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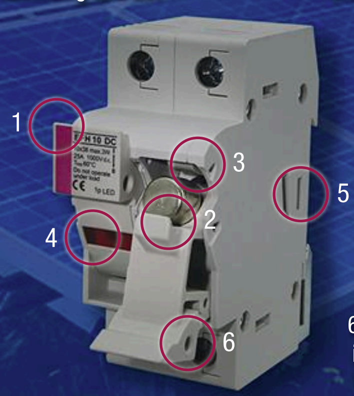

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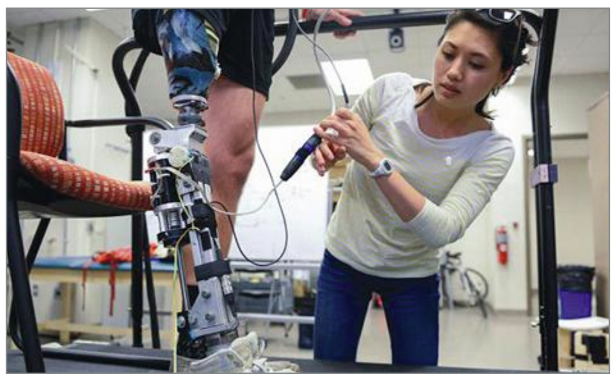

More Than Meets the Eye: The Future of Bio-Robotics

Integrating man with machine is nothing new, as motorized prosthetics have existed for years. However, advances in robotics have created a new wave of technology, pushing the mechanical human body to new limits.

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MachineDesign Magazine (@MachineDesign)

Editorial

CARLOS M. GONZALEZ | Content Director
carlos.gonzalez@informa.com

For Future Engineers, the Robot Market Shines Bright

The future of engineering lies in our youth. If we want the future engineers of tomorrow to thrive, they need to learn how to navigate new technology fields. One such tech wave is the evolution of robotics. As the labor force continues to give the manufacturing industry headaches, robots will become the number one automated labor source. I recently took a trip Yale University, along with Universal Robots, to speak to the ASME students about the future of robotics and the robot market.

Robots are now becoming the go to solution to ease labor concerns. In the past, industrial robots were used for large assembly for tasks humans could simply not accomplish; car manufacturing being a prime example. The highest number of orders for robots ever recorded happened in the first nine months of 2017. 27,294 orders of robots valued at approximately $1.473 billion were sold in North America. Today we live in the world of collaborative robots (cobots). In 2017, these began to overtake the robotic market. According to BIS Research, by 2021, the collaborative-robot market is expected to grow to approximately $2 billion and 150,000 units.

To help drive home the idea of cobots, Universal Robots brought its UR3 to demonstrate the ease of programming and safety of cobot design. Universal Robots can be programmed via the GUI-based programming with a computer or tablet, or by placing the robot in the desired position, recording the placement, and repeating. The robot is force limited and registers if there is an abnormal force experienced during its trajectory for safety.

The driving point I stressed to the students at ASME is that the future of robots is bright. In 2015, a poll of 200 senior corporate executives conducted by the National Robotics Education Foundation identified robotics as a major source of jobs for the United States. Indeed, some 81% of respondents agreed that robotics was the top area of job growth for the nation. Over the seven-year period from 2010 to 2016, 136,748 robots were shipped to US customers—the most in any seven-year period ever recorded by the U.S. robotics industry. In that same period, manufacturing employment increased by 894,000, and the U.S. unemployment rate decreased from 9.8% in 2010 to 4.7% in 2016.

Currently, we are entering a robot war with China. China's government have initiated the technology program "Made in China 2025," and one of its goals is to increase the country's robot production and usage. This is a five-year plan to rapidly expand its industrial robotic sector. China wants to be able to manufacture at least 100,000 industrial robots per year by 2020. The U.S. will need robotic engineers to keep pace.

Robots are being augmented with data gathering technology, turning them from simple labor replacements into data gathering tools. This opens doors for engineers to become data analysts. Robots as medical tool is also an expanding field. An engineer with a biology or medical background could excel in medical robotics. As robots continue to find new use cases, your field of work will include the industrial manufacturing space and beyond. md

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CONTENT DIRECTOR: **CARLOS GONZALEZ** carlos.gonzalez@informa.com
SENIOR EDITOR: **STEPHEN J. MRAZ** stephen.mraz@informa.com
TECHNOLOGY EDITOR: **JEFF KERNS** jeff.kerns@informa.com
ASSOCIATE EDITOR/COMMUNITY MANAGER: **JEREMY COHEN** jeremy.cohen@informa.com
ASSOCIATE EDITOR/COMMUNITY MANAGER: **ROGER ENGELKE** roger.engelke@informa.com

INDUSTRY COVERAGE:

FASTENING & JOINING, PACKAGING, MANUFACTURING: **STEPHEN J. MRAZ**
MOTION CONTROL, CAD/CAM, FLUID POWER, MECHANICAL: **CARLOS GONZALEZ**
3D PRINTING, MATERIALS, ELECTRONICS/ELECTRICAL: **JEFF KERNS**

ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@informa.com
CONTENT DESIGN SPECIALIST: **JOCELYN HARTZOG** jocelyn.hartzog@informa.com
CONTENT & DESIGN PRODUCTION MANAGER: **JULIE JANTZER-WARD** julie.jantzer-ward@informa.com

PRODUCTION

GROUP PRODUCTION MANAGER: **GREG ARAUJO** greg.araujo@informa.com
PRODUCTION MANAGER: **SAM SCHULENBERG** sam.schulenberg@informa.com

AUDIENCE MARKETING

USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@informa.com
INFORMA REPRINTS: **WRIGHT'S MEDIA** **T** | 877.652.5295
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DIGITAL

GROUP DIGITAL DIRECTOR: **RYAN MALEC** ryan.malec@informa.com
CLIENT SUPPORT MANAGER: **KIM BLASKI** kim.blaski@informa.com

SALES & MARKETING

MANAGING DIRECTOR: **TRACY SMITH** **T** | 913.967.1324 **F** | 913.514.6881 tracy.smith@informa.com

REGIONAL SALES REPRESENTATIVES:

AK, AR, AZ, CA, CO, HI, IA, ID, IL, IN, KS, KY, LA, MI, MN, MS, MO, MT, ND, NE, NM, NV, EASTERN OH, OK, OR, SD, TN, TX, UT, WA, WI, WY, WESTERN CANADA: **PAUL MILNAMOW** paul.milnamow@informa.com **T** | 312.840.8462 **F** | 913.514.3957

DE, MD, NC, NJ, NY, WESTERN OH, PA, SC, VA, WV:
BRANDY BISSELL brandy.bissell@informa.com **T** | 234.678.8401 **F** | 913.514.6357

AL, CT, FL, GA, MA, ME, NH, RI, VT, EASTERN CANADA:
LIZ STOTT liz.stott@informa.com **T** | 857.636.9737 **F** | 913.514.6914

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ITALY: **DIEGO CASIRAGHI** diego@casiraghi-adv.com

PAN ASIA: **HELEN LAI** helen@twoway-com.com **T** | 866.2.2727.7799 **F** | 866.2.2727.3686

DESIGN ENGINEERING & SOURCING GROUP

EXECUTIVE DIRECTOR, CONTENT: **KAREN FIELD** karen.field@informa.com
VP OF MARKETING: **JACQUIE NIEMIEC** jacquie.niemiec@informa.com

INFORMA MEDIA INC.

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News

8 of ASME's Space Age
Milestones in Mechanical Engineering

The American Society of Mechanical Engineers has recognized eight spacecraft and test facilities as landmarks in engineering.

Mechanical engineers played a pivotal role in the Space Race, designing engines, structures, and components, as well as test facilities that helped propel the U.S into space and to the Moon and beyond. Here's a look at some of them.

PROPULSION WIND TUNNEL AT ARNOLD AFB (1955)

The wind tunnel at Arnold Air Force base was the first large-scale facility for testing jet and rocket engines in simulated high-speed flight conditions. It ended up combining transonic (1955) and supersonic (1960) tunnels with both using a common 236,000 hp drive, the world's largest when it was built. It can replicate air speeds of Mach 4.75 at altitudes up to 150,000 ft in its 16 ft^2 test sections. The tunnels were designed to test full-scale engines, large aircraft models, or large and full-scale missiles. It has contributed to nearly every major U.S. military aircraft and it hardware. That included the Titan ICBM, Mercury program escape tower, SRAM-A missile, MCX ICBM models, and the NASA shuttle orbiter.

ATLAS LAUNCH VEHICLE (1957)

America's first launcher was the Atlas E-2 Space Booster, a modified ICBM developed by engineers at the Convair Div. of General Dynamics and the U.S. Air Force. The first of its more than 500 flights was in June of 1957. After that, it was responsible for launching the Pioneer, Ranger, Mariner, and Surveyor, as well as the first communication satellite. Many payloads were sent into orbit as detachable sections of the Atlas. And in 1962, John Glenn road atop an Atlas to become the first American to orbit the Earth.


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RL-10 ROCKET ENGINE (1958)

The RL-10, the first rocket engine to use high-energy liquid hydrogen as fuel, began development at Pratt & Whitney in the fall of 1958. By November of 1963, a pair of them boosted a Centaur space vehicle into orbit. Two months later, a cluster of six RL-10 took part in the first test flight of the Saturn S-IV stage. The engine generates 15,000 lb. of thrust and has the highest specific impulse of any operational rocket engine. Among the innovations it pioneered was the bootstrap cycle, in which the fuel was used for several purposes before being burned. In the RL10, icy cold hydrogen circulated around the thrust chamber, cooling it and preventing the 5,000°F temperatures inside from damaging anything. Then it was expanded through a turbine into a high-pressure gas to power the fuel pumps and drive engine accessories. The engine can also be restarted several times in space (seven times in one mission), and be throttled to less than 10% of rated thrust. It was used on more than 140 flights to take satellites and payloads into orbit. It never failed.

ADVANCED ENGINE TEST FACILITY (1964)

NASA's Advanced Engine Test Stand was designed by ex-Nazi Werner von Braun to do testing on the Saturn V rocket's booster engine, but it has since been used for a host of other rocket engines, including those used on the space shuttle. The 400-ft structure stands on four partially hollow concrete legs, each four-feet thick and 144-ft tall. These legs required 12 million lb. of concrete to construct. There are instruments inside the legs that monitor


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850 engine parameters during firing. The structure includes a 200-ton crane and boom sitting 144 ft up. The test stand can withstand 12 million pound of thrust, and a 1,900-ton flame deflector keeps the structure and surroundings safe. The deflector has more than 387,000 holes, each 5/32 of an inch in diameter, and during tests, 237,000 gallons of water were pushed through these holes to keep the deflector cool. The water is pumped by 13 diesel engines, each using its 2,577 hp to pump 21,000 gallons per minute.

SATURN V ROCKER (1967)

The Saturn V was the first purpose-built rocket, and its purpose was to carry the 45-ton Apollo spacecraft to the moon and back (which it did—several times). It also put the 120-ton Spacelab into orbit. The three-stage rocket stood 363 ft tall and weighed about 6.1 million lb. when loaded. It carried out 13 missions between 1967 and 1972, and the Saturn program racked up charges of about $7 billion. Three unused Saturn Vs are on display at NASA centers in Florida, Alabama, and Texas.

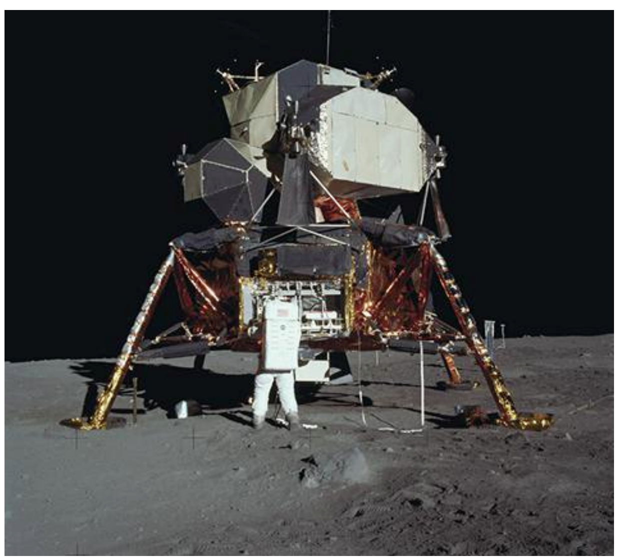
APOLLO SPACE COMMAND MODULE (1968)

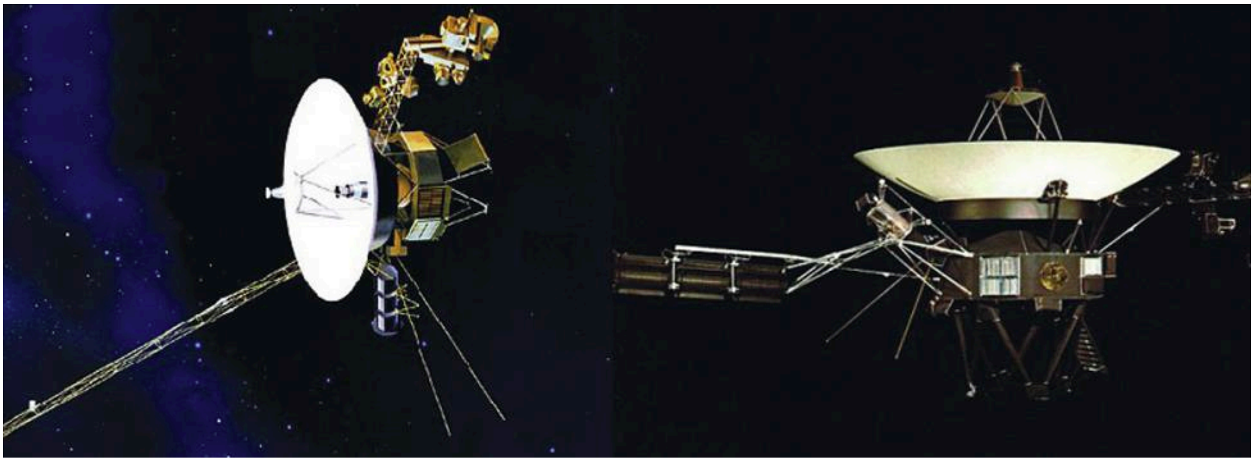
The Command Module, built by North American Aviation, was the section of the Apollo spacecraft in which three astronauts lived and operated the missions that took them from Earth to the moon orbit and back. It is the only part of the entire spacecraft that came back to Earth in one piece. This means it was the only part of the ship that needed to survive

the wicked heat of the re-entry to Earth's atmosphere at 25,000 mph. The crew had 210 ft^3 that was kept at 70 to 75°F and a pure oxygen atmosphere pressurized to 5 psi. The oxygen proved a problem on Apollo 1 while it was being tested on the ground prior to launch. A fire got started, and the three astronauts—Virgil "Gus" Grissom, Edward White, and Roger Chaffee—were killed. The module was redesigned for future flights, though it still used pure oxygen in space.

APOLLO LUNAR MODULE LM-13 (1968)

Like the last two ASME milestones, this one—the Lunar Module (aka Eagle)—was critical in putting a person on the moon. Built by Grumman Aircraft Engineering Corp., it carried two astronauts from lunar orbit down to the moon, and





then a portion of it launched from the moon to rendezvous and dock with the command module. It served as shelter and base for two astronauts as they explored the moon and carried a variable-thrust engine for descent and a fixed-thrust engine for launch. Engineers wrestled with constant compromises between weight, available space, and performance requirements while designing the lunar module. For example, to save space and weight, there were no seats. The astronauts could access the controls, see out the windows, and navigate while standing up. The gravitational loads were minimal, so they could also sleep while standing, if necessary.

VOYAGER I AND 2 SPACECRAFT (1977)

Voyagers 1 and 2 are identical spacecraft designed for five-year missions to explore Jupiter and Saturn, and both launched in the late summer of 1977. *(In the illustration above, Voyager 1 is on the left and Voyager 2 on the right.)* Each 1,825-lb. spacecraft carries three thermoelectric generators powered by the radioactive decay of plutonium. They also each have three computers and an array of sensors (detecting visual, IR, UV, plasma, cosmic rays, charged-particles, and magnetic fields signals). After their missions were over, engineers and scientists kept working on them; they have continued to operate and send back valuable data ever since—for almost 40 years now. Both are now leaving the solar system, having already explored Jupiter, Saturn and its rings, Uranus, Neptune, and the 48 moons of these planets. ■

NEW MEMORY METAL Allow Wings to Take Shape in Flight

The subscale testbed PTERA flies over NASA Armstrong Flight Research Center in California with the outer portions of its wings folded 70 deg. upward. The aircraft took off with its wings at 0 deg. deflection, keeping them level during takeoff. The wings were folded during the flight using a thermally-triggered shape memory alloy, developed at Glenn Research Center and integrated into an actuator at Boeing Research & Technology. This technology would alloy pilots to fold their aircraft's wings to different angles to adapt to multiple flight conditions for aerodynamic benefit. *(Credit: Area-I Inc)*

THE NASA PROJECT Spanwise Adaptive Wing (SAW) has been around for a few years. The idea is to control outboard wing tip positions as much as 75 deg. to meet optimal demands in landing and takeoff, as well as flight. Folding wings in has been studied on aircraft in the past, including the North American XB-70 Valkyrie in the 1960s. Yet, to fold wings in flight requires heavy and bulky conventional motors and hydraulic systems, which are burdensome to the aircraft.

The SAW concept allows for aeronautical engineers to create airplanes that have smaller vertical tails by installing adjustable tips on the aircraft's wings. These tips can be positioned upward or downward to assist in takeoff, flight, and landing. The SAW project took another step forward in creating a successful application case by adopting a new lightweight material known as shape memory alloy (SMA).

SAW is a joint effort between Armstrong, NASA's Glenn Research Center in Cleveland (GRC); Langley Research Center in Virginia; Boeing Research & Technology in St. Louis and Seattle; and Area-I Inc. in Kennesaw, Ga. The SAW researchers intend to use the shape memory alloy to obtain several aerodynamic benefits while they fold wings. The alloy will be built into an actuator on the aircraft. The actuator is vital to the moving parts on the airplane. It can fold the outer portion of an aircraft's wings in flight without putting strain on the hydraulic system. This help the system weight up to 80% less than traditional systems.

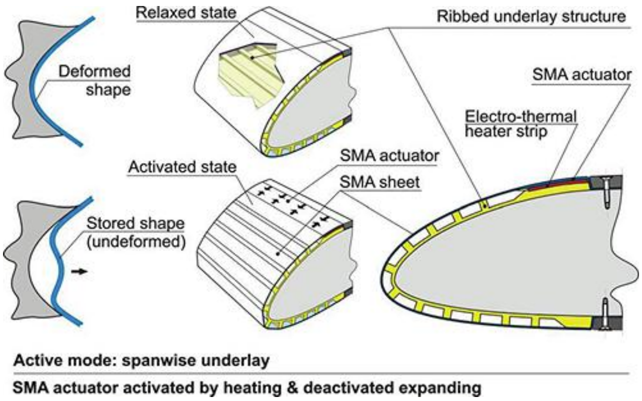
Shape memory alloys have two distinct crystal structures or phases. Temperature and internal stresses determine the phase of the SMA and its super-elasticity. Martensite exists at lower temperatures; austenite exists at higher temperatures. At low temperatures the SMA is in martensite form and can easily be deformed into any shape. As the alloy is heated, it transforms from martensite to austenite.

In the austenite phase, the memory metal retains its previous shape from before it was deformed. Memory alloys also have great rates of super-elasticity. Austenite is not stable at room temperature, and because systems always seek lower energy states, the austenite will change back to the martensite phase—and to do this, the arm must bend back.

A common example of an SMA are eyeglass frames that exist in the martensite phase. Bending the arms in half at room temperature introduces a phase change at the bend to austenite. The most common SMA is NiTinol, which consists of equal parts nickel and titanium.

The shape memory alloy used by NASA for their test is triggered by temperature. It works by using thermal memory in a tube to move and function as an actuator. When the alloy is heated it activates a twisting motion in the tubes, moving the wing's outer portion up or down. The GRC developed the initial alloy material, working with Boeing to employ the alloy with an actuator in flight.

NASA used the remotely-controlled flight testbed Prototype Technology-Evaluation Research Aircraft (PTERA) to test the SMA. PTERA was designed and built by Area-I, which helped design and integrate a shape memory alloy-actuated, wing-folding mechanism for the aircraft. The PTERA is a small-scale UAV that features extensive flight instrumentation for data gathering and can accommodate newly-designed wings for testing.



The Spanwise Adaptive Wing concept seeks to enhance aircraft performance through allowing the outboard portions of wings to adapt, or fold, according to different flight condition demands. NASA engineers believe this could create lateral-directional stability and reduce drag. *(Credit: NASA)*

Shape memory alloy has several possible aerospace applications. Along with being used as a method for wing folding during flight, it has also been proposed to be used for deicing and anti-icing. Its shape changing properties can be used for ice removal when required. *(Credit: "An Overview of the Deicing and Antiicing Technologies with prospects for the Future," by Zdobyslaw Goraj)*

The SAW test flights were conducted over two days. The PTERA took off with its wings at a level, zero-degree deflection, and during flight maneuvers, the onboard controllers heated and cooled the SAW actuators. The actuators folded the wing panels to different angles between 0 and 70 deg. For the first two flights, the wing tips were rigged to fold downward. Later flights featured rearranging the aircraft hardware to fold the wings in a 70-deg. upward deflection. Each wing-folding maneuver was achieved within three minutes.

The aerodynamic benefit of having foldable wings varies between subsonic and supersonic aircraft. For subsonic aircraft, such as drones or commercial airlines, the potential aerodynamic benefit of folding the wings includes increased controllability, resulting in a reduced dependency on heavier parts of the aircraft like the tail rudder. This creates a more fuel-efficient aircraft and allows long-winged aircraft to taxi in airports. The other added benefit is that pilots can take advantage of different flight conditions, including wind gusts.

With supersonic aircrafts, one of the most significant potential benefits is to achieve faster than the speed of sound flight. "There's a lot of benefit in folding the wing tips downward to sort of 'ride the wave' in supersonic flight, including reduced drag," said SAW Principal Investigator Matt Moholt. "This may result in more efficient supersonic flight.

"Through this effort, we may be able to enable this element to the next generation of supersonic flight," he continued, "to not only reduce drag but also increase performance, as you transition from subsonic to supersonic speeds. This is made possible using shape memory alloy." ■

HOW WILL 3D PRINTING Affect Import/Export in the U.S.?

WORRIED ABOUT YOUR JOB or the health of the U.S. economy? You don't have to be an economist to see that if a country exports less than imports, it could have a negative effect on the economy. As the Gross Domestic Product decreases, so does the number of jobs. Interestingly, the U.S. has been operating at a deficit for years. According to *Census.gov*, since 1976 we've been importing more than exporting.

The same site published: "For goods, the deficit was $810.0 billion in 2017, up from $752.5 billion in 2016. For services, the surplus was $244.0 billion in 2017, down from $247.7 billion in 2016."

So what can we do to help turn the tables? 3D printing.

A 3D-PRINTED ECONOMY

In a report titled "3D printing: a threat to global trade," ing predicts that printing good could cut trade between countries by 40%: "For now it has very little effect on cross-border trade. This will change once high speed 3D printing makes mass production with 3D printers economically viable. The first technical steps have already been taken…3D printers use far less labour, reducing the need to import intermediate and final goods from low wage countries."

Admitting that it is tricky to define the exact potential of 3D printing, ing said some experts expect a share of 50% in manufacturing over the next two decades. Depending on growth and investment the report suggested that 50% of manufactured goods will be printed by 2060 with current investment growth. This figure could possibly be achieved as early as 2040 if investments double every five years.

In addition, 3D printing is estimated to wipe out almost one-quarter of world trade by 2060 under scenario I (or two-fifths by 2040 under scenario II). This would largely affect the automotive industry. This might change the way car manufacturers and aftermarket conduct business. Not only are you eliminating logistics and import tariffs, 3D printing parts will affect the intellectual property. If you thought intellectual property was difficult now with 3D printing, wait until every local parts shop is able to access this technology.

Intellectual property is one of the largest U.S. service exports. This will affect industrial machinery, and consumer products are the other industries we can expect to suppress cross-border trade. These industries are the top investors in 3D printing. A little over 10 years ago, some were wondering if 3D printing was a fad. Today, investors might be able to predict what companies will increase or decrease revenue based on its investment in 3D printing.

BY THE NUMBERS

IP-intensive industries continue to be an important and integral part of the U.S. economy. A report from the United States Patent and Trademark Office (USPTO) identifies 81 industries (from among 313 total) as IP-intensive. These industries directly accounted for 27.9 million jobs in 2014, up 0.8 million from 2010.

The report noted that trademark-intensive industries are the largest in number and contribute the most employment, with 23.7 million jobs in 2014 alone (up from 22.6 million in 2010). Copyright-intensive industries supplied 5.6 million jobs (compared to 5.1 million in 2010) followed by patent-intensive industries with 3.9 million jobs (3.8 million in 2010).

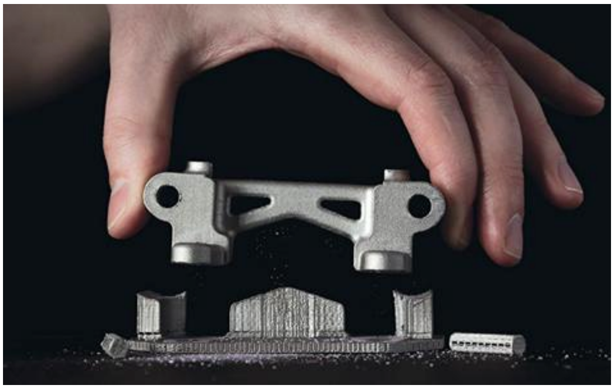
- Revenue specific to the licensing of IP rights totaled $115.2 billion in 2012, with 28 industries deriving revenues from licensing.
- Total merchandise exports of IP-intensive industries increased to $842 billion in 2014 from $775 billion in 2010.

So if the U.S. invests heavier in 3D printing, it would reduce its imports and theoretically increase our economy. However, this technology is also a double-edged sword. Since IP, aerospace, gas, and automotive are large contributors to the U.S.' exports, we might actually see a reduction in the exports of these markets.

Once a part is out in the field, there isn't much keeping someone from taking some measurements and pictures. 3D printing might make pirating parts easier. Part pirates would still have the ability to

The new Markforge carbon fiber printer is able to produce load-bearing parts that require high strength. In some examples, it is possible to print parts faster and cheaper than machining metal.

take measurements and pictures in the field, but they could also find or hack an online database that would streamline the IP stealing industry. As more companies use online services and storage, once a blueprint is hacked, or accidentally emailed to the wrong person, there is no taking it back. Even if a company wanted to take legal action, with things like the dark web, it will be increasingly difficult to get the design back under the control of the IP's owner.

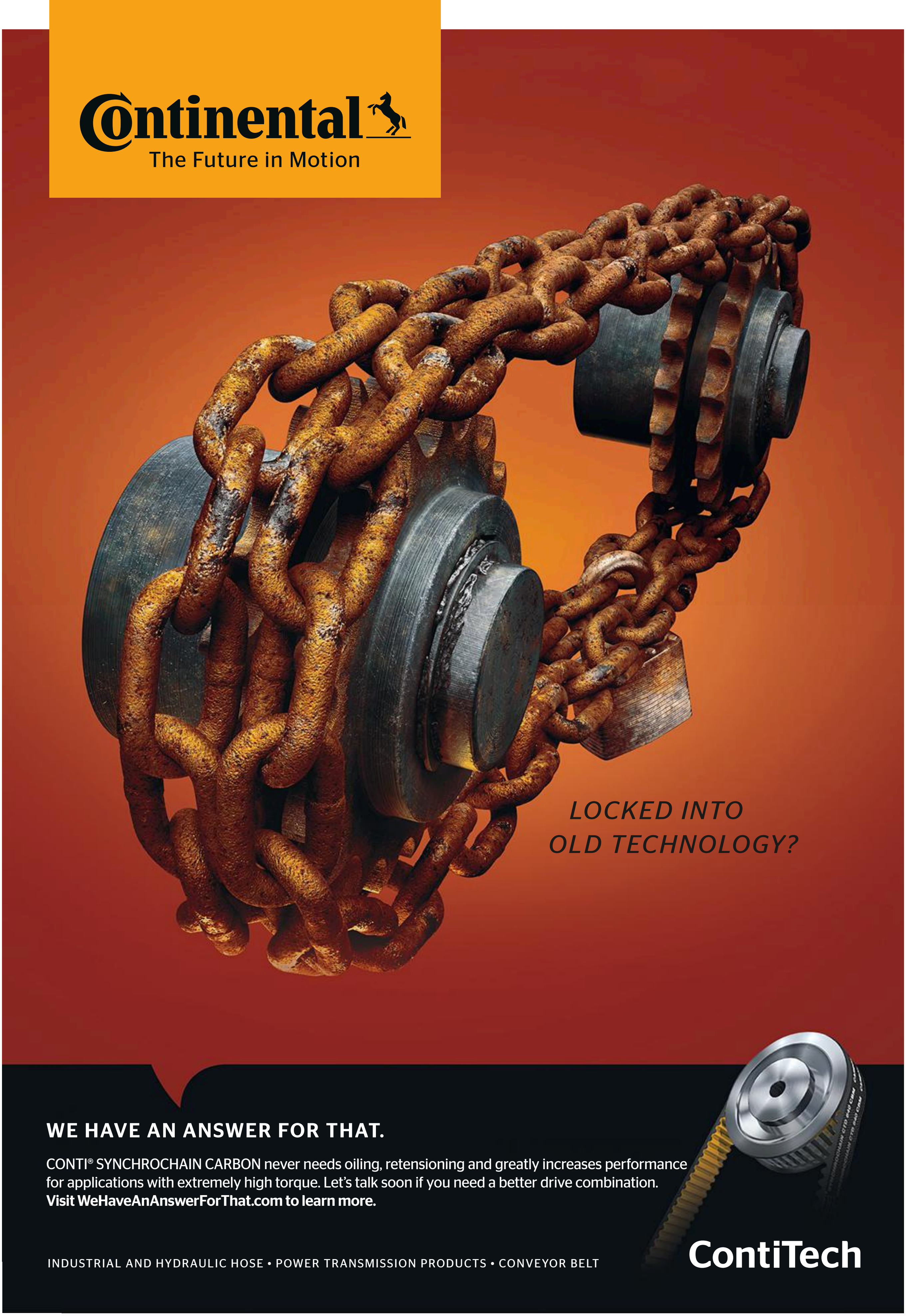


The new Desktop Metal metal 3D printer uses powder metallurgy to print quickly and sinter parts in one step. In one example, an impeller was printed using a laser-based printer and the new Desktop Metal. In the time it took the laser based printer to produce 12 parts, Desktop Metal made more than 500.

Additionally, this will make things harder for emerging markets, companies, or countries, but again the focus will have to be where the money is: design. From *inside3dprinting.com*: "Global trade could become a thing of the past if 3D printing reaches a tipping point," said Maxime Alimi, head of investment strategy for AXA Investment Managers in France. "The digital economy jeopardizes the development model of emerging markets entirely. If the export model is no longer available, it will become a lot more difficult for a market to emerge in the next decade—an issue that would greatly affect still-emerging countries in Africa."

NOT ALL BAD NEWS

If proper investments are made in 3D printing and international agreements, it is possible to mitigate the bad and magnify the good. By focusing on IP, design, and cybersecurity, companies that find a way to make it easier and more cost effective to gain access to prints or parts legally will thrive. This will help develop easier-to-use online tools and 3D printers, as well as accelerate new designs. If a part is hacked, a company would be smart to upgrade the design. While some equipment might remain in operation for many years, it is impressive to see how new features and upgrades make old parts useless.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To minimize cost and maximize benefits, the U.S. must invest properly into technology. While 3D printing is new, the economy game is the same. The government already knows the importance of IP, and like many other industries, the U.S. needs to be on the leading edge with technology and grab the IP surrounding it. You can debate on the ethics or philosophies, but this is the main driver. And this new driver is obviously mitigating the technology to be user-friendly so it is easier to buy than steal. However, this is easier said than done, as the music industry—one of the first industries exposed to pirating—found out more than 18 years ago.

Porsche is one company starting to adopt 3D printing. To help its aftermarket, the automaker is focusing on its classic and rare parts that are difficult to get a hold of. Porsche identified 52,000 parts that could breathe life into some of its classic models if there was a way to reproduce parts in a cost-effective, low-volume manufacturing process. 3D printing these difficult-to-get parts is great for collectors, and as the technology expands, more common parts may be produced this way that will change the aftermarket and accessory automotive business.

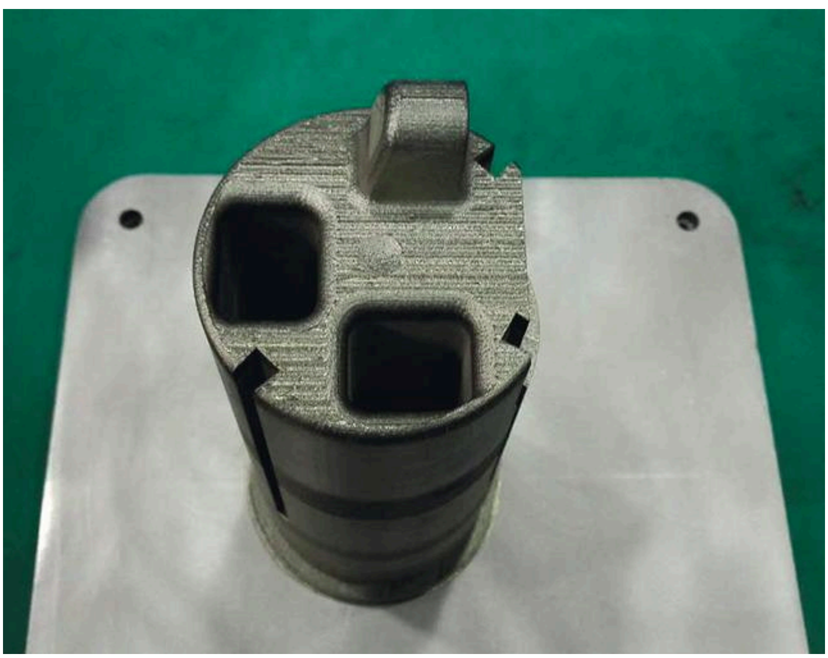
To keep up with automation and customization, parts companies that offer online ordering and estimates for specific and custom parts will excel. Many of the prototyping and low-volume manufacturers already have this software, and some have said you couldn't compete in this type of manufacturing without it.

For now it looks like we have time until 3D printing gains a large share in the shipping and logistics. However, companies that find a solution to these issues and develop a platform while the technology grows will stay ahead of the 3D-printed ball. ■

Most companies will only stock parts for so long, and pulling the tooling out for a short run can be difficult to justify the cost. 3D printing doesn't require any tooling and specializes in low-volume production.

3D PRINTING NOT YET READY to Disrupt Plastic Injection Molding

GORDON STYLES | President and CEO of Star Rapid



This core was 3D printed from steel at Star Rapid using a Renishaw AM 250 printer.

PRODUCT DEVELOPERS AND ENGINEERS who design and manufacture plastic parts now have a powerful new weapon in their arsenal: 3D printing. This disruptive technology has great promise for rapid prototyping and low-volume manufacturing, but is it ready to replace high-volume plastic injection molding using dedicated metal tools and dies?

The short answer: 3D printing is better used as a complement to plastic injection molding rather than as competition, though that may change. Here's where we currently stand and what the future may hold.

PLASTIC 3D PRINTING VS. INJECTION MOLDING

Plastic injection molding using dedicated tools and dies has been around since 1872, although it took until after World War II for it to really take off. That's

well over 100 years of development, so designers know how to dial it in for maximum efficiency in mass production. But there are still some limitations. The first of these is the design of the part itself. You can't make hollow walls, for example, and internal threads can only be made with inserts that must be unloaded from the molds and parts after each cycle.

The advantage of 3D printing is that it can make these and other previously impossible or impractical geometries, as well as internal-lattice structures, with optimal strength and low weight. These are huge engineering advantages that can't be done conventionally or without high costs. But 3D printing takes much longer per part and is only commercially viable for a relative handful of parts. Once volumes increase, plastic injection molding is currently the only way that makes financial sense for many types of parts. Also, the surface finish quality of 3D parts is (so far) pretty poor, but that's one area that's rapidly improving.

We are also seeing improvements in how quickly near-net finished parts come out of printers such as HP's Jet Fusion line. These improvements have not matched initial expectations, though eventually some company will work all the bugs out of this process. But for now, 3D printing will remain viable only for low-volume bridge production or rapid prototyping.

3D PLASTIC PRINTED INJECTION MOLDS

It is possible to make injection mold tools using 3D printing, albeit with some caveats. There are definitely limitations in durability, for one thing. Plastic molds might be good for—at most—100 shots, and usually much less. There are also major tradeoffs in gate design and location, and tool-wall thickness must be increased to provide more strength.

That said, operators can put an aluminum resin "skin" coating over the tool to increase wear life, and this makes the entire build process much faster and cheaper than using a true aluminum tool. For short runs of basic part shapes, this might be a viable niche solution.

3D METAL PRINTING AND CONFORMAL COOLING

The highest potential for improving part quality and speed lies with metal 3D-printed, conformally-cooled injection mold tools. Right now, the vast majority of conventional tools uses line-of-sight cooling channels machined out of aluminum or steel cores and cavities.

These are relatively straightforward to manufacture, but they are inherently limited in their ability to follow the geometries for complex parts. As such, cooling efficiency decreases, with corresponding increases in cycle times (and therefore, costs). Part quality can also suffer with sink marks, weld lines, and distortions caused by unbalanced heat transfer in the mold.

A plastic injection mold tool made with 3D printing uses cooling channels that conform closely to the shape of the cavity. These channels deliver water exactly where it's needed for maximum efficiency, and in the right volume.

It took complex modeling software to determine the best architecture for internal, conformal cooling channels for this cylinder.

Conformal channels printed this way can have different cross-sectional sizes and shapes at different points along their lengths as necessary, and also be printed close to the tool wall. The results of this improved cooling are drastically reduced cycle times and significantly improved part quality.

To get the most out of this innovation, tooling engineers will need to become more familiar with sophisticated mold-flow analysis to model heat transfer. Also, printing such a tool successfully is a complex operation that requires another skilled engineer operating a 3D printer the can create metal parts. Tool size will be limited to the size of the print bed, which is smaller than conventional CNC machines allow.

Also, there are fewer raw materials to choose from. Taken together, 3D printed injection mold tools are likely to be more expensive than their conventional counterparts, but these costs can be recovered over a long production runs due to faster cycle times and better parts.

OUTLOOK FOR 3D PRINTING AND PLASTIC INJECTION MOLDING

The relationship between 3D printing and plastic injection molding is complicated. The 3D printing conformal cooling channels in metal parts proves the two technologies can be complementary to each other. However, many still hope plastic 3D printing advances to the point it becomes a true high-volume production method that absorbs a bigger share of the plastic injection molding market. All we can do is wait and see what's in store as these technologies continue to be improved over the years to come. ■

GORDON STYLES is president and CEO of Star Rapid (www.starrapid.com), a company that specializes in rapid prototyping, rapid tooling, and low-volume manufacturing of custom parts.

SAFETY TIPS for 2018

FOR SEVERAL OF the major buzz topics floating around the last few years, 2018 may be the year these innovations finally take hold. To wit: Several companies are starting to implement smart automation, sensors, big data analytics, and cloud computing.

However, several of the same problems that have persisted in the past will still plague us in 2018. The labor shortage is ongoing, as are security concerns—especially in the cyber realm. The globalization of several industries will be challenged as many companies will rely on partnerships to succeed.

With the implementation of the Internet of Things, learning how to deal with big data and the best way to analyze said data will be a pressing concern. And lastly, how does one future-proof their systems to handle new innovations as they arise?

To help guide you through these concerns, Rockwell Automation *(http://bit.ly/2DrvYx3)* has compiled a list of nine tips to help achieve improvements in safety and productivity.

IMPROVE YOUR SAFETY MATURITY

Safety maturity is a combination of culture (behavior), compliance (policies and procedures), and use of capital (technologies). Studies show that the top 20% of manufacturers achieve 5 to 7% higher overall equipment effectiveness, 2 to 4% less unscheduled downtime, and less than half the injury rate of average performers. These top companies are not only leading the way but are extending that lead over competitors.

A survey from LNS Research *(http://www.lnsresearch.com/)* found that 75% of industrial companies have seen operational improvements from the use of advanced safety technology. The leading companies see safety as a key element in their business plans. They use contemporary safety methodologies to achieve such a high standard.

To achieve a high safety maturity, start by assessing your own safety maturity level and see how you compare to some of the companies at the top. Understanding what your performance level is and which areas are in need of improvement is critical to optimizing safety.

ADDRESS SAFETY AND SECURITY TOGETHER

Cyberthreats will increase as companies increase the connectivity of their operations. The IoT brings more sensing capability and with data analytics a better understanding of one's systems. However, it also opens the door for more threats as devices are being connected directly to the internet.

Organizations should be reviewing their security risks in relation to their safety risks. By integrating safety and security programs, companies can assess, manage, and mitigate the safety implications of security risks.

IMPROVE COLLABORATION

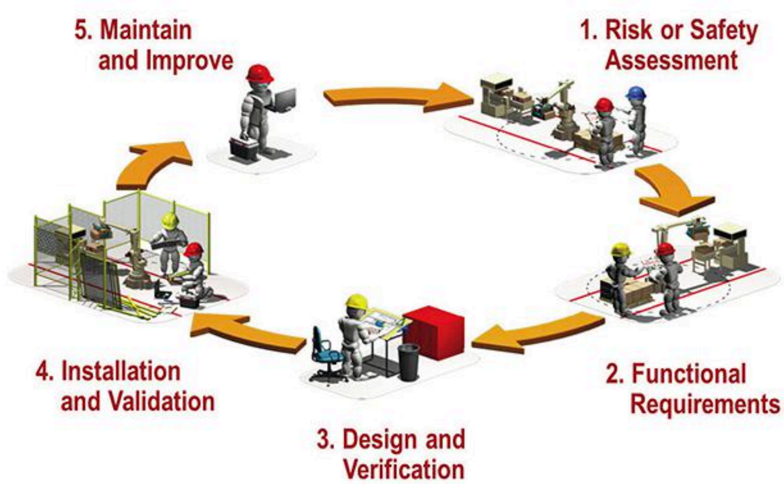
Environmental, health, and safety (EHS) programs are responsible for workers safety. However, the EHS programs only directly control the least effective machinery safety methods. Engineering teams focus on technical standards and control the most-effective machinery safety methods. Both groups usually have a hard time working together, which results in reduced safety and productivity.

The key element for safety maturity is collaboration between different groups. According to LNS Research, companies that have high collaboration between operations, engineering, and safety groups experience a 15% lower median incident rate.

PERFORM RISK ASSESSMENTS EARLY

Many times when we design a product, we worry about its safety toward the end of the design. This is a common practice as many companies build first, test for falls, and then redesign. However, by performing a risk assessment early in the design process, several risks can be designed out.

Studies show that 60 to 70% of safety incidents occur outside of normal operating mode. These take place during maintenance, repair procedures, or other non-routine behavior. Performing a risk assessment early in the design process—and then again after the machine is in place operating at its location—can help verify compliance, safety, and productivity.



The diagram above from Rockwell Automation highlights its safety cycle from early risk assessment to installation and maintenance

ERGONOMIC DESIGN FOR MACHINES

Our labor force is aging. Older workers are at a high risk for musculoskeletal and repetitive stress injuries, which can often be chronic or career ending. On the other side of spectrum, young and inexperienced workers are at higher risk for acute injuries due to their lack of knowledge. Modern machinery must be constructed with the ability to adapt to a broad range of workers. For new machines, features to consider include ambidextrous features and reducing repetitive motion, lifting, and awkward placement of the body.

LOCK-OUT/TAG-OUT ALTERNATIVE MEASURES

U.S. and Canadian safety standards require lock-out/tag-out during machinery servicing to prevent unexpected start-up, energization, or release of stored energy that could cause injury. In practical terms for the worker, that means performing the lock-out/tag-out process several times per day for servicing events, such as regular cleaning and maintenance, which causes exhaustion and can lead to injuries.

Safety should not come at the expense of productivity. Written within the safety standards, alternative safety measures can be used for minor service when the procedures are routine, repetitive, and integral to the use of the equipment. When used correctly, these measures can improve productivity by reducing LOTO-related downtime.

The minor-service exception should never be used as a safety workaround, and a proper risk assessment is still required. For reference, see these key standards on how to perform alternative measures.

- ANSI/ASSE Z244.1 – Control of Hazardous Energy – Lockout/Tagout and Alternative Methods
- CSA Z460 – Control of Hazardous Energy – Lockout and Other Methods

MACHINE SAFETY STANDARDS

Document title	Description
EN ISO 13849-1	Safety-related parts of control systems: Principles for design
EN ISO 13849-2	Safety-related parts of control systems: Validation
EN IEC 60204-1	General requirement for electrical equipment of machines
EN IEC 61508	Functional safety of electrical/electronic/programmable electronic safety-related systems
EN IEC 62601	Functional safety of electrical/electronic/programmable electronic safety-related systems (based on 61508)
EN ISO 11161	Integrated manufacturing systems
EN ISO 12100-1/EN ISO 12100-2	Governs safety of machinery. Part 1 describes basic terminology, while Part 2 lists technical principles and specifications.
EN ISO 14221	Defines risk assessment
IEC 61784-3	Safety networks

Above is a list of machine safety standards that can serve as a reference to engineers who work in industrial settings.

USING THE POWER OF THE IoT

Interconnecting your equipment not only provides you with more data and faster control, but also provides a better safety network. Before, if a machine required service, it may have only been caught when the engineer would survey it for scheduled inspection or maintenance. This could mean days with faulty running equipment. Now with connected networks, such as the Connected Enterprise from Rockwell, failure can be detected the minute it occurs. Sensors can capture vibration, fluid leaks, or abnormal rises in temperature, all indicators of machinery malfunction. Connected device provide safety professionals with a real-time understanding of worker behaviors, machinery compliance, causes of safety shutdowns or stoppages, safety anomalies, and machine trends.

Along with connected networks are smart devices. New smart-safety designs and devices can reduce design costs and unscheduled downtime. Smart devices, along with connected networks, allow for engineers to implement predictive maintenance feedback. Smart devices also regulate access to only authorized and trained personnel, which improves productivity, safety, and security.

INTEGRAL SAFETY IN CONTROL SYSTEMS

Besides having the latest safety-rated inputs, logic, and output devices, your control systems should also be designed with the latest safety software. There are several risk assessment software options currently available that allow engineers to design effectively, helping to streamline the process and gain compliance. An example of such software is RASWin from Rumsey, a subscription-based application that helps manage progression through the safety lifecycle. Safety function documents can also help implement machinery safety functions, including safety-performance calculations, wiring, programming, verification, and validation.

BUILD YOUR SAFETY EXPERTISE

At the end of the day, people are in charge of making the decisions with regard to safety. You may have all the warnings and indicators in place, but without the proper personnel to execute the safety plans, you may be no better off than before. Companies need engineers with a deep understanding of current safety standards and knowledge of productivity-enhancing safety system design processes and technologies.

There are two ways to acquire the right safety people. The first is to train your existing team. Bring your safety workers up-to-date to the latest safety standards available. The other way is to hire trained professionals. The TÜV Rheinland Functional Safety Training Program is good place to start. It is the only worldwide extended vocational training program in the area of Functional Safety. The students' knowledge and competencies are approved of by a third neutral party which certifies the training. Look for applicants who have this certification or, better yet, sign up your current employees to advance their education. ■

CLOSING THE SKILLS GAP with In-House Robotics Expertise

DAVID MALTAIS | Robotiq

SKILLED MANUFACTURING WORKERS are becoming more difficult to find over time. In one of Bucharest, Romania's main plants, Assa Abloy (AA) Romania, the skills gap is widening every year. The factory's management invested in robotics to automate simple tasks and fill value-added positions with their actual workers. This generated in-house robotics expertise that set an example for the whole AA group.

A walk into AA Romania's factory may seem endless. About 500 people work here, assembling locks that are sent to its factories worldwide, where they're transformed into finished products. Tons of different processes are performed, most of them manually by employees who have been working there for decades.

Through the alleys, young faces are a rare sight. "The unemployment rate in Bucharest is very low," says Adrian Iosif, a mechanical design engineer at the company. "Manufacturing work is not a desired place for most of the people. It's very hard for us to find workers."

In the fall of 2015, the time to break the status quo had come. AA plants across Europe, the Middle East, and Africa were asked by the company's global management to develop robotics projects that would improve productivity in their factories. Due to its lack of personnel, the Bucharest factory rapidly emerged as a leader in robotics for the AA group.

The facility started by automating the most simple and repetitive processes. "We wanted to automate the welded assembly between a front plate and a case," explains Iosif. "There used to be an operator who put both parts together manually. We had in mind to build a flexible cell that could handle lots of parts at lots of stations."

A COLLABORATIVE SOLUTION FOR HIGH-/LOW-VOLUME PRODUCTION

Collaborative robots rapidly emerged as a top solution. Iosif reached out to Razvan Isac, from local cobot distributor Robotsnet, to give this technology a try. "We were in discussion with AA for some small application project in the beginning," says Isac. "We decided to lend them a Universal Robots model for one month. Since then we had very positive feedback from their side."

"We also needed flexible end-effectors to suit our high-mix, low-volume production," says Iosif. "We found an electrical gripper, made by Canadian company Robotiq, which adapts to parts of many different sizes and shapes. We also bought their wrist camera to locate parts. Anytime there is a new lock to assemble, I teach this new part to the camera. I can teach as many parts as I want. Then I choose which part I need, and that's it—I changed the production."

LOCATE, PICK AND PLACE TWO PARTS IN 20 SECONDS

Iosif wanted to automate the setup of a welding assembly that used to be done by a human operator. This included locating the front plate, placing it in the welding machine, picking the case, and placing it correctly over the plate on the fixture. Finally, the operator would press the button for welding. Beating this time with a robot wouldn't be easy.

The robot must detect a case on a table with its camera, grip it, and put the case in the welding fixture. Then the robot goes for the front plate and puts it on the fixture. After that, the command is given for the machine to weld.

Cobots are able to load and unload parts to and from machines. In some factories there isn't enough space to have robots that require safety enclosures.

At first the robot couldn't obtain faster cycle time than workers. Since it was so easy to program, however, Iosif and his team were eventually able to reach a 20-second cycle time. This would represent a 20% productivity gain while freeing human hands from a highly repetitive task.

This new process still requires a human presence (for now), but makes life a lot easier for operator Moise Nicolae. "At the beginning, I had some technical challenges with the robot," Nicolae recalls. "But after a bit of time it became really easy, and it's very simple to work with it. It's a big difference for me working with a robot because my task is much easier."

IN-HOUSE ROBOTICS EXPERTISE

While an operator is still required at AA Romania's first collaborative cell, tedious, repetitive tasks can be minimized or eliminated so workers are able to focus on more complex duties. Plus, each operator will eventually be in charge of two collaborative cells. This step into automation is the first of many for Iosif. He learned a bit about robots in his previous job and started working with collaborative robots on this project: "I didn't have programming skills, but I found it very easy—with logic knowledge—to program the robot, the gripper, and the camera.

"It is tough and expensive to find integrators in Romania. They have a different solution for every part," Iosif continues. "In our team, we have a manager and four engineers. We also have three students with us part-time and two technicians who help us build what we plan. The main role of the automation revolution happening here at the Romanian plant is to set an example for our colleagues in other plants in Europe.

"We have lots of opportunities in this factory, because it's a big plant and most of the work is done manually," he concludes. "The robots help us move our colleagues to the empty places that we have here in the factory."

For Isac, the AA case is a regular story in Romania, where manufacturing recruitment is a tough endeavor in which robots are used as backups: "This solution is an alternative. Factories don't buy a robot to replace people—they buy it because they cannot find people. I've never seen someone lose his job to a robot in Romania."

With man and machine working together more and more each day, adding to an economy that is more open to other markets than ever before, Romania now seems on the right track to fulfill its manufacturing potential. ■

DAVID MALTAIS is a public relations specialist at Robotiq. He travels the world looking for stories of manufacturers who overcame production challenges with robotics.

ROBOTS TACKLE 3D Waterjet Cutting for Aerospace

An abrasive waterjet controlled by a robot cuts a 3D part, a titanium blisk for a commercial jet engine. *(Courtesy of Shape Technologies Group)*

WATERJETS USE A STREAM of high-pressure water mixed with abrasives to slice through titanium up to a foot thick, under control of a six-axis robot that can maneuver the waterjet nozzle across the part, shaping the graceful contours of jet engine turbine blades and blisks (bladed rotors).

Traditionally, robotic waterjet has been more common for softer materials and other industries. More recently, though, it's been adopted by the aerospace industry for cutting metals and composites, as robots have proven to be durable and accurate enough to meet the demanding tolerances required by the aerospace industry.

One company in the forefront of this technology is Shape Technologies Group in Kent, Wash. It includes Aquarese, a firm that assembles waterjet cutting robots, including the only abrasive waterjet that shoots water out at 94,000 psi (6,500 bar). Flow International Corp. manufacturers the ultra-high-pressure pumps and waterjets used by Aquarese in its turnkey machines for the aerospace, energy, and automotive industries. The robots themselves are provided by Stäbuli.

Robotic waterjet cutters use an articulated arm with six degrees of freedom, letting the cutting nozzle approach the workpiece from virtually any angle. Once cutting, the nozzle follows a smooth, accurate, and repeatable toolpath to create precision cuts and contours. For metal cutting, waterjets typically rough-cut components which are then sent to final milling operations.

"One of the primary benefits of waterjet is that it's extremely versatile," says Dylan Howes, Shape's VP for business development. "You can cut metal, composites, glass, stone, paper, food…just about anything. With a waterjet, you can cut metal one day and cut foam the next day on the same machine."

Waterjets from Aquarese can cut titanium alloys, Inconel, Ni-based alloys,

Robotic waterjet cutters use an articulated arm with six degrees of freedom, letting the cutting nozzle approach the workpiece from virtually any angle. Once cutting, the nozzle follows a smooth, accurate, and repeatable toolpath to create precision cuts and contours.

A robotic waterjet cutter form Shape Technologies Group uses supersonic water and garnet (an abrasive) to slice through and shape a variety of metals, including superalloys, used in the aerospace industry. *(Courtesy of Shape Technologies Group)*

other superalloys, stainless steels, and composites. Abrasives must be added to the water, and garnet is the abrasive of choice for 99% of abrasive waterjets. Water and garnet are shot out of the nozzle (cutting head) at nearly four times the speed of sound.

Despite its power, waterjet machining is a cold-cutting process, so there's no heat-affected zone (HAZ) or thermal fatigue as there are in laser and plasma cutters. There are also no mechanical stresses on the part, so part integrity is not compromised and the fixturing needed is light compared to that needed for milling or conventional machining.

"Waterjet is more efficient than rough milling or wire EDM (electrical discharge machining)," says Howes. "It's much faster, has a lower operating cost, and produces large offcuts which are easier to recycle than the chips created by milling machines."

The waterjet process is chemical-free and environmentally friendly. The water, as well as any garnet used as an abrasive, can be recycled. "There are no hazardous fumes," he explains. "You can use closed-loop water systems. There's none of the dross waste you would find in a laser or plasma application.

"We use Stäubli robots because of their durability and path accuracy," Howes adds. "We worked closely with Stäubli to refine this process for our needs and it's been a great partnership."

(Continued on page 64)

TODD SCHWANGER | Global Product Manager, Southco, Inc.

Fastening and Positioning Technologies Conquer Lighting Challenges

Hardware developed for latches and enclosures easily adapts to accommodate lighting fixtures that now use LEDs and other light sources.

Lighting fixtures are one of the broadest classes of appliances—one that includes a wide range of applications and industries. Within the last decade, one of the most significant changes in these appliances has been the light source itself. In the past, most fixtures could handle either incandescent or fluorescent bulbs, and that was it.

The increased use of LED-based lighting, along with efforts to combine lighting with exterior and interior design schemes, is leading to new fixture designs. This gives engineers an oppor-

Light fixtures and appliances, even those that use the newer LEDs, can meet functional and industrial needs by being designed with modern fasteners and positioning hinges.

tunity to use a broad range of fastening and positioning mechanisms to improve the performance—not to mention, the visual and ergonomic appeal—of these devices.

Captive fasters, such as this 82 Dzus Lion Quarter, are great solutions for overhead light fixtures. They have a low profile and open simply with a quarter-turn, plus they cannot be over-tightened, so there's little risk of damaging the diffuser when installing them. In addition, the hardware is all connected so it cannot get lost or dropped.

TWO KEY ELEMENTS OF FUNCTIONAL DESIGN

Whether they are designed for outdoors; factories and warehouses; offices and residential interiors; or even architectural applications, most light fixtures have features that address access and position control. Access control secures lighting fixtures, such as latches or locks. Position control lets users to move, adjust, and point the light beam on a specific point or area of work or display. Some lights, once positioned, are fixed in place; many others need to be moved and pointed according to changing needs.

Most lights, whether on desks and workstations, or mounted flush to walls and ceilings, have enclosures that seal the light source from the outside environment. Some enclosures are clear-paned, while others have diffusers; what they have in common is the need to be routinely and easily opened and securely closed to change burnt-out lights or perform routine cleaning.

In addition, many desktop and workstation lights have positioning hinges so they can be aimed to light areas that need it. These lamps are supposed to be attractive, so designers search for ways to add positioning hinges without disrupting the design.

Access control and positioning components are typically the only "moving" parts of a lamp. As such, they are more than purely functional: They include design and performance characteristics that contribute to users' "touch point" experience. These characteristics can include:

- Being easy and intuitive to use.
- Providing tactile feedback when turned on or off or repositioned.
- Enhancing its perceived value.
- Increasing product reliability and durability.

By considering and evaluating these characteristics, designers can choose latches, hinges, and other components that help ensure the lamp offers users more value.

ACCESS CONTROL

Enclosed lighting fixtures, whether equipped with clear or diffuser panels, need access controls. There are wide range of clips and latches available for this from many suppliers due to the simplicity of easy opening and secure closing.

Simple access is important, especially to maintenance staff in large facilities such as warehouses, airplane hangars, and parking lots. If access hardware is too complicated, it can slow maintenance.

In addition, because many of the latest light sources operate for several years, it might be some time between when the light panels or fixture are opened. Therefore, latches, particularly those used outdoors, need to keep panels tightly closed against moisture for longer periods of time.

Finally, most designers want to combine form and function, so they want latches and hinges that fit cleanly into fixtures, with surfaces and materials that work well together.

Access controls take many forms; several of the most useful for lighting include:

Quarter-turn fasteners. The simplest option, these fasteners are secured to the frame and open and reseal with a quick quarter-turn. Being fastened to the lamp ensures there's no risk of lost components, so whenever the panel is opened, it can always be fully resealed when closed.

For lighting panels made of plastic or Lexan, quarter-turn fasteners can't be over tightened like a screw, potentially cracking the panel. Quarter-turn fasteners that have a set torque help ensure consistent operation over long periods of time.

In addition, these fasteners can require a special "key" rather than a standard tool to operate them. This helps ensure that only authorized personnel can access the panels.

Because they're quick and simple to operate, quarter-turn fasteners are good options for large, flat lighting panels, as well as other interior fixtures that must be secured.

Compression and draw latches. These latches are also effective devices at providing access to lighting controls. They are typically two-piece devices with a lever-like mechanism that securely latches a cover panel to the fixture's main body. One of their advantages is that they can adapt to cover any manufacturing variations between the cover panel and fixture. On industrial lights that are not as precisely fabricated as high-end interior lamps, the draw latch pulls the covering panel to a closed, tight seal.

Compression latches perform a similar function with a different mechanism. They hold a door, panel, or cover shut by using a cam, while also compressing a gasket around the inside of the door to seal out moisture, dirt, and dust. This makes them particularly well-suited for basic outdoor applications (parking lot lights, for example), as well as exterior architectural fixtures.

Both compression and draw latches can be easily modified to incorporate locks that need keys or special access tools to open—another advantage for outdoor lights.

Hinges and constant torque. The other major "moving" part of a light fixture is the panel hinge. Although relatively simple components, the latest hinges give engineers new options for stationary overhead lights, as well as floor and desktop lamps that are routinely repositioned and adjusted.

Constant torque hinges, for example, provide smooth operation and a wide range of possible light positions. One can be embedded in a desk lamp's pivoting joint, for example, where it lets users move and reposition the light, but it will then remain in place once they let go of it. The effort required to move the light lets it respond to a user's deliberate actions, but it will remain in place if just casually brushed.

On many lights designed to be repositioned, this capability is done with clamps or latches. These often do not provide the range of possible positions or the smooth, flowing motion that constant-torque hinges supply. Also, constant-torque hinges can be moved with one hand; there's no need to push a button or flip a lever to move it around.

In addition, constant torque hinges can be compact, letting them be cleanly and easily installed on lamps. They also deliver an extended service life, which is valuable for lamps on industrial workstations and anywhere constant movements and adjustments are common. Constant torque hinges provide repeatable and consistent motion and last much longer than hinges that use plastic bearings or wave washers to provide tension.

SELECTING COMPONENTS

Getting the right hardware for a light fixture depends to a large extent on where that fixture will be used. Here are some key factors in selecting the right device based on the environment:

Industrial. Quarter-turn fasteners for large, overhead fixtures keeps access reliable and simple. For overhead panels, constant-torque hinges prevent panels from dropping onto anyone accessing them when they are opened. The hinges also eliminate the need for lanyards that can get in the way during maintenance. If the factory or setting includes equipment that creates strong vibrations, engineers should opt for latches that compress panels together or look for hardware that compensates for misalignments.

Constant-torque hinges, such as Southco's ST Series, provide a constant and defined resistance through its range of motion. This lets a desktop lamp remain in any position without mechanical assistance. They are also compact, so they can be molded or bolted directly onto thin-profile housings to complement the design.

Quarter-turn fasteners for large, overhead fixtures keeps access reliable and simple. For overhead panels, constant-torque hinges prevent panels from dropping onto anyone accessing them when they are opened. The hinges also eliminate the need for lanyards that can get in the way during maintenance.

Draw klatches, such as Southco's Series 97, accomodate misaligned lighting panels and draw them tight when closing to compress gasketing around the edge, sealing the light source against the outside environment.

Outdoor. For outdoor applications, the main concern is that any access devices fully secure covers against threats like moisture and exterior corrosion. For keeping out water (rain, snow, ice, or fog), compression latches with IP65 ratings are usually required. Engineers may also want to specify hinges and latches made of corrosion-resistant stainless steel and/or includes powder-coated surfaces.

Architectural. Selecting the right hinge to precisely control where a lamp points and the beam lands is critical in larger fixtures that create lighting effects on buildings, as well as in smaller fixtures for interior lighting.

Residential/Office. As noted earlier, fixtures mounted overhead or on walls are typically covered or enclosed, making simple quarter-turn fasteners a good solution. They attach to the fixture and are nearly impossible to lose. For desktop lights, positioning hinges with one-handed, intuitive operation, built-in feedback, and smooth motion can add to the aesthetics and user appeal both of the lamps and the entire work area. md

JACOB PASO | Delta Computer Systems Inc.

Design Essentials: Synchronize Position and Force with an Electro-Hydraulic Motion Controller

By upgrading their motion control systems, multi-axis synchronization improves the productivity and quality of output and reduce maintenance problems compared to using older hydraulic technologies.

Hydraulics is great for lifting heavy loads and applying large amounts of force, but the same power that is required to exert a large amount of lifting or compression force can also do damage or produce waste if not controlled. A sawmill in British Columbia used a pair of 31-ft.-long hydraulic cylinders to operate a carriage that lifts log bundles into the mill *(Fig. 1)*, but the lifting carriage occasionally sustained damage by the hydraulic cylinders moving at different rates of speed.

In China, a 3,000-ton automotive body panel press *(Fig. 2)* failed to reliably keep the platen level during a compression cycle. In Indiana, a vehicle roof-crush test system *(Fig. 3)* needed to exert a precisely executed and documented amount of force up to 100 tons on a vehicle roof as large as that of a school bus in order to meet industry safety specifications.

1. The arms that lift bundles of logs out of the bay and into the sawmill is operated by two 31-in.-long hydraulic cylinders.

What's the common problem that design engineers needed to deal with in each of these applications? It is the precise synchronization of multiple hydraulic axes. In a machine whose functionality depends on coordinated motion, the lack of synchronization can damage the machine or damage the machine's output, or both.

2. The platen in the automotive panel press must remain level even as up to 3,000 tons of force are being applied.

3. The vehicle roof-crush test system is operated by four hydraulic cylinders at the corners that must apply up to 100 tons of synchronized target force.

What's the common problem that design engineers needed to deal with in each of these applications? It is the precise synchronization of multiple hydraulic axes. In a machine whose functionality depends on coordinated motion, the lack of synchronization can damage the machine or damage the machine's output, or both.

THE SOLUTION: SYNCHRONIZATION

Each of the shown applications used multi-axis synchronization to improve the productivity and quality of output and/or reduce maintenance problems compared to using older hydraulic technologies.

To improve the reliability of the log lifting operation, the sawmill managers upgraded the motion control system operating the arms. To fix the potential platen skewing problem, the automotive press manufacturer added cushioning cylinders at the four corners of the platen to ensure that it remained level during a compression stroke. And to control the vehicle roof crush test system, the design engineers in that company set up a test rig with four hydraulic cylinders working together to apply a tightly controlled amount of force.

All of these design teams added a new motion controller to their systems, a controller with special support for closed-loop control with the ability to link the motion of multiple axes. *Figure 4* shows a motion controller with special capabilities for synchronization and controlling both position and force in hydraulic systems.

SELECTING THE RIGHT TRANSDUCERS

Precise closed-loop control requires precise feedback. Cylinder position information for all three of the applications discussed here comes from linear magnetostrictive displacement transducers (LMDTs). Typically mounted in the cylinder itself, LMDTs are useful because they provide precise position measurements and don't require adjustment or homing steps at machine startup.

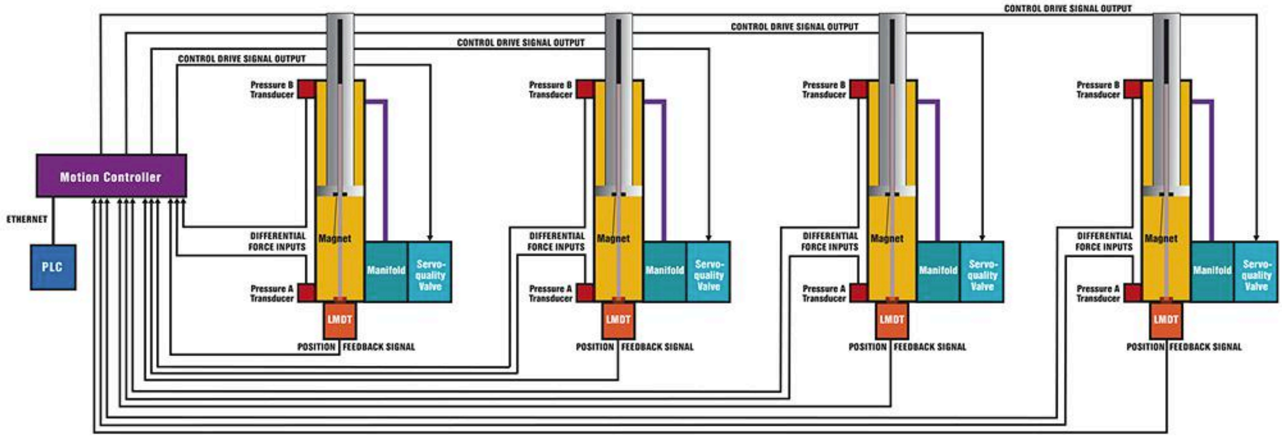
Pressure or force information is typically provided by load cells mounted at the end of the piston rod, or pressure transducers mounted in the cylinder on either side of the piston. In the event that pressure transducers are used, force applied by the cylinder can be calculated by computing the pressure difference between the sensors.

4. The RMC200 from Delta Computer Systems Inc. can control up to 32 motion axes simultaneously, plus it can serve as a data acquisition subsystem in test applications. A built-in Ethernet interface is provided for downloading motion programs or uploading motion status or test data from registers inside the controller.

The usual thought when designing a motion control system is that one needs transducers that offer just a little more resolution than what is required by the application's positioning or pressure requirements. This view may be correct for relatively simple applications involving continuous or start/stop motion, but it is often not true for those involving dynamic conditions. The need for finer resolution increases for applications requiring that accurate velocity or acceleration measurements be factored into the control algorithm. In synchronization or gearing applications—where the motion of a slave axis is proportionally related to that of a master axis—the master axis feedback should have as much resolution and accuracy as possible so the slave axis (or axes) can follow a smooth motion profile. Applications that move very slowly also need high-resolution feedback so that the motion controller can detect changes in position or force each time the control loop is executed.

SELECTING/SIZING CYLINDERS AND VALVES

No matter how much attention is given to motion controller selection and programming, fluid power system performance may be limited due to incorrect sizing or physical location



5. Each leveling cylinder is instrumented with a linear magnetostrictive displacement transducer (LMDT) to provide position feedback. Pressure sensors in the cylinders mounted on each side of the piston produce data which are differentiated to provide force feedback.

of fluid power system components. For actuators moving moderate to heavy masses, the acceleration, velocity, and deceleration are limited by the available force—not by oil flow. Since cylinder size determines the force that an actuator can produce, if the cylinder diameter is too small, the actuator may not be capable of attaining the desired speeds or cycle times required by the application.

Choosing the size (flow rating) of the valves is relatively easy once the correct size of the cylinder is identified. Servo-quality valves should always be used because they provide an infinitely variable flow of hydraulic fluid, and typically have a faster and more linear response than other proportional valves. Linear valves with a fast response are necessary for high-performance position/pressure control systems.

Old two-position "bang-bang" valves are not suitable for closed-loop control. They cause hydraulic shock and vibration, which results in machine maintenance problems. Of course, no valves perform perfectly, and a good motion controller is still required to compensate for the valve response and the mass and spring effect of the actuator and load.

Figure 5 shows the hydraulic system block diagram for the four platen-leveling cylinders in the automotive panel press. The transducer and valve connections to the motion controller are clearly visible.

MOTION PROGRAMMING TECHNIQUES: VIRTUAL GEARING

The key to motion controller programming is setting up a connection and relationship between the control loops of the axes to be synchronized. Some multi-axis motion controllers have built-in functions that support synchronization.

The vehicle roof crush test application uses four hydraulic actuators (cylinders), mounted at the four corners of a heavy-gauge pressure plate and controlled as four separate motion axes. System design engineers used a special function of the motion controller called "virtual gearing" to cause all four axes to move in precise synchrony to ensure that the pressure plate is kept completely level during a compression operation.

The four "slave" axes follow a virtual "master" axis, which is set up to control the position of the pressure plate and the cumulative force being applied. The motion controller tracks the position of each corner cylinder using inputs from an LMDT attached to the cylinder, and controls the compression force using a load cell mounted on each cylinder rod end.

MOTION PROGRAMMING TECHNIQUES: CASCADED CONTROL LOOPS

The motion controller in the automotive panel press performs its control functions using a "cascaded-loop" architecture. An inner control loop works to level the platen, while the outer loop simultaneously adjusts the target positions of the cushion (leveling) cylinders to follow the motion of the platen. The outer control loop also monitors the force exerted by the cushioning cylinders to make sure that it remains under the limit provided by a supervisory PLC. If the cumulative force is too high, the motion controller will change the position of the platen to maintain the force below the set limit.

The cascaded control architecture is shown in *Fig. 6*. To level the platen, the motion controller computes the average position of the cushion cylinders, which it treats as a virtual master axis position, and works to move each cylinder position to match this average. To calculate the force being applied by each cushion cylinder, the motion controller computes the difference between the hydraulic fluid pressure on each side of the piston.

MOTION PROGRAMMING TECHNIQUES: CUSTOM FEEDBACK

In the automotive press application, mathematical computations are done by the motion controller on the raw feedback from the position and pressure transducers using a feature called "custom feedback." Custom feedback refers to the ability of the motion controller to do mathematical or logical pre-processing of the raw feedback sensor data before the resulting value is provided to the control loop algorithm. By doing math on the raw data before that feedback is used by the control loop, the control algorithm itself can be much more straightforward and simpler to implement and tune.

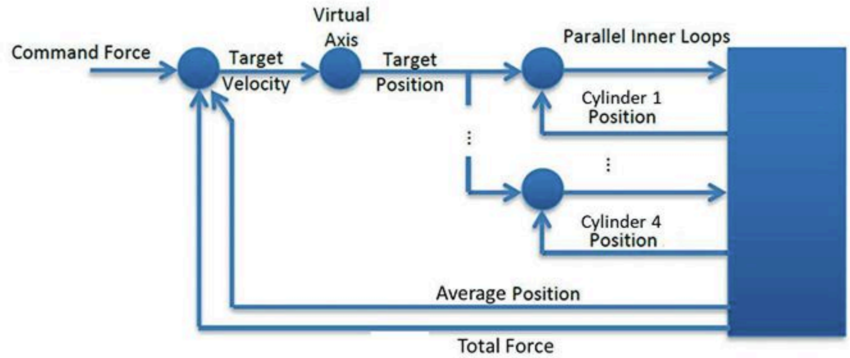
MOTION PROGRAMMING TECHNIQUES: POSITION-PRESSURE/FORCE CONTROL

Both the automotive panel press and the vehicle roof crush test application take advantage of the motion controller's ability to control based on force, as well as position, and to smoothly transition between the two. The outer loop of the press starts in position control, monitors the total force applied by the main cylinders, and transitions to force control when the force reaches a certain value—all while the inner loops are controlling position.

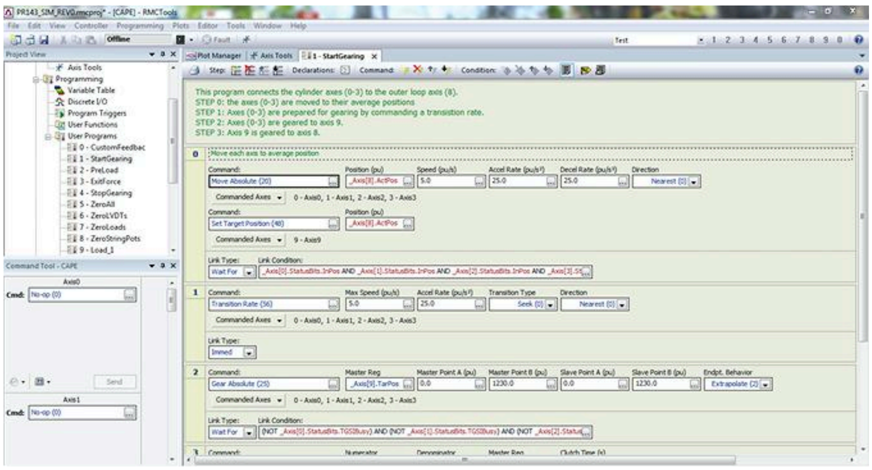
The vehicle test system similarly starts in position control, then applies a controlled force when commanded. The bundle lift system just monitors the force now; force control may be implemented as feature later.

DEVELOPING/TUNING THE APPLICATION

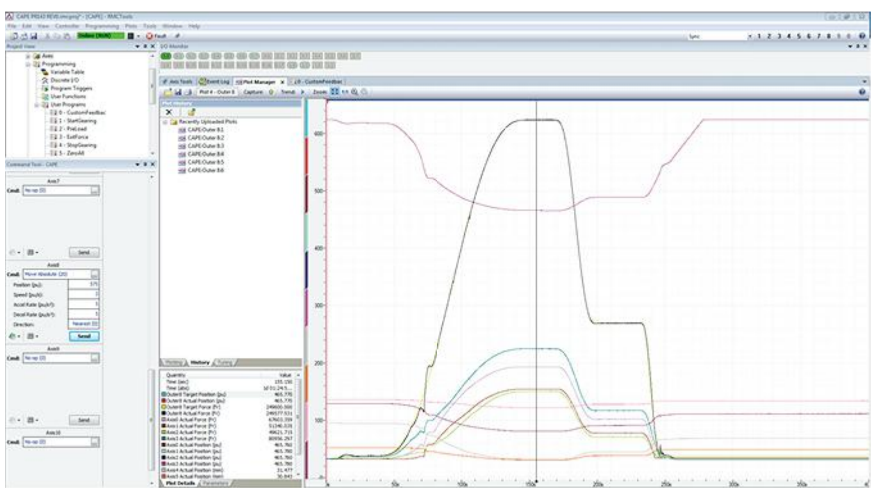
Programming the motion steps is typically done using development soft-



6. Cascaded control loop diagram showing how the motion controller in the automotive panel press works to keep the platen level while it follows the motion of the platen and monitors the force exerted.



7. Delta Computer Systems' RMCTools software lets designers build motion programs using drop-down menus to select motion parameters.



8. In the vehicle roof crush test system, the RMCTools Plot Manager from Delta Computer Systems Inc. enables the test operator to visually track the values of all transducers and the values of the geared axis parameters during a test.

As the design teams discussed in this article have found, with synchronized motion control set up and tuned correctly, system motion is made smooth, machine productivity is increased, and waste and machine maintenance costs are decreased

ware provided by the motion controller vendor. While some motion controllers need to be programmed by low-level machine instructions similar to those used with a general-purpose computer, others have graphical programming tools available that can set up motion algorithms, including axis synchronization relationships using drop-down menus.

The screen in *Fig. 7* shows how programming the operation of the four corner cylinders in the roof crush test application is done by filling in boxes and selecting options from pull-down menus. As the figure shows, the velocity and acceleration and deceleration rates can be set to cause the axes to start, stop, and move smoothly.

Following programming, all motion systems need to be tuned. In the case of the vehicle roof crush tester, the test rig initially shook. Then the system designers used the motion controller vendor's automated tuning tools to stop the vibrations and get the system pretty close to the desired motion profile. After that, the team did fine-tuning, operating the press plate up and down at various speeds, and by testing different vehicle cabs with different amounts of crushing force.

The fine-tuning process is made easier if the motion controller vendor provides a graphical motion plotting tool. See *Fig. 8* below for an example.

As the design teams discussed in this article have found, with synchronized motion control set up and tuned correctly, system motion is made smooth, machine productivity is increased, and waste and machine maintenance costs are decreased. md

LEE S. LANGSTON | Professor Emeritus

Single-Crystal Turbine Blades Earn ASME Milestone Status

Improved turbine blades have been critical for many of the advances in jet engines over the last 50 years and will hopefully continue to push the envelope in aerospace industry, as well as in turbines for electrical generation.

The American Society of Mechanical Engineers (ASME) recently named the Pratt & Whitney single crystal turbine blade an historic mechanical engineering landmark.

These blades, which can be found in many modern, high-performance gas turbines (a.k.a. jet engines)—including the ones powering the F-22 Raptor, and larger electricity-producing turbines—are grown from a single crystal in a vacuum casting furnace from superalloys. They increase the turbine's efficiency and individual blade's service life, while giving it unmatched resistance to high-temperature creep and fatigue.

About 60 years ago, a small group of Pratt & Whitney gas turbine industry mechanical engineers and metallurgists set out to develop single crystal blades and did so in the relatively short space of about 10 years, going from concept to manufactured product.

A technician opens the door to a vacuum furnace after casting a cluster of directionally solidified gas-turbine blades just after being cast in a ceramic mold. The castings rest on a chill plate, a key in forcing the molten metal to solidify into a single crystal. *(Photo courtesy of Howmet Corp.)*

THE SUPERALLOYS

The thermal efficiency of gas turbines increases with the temperatures of gases leaving the combustor and entering the turbine—the work-producing component. Turbine inlet temperatures in the gas path of modern high-perfor-

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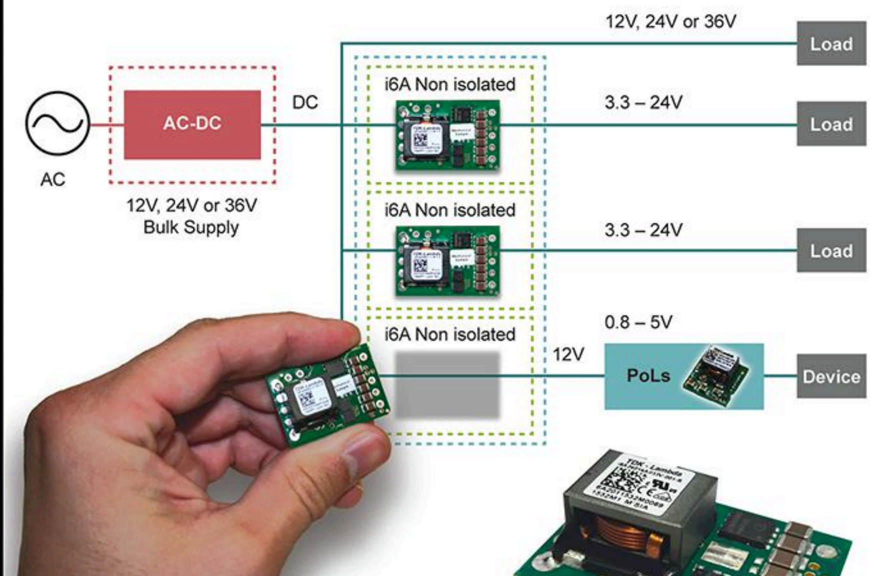

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TDK

Turbine blades progressed (left to right) from equiaxed, to directional solidified, to single crystal. *(Photo courtesy of Howmet Corp.)*

mance jet engines can exceed 3,000°F (1,649°C), while non-aviation turbines operate at 2,700°F (1,482°C) or lower.

In the turbine's high-temperature regions, high-melting-point nickel-based superalloy blades and vanes retain their strength and resist oxidation at extreme temperatures. These superalloys, when conventionally vacuum cast, soften and melt between 2,200° and 2,500°F (1,240° to 1,371°C). This means the blades and vanes closest to the engine combustor may operate in temperatures far exceeding their melting points and must be cooled to 80% to 90% of their melting temperatures to keep working. (Military jet engines can reach 3,600°F (1,982°C), which exceeds the boiling point of molten silver.)

Thus, engineers needed to design cast turbine blades with intricate internal passages and surface hole patterns that channel and direct cooling air (bled from the compressor) within and over exterior blades. To eliminate the harmful effects of impurities, blades are investment cast in vacuum chambers. After casting, the blade's working surface is often coated with a ceramic thermal barrier that increases life and acts as a thermal insulator, letting inlet temperatures be 100° to 300°F or higher.

EXPLORING AND REDUCING GRAIN BOUNDARIES

Conventionally cast turbine airfoils are polycrystalline, consisting of a three-dimensional mosaic of small metallic equiaxed crystals, or "grains," formed when the metal solidifies in the mold. Each grain differs from its neighbors in how its crystal lattice is oriented. These lattice misalignments form interfaces called grain boundaries.

Damaging events happen at grain boundaries, such as intergranular cavitation, voids form, chemical activity increases, and grains slip passed one another under stress loading. These conditions lead to creep, shorten cyclic strain life, and decrease overall ductility. (Creep is the tendency of blade materials to deform at a temperature dependent rate under stresses well below the materials' yield strength.) Corrosion and cracks also start at grain boundaries. In short, physical activities that begin at grain boundaries in superalloys greatly shorten turbine vane and blade life and are accelerated by high temperatures. But lowering temperatures decreases engine efficiency.

In the early 1960s, researchers at jet engine manufacturer Pratt & Whitney Aircraft (now Pratt & Whitney, owned by United Technologies Corp.) set out to deal with the problem by eliminating grain boundaries from turbine airfoils altogether. Their goal was to invent techniques that would let them cast single-crystal blades and vanes, and design alloys that would only be used in single crystal form.

Most of this work was done at the Advanced Materials R&D Laboratory (AMRDL) in Middletown, Conn., for Pratt & Whitney in the 1960s. AMRDL was an excellent example of industry using fundamental and applied research to create and bring to market a superior product within a decade. At its peak, ARMDL staff numbered more than 200 scientists, engineers, and technicians. They conducted research and development on all aspects of single crystal technology, ranging from casting, alloy development, and coatings to joining and repair. Over its subsequent 10-year life, AMRDL pioneered single-crystal superalloy technology.

At AMRDL's start, Frank VerSnyder from jet engine manufacturer General Electric had developed a concept that transverse (spanwise) grain boundaries could be eliminated in the casting of turbine blades and this would make them stronger. (General Electric never exploited or patented VerSnyder's concept.)

DIRECTIONAL SOLIDIFICATION

By 1966, VerSnyder invented and patented the directionally-solidified columnar-grained turbine blade, the first major step toward a single-crystal blade.

Directional solidification is done in a vacuum chamber and involves pouring molten superalloy metal into a vertically mounted mold heated to metal

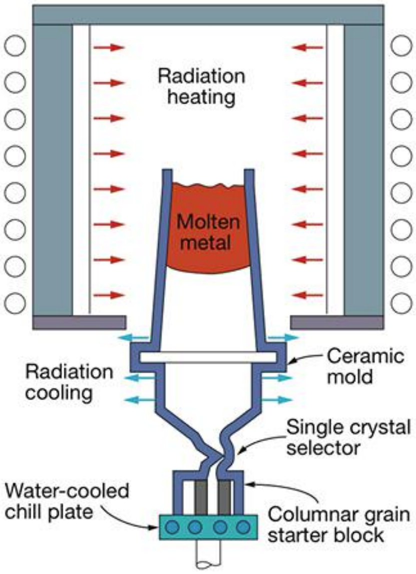
Damaging events happen at grain boundaries, such as intergranular cavitation, voids form, chemical activity increases, and grains slip passed one another under stress loading. These conditions lead to creep, shorten cyclic strain life, and decrease overall ductility.

melt temperatures, and filling the turbine airfoil mold cavity from root to tip (bottom to top). The bottom of the mold is formed by a water-cooled copper chill plate having a knurled surface exposed to the molten metal. At the chill plate surface, crystals form from the liquid superalloy, and the solid interface advances until it reaches the top.

The ceramic mold is surrounded by a temperature-controlled enclosure, which keeps the sides of the mold at a constant temperature distribution, and all the latent heat of solidification is removed by the chill plate. As solidification climbs through the mold, it is slowly lowered out of the enclosure.

The result is a turbine airfoil composed of columnar crystals or grains running spanwise. For rotating turbine blades, where spanwise centrifugal forces can see accelerations of 20,000 *g*, the columnar grains are aligned with the major stress axis. This alignment strengthens the blade and effectively eliminates destructive intergranular crack initiation normal to blade span. In gas turbines, directionally solidified (DS) blades have improved ductility and thermal fatigue life. They also provide more tolerance to localized strains (such as at blade roots), and have allowed small increases in turbine temperature and, hence, performance.

Once material properties were measured and manufacturing technique perfected, DS turbine blades and vanes were ready for engine application. Their first use by Pratt & Whitney in a production engine was in 1969 in the J58, two of which powered the SR-71 Blackbird supersonic aircraft. Commercial jet engines began using DS blades in 1974.



This schematic shows how manufacturers make single-crystal turbine blades in a mold inside a vacuum furnace.

A ceramic mold created by repeatedly dipping wax molds of turbine blades into a ceramic slurry gets ready to go into the vacuum furnace at Howmet's Terai, Japan foundry. There it will be filled with molten superalloy to form directionally solidified turbine blades. *(Photo courtesy of Howmet Corp.)*

The success of the DS blades set the stage for the invention of single crystal turbine airfoils.

SINGLE CRYSTAL DEVELOPMENT

While casting DS crystals, AMRDL researchers found that if they put a right-angle bend in the casting mold just a short distance above the chill plate (called the "starter" chamber), the number of crystals climbing above the bend would be reduced. Putting in two such bends reduced the number even more. Later, it was found that a helical channel with smooth continuous turning was a natural filter, admitting columnar crystals from the starter and letting just one crystal rise above the helix and start to form the entire blade. This single crystal selector was dubbed the "pigtail."

As the single crystal structure forms, the mold must be kept at the right temperature as the mold is taken from the heat-controlled enclosure. Any heat conducted to the sides of the mold lateral surfaces could lead to localized crystallization, which disrupts the single crystal structure with secondary grains.

In the 1970s, Pratt & Whitney developed techniques to manufacture single crystal (SX) turbine airfoils to overcome casting defects (such as secondary grains, recrystallized regions, and freckle chains). This early pioneering work was carried on by several manufacturers and improved upon over the past 50 years. Companies now see prosecution yields greater than 95% in casting of single crystal blades for aviation gas turbines. This helps offset cost of SX casting compared to equiaxed casting.

The first SX castings were made from conventionally-cast polycrystalline alloys, such as Mar-M200 and IN100. These alloys contain carbon, boron, and zirconium, three elements which segregate preferentially to grain boundaries and provided high-temperature grain-boundary strength and ductility for creep resistance. But in SX castings, which have longer solidification times and no grain boundaries, these three elements generated primary carbides, which hurt the blades high and low fatigue properties.

By the early 1970s, SX alloys were developed that eliminated carbon, baron, and zirconium, giving the alloys higher melting points, higher creep strength, and greatly improved high and low cycle fatigue resistance in SX blades and vanes.

SX alloys consist of many metals, each serving a specific purpose. For example, alloy PWA 1484, which P&W developed in the early 1980s, consists (by weight) of nickel (59%), cobalt (10%), tantalum (9%), aluminum (6%), tungsten (6%), and others (10%). One of the others is rhenium (3%), which lets the final alloy endure higher temperatures before weakening and melting. Rhenium is a "by-product of a by-product," derived from specific copper-molybdenum ores, and a costly element in limited supply.

Before committing to using PWA 1484, P&W management had to be assured rhenium could be supplied over time at a known, acceptable price.

This pigtail (or starter chamber) was used to create a single-crystal blade. It was then cut off and the inside metal exposed and acid etched to bring out grain boundaries. You can see several directionally solidifying crystals growing up from the bottom (nearest the coin) and then they disappear to leave only one crystal emerging form the helical portion.

In the 1970s, Pratt & Whitney developed techniques to manufacture single crystal (SX) turbine airfoils to overcome casting defects (such as secondary grains, recrystallized regions, and freckle chains). This early pioneering work was carried on by several manufacturers and improved upon over the past 50 years.

The solution was that P&W entered a long-term contract with a Chilean mining company to provide rhenium to Pratt for its internal inventory. Rhenium would then be delivered to casting vendors in sufficient quantities to meet Pratt's requirements.

In the 1970s, within 10 years of the start of the single crystal program, SX turbine airfoils were installed in P&W F100 production engines to power the F-15 and F-16 jet fighters. The first commercial aviation use was in P&W's JT9D-7R4 jet engine, which received flight certification in 1982 and powered the Boeing 767 and Airbus A310.

In 1986, Pratt & Whitney earned the ASM International Engineering Materials Achievement Award for the development of single crystal turbine blades.

In jet engines, single-crystal turbine airfoils have proven to have up to nine times the relative life in terms of creep strength and thermal fatigue resistance—and more than three times the relative life for corrosion resistance—compared to equiaxed crystal blades. Modern jet engines with their high turbine inlet temperatures and long lives (on the order of 25,000 hr of operation between overhauls) would be impossible without those single crystal airfoils. By eliminating grain boundaries, they have extended the thermal and fatigue life of jet engines and provided more corrosion resistance. In addition, the blades use less material because they are hollow and therefore reduce the weight of jet engines. They also have higher melting points. All these improvements contribute to more efficient gas turbines.

The next chapter of the SX story concerns their introduction to large gas turbines used in electric power plants. These units, as big as 500 MW, use supersized SX blades and vanes both for corrosion resistance and increased operating temperatures.

Their first use was for corrosion resistance (using PWA 1483 alloy) in the 163-MW Siemens V84.3A electric power gas turbine, introduced to the market in 1995. In more recent years, to increase thermal efficiency, these gas turbines' inlet turbine temperatures have been increased to aviation levels, so SX airfoils with higher temperature capacity are needed for long life.

General Electric's 9H, a 50 Hz combined-cycle gas turbine, is one of the world's largest. The first model went into service in 2003 in Wales, feeding as much as 530 MW into the UK's electric grid at a combined-cycle thermal efficiency just under 60%. The 404-ton 9H uses first-stage turbine vanes that measure almost a foot long and blades close to 18 in. long. Each comes from finished casting that weighs about 30 lb and each is a single crystal airfoil. md

LEE S. Langston is Professor Emeritus of Mechanical Engineering at the University of Connecticut.

ASME MILESTONES

WITH THE RECENT designation of the single-crystal turbine blade, ASME now counts 265 machines and devices from around the world which have been singled out for engineering attributes, innovations, and technological significance. ASME established its landmarks program in 1971 to promote the heritage of mechanical engineering and preserve historically important machines.

ASME landmarks span centuries and run the gamut from water pumping stations and electrical power plants to rail locomotives, earth movers, and space vehicles. Landmarks include the giant Big Brutus strip-mining shovel (shown) and the Saturn V rocket, which launched the Apollo spacecraft that took humans to the moon.

ASME's landmarks roster also includes relatively obscure devices from America's early steam engine and agricultural eras—machines that advanced production and forged the country's Industrial Age. Although lacking the name recognition of Saturn V, these early machines are engineering marvels and historically important works. They stand as reminders of where we have been and where we are going.

"Big Brutus" was the 11-million-lb. mine shovel used from 1963 to 1974 to move coal for the Pittsburg & Midway Coal Mining Co. in Kansas. Standing 160 feet tall, Big Brutus was a workhorse, averaging 5,000 cubic yards of coal per hour and able to dig in thick seams of coal. It was Built by the Bucyrus-Erie Co., and worked with a bulldozer and two smaller shovels to extract and load coal, which was transported to regional power plants.

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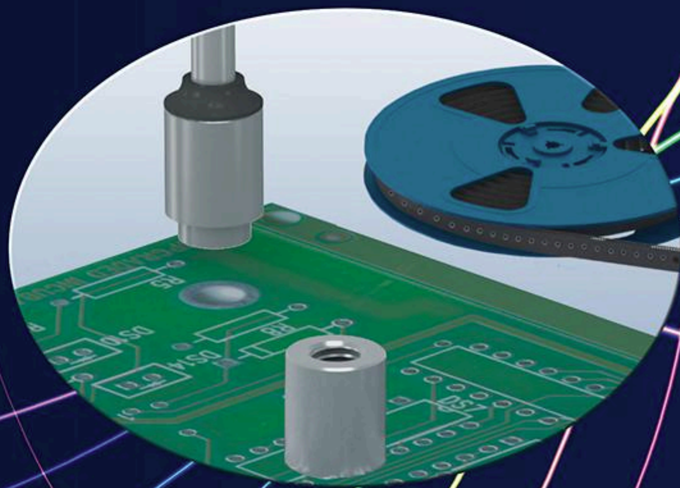

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JONATHAN GRIFFITH | Product Manager, Industrial Communications & Power Supplies at AutomationDirect

IIoT Connectivity to Automation Components

When connecting automation components to the IIoT, consider the capabilities and advantages of these two main methods of VPN-based remote access.

Connecting programmable logic controllers (PLCs), human machine interfaces (HMIs), and other automation system components to the Industrial Internet of Things (IIoT) for remote access is important for many manufacturing plants, and to the machine builders providing equipment and services to these plants. In the past, remote access was often accomplished via a router without a virtual private network (VPN), but these router-only connections to the internet should not be implemented today due to security risks.

Instead, a VPN should be used, as it is one of the key elements to a defense-in-depth strategy. However, implementing a secure IIoT connection to automation system components via a VPN often presents cost, technical, and resource allocation issues. The two solutions presented in this article address these challenges, but in different ways. Each solution has its own advantages and design considerations, as noted in the table. The two options are hosted VPN and traditional VPN.

The choice to use a hosted VPN versus a traditional VPN depends on three main factors:

- Will all of the IIoT connection needs fall under similar IT conditions, and will each site be able to use the same router configurations?
- Is IT expertise available to support a traditional VPN solution?
- Is high bandwidth required for this solution?

IIoT CONNECTION CONSIDERATIONS, ROUTER WITH VPN		
External Cost	**Hosted VPN**	**Traditional VPN**
Initial	Medium	High
Sustaining	Bandwidth Dependent	Low
Internal Support Cost	Low	High
Required Technical Expertise	Low	High
Changes to Existing Firewall	Not Required	Required
Security Risk	Low	Low
Data Dashboards	Available through Subscription	Typically Not Available
Data Storage & Access	Available through Subscription	Typically Not Available

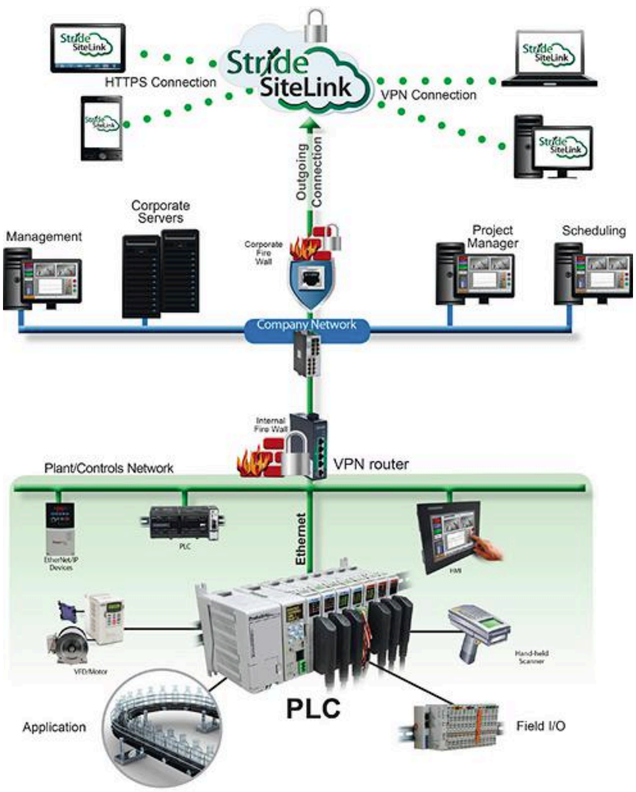
If the answer to any of these three questions is "no," then the best option is likely the hosted VPN solution. If all three questions are answered "yes," then the preferred option is likely the traditional VPN solution.

HOSTED VPN SOLUTION

A hosted VPN solution provides secure IIoT connectivity with simple setup and network configuration. These solutions usually include a local VPN router, a cloud-hosted VPN server, and a remote VPN client. Automation system components are connected locally to the VPN router, which connects to the cloud server. The VPN client connects by laptop or PC to the cloud, and ultimately to the local automation system components *(Fig. 1)*.

To accomplish this, the local VPN router makes a VPN connection to the cloud server immediately upon startup, but the VPN client only connects upon a verified request from the remote user. Once both connections have been made, all data passing through this VPN tunnel is secure.

Communication is initiated by the local router to the cloud-based server via an outbound connection through standard ports that are typically open, such as HTTPS. This usually requires no changes to the corporate IT firewall, thus satisfying IT security concerns.



1. AutomationDirect's STRIDE SiteLink Secure hosted VPN solution for IIoT connectivity has no monthly fees if data use is under 5 GB a month. *(Courtesy: AutomationDirect)*

Traditional VPN solutions require IT involvement and oversight in order to open inbound firewall ports, which often poses problems.

Hosted VPN solutions only require simple router configuration because the router *(Fig. 2)* is connected to a predefined cloud server. This allows the hosted VPN vendor to deliver the router preconfigured, so the user only needs to add basic network information. The router's default firewall settings keep the plant floor network separate from the corporate network.

The VPN router should include Wi-Fi and 4G LTE connectivity options, in addition to a wired LAN option. The Wi-Fi option allows the router to operate in access point or client mode. With access point mode, wireless devices connected to the router are on the LAN network, allowing plant personnel to access the control system local area network (LAN) wirelessly, rather than opening the panel to access the physical LAN connection ports. With the 4G LTE option, access can be provided from remote locations without internet access, or from locations that will not provide access to their corporate network.

Security risk is minimal with this solution because the remote client connection to the cloud server uses the robust encryption standard SSL/TLS. The required TLS key exchange, crucial for security, is done in accordance with industry standard 2048-bit RSA with SHA-256.

To further enhance security, some vendors provide advanced user management, event logging, and two-factor authentication. This method of authentication requires a second time-based password generated at login, providing an extra level of security.

A typical hosted VPN solution has a free monthly bandwidth allocation for basic operation, and then offers a premium plan for additional bandwidth. Normal troubleshooting and programming needs normally fall under the free data allocation, but extensive data monitoring or video surveillance may require additional bandwidth.

2. By only providing the functionality needed for IIoT connectivity, this AutomationDirect STRIDE SiteLink VPN router, installed on the far right of the DIN rail and connected to the PLC, simplifies implementation and use. *(Courtesy: AutomationDirect)*

HOSTED VPN REQUIREMENTS

With the recent rash of data breaches, it's important to have a high level of trust in the selected hosted VPN vendor, as it will be responsible for securely storing data and making it available to only those who need it. This is of course a concern for any IIoT implementation, and some hosted VPN vendors have much better security measures in place than others.

Monthly costs incurred for exceeding the free data bandwidth usage must also be considered, particularly as those costs are zero for a traditional VPN solution. Again, these costs vary widely from one vendor to the next, and should be evaluated closely. IT support is not needed because the solution is simple to implement and maintain, with acceptable security built in.

With this solution there are some limits in terms of advanced routing features, although these features aren't required in most applications. Complex IIoT implementations such as machine-to-machine networking, advanced Network Address Translation (NAT) configuration, and access control lists may require a traditional VPN implementation.

Specific features offered by the router vendor can enhance design flexibility and value, easing design considerations. Some of the leading features include IIoT data logging, widgets for configuring remote access dashboards, a web-based platform for router configuration, and a digital input for enabling/disabling remote access.

IIoT data logging provides collection, storage, and display of data via a cloud-based platform, allowing storage of and access to a virtually unlimited amount of data, while only requiring payment for the required capacity. This makes it feasible to start with a minimal amount of storage, and then increase if needed by paying more each month. The vendor's cloud-based data logging usually requires an additional license or subscription to collect and store the data in the cloud platform.

3. When traditional VPNs are used, a local HMI, such as this AutomationDirect C-more panel, is often part of the solution. *(Courtesy: AutomationDirect)*

4. This AutomationDirect STRIDE SiteLink Secure Remote Access dashboard is easy to configure using provided widgets. *(Courtesy: AutomationDirect)*

A traditional VPN solution requires a third-party HMI, either PC-based or embedded *(Fig. 3)*, to provide data logging and widgets for configuring remote access screens. Many hosted VPNs do not require an HMI because they provide their own graphical interface capabilities. With these solutions, users can configure dashboards using widgets for remote access via their PC or mobile device *(Fig. 4)*. Users can also configure alerts and notifications to indicate when parameters fall outside a predefined range. Creating remote access viewing screens can be cumbersome if this feature is not provided, so this must be taken into account when evaluating competing hosted VPN solutions.

Some hosted VPN solution vendors provide quick and easy configuration of the VPN router via a web-based platform. Ideally, this will only require account registration, configuration, and downloading of router settings, and installation of a secure client on a PC. A web-based platform is better than PC-based configuration because updates can be made without having to reinstall a new version of the configuration software on a PC—particularly important when new features are added on a regular basis.

For enhanced safety, the VPN router should have a discrete input to locally enable or disable communications via a manual switch to prevent remote control of a machine during maintenance periods.

TRADITIONAL VPN SOLUTION

This solution uses a local VPN router to connect through the internet, with a secure VPN tunnel to a second remote

For many companies, a security concern is created because IT must open an inbound VPN port on the firewall. This is done to provide full remote control and monitoring by creating a single IIoT network joining local and remote users. This raises a security concern as the inbound VPN port must constantly be protected with a high level of access control.

VPN router or software client *(Fig. 5)*. After these connections are made, remote users can access automation components connected to the local router through the VPN tunnel.

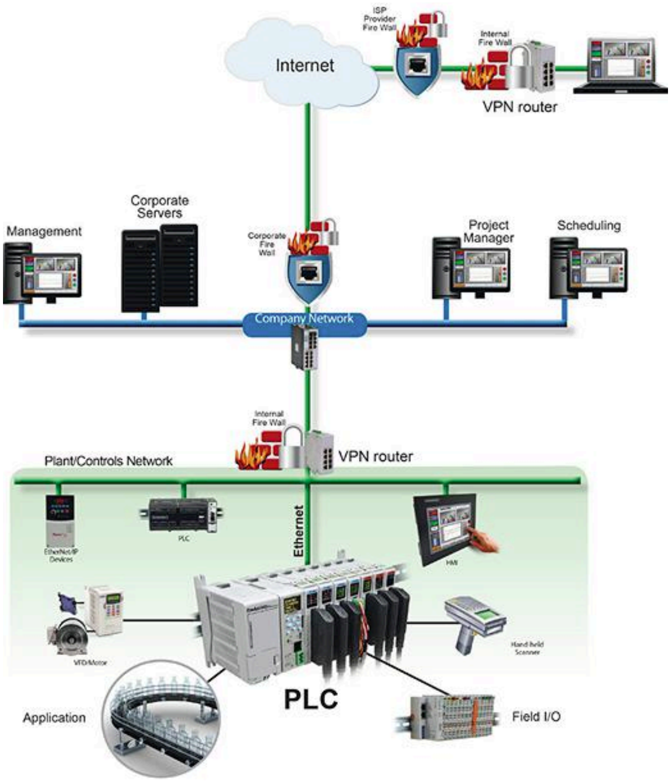
There is no cloud server between the two devices with either method of connection: VPN router to VPN router, or VPN router to VPN software. This traditional VPN solution may be needed when large amounts of data must be continuously exchanged between the local and remote sites, as with remote viewing of local video.

This solution was the only method of secure two-way access prior to the fairly recent introduction of cloud-based remote access solutions via a hosted VPN around 2012, so it's widely used. But it is complex, and can therefore be costly in terms of internal resources required for support, both at the local and the remote site.

TRADITIONAL VPN REQUIREMENTS

The IT team must have the capability and willingness to support this solution at both the local and remote sites for each installation. If this solution is being implemented by an original equipment manufacturer (OEM) machine builder, for example, the OEM must consider every customer site, and make sure all of its customers can provide the required high level of IT support. In some cases, the OEM may have to customize its remote access solution for each customer, greatly adding to implementation and support costs.

Depending on the networking requirements, this solution may have approximately the same initial costs as a



5. With this traditional VPN solution, two routers are commonly used, each requiring IT support both locally and remotely. *(Courtesy: AutomationDirect)*

hosted VPN solution if a router and VPN client implementation is chosen. For applications such as machine-to-machine where two routers are required, the traditional VPN solution has a more expensive initial cost.

IT resources are required to configure the connection, adding to design and implementation costs. Larger companies may have a dedicated IT staff to provide this support, but most smaller companies will not, requiring outsourcing of required IT resources. Although ongoing external costs are lower because there are no monthly cloud service fees, internal costs are higher due to the need for IT support.

For many companies, a security concern is created because IT must open an inbound VPN port on the firewall. This is done to provide full remote control and monitoring by creating a single IIoT network joining local and remote users. This raises a security concern as the inbound VPN port must constantly be protected with a high level of access control. In addition, ongoing security vigilance is needed to ensure router and VPN protocols remain up to date. Other technical considerations must also be addressed, including:

- Configuring firewalls
- Addressing subnet conflicts across sites with similar network design
- Controlling user management and access
- Implementing event logging
- Creating and managing security certificates
- Applying advanced networking knowledge
- Configuring clients at each connection point

Even with these challenges, a tradition VPN is preferred if the required IT staff is available and the application requires high data bandwidth, or if there is a requirement to not rely on a vendor for a hosted VPN solution.

USING A HOSTED VPN

In our first example, an OEM's machine does not require remote video monitoring. Local operator interface is provided by an embedded HMI with limited data logging and storage functionality.

The OEM machine builder needs secure remote access and an easy-to-configure data dashboard for remote monitoring. VPN access is required to provide remote troubleshooting, debugging, and programming of the machine's PLC and HMI. Both the OEM and its customer require monitoring of the machine's most important operating parameters on mobile device dashboards.

The OEM machine builder doesn't have an IT department—just one part-time person who set up its internal network. Its automation staff consists of one control systems professional who is an expert when it comes to programming PLCs and HMIs to automate their machines, but is not very familiar with IT, VPN, and router technology. Most of the OEM's customers are not willing or able to reconfigure their firewall, eliminating the traditional VPN option.

In this case, a hosted VPN solution is the best choice because it will satisfy the OEM and customer requirements, and it can be implemented without the assistance of IT staff.

Data logging is provided in the cloud, so the local HMI's limited data storage capability is not an issue. Widgets can be used by the machine builder to create dashboard screens for viewing on remote devices by many different users. When full remote control and monitoring is required via the IIoT, it can be provided by installing a lightweight software client on a PC, which can connect to the cloud from any location worldwide.

USING A TRADITIONAL VPN

In this second example, the OEM sells very large and com-

When implementing an IIoT solution for remote access, a VPN is necessary to provide the required security. Older solutions without a VPN simply don't provide the needed level of protection from intrusion.

plex printing presses with thousands of automation system I/O points, and its customers require the OEM to provide support of the machine, including uptime and throughput guarantees. The OEM needs to remotely monitor and support its presses worldwide to make sure guarantees to customers are met.

The OEM has considerable IT expertise and is capable of implementing a traditional VPN, and each of its customers is willing to allow the required firewall modifications.

Each press also has multiple video cameras installed for remote viewing, a necessity for solving some of the more complex troubleshooting issues. Each printing press has a full-featured PC-based HMI installed to provide local viewing and data storage, with high-speed remote access to the HMI and its stored data required at all times. Therefore, large amounts of operating data must be continuously transmitted to the remote corporate control center.

A traditional VPN is the right solution in this application because of the significant amount of data exchange required, which could be cost-prohibitive for a hosted VPN, and because the right IT resources are available to support the solution at the control center and at each site.

DECISIONS

When implementing an IIoT solution for remote access, a VPN is necessary to provide the required security. Older solutions without a VPN simply don't provide the needed level of protection from intrusion.

Once the decision has been made to use a VPN for remote IIoT access, the two main types of solutions are a hosted VPN and a traditional VPN. The hosted VPN is the more modern solution and works well in most instances. The traditional VPN provides the utmost in performance for implementations requiring very high bandwidth, but is more complex to design, install, and support. md

design FAQs

Alternative Solutions for Backup Power

FREQUENTLY ASKED QUESTIONS

Q. What current options are available for backup power solutions?

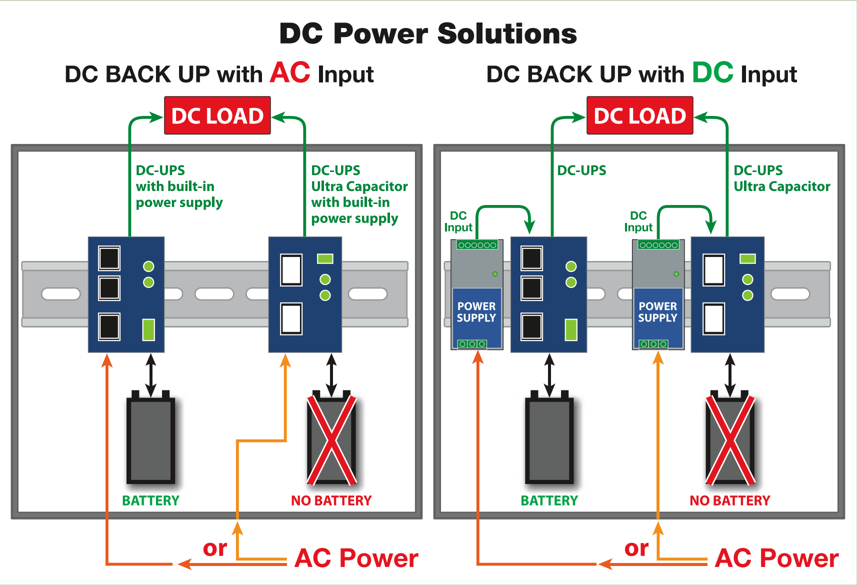
A. Systems that require backup power solutions usually have small battery backups or generators. Small backup systems traditionally rely on batteries for energy storage while larger systems may use generators or more uncommon systems such as flywheels, superconducting magnetic energy storage, or fuel cells for larger installations. While there can be a need for a battery based solution, batteries have a limited life span. Their life is based on the number of discharges and charges they undergo. Battery installations are difficult due to the long list of regulations and standards they must abide. Their installations must comply with local and national health and safety standards. Environmental regulations, which mainly affect larger installations, can include requirements for ventilation, handling, and disposal of batteries. Flywheels, for example, require an extreme amount of maintenance. Also, systems that use generator sets and fuel cells have poor turn-on response and are not very reliable.

Q. What alternatives provide a more secure and reliable power source?

A. Two alternatives that can be used instead of generators are an all-in-one power solution system and an ultra-capacitor system.

An all-in-one power solution combines a power supply unit, battery charger, battery care module, or backup module. The all-in-one battery solution is based on the battery operating as a storage device (batteries are not included). The available power is automatically distributed among load and battery, while supplying power to the load always is the first priority. The maximum available current of the load output is two times the value of the device's rated current. If the device is disconnected from the main power source, the battery will supply the load until the battery voltage reaches 1.5 V per cell. This prevents the battery from deep discharge. The battery charging is controlled via a microprocessor. Using algorithms, the battery's condition will be detected and based on that, an appropriate charging mode is chosen. The real-time diagnostics system will continuously monitor the charging progress and indicate possibly occurring faults such as elements in short circuit, accidental reverse polarity connection or disconnection of the battery by the battery fault LED and a flashing code of the diagnosis LED. The all-in-one solution can provide a variety of charging voltages: 12VDC, 24VDC, and 48VDC. The solution is highly efficient; up to 91% via switching technology.

The ultra-capacitor solution stores energy within a compact design that does not use a battery but supper capacitors to store energy. The load is energized from the buffer module until it is depleted. The capacitors are either a 12 or 24V system design. It operates between temperatures of -40°F to 140°F and can provide up to 10,000 watts of energy plus extension modules. The system can be customized up to 600A. Backup times depend on the state of the charge of the ultra-capacitors and the load in which they are supplying. Compared to standard buffer modules, ultra-capacitor units are capable of prolonged backup times (up to 55 minutes) and fast discharges. Capacitors excel at controlled shutdown functions and allowing for the protection of computer systems. Backup times are dependent on the load and amount



of capacitors within the unit. Backup times can be calculated to better serve the requirements of required functions.

Q. In which situations would one prefer to use an ultra-capacitor versus an all-in-one multi-power solution?

A. An all-in-one solution is beneficial for cleaner power and versatility of use. The solution is suitable for most common battery types and the device itself is mounted in a compact design case for protection. A higher efficiency of the battery is achieved thanks to continuous control over time. They offer more monitoring in the main connection nodes: input, output load, battery. The solution provides adjustable current if that is a requirement and ease of battery diagnosis. The all-in-one solution has several output protection features as against troubleshoots like short circuiting, overload, deep battery discharge, etc. The ease of diagnosis is possible through the event logging of: number of battery charging cycles, charge cycles completed, aborted charge cycles, Ah charged, charging time, total number of transitions standby / backup, etc. Examples of the event management are: checking the load output, shutdown management of PCs (UPS function), RESET management of a generic equipment.

The all-in-one solution offers DIN rail mounting. Also, the load output will not be affected by battery conditions. The solution insures continuous power supply to the load even in conditions of completely discharged batteries. The automatic multi-stage operation optimizes and adapts to the battery status. It can recharge deeply discharged batteries even when their voltage is close to zero, thus allowing recharge and complete recovery of flat batteries.

The downside of the all-in-one solution is that it uses a battery. They are used more widely in industry and are easier to implement. Battery has a shorter life cycle and more maintenance required. Also, they have to be replaced more often; standard lifetime is three to five years. Charging batteries also takes a significant long time. The ultra-capacitor solution is beneficial for customizable systems but could incur high cost on initial-purchase hardware and installation. They are resistant to shocks and vibration, environmentally safe, have no toxic chemicals, and are virtually maintenance-free. The ultra-capacitor modules are built with supper capacitors that last up to 20 years. The use of ultra-capacitors also reduces wiring time due to integrated energy storage. The wiring is also vibration-secured via spring-loaded plugs. There is no limitation on their use; they can be incorporated into any design. Ultra-cap modules are also chargeable in a short time and able to provide large amount of energy when needed. They have microcontroller-based charging and discharging of the ultra-capacitors. The ultra-capacitors have seamless switchover and a long operational life.

Q. What are the industry benefits to using such systems?

A. All-in-one solutions can be found in several industries. They are used in infrastructure industries like industrial water pumping, fire protection systems, power supply continuity, and remote measurement stations. They are also used in commercial industries like audio, lighting, electric vehicles, off-highway equipment, and wireless control.

Ultra-capacitor solutions can be found in manufacturing industries, data collection services, and energy and construction industries. Among manufacturing industries using them are textile manufacturing, molding machinery, automotive, automation, packaging, and steel production. They are also used as power backups for data centers, feeding systems, wind turbines, and tunneling machines. ■

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(Continued from page 33)

"Waterjet machining has become more common because we can now achieve the desired level of performance," says Sebastien Schmitt, North American Robotics division manager for Stäubli Corp., Duncan, S.C. "We've made so much progress with the rigidity of the arm and precision, it's possible today to work in the aerospace industry.

"Accuracy, repeatability, and rigidity all come from our patented gear box we manufacture and design in-house," continues Schmitt. "We're the only robot manufacturer that designs its own gear box. That gives us better trajectory performance."

The robot commonly used is a high-payload, 100 kg TX200 HE robot, which Schmitt says you need for rigidity. But it's also important for handling the counterforces from the ultrahigh-pressure waterjet. Aquarese found minimal to no push-back with the Stäubli robots.

The HE in the models name stands for humid environment. This robot was developed specifically for wet environments. The enclosed arm structure carries an IP65 rating, and it's reinforced by arm suppression for added waterproofing. The IP67-rated wrist resists corrosion and is protected against low-pressure immersion. The tool flange and critical parts are made of stainless steel to hold up in corrosive environments.

The TX200 HE was developed specifically for wet environments. The enclosed arm structure is IP65-rated and reinforced by arm suppression for added waterproofing. The IP67-rated wrist is corrosion resistant and protected against low-pressure immersion. The tool flange and critical parts are made of stainless steel to hold up in corrosive environments.

"The rigidity, precision, and repeatability lets companies push the edge of performance," says Schmitt, noting they can now compete with traditional milling methods. "For example, the cost of a 5-axis CNC machine is three or four times the cost of the waterjet cutting machine."

Waterjet cutters can be modified to handle stripping to remove coatings from turbine engine components used in jet engines. *(Courtesy of Shape Technologies Group)*

Material savings is another major advantage of robotic waterjet. It commonly roughs out two turbine blades from one bar of lightweight alloy.

"For one slug, you get two parts that are near net shape before final machining and grinding," says Howes. "This is a huge advantage with waterjet and comes courtesy of 3D nesting, which can't be done with milling. The only other way you can do this is with wire EDM, which is expensive."

Companies can also use common cut lines when cutting sheet metal. The waterjet's thin cutting width—ranging from 0.003 to 0.015 in. for a pure waterjet stream, and 0.015 to 0.070 in. for abrasive waterjet—can handle intricate detail. Howes says you can't do this efficiently with conventional machining where the kerf, or width of the cut, is too wide. Common cut lines, 3D nesting, and larger offcuts all provide significant material savings.

Aquarese's machines can also handle robotic waterjet stripping for removing coatings on aircraft engine parts, including boosters and combustors, for the maintenance, repair and overhaul (MRO) companies. They also have versions that remove ceramic shells and cores for investment casting foundries typically in the aerospace or industrial gas turbine market.

"We can also combine core removal with cutting for de-gating, as well as removing the flashing from forged materials," says Howes. "All of these are robotic applications."

Still, robotic machining, whether with waterjet or more conventional means, has its limitations when it comes to rigidity and accuracy. Researchers are exploring novel ways to address these limitations.

For example, research at the recently inaugurated Boeing Manufacturing Development Center on the campus of Georgia Institute of Technology, focuses on implementing industrial automation in non-traditional ways, such as shimless machining. To compensate for the lack of stiffness and accuracy, they are developing sensing, compensation, and metrology approaches. For example, the researchers are developing laser trackers and new types of measuring systems, along with in-process sensing of forces, to address accuracy issues when using robots in high-force applications. ■

Up in the Sky!
It's Flying Cars!

CARLOS M. GONZALEZ | Content Director

This past month at the Geneva Motor Show, two car companies debuted their flying car concepts. Each took a different approach toward designing a vehicle for both land and air.

The Personal Air and Land Vehicle (Pal-V) Liberty vehicle is a runway take-off aircraft as well as a driveable land vehicle, offering the best of both worlds. It uses gyroplane design for stable flight and is certified by the FAA and EASA in Europe.

I REMEMBER WATCHING "The Jetsons" or "Back to the Future" thinking that flying cars would be cool. You just can't get around that fact. Having a car that could transform from driving on the ground to flying the air would be an amazing way to travel.

Logistically, there are questions of air traffic and how to regulate flying cars. Are they street legal? Do they run on regular fuel? How can you land, and where? At this past month's Geneva Motor Show, two different companies showed us how they plan to turn the fantasy of flying cars into a reality.

THE FLYING PAL-V LIBERTY

The Personal Air and Land Vehicle (Pal-V) Liberty vehicle has two seats, retractable helicopter blades, and is powered by a gasoline-fueled engine. The vehicle has a dual engine propulsion drive train, based on a two fully certified airplane engine from Rotax. The Pal-V Liberty is certified under both the EASA in Europe and the FAA in the U.S. The driver will need a pilot license to fly the vehicle.

On the ground, the speed range is 50 kilometers per hour up to 160 kilometers per hour (30 to 100 miles per hour). The top speed acceleration is just under nine seconds. The engine of 100 horsepower has a fuel economy of 7.61/100 kilometer with a range of 1315 kilometer (817 miles).

When in flying mode, the plane has gyroplane technology to maintain stable flight that provides safe landing even when there is total power failure. The take-off distance is 90 to 200 m (300 to 650 ft). Landing without an engine can be done with

±30 kilometer per hour ground speed. The design cannot stall, and crosswind landings are easier when compared to a fixed wing aircraft.

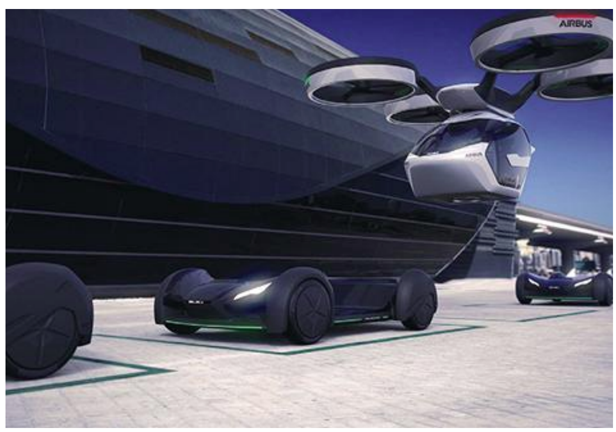
The aircraft needs a runaway space of 90 to 200 meters by 20 meters (100 to 650 ft by 60 ft) to take off and land. Runways designed for glider sites or ultralight aircraft will suffice. The max flying speed is 180 kilometers per hour (112 miles per hour) with a fuel range of 400 to 500 kilometers (249 to 311 miles) depending on the model.

"The Pal-V is the perfect product for city-to-city mobility," said CEO Robert Dingemanse, highlighting that "outside the cities you fly, inside the city you drive." The availability to fly is easy, he noted—well, at least in Europe. "You can use the 10,000 strips available in Europe, and because you can drive, that's already enough," Dingemanse said, adding that "every German will have a small airport within 10 or 20 kilometers of his home."

The price point is not cheap. Future buyers will need to pay €10,000 to €20,000 ($12,000 to $25,000) for pilot training, in addition to the €300,000 to €500,000 ($367,914 to $613,120) for the vehicle itself. That's the price of a small helicopter. The benefit, according to Dingemanse is that the Pal-V Liberty

The inside of the Pal-V Liberty offers a hybrid look of plane controls and a vehicle steering wheel.

The joint design of Airbus and Audi is the Pop.Up Next. It is designed as an electric vehicle autonomous shared driving service that has the ability for vertical take-off.



The main body of the car mounts to sleds which provide ground transportation. The rider can then request an air module from a nearby charging station to dock with the main body, which detaches from the sled for vertical liftoff.

Audi brings its expertise in autonomous driving and design to create a stylish and futuristic interior. The touchscreen detects eye movement, speech, and faces for a better interactive experience.

is “easier, maintenance costs are much lower, [and] it’s much more useful than a normal plane or helicopter.”

THE POP.UP NEXT FROM AIRBUS AND AUDI

The power of a driving vehicle with autonomous driving was also on display at the Geneva Motor Show. Airbus and Audi introduced the Pop.Up Next, the follow to the Pop.Up now with self-driving technology on the road that can vertically lift into the air like a helicopter.

The vehicle is a two-seat passenger that has a 60-kW (80-hp) electric powered sled for autonomous driving on the ground. The top speed is 100 kilometers per hour (62 miles per hour) and the 15 kilowatt-hour battery has a 130-kilometer (81-mile) range.

To fly, the vehicles connect to one shared network, where a passenger can request for the attachable air module. Air modules would be stored in a nearby charging station and when requested would dock on to the top of car, disconnecting from the sled for vertical liftoff. The air module can fly 50 kilometers (31 miles) per charge. It is equipped with a 70 kilowatt-hour with eight electric motors and a top speed of 540 kilometer per hour (336 miles per hour).

Audi’s role, with the help of Volkswagen Italdesign, is to bring its autonomous vehicle and battery expertise into the design along with fine tuning the cabin’s interior. The inside features a 49-in. touchscreen that incorporates eye-tracking, speech, and facial recognition. The seats use a mix of aluminum framing and ultralight meshing to keep weight low.

“This vehicle was not conceived to be sold to individuals, [but] as a shared means of transport,” said Mark Cousin, the project chief at Airbus. The company plans to launch the first urban trials in 2022 and hopes to expand its use cases into medical transportation of patients and goods. ■

How to Protect Energy Plants from Cyberattacks

CARLOS M. GONZALEZ | Content Director

This month saw a hacking attack from Russia on our energy infrastructure. In an increasingly IoT-dominated world, plants have to be more vigilant than ever.

CYBERSECURITY is one the biggest fears of engineers and industrial companies as we enter the interconnected age. The Internet of Things (IoT) is connecting several of our new devices to online networks and cloud computing, as well as retrofitting our legacy systems. Placing these systems on accessible networks opens the door for cyberattacks. This past month, cyber activity from the Russian government targeted U.S. power plants along with other infrastructure facilities. As we place our systems online, what can be done about protecting our infrastructure from cyberattacks?

GOVERNMENT AND IoT

In 2016, the Center for Data Innovation conducted research into how IoT devices are being used by the government. Some of the areas where the government is using IoT include smart buildings, vehicle fleet monitoring, asset monitoring, and agriculture. As result of increased use of IoT devices, Congress passed the Internet of Things Cybersecurity Improvement Act of 2017 to help secure future IoT devices and their data.

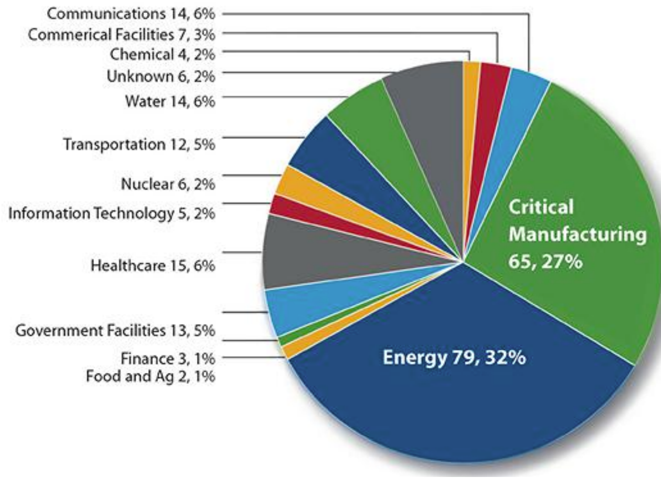
Within our energy infrastructure, the Office of Electricity Delivery and Energy Reliability's (OE) mission statement is to "pursue technologies to improve grid reliability, efficiency, flexibility, functionality, and security; and making investments and sponsoring demonstrations aimed at bringing new and innovative technologies to maturity and helping them transition to market." The four critical challenges that need to be addressed per the OE are as follows:

- Changes in demand driven by population growth, adoption of more energy efficient technologies, dynamic economic conditions, and broader electrification, including possible mass-markets for electric vehicles.
- Changes in the supply mix (such as renewables, nuclear energy, natural gas, and coal) and location (centralized, distributed, and offshore) of the Nation's generation portfolio driven by technology, market, and policy developments.
- Increasing variability and uncertainty from both supply and demand, including integration of variable renewables, more active consumer participation, and accommodating new technologies and techniques.
- Increasing challenges to the reliability and security of the electric infrastructure (such as more frequent and intense extreme weather events, cyber and physical attacks, and interdependencies with natural gas and water).

Several of these challenges will be addressed by introducing new technology, and these devices will be IoT-enabled devices, connecting them to the internet and other energy networks.

CYBERATTACKS ON U.S. ENERGY

Our current energy infrastructure is already under attack from cyber threats. This month, as mentioned above, the U.S. Computer Emergency Readiness Team reported *(https://www.us-cert.gov/ncas/alerts/TA18-074A)* that Russian cyberattacks targeted our government and domestic sectors in energy, nuclear, commercial facilities, water, aviation, and critical manufacturing sectors.



In 2014, Industrial Control Systems Cyber Emergency Response Team received and responded to 245 incidents reported by asset owners and industry partners. The Energy Sector led with the most reported incidents, which according to the Statista Research firm had an average financial cost of $26.5 million. *(Image Credit: ICS-CERT)*

These attacks are part of an ongoing trend. According to a report from The Hill, the Department of Energy was hacked 159 times between 2010 and 2014 *(http://thehill.com/policy/cybersecurity/253130-hackers-cracked-energy-department-150-times-over-four-years)*. Records obtain by The Hill under the Freedom of Information Act revealed that hackers targeted DoE networks 1,131 times over the four-year span.

The problem is only increasing as we expand our energy networks. A 2016 MIT study *(http://energy.mit.edu/wp-content/uploads/2017/07/Cybersecurity-White-Paper.pdf)* found that due to grid expansion and the growing demand on our energy infrastructure, "system operators must have the capacity to operate, maintain, and recover a system that will never be fully protected from cyberattacks."

A recent Forbes article *(https://www.forbes.com/sites/jamesconca/2018/03/16/russia-hacks-into-u-s-nuclear-power-plants/#741cef7857b9)* highlighted the many exposed access points in our energy networks. According to the article, a study from the U.S. National Institute of Standards and Technology Cybersecurity Working Group *(https://www.nist.gov/itl/voting/cybersecurity-working-group)* identified 137 types of vulnerable access points between different grid systems: "For example, every smart meter and most sensors and major pieces of equipment at generating plants and substations will have communications modules, using millions of components from potentially hundreds of manufacturers. Software applications will also be provided by many different developers."

Currently there is no one organization in place to oversee cybersecurity for electric grid systems. The OE and The North American Electric Reliability Corporation have developed standards on how to properly protect these systems, but the responsibility for implementation is left to the industrial companies.

APPROACHES TO CYBERSECURITY

Currently there is no one organization in place to oversee cybersecurity for electric grid systems. The OE and The North American Electric Reliability Corporation have developed standards on how to properly protect these systems, but the responsibility for implementation is left to the industrial companies.

Holistic industrial security is an effort that involves the entire plant and encompasses every device. It should address risk from people, unsecure processes, and vulnerable technologies. According to the MIT study, here are some important points to consider when developing a security plan:

- Industry needs to adopt cybersecurity best practices and develop a risk management culture; cybersecurity regulations are important, but because there is a delay in developing and implementing them, regulations lag behind evolving threats
- It is important to rapidly share information about cyber threats while respecting privacy guidelines
- Good cybersecurity requires skilled teams to understand baseline operations, detect and respond to anomalous cyber activity, reduce the "dwell time" of cyber attackers, and implement layered cyber defenses
- The is a need to understand and increase system resilience to avoid prolonged outages and better recover from cyber attacks
- In the future, utilize advanced cybersecurity technologies, international approaches to cybersecurity, and machine-to-machine information sharing so the response to cyber incidents takes place in milliseconds—not months

A recent article from Rockwell Automation *(http://bit.ly/2GKUOuI)* listed its approach to power plant cybersecurity in three steps:

SECURITY ASSESSMENT

Cultivate a deep understanding of all risks and vulnerabilities that exist within your organization. A security assessment offers thorough review of site infrastructure nuances, software, networks, control systems, policies, procedures, and even employee behaviors. It's the foundation for a successful security policy.

A proper security assessment should include:

- Inventory of authorized and unauthorized devices and software
- Detailed observation and documentation of system performance
- Identification of tolerance thresholds and risk/vulnerability indications
- Prioritization of each vulnerability based on impact and exploitation potential
- Mitigation techniques required to bring an operation to an acceptable risk state

DEFENSE-IN-DEPTH SECURITY

Defense-in-depth (DiD) security is the idea that if any one point of protection is defeated, there are additional layers to protect the system that will need to be defeated for a hacking attempt to be successful. DiD security approaches establish multiple layers of protection through a combination of physical, electronic, and procedural safeguards. A DiD security approach consists of six main components:

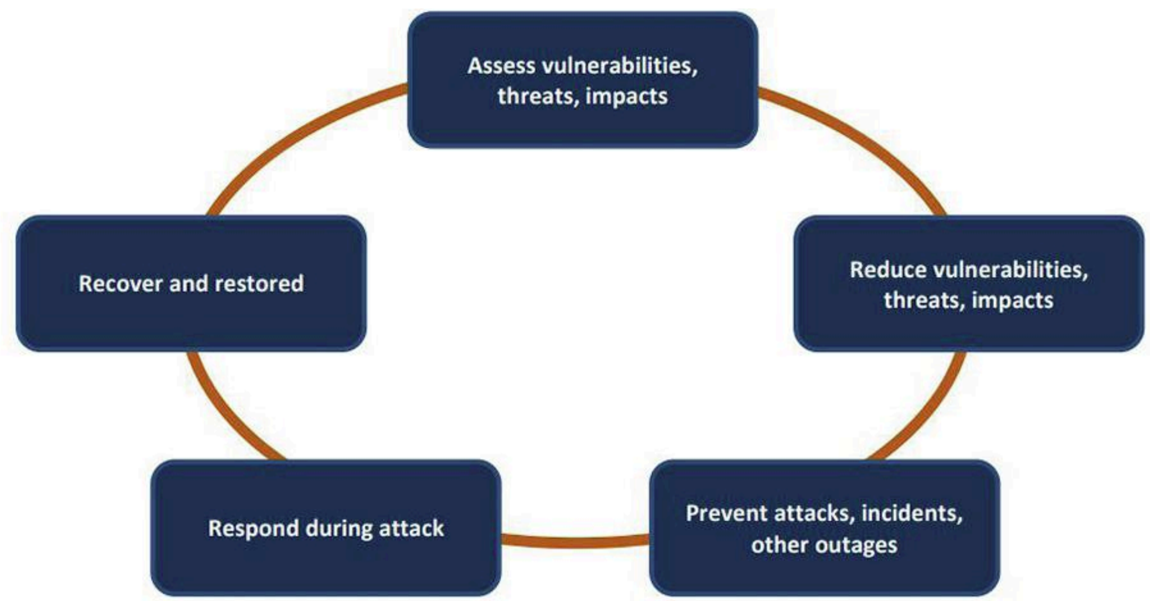
1. Policies and procedures
2. Physical
3. Network
4. Computer
5. Application
6. Device

TRUSTED VENDORS

Selecting vendor partners that have the appropriate level of security can have a large impact on helping you meet your security goals. Before selecting vendors for any system that will be connected to your network, request that they disclose their security policies and practices. Rockwell Automation, through its partnership with Cisco, has defined five core security principles for designing products used in a control system:

1. Secure network infrastructure
2. Authentication and policy management
3. Content protection
4. Tamper detection
5. Robustness

Power plants that run our energy networks should look for a structured and tailored approach to meet physical and cybersecurity requirements. As the world of IoT continues to grow, companies will have to adopt multiple layers of protection and backup systems to ensure a secure energy system that can function without interruptions. ■



According to the MIT study on cybersecurity, vulnerabilities need to be assessed and reduced to prevent cyberattacks whenever possible. When attacks do occur, an effective, speedy response and a well-thought-out plan for recovering and restoring operations are needed, as highlighted in the Cybersecurity Life Cycle above. *(Image Credit: MIT)*

SOFTWARE INCREASES TIME to Market for Electric Cars

by GEMMA CHURCH

THE AUTOMOTIVE INDUSTRY is in the midst of a disruption, and the transcendence of electric vehicles from niche to mainstream is a driving force behind this change.

Challenges remain to improve the motor designs used in electric vehicles. One potential solution is the use of power magnetic devices (PMDs), a category of devices that includes motors, generators, transformers, and inductors. In simple terms, these components utilize an electromagnetic field to convert electrical energy to mechanical energy, or vice versa.

In the field of power engineering, and particularly in the design of PMDs, modern advances are targeted at reducing system losses, mass, volume, and cost, while simultaneously increasing power capability, reliability, and large-scale manufacturability.

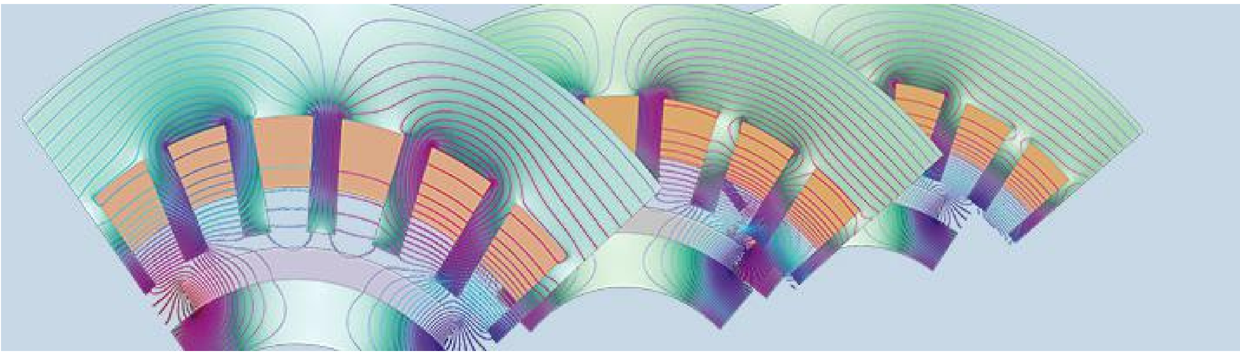
Achieving these competing objectives in modern applications requires advanced methods to optimize the design of various PMDs such as electric motors. These include computationally efficient device models in conjunction with state-of-the-art optimization techniques. Furthermore, the design constraints pertaining to electric motors represent a complex multi-physics problem from a mechanical, electrical, and thermal perspective.

Faraday Future is a start-up technology company focused on the development of intelligent electric vehicles, using software that offers a multi-physics finite element analysis program to produce electric motors for automobiles. The organization is also taking an innovative, modular approach to electric vehicle design.

"My group develops motor designs for a generic set of vehicles, primarily suited to our variable platform architecture, which allows for modular development of electric vehicle powertrains," explained Omar Laldin, Faraday Future's lead electromagnetic engineer. "We can add or remove motors, adjust battery quantities, and collapse or increase the size of the chassis.

"To be able to do that, we have to design the motor for a variety of conditions, and need to take into account several different aspects of the motors beyond just the electro-magnetic components, such as the mechanical and thermal behavior," Laldin added.

The example in *Fig. 1* involves completing a series of advanced optimization algorithms, which quickly model how particular designs will behave. Speed is of the essence, as these optimiza-



1. COMSOL is able to perform Finite element analysis (FEA) of a nonlinear-surface permanent magnet synchronous motor (PMSM). This is an example of an electromagnetic analysis conducted by Faraday Future.

tion algorithms are required to perform numerous iterations to ensure a variety of designs are investigated. As a result, some aspects of the models need to be simplified.

"It could take several weeks to do a full CFD analysis to predict thermal behavior," Laldin said. "There are often thousands of designs to be considered and hundreds of operating points for every given design, making it impractical to do detailed multiphysics analysis with a very computationally heavy tool. Software that allows us to conduct thorough electromagnetic and mechanical analyses—along with simplified thermal analysis—work in a stable way, and give us quick feedback on each of these aspects during the design process."

The versatility of advanced software also helps the electromagnetic motor design group collaborate with the other teams within Faraday Future, including motor mechanical, inverter, motor control, powertrain control, systems engineering, and so forth. Collectively, these groups form the Powertrain Group within the organization.

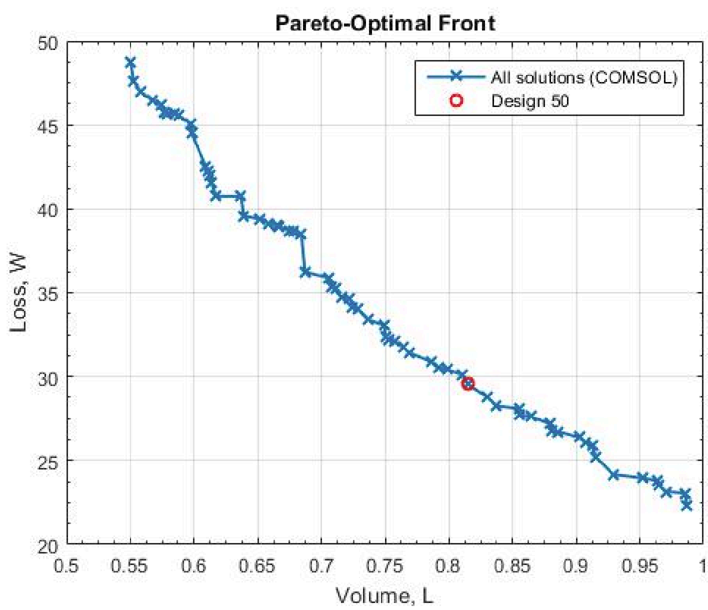
"We do all the early stage analysis before we send data to other teams to make sure we're in the right ballpark, and that limits the number of iterations we have to do with other teams," Laldin added. "I think that's one of the most beneficial aspects of the COMSOL simulation and modeling tools."

DESIGNING AN ACTUATOR

The electric motor team designed an Electric-core actuator to meet certain constraints, all the while obtaining a compromise between competing volume and power loss objectives. While the power loss must be minimized, the team did not want to increase the size of the component to do so, as package size is a critical metric in most vehicular systems. The actuator was made up of a coil of conducting wire wrapped around a stationary Electric-core, along with a movable Inner-core.

Using advanced software to perform a 2D electromagnetic field analysis and genetic algorithms, the model accounted for the highly nonlinear behavior of the various steel materials, while the genetic algorithm provided the globally optimized and multi-objective Pareto-Optimal Fronts. This data was used to find the tradeoff between reducing the volume and power loss.

The team used geometric parameters of the actuator as inputs in the algorithm and obtained losses based on the coil resistance. This allowed for the rapid investigation of numerous designs of the electro-



2. Shown is the Pareto-Optimal Front providing mass vs. loss tradeoff.

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INVESTIGATING LOSSES

The team investigated the nonlinearity of the steel used in electric motors, which changes the nature of high-frequency conductor losses in a slot. These losses increase at high speeds due to the increase in skin and proximity effect in the conductors; they are also affected by the temperature. Due to the geometry of the motor, some winding architectures and their conductors are more easily cooled than others. For example, the spacing of the conductors and their dimensions can affect the heat transfer in the slot.

Laldin and his colleagues performed further multi-physics analysis, coupling the electromagnetic components with the thermal behavior to identify hotspots in the motor that could cause catastrophic failure. They discovered that the current density within the conductors changed significantly due to changes in flux density across the slot. The researchers calculated the loss density in each of the conductors and then obtained the temperature distribution, which provided the maximum hot spot temperatures in different areas of the motor.

"The loss in different conductors can vary even if we have the same current," Laldin said. "We model these variations and do some approximate and quick thermal analysis in COMSOL, which allows us to study the temperature distribution." Identifying the maximum hot spot temperatures enables manufacturers to determine the reliability of the design and prevent destructive motor events.

This multiphysics approach brings further time savings to Faraday Future, as one person can both design and analyze a motor and/or its components. "Instead of doing 10 iterations with the various teams, our tools allow us to complete the design in 1 to 2 iterations," Laldin noted. 'This is one of the biggest advantages of having a multiphysics analysis tool—we can cut down on the number of iterations we need to do between different groups. It's a lot quicker for one person to optimize the design, followed by minor refinements across the teams, than it is for each team to independently analyze each aspect of the physics." ■

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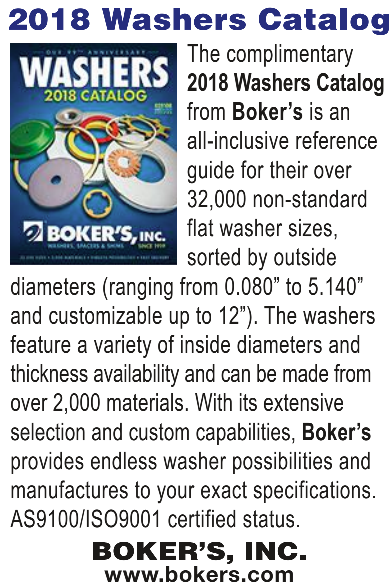
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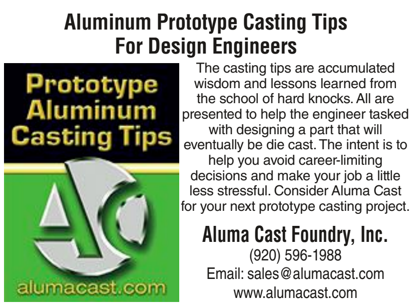
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BRADFORD L. GOLDENSE | Contributing Technical Expert

R&D Spending Trends: More Innovation On The Horizon!

Have you ever wondered how much money is spent on research and product development each year? Or where all the money comes from that enables what we generically refer to as "innovation"? Or how these monies are allocated across basic research, applied research, advanced development, and product development? Probably not. Most practitioners are mostly concerned with whether their budgets will be cut or increased. "Up or down is what I need to know," holds true whether one is innovating in academia, government laboratories, for-profit companies, or makers funded by venture capital.

Information Sources: There are two primary sources of funding information. The first is the Business Research and Development Innovation Survey (BRDIS), a survey conducted annually by the Census Bureau for the National Center for Science and Engineering Statistics (NCSES), which is part of the National Science Foundation.

Enacted into law in 2010, the NCSES is the official Federal clearinghouse for collecting, interpreting, analyzing, and disseminating objective data on science, engineering, technology, and research and development. Importantly, NSF tracking is not new; predecessor organizations compiled this information for many decades. Although data is collected each year, it takes roughly two years to assemble it into a comprehensive report—which typically comes out in August. In August 2017, the report for 2015 was released.

The second source is the Global R&D Funding Forecast (GFF) published by *R&D Magazine* for the last 60 years. GFF's goal is to make a projection at the end of each year on the R&D monies that will be spent the year ahead. The full GFF typically comes out early in each new year. It is the only consistently produced report that looks ahead.

Noisy Data: This is a terribly complicated subject. There are a gazillion sources of funds and a gazillion spenders of funds. Not all spenders are public companies. Many private companies do not track R&D unless there is an active tax credit law. Tax credit laws come and go. I've followed both sources for some 15 years. As best I can tell, there is a different counting method as the GFF forecast seems to be two percentage points lower in projection versus what the NCSES ends up counting three years later. Why? Does the government give GFF researchers accurate figures on planned spending? Perhaps it is a matter of national security. Will academic and corporate sources reveal their true plans in advance, alerting competitors early on to increases? Maybe yes, maybe no. So, in this sense, the noise limits a practitioner's view to simply looking at whether spending is up or down.

Spending Trends: Although *Machine Design* is a global publication, and there are interesting global trends as China and Scandinavian countries are tearing up the pavement on spending, global is too large a subject for now. Focusing on United States R&D for the nine years after 2010 (when spending returned from a 2008 Great Recession flat line) tells a story. As expected, there was optimism as folks thought the economy would rebound quickly. That optimism gradually decreased until the economy began to rebound, then the optimism returned. Here is the nine-year GFF sequence from 2010 to 2018: 3.2%, 2.4%, 2.8%, 1.9%, 1.0%, 3.2%, 3.4%, 2.9%, and 2.9%.

Real Money: According to the R&D Magazine 2017 Survey for the 2018 GFF, $553 billion will be spent on R&D in the U.S. this year—more than a half-trillion dollars. The Federal Government and other government agencies will spend $144B. Industry will spend $367.7B. Academia will spend $20.5B. And Non-Profits will spend $20.8B.

Observations: First, given that inflation has remained low, the growth in R&D spending over each of the past four years represents a real spending increase. Second, noting that only 75 to 78% of these monies go to product development and the rest to basic and applied research, and if time-to-market is 2 to 4 years, then product plans and pipelines have been steady now for 1 to 2 product cycles. Third, all current public economic forecasts predict continued growth, indicating that businesses and consumers will have predictable purchasing power. Taken together, this indicates the next few years will be great for engineers and scientists who innovate and invent. And businesses and consumers will have a steady wave of new products to consider. md

BRADFORD L. GOLDENSE is founder and president of Goldense Group Inc. (GGI; *www.goldensegroupinc.com*), a consulting, market research, and education firm focused on business and technology management strategies and practices for product creation, development, and commercialization.


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