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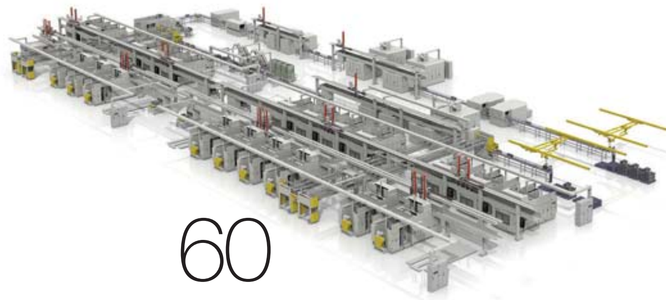

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DEPARTMENTS

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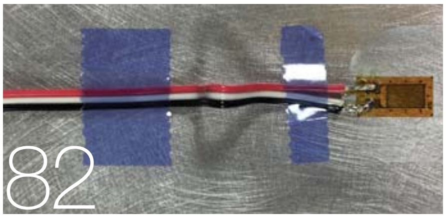
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ON THE COVER: A showroom model of a propeller printed using stereolithography.

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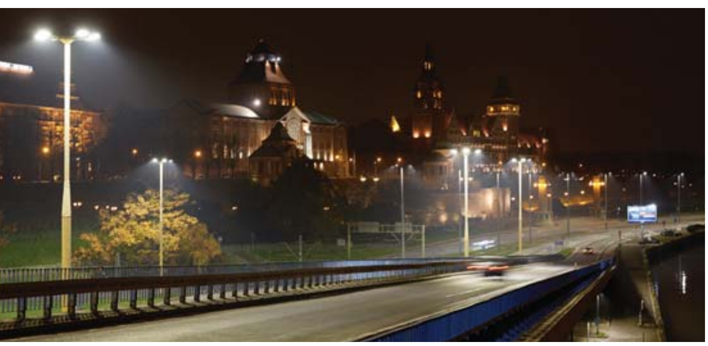
HITTING THE ROAD WITH MACHINE DESIGN

In the past month, our editors have been hitting the road to attend some of the most exciting and informative events in the industry—from the Inside 3D Printing Conference in New York, to the USA Science and Engineering Festival in Washington, D.C., and overseas to the mammoth Hannover Messe Fair in Germany. You can see all the coverage from these shows, including news, blogs, and lively image galleries, at machinedesign.com.



CONNECTIVITY IS KEY TO SMART CITIES

http://machinedesign.com/blog/smart-cities-need-connectivity-thrive

With smart cities, the plan is that the Internet of Things will enhance all aspects of a city's utilities. Water plants will regulate flow water based on high-usage periods throughout the day, or energy consumption will be controlled for the city based on usage. Innovations such as these lead to better efficiency of resources. As Tech Editor Carlos Gonzalez notes in his latest blog, testing sites have already started to appear in the United States and in other parts of the world.

LUBRICANTS FOR BALL SCREWS

http://machinedesign.com/mechanical-drives/selecting-lubricant-ball-screws

Lubricants on ball screws are as important to their performance and life as are their operating loads, speeds, accuracies, environments, and power requirements. Lubricant reduces the already low friction by minimizing contact between the balls and grooves, thus adding torque and increasing efficiency, while extending the screw's life by a factor of 10. Proper selection and application of lubricants also affects contamination, a leading cause of premature ball-screw failure.

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A SHORT HISTORY OF MEMBRANE SWITCHES

http://machinedesign.com/manufacturing-equipment/short-history-membrane-switches-0

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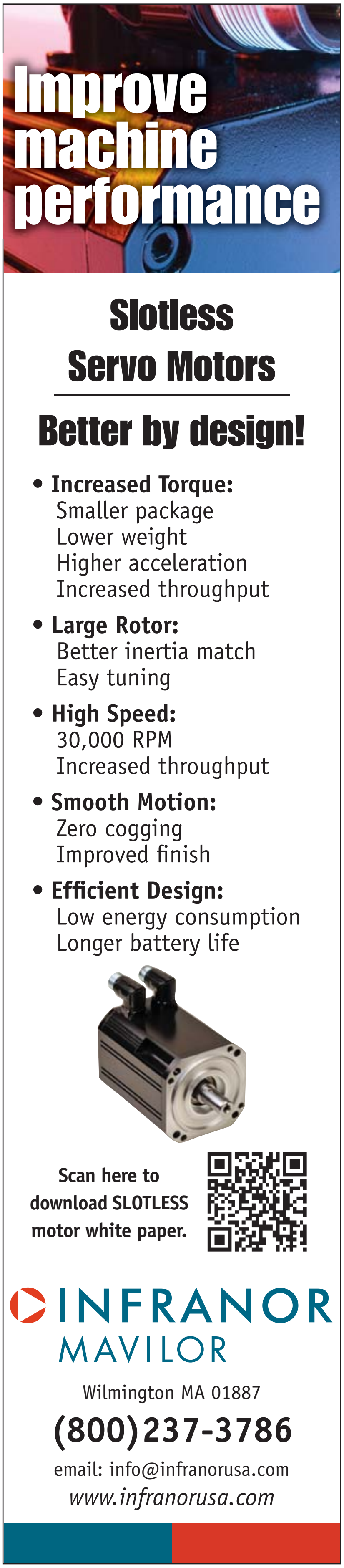

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MAY 2016

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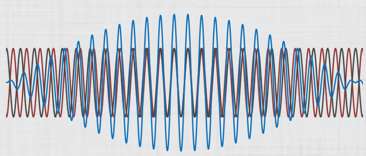

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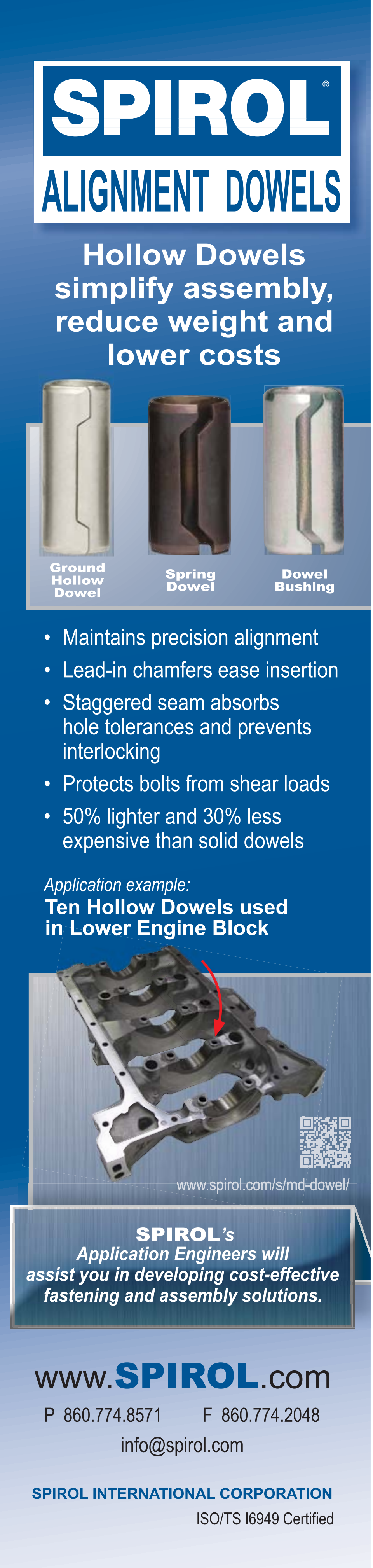

Editorial

JEFF KERNS | Technology Editor
jeff.kerns@penton.com

Curiosity Evolved the Cat

This is how William Least Heat Moon defined curiosity in his book, *Blue Highways*: "Curious, related to cure, means 'carefully observant.'" It is applicable to engineers, as we tend to be curious and carefully observe the world around us. I thought about this before I left for the USA Science & Engineering Festival. By taking advantage of kids' natural tendency to be curious, we can teach a generation to be "carefully observant" about patterns in our world and science, technology, engineering, and math (STEM). In doing so, we can improve the likelihood of new discoveries and inventions.

We could all use a little more curiosity. More people seem to be asking what is happening to jobs and industry in the United States. As of January 2015, the U.S. as a nation ranked 27th in math and 20th in science, according to a Pew Research Center study on education. How are we going to stay on the cutting edge while our education is not keeping up with the rest of the world? In order to fix a problem, we must first admit we have one. Second, we must ask, what are we going to do about it?

The 2016 Science and Engineering Festival in Washington, D.C., celebrated STEM with such notable guests as Bill Nye, Wil Wheaton, and Neil deGrasse Tyson.

The approach of today's U.S. education system increasingly revolves around tests, which can intimidate students and might not teach them the importance of what they are learning. But what we really need are people who are curious, who are free to explore, tinker, and not afraid to fail. "Curiosity is what drives technology and keeps people on the cutting edge," says Matteo Dariol, product support engineer for Bosch Rexroth. Instilling curiosity about the "guts and gears" of the world at an early age is the best way to make kids curious about STEM, rather than instilling a fear of "wrong answers" on tests that will lead to insufficient grades.

Neil deGrasse Tyson says that no matter what you want to be, scientist or artist, being scientifically literate will help make you better at it. If we fail to spark curiosity, future generations will never understand the benefits of being scientifically literate. Our youth should know calculus. Perhaps, more importantly, they need to understand that it's not about when they will use it in real life, but engaging the brain in that problem-solving process. Scientific literacy is about knowing how to use the "prime mover" of tools—the brain.

Please let me know any organizations you are a part of that help inspire scientific literacy. In addition, what do you think about the current state of STEM in the USA? What, if anything, should be done to help inspire STEM in the next generation? Email me at jeff.kerns@penton.com. md

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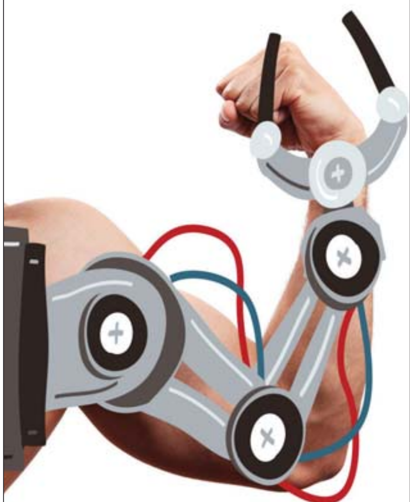

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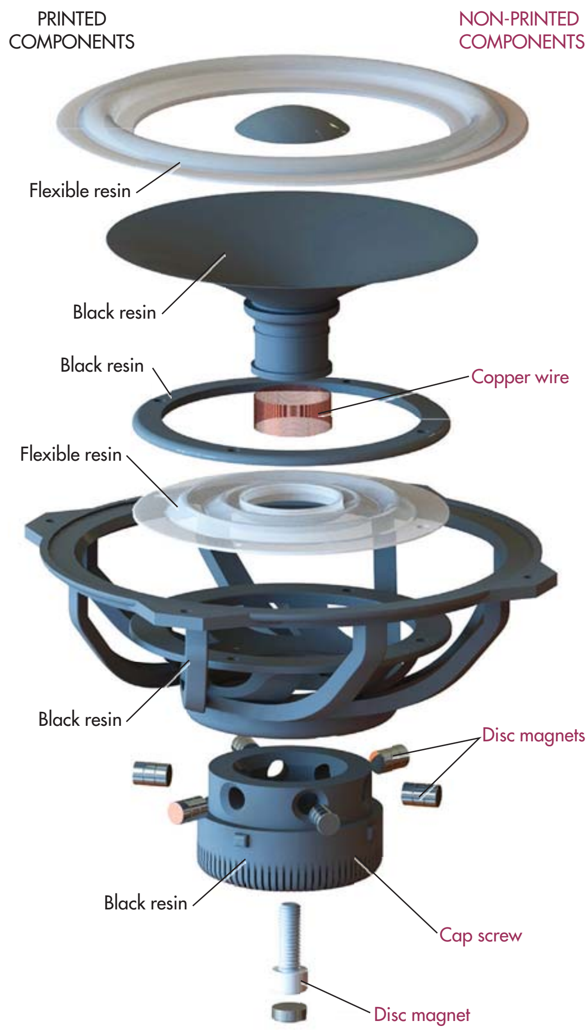
Software Updates Help Improve 3D Printing

WITH THE ONSLAUGHT of innovations continually changing the industry's landscape, designers maintain their focus on software to get even more out of the hardware. An example of this occurred last year when Formlabs updated software to include a 200-micron setting to the printer's resolution. Printing in thinner 200-micron layers allows for quicker prints.

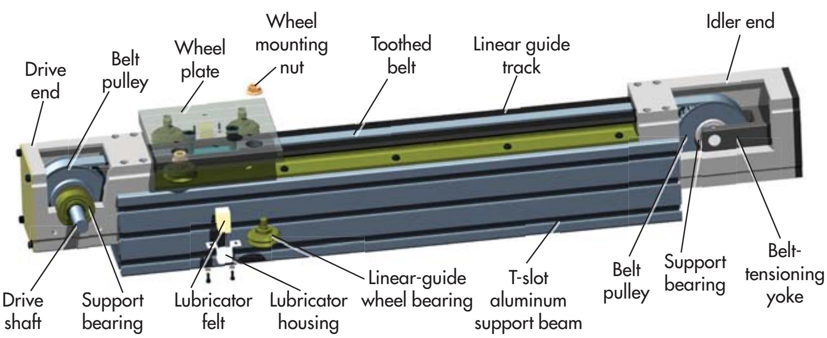
The update was for the Form 1+ SLA model, and the software update improved print speed further by reducing structural supports. Less support doesn't necessarily affect quality if used effectively, and can greatly reduce print time.

FormLabs said this one update reduced support material by as much as 60%. Updates in software allow objects such as this 3D-printed speaker, created by Adam Lebovitz, to be printed with the same quality, but faster and cheaper. md



Linear Actuators Accelerate Motion-System Design

A LINEAR ACTUATOR is a combination of linear guides and power-transmission components contained in an assembly. Sometimes these are referred to as a linear motion system, or an actuated system. Designing with a complete actuated linear system can reduce overall machine design and fabrication costs. Standardized actuator products eliminate the effort associated with integrating lower-level components and assemblies, and they contain application-tested and -optimized construction.



The LoPro Linear Actuator product line from Bishop-Wisecarver Corp. is an industry-tested solution for accelerating motion-system design. LoPro actuators are made from standardized sub-assemblies and options that are customized for specific application requirements. They utilize DualVee Motion Technology for the linear guides, which are double-row, angular contact ball-bearing guide wheels that provide smooth and quiet motion over long length. The guide wheels feature 90-deg. surfaces that roll on long linear tracks. The tracks can be up to 20 feet long and butt-joined for unlimited lengths. LoPro actuators are produced in user-specified stroke lengths, and motion systems in the 15-meter range are common for long-distance pick-and-place applications.

Several drive types are available, including ball screw, lead screw, AT belt, and ANSI roller chain. Power transmission via an AT-style belt provides for a good balance of precision locating accuracy, long travel stroke lengths, and high speed. The AT belt is a high durometer polyurethane belt with internal steel-cable reinforcement. LoPro linear actuators with belt drives include a complete system to support and tension the belt. The drive end is where a motor or manual hand wheel is attached to a keyed output shaft. The shaft is held with support bearings and holds a toothed pulley. The idler end also contains a toothed pulley and support bearings, and includes a yoke to apply belt tension. The belt is attached to a wheel plate that includes the linear-guide wheel bearings. Motion is generated at the wheel plate when the drive shaft is rotated. smd

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News

WATER-EXCAVATING ROBOT
Set for Moon Launch by End of Decade

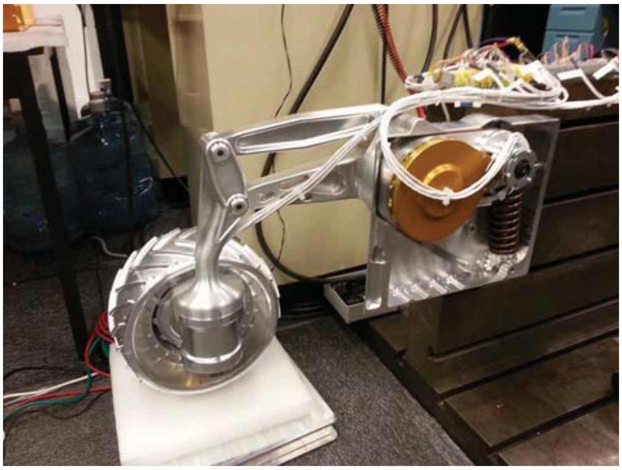
After years of testing, NASA's excavating autonomous robot, the Resource Prospector, now appears equipped to investigate the availability of water and other elements on the moon. If authorized, NASA will launch the robot to the moon in 2020.

The initiative builds on the Lunar Crater Observation and Sensing Satellite (LCROSS) and the Lunar Reconnaissance Orbiter (LRO) missions, both of which were successful in finding water on the moon. NASA has been testing the Resource Prospector in simulated environments on earth to develop its ability for analyzing, harvesting, and processing natural elements from underground.


The Resource Prospector incorporates a solar-tracking solar panel to boost and store energy when in sunlight.

The robot contains a drill unit, suspended wheels for covering rocky terrain, and a neutron-spectrometer tool that can determine the quality and quantity of atoms and isotopes in volatiles such as hydrogen, nitrogen, helium, methane, ammonia, hydrogen sulfide, carbon monoxide, carbon dioxide, sulfur dioxide, and water.

NASA hopes that the elements can be harvested for future shipment to extraterrestrial human colonies and missions. Not only will these elements help sustain life, but they will also be key ingredients in developing fuel and materials. Utilizing resources directly from the moon, and eventually other planets and asteroids, could ultimately lead to decreasing the weight of payloads, saving thousands of dollars in attempts to colonize our solar system. ■


The robot's custom wheel-suspension system will enable it to drive along the rocky terrain of the moon.

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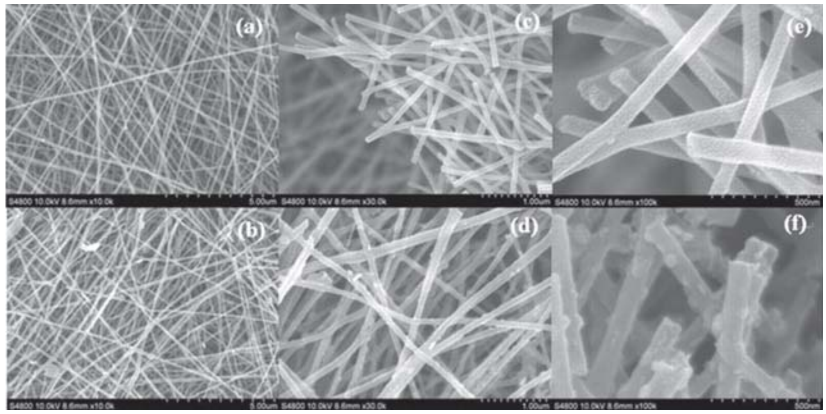
HARMFUL GREENHOUSE GASES Repurposed into Carbon Nanofibers

AFTER PRESENTING METHODS for producing carbon nanofibers to the American Chemical Society this past August, George Washington University (GWU) professors set a conference in Boston abuzz with excitement, and, quite likely, reasonable doubt. Here's why:

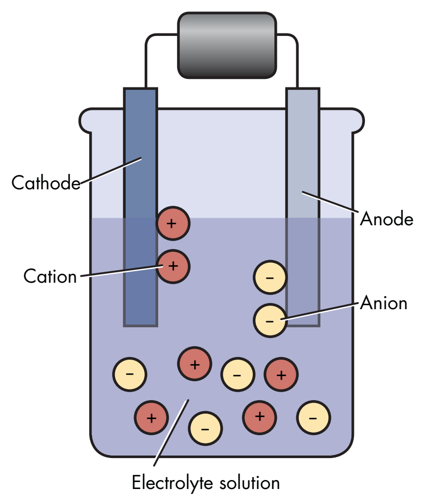


Carbon nanofibers (CNFs) are exquisite conductors of heat and electricity, and have very high tensile strength. They show promise in high-performance electronics, textiles, and other industrial and consumer applications. They also exhibit quantum behaviors that make them unique for a range of metamaterials.

A simple and economic method to synthesize carbon nanofibers (CNFs) has eluded scientists for decades. But the most impressive feature of GWU's "one-pot" synthesis is that it repurposes carbon dioxide directly from the atmosphere. According to the report, published in *Nanomaterials*, the process successfully produces a high yield of CNFs with great structural integrity, and at lower costs than other methods. In addition, it doesn't require a separate process to concentrate the atmospheric CO_2.

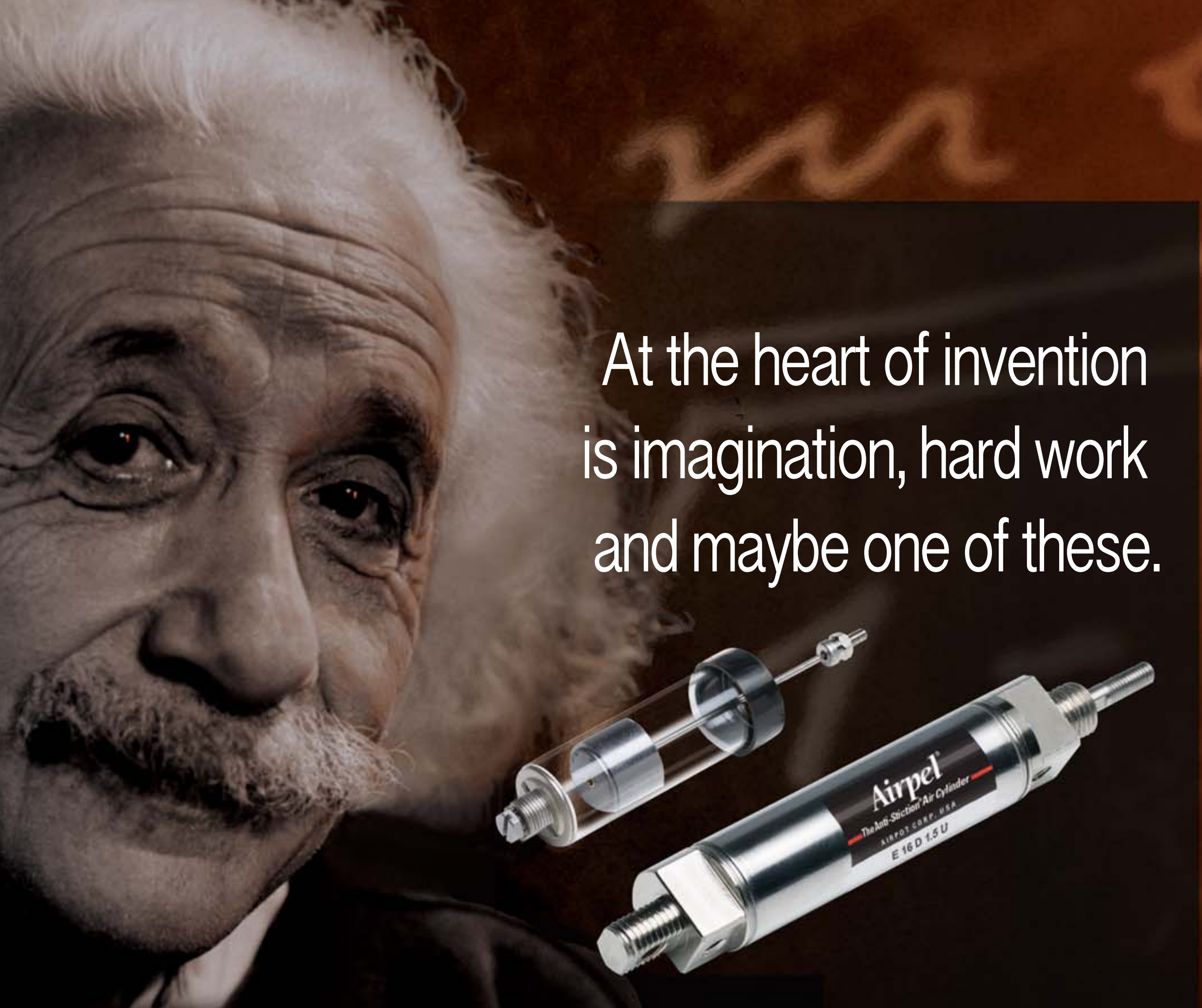
A controlled method of electrolysis resulted in deposition of carbon atoms at a cathode in the form of nanofibers. The basis of electrolysis is simple. Two electrodes are submerged into an electrolyte, which contains free ions suspended in a solution. The ions are drawn to either cathode, depending on their charge. For the GWU project, the electrolyte is molten, meaning that a salt in its solid form is turned into a viscous electrolyte under high heat.

The team used a steel cathode and nickel anode (both notably inexpensive), and submerged them into molten lithium carbonate (Li_2CO_3) at temperatures below 800°C. They also dissolved lithium oxide (Li_2O) in the molten carbonate at 6 moles per kilogram. As clarified in the report, Li_2O mixed with Li_2O_3 can rapidly absorb CO_2, no matter how highly concentrated. Consequently, they bubbled gaseous carbon dioxide from the atmosphere into the molten carbonate.



Electrolysis attracts ions in a solution to electrodes, depending on their charge. This is a rough depiction and does not represent what was used in the project. (Source BBC)

At the heart of invention is imagination, hard work and maybe one of these.



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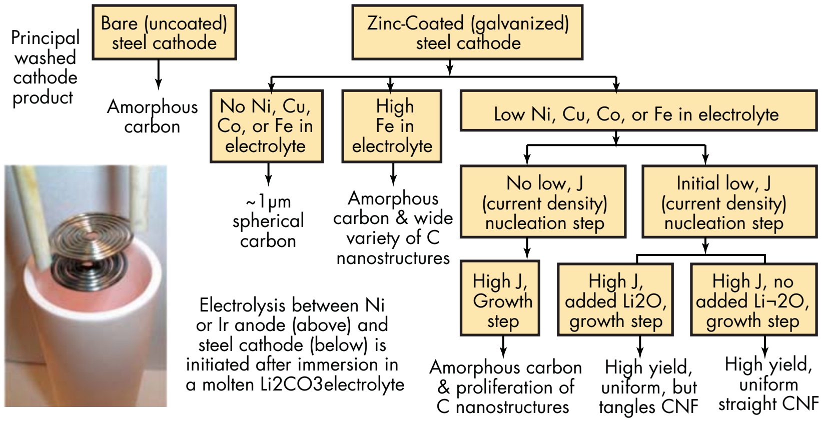

Different environments resulted in different carbon allotropes, from amorphous carbon (non-ideal conditions) to straight carbon fibers (ideal conditions).

The scientists then presented the following equilibrium equation:

CO_2 (atmospheric or stack) + Li_2O (dissolved) ⇌ Li_2CO_3 (molten) (1)

This shows that any CO_2 removed from the molten Li2CO3 can be replaced by CO_2 from the atmosphere, simply by recombining it with the added 6 m of Li_2O. Looking right-to-left, electrolyzed Li_2CO_3 can be split into Li_2O and CO_2 via electrolysis. But looking left-to-right, added CO_2 from the atmosphere can recombine with the lithium oxide (Li_2O) in the solution to keep concentrations of all materials constant, so long as carbon dioxide is continually sourced.

THE ELECTROLYSIS PROCESS

How did the scientists collect solid carbon? During electrolysis, the cations and anions that make up molten Li_2CO_3 are drawn to different electrodes. At the anode, or more positive electrode, oxygen ions accumulate and turn into gas due to oxidation. Meanwhile, carbon ions are attracted to the cathode, or the more negative electrode, and ultimately reduce to solid carbon. This can all be seen in Eq. 2, which shows the final products of electrolysis:

Li_2CO_3 (molten) → C (solid) + O_2 (gas) + Li_2O (dissolved) (2)

Finally, to find a conclusive net equation, the scientists crossed out any of the reagents in the reversible equation if they occur on either side of the second equation. Notice that CO_2 does not cancel out of the net equation because it is entering the system from a continuous source:

CO_2 (atmospheric or stack) ~~+ Li_2O (dissolved) ⇌ Li_2CO_3 (molten)~~ (3)

~~Li_2CO_3 (molten)~~ → C solid + O_2 (gas) ~~+ Li_2O (dissolved)~~ (4)

They eventually came up with the following net equation:

CO_2 (atmospheric or stack) → C solid + O_2 (gas) (5)

This equation concludes it all: GWU scientists generated solid carbon via electrolysis of a molten electrolyte by sourcing CO_2 from the atmosphere. Success? Not quite.

GETTING THE RIGHT STRUCTURE

First, the system needed to be heated to below 800°C; otherwise, carbon monoxide would generate at the cathode instead of solid carbon. Second, they required a current that would supply four moles of electrons per mole of carbon in order to produce tetravalent carbon (carbon's standard "four electrons in the outer shell").

Third, the solid carbon that was deposited at the cathode still did not have the uniform and straight structure that was desired by the scientific team at GWU. Consequently, they experimented with different cathodes, temperatures, additives, and currents until they finally got it right.

Continued on page 20

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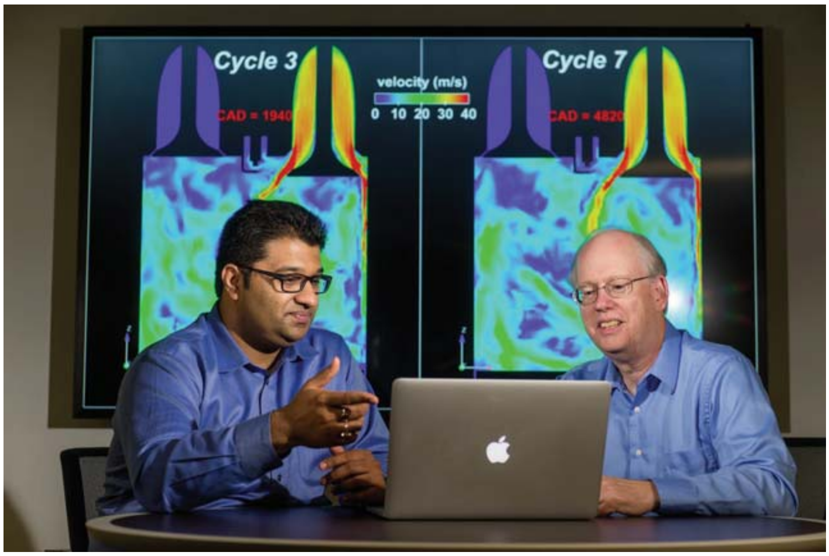
SUPERCOMPUTER SIMULATES UP to 10,000 Engine Designs at a Time

WHEN CONSIDERING ENGINE designs, certain extensive variables and configurations influence performance. While current simulation software offers proficient tools for preliminary design testing, generating more than 100 simulations can take up to several weeks. Ultimately, it costs a company significant time, money, and resources, especially if there are better designs left undiscovered.

Addressing the problem, the Argonne National Laboratory (ANL) uses the power of supercomputing to simulate of up to 10,000 various engine designs simultaneously. Through its Virtual Engine Research Institute and Fuels Initiative (VERIFI), ANL is able to squeeze a comprehensive design process into just a few days, instead of weeks.



Argonne principal mechanical engineer Sibendu Som (left) and computational scientist Raymond Bair (right) discuss the mechanisms of fuel combustion for an engine design simulated by Mira in the Virtual Engine Research Institute and Fuels Initiative.

VERIFI uses the supercomputing power of IBM's Mira at the Argonne Leadership Computing Facility to simultaneously simulate thousands of complex engine-designs in as little as a few days. Mira consists of 48 racks and contains 768 terabytes of memory.

> Argonne National Laboratory (ANL) uses the power of supercomputing to simulate of up to 10,000 various engine designs simultaneously.

VERIFI harnesses the power of Mira—the fifth fastest supercomputer in the world—to process its high-performance simulation program at speeds of 10 petaFLOPS, or a quadrillion (thousand-trillion, 1,015) calculations per second. Located at the Department of Energy's Argonne Leadership Computing Facility (ALCF), Mira saves more energy than the ALCF's previous supercomputer through use of innovative chip designs and a unique water-cooling system.

The simulation program is based off of CONVERGE software developed by Convergent Science Inc. Using an Argonne-developed programming language called Swift, VERIFI and partner developers created an enhanced version of CONVERGE that can function with Mira's 786,432 processors and manage massive workflows.

VERIFI is granted 60 million core hours to carry out simulation programs with Mira. ANL anticipates that the initiative will significantly increase engine-prototype success rates, as well as drive innovation for highly complex systems and designs.

"We're talking about bringing the power of supercomputing to engine design, which will accelerate deployment of new technologies," says Janardhan Kodavasal, a mechanical engineer at the Argonne facility.

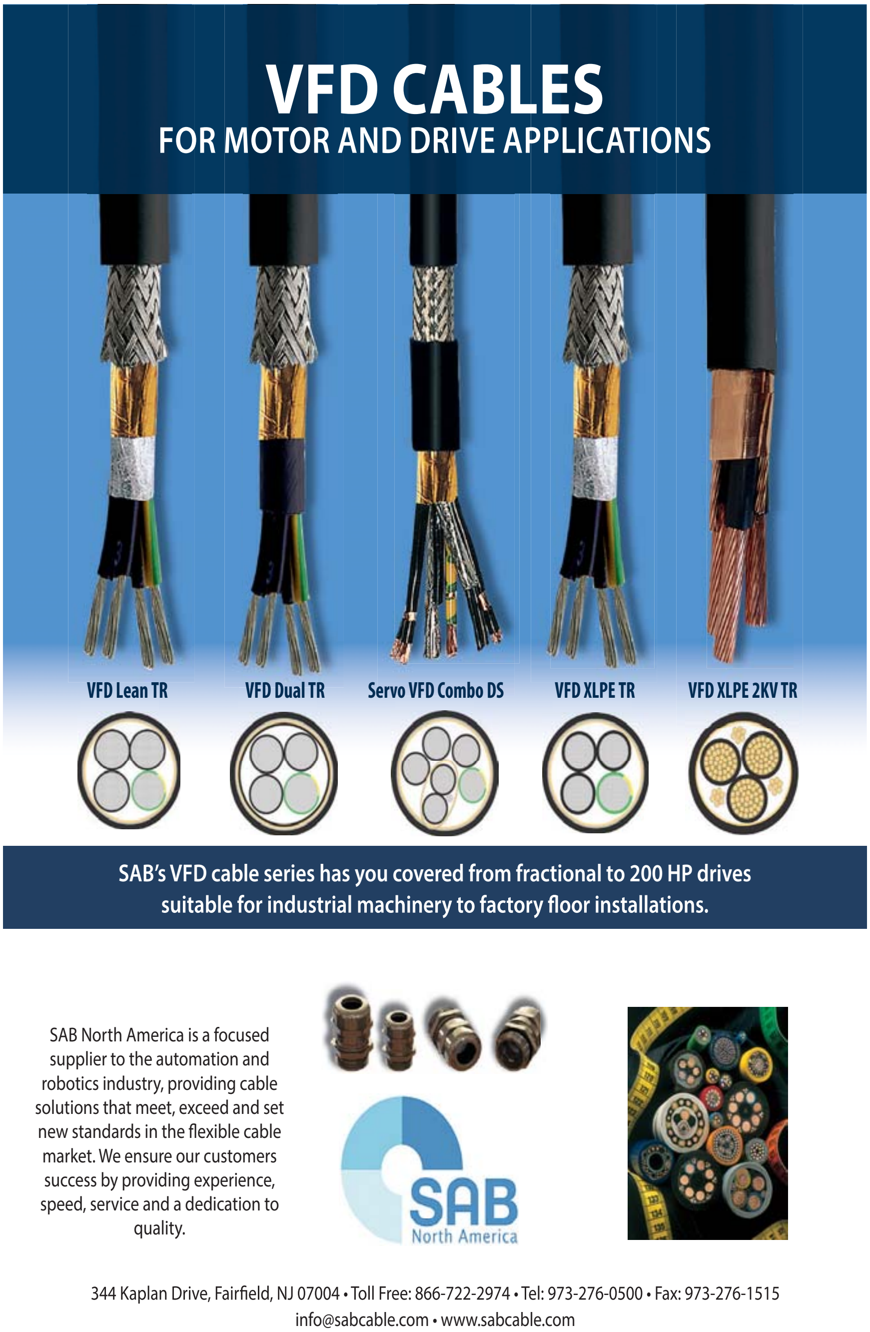
VERIFI is looking for partners that want to invent new, advanced engine designs. It is currently performing comprehensive simulations for a major auto manufacturer, an energy/transportation company, and a global fuel supplier. ■

Continued from page 16

Using a zinc-coated (galvanized) steel cathode and an initial low current density, they also added nickel, cobalt, copper, or iron to the electrolyte. These additives joined carbon at the cathode and bonded to it create nucleation sites, or highly reactive locations on carbon chains that force incoming atoms to bond at the sites that generate a stacked structure. Temperatures, extra materials used, and voltage can all be carefully altered to fine-tune the structure of the carbon nanofibers.

In the figure on pg. 16, you can see the different outcomes of different methods that were employed.

The last revelation that really impressed the Chemical Society is the range of applications that can be achieved using similar electrolysis chambers and the power of the sun. For more on "Solar Thermal Electrochemical Process (STEP)" go to *http://machinedesign.com/sustainable-engineering/harmful-greenhouse-gases-repurposed-carbon-nanofibers* and click on the link at the bottom. ■



EXPRESS SOFTWARE SIMULATES Aerospace-Grade Composite Parts

COLLIER RESEARCH HAS released an Express version of its HyperSizer finite-element-analysis (FEA) software for developing high strength-to-weight ratio composite designs. HyperSizer Express includes the same margins of safety and material simulations as the Pro version. It incorporates a new interface to easily form efficient composite designs.

Generally speaking, HyperSizer knows composites. It can analyze a FEA part that is directly imported to show the user where composite laminate plies would benefit the design for static- and dynamic-loading requirements. Its user-friendly interface allows users to try different composites and orientations, virtually place the part under loads, and observe the areas of stress on that part.

Available at a significantly lower price than most composite software, HyperSizer Express offers aerospace-grade capabilities to a wide audience of engineers and product designers to create strong, lightweight final products. ■

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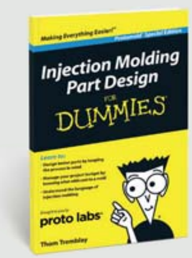

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Interview

MARK DUNCAN | Segment Manager
Schneider Electric

Upgrade Old Networks with IoT Smart Machines

Please tell us a little bit about yourself and your background with Schneider Electric.

I joined the Square D Company in April 1983, which became part of Schneider Electric in 1991. Over the decades, I have worked in various positions from product management, project engineering, and marketing to business development, including a three-year stint in France. Schneider Electric today is a global specialist in energy management and automation, with 160,000 people in over 100 countries.

Schneider Electric sees the advent of the Industrial Internet of Things (IIoT) as an "evolution," not a "revolution." We invest about 5% of our revenues into R&D annually. We draw on our long history of innovation in open architectures and Ethernet-based technologies to guide our customers through this transformation. The IIoT brings about a world where our smart connected products and subsystems operate as part of larger systems of systems. We see the plant of tomorrow as a smart plant—a truly connected and sustainable ecosystem where plants and machines work together in a secure and collaborative way to put technology at the service of people for greater empowerment and efficiency.

What area of the industry is most affected by the IoT?

Manufacturing is the sector most affected by the Internet of Things (IoT), but data capture in particular. Smart manufacturing is the implementation of IoT for better asset performance and optimization. The goal is to produce a more efficient product line, which means less energy is consumed, better machine-to-machine (M2M) integration, and better use of the supply chain. The IIoT is not about ripping out current automation systems in order to replace them with new ones.

The potential lies in the ability to link automation systems with enterprise planning, scheduling, and product-lifecycle systems. We will see self-organizing machines and assets that enable mass customization and lot sizes of one. In the realm of asset performance, the collection and analysis of data from increasing numbers of cost-effective and intelligent sensors will increase business performance and asset uptime.

A new generation of "augmented" workers will leverage cutting-edge technologies, including mobile devices and augmented reality. With easier access to information across the enterprise, their work becomes simplified and production systems grow more profitable. Some of these changes can be implemented in the short to medium term; others will require a gradual evolution with end users and original equipment manufacturers (OEMs) incrementally adding functionality to their existing legacy systems as new international IIoT standards are established.

What trends do you see occurring with the implementation of IoT?

OEMs and end users can leverage IIoT to better monitor and control machinery. Within today's industrial environments, some devices are connected, but many are not. IIoT applications will include not only M2M communication, but also machine-to-people, people-to-machine, machine-to-objects, and people-to-objects communication. These connections enable the ability to collect data from a broad range of devices and applications. This "big data" can then be accessed via the cloud and analyzed using sophisticated analytics tools.

Use of sensors is increasing on the factory floor. The cost of sensors and the fact that it is getting easier to install sensors with current interfaces allow for more tracking and more data collection. Another growing trend is greater distributed control, moving away from centralized control. For example, imagine a long conveyor system with a centralized PLC for the motors and ac drives. All of the wiring runs through a single centralized panel, which manages all of the motors, starts, stops, and speed controls. New IoT products allow a small, low-cost PLC to be placed on top of an individual conveyor and provide individualized control. One can add different, self-contained PLCs to control different conveyor processes. The Ethernet connections between PLCs also help reduce cost due to decreased usage of copper wire.

This new type of distributed control improves efficiency and flexibility. It also ties into machine optimization. The current concern is that machines need to look externally toward other machines. Communication of data and information to other machines is crucial to IoT systems, requiring a more service-oriented approach around the individual machine.


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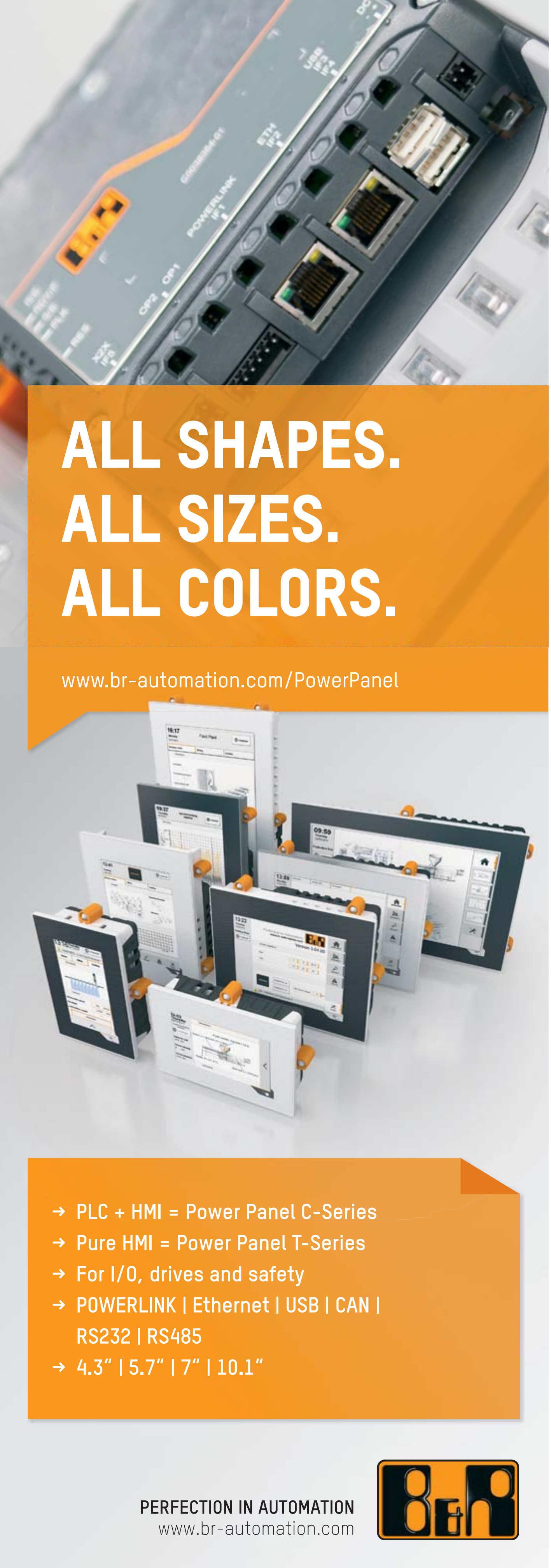

The new Modicon M580 from Schneider Electric is an Ethernet Programmable Automation Controller (ePAC) that features redundant processors, native Ethernet, and cybersecurity embedded in its core.

Define smart machines and what role they play in IoT systems.

Smart machines are more efficient, flexible, connected, and safer. Some important aspects include their connectivity (i.e., the ease of Ethernet connections), ability to self-monitor and monitor the devices they are connected to, and ability to adapt on-demand. They also offer predictive maintenance. This helps decrease the amount of downtime a system can see due to failures or product-line readjustment.

When it comes to connection to other machines, they can help solve miscommunication between different pieces of equipment. For example, four to five machines each speaking the same language are able to communicate with each other using a new smart machine as a central hub. New communication standards like PACKML for packaging machinery can help to translate different devices speaking different languages. The transition from dedicated fieldbus to industrial Ethernet protocols and the emergence of smart manufacturing initiatives are reflected in the evolution of communications.

What new improvements and security features are available in smart machines, considering their connection to the internet?

Examples of new smart-machine devices are human-machine-interface (HMI) -based PLC controllers. They integrate two different types of tech: display and logic controller in one platform. New PLCs have higher CPU power and dual-core technology: one processor for logic and one dedicated to communication.

In terms of digital mobility, machine operators and factory-floor engineers are embracing in ever-greater numbers the concept of using mobile devices at work. With mobile HMI, the machinist is not tied to the machine and can take the information, with data displayed on mobile devices, anywhere. In terms of security, the devices themselves have built-in security with encryption and firewalls, but also offer biometric security. One example is a biometric pushbutton for access control.

On the safety and cybersecurity front, with security built into their fundamental designs, smart machines will enhance operator safety and minimize the security risk of increased networking. Improvements in machine performance and lifetime cost reductions cannot be offset by reducing the safety or security of the machine or production line.

With regard to safety, machine builders need to offer a broad range of flexible options. This will include dedicated safety components, such as laser scanners and safety cameras, together with automation components that have embedded safety, such as safety PLCs and safety drives. The ability to utilize a mix of safety components and controllers will allow machine builders to fit the solution to specific end-user application requirements, helping to improve overall performance and productivity.

Today, data security is the leading inhibitor of end-user adoption of new networking technologies and work processes. The perceived risk of networking components and machinery in order to achieve production benefits is high.

What problems arise when integrating IoT into older systems?

The problem is usually what kind of investment you want to make—immediate or long term. Both come with different solutions and cost. For immediate solutions, integration into older PLC products is done via software. Software solutions offer the ability to communicate with different kinds of data and hardware. Software is an enabler. It links all of these disparate systems together. Software solutions also enable simulation and prototyping, with the ability to create virtual models of the machines.

A long-term solution is upgrading your automation equipment. New equipment will have the latest tech and many are designed for future-proofing—the ability to use giga-Ethernet speeds, for example—so that the technology is adaptable for years to come.

With smart manufacturing and IIoT, a transition is now underway to replace fieldbus protocols with industrial Ethernet variants. The outlook suggests that adoption of industrial Ethernet will future-proof end-user facilities in terms of industrial communication. Continuing reliance on and adoption of fieldbus, without considering Ethernet-based alternatives, will likely hurt overall production in the long term.

Today, fieldbus protocols still account for about 66% of new node connections, with industrial Ethernet increasing its share by about 1% per year. Currently, the move to Ethernet-based networking is slow, but will likely accelerate as smart manufacturing and IIoT benefits become more substantial and widely recognized.

Perhaps one of the biggest barriers to the adoption of IIoT, smart manufacturing, and smart machines is the creation of suitable standards. New standards must encompass creation of standard semantics that will allow smart devices to connect and "talk" to each other without the need for custom programming (as is the case today). These smart devices will also need to "discover" each other and interact.

The development of open standards will provide structure and guidance to OEMs and end users, helping them to implement new working processes and leverage the benefits of IIoT. These standards will need to focus the overall integration of systems and uniformity across the factory floor. md

STEPHEN MRAZ | Senior Editor
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What's the Difference Between the Elastic Modulus and Kinetic Modulus?

In 1807, Thomas Young discovered that stress in a material (F/A) is linearly proportional to the strain (change in length/original length) in that material. This, in turn, led to the discovery of a proportional constant, the elastic or Young's modulus, E, and the equation, $\varepsilon E = \sigma$, where ε is strain and σ is stress, the foundation of stress analysis.

However, this relationship between stress and strain in a material is linear only when the force applied is within certain limits, and only under static loads. That hasn't stopped engineers and designers from misapplying Young's modulus outside those limits and under dynamic loads.

This misuse of Young's modulus does not cause problems if the structure is so over-designed that the bulk conceals the nonlinear relationship. But the emphasis on reducing weight and size in structures and components leads to some materials being used close to their design limits. This requires a more precise definition of modulus, the kinetic modulus, which can be used under any load conditions to describe a material's or part's resistance to stretching or deforming.

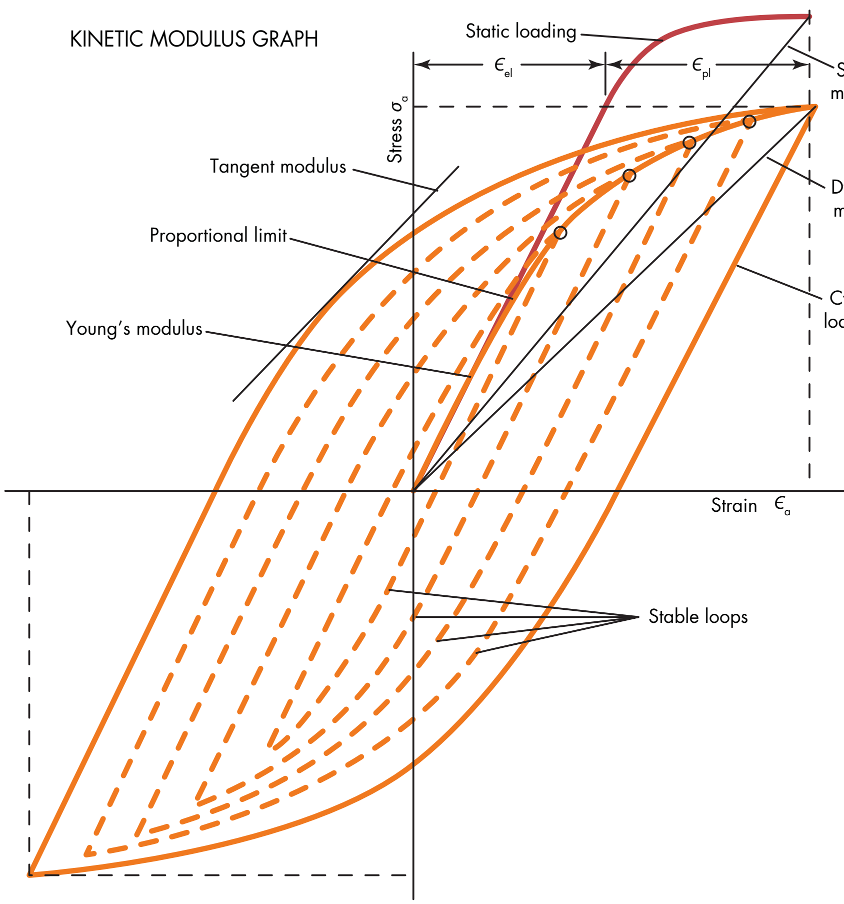
THE KINETIC MODULUS

The basic equation for the kinetic Modulus is:

$$E_k = f(\sigma, \varepsilon, \sigma_y, t, T \ldots.)$$

The exact equation for E_k can be determined from the conventional stress-strain curve for a material. The equation will depend on the magnitude as well as the type of load applied to a component.

Using the term kinetic modulus is simply another way of implying that the instantaneous ratio of stress to strain varies with the fundamental characteristics of materials in motion.



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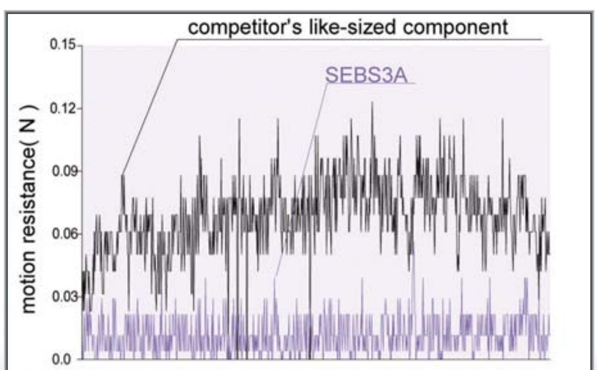

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The type of motion and resistance to that motion defines the range of kinetic modulus values. In most applications, there are three common types of motion and resistance:

- No motion/static load resistance
- Unidirectional motion/impact resistance
- Cyclic motion/vibration resistance

Static load resistance normally implies stress-strain condition within the proportional limit, in which case Young's modulus applies. The modulus is determined by the slope of the linear portion of the stress-strain curve via this equation:

$$E = \sigma/\varepsilon$$

Traditionally, Young's modulus is used up to the material's yield stress. (Yield stress is the stress at which a material begins to deform plastically. Prior to the yield point, the material deforms elastically and returns to its original shape when the applied stress is removed.) In many structures, stress concentrations (such as welds and joints) cause local yielding even though the applied stress is quite low. Local yielding arises when the applied stress is above the proportional limit but below the yield stress, which ranges from one-half to two-thirds of the yield stress, depending on the material's ultimate strength.

For static loads above the proportional limit, the secant modulus must be used. This modulus accounts for local plastic deformation and resulting strain hardening or softening. The secant modulus is derived from the slope of a line connecting the origin of the stress-strain curve to the applied stress. Its equation is:

$$E_s = \sigma_a / \varepsilon_a = \sigma_a / (\varepsilon_{el} + \varepsilon_{pl})$$

For materials stressed in the plastic region, stress and strain are related by Ludwig's equation:

$$\sigma = K\varepsilon^n$$

where coefficients K and n describe the deviation of the stress-strain curve from a straight line as the material plastically deforms.

Impact resistance implies a wide range of modulus values depending on the stress distribution throughout a structure. Under impact, the kinetic modulus can vary from zero at the ultimate strain value to the elastic modulus. Resistance to motion under these conditions is described by the tangent modulus, E_t, which is found from the tangent to the stress-strain curve or hysteresis loop. The equation for E_t is:

$$E_t = nE_s = n'E_d$$

where the unprimed variables refer to unidirectional loading and the primed variable refers to cyclic loading.

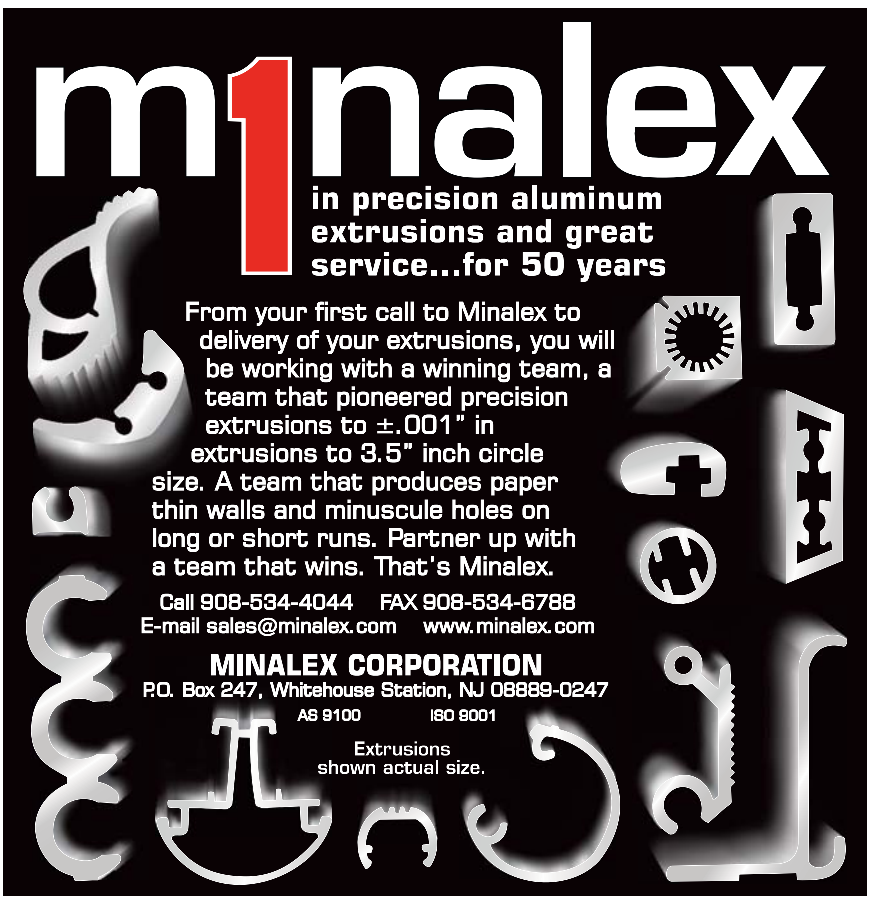
Vibration resistance implies a wide range of modulus variables, depending on the amplitude of stress applied and the yield strengths of the material. Under cyclic loads, the relationship between stress and strain is described by a hysteresis loop, with the area inside the loop being absorbed by the material in one cycle.

Under cyclic loading, local plastic deformation neither hardens nor softens a material, so the material displays a variable resistance to motion. After about 100 cycles, the material stabilizes and resistance to motion can be described by the so-called dynamic modulus (also called the cyclic secant modulus).

Dynamic modulus accounts for strain hardening or softening and is found from the slope of the hysteresis loop. Its equation is:

$$1/E_d = 1/E + \varepsilon_{pl}/\sigma_a$$

where the relationship between ε_a and σ_a is again described by Ludwig's equation except that K and n are modified to account for cyclic loading.



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HOW THE KINETIC MODULUS CHANGES

As noted above, the kinetic modulus is hardly constant; it varies with stress, strain, yield strength, and time. The effects of stress and strain are indicated by the use of different moduli for various load conditions. However, variations with yield strength and time are less obvious and only show up after extensive testing.

Measurements of dynamic modulus have revealed that the higher the yield strength for a given stress amplitude, the higher the dynamic modulus during motion. The relationship between dynamic moduli for high and low yield strength material has been found to be:

$$(E_d)_h = (\sigma_h'/\sigma_l')(E_d)_l$$

where h and l in the equation refer to high and low yield strength, respectively.

For high-strength, low-alloy steel (50 ksi yield strength) and mild steel, the ratio of σ_h/σ_l is 1.6. That means HSLA steel has the higher dynamic modulus and, thus, is stiffer. That means that in a stiffness control application, one with cyclic loads above the proportional limit, higher strength materials resist motion better. This contrasts with traditional theory, which holds that because modulus is constant, strength is of no value in resisting vibrational loads.

The effects of time are revealed by studying the change in modulus as the number of stress cycles increases. Tests show that dynamic modulus decreases with time, the rate of decrease depending on the stress amplitude. In general, the dynamic modulus remains relatively constant for stresses near the proportional limit, but drops off rapidly as the amplitude of the stress reversal nears the yield strength.

DESIGN RAMIFICATIONS

Tests on cyclically loaded parts indicate that you can have considerable plastic deformation despite the fact the applied stresses are quite low. Deformation is normally confined to areas around welds, joints, bolt holes, and geometric discontinuities, indicating that these areas are the main points of energy dissipation in structures. (The amount of energy dissipated is the area inside the stress-strain loop.)

In general, these points are subjected to multiaxial stress, which significantly affects a part's damping energy. Because most structures have a considerable number of discontinuities, researchers believe that the multiaxial stress distribution and corresponding hysteretic energy dissipation exert an important influence on natural frequency.

Evidence supporting this conclusion is that FEA on structures typically predict higher natural frequencies than are

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A 3D printed structure produced using an Aerotech motion system.

Photo provided by Professor Jennifer A. Lewis, Harvard University

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NOMENCLATURE

E = Young's modulus (psi)
E_d = Dynamic modulus (psi)
E_s = Secant modulus (psi)
E_t = Tangent modulus (psi)
K = Monotonic strength coefficient
n, n' = Monotonic and cyclic strain hardening coefficients
T = Temperature, F°
t = Time (min)
ε = Strain
ε_a = Applied strain
ε_{el} = Elastic strain
ε_{pl} = Plastic strain
σ = Stress (psi)
σ_a = Applied stress (psi)
σ_h, σ_l = Applied stress (psi)
σ_y = Yield strength for high and low-strength materials (psi)
σ_y = Yield strength (psi)

actually measured. This discrepancy can be explained by the widespread use of rigid joints rather than flexible ones, which would better describe or model plastic deformation at these points.

The important characteristic of plastic deformation at a joint is that the modulus is neither constant or linear. Instead, it decreases with increasing load amplitude. Therefore, natural frequency, which varies directly with modulus, also decreases at high load amplitudes. This is key because natural frequency governs the design thickness and shape of structural parts.

Here are a trio of relationships between structures and the stress-strain curves and loading:

• *Structures of constant yield strength:* As cyclic load amplitude increases, the natural frequency decreases. And as thickness decreases, stress amplitude increases and natural frequency decreases.

• *Structures subjected to constant cyclic-load amplitude:* As thickness decreases (with yield strength held constant), stress amplitude increases and natural frequency decreases. As yield strength increases, dynamic modulus increases and natural frequency decreases.

• *Structures requiring weight reduction (or thickness decrease):* As thickness decreases while yield strength remains constant, stress amplitude increases, and dynamic modulus and natural frequency decrease. With a 10% to 20% decrease in thickness and a 50% increase in yield strength, an increase in dynamic modulus offsets the decrease in section modulus to maintain a constant natural frequency. md

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VICTORIA FRAZA KICKHAM | Distribution Editor

TOP 2016 DISTRIBUTORS

Another Slow-Growth Year, Say Top Distributors

Technology, lackluster growth shape leading electronic components distributors' business strategies in 2016.

THE ELECTRONIC COMPONENTS INDUSTRY'S largest players expect another slow-growth year, though they say the outlook calls for an improvement over 2015. Customer demand for the newest technology—in products, services, and in their online business experience—is driving the need for more technical expertise and a solutions-based selling approach that has authorized and independent distributors alike focused on delivering better service levels across the board. These are just some of the insights unveiled in *Global Purchasing's 2016 Top Electronic Components Distributors* report.

Avnet Inc., which takes the No. 1 spot again this year with $27.35 billion in sales, is "upping its game" in software, technology, and embedded offerings in response to greater demand for product and technology integration across its customer base, says Gerry Fay, global president of Avnet Electronics Marketing, the company's global business unit focused on electronic component solutions. The technology trend crosses over into business process and digital platform issues, as well—another area on which Avnet is focused. "Digital business is becoming even more important. Customers want to create relationships with distributors online as well as offline," says Fay, emphasizing an "omni-channel" experience that is increasingly in demand among buyers of electronic components.

Avnet's efforts to address the converging technology issues are evident in the executive-level changes the company has made in the last six months alone. In

NOTEWORTHY DISTRIBUTORS (WITH GLOBAL ANNUAL SALES OF LESS THAN $75 MILLION)

Company	2015 Global Revenue
Hughes Peters	$70.7 million
Edge Electronics	$47.4 million
Marsh Electronics	$44.2 million
NRC Electronics	$39 million
IBS Electronics Inc.	$37.8 million
Crestwood Technology Group	$37.3 million
SMD	$30.6 million
Arco Inc.	$27 million
Air Electro Inc.	$25.7 million
March Electronics	$22.7 million
PUI (Projections Unlimited)	$19.1 million
Gopher Electronics	$18.3 million
Area 51 ESG	$18 million
Cumberland Electronics Strategic Supply Solutions	$17.7 million

TOP DISTRIBUTORS OF ELECTRONIC COMPONENTS (WITH GLOBAL ANNUAL SALES OF AT LEAST $75 MILLION)

Company	2015 Global Revenue
1. Avnet Inc.[1]	$27.35 billion
2. Arrow Electronics[2]	$23.3 billion
3. WPG Holdings Ltd.	$16.24 billion
4. Future Electronics[3]	$5 billion (EST)
5. Macnica Inc.	$3.25 billion
6. TTI Inc.	$1.95 billion
7. Electrocomponents plc/Allied Electronics[4]	$1.94 billion
8. Digi-Key Corp.	$1.7 billion
9. Newark/element14[5]	$1.5 billion
10. Mouser Electronics	$936.6 million
11. Rutronik Elektronische Bauelemente GmbH	$900 million
12. DAC/Heilind	$761.6 million
13. N.F. Smith & Associates	$516.2 million
14. Fusion Worldwide	$340 million
15. America II Electronics	$260 million
16. Sager Electronics	$242.9 million
17. PEI-Genesis	$194.2 million
18. Master Electronics	$183.1 million
19. Rebound Technology Group Holdings Ltd.	$148.4 million
20. Advanced MP Technology	$145 million
21. Bisco Industries Inc.	$141 million
22. Powell Electronics	$135 million
23. Classic Components Corp.	$104 million
24. Flame Enterprises	$94.8 million
25. Electro Enterprises Inc.	$89.6 million
26. Steven Engineering Inc.	$85 million
27. RFMW Ltd.	$77 million

[1] Sales figure reflects sales of computer/peripheral products.
[2] Sales figure reflects sales of computer/peripheral products.
[3] Future Electronics does not disclose yearly sales; rank is based on Global Purchasing estimates.
[4] Company-provided estimate for fiscal year 2015 ended March 31, 2016; sales expected to exceed $1.94 billion.
[5] Sales figure reflects worldwide sales for Premier Farnell, Newark, element14 for the financial year ended Jan. 31, 2016.

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December, the distributor announced the newly created role of chief information security officer (CISO), naming Sean Valcamp to the post. Valcamp is responsible for Avnet's global IT security as well as enterprise architecture and strategic planning for IT. The company followed up with a January announcement that

Rapidly changing technology continues to drive change in the distribution channel, says Avnet's Gerry Fay (right).

Ed Smith, president of Avnet Electronics Marketing Americas, will lead the company's embedded solutions business worldwide as senior vice president, global embedded business, effective this July. Also in January, Avnet created its first executive-level Internet of Things position, hiring Eric Williams as vice president of IoT. Williams will work across Avnet's technology, embedded, and electronic components businesses to develop a global IoT strategy.

Commenting on the latter position in particular, Fay emphasized the importance of a company-wide, global approach to technology issues.

"For the first time in history, we've hired an executive to drive a business strategy across the business," explains Fay. "And we will continue to grow that."

Other top distributors are focused on similar demands, especially as they relate to services.

"The overall makeup of our operations group is different today than it was 10 years ago in terms of the skills and talents we're looking for," says Mark Bollinger, president of Houston-based independent distributor N.F. Smith and Associates, which ranks 13th in this year's report, with sales of $516.2 million. He explains that N.F. Smith has hired more technically proficient employees in recent years and has dedicated more space in its Houston headquarters facility for component testing and services—all in response to changing customer demands.

"[Independent distributors], because we don't make a product and because we don't have franchised lines, a lot of our business is driven by what specific customers need," he says. "We're effectively service organizations—and like any service organization, you have to be meeting the needs of the customer."

BY THE NUMBERS

This year's *Top Electronic Components Distributors* report highlights 27 companies serving customers in North America and around the world,

with sales of more than $75 million. It also recognizes a handful of noteworthy U.S.-based firms with sales of less than $75 million, which also serve customers across North America and around the world. Twenty of the companies in this year's report cited a sales increase in 2015 compared to figures they provided last year—an average 6% increase. Three companies reported flat sales, and 15 reported a decline in year-over-year sales—an average 7% drop. (Year-over-year figures were not available for three of the companies in our list). Looking ahead, most distributors in the electronic components channel are predicting another modest year in 2016.

"We're building a little better momentum coming off 2015," says Michael Knight, senior vice president, Americas, for distributor TTI Inc., No. 6 on this year's list with $1.95 billion in sales. "Last year ended on a disappointing note. It started hot and finshed cold. I wouldn't say this year is starting hot, but medium-warm—which is a lot better than cold."

North America continues to be soft, with better conditions reported in Europe and Asia, distributors agree.

"In North America, it will be another one of those years—not good enough to throw a party, but not bad enough for a wake. Something in between," says Knight. "We continue to see good things happening in Europe…the weaker euro is helping everyone."

He says he expects to see slower growth in Asia due to the slower global economy and slowing conditions in China, especially.

Minnesota-based global distributor Digi-Key Electronics, No. 8 on this year's list with $1.7 billion in sales, reported strong growth in China in 2015, pointing to recent investments the company has made in the region, including infrastructure, an expanded product offering, ongoing development of design tools, and localized customer service and currency options. The distributor opened its first location in China in late 2013 and began doing business in local currency there at around the same time. Company leaders say they will continue to expand their product breadth to meet customer demand.

Despite a modest outlook for 2016, TTI's Michael Knight (right) points to a bright long-term outlook for the electronic components supply channel.

Continued on page 88

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design FAQs Thin Section Bearings

FREQUENTLY ASKED QUESTIONS

Thin section bearings can take from 85% to 99% less space and weigh 83% to 99% less than traditional bearings. Their constant cross-section design facilitates compact designs and standardization across product sizes.

Q: What are thin section bearings?
A: Thin section bearings are rolling element bearings designed with slim cross-sections. Their radial cross-sections are less than 1/4 of the bore diameter and less than twice the diameter of the rolling element. The radial cross-section is held constant as bore size increases.

Q: Where are thin section bearings used?
A: Thin section bearings are found across a variety of industries from aerospace and defense, to oil and gas drilling, to packaging and semiconductor manufacturing. Their space-saving design works well in satellites, radar equipment, medical devices, robotics, food-processing equipment, and machine tools.

Q: What are the benefits of thin section bearings?
A: Thin section bearings can provide space savings of 85% to 99% for common rolling-element bearing designs. Their bore-to-cross-section ratio can be as high as 80:1 as compared to 7.1:1 for conventional bearings.

Thin section bearings can also cut weight by 83% to 99%, especially for large-bore applications. Implemented at the start of a project, this space savings can lead to an overall lighter and more compact design, which in turn reduces system cost.

The constant cross-section is particularly helpful when designing a product in various sizes, as it allows standardization on a maximum shaft size while minimizing the size of the housing.

And don't assume a compact design is flimsy. Because thin section bearings have more rolling elements as their bore increases, they experience less deflection at maximum load than traditional bearing designs.

Q: What standard sizes are available?
A: Standard thin section bearings support bore diameters from 0.750 to 40 in. with custom bearings offering bore diameters up to 52 in. The bearings have standard cross-sections from 0.1875 to 1 in. square over the full range of bore diameters.

For applications that require even slimmer bearings, bearing experts like Kaydon have offerings that are as small as 0.098 in. wide and 0.118 in. in cross-section. These thinner bearings are available with bores 1.378 to 6.693 in.

In addition to looking for a manufacturer who has the size you need, make sure their bearings meet American Bearing Manufacturers Association (ABMA) standards. Also look for a range of tolerances that will fit your needs.

Q: What are my design options?
A: When incorporating thin section bearings early in the design process for the greatest space, weight, and cost efficiency, it helps to know your design options. Thin section bearings come in radial, angular, and four-point contact designs.

Radial designs work with purely radial loads, although they can handle thrust with modifications. Angular bearings are for applications with radial loads and unidirectional thrust. Both types of bearings keep rolling elements in place with circular-pocket, continuous-ring separators.

For applications with radial loads, thrusts, and moments, choose four-point contact bearings. These use snap-in continuous ring separators. Most of these bearings are available open or sealed and come in both inch and metric sizes.

Q: What materials are best for thin section bearings?

A: For most applications, choose rolling elements and races made of AISI 52100 steel, M50 tool steel, or 440C stainless steel. Some designs may require custom components made of beryllium copper or aluminum. For additional corrosion resistance, choose thin, dense chrome coating on 52100 steel. Rolling element separators are usually brass, low-carbon steel, glass-fiber-reinforced nylon, stainless steel, or phenolic laminate.

Q: What other design considerations should I be aware of?

A: When designing with thin section bearings, you'll want to consider many aspects that also affect traditional bearings. These include compensating for thermal expansion differences and being sure to match housing, shaft, and bearing tolerances. Also be sure to compensate for the additional flexibility thin section bearing rings offer.

Lubrication is another consideration for all kinds of bearings. Many thin section bearings can be specified with seals or shields to keep lubricants clean and in place. You might also turn to custom lubricants to meet challenging operational or environmental needs.

Finally, consider duplexed bearings, races that are ground together to provide accurate shaft location, increase stiffness, or boost load capacity. Duplexed bearings are helpful in high accuracy applications like semiconductor manufacturing and aerospace.

Q: How can I choose the thin section bearing that is right for my application?

A: Although thin section bearings share many attributes you are familiar with from traditional bearings, there are also important differences. An experienced supplier such as Kaydon can help you select the best thin section bearing for your needs by recommending the dimensions, materials, and design attributes that will give you the best performance. ■

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IDENTIFY THE Best 3D-Printing Process FOR YOUR APPLICATION

Boiling down 3D-printing processes into simple questions can facilitate applications-based decision-making.

The dynamic 3D-printing landscape is a challenge to navigate for industry experts, and even more so for those who are not aware of the capabilities, limitations, and idiosyncrasies of the different technologies. Further adding complexity, 3D-printing processes don't always translate comparably with conventional manufacturing technology, even when the material output is virtually the same. This is typically due to the dissimilar build parameters, environment, and material delivery methodology. To learn the nuances, you must grasp the basics behind each technology and know the full spectrum of available material options.

This article will help you determine the technologies and materials that are right for your application. Many 3D-printing processes are in use today, but for the purposes of this article, we will only touch on the most commonly used in design and manufacturing engineering today: photocuring, filament deposition, polymer laser sintering, and direct metal laser sintering.

Reducing parts is one way to save cost with 3D printing. Air intakes and ductwork have been used to simplify single prints with multiple parts. For more extreme temperatures, the fused-deposition-modeling (FDM) process and materials like ULTEM work well in end-use parts to simplify assemblies.

PHOTOCURING

This group of 3D-printing processes employs liquid photopolymer resins that are solidified and cured with ultraviolet (UV) light, mostly to serve as models, light-duty prototypes, and patterns for secondary casting. Photopolymers vary in color, transparency, and mechanical and thermal properties, ranging from low-temperature soft and flexible elastomers to hard and rigid nanocomposites able to withstand elevated temperatures. For example, Somos NanoTool, a composite stereolithography (SL) material, has a heat deflection of up to 437°F at 66 psi.

An advantage of photocuring is the refined quality of the output. Photocuring processes produce parts with smooth surfaces and fine-feature detail—16-micron layer height with PolyJet—ideal for cosmetic and aesthetic applications. However, UV stability and durability falls short for high-performance and end-use product applications. Continued exposure to UV light causes photocured objects to become brittle and change in appearance. In addition, some materials can lose shape and dimensional accuracy from moisture absorption and sag or creep from prolonged pressure.

The two most widely used photocuring technologies are PolyJet and SL. PolyJet deposits tiny droplets of photopolymer and simultaneously cures the thin layers with UV light. This process can print in a very high resolution with layer thicknesses as thin as 16 microns, which minimizes post-processing. Also called multi-jet printing, PolyJet is one of the only technologies with the ability to print multiple materials in one print with varying durometers.

On the other hand, SL builds 3D objects layer upon layer by using a UV laser to draw and solidify cross-sectional slices in a vat of liquid resin. It too can produce smooth parts requiring minimal finishing, but does not offer multi-material printing. Multi-jetting and SL typically have minimal shrink-related deformation. Finally, both processes are ideal for producing casting patterns aimed at silicone tooling and urethane casting, and sacrificial patterns for investment casting.

FILAMENT DEPOSITION

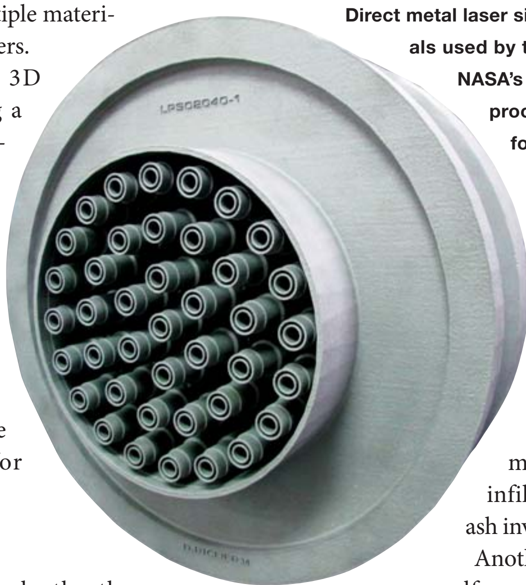
Guided by software-generated toolpaths, the filament-deposition processes build 3D objects by drawing cross-sectional slices of parts one upon another via a heated extruder head. One chief advantage of filament deposition is the ability to produce strong, durable functional prototypes and end-use parts in a variety of high-performance materials commonly used in conventional machining and molding manufacturing processes.

Fused deposition modeling (FDM) is the most mature and widely adopted filament deposition process. FDM can maintain dimensional accuracy over distance while having the ability to save material and weight. Some companies will post a general tolerance of ±0.008 in.; however, it's difficult to give an exact number or even a range for this accuracy because it depends on the machine, material, geometry, and size of the part. Furthermore, FDM is less prone to warp and curl than laser sintering.

The most significant drawback of filament deposition is the pronounced layer lines in the surface of its output. It necessitates more effort than other 3D-printing technologies to smooth the surfaces and create aesthetic qualities comparable to conventional manufacturing processes, such as injection molding. Additionally, applications that call for airtight or watertight functionality may require a denser build style, which increases build time and material consumption, and/or application of a sealant to alleviate surface porosity.

POLYMER LASER SINTERING

These practical processes fuse or melt powdered polymers and composites with a low-wattage CO_2 laser that sinters cross-sections of 3D objects layer upon layer. Polymer laser-sintering (LS) materials primarily have bases of Nylon 12 and Nylon 11, with a variety of filler options such as glass beads, mineral fiber, and carbon fiber, which provide substantial strength and durability for functional prototyping and end-use part production.



Direct metal laser sintering (DMLS) can use the same metals used by the medical and aerospace industries. NASA's Marshall Space Flight Center used the process to 3D-print an injector fuel nozzle for rocket advancement in NASA's space launch system program.

Other specialty materials that serve niche applications include thermoplastic elastomer, which can have rubber-like qualities for prototype hoses, seals, and grommets. Also, low-density polystyrene infiltrated with wax can serve as a low-ash investment casting.

Another advantage of LS is that 3D objects are self-supporting within the build chamber, enabling three-dimensional nesting. Efficient and economical production of complex geometries with internal cavities and channels are possible with LS without the need to remove supports.

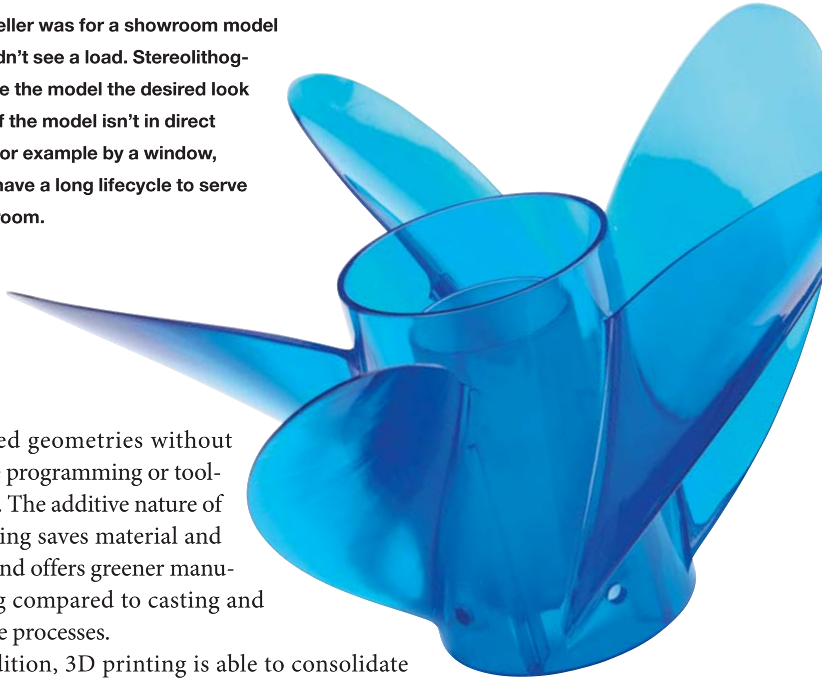
The thermal nature of the process and absence of supports to anchor laser-sintered objects makes them more prone to warp during the build or cool-down cycle. In addition, an inverse relationship often exists between the mechanical strength and dimensional accuracy of the output. Laser power and build-chamber temperature increase to optimize particle adhesion, and build a stronger part. However, higher power and temperatures can cause expansion; the walls and features of a part can become oversized, warp, and curl. Generally, dimensional problems arise with higher laser-power and powder-bed temperatures. That's because more of the surrounding powder sticks to the sintered/melted part, which causes the surfaces to grow and walls to thicken.

This commonly results in fitment problems with mating parts. Yet, experienced LS operators might be able to adjust laser offsets, adjust build orientation, and modify the design to work better with the process.

DIRECT METAL LASER SINTERING

Using an yttrium-aluminum-garnet-fiber laser, commonly referred to as a YAG-fiber laser, metal laser-sintering systems essentially micro-weld powdered metals and alloys layer upon layer to produce fully dense 3D objects with properties similar to castings. Through post-processes, such as heat-treating and hot isostatic pressing (HIP), it's possible to improve metallurgical properties for high-performance applications.

There are several advantages to direct-metal-laser-sintering (DMLS) types of processes over conventional manufacturing methodologies, including their ability to produce complex



This propeller was for a showroom model that wouldn't see a load. Stereolithography gave the model the desired look and feel. If the model isn't in direct sunlight, for example by a window, it should have a long lifecycle to serve the showroom.

contoured geometries without excessive programming or tooling costs. The additive nature of 3D printing saves material and weight, and offers greener manufacturing compared to casting and deductive processes.

In addition, 3D printing is able to consolidate assemblies, reducing the number of components that can reduce labor cost and fasteners, and simplify a product. Taking advantage of these features with the DMLS process is ideal for low-volume manufacturing of end-use parts and products, and high-performance functional prototypes.

On the downside, the learning curve to build quality DMLS parts and products is substantial. A knowledgeable technician or designer should understand how to use a CAD model to verify that a print is economically viable before it goes to print. A skilled operator will need to develop effective build strategies to mitigate warping and minimize support structures. Furthermore, for optimal dimensional accuracy, smooth surface finishing, and tiny features, DMLS users often have to utilize more sophisticated post-processing and finishing systems, such as CNC machining, wire EDM, chemical etching, liquid honing, tumbling, media blasting, or coating.

SELECTION METHODOLOGY

A trained staff can screen and qualify the best processes and materials for each customer's specific applications and needs. There isn't a single technology well-suited for every application, and there isn't always a clear-cut solution for a customer's specific needs. Often multiple options could work, each with a different set of pros and cons. The following seven considerations can help you qualify and disqualify processes and materials for each of your unique projects:

1. Application: What is the purpose of the object?

The intent for 3D-printed objects could range from cosmetic show models and mockups, to functional prototypes, R&D test pieces, or end-use production parts and products. The requirements of each of these applications can vary greatly, and therefore are better suited to some processes. It often comes down to cosmetic, dimensional, or performance requirements.

2. Functionality: What does the part need to do?

A 3D-printed part may simply need to hold shape as a static model or bear a close resemblance to a conventionally manufactured product with fine detail and smooth surfaces. In this case, PolyJet or stereolithography may be the ideal process. Hard-working parts that must bear a load or resist impact could be better suited to the FDM

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Aesthetics:	Smooth surface finish
Economics:	Quick lead-time more important than price
Priorities:	Rapid turnaround time and smooth surface finish
Selection:	Stereolithography investment casting pattern, SC 1000 material
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NASA JPL SATELLITE PARTS	
Application:	Satellite antenna array
Function:	Holds radio antenna wires
Stability:	Withstand extreme temperatures, vibration, and exposure in outer space
Durability:	Indefinite lifespan
Aesthetics:	Compatible with a protective paint
Economics:	Lead-time reduced by consolidating multiple assemblies into one part
Priority:	Stability and durability
Selection:	Fused deposition modeling (FDM) and ULTEM 9085
Read the full story: https://www.stratasysdirect.com/case-studies/nasa-3d-printed-satellite/	

process. If the application involves a snap fit or durable living hinge, LS may be the better option.

3. Stability: In what environment does the part need to function?

The need to maintain properties and function in higher temperatures rules out some 3D-printing processes and materials. In addition, outdoor applications require a UV-stable material such as acrylonitrile styrene acrylate (ASA) or durable laser-sintered nylon with a UV-inhibitive coating. Photopolymers will not work well for outdoor environments because they react to UV light. Moisture is another common factor that adversely affects many materials. If biocompatibility is necessary for a surgical device, then metals such as titanium Ti-64 for DMLS or electron beam melting could be the best, if not the only, option.

4. Durability: How long does the part need to last?

The number and duration of use cycles can eliminate some processes and materials. For example, a 3D-printed mold or form tool may need to go through hundreds of cycles and withstand prolonged stress and friction, whereas a fit-check prototype may only need to function once. Photopolymer materials are often effective for short-term, low-stress applications and are typically unable to withstand prolonged stress. Engineered thermoplastics from the FDM and LS processes can serve many functional prototyping and end-use purposes for increased cycle life.

5. Aesthetics: How does it need to look and feel?

You can generally expect photocured 3D objects to be fairly smooth and have high resolution right off of the machine, and can easily be hand-finished to a cosmetic state. While thermoplastic and powdered plastic processes such as LS and FDM produce stronger and more durable parts, cosmetically they will require more labor and skill to achieve a smooth surface, leading to higher costs and increased lead time. With the rugged metals and alloys of DMLS, it takes

much more time, effort, and expertise to produce a polished look.

6. Economics: What is your budget, timeline, and quality expectation?

If you have a firmly capped budget, the decision may come down to price rather than other factors. Time and quality are often in conflict with one another; rapid turnaround and high-level cosmetic finishing can be mutually exclusive. However, shortcuts, workarounds, and efficient systems can reduce lead times and costs while maintaining high quality standards.

Efficiencies can be gained from working with a service bureau that can creatively batch, nest, strategically section, shell, adjust fill, and modify build orientation to reduce machine time and material consumption.

7. Priorities: Of all these factors, which is the most important?

Ultimately, you must consider all factors and decide on those that are most important to achieve the primary objectives and project goals. Often there are several competing requirements. However, your main priorities should drive your decision and filter the 3D-printing technology and material options. If you have a short timeline, economics is generally the determining factor. If long life is the priority, durability may be the determining factor.

Selecting the optimal technology and material for a project is imperative to maximizing success. The primary point to remember is that the "one-size-fits-all" approach doesn't apply to 3D printing. It is essential that you either invest time to learn the pros, cons, and nuances of the major processes, materials, and post processes, or find an objective partner or expert who has the experience and know-how to provide you with sound guidance. md

ABOUT THE AUTHOR

Ron Clemons is the director of business development at Stratasys Direct Manufacturing. Ron has 19 years of experience in the 3D-printing industry and leads a group that works on developing advanced manufacturing solutions for key vertical industries.

100 Turns

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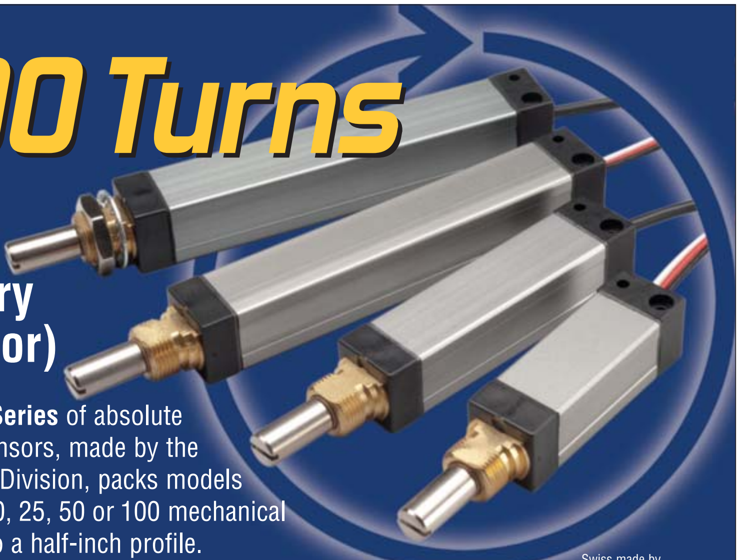

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Soaring to NEW HEIGHTS

Quadcopters carry an extraordinary array of sophisticated equipment that makes them simple and fun to fly.

A confluence of technologies and manufacturing capabilities has led to an onslaught of remotely controlled quadcopters in the hands of hobbyists. Low-cost motors and mass-produced propellers provide the power to keep them in the air. Weight is kept down, but structural integrity is maintained by strong, engineered plastics and composites. And chip-based controllers, gyros, navigation, and cameras give them high-end capabilities and features while keeping costs down.

Currently, it looks like aerial photography is one of the main attractions for those people flocking to purchase RC quadcopters (qcopters). The aircraft are so useful for photography (and inexpensive compared to the alternatives), even professional videographers are jumping on the qcopter bandwagon and referring to them as flying cameras rather than qcopters or drones. In fact, some qcopters come with cameras as built-in equipment that are not designed to be removed.

It's also possible that interest in racing leagues and even air-to-air combat competitions will add to qcopters' popularity. In fact, one wing of the quadcopter fan club is dedicated to first-person-viewing (FPV) racing. Users fly mid-priced qcopters with cameras mounted on the front. The drone sends images back to the pilot who views them on a small screen or, preferably, on immersive googles. The view as the agile little flyers zip across the landscape and up and around trees and other obstacles is breathtaking. (There are hours of FPV videos on YouTube.)

Quadcopters are relatively easy to fly, thanks to six-axis gyros and well-thought-out control algorithms. They can also be controlled through smartphones, as seen here.

Quadcopters can take pictures and videos from angles no photographer can access. And companies are catering to photographers by offering drones with high-end cameras with three-axis gimbal stabilization that can take 12 megapixel photos or HD, FHD, or UHD videos, and store up to 64 GB of data.

Accidents can be catastrophic, but the high-value components—the motors, camera, and microprocessor controls—are fairly well protected and can be cobbled into another qcopter. Do-it-yourself qcopters are common in the FPV world. There are even rumors of one homebuilt drone with souped-up components and all the extra weight removed that can fly 62 mph.

Quadcopters come in a wide variety of sizes, complexities, capabilities, and cost. It's no surprise that on the low end, size and payload are extremely limited, as is control range, top speed, and how long they can remain airborne on a charged battery. Some are so small that they are almost restricted to indoor flying where there is no wind. Less-expensive quadcopters also lack the control algorithms that make it easy for novices to control them in the air rather than watch as they slam into trees and buildings while flailing with the RC controller. The high-end qcopters, those costing over $3,000, are chockful of features and capabilities that likely wouldn't have been possible 10 years ago.

KEEPING THEM IN THE AIR

Qcopters have four identical motor and-vertical-propeller (rotor) assemblies divided in two pairs, with each pair spinning in opposite directions (CW and CCW). There are also six-, eight-, and 12-rotor versions, but they all use the same basic principles. The motor and rotor assemblies that spin in the same direction are mounted opposite each other.

Each rotor creates lift in direct proportion to the speed of the motor and only spins in one direction. They are simple, inexpensive single-piece rotors that do not change their pitch. When all four motors spin at the same speed, a qcopter will climb, descend, or hover (neglecting wind). The torque from the motors is balanced and the aircraft will not spin.

To control a qcopter's direction of flight, speed, altitude, and attitude (in response to the user's controls), the motors spin at different speeds to set up the desired turning moment and thrust vector. Qcopters' design makes them inexpensive yet reliable in doing this split-second torque-balancing act. For example, the rotors are plastic or composites and lightweight. So the motors can almost instantly slow down or speed up their rotation, something much more difficult, if not impossible, on a full-sized helicopter's rotors. This lets the control chip balance torques quickly and smoothly.

The motor-control subsystem is also relatively

THE FAA ON QUADCOPTERS

ANYONE OWNING A QUADCOPTER OR DRONE weighing more than 0.55 lb (8.8 oz.) must register it with the Federal Aviation Administration if they intend to fly it outdoors, in accordance with FAA regulations. It will cost those owners $5. If the qcopter tips the scales at over 55 lb, including any extra equipment or cameras attached, the FAA no longer considers it a model aircraft or a recreational Unmanned Aircraft System, and a long list of other regulations apply.

Model planes can also not be used for commercial uses or for payment. They can only be used for hobby and recreational uses.

There are not that many other FAA guidelines that quadcopter "pilots" need to follow. Among the few guidelines:

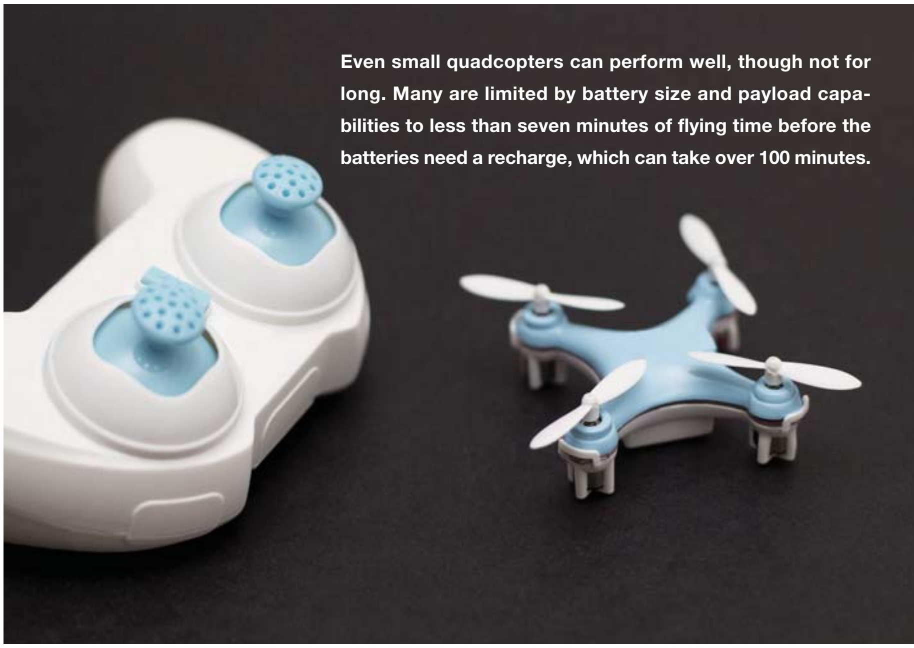
- Quadcopters (or any unmanned recreational aircraft) cannot fly above 400 ft.
- They must remain within sight of the operator.
- Quadcopters cannot fly within 5 miles of an airport without prior FAA approval.
- Quadcopters cannot fly over military bases, national parks, or the Washington, D.C., area and other sensitive government buildings (CIA, NSA, FBI).

The FAA has been hustling to keep up with the widespread use of quadcopters and other radio-controlled planes by expanding its rules and definitions. For example, back in 2014, it extended the ban on planes flying over open-air stadiums with 30,000 or more spectators to cover "unmanned and remote controlled aircraft." The model aircraft community can expect more regulations as time goes on. In the meantime, the FAA has a blanket regulation that covers unwritten, common-sense-based transgressions. It says, "Flights must not pose a hazard to people or property or other aircraft in the sky." So flying in and around power lines, over crowds, or through shopping malls can still get you in trouble with the law.

If you have any questions, check out Know Before You Fly (knowbeforeyoufly.org), which has guidelines for safely flying recreational radio-controlled aircraft. And the FAA also has an app, B4UFLY, free for downloading in the App Store for iOS and Google Play store for Android. It will let you know of any flight restrictions or requirements that affect the area in which you plan on flying a drone.

inexpensive, thanks to Moore's law and a large number of chips being manufactured. Chips also control GPS navigation, aiming and controlling the camera, and gyros and accelerometers.

The motor controller, for example, is driven mainly by command inputs from the RC controller the operator uses. It delivers commands for throttle, pitch, yaw, and direction of flight though joysticks and a few buttons. (The controller setup depends on the qcopter's make and model.) The controller meshes the command inputs with those from its suite of sensors, which differ for various make and model of qcopters. One of the most important sensors for control—and most of these aircraft carry one—is a six-axis gyro.


Even small quadcopters can perform well, though not for long. Many are limited by battery size and payload capabilities to less than seven minutes of flying time before the batteries need a recharge, which can take over 100 minutes.

The term "six-axis gyro" is somewhat of a misnomer. They are actually three-axis gyros, with gyros for the pitch, roll, and yaw axes that are either combined with a three-axes accelerometer or wired and programmed to also function as a three-axis accelerometer. In simple terms, the gyro determines the rotational rate about an axis and the accelerometer determines the rotational position about an axis.

Adding the three accelerometer readings to the motor con-

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troller gives it some additional capabilities. For example, if the operator gets the qcopter in an inverted attitude or a spin, letting go of the controls lets the aircraft right itself based on the accelerometer inputs and come to a hovering halt (assuming there's enough vertical distance to recover). The accelerometers also let the qcopter fly relatively straight and level despite winds or overcome sideslip to make smooth turns. Another favorite among qcopter enthusiasts are aerial flips, which are difficult without a six-axis gyro.

HIGH-END FEATURES AND CAPABILITIES

Many qcopters let operators choose from several flying modes. At the lowest level, operators are limited in the amount of pitch and roll they can command. This helps eliminate over-control and subtly teach the pilot how to keep the qcopter flying and headed in the right direction. Higher modes then expand the control

The Phantom 3 quadcopter from DJI lists for about $800, but can be found online for just under $500. It weighs almost 3 lb, can climb at about 16.5 fps and descend at 10 fps, and has a top speed of practically 36 mph. It can climb to 19,690 ft. above sea level, but it is usually set to a default of 400 ft. to stay within FAA guidelines.

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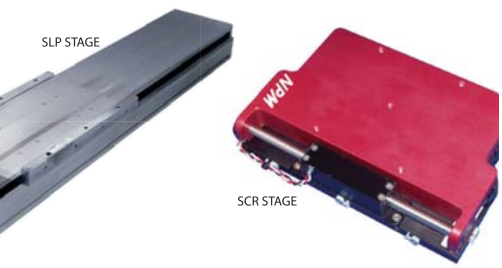

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Propellers for quadcopters come as two matched pairs, one for spinning clockwise, and the other for spinning counter clockwise.

envelope, giving the operator more responsibilities and more capabilities. This lets operators climb the learning curve at their own pace without crashing too many qcopters.

Another feature that prevents operators from losing their drones is the "return home" command. Hit the right button, or tap the right sequence and your quadcopter makes a beeline for you, having stored its departure point in its GPS. More sophisticated drones take this feature one step farther. They monitor their battery power and the distance to "home base" and when their computer determines they have just enough power to make it home, they stop the mission and fly to you.

GPS also lets qcopters fly from one way point to another, getting out of range of the operator's controller sight, and flying on their own. Some drones, those with flying times of almost 30 minutes, can fly up to eight or nine miles from their launch point. (Don't tell the FAA.)

High-end video models let operators program them to track a transponder small enough to fit in a shirt pocket. Operators can set certain parameters so that, for example, it flies 30 ft. behind and 20 ft. above the transponder. The operator can then ski, surf, ride a bike or motorcycle, and the qcopter tracks the transponder's radio signal to stay above and behind while it films the action.

Both the qcopters and their cameras can carry out quite complex commands, almost more than one person can cope with. To spread the workload, higher-end drones have two controllers: one for flying and navigating, and the other for controlling the camera. Other qcopters let a second person use a smartphone to handle some functions. This lets the camera operator pan and change focus on the gimbal-mounted camera while the pilot swoops down for a circling shot. Meanwhile, three-axis stabilization isolates the camera from vibrations for smoother shots.

Qcopters can also be equipped with obstacle avoidance. Using ultrasound transceivers sweep the air in front them, detecting objects or obstacles 65 ft. in front of them. If they spot something, they try fly around it, then get back on course or head to the next waypoint.

Some companies are making aftermarket add-ons for qcopters. There are "missile launchers" that shoot up to six small, plastic missiles singularly or all at once; "water cannons" that are more like aerial squirt guns; bubblers that leave a trail of bubbles in the drone's wake; and grappling hooks that can lift items, as long as they don't weigh too much. md

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THE IMPACT OF IoT ON Fluid-Power Systems

Experts explain how fluid-power systems are becoming more interconnected in the ever-expanding Internet of Things.

When we talk about the Internet of Things (IoT), we usually discuss electrical technology. Obviously, IoT is powered by computers, Ethernet, and wireless devices, but it is also reaching out and updating different fields of industry. For instance, IoT's influence is being felt within the realm of fluid-power systems (i.e., hydraulic and pneumatic systems). We spoke to three experts in this field to give their take on how IoT is affecting the fluid industry:

- Dr. Steffen Haack, Bosch Rexroth, Member of the Executive Board responsible for the Business Unit Industrial Applications and Coordination Sales
- Frank Langro, Festo Corp., Director - Marketing/ Product Management
- Gary Grotting, Sun Hydraulics, Marketing Manger

Ready-to-install servohydraulic axes, like those from Bosch Rexroth, have an integrated fluid loop and are driven by the same servo drives as the electromechanical versions.

How are hydraulic or pneumatic devices (pumps, actuators, pipes, valves, etc.) being modernized for the Internet of Things (e.g., sensors, Ethernet connections, etc.)? What are the current technology trends?

Haack: Hydraulics and electronics have belonged together for decades. We are currently seeing a strong trend toward the broad digitalization of the hydraulic product portfolio. We have systematically expanded our portfolio of electrohydraulics components and modules with digital interfaces and sensor intelligence. The products have a decentral intelligence and exchange data via multi-Ethernet interfaces with other devices like controls. Standardized, integrated digital electronics offers a wide range of functionality driven by software applications. Modern hydraulics is as intelligent and has the ability to be as connected as electronic products or electromechanical actuators.

Grotting: Promoting and embedding low-power Bluetooth connectivity for remote valve-controller configuration is a crucial update for products without a direct line of sight. Safety is the driving factor here, seconded by ease of use, with a com-

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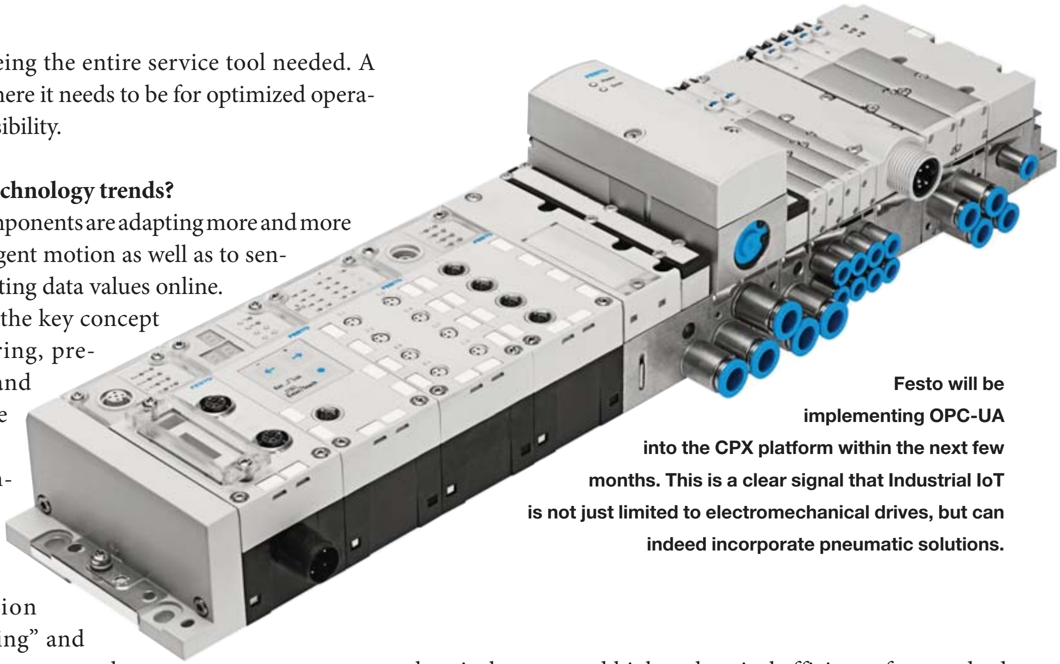
mon cell phone now being the entire service tool needed. A valve can be installed where it needs to be for optimized operation instead of for accessibility.

What are the current technology trends?

Haack: Hydraulic components are adapting more and more to electronics for intelligent motion as well as to sensors for gathering operating data values online. Analysis of this data is the key concept for condition monitoring, predictive maintenance, and machine-to-machine communication.

Langro: Sensor technology and Ethernet connectivity is definitely leading the way for implementation of "Smart Manufacturing" and "Industry 4.0." Both are current methods of implementing IoT systems and its key enablers.



Festo will be implementing OPC-UA into the CPX platform within the next few months. This is a clear signal that Industrial IoT is not just limited to electromechanical drives, but can indeed incorporate pneumatic solutions.

Grotting: Current technology trends driving development include smaller valve envelopes with embedded controllers that are matched to mechanical parts and nulling tolerances. Lower electrical power and higher electrical efficiency for standard, hybrid, and electrical vehicle systems are also creating need. We are working to lower battery demand, standby/idle drain, battery, and connector size, and reduce harness AWG requirements for current capacity and weight.

What are the benefits of using hydraulics or pneumatics over electromechanical drives, considering that many electromechanical drives can be easily connected to IoT equipment (e.g., PLCs, Ethernet hubs)?

Haack: Hydraulic controls and drives have some unique physical properties, such as higher power density or robustness against overload and shocks. In combination with digital electronics, modern hydraulics offer the best out of two worlds: the advantages of the fluid technology together with the flexibility of modern controls architecture. For superior controls, it does not matter if an actuator is electromechanical or electric or electrohydraulics, as long as both have their own decentral intelligence with software functionality and open standardized interfaces for communication.

Langro: Application is what should really drive the selection of pneumatic, electromechanical, or hybrid solutions. Aspects such as force requirements, precision, and speed are most important. Today, with intelligent valve terminals, things such as Ethernet connectivity and sensor technology are now possible with pneumatic solutions and not only electromechanical solutions. A great example of this would be the Festo CPX-MPA-based valve terminal system. This was the first pneumatic valve manifold to incorporate serial communication on the pneumatic valve side, which enabled sensor technology to be incorporated very easily, whereas before with parallel communication it was practically impossible. Once you have a pressure or flow sensor present and feeding information to the control, you now have intelligence to create more efficient or adaptive systems.

Grotting: Fluid-power drives can be compact, with no gearboxes needed to increase torque or speed. Trace fluids can be a visual cue to a field-service person for impending issues. Hydraulic solutions can offer substantially more power relative to total weight than electric motors.

What is the role of software in current IoT fluid-power systems?

Haack: There is a massive shift of functionality in the software architecture of drive technologies. The challenge is to standardize across different technology interfaces, communication protocols, and engineering tools such as electromechanical and electrohydraulics drives. This applies for all drives, controls, and the sensor landscape. The same electronic hardware is used in both drives and controls. Along with wizard engineering tools and control algorithms for hydraulic actuators, commissioning engineers and operators do not need an in-depth knowledge of hydraulics. The software wizards lead them through the process and suggest parameters

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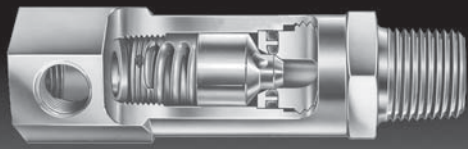

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that are adequate for a first commission and fast startup in most applications.

Grotting: Embedded software is now commonplace for individual valve control, giving OEMs a good way of protecting their IP. Optimizing the product at this base level allows the system builder to utilize a stable, known building block to achieve correct operation.

Langro: To standardize across different technology interfaces, Ethernet connectivity is important, but standardizing the communication protocol will be instrumental in making Industrial IoT a reality. Open Platform Communications Unified Architecture (OPC-UA) enables data exchange from products by different manufacturers and between different operating systems.

Haack: Current software is offering different levels of analytics, from decentral to cloud-based big-data approaches, helping our customers to significantly increase the performance and availability of their equipment. That leads to an increase in efficiency, easy diagnostics, and energy savings, which all leads to direct cost savings.

Grotting: We see mobile applications as a now-accepted way of sharing tools, updates, and information with our users. Software is also important when complex functions are reduced to point-of-use products. As an example, High Country Tek's

The Bluetooth Embedded Amplifier is a commercially available Bluetooth-configurable product—a fluid-power industry first. The smartphone app is able to wirelessly configure four valves in an installation using Bluetooth connectivity. An operator can be in close proximity to observe valve operation and not be tethered to the machine.

EVC is capable of multiple functions, allowing the end user to easily incorporate complex functions without needing to be a programming expert. Software offers customers more product flexibility, increased capabilities, system repeatability, and more operational options at much lower cost.

What are the disadvantages of using fluid power for IoT systems?

Haack: Technology-wise there are no disadvantages, as long as the hydraulic system uses well-known and established standards and interfaces. IoT does not care for the drive technology itself; rather, it stands for seamless horizontal and vertical integration with continuous exchange of data.

Grotting: To properly accept signals and transmit details of controller operation, health, temperature, and other values, the fluid-power system requires an embedded digital controller. If valve

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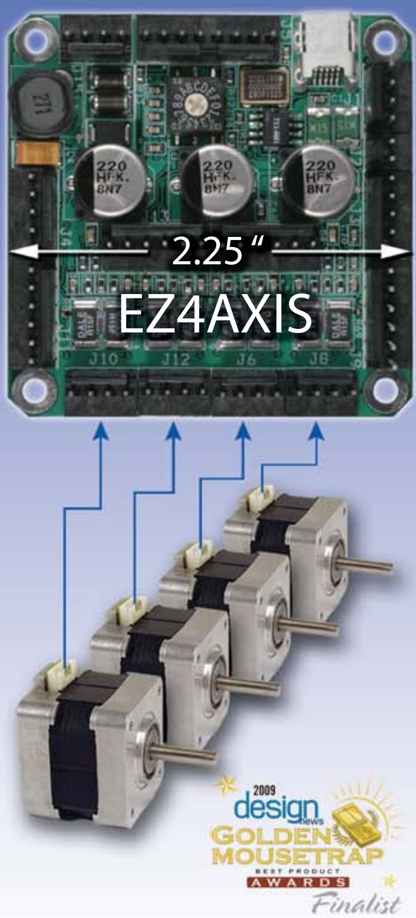

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position, pressure, or another parameter is critical, the relative sensor needs to also be connected to the controller so that it can share information through the bus.

Does the nonlinearity of fluid-power systems cause a problem with sensor and data feedback for connected systems?

Langro: There should be no problem with sensor and data feedback. This is where software can compensate and is typically used to model feedback accordingly.

Haack: Definitely not. Analog and digital electronic components have long been integrated into hydraulic products. Electronic interconnectivity is a basic requirement for the interaction between hydraulic and electric components in modern hydraulic systems. In this context, the nonlinearity of hydraulics is deeply considered in the engineering process for all kind of hydraulic components, such as valves, pumps, cylinders, and sensors. The electric controllers themselves (whether located on board or externally) contain intelligent algorithms and allow the interpretation and translation of the different hydraulic sensor signals.

The software of intelligent and interconnected hydraulic products compensate for the nonlinearities of fluid technologies. We have developed and integrated algorithms based on our extensive application experience into the drive electronics, ranging from cabinet-free single-axis controllers to complex motion-logic controls for a large number of axes. This allows hydraulic systems to work exactly like electric or electromechanical drives.

Grotting: Sensors are more readily available now and provide information from more than one element. They are used for diagnostics, prognostics, and for measuring several parameters. The measurements in turn can be used to correct a valve's operation to effectively reduce or null nonlinearity. Some sensors are now Bluetooth-compatible, which aligns with Sun's use of this protocol in valve configuration, using the same cell phone tool for all machine overview actions.

What new technology is coming out to help integrate the Internet of Things into fluid-power systems?

Grotting: Hydraulics has come a long way in just the past 10 years. The rise of technology has pushed the industry toward ease of use, intelligent design, configurability, and precision control. Entire machines can be monitored, configured, and maintained from a single display interface. The only means of developing such a system is through intelligent communication networks exchanging data in real time. Combine this intelligence with the vast capabilities that we have become so accustomed to: texting, downloading smartphone apps, or connecting to wireless speakers via Bluetooth.

Developing human machine interfaces using technologies that the average person is comfortable with makes system design intuitive and more easily manageable. Machines can send update messages via text or contact specific service people when systems fail. Utilizing Bluetooth technology offers the first-ever wireless and configurable hydraulic-flow-control device. Calibration of valves, which were once dangerous or difficult to reach, can now be done from a safe distance. Even if the job does not require added safety, wireless connections like Bluetooth offer an easy, quick, and intuitive way to calibrate valves, making training and troubleshooting a breeze. The added cost of additional communication harnesses or costly software disappears with the average person equipped with an iPhone or Android.

The industry will continue to see products that utilize common technology in order to increase efficiency, make complex functions intuitive, and reduce wiring and install costs, ultimately adding value to the end user. Sensor technology is expanding what information we can measure and digitally share, making interfaces easier with less conversions and losses. md

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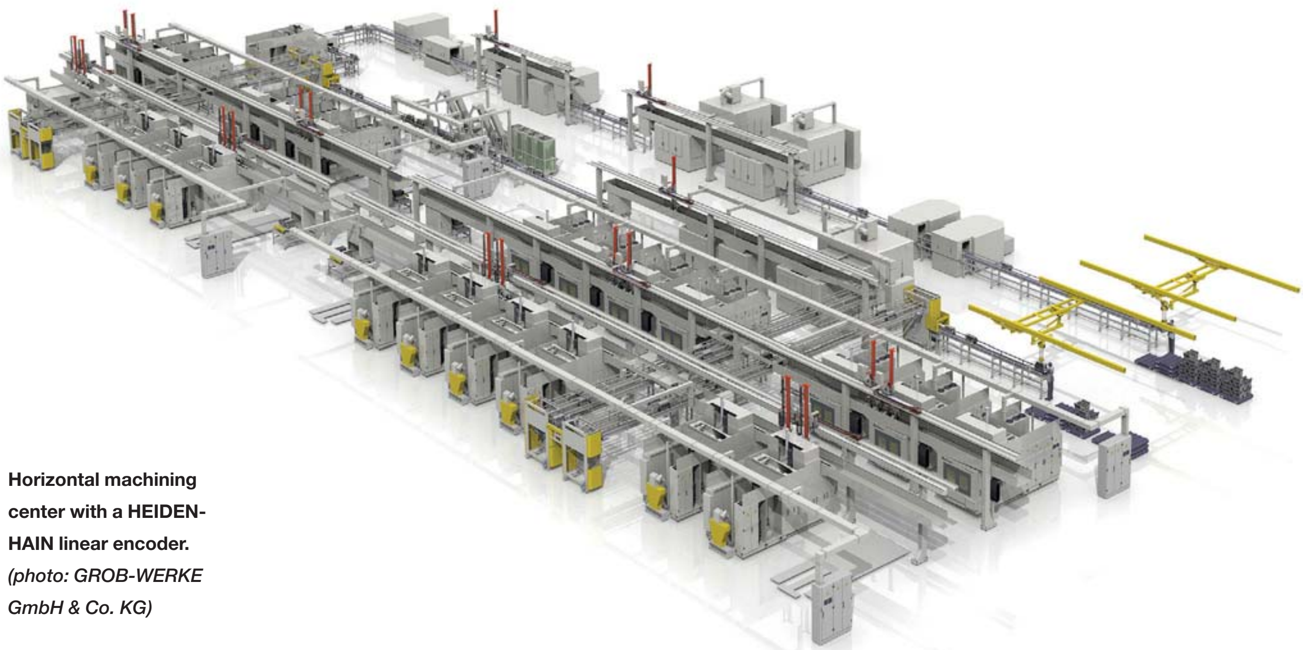
GREATER MARGINS FOR Linear Encoder Tolerances

Modern linear encoders for machining centers in automated large-batch production contribute to reduced production costs.



Horizontal machining center with a HEIDENHAIN linear encoder. ***(photo: GROB-WERKE GmbH & Co. KG)***

Large-batch production in the automotive industry is in the midst of a change. Over the past years, the purchasing behavior of car drivers has distinctly changed. They want ever-more versions of models and engines and, at the same time, vehicles with increasingly greater efficiency. The automobile manufacturers react with more frequent model changes and more engine versions. For example, inflexible transfer lines are increasingly being replaced by lines with chained machining centers to improve flexibility in the mechanical machining of vehicle powertrain components. For their large-batch production this means shorter product cycles, greater diversity, and smaller batches, all of which translates into greater all-round flexibility. Linear encoders in a closed-loop configuration help increase machining accuracy. This affords margins in the tolerance budget for other errors.

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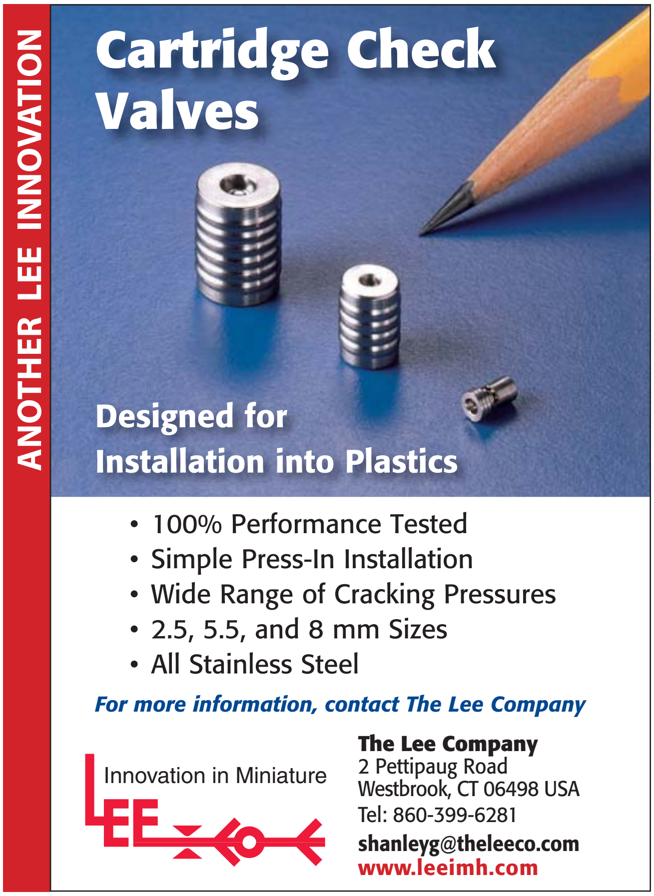
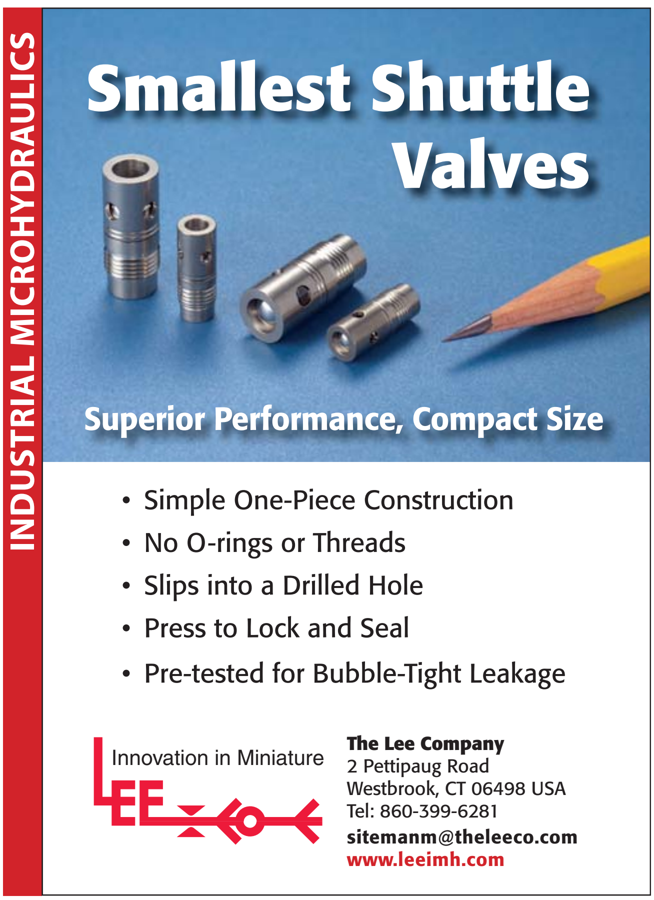
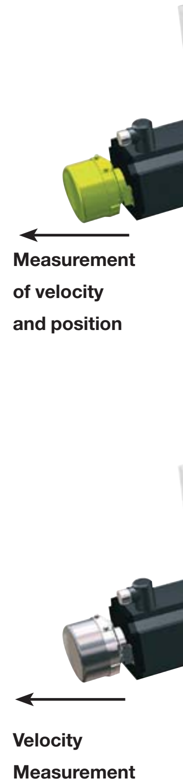




FLEXIBILITY THROUGH LINKED MACHINING CENTERS

Automobile manufacturers boost flexibility by switching to production with linked machining centers as seen in the image above. Machining centers permit faster reaction to fluctuations and changes in demand, the machining of different versions of a workpiece without retooling on the same production line (version flexibility), and the adding or removing of machines relatively easily to and from the production line (reuse flexibility).

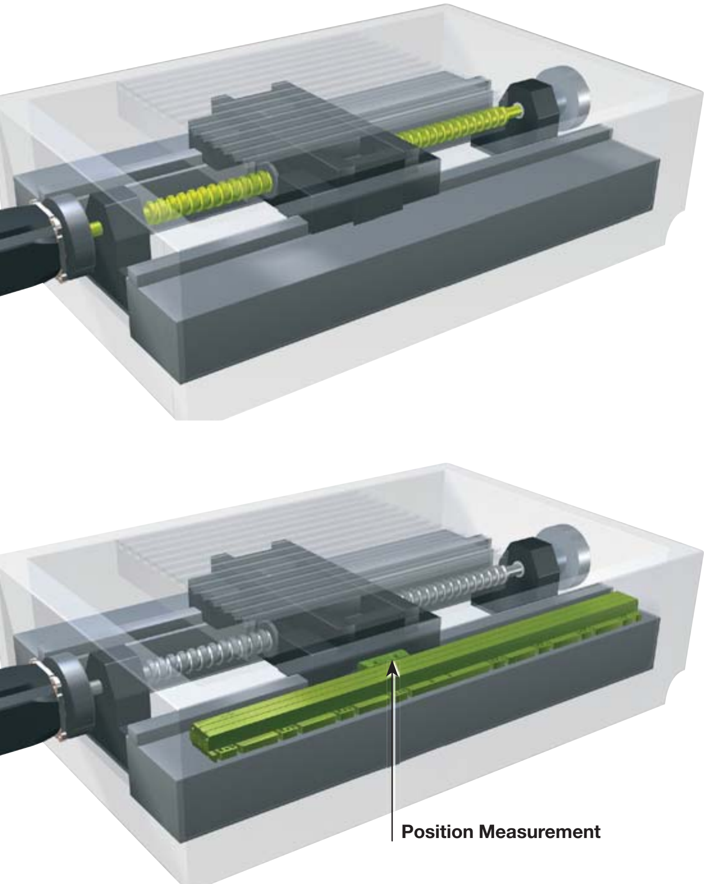
The produced tolerances of a workpiece depend on the individual machines or sub-processes of the complete production system. The aim, therefore, is to reliably maintain workpiece tolerances throughout the entire process. Each single machining center should only use up as little as possible of the available tolerances. Then, the greater the remaining tolerance reserve, the greater the margin automobile manufacturers have to compensate process influences that are hard to control, and to optimize the accuracy of their components.



TOLERANCES IN A CLASS OF THEIR OWN

Compared with the demands in other areas of production like tool and mold making, the tolerances in large-batch production seem quite large. However, the required tolerances have to be maintained over a long period of time and for large numbers of workpieces at a defined level of reliability. To ensure this, the automobile manufacturers perform statistical capability tests with the machining centers.

Representation of a modern production line with linked machining centers. (photo: MAG IAS GmbH)



Position measurement in semi-closed-loop mode (top) and in closed-loop mode (bottom).

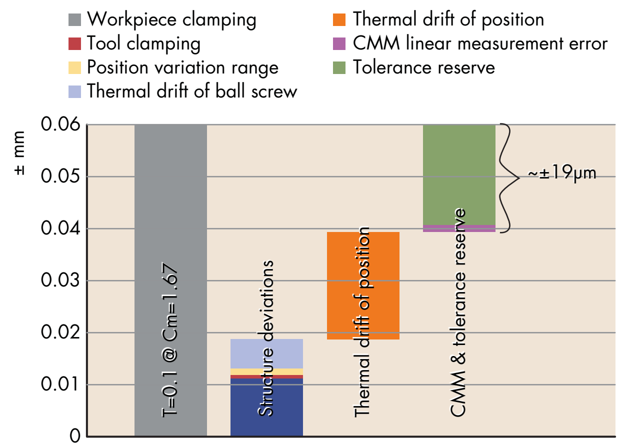
The following example demonstrates the effect of these capability tests: a hole in the bearings of a gearbox, for example, has a specified tolerance of ±0.1 mm in depth. In order to reliably maintain the required specified tolerance in production, there is a further restriction of the tolerance through so-called capability values. This restriction means that the actual finished depth tolerance of the hole has to be in the range of ±0.06 mm for a large number of finished parts.

This tolerance is now shared by different potential errors of the machine tool and the process chain including workpiece clamping, tool clamping, thermal axial drift on the ball screw, thermal expansion of the ball screw on the feed axes, and many more. Furthermore, there should be a tolerance reserve left permitting the machines and process to compensate unforeseeable influences on production that are difficult to control.

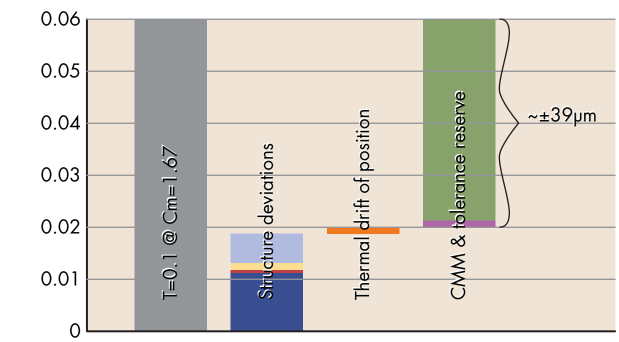
POSITION MEASUREMENT ON FEED AXES WITH BALL SCREW

The position of an NC feed axis can be measured in principle through the ball screw in combination with a rotary encoder (semi-closed loop), or through a linear encoder (closed loop). Semi-closed loop means the position-control loop of the feed axis is closed via the encoder of the feed motor. The pitch of the ball-screw drive in conjunction with the rotary encoder identifies the position of the axis slide here. However, thermal expansion and wear of the ball screw are not included as factors in the position measurement. You could say that the semi-closed loop control is blind to such alterations of the machine tool's mechanics.

It is therefore recommended also for large-batch production with linked machining centers to implement machine tools with closed-loop control. In this case, the position of the feed-axis slide is measured with a linear encoder and fed back into the axis control as actual position value. In this



Composition of the evaluated error limits on a machining center with Semi-Closed Loop control; thermal expansion of the ball screw takes the major share.



In the closed loop, the thermal expansion of the ball screw no longer plays a major role. The tolerance reserve increases to over half the tolerance.

way the thermal expansion of the ball screw is determined directly on the axis slide and compensated accordingly.

CLOSED LOOP: DETERMINING THERMAL EXPANSION

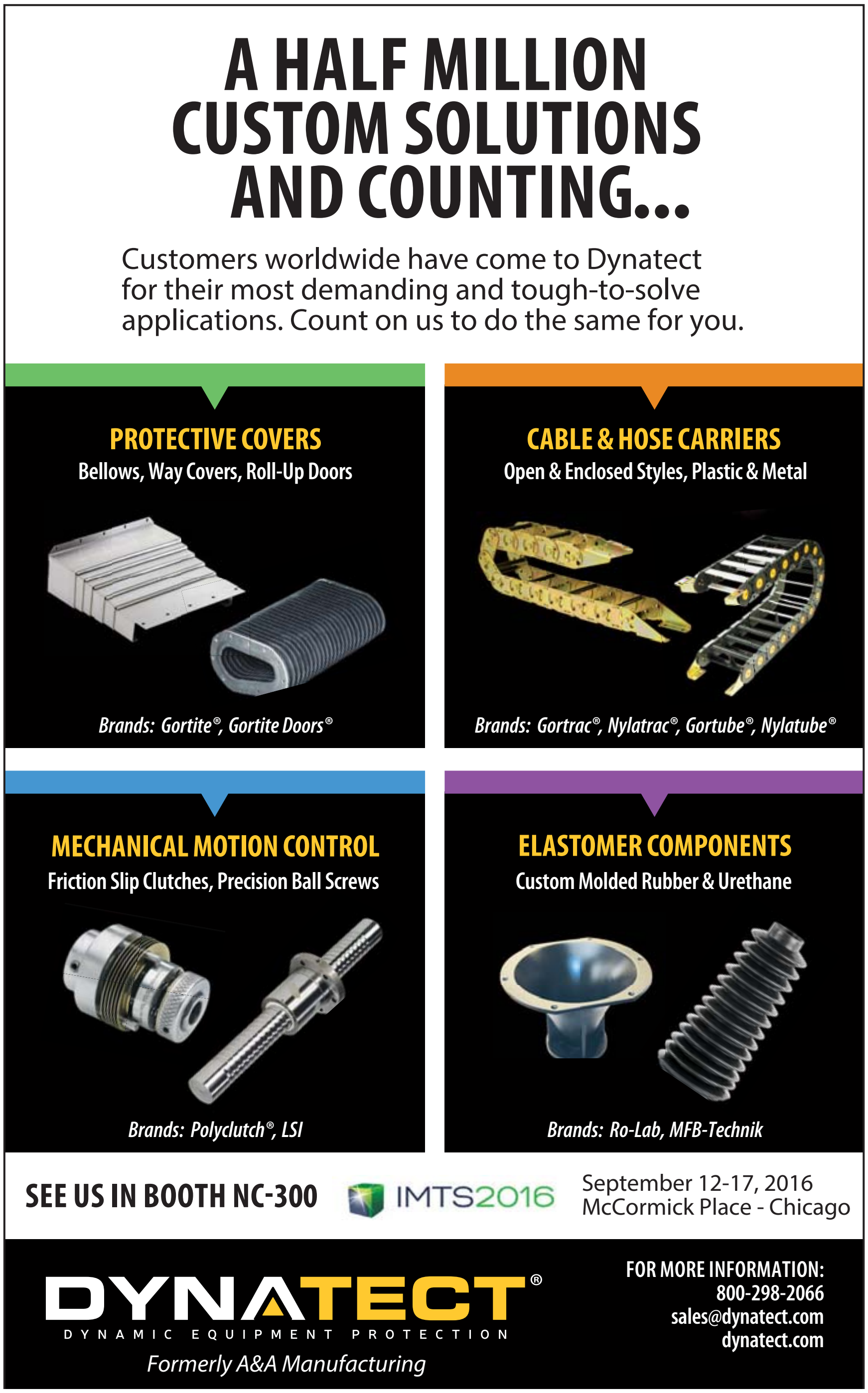
Evaluations of the error limits show that one of the biggest consumers of the available tolerance in the machining center is the uncontrolled thermal axial expansion of the ball screw when using semi-closed loop position measurement. The graph below shows the distribution resulting from examinations of the composition of error limits based on the example described above of a hole with a restricted tolerance of ±0.06 mm.

The error limits of this machining example show that a closed-loop control practically eliminates the influence of thermal expansion and wear of the ball screw. In our machining example, this increases the tolerance reserve by 20 µm to 39 µm. This makes about two-thirds of the tolerance available to compensate unforeseeable influences in the production chain that are difficult to control, like fluctuations in the shop, coolant, and workpiece temperatures, for example.

ACTIVELY USING THE TOLERANCE RESERVE

To meet future demands for reduced exhaust emissions and fuel consumption, design will have to reckon with higher part accuracy—in other words, tighter workpiece tolerances and more stringent surface-quality values. The reason is that this will decrease friction in the vehicle's powertrain and therefore deliver the desired reductions. The tolerance reserve from the closed-loop control thus provides the margin for large-batch production to implement the even tighter design tolerances to be expected in the future.

The increased tolerance reserve no longer has to be kept exclusively as a safety net for all eventualities. It can now be actively used to boost productivity and quality. For example, it would be possible to expend part of the tolerance reserve for tool wear. For the machining of workpieces of cast iron (e.g., crank cases) or high-temperature-resistant cast steel (e.g., exhaust gas turbochargers) with high levels of tool wear, such raising of the wear limit leads to significant savings and increased productivity. Among other things, this is due to longer tool life, reduced testing and compensation, and longer machine runtimes. Therefore, using linear encoders in the feed axes of machining centers contributes to reducing production costs. md



MARISSA K. TUCKER | Product Manager, Controls
JIM WILEY | Product Manager, Servo Drives
Parker Hannifin Electromechanical and Drives Division

PLCs, PCs, and PACs: When the Lines in Motion Control Become Blurred

Asking the right questions early simplifies optimizing your next motion control system.

A programmable logic controller (PLC) is an industrial solid-state computer that monitors inputs and outputs, and makes logic-based decisions for automated processes or machines. PLCs were designed to replace relays, timers, and I/O.

Historically, motion controllers, programmable logic controllers (PLCs), and industrial personal computers (PCs), which have clearly defined functions in a control system, were separate components. With the rise of programmable automation controllers (PACs), motion controllers are increasingly difficult to distinguish from PLCs. Programmers are building custom applications on PCs to create decentralized control schemes that command a wide array of sub-control devices, including motion controllers, drives, vision systems, etc. The trend of merging traditionally separate control components can add confusion and complexity to the task of designing a new machine or expanding the functionality of an existing one. With a bit of knowledge of the different control architectures and knowing the right questions to ask, designers can quickly identify which control scheme will be best for their application. Before starting the controller selection process, it is important to understand what the different options are and why they are used.

THE DIFFERENCE BETWEEN PLCS, PCS, AND PACS

Essentially, a PLC is a ruggedized control device made up of a microprocessor, memory, and a variety of peripherals. PLCs typically use IEC 61131-3, an industry-standardized set of programming languages, including Ladder Diagram. Ladder logic, a language that reads the same as the electrical diagrams maintenance crews are already familiar with, makes the PLC a popular choice. Most developers and maintenance personnel have experience with programming and debugging Ladder, minimizing the need for training. Standardized programming ensures longevity as the machine can easily be serviced in the future, and reduces the dependency on the original programmer. The major limitation with PLCs is that they were designed

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to replace relays, timers, and I/O. This left their functionality limited when it came to the realm of motion control and visualization.

Traditional PLCs typically rely on peripheral devices such as smart drives and stand-alone motion controllers to provide advanced functionality. A potential drawback of this motion-control architecture is the need to maintain separate programs for each device. Smart drives and stand-alone motion controllers often use proprietary languages, canceling out the benefit of using an IEC 61131-3 PLC in the first place.

Future maintenance in this type of control scheme is incredibly difficult because it is not always obvious what is being controlled by the PLC and what is being controlled by the motion controller. In the absence of proper documentation, understanding the machine often involves opening up the cabinet and using a multi-meter to trace connections or directly connecting to the peripheral motion systems via a laptop. If the repair person is not familiar with the proprietary language used by the motion controller, the diagnostics process could lead to excess downtime and increased expenses.

Industrial PCs, first introduced in the mid-1980s, are high-reliability computers with hardware and operating systems engineered to withstand the constant vibrations, temperature extremes, and wet or dusty conditions common in industrial environments. Industrial PCs are most powerful to developers who are comfortable programming their own custom applications using either Visual Basic, C#, C++, etc. Using an industrial PC increases flexibility, giving users the freedom to communicate to any device using either pre-built APIs or by writing their own communication drivers. This freedom leads to the creation of novel applications using smart subsystems that may not have been intended or initially designed to work together. Stand-alone motion controllers, in the form of smart drives or multi-axis, are examples of smart subsystems. Motion-controller manufacturers typically provide an API that allows the developer to send motion commands to the controller—limiting the need to learn a full, separate language. Alternatively, some developers will choose to leverage the real-time capabilities of the motion system and program the device in its native, embedded language, with the PC application calling for these complex routines to run when needed.

Personal computers such as Parker's Industrial PC PowerStation allow users to develop their own application to control multiple sub-devices such as controllers and visualization systems.

Beyond increased flexibility, these applications have several benefits over traditional PLC systems. The HMI (human machine interface) is built right into the control application itself, reducing the need for additional devices for visualization. In addition, a single programming language can be used to control all subsystems. This single PLC application can also be a major downfall as the machine ages. As an organization matures or technology changes, preferred programing languages may shift, making it difficult to develop, change, or maintain older applications. In addition, API is not a set standardized by any organization, so migration to a new language or OS may not be possible, even when using the same subsystems.

Motion controllers offer designers highly specialized functionality for controlling and coordinating the movement of motors within a machine. A range of form factors are available as motion-control providers have developed solutions based on smart drives, PCI cards, Ethernet, and just about every field bus ever created. Centralized or distributed solutions offer machine designers nearly endless possibilities for crafting a system that best fits their needs in terms of performance, size, and cost. In general, motion controllers rely on a proprietary language that is tailored to fit motion commands. Most motion controllers have also evolved to incorporate some of the machine-control functions usually associated with PLCs, such as temperature monitoring and discrete I/O control.

Due to the proprietary nature of motion languages, machines designed around a specific controller may include advanced functionality but can sometimes be limited when it comes to expansion. Single-PCB motion controllers cannot easily add additional axes of motion control without ordering a new unit from the factory. Bus-based motion controllers have more flexibility to add axes, but it is important to ensure that the bus is both widely offered by other device makers and increasing in market adoption.

The Parker Automation Controller is an example of a programmable automation controller (PAC). PACs provide the ability for users to develop their own drivers to connect to unique devices using ASCII. Like a PC, it has visualization capabilities built in, allowing the user to develop a complete application that incorporates programming the logic and the human machine interface all in one software suite.

PACs merge PLCs, PCs, and motion controllers into a single device. Rather than requiring a separate stand-

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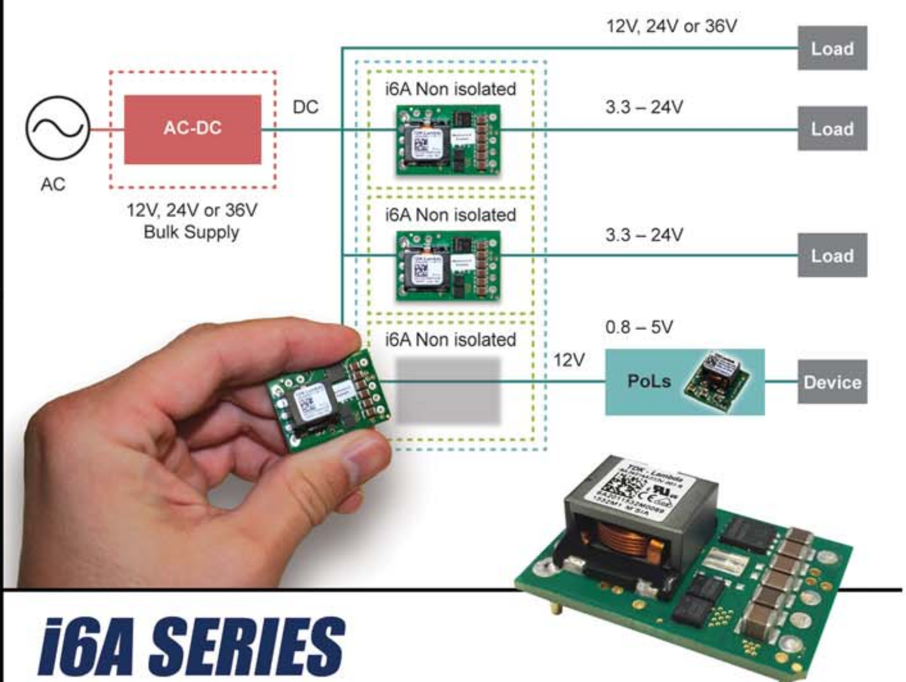

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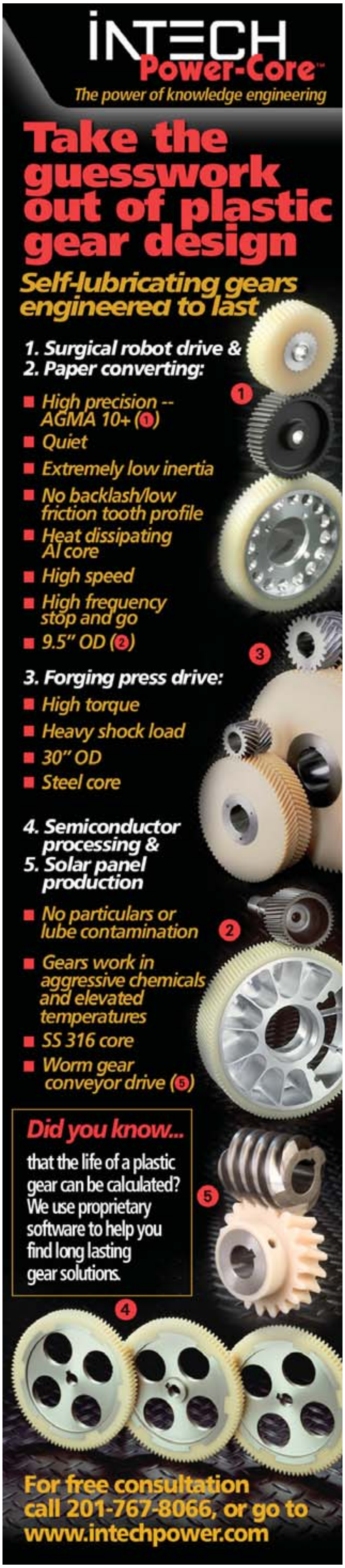

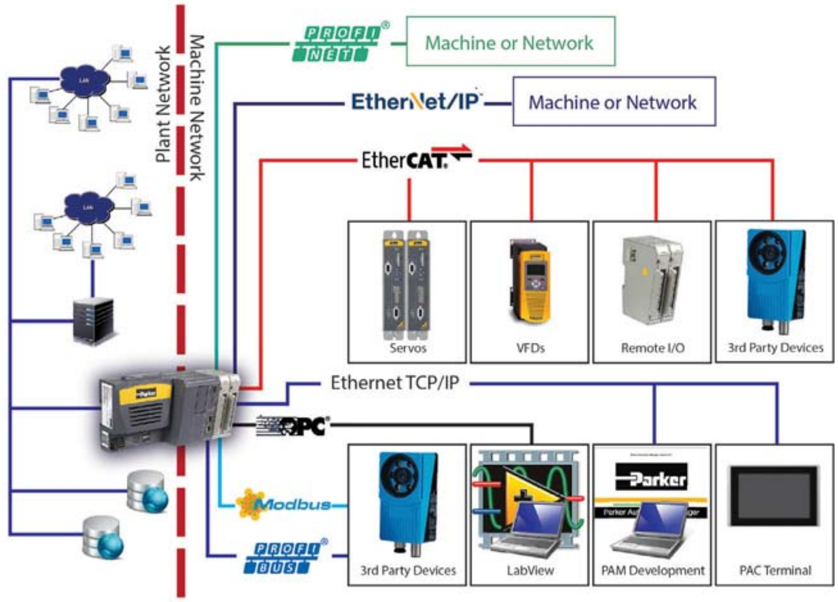

In response to the demand for more connectivity options, today's motion controllers increasingly offer support for multiple communication protocols. For example, a modern PAC controller provides EtherCAT communication for real-time motion, I/O, and third-party device connectivity as well as EtherNet/IP, PROFINET, and an OPC Server for machine-to-machine and plant-level communications.

alone motion controller, PACs provide multi-axis motion trajectories over a bus—such as EtherCAT—while drives close the local PID loop around the motor. This architecture not only allows the entire system to be programmed with IEC 61131-3, but also within a singular development environment—reaping all the benefits of standardized programming. Maintenance is significantly reduced as the PAC queries the drives to determine the failure mode. Rather than needing to open up a machine to gain access to data either through manual multi-meter readings or direct connection to sub-devices, all the information can be accessed by connecting to a single PAC.

Connecting to other machines on the factory floor and integrating internal drives are important considerations of machine design and controller selection.

When choosing a PAC, it is important to select a bus system that will allow flexibility when choosing devices as well as withstand the test of time. A PAC controller that supports EtherCAT as its

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main field bus but also offers support for EtherNet/IP, OPC client/server, Modbus TCP, PROFINET, and PROFIBUS, ensures that the controller is "future-proof" and also compatible with current industrial devices.

UNIVERSAL APPLICATION QUESTIONS

It is critical to weigh a variety of considerations to avoid ending up with a less-than-optimal motion control solution. By asking the right questions before beginning the specification process, the designer can avoid making the wrong control choice:

How is the application likely to evolve over the next 20-25 years? Consider what new functionality/subsystems are likely to be required. Take the time to assess whether the solutions you are considering have the flexibility to allow integrating new devices/subsystems readily.

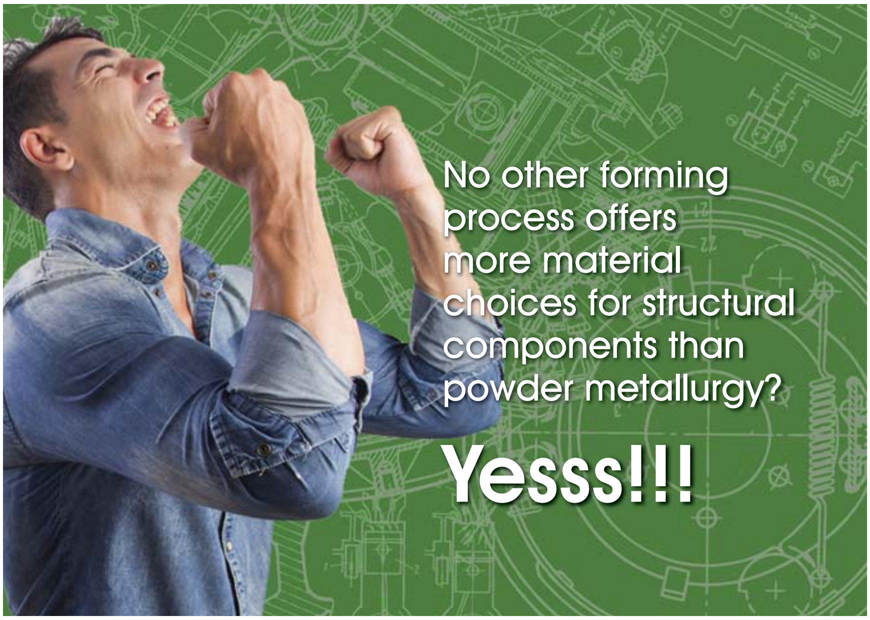
Will the system require centralized, deterministic control scheme? This is common in industrial applications where a single PAC is in control of an entire system. Or does the design require a combination of multiple, decentralized smart devices, such as optical lab instruments, in addition to motion control?

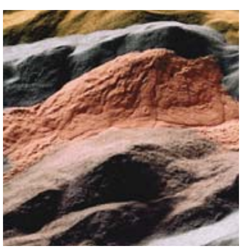
What communication protocols offer the greatest flexibility and longevity? There are so many choices. It is important not only to select a bus that works best for your system (for example, EtherCAT is best for high-speed motion control) but also a bus that is proven, widely used, and growing in installation.

How will space constraints dictate system architecture and component choices? Must the system be compact enough to sit on a benchtop or can it span many meters? For instance, Ethernet-based bus systems can transmit data over extended distances, whereas traditional motion controllers are limited by the quality of digital and analog signals and are limited to smaller ranges.

What existing integration and programming resources are available? Many organizations are reluctant to take the time to acquire a new skill set and third-party services may be used in the future to maintain a machine. The choice of programming language is critical in determining how quickly an organization or maintenance crew can diagnose, change, and develop an application.

Designers that do not take the time to determine the best control scheme or choose components too quickly without asking these critical questions have the potential for serious consequences further down the road. It is important to know and avoid these common design mistakes:





Any element that can be found at room temperature and above in solid form can be produced as a powder by chemical, mechanical, or pyrometallurgical means. Powders, in whatever form, can be mixed into any chemical combination, typically by combining pure elemental powders, or by prealloying them to impart the same chemistry to each particle. And combining ceramic and metals makes possible composites and functionally graded materials with unique microstructures unobtainable by any other means.

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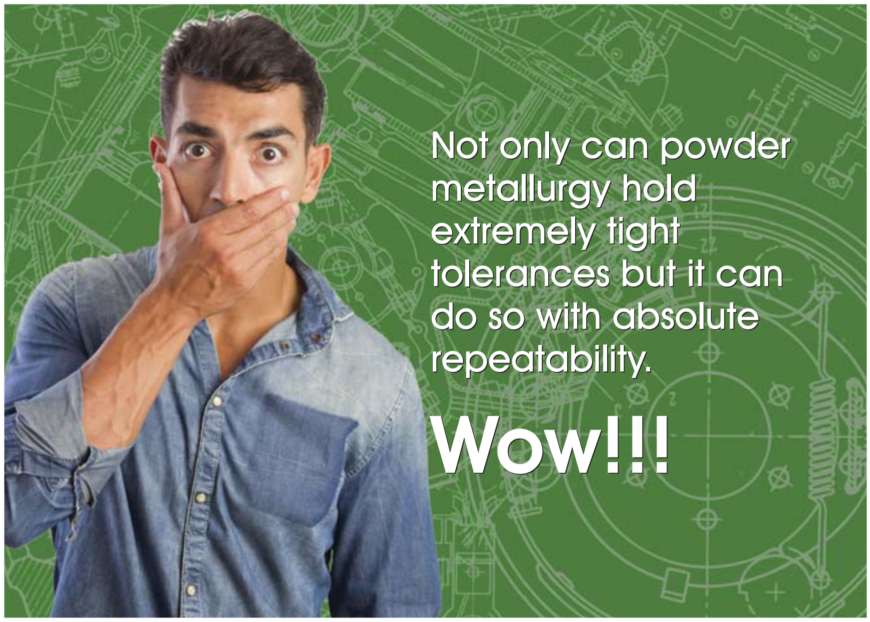
Choosing a device without application consideration. When a controller is selected first, with insufficient regard for the application, it constrains the designer's choices, leading to longer and more expensive development cycles. The controller is often selected first when the designer either defaults to a controller he or she is familiar with or "falls in love" with a controller gussied up with all the latest bells and whistles, forcing the designer to use components that may not be ideal for the application but that work with the controller selected. As a result, the designer may need to find work-arounds to get a system to operate correctly, increasing development time. Similar problems can arise when a designer does not take the time to understand all that the application entails.

No place to grow. When new functionality requirements emerge, the wrong controller can mean great difficulty in expanding or extending the system. Without careful consideration of how a motion-control system is likely to evolve over its lifetime, it is far too easy to select a controller (such as a traditional controller based on I/O) with limited ability to accommodate new devices or functionality.

Invest for the future. Selecting an inadequate controller for a given application to save a little money now or failing to plan for future necessary expansions of an application all but ensures a less-than-optimal return on investment. Selecting the wrong controller in the early stages of system development will demand additional design time and could force the designer to employ less efficient components to allow the poorly chosen controller to work. As the machine matures and requires maintenance, it may be difficult or impossible to keep it running, especially if the programming language used was proprietary or no longer commonly used, especially if the original designer has moved on to another organization. If expansion is required to add a feature or device to extend the system's lifespan and usability but the control bus used is no longer available, the system may have to be redesigned from scratch instead, costing significant development time and resources.

All too often in today's quarterly bottom-line-driven business environment, designers are pushed to design the least expensive solution that will serve the application right now. Asking honest questions and answering them fully is the best way to ensure that a new motion control system can continue to evolve along with the application is changing requirements and continue to provide a return on investment for many years to come. md



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STEPHEN MRAZ | Senior Editor
stephen.mraz@penton.com

Radial and Orbital Riveting Add Finesse to Fastening and Joining

Knowing where and how to apply pressure is more important than brute force for these two riveting techniques.

Most engineers tend to rely on traditional fastening methods to join parts. However, a couple of similar, lesser-known techniques for putting heads on rivets and studs for permanent joints —orbital and radial riveting—can bring better results at lower costs for many applications.

An EcoLine orbital riveter from Baltec uses 2 to 7 bar of pneumatic pressure to form heads on rivets. Maximum riveting force ranges from 20 kN on the Model 20 to up to 35 kN with the Model 35.

ORBITAL RIVETING

Orbital forming is a cold-forming process used on parts in which an angled peen or forming tool attached to a spindle spins 3 to 6 deg. off center and applies axial and radial forces to a portion of a part. This progressively moves some of that material, forming it into a predetermined shape.

The process works on a wide variety of malleable materials, including steel (even high-alloy steel with a hardness of 54), aluminum, brass, bronze, copper, lead, and zinc, as well as many polymer composites and other plastics, such as ABS. Depending on the tool, the process can create swages, crowns, and flares, or, as it is most commonly used, put heads on studs and rivets (also called upsetting or bucking rivets).

Peens are shaped with the final shape of the finished part in mind. Specific peens have been designed to produce conical, flat, eyelet, and crown heads. The forming tools are usually made of M2 drill-rod steel and heat treated to a Rockwell C hardness of 60 to 64. On the riveting or forming machine, they are held in place by a setscrew and can be quickly changed.

In orbital riveting, which is also called radial or spin riveting, the forming tool is in contact with a small area on the part being formed at any one time. As a result, the compressive forces on it are 80% less than in impact riveting, a brute-force approach to riveting. The line of contact between the tool and rivet does not vary.

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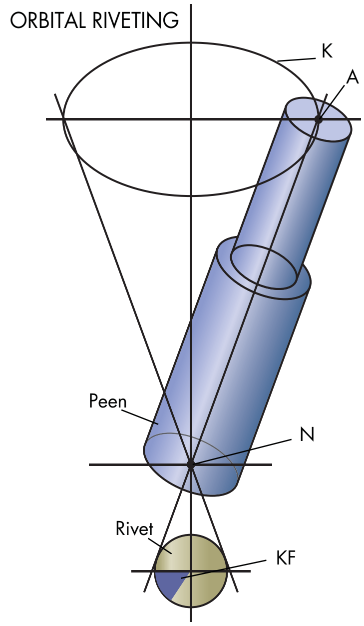
On each revolution of the spindle, the same line of contact is maintained. Because the same point on the tool is always in contact with the same point on the rivet, there is little friction and no tearing of the material. This means it will not create a galled or hammered finish. Solid rivets formed with orbital riveting will have smooth finishes whether they are crowned, conical, or flat head.

The lower forces reduce internal stresses in the final rivet and the parts being joined, which increases the finished assembly's fatigue life. The lower forces also give the rivet's formed head a smoother finish, eliminating cracks caused by impact riveting, and extending the life of the forming tool. However, the constant side thrust on the rivet generated by the peen necessitates the use of a fixture to hold the workpiece steady and prevent lateral creep.

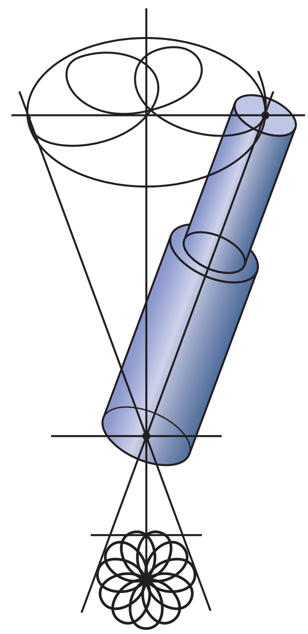
It takes three or four passes over the part to create a 0.02- to 1.5-in.-diameter hardened and slightly compressed head. This takes from 1.3 to 3 seconds. But it usually takes longer than that to manually or automatically load and position the parts being joined and insert the rivet. The forming time ultimately depends on the hardness of the rivet and its total surface area. Therefore, small-diameter rivets made of soft materials can be bucked quicker than thicker ones.

Equipment employed for orbital riveting allows technicians to monitor and control the forming process based on data that includes forming forces, variable rate of forming forces, form height, and clamp loads between fastened parts. This gives the finished rivets and joints consistency and uniformity. Among other advantages that orbital riveting offers over impact riveting are:

- The forming forces do not usually exceed the strength of the rivet's shank, so the process does not need to bend or swell the rivet's shank.
- A smaller press can be used, which translates into a smaller footprint and a smaller motor, both characteristics that can save money.



In orbital riveting, the changing longitudinal axis, A, of the peen describes the surface of a cone, K, whose tip, N, lies within the rivet. The peen works on a crescent-shaped contact surface, KF, and pushes metal along in front of that area.



In radial riveting, the tool does not spin, but rather is moved around the rivet, pushing small amounts of metal into shape gradually to form the finished head.

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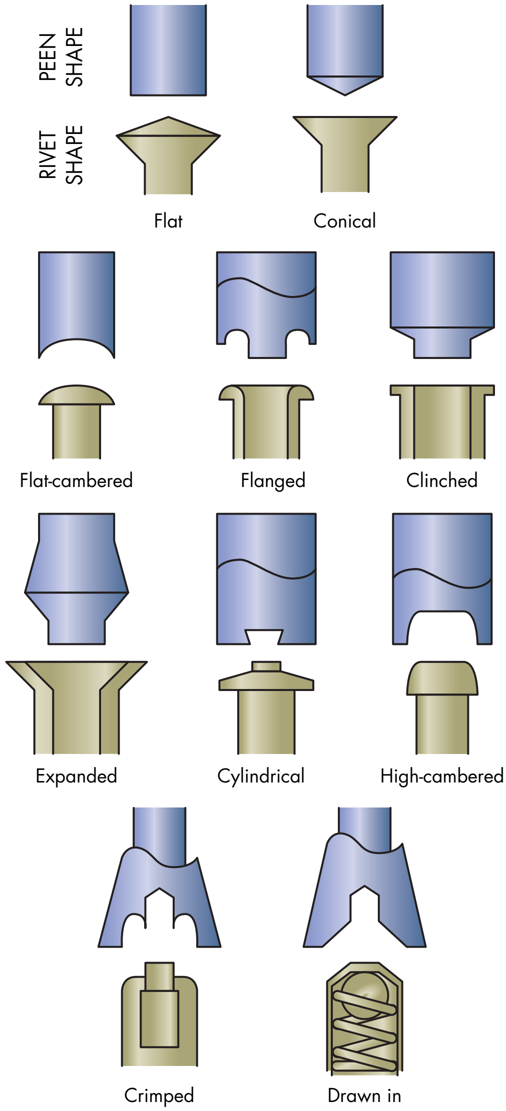

The peen's shape determines the shape of the rivet head. Here are some of the more commonly used tools and resulting rivet heads.

- Because the forming forces are lower, the fixturing need not be as rigid and is less costly.
- Orbital riveting is practically silent and vibration-free.

Orbital-riveting machines need less force than impact riveters. Pneumatic versions, for example, exert 1,000 to 7,500 lb. of force, while more powerful hydraulic orbital riveters can exert 6,000 to 50,000 lb. of force. Precision orbital machines spin the spindle at about 1,700 rpm. Heavier-duty machines run at 900 to 1,200 rpm.

Orbital riveting will not work on blind rivets because with them, installation requires access to both sides of the assembly.

RADIAL RIVETING

Rivets can also be created using radial forming, which is similar to orbital forming. With radial riveting, though, a punch rather than a peen rotates around the workpiece, tracing out an 11-sided rosette path (actually a hypocycloid, much like what could be created with the Spirograph toy). It gently deforms the material. There is little axial force and the material predominantly flows radially.

So little lateral force means that fixtures and clamps are usually unnecessary. There is also little downward force, so rivets can be placed in brittle materials, including ceramics and bakelite. The lower forces extend the life of the tool. Thus, for metal rivets, this lets the material retain its grain structure and structural strength.

IMPACT RIVETING: THE OLD SCHOOL APPROACH

WHEN MOST ENGINEERS think of riveting, they think of impact riveting. In this relatively simple process, a rivet gets placed automatically or manually in the jaws of the riveting machine. A force, usually a flywheel (hydraulic and hydra-pneumatic forces are also used), slams a driver into the rivet and through a hole drilled through the two or more parts being permanently joined. These parts are often sheet metal or flat panels.

For solid rivets, this force causes the shank of the rivet to swell to fill the hole. Then metal protruding from the two parts being joined gets compressed and cold formed in the rollset. The rollset is a tool that shapes the metal into a second head that holds the parts together.

For semi-tubular rivets, the rollset flares out the hollow end of the rivet, rolling it down to form the other head. It takes about 40% less force to install a semi-tubular rivet than a solid rivet.

Semi-tubular and solid rivets are usually made of steel, but they can also be made out of aluminum, brass, and stainless steel. Semi-tubular versions have shank diameters that range from 0.06 to 0.3 in. in diameter. Solid rivets can have diameters up to one inch wide.

In general, impact riveting is reliable, inexpensive, and quick, installing a rivet in as little as 0.5 sec. Up to four rivets can also be installed at once. This usually requires fixturing to hold the parts still and with the holes all aligned. With an offset driver, rivets can be installed more closely together so there is only 1/16th of an inch between heads.

To keep operators safe, many riveting machines have safety devices such as Lexan guards, light curtains, and dual-palm buttons. These buttons require that both the operator's palms be on them before a rivet will be installed. This prevents any fingers from getting damaged in the installation process.

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The RN Series of radial-riveting machines from Baltec exert from 2 to 50 kN of force.

AVOIDING CORROSION ON FASTENERS

A MAJOR CAUSE of failures in metal fasteners is electrochemical corrosion (rust), or so-called galvanic action. Engineers and designers alike can greatly reduce this type of corrosion by specifying fasteners made of the proper materials or with the right coatings.

All metals have an electrical potential. When metals with different potentials (steel and copper, for example) come into contact in the presence of an electrolyte such as water, it sets up a galvanic cell in which a low-energy current flows between the two metals. This galvanic action corrodes the metal with the higher potential. This makes it critical for engineers to know the potentials of the metals that are in contact—especially fasteners.

Anode (least noble) +	Magnesium and its alloys
	Zinc
	Aluminum 1100
	Cadmium
	Aluminum 2024-T4
	Steel, iron, and cast iron
	Chromium iron (active)
	Ni-resist
	Types 304 and 313 stainless steel (active)
	Hastelloy C
	Lead, tin, and lead and tin solders
	Nickel (active) Inconel
	Hastelloy B
	Brasses, copper, bronzes, copper-nickel alloys, and Monel
	Silver solder
	Nickel, Inconel (passive)
	Chromium, passive
	Type 304 and 316 stainless steel, passive
–	Silver
Cathode	Titanium
(most noble)	Graphite, gold, platinum

The punch itself does not rotate. This minimizes friction between the tool and workpiece, and creates a smooth finish with no galling or scuffing.

One of the differences between radial and orbital riveting is that radial forming moves material at a constant speed and at a uniform rate. Orbital forming moves materials at different rates, with the material near the rivet's perimeter moving faster and farther than material near the center. This gives radial rivets higher joint strength.

Radial riveting also improves the electrical conductivity of metal rivets, according to some. As a result, it is well-suited for making rivets that serve as electrical contacts. The process also works well on delicate parts with small diameters (less than 1/8 of an inch). In fact, the process was originally developed to install tiny rivets in watches. Thanks to these two characteristics, it can be used to form rivets on printed circuit boards (PCBs) that connect components while also serving as an electrical pathway on PCBs.

However, radial riveting is more complex and the forming tools cost more than orbital-riveting peens. It also takes longer to radially form a rivet than using the orbital process.

The accompanying chart shows the relative potential for galvanic corrosion for a number of commonly used fastener materials. The more widely separated two metals are on the chart, the more likely the metal with the higher potential will corrode. Usually, metals in the same group can be in contact without galvanic action taking place.

Here are some other tips for preventing electrochemical corrosion on fasteners and other components:

- Maintain constant stress in the fastener. Irregular loading leads to corrosion.
- Separate dissimilar metals with a dielectric material (insulation, paint, or coatings).
- Avoid metal-on-metal situations in which the less-noble material has the smaller contact area.
- Current density and corrosion are greater when current flows from a smaller to a larger area. Because fasteners are always smaller than the rest of the assembly, they should be of the same material or lower in the galvanic series than the materials being joined.

You can use the galvanic process to your advantage by coupling parts to be protected to non-functional pieces of a less-noble metal. The less-noble parts (sacrificial anodes) will corrode instead of the protected part.

MICHAEL HEFLIN | CEO
Sensuron

Don't Stress Out:
How to Pick the Best Tool for Strain Measurements

Michael Heflin, CEO of Sensuron, explains the differences between modern strain-measurement tools and the applications for which they are best suited.

The Global Observer wing was instrumented with fiber-optic sensors under 100% of design load during ground testing. *(Photo: Center for the Study of the Drone)*

Strain measurement is imperative during prototype design and testing. Measuring strain ensures that materials perform as they should and that equipment is safe, functional, and durable. The resistive strain gauge (RSG) has been the benchmark for measuring structural deformation for over eight decades, but today there are many technologies available to test and monitor stress and strain. Below, we discuss the use cases of strain measurement technologies in the aerospace and energy fields. This comparison will highlight the unique capabilities of each strain measurement device and determine the best technologies for strain measurement in each use case.

STRAIN MEASUREMENT IN THE AEROSPACE INDUSTRY

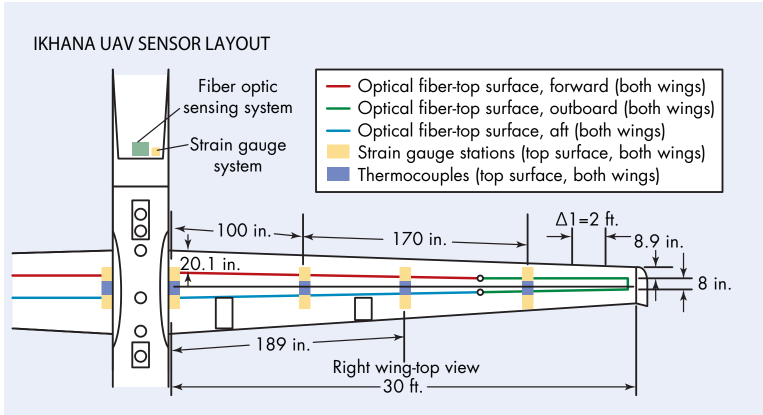
Stress and strain are the variables that determine the structural longevity and operational safety and efficiency of any aircraft. By testing, monitoring, and analyzing the integrity of an aircraft's components, engineers can prolong a vehicle's lifecycle and enhance in-flight efficiencies.

WING-LOAD TESTING

During a wing-load test, engineers depend on strain measurements to determine the structure's performance and limitations under the lifting forces seen during flight. Two of the most effective methods of wing-load testing are fiber-optic sensing (FOS) and the resistive strain gauge (RSG). While both technologies are comparably accurate, each possesses its own unique merits.

NASA, to test the wing-load distribution and wing deflection of the Global Observer aircraft in NASA Armstrong's Flight Laboratory, has used FOS. The benefits of an FOS installation for this type of application are numerous. For instance, FOS technology provides strain measurement using thousands of spatially continuous sensors. This ensures maximum coverage from a single lightweight optical fiber. As FOS is immune to electromagnetic interference (EMI), radio frequency interference (RFI), or other electrical influences, these systems are ideal for use in hazardous environments and rugged applications, such as flight. FOS can be significantly less cumbersome to install than other sensing technologies. However, while the benefits of FOS are numerous, historically the initial cost of installing a system and lack of awareness has slowed mass market adoption. Moving forward, we anticipate reduction in the cost of FOS systems by 20% to 30% over the next five years, which will open up new opportunities in the automotive, medical, aerospace, and energy markets.

Strain gauges are still used today to verify the accuracy of analytical models that drive the design and manufacturing of structures and structural components. For example, Boeing has used strain gauges to test the durability of wings under load for some time. Although well understood and relatively inexpensive, strain gauges are difficult and time-consuming to install without the help of an expert; they can be affected by EMI and RFI, and are prone to hysteresis. A strain gauge only collects data from critical points and as a result does not provide a holistic picture of the load distributions.



In 2009, NASA Armstrong (formerly known as NASA Dryden) conducted flight validation testing for a fiber optic shape and strain sensing system. Sensing fiber with approximately 3,000 fiber Bragg gratings (sensing points) was installed on the wings of NASA's Ikhana UAV along with 16 strain gauges as indicated in the image above, right. The gauges were used to validate the strain data provided by the fiber Bragg gratings (FBGs). During flight, the FOS system was used to sense the shape and monitor the stress of the wings in real time. Strain data collected by the FOS was in agreement with the data provided by the strain gauges. A total of 18 flight tests adding up to 36 flight hours were conducted. During these flights, the tests consisted of the pilot pushed down on the stick quickly, then quickly pulled up for several cycles. The real-time shape and strain data of the wings obtained by the FOS system was the first step toward controlling the shape of fixed wing aircraft. Strain gauges could not provide the density of information needed in order to monitor wing shape in real time, but were useful to confirm the validity of the strain data.

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FATIGUE TESTING

A material experiences fatigue after it is subjected to repeated loading and unloading. An estimated 90% of structural failures that occur in all industries are a result of fatigue. Many engineers use a strain-controlled testing method that uses cyclic loading to predict the life of an application under fluctuating loads.

The objective of a fatigue test is to determine the life and breaking point of a structure or component, i.e., the location of and number of cycles until failure when a material is subjected to a sequence of stresses. A number of methods are used to obtain stress and strain data, including strain gauges. The lifecycle of strain gauges themselves decreases dramatically as strains reach values of 2000-4000 μ-strain. This means that strain gauges are unable to accurately assess fatigue over certain parameters and over long periods of time.

FOS technology can provide engineers with accurate, real-time data on strain fields, load distributions, and residual strains resulting from overloading. Fiber optic sensors are resistant to temperatures ranging from cryogenic (< -150°C) to upwards of hundreds of degrees Celsius. This enables embedded fibers to be monitored during the high temperature cure phase of composite fabrication to determine the through-thickness residual stresses and strains. Because optical fiber is

FIBER OPTIC SENSING AND RESISTIVE STRAIN GAUGE COMPARISON

	Operating temperature	Strain range	Lifecycle*	Distributed sensing	Parameters measured
Fiber optic sensing	-250 to 700°C	+/- 20,000 με	27,000+ Cycles	Yes	8+
Strain gauges	-75 to 200°C	+/- 30,000 με	200 Cycles	No	1

*Under high cycle, high amplitude monitoring

A comparison of fiber optic sensing technology and resistive strain gauges.

FIBER OPTIC SENSING AND RESISTIVE STRAIN GAUGE COST COMPARISON

	System cost	Implementation cost	Maintenance cost
Fiber optic sensing	High	Low	Low
Strain gauges	Low	High	High

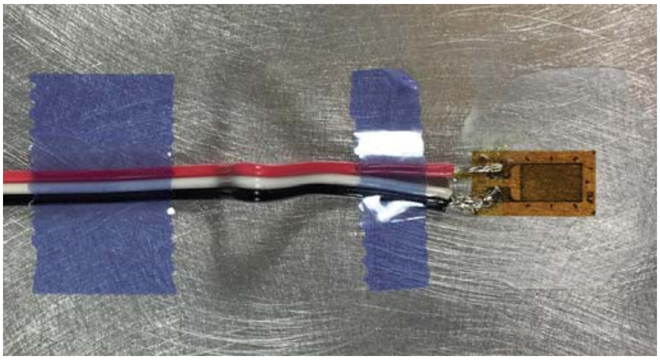
A high-level cost comparison of fiber-optic sensing technology and resistive strain gauges.

a ceramic and not a ductile material, its fatigue life far surpasses that of strain gauges and it does not exhibit hysteresis. For these reasons, continuous monitoring of composite structures can have far-reaching advancements. For example, commercial airlines will always know the state of fatigue damage on critical components, allowing them to fine-tune maintenance schedules and minimize aircraft downtime.

STRAIN MEASUREMENT IN ENERGY

The wind industry is changing and renewable energy is gaining market momentum. Wind turbines can be found throughout the United States, positioned in locations where they can gather and convert as much energy as possible. For this reason, wind turbines must be durable. In addition, to improve efficiencies wind turbines are now being built taller and with longer blades. With bigger structures, loads become more significant, and maintenance becomes even more complex. The design of stronger, lightweight materials is imperative, but small inefficiencies during manufacturing or damage during operation can cause catastrophic operational failures.

More accurately detecting damage during runtime and at the finest resolution level offers benefits that translate into lower maintenance costs and the assurance of blade integrity. Blade geometry is carefully designed to maximize turbine



This installation compares one resistive strain gauge to approximately 50 FBG sensors. The fiber is the transparent line adhered around the strain gauge.

efficiency, but the aerodynamic loads encountered during operation inevitably cause them to deflect, twist, and vibrate, leading to an altered aerodynamic response and decreased efficiency.

Strain gauges can be used to monitor wind turbine blade load during design validation. Some of the world's largest turbine blade manufacturers rely on strain gauges to ensure optimal performance of rotor blades. Strain gauges can increase the reliability and function of wind energy technologies and

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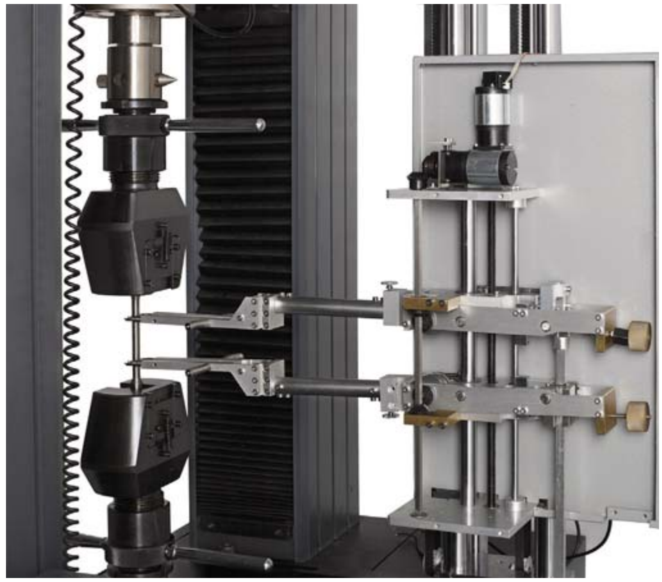

A motorized extensometer is used during tensile testing.

thus reduce downtime. They provide critical measurements that help to maintain the operational integrity of wind turbines. For example, engineers use both strain gauges and FOS technology for chordwise bending tests on a full scale blade.

In addition to bending tests, FOS technology can take real-time measurements for operational data. By utilizing FOS technology to obtain real-time knowledge of turbine blade shape and load distributions, it is possible to compensate for performance changes. Control schemes utilizing this information may be developed to autonomously adjust the blades to decrease deflections, or to dampen out individual vibrational frequencies. Therefore, the blades would see less deviation from their nominal and most efficient shape. Data taken over longer periods of time would aid in the development of future designs, improving the future of wind turbines in the mix of renewable energy products.

TENSILE TESTING AND STRAIN MEASUREMENT

Tensile testing is a principal test, in which a material is subjected to tension until it reaches failure. This material test is used to select a material for an application, as well as predict the material's behavior under different forces and strain parameters. This test measures properties for ultimate tensile strength, maximum elongation and reduction in area and is often used to ensure quality control of materials like metals and plastics. The strain measurements of a tensile test are often taken with an extensometer, but strain gauges can be used on a small test specimen or when Poisson's ratio is being measured.

The extensometer and strain gauge both provide reliable data; however, the extensometer offers several advantages over the strain gauge for tensile testing. Strain gauges with their accuracy, low cost, and ease of use are among the most common tools used in strain measurement and tensile testing. However, they can be difficult to apply and, as a result, can be misused and cause uncertainty in measurement. When tensile testing, strain gauge errors can be caused by temperature, misalignment, and the transverse sensitivity of the strain gauge. Additionally, bonding the strain gauge to the test piece can influence the outcome of the test.

The extensometer can be used up to the material breaking point without damage, even when testing specimens which are conducive to whiplash. Additionally, extensometers can more accurately determine strain when test samples undergo large deformations. The long gauge length of the extensometer also means that it can measure large applications. For example, the energy industry uses extensometer to measure displacements on high walls. Understanding displacement versus time helps engineers to determine when a wall failure is imminent. However, one large drawback of this technology is that it is dependent on the material that it measures. Additionally, extensometers can be more expensive to implement than strain gauges.

SMARTER PRODUCTS MEAN SMARTER DATA

Ever-increasing competition challenges companies to innovate, and do business faster and safer while keeping costs to a minimum. Utilizing the most appropriate technologies for your application can help improve prototype design and validation, helping businesses to create products more efficiently and safely. One way companies are able to overcome these challenges is by developing smart products. Global trends indicate that the demand for smart products, both industrial and consumer, is rapidly increasing. As the demand for these products increases, so does the necessity of not only more data, but actionable data. Over time, this data will help companies build safer solutions while pushing the limits of technology. As such, strain sensing solutions that provide spatially continuous strain information in real-time will be able to solve problems engineers face today and into the future. md

ABOUT THE AUTHOR

Michael Heflin is CEO of Sensuron, a global provider of fiber optic sensing systems whose mission is to solve problems on a global scale by utilizing light-based technologies that ensure equipment is functional, reliable and safe. He has been leading companies and inspiring teams for over 20 years. Specializing in identifying, growing, and increasing value in emerging technology markets, he has held executive roles at companies like Vantive, ADP, Fracta, Convergys, and Whisperwire. Before joining Sensuron, Heflin guided four companies to lead their industry in sales, including two publicly traded companies with valuations worth $2 billion. He has experience navigating domestic and international companies through successful acquisitions. Passionate about forming and counseling value-driven teams, he has a history of successfully guiding and inspiring teams worldwide.

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Continued from page 35

"Our core strength is the number of components we have in stock and available for immediate shipment, with access to over [4 million components] via our website," said Dave Doherty, Digi-Key's president and COO, in a statement earlier this year citing the firm's growth in China.

For independent distributors such as N.F. Smith, 2016 is shaping up to be an improvement over 2015 as well. N.F. Smith saw a 30% drop in annual sales in 2015, which Bollinger attributes to the nature of the firm's business serving open-market needs.

"We don't look at 2015 as a bad year, just as a year with a very different mix of components that were in demand," Bollinger explains. "For independent distributors, that's generally the case. It's difficult for our revenue numbers to match up year to year, because we're dealing with the open market—with whatever is in demand.

"When I look at 2015, it was not a banner year from a revenue perspective, but we still experienced growth in our global footprint," Bollinger adds, pointing to the opening of the company's Bangalore, India, office.

"So far this year we're seeing a not terribly exciting market; it's not bad, but it's pretty flat. There are certainly some bright spots. Automotive is very active for us; there is a lot of excitement in that market. Obviously, anything cloud-based is pretty robust right now."

Knight says he sees the automotive market as a continued bright spot as well, driven by demand for new features and electronic enhancements on both the commercial and passenger sides of the equation. Medical markets and commercial aerospace continue to perform well, too, he says, adding that the proliferation of electronics across all aspects of life continues to bode well for the electronic components supply channel.

"Conditions have been flat for, [say], 10 years, so it's easy to start to thinking that it's going to be this way always," says Knight. "I don't believe that. There is so much going on in technology that, once it's realized, it will spur growth."

Sensors embedded in everything from health and wellness devices to smart-city applications are likely to produce widespread demand for new products and the replacement of outdated ones, for example.

"There is going to be a wave of products that have really interesting and new features that will add value in our businesses, our lives, and we will start buying them," Knight explains. "I think before I'm done in this business we will see at least one, maybe two more surges, when it feels like things are on fire. It won't be this year or next year…but it could be in the early 2020s that we'll see something. There is just too much really interesting stuff going on in technology [to not expect that]."

Services are a growing opportunity across the board as well, and one Bollinger says independents are beginning to home in on. "An interesting thing for independents right now is that there is an increasing amount of supply chain service business," he explains. "We're seeing more supply chain service opportunities—managing inventory, logistics, supporting warranty, and repair-type work. We're working on cost-savings opportunities and using the market to bring down the average cost of inventory." md

TOP DISTRIBUTORS REPORT: METHODOLOGY

GLOBAL PURCHASING IS proud to publish its sixth annual *Top Electronics Distributors* report, compiled from nomination forms submitted during February and March of this year. Each company in our list is ranked according to its total global sales volume, and all figures are reported in U.S. dollars. We used self-reported data from each company and verified the information against annual reports and earnings statements, where possible, as well as in follow-up interviews with some of the companies at the top of the list.

Figures for Avnet Inc., ranked first, and Arrow Electronics, ranked second, include the sale of computer products, which comprise large segments of each company's business. The ranking for privately held Future Electronics, fourth, is based on a *Global Purchasing* estimate.

Figures for Allied Electronics, seventh, reflect its worldwide sales as part of UK-based Electrocomponents plc, which also operates RS Components in Europe. The figure here is a company-provided estimate for global sales for the year ended March 31, 2016. Likewise, sales for ninth-ranked Newark element14 reflect worldwide sales as part of its parent company, Britain-based Premier Farnell, for the year ended Jan. 31, 2016.

For this year's report, we have highlighted 41 of the largest authorized and independent distributors serving customers in North America and around the world. We broke our list into two segments, those with $75 million or more in annual sales, and those with less than $75 million in sales. The top portion represents the largest companies doing business in the market today, while the bottom portion represents noteworthy U.S.-based companies serving customers primarily in North America.

Our goal is to provide a look at the largest electronic components distributors serving manufacturing customers around the world. We will compile information for next year's report early in 2017 and we welcome your input. Send your comments to sourceESBeditor@penton.com.

Servos and Amplifiers Feature Quick Response Time

THE SIGMA-7 line of rotary-, linear-, and direct-drive servos and amplifiers target automated equipment. With nearly double the bandwidth of the previous Sigma-5 series, they respond quicker to system commands, and leverage a 24-bit encoder to surpass industry precision standards. They feature a 20% smaller footprint than the previous series, and the new SERVOPACK amplifier design saves control-panel space. SERVOPACK amplifiers can be interfaced with EtherCAT, MECHATROLINK, or analog connections, and a SigmaLogic SERVOPACK can sequence motion via Add-On Instructions (AOIs) used by programmable logic controllers. A SigmaTrac option is also offered for easy bolt-on, plug-in implementation of all products.
YASKAWA, Yaskawa.com

DIN Carriers Cater to 221-Series Splicing Connectors

DIN-RAIL-MOUNT CARRIERS are now offered for use with 221-Series splicing connectors. The carriers feature a compact, transparent design for easy mounting to the DIN rail. They are open on one side for interchanging wires. The 221 operating levers can easily be accessed after installation; no tools are required for installation. They are able to be mounted vertically or horizontally, employing miniature mounting clamps to ensure that the carriers tightly grip the connectors. The devices are compliant with VDE standards.
WAGO, www.wago.us

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Joysticks Come in a Range of Configurations

THE JS1 platform for joysticks in the JS1-H family enables usage in heavy-duty applications. Customers can choose from a standard portfolio of joysticks that consists of

three base options (single-axis with spring return, friction hold, and dual-axis with spring return); five grip types; and pushbuttons, rollers, and other controls that can be custom-positioned.

DANFOSS POWER SOLUTIONS, www.powersolutions.danfoss.com

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NOVOTECHNIK INC., www.novotechnik.com

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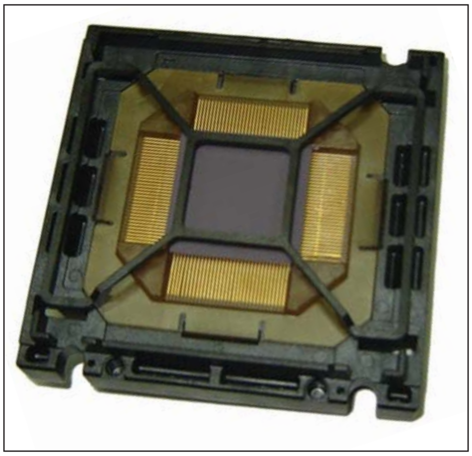

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PARKER HANNIFIN CORP,
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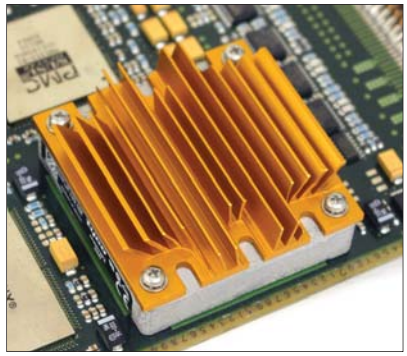
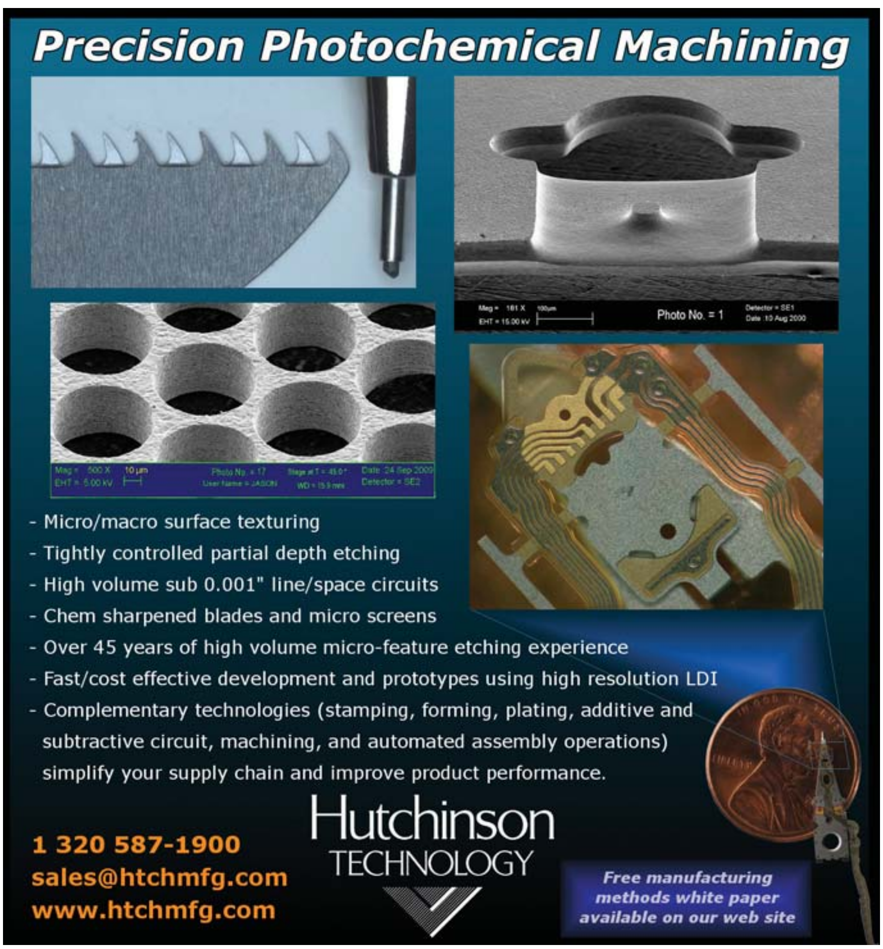
MENCOM, www.mencom.com

Heat Sinks Drastically Reduce Junction Temps



HIGH-PERFORMANCE maxiFLOW heat sinks reduce junction temperatures of dc-dc power converters by more than 20% at their maximum operating temperatures. The spread-fin design provides more surface area for heat spreading and convection cooling in low-airflow environments, and reduces pressure drops on passing air. They are available with Philips-head screw sets of various lengths, and are shipped pre-assembled with an effective thermal-interface material.

ADVANCED THERMAL SOLUTIONS, www.qats.com



Welding System Uses Laser To Fuse Transparent Materials

A NEW laser-welding system leverages a 2-micron laser that can be absorbed by optically clear polymers for clear-to-clear plastic welding without the need for laser-absorbing additives. The system achieves highly controlled melting through clear parts of specified thickness. The new beam-delivery system integrates a programmable multi-axis servo gantry and a scan head, both supported by LaserLinQ software, which harmonizes the action of both components moving the beam. The software also lets users break down complex weld patterns into separate geometric segments and assign different welding parameters to each. In addition, it features a CCTV camera for a live-weld preview on a HMI screen. All laser enclosures are Class-I CDRH-certified, and feature laser-safe glass for viewing.

DUKANE, www.dukane.com

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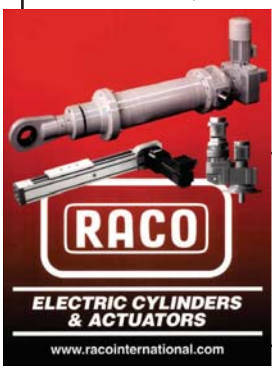

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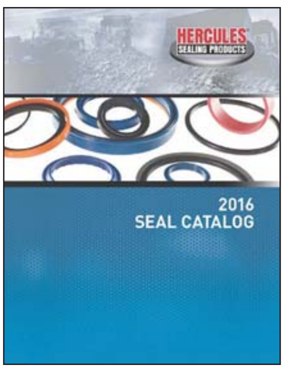

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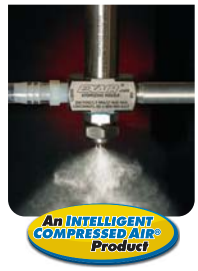

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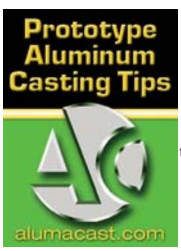

The casting tips are accumulated wisdom and lessons learned from the school of hard knocks. All are presented to help the engineer tasked with designing a part that will eventually be die cast. The intent is to help you avoid career-limiting decisions and make your job a little less stressful. Consider Aluma Cast for your next prototype casting project.

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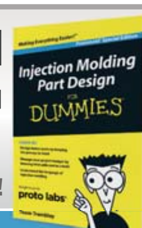

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BRADFORD L. GOLDENSE | Contributing Technical Expert

Breakthrough Innovations: Nine Techniques

Clayton Christensen introduced "disruptive innovation" to the world in 1995. Last year, 2015, marked its 20th anniversary. Over the past two decades, many companies and makers have targeted the creation of new-to-the-world products. This has resulted in a number of approaches that are all disruptive in their own way. At this time, nine different techniques for achieving breakthrough innovation have evolved.

1. Disruptive Innovation: Christensen's original work focuses on identifying a next-generation technology that will disrupt the existing base of products, leading to companies abandoning the older products as they move to the next-generation technology (*Harvard Business Review*, Jan.-Feb. 1995).

The essence of Christensen's strategy is to be the first to market with the next-generation technology in existing markets.

2. Big Bang Disruption: Larry Downes and Paul Nunes suggest that markets can be disrupted by moving away from traditional innovation models that "seek innovation in lower cost, feature-poor technologies that meet the needs of underserved customer segments" (*Harvard Business Review*, March 2013). They suggest that a "big bang" can be achieved by "seeking innovation through rapid-fire, low-cost experimentation on already popular platforms."

3. Emerging Technology Innovation: Robert Phaal, et al., map out a structured "S-T-A-M" approach for taking an emerging technology still in its "science-dominated" stage and managing it through three successive stages: from "technology-dominated" to "application-dominated" to "market-dominated" (*RTM* Mar-Apr 2012). The evolution of digital imaging into today's digital cameras provides a case in point.

4. Digital Innovation: Darrel Rigby's approach centers on "digital-physical mashups." He believes that to consumers, the real and virtual worlds are one, and the same should go for your company (*Harvard Business Review*, Sept. 2014). Online versus retail shopping is a good example. Today, one cannot physically stand in a retail store, purchase an item off the retailer's website, and then take the item off the store shelf and head home.

5. Reverse Trickle-Up Innovation: Vijay Govindarajan and Ravi Ramamurti espouse looking for solutions that work in economically poor and developing countries, then adding selective capabilities and moving them upmarket into more established economies (*IEEE Engineering Management Review*, 2Q 2014). In more established economies, these types of products would appeal to poorer people living in the rich economy.

6. Bottom-of-Pyramid Innovation: C.K. Prahalad, recently deceased, came up with a radical approach to generate corporate wealth in the early 2000s. Rather than target affluent consumers in strong economies, why not target the millions of consumers at the bottom of the economic pyramid (*Harvard Business Review*, Aug. 2003)? The total wealth generated may be comparable due to the large size of the unserved market.

7. Design Thinking: Tim Brown (*Harvard Business Review*, June 2008), and many others since, suggest a thinking process that starts with a clean sheet of paper before the direction has been set for a product. "Along with business and technology considerations, innovation should factor in human behavior, needs, and preferences. Human-centered design thinking will capture unexpected insights and produce innovation that more precisely reflects what consumers want."

8. Ambidextrous Innovation: Michael Tushman, et al., write that "firms thrive when senior teams embrace the tension between old and new and foster a state of constant creative conflict at the top," and that "balancing the needs of core businesses and innovation efforts is a central leadership task" (*Harvard Business Review*, June 2011). They add: "When conflicts about funding old and new businesses are resolved at lower levels, innovation usually loses out."

9. Sustainable Innovation: Green design has been practiced across many industries. Companies that employ this manner of design encounter many challenges, ranging from the raw materials they use to how customers ultimately dispose of products. The financial performance of sustainable products approaches that of breakthrough products. In a sample of 12 S&P Global 100 companies, revenues from green products grew 91%, while overall sales climbed just 15% (*CFO*, July 2015).

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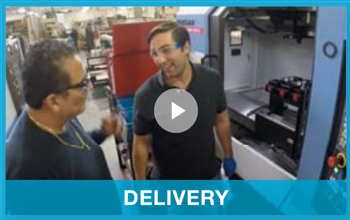

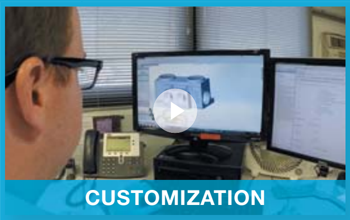

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