chemical energy to electrical energy. For nearly 20 years, they have been the focus of a vigorous research program at Los Alamos that has included a number of successful industrial partnerships.

They were invented in 1839 by Sir William Grove of Great Britain, but they did not attract serious practical interest until the 1960s, when NASA selected them to power electrical systems aboard the Gemini and Apollo spacecraft.

Fuel cells operate like batteries, but they do not run down or require recharging and will produce electricity as long as fuel is supplied. In fuel-cell systems built so far for vehicles, the actual fuel is hydrogen, which can come from a variety of sources, including gaseous hydrogen and hydrogen generated on board from gasoline, methane, methanol, ethanol or natural gas.

The cells consist of two electrodes separated by an electrolyte. Hydrogen gas from the fuel reacts at one electrode, called the anode, producing protons and electrons.

The protons move through the electrolyte to the other electrode, the cathode, while the electrons flow through an external circuit with a motor or other electrical device to the cathode, where they combine with the protons and oxygen from the air to form water vapor, the only emission. Catalysts are used at both electrodes to boost the reaction rates.

Much of the research at Los Alamos has focused on polymer electrolyte membrane, or PEM, fuel cells, which appear to be the most promising of various types of fuel cells for motor vehicles. They are highly efficient, stable and reliable. They can be packaged effectively into a small volume, and they operate at relatively low temperatures.

The success of fuel cells in the U.S. space program led industry to look at their commercial potential, but technical problems and high costs kept them from being economically competitive with other technologies until recently. Now, integrated fuel-cell systems appear attractive for worldwide power needs.

There were three main technical obstacles to building practical PEM fuel cells: the cost of the platinum as a catalyst for the electrochemical reactions; effective control of the amount of water in the thin membrane used as the electrolyte; and the intrusion of carbon monoxide, a “catalyst poison” that seriously degrades the efficiency of the electrolyte and is always found in hydrogen derived from methane, gasoline or alcohol.

Beginning in the mid-1980s, Los Alamos researchers began to develop ways to reduce the amount of platinum needed as the catalyst through a number of technical innovations. The earlier estimate of about $30,000 worth of platinum needed for a vehicle has been lowered to about $200 per vehicle.

Los Alamos helped solve the water-management problems by conducting some basic experiments in understanding the processes by which water moved in the electrolyte. Researchers found that thinner membranes of 50 to 100 microns worked much better than the earlier membranes of 175 microns thick.

The third big problem, carbon monoxide contamination, was solved at Los Alamos by developing a way to bleed small amounts of air into the fuel stream, which removed the impurity, and by improving upstream fuel-processing technology to reduce the amount of carbon monoxide that enters the fuel cell.

In addition to working on the fuel cell itself, Los Alamos researchers are involved in developing technologies to process the fuel, manage the buildup and dispersion of heat, control the air supply and other systems required by electrically powered vehicles.

The Los Alamos research team has worked on such systems involving hydrogen and methanol as fuels. Recently, it has made significant progress with fuel-cell-processing technology, demonstrating the feasibility of using gasoline as a fuel. The purpose is to use the existing fuels infrastructure in ways that are environmentally sound.

The work earned the team, along with its collaborators at Arthur D. Little, Plug Power LLC, Argonne National Laboratory and GM, the 1998 PNGV Award for technical accomplishment.

While using gasoline as fuel appears to conflict with an expected benefit of electric vehicles — reducing dependence on fossil fuels — the work is important in developing the necessary steps for a transition from current practices to a sustainable-energy future.

The fuel-processing system presents a difficult engineering problem, but the Los Alamos' expertise in catalysis, heats transfer and control engineering offers real hope for continuing technological advances. The challenge is to combine design and improved catalysis to achieve the required goals in performance, size and cost.

The team continues to work to improve the preferential oxidizer, the primary device for carbon monoxide control. It also is learning more about processes that tend to limit the lifetime of catalysts and investigating a number of related fields such as heat management and alternate fuel-processing concepts.

Other current lines of fuel-cell research at Los Alamos include developing an infrastructure to deliver gaseous hydrogen to consumers, developing a system with methanol as the fuel rather than hydrogen and manufacturing components with stable, low-cost materials such as stainless steel or composites.

Los Alamos also is involved in research into applications of fuel-cell technology in areas other than transportation, including electricity generated by the utility sector and power generation for individual homes.

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INDUSTRY COLLABORATIONS

FUEL RESEARCH

Collaborations with industry have been an important part of the Lab's work in fuel cells for many years. The approximately 20 industrial partners have included General Motors Corp. and Ford Motor Co., as well as chemical firms and automotive suppliers.

The Laboratory and GM formed a major engineering partnership in 1988 and worked for nearly eight years to develop a polymer electrolyte membrane, or PEM, fuel cell and improve fuel-processing systems.

The partnership at Los Alamos resulted in a prototypical fuel-cell system and pioneered manufacturing technology for U.S. industry. It also contributed to advanced component and system diagnostics and the development of models and system controls.

The GM partnership was one of the longest-lived tech-transfer projects involving the Lab. Its results included a 1992 report stressing that fuel-cell-powered vehicles were a cost-effective technology that could work, leading to worldwide interest in the approach.

Today, hundreds of companies around the world are working on fuel-cell technology. Demonstration fuel-cell-powered buses are in operation in Chicago, while tests are being conducted across Europe and in Japan on automobiles that use fuel cells. The total worldwide investment in fuel-cell research and development has been estimated between $1.5 billion and $2 billion.

The U.S. government's Partnership for a New Generation of Vehicles has announced that fuel-cell development would be one of its key focus areas. The partnership is a collaboration of the private and public sectors created five years ago to strengthen U.S. competitiveness by developing advanced transportation technologies.

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BRIEFLY ...

JUDITH MOURANT OF THE BIOSCIENCE AND BIOTECHNOLOGY GROUP HAS WON THE BIOPHYSICAL SOCIETY'S MARGARET OAKLEY DAYHOFF AWARD. The society's main purpose is to encourage the development and dissemination of knowledge in biophysics; its worldwide membership is about 6,000. The award is given to a woman who has demonstrated achievement and promise while not yet achieving a position of high recognition in her field. In this context, achievement means that the candidate has published articles that contribute substantially to science; promise means that the candidate has demonstrated "leadership in ideas, organization or other ways manifest for her colleagues within the scientific community." Mourant won an R&D 100 Award in 1994 for her role in the Optical Biopsy System, a noninvasive fiber-optic and spectroscopy system being developed to diagnose cancer. The system currently is licensed to a company in Florida for clinical applications. She and a colleague also currently are developing the same technology to diagnose other forms of cancer, such as colon and breast cancer. Mourant also holds a patent for developing a method for welding small bones together with a laser. To date, Mourant has had 21 articles published in various scientific journals.

IN THIS ISSUE:

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