Advances toward hydrogen storage

General Motors and **Sandia National Laboratories** have embarked on a four-year, $10-million program to develop and test tanks that store hydrogen in a complex hydride, sodium aluminum hydride, or sodium alanate. Metal hydrides—formed when metal alloys are combined with hydrogen—can absorb and store hydrogen within their structures. When subjected to heat, the hydrides release their hydrogen. In a fuel-cell system, the hydrogen can then be combined with oxygen to produce electricity.

The goal of the partnership is to develop a pre-prototype solid-state hydrogen storage tank that would store more hydrogen onboard a fuel-cell vehicle than current conventional hydrogen storage methods. Researchers hope to create a tank design that could be adaptable to any type of solid-state hydrogen storage and hold enough hydrogen to equal the driving range obtained from a typical tank of gas.

"Hydrides have shown significant early promise to one day increase the range of fuel-cell vehicles," said Jim Spearot, Director, GM Advanced Hydrogen Storage Program. "A lot of research still needs to be done, both on the types of hydrides we use, as well as the tanks we store them in."

The current leading methods of storage are liquid and compressed gas. However, neither of these technologies has yet been able to provide the needed range and running time for fuel-cell vehicles.

"We are designing a hydrogen-storage system with challenging thermal-management requirements and limits on volume and weight," said Chris Moen, Manager of Science and Engineering Technologies at Sandia.

The GM-Sandia project is privately funded and separate from President Bush's Hydrogen Fuel Initiative to accelerate hydrogen research. It will be conducted in two phases, with Phase One entailing the study of engineering designs for a sodium alanate storage tank. Researchers will analyze these designs using thermal and mechanical modeling, develop systems for hydrogen transfer and storage, and develop designs for external heat management. GM and Sandia scientists will also be testing various tank shapes—from cylindrical to semi-conformable—to see which are the most promising.

In Phase Two, researchers will subject the tank designs to rigorous safety testing and ultimately fabricate pre-prototype sodium alanate hydrogen storage tanks based on knowledge gained from the program's first phase.

A possible scenario for filling up with a solid-state storage solution could involve sodium alanate being preloaded in the tank, where it would remain, giving up its hydrogen, and becoming a mixture of sodium hydride and aluminum. The customer would fill up using gaseous hydrogen. During filling, the mixture of aluminum and sodium hydride would absorb the hydrogen and turn it back into alanate, which would be ready to yield hydrogen when needed by the fuel cell. Once the tank is filled, the hydrogen would be stored at low pressure.

One current drawback of hydride-based hydrogen

A critical aspect of hydride storage tank development is the act of recharging and discharging hydrogen. Here, Sandia National Laboratories engineer Mark Zimmerman integrates a hydride bed with temperature-monitoring sensors. (Photograph courtesy of Bud Pelletier.)

Recharging of the hydrides and release of the hydrogen from metal hydrides such as sodium alanate requires heat, which can reduce overall fuel economy. Sandia National Laboratories engineer Terry Johnson sets up a test apparatus that, when verified, will generate external heat that improves the overall energy density compared to traditional heat sources. (Photograph courtesy of Bud Pelletier.)

storage is that most complex metal hydrides, such as sodium alanate, operate at very high temperatures, which causes an inefficiency that forces some of the hydrogen to be used to release the remaining hydrogen. Another challenge is reducing the time it takes to reabsorb hydrogen. It currently takes at least 30 minutes to recharge.

In separate, independent projects outside of this collaboration, both GM and Sandia are working to identify alloys that will store greater amounts of hydrogen that can be released at lower temperatures. Reducing filling and recharging times is another key area of research.

The research conducted through the GM-Sandia partnership is independent from that of Sandia's participation in the Metal Hydride Center of Excellence. The Center of Excellence, to be funded in Fiscal Year 2005 through a **Department of Energy** "Grand Challenge," aims to develop a new class of materials capable of storing hydrogen safely and economically.

Jean L. Broge

Tire and wheel fusion

An airless tire under development may eventually deem obsolete conventional air-filled tires. While **Michelin** researchers are still years away from offering a production-ready non-pneumatic tire with integrated wheel for passenger vehicles, the unique construction of the tire-wheel combination—dubbed Tweel—represents a mobility milestone.

Tweel bypasses the need for tire pressure by a unique use of specific components, mainly consisting of a cable-reinforced band of conventional tread rubber that connects to a shear band to generate the contact patch and replace inflation pressure. That, in turn, connects to a hub via Michelin's patented flexible, rectangular polyurethane spokes.

A production-ready skid-steer loader application for Michelin's Tweel is possible in a couple of years while active research projects are under way with the military.

"The mechanical structure provides weight-carrying ability, shock absorption, ride comfort, rolling resistance, and mass similar to pneumatic tires while adding suspension-like characteristics that greatly improve handling," said Terry Gettys, President of Michelin Americas Research & Development in Greenville, SC. The design allows the wheel stiffness to be soft under vertical loads for comfort, but laterally stiff for accurate handling.

Michelin's Tweel grabbed its first production application on an iBOT wheelchair from **Independence Technology**, a **Johnson & Johnson** company. Using technology invented by **Segway** founder Dean Kamen, the iBOT wheelchair can climb stairs and navigate uneven terrain. Segway's Concept Centaur, a four-wheel transportation vehicle that applies a self-balancing method first used on the Segway transporter, also employs Tweel technology. Other future applications include skid-steer loaders and military vehicles. A production-ready skid-steer loader application is likely in a couple of years, while "active research projects are under way with the military," said Gettys.

In the long term, passenger vehicles could be fitted with Tweel technology in the next 10 to 15 years. Preliminary findings are proving positive. "Michelin has increased the lateral stiffness by a factor of five, making the prototype unusually responsive in its handling," said Gettys

Lessons learned from the first applications of Tweel, which are low-speed, low-weight vehicles, will influence other vehicle developments. "Our expectation is the Tweel components will be application specific. For example, Michelin's early **Audi** A4 prototype uses an inset aluminum wheel, while the wheel of the iBOT is comprised of polyurethane, except for a small metal hub for attachment to the device," said Gettys.

The use of polyurethane in the wheel area allows the wheel as well as the flexible spokes to deform—increasing the suspension capabilities of Tweel. The ability to add compliance without multiple moving parts, plus freedom from the threat of a puncture, are valuable features to designers of many types of vehicles.

David Alexander and Kami Buckholz

Heavy-duty test facility

Last year, **Ricardo** invested $4.8 million to expand its Chicago Technical Center and increase its North American heavy-duty engine performance and emissions testing and development capabilities. The test cells were specifically designed to carry out engine development to comply with **EPA** emissions requirements for 2007 and beyond.

The completion of the advanced test facilities a couple months ago augments Ricardo's heavy-duty engine engineering capabilities, which include design, structural, and thermofluids system analysis; performance, emissions, and mechanical development; aftertreatment systems; and controls systems expertise.

With the expanded capabilities, Ricardo engineering teams can take engine projects from conceptual design through to

Ricardo has completed its Chicago Technical Center Test Cell Expansion Project—which represents an investment of $4.8 million and strategically increases the company's North American heavy-duty engine performance and emissions testing and development capabilities.

production launch. The company provides comprehensive vehicle engineering capabilities to the heavy-duty sector, with a focus on chassis systems engineering, controls/electronics, and powertrain systems integration.

While diesel engines are the primary target of the expansion project, Ricardo's facility is also equipped for heavy-duty natural gas, dual-fuel, and gasoline engines and for serving both on- and off-highway markets—including trucking, agriculture, construction, marine, government, and military.

The first phase of the expansion project, completed in late 2001, included a full dilution constant volume sampling (CVS) tunnel, dilute exhaust analytical instrumentation, and engine and dynamometer control software that meet the requirements of the U.S. Federal Test Procedure and other transient emissions cycles.

The project just completed added two additional test cells, one featuring a fast-response, heavy-duty ac dynamometer capable of absorbing up to 750 hp (559 kW) and the second featuring a similar machine rated at 600 hp (447 kW), both with transient drive-cycle capability.

The facility also uses the STARS control and data-acquisition system developed by a partnership of Ricardo, **Schenck**, and **Horiba** and introduced at the **SAE** World Congress in 2002. STARS uses standard PC hardware to support a wide range of testing and data management, from heavy-duty emissions testing to advanced engine calibration or simple durability testing.

Schenck worked with **Interautomation** to provide system integration services and foot-mounted DYNAS3 dynamometers for the new facility. Horiba supplied the emissions equipment—including two new raw and dilute gas emissions benches, plus upgrades to the CVS dilute gaseous and particulate measurement systems in line with the latest EPA requirements.

Ricardo's North American headquarters are in Van Buren Twp., MI.

Jean L. Broge

Fuel-cell forklift

Over the past year, **Hydrogenics** and a consortium of technology and end-use partners have been working to develop and demonstrate a fuel-cell-powered forklift, toward the ultimate goal of commercialization. The project is being financially supported by a $1.45 million contribution from Sustainable Development Technology Canada (SDTC), which is leveraging a $1.98 million commitment from the Hydrogenics-led consortium. The consortium members include **Deere**, **FedEx Canada**, **General Motors of Canada**, **NACCO** Materials Handling Group, and the Canadian Transportation Fuel Cell Alliance. SDTC's funding supports testing and refinement of the technology as part of the development and demonstration process.

Last month, Hydrogenics demonstrated a hydrogen fuel-cell-powered forklift and a Hydrogenics HyLYZER hydrogen refueling station at GM's car plant in Oshawa, Ontario. The HyLYZER refueling station is compact and can be transported easily from site to site. It can produce a variable amount of hydrogen, depending on requirements, and it can refuel a forklift in a fraction of the time that the batteries can be changed or recharged on a battery-powered unit, claims the company.

This is the first time a fuel cell vehicle supported by an on-site hydrogen fueling station has been demonstrated at a GM facility.

"Demonstration projects like this are critical to the development of fuel-cell technology," said David Paterson, Vice President, Corporate and Environmental Affairs, GM Canada. "With predictable duty cycles, lift trucks are an ideal application from which to learn; and a large plant like ours, where external elements are not a factor, is an ideal place in which to conduct a trial like this."

As part of a consortium that includes GM Canada, Deere, and NACCO, Hydrogenics has set out to prove and demonstrate that commercially viable hydrogen-powered industrial vehicles "are closer to the market than many people think."

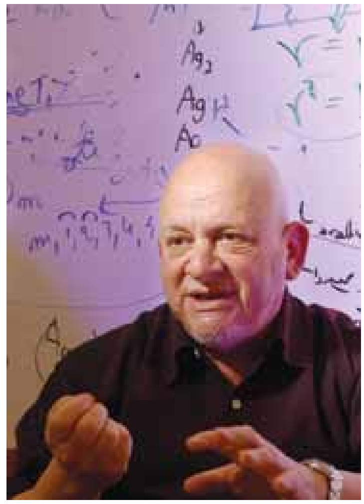
According to Pierre Rivard, President and CEO of Hydrogenics, industrial vehicles currently contribute almost 13% of the global total of transportation-related greenhouse gas emissions.

"We believe that one of the first commercial uses for hydrogen-powered vehicles will be in industrial vehicle fleets, such as forklifts, where dedicated on-site refueling stations can meet immediate refueling needs," said Rivard. "Fuel-cell-powered forklifts produce no exhaust emissions, and they have significant operational advantages over traditional battery-powered forklifts."

Jean L. Broge

Charging nanocatalysts to reduce costs

Studying nano-sized clusters of gold on a magnesium-oxide surface, researchers at the **Georgia Institute of Technology** and **Technical University Munich** have found evidence for the electrical charging of nano-sized catalysts. The findings may prove to be an important factor in increasing the rate of chemical reactions during the manufacture of a range of materials from plastics to fertilizers.



Georgia Tech professor Uzi Landman and colleagues are studying the particulars of nanocatalysis, which they believe will lead to the manufacturing of synthetic materials at lower costs.

"The fabrication of most synthetic materials involves using catalysts to promote reaction rates," said Uzi Landman, Director of the Center for Computational Materials Science, Regents' Professor, and Callaway Chair of Physics at Georgia Tech. "Designing catalysts that are more efficient, more selective, and more specific to a certain type of reaction can lead to significant savings in manufacturing expenses. Understanding the principles that govern nanocatalysis is key to developing more effective catalysts."

The study builds on joint research done since 1999 by the two groups that found gold, which is non-reactive in its bulk form, to be a very effective catalyst when it is in nanoclusters of eight to about 24 atoms in size. Those specific sizes allow the gold clusters to take on a 3-D structure, which is important for its reactivity.

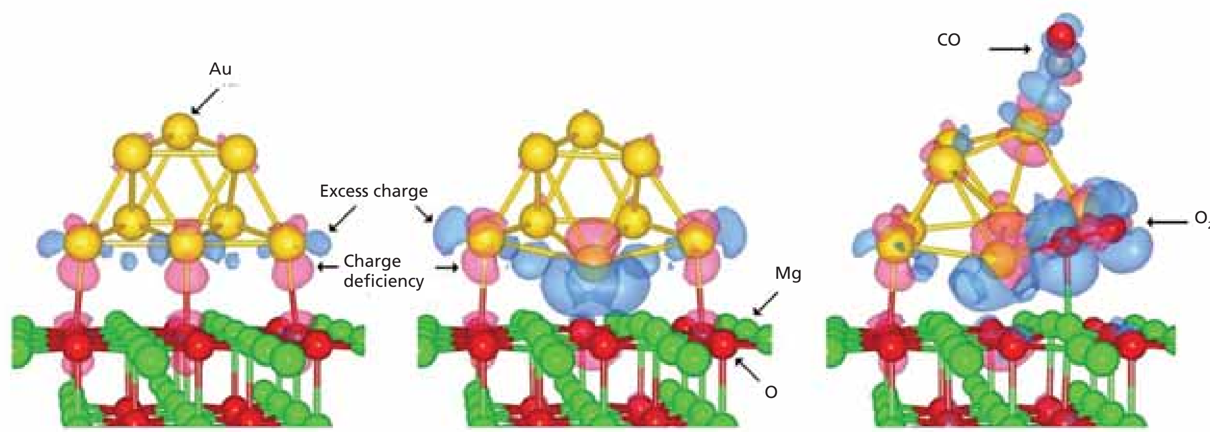
"It is possible to tune the catalytic process not only by changing the composition of the materials, but also by changing the cluster's size, atom by atom," said Ueli Heiz, Professor of Chemistry at Technical University Munich.

In earlier studies of the reaction where carbon monoxide and molecular oxygen combine to form carbon dioxide, Landman's group used computer simulations to predict that when gold nanoclusters of eight atoms are used as the catalyst and magnesium oxide is used as the catalytic bed, reactions would occur when the bed had defects in the form of missing oxygen atoms, but would not occur when the magnesium oxide was defect-free.

Heiz's experiments confirmed this prediction, and the teams concluded that the gold must be anchoring itself to the defect where it picks up an electron, giving the gold a slight negative charge. Theoretical simulations showed that the electronic structure of the gold clusters match up with the oxygen and carbon monoxide. The charged gold transfers an electron to the reacting molecules, weakening the chemical bonds that keep them together. Once the bond is weak enough, it breaks, allowing reactions to occur.

Using eight-atom gold clusters as the catalyst and magnesium oxide as the catalytic bed in the most recent study, the team measured and calculated the strength of the bonds in the carbon monoxide by recording the frequency of the molecule's vibrations.

"If carbon monoxide is a strong bond, then there is a certain frequency to this vibration," said Landman. "If the bond of the carbon monoxide becomes weaker, then the frequency becomes lower. That's exactly what we saw—when we had defects in the magnesium oxide, we had larger shifts than when we had magnesium oxide without defects."



Charge difference for a bare gold octamer supported on a perfect magnesia, (MgO) surface.

Charge difference for the cluster anchored on an oxygen-vacancy surface F-center, showing enhanced charging of the cluster.

Charge difference for the cluster with adsorbed reactants, supported on a surface F-center, showing charging of the CO and O_2 molecules.

"And all this happens at low temperatures," said Heiz. Reactions requiring catalysts typically need heat or pressure to get the reaction going, adding to manufacturing costs. Since the properties of the catalytic beds can increase the rate of reactions for nanocatalysts, new and better low-temperature catalysts may be found.

"We knew the specific number of atoms in the catalyst and that defects in the catalytic beds are important. Now we know why those defects are so essential—because they allow the catalyst to be electrically charged," said Landman. "It's possible that at the nanoscale you may find catalysts that can do things under more gentle and cheaper conditions."

Jean L. Broge

Orbital motors from Sauer-Danfoss

The new TMKW, TMTW, and TMVW wheel-mount versions of orbital motors have arrived, adding to **Sauer-Danfoss**' family of existing T-Series motors for demanding work situations, such as skid-steer loaders and forestry equipment. According to the company, the motors are optimized for both travel and digging conditions, consuming less power, while maintaining a high tractive effort during digging operations. The new motors also provide operators more controllability and smoother operation due to better torque symmetry (equal performance left motor to right motor), as well as "trouble-free service and long life."

"The TMKW, TMTW, and TMVW bridge the gap in price and technology between cam lobe and orbital motors for demanding applications," said Jeff Brenner, Product Manager. "They provide an alternative to an OEM who prefers not to pay the cost of a traditional cam lobe (radial piston) motor, like you may find in many road rollers, skid-steer loaders, and forestry equipment. They provide a new solution where a high-pressure, efficient, and durable orbital motor was never before available."

Designed specifically for challenging propel applications, the smaller TMKW is suitable for small frame skid-steer loaders, heavy lawn and turf vehicles, small road rollers, rough terrain scissor lifts, and other construction applications that require smooth low-speed operation, high pressure, and a compact design. The TMKW maintains a consistent high efficiency throughout machine operation—the continuous and intermittent pressure being 250 and 325 bar (3.6 and 4.7 ksi), respectively. High-starting torque contributes further to the wheel motor's suitability for operation on rough and hilly terrain, says Sauer-Danfoss. Displacements range from 160 to 470 cm^3, while side and end ports provide flexible installation options. The TMK is also available with a compact integrated hydraulic parking and emergency brake. The TMK is available in a wheel mount (TMKW), brake mount (TMK FL), magneto mount, and **SAE** "C" mount.

The next largest in the T-Series family is the TMTW, which is the wheel-mount version of the existing TMT series motor. The TMTW works well on applications such as medium-frame skid-steer loaders (propel) and forestry equipment (harvester heads).

Sauer-Danfoss has added to its family of high-performance orbital motors with the wheel-mounted, high-torque TMKW (a), TMTW (b), and TMVW (c), which can be used to replace higher-priced radial piston motors in a wide range of off-highway equipment.

The TMTW is said to be efficient and robust, with the continuous and intermittent pressure being 250 and 350 bar (3.6 and 5.1 ksi), respectively. The TMTW is available in displacement from 250 to 630 cm^3. The TMT Series is available in standard mount (TMT), brake mount (TMT FL), bearingless (TMT U), and wheel mount (TMTW).

TMVW is the largest and most suited for heavy-duty propel and work functions such as road-building and forestry equipment, which require high power and high levels of robustness. The TMVW is rated at the same pressure levels as the TMTW but with displacement ranges from 400 to 800 cm^3 and a larger drivetrain for high-duty cycle applications.

Jean L. Broge

Engineered air

Compressed air is used for a variety of applications—from powering pneumatic tools, to paint-spraying parts and entire vehicles, to driving a conveyor line. All compressed air might be the same, but the engineering of that air is not.

Engineered air is a term used to describe compressed air tailored to meet specific industry needs—100% oil-free, particulate-filtered, and completely reliable. It goes beyond the simple output of compressed air at a specified pressure. Engineered air provides three fundamentals key to maximizing automotive plant manufacturing capabilities: reliability, maintainability, and control.

If the compressed air systems in an automotive plant cease to work, the entire line is affected, from painting/spraying systems to pneumatic tools and robotics, such as riveters and surface finishers. Lengthy shutdowns can mean loss of revenue due to reduced throughput.

Redundant systems can help eliminate the possibility of system failure, allowing a plant to meet or even exceed production quotas. For example, much like most off-highway equipment, within an air compressor the oil pump is the heart of the lubrication system. A redundant system, such as that found in an **FS-Elliott** PAP Plus Compressor, includes not one but two full-capacity, full-pressure pumps providing a reliable source of engineered air. A back-up pump operates automatically in emergency situations to provide additional overall package protection.

Despite system redundancies, every compressed-air system will need to be accessed for cleaning and maintenance. While requiring additional time and attention from plant engineers, cleaning and maintenance are a sound investment. Compressed air systems that are cleaned and maintained are less likely to break down, allowing for increased production. In addition, consistent cleaning and maintenance help keep wear and tear to a minimum, saving money on replacement parts.

A 9000 ft^3/min (15,300 m^3/h) air compressor is one of several duplicate units supplying oil-free air in an automotive electronics component facility in Asia.

The only moving parts of the FS-Elliott PAP Plus compressor are a gear and the rotors. Because it is a centrifugal design, there are no lubricated parts in the air passage.

FS-Elliott's Regulus Control System allows for management of air compressor needs at the unit or from a remote location.

Many manufacturers have designed their systems with accessibility and maintenance in mind. For example, straight intercooler tubes and horizontally split bearings are easier to access and maintain.

Engineered air gives manufacturing plant operators greater control over their manufacturing systems. Advanced control and monitoring systems—like FS-Elliott's Regulus Control System—allow operators to manipulate an entire compressed-air system from anywhere in the world, using PLC-based systems with human-machine interface features such as touch screens and color graphics. These systems allow for precision control and accurate trending for preventative maintenance. In addition, they feature control adaptability to suit the specific needs of an off-highway manufacturing operation (*i.e.*, wire brushing, grinding, polishing), offering a higher degree of control over the manufacturing process.

Engineered air can increase reliability and efficiency. Simply recognizing that engineered air is not the same as compressed air is only one step toward maximizing manufacturing capabilities.

This article was written by **Addison Kelley**, Vice President Global Customer Support, FS-Elliott.

Changing metal shapes at nanometer level

A nanocrystalline metal has an average grain size measured in billionths of a meter, according to researchers at the National Center for Electron Microscopy (NCEM), **Department of Energy**'s **Lawrence Berkeley National Laboratory**. This is a much smaller size than in most ordinary metals.

As the grain size of a metal shrinks, it can become stronger. The down side is that the metal also usually loses ductility. To take advantage of increasing strength with decreasing grain size, researchers must first understand a fundamental problem: By what processes do nanosized crystals of metal stretch, bend, or otherwise deform under strain?

A team of researchers headed by Scott X. Mao of the **University of Pittsburgh**'s Mechanical Engineering Department, working at the NCEM and using high-quality samples of nickel prepared at DOE's **Sandia National Laboratories**, has identified a prominent way in which nanocrystalline metals deform.

Ordinary coarse-grained metals deform when parts of a grain slip past one another as extra planes of atoms, called dislocations, move through the material. The process has been compared to moving a rug by flapping one end of it to create a wave, causing the rug to inch along bit by bit. But the trick won't work if the rug is too short; likewise, if the dimensions of the crystal grains are too small, dislocations can't be created or glide through the grain to allow deformation.

Theorists have proposed that when grain sizes are too small for dislocations, a different mode of deformation comes into play: The grain boundaries themselves move, sliding past one another and allowing the grains to rotate to find new ways of fitting together.

"It's a simple idea," said Zhiwei Shan of Mao's laboratory at Pitt, "and many groups have researched aspects of it, but no one has reported direct evidence of a shift from dislocation-mediated deformation to grain-boundary-mediated deformation." Until now, no one was even sure where to look for the transition from one mode of deformation to the other. "When the grains were reduced to 20 nm across? 10? Perhaps as small as 5?"

Zhiwei Shan (sitting) of the University of Pittsburgh works with Eric Stach of Berkeley Lab at the National Center for Electron Microscopy's In-Situ Microscope.

To search for the effect, Shan used NCEM's In-Situ Microscope. NCEM's Eric Stach explained that what makes the In-Situ's otherwise standard transmission electron microscope unique is that it combines a stage area in which samples can be stressed or manipulated in other ways—and meanwhile videotaped—with a high-voltage, 300-kV electron beam that can penetrate thick samples and yield 0.2 nm resolution.

The nanocrystalline nickel samples were mounted in a probe that placed them under load—stretched them—while images of small regions of the sample were captured on videotape at the standard rate of 30 ft/s (9.1 m/s).

But besides having an excellent instrument, Shan made a crucial observation. An effect that was far from obvious in the most common TEM imaging method, called bright-field imaging, stood out clearly with the different technique of dark-field imaging.

"As the TEM's electron beam passes through a sample, some of the electrons are diffracted," Stach explained. "Bright-field images are constructed using the direct electrons, while dark-field images use the diffracted electrons. In bright-field imaging, regions of the sample that scatter a lot of electrons, like defects such as dislocations, look darker. With dark-field images, strongly diffracting regions look brighter."

Shan concluded that dark-field imaging was critical to the result. When he viewed videotapes of the nickel sample under strain, he saw small regions rapidly brightening and growing larger—direct confirmation of grains sliding and rotating into positions of strong diffraction.

In a bright-field image, these grain-boundary processes would have been impossible to distinguish from lattice dislocations, which in prior attempts is what other groups assumed they were seeing. It took dark-field observations to confirm that below a certain size, grain-boundary rotation indeed becomes prominent. The cutoff isn't sharp, however.

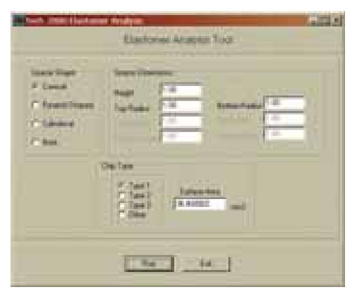
"It's continuous, not a sharp change," Shan said. "In describing grain-boundary deformations, we chose the word 'prominent' carefully, because even in nanocrystalline metal, dislocations still play a role." Trapped dislocations in the crystal lattice were observed even when the average grain size was as small as 10 nm.

"The material always chooses the easiest pathway to deform, and that can differ through a range of sizes," said Stach. Although the In-Situ Microscope observations confirm the grain-boundary model of nanocrystalline deformation, whichever process predominates at a given grain size depends on a variety of conditions.

Patrick Ponticel

Automating non-linear analysis

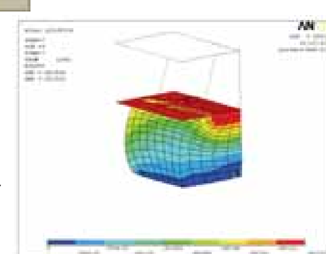
Silicone rubber spacers in the shape of truncated cones are used in electronic applications to ensure thermal or electrical contact between different components. In one such application at **Delphi** Electronics and Safety, the cones are used in engine control modules (ECMs) to press the integrated circuit (IC) against metal heat sinks to provide a conduction heat transfer path to cool the circuitry.



Delphi specialists have developed an automated tool using ANSYS parametric design language to allow engineers not experienced in FEA to analyze non-linear elastomer spacers.

Determining the force exerted by the spacer is critical to the design of the module. Insufficient force would not adequately cool the IC or properly secure it, resulting in premature failure due to overheating or excessive shock and vibration. However, the force cannot be set too high because of constraints in the ECM housing and printed-circuit board (PCB).

Previously, design engineers estimated the elastomer force using linear calculations, which could lead to large errors because of the hyperelastic material properties. This issue was particularly significant in the case of spacers for larger ICs and rectangular ICs with very high aspect ratios between length and width.



Output from Delphi's in-house tool shows the deformed shape of a spacer analyzed with ANSYS.

Engineers at Delphi used ANSYS Structural from **Ansys**, to more accurately represent the elastomer material properties so that spacers could be designed to provide optimal force against the circuit board. Mooney-Rivlin material constants for the FEA model were derived from experimentation, where spacer samples were compressed and the resulting force-deflection curves derived through curve-fitting techniques.

Once the properties were established, FEA models were developed, and the results validated by accurately reproducing measured data. The FEA models were then used to accurately predict force-deflection curves for new spacers as well as establish curves for spacers already in use. ANSYS contact elements were particularly useful in these models to represent surface-to-surface contact between the spacer and PCB.

ANSYS provided an efficient way to predict the force-deflection curve for the compressed spacers in less time and with greater accuracy than previous methods of linear estimation. As a result, engineers can now develop optimal designs that extend the life of ECMs in harsh environmental conditions present in off-highway applications.

Due to the simplicity of the various geometries involved, creating an automated tool to calculate force-deflection data for spacers was a natural development. Delphi engineers used APDL (ANSYS parametric design language) and the C++ programming language to develop a generic model of a spacer, extract FEA results data of interest to product engineers, and present the information in tabular form. Once the scripts were tested, a graphical user interface was developed to collect the dimensional data from a product engineer and to execute the model.

The Delphi "Elastomer Analysis Tool" now allows a product engineer—without any experience in FEA tools—to use the power of non-linear analysis technology. The engineer enters only the spacer shape and dimensions in the tool, which then provides a tabular output report of force and pressure as a function of compression and shape.

Fereydoon Dadkhah, Sr. Mechanical Engineer, Mechanical Analysis and Simulation at Delphi Electronics and Safety, wrote this article.

Making sense of sensor placement

Conventional ways of gathering steering wheel position data are to utilize a contacting position sensor or a magnetic sensor, but both sensing technologies have limitations.

"The contacting position sensor is accurate, but it generates electrical noise. And it has a limited life span," said Steve Kennelly, **Microchip Technology**, Inc.'s Marketing Manager for the Automotive Product Group, adding, "The magnetic sensor is more robust than the contacting position sensor, but it has limited accuracy."

To avoid the limitations pitfall, Microchip and **TAOS** (Texas Advanced Optoelectronic Solutions) have developed a reference design that uses light sensing technology to create a position sensor. "The optical rotary encoder, shown at Convergence by TAOS and Microchip Technology, is noncontacting, so there are no wearing parts. And in our example implementation, the demonstration device has a remarkably high accuracy—0.088 degrees of angular resolution," said Kennelly.

The optical rotary encoder uses off-the-shelf parts, including a linear array from TAOS and a microcontroller from Microchip Technology. "The optical rotary encoder can measure steps of 0.088 degrees, or 4096 unique positions per revolution, which makes it ideally suited for applications such as electronic power assist steering and electrohydraulic power steering," said Bill Holland, Market Specialist for TAOS.

The TAOS/Microchip Technology optical rotary encoder was shown as a demonstration device during Convergence.

An optical rotary encoder is especially beneficial for by-wire technical designs "because by-wire requires a higher accuracy than other types of encoders are capable of providing," said Kennelly, adding, "The idea behind this demonstration of an optical rotary encoder is to show how an electrical/electronics engineer can implement a steering wheel angle sensor using a TAOS linear array and a Microchip microcontroller to realize the benefits of a highly accurate optical system simply and easily."

Kami Buchholz