Pardon the Disruption

Emerging technologies such as robotics/automation, new materials, additive manufacturing and IIoT can and will change the course of gear manufacturing for the foreseeable future.

Matthew Jaster, Senior Editor

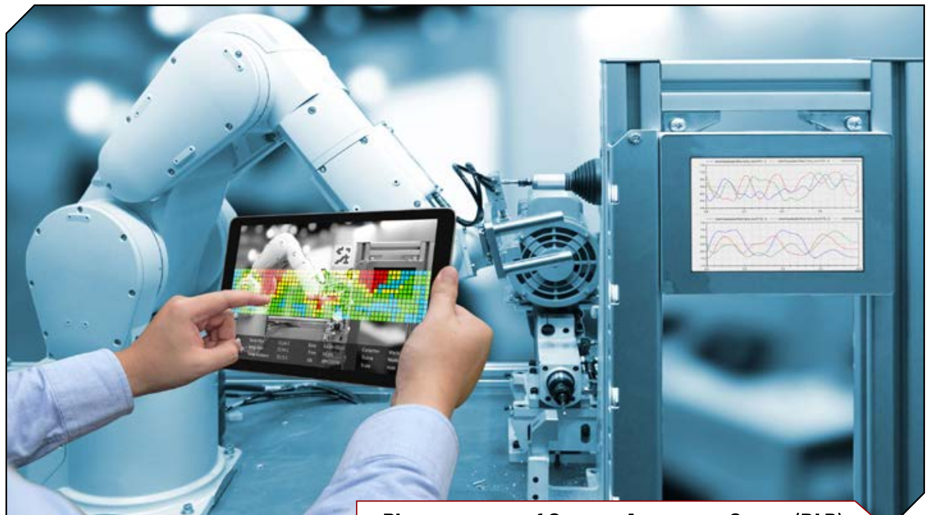


Photo courtesy of German Aerospace Center (DLR).

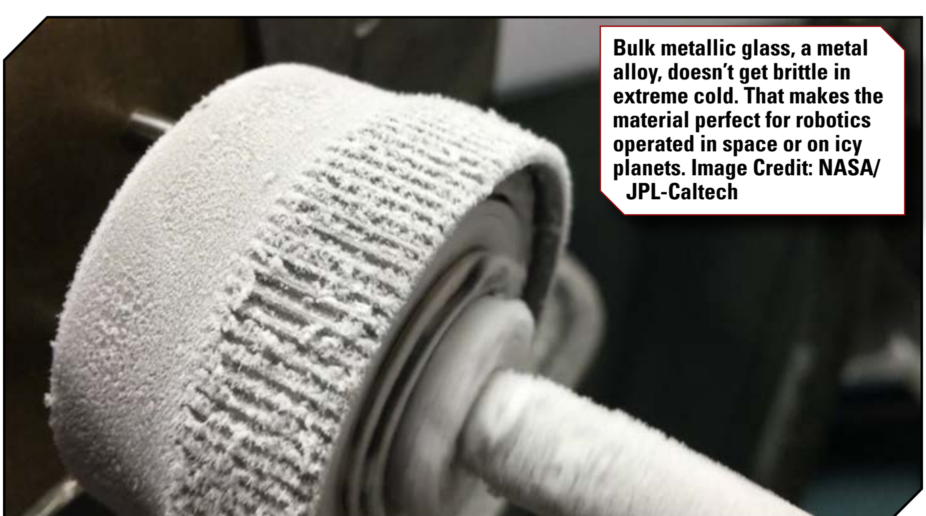
Early last year Matt Croson, AGMA president, spoke with *Gear Technology* about the emerging technologies and trends in gear manufacturing he believed would play a significant role in the coming years. These megatrends included additive manufacturing (3D-printing), the Industrial Internet of Things (IIoT), robotics/automation and emerging alloys and new materials. The conversation carried on throughout 2017 in the pages of this magazine, during AGMA meetings and on the exhibition floor at Gear Expo. As optimism grows for 2018, we continue to explore how these technologies can potentially increase productivity and efficiency in gear manufacturing.

NASA Discusses Bulk Metallic Glass Gears & Additive Manufacturing

First, let's look at the science. Metallic glass is a mysterious material that offers a unique atomic structure, according to Douglas Hofmann, technologist for the Materials Development and Manufacturing Technology Group at NASA's Jet Propulsion Laboratory at Caltech.

"Metallic glasses are non-crystalline metal alloys and they are not transparent. The fact they are called glass just means that they are cooled so rapidly that the atoms are completely random as opposed to being located in a crystal (where all the atoms are in a well-defined location)," Hofmann said.

It was first developed at Caltech back in the late 1950s, early 1960s. "The first paper was published by my advisor's advisor (basically my grand advisor)," Hofmann added. "Some of the big innovations regarding this technology occurred in the early 1990s when it was discovered that a few metallic glass compositions (mostly based in the element zirconium) could be cast into parts thicker than one millimeter."


Bulk metallic glass, a metal alloy, doesn't get brittle in extreme cold. That makes the material perfect for robotics operated in space or on icy planets. Image Credit: NASA/JPL-Caltech

Those parts became known as Bulk Metallic Glass (BMG) and those parts were able to be cast into thick components yet still retained their glassy or amorphous microstructure.

An interesting side note about BMG: If you Google the terms "bulk metallic glass," "liquid metal," and "amorphous metals," you'll get thousands of different entries for each term. None of these web searches will overlap despite the fact that all three search words are the exact same material.

"So, the most confusing aspect of BMG might simply be what exactly we should call it!" Hofmann said.

The development of thick alloys in the 1990s opened up the door to be able to make net-shaped parts through casting. The company Liquidmetal Technologies was founded at Caltech in the 1990s and they went off and made cell phone cases, golf clubs and watches, taking advantage of the fact you could cast metallic glass that had exceptional metallic properties—they we particularly scratch resistant and very flexible.

For NASA, BMG has the necessary properties to handle hostile environments that often don't have an Earth equivalent. It is perfect for spacecrafts that will go to the Moon, Mars, land on asteroids or comets or conduct research on the moons of Saturn (Titan) and Jupiter (Europa).

BMGs have properties other materials don't for specific applications, Hofmann said. "For example, they operate at low temperatures very well. They don't become particularly brittle. They also have very good wear resistance if you design the alloys correctly so you can make gearboxes that don't require lubricants. This was one of the big reasons why we started getting interested in metallic glass gears for our Mars Rover as well as some future planned rovers to other very cold planets and moons," Hofmann added.

While the Mars Rover Curiosity uses steel gears, the gearboxes need cartridge heaters to heat the lubricant to work effectively. Without the cartridge heaters, Hofmann said the lubricant would become sticky at those extreme temperatures and the gears wouldn't turn.

An example of a strain wave gear, also known as a harmonic drive — one of the most expensive types of gears used in high-precision robotics. As the gear turns, the flexible ring inside it squeezes, becoming an oval shape. Image Credit: NASA/JPL-Caltech

"If those cartridge heaters ever broke, the Rover would no longer operate. So there was a huge motivation to be able to make gears that could run without lubricant," Hofmann said. "The natural alternative is making ceramic gears because they would definitely run without lubricant, but the fracture toughness is really low so we fear a gear fracture on landing."

Scientists and engineers began discussing how they could make gears that were 10 times tougher than ceramics, but were much more wear resistant than steel and could run without any lubrication.

This was simply necessary to make the appropriate engineering workarounds for future spacecraft missions beyond Mars.

"When you start looking at landing a spacecraft on Europa, for example, you realize that cartridge heaters need cabling, they need a controller and they need power," Hofmann said. "You're going to want to get rid of as many things as possible on this spacecraft that aren't pivotal to the mission at hand."

So how did bulk metallic glass gears come into play?

The commercially available metallic glass alloy has been used widely in industry, but it's not a great gear material. Generally speaking, it has pretty poor wear resistance compared to steel. Also, manufacturing gears is not trivial—you need specialty gear equipment to make great gears. This challenge was solved by bringing the Materials Development and Manufacturing Technology Group together with JPL's Robotics and Gear Groups to collaborate on possible solutions.

"We came up with a strategy to make gears cheaply and easily and test them in hundreds of different alloy iterations to arrive at the alloys that had superior wear performance," Hofmann said. "We were able to balance the wear resistance and the toughness so that the gears worked effectively. Manufacturing was by far the greatest hurdle we had. This is what prevented people from making metallic gears in the past. The collaboration between divisions was vital to our success. The end result was metallic glass gears that can be utilized for future space missions."

During the development of this technology, Hofmann said JPL filed several patents and began exploring the potential commercialization of metallic glass gears. One of the things that conspired against bringing new materials into gear applications is that lubricant basically works at any temperature on Earth. You're not mass-constrained in any gearbox application and steel is cheap and easy to machine. So, there's not a lot of motivation in many gear applications to try new materials.

"That being said, there are all kinds of specialty applications where you're mass–constrained or temperature-constrained or working in a hostile environment where there's contamination, debris, and corrosion. These are the types of applications where lubricants might not work," Hofmann said. "We're looking into niche applications where metallic glass gears might compete with steel or ceramic gears."

Hofmann said that metallic glass can be injection molded into gears and the result is a gear that out behaves steel in many applications. "This is pretty innovative. There is no other metal that can be injection molded like plastic into molds that has wear performance characteristics like BMGs. We can net-shape cast our gears without having to machine or hob them," he added. "That means we can get surface finishes that can't be replicated without having to go to micro-grinding or chemical-etching. That's a really big selling point, the mass production through standard injection molding capabilities. "

If BMG gears weren't innovative enough, Hofmann's group at JPL is also hard at work at some innovative additive manufacturing projects.

"There's interest in developing extremely customized gears that would be impossible to machine," Hofmann said. "We're also examining functionally-graded metals with a 3D-printer here at JPL. This can print up to four metals on a single print so we can blend from one metal to another metal."

This is the kind of technology the industry hoped to hear about when they first started discussing the potential for additive manufacturing. (*Editor's note: Look to a future issue of Gear Technology to read more about JPL's additive manufacturing technologies.*)

"As applied to gears, this is fascinating because we can make the interior of the gear out of something tough and lightweight like titanium and then you can blend the gear into something much more wear resistant at the teeth like titanium carbide. You can make a single gear that satisfies multiple requirements. Extreme hardness and wear resistance on the teeth, but toughness and low density on the interior, so I think functionally graded metals is really an exciting area."

But in all this research and testing, additive manufacturing will first and foremost be a priority for NASA's exploration of the galaxy.

"We're creating gear technologies for 3D-printing in space, customized excavating tools, for example, that can cut through rock and ice," Hofmann said. "When these prototypes work well, we will increase the readiness level so they can be utilized on upcoming space missions."

Thoughts on the Automated Gear Shop

Quality and productivity come into play each and every day on the shop floor. How fast can we produce this gear? What tools will make us better, more efficient and more flexible for future projects? The answer might be hidden away in that robotic arm being utilized for deburring in the corner of the factory.

"We all know the skills gap is coming, we've been talking about it for some time," said Geoff Dawson, director, FANUC America. "There's a shift in the paradigm of the types of jobs people want coming out of college today. The emphasis is on building a smarter workforce. This can be accomplished with the right personnel working hand-in-hand with robotic and automation solutions on the shop floor."

Dawson believes the focus should be on using the new labor force *smarter* not *harder*. "Just look at our smartphones. Look at how this technology has evolved since these products were first released and how the users have adapted to the technology over time. Robotics and automation can play a similar role in the future of manufacturing."

OEMs know this and have known it for some time. For years, the automotive and aerospace industries have incorporated robotics and automation for assembly, motion control, complex machining, material removal, part transfer, picking/packaging and more.

But look at general manufacturing and North America lags behind its counterparts in Japan and Europe in large numbers. The good news is that FANUC and other system integrators are starting to help other areas in manufacturing pick up the pace.

"As robotic systems become more intelligent through increased vision and force sensing capabilities, manufacturers will be able to broaden the areas where these systems can be applied," Dawson said. "We have all this automotive experience, particularly the focus on the powertrain—engine, transmission and drivetrain. The push is to take these technologies and make them simpler for everyone across the board."

This FANUC M-20iB-35S robot has been utilized to deburr components (courtesy of FANUC).

Force-sensing robots, for example, give manufacturers the ability to deburr gears on the shop floor. "We have collaborated with many gear companies on force-sensing robots that take care of burrs and are also used in assembly to mesh gears," Dawson said.

Another gear application is looking at gear blanks. FANUC offers 3D vision systems where the robots pick parts directly out of a bin and can save a gear operation on expensive fixturing on conveyors.

Dawson believes the challenge in robotics and automation specifically for gear applications involves the high product mix and the existing machine layouts. There are opportunities to take advantage of automation that can work with multiple machines, but you're constrained by current layouts or manufacturing methods that weren't made to be automated.

Adapting to certain products can also be challenging.

"Gears are nice, round parts because the center of the circle is always the center of the circle. When you're handling gears, your data points typically are the same and the point that you're loading is pretty straightforward," Dawson said. "Complex gears, however, may have an array of tooling to handle an array of sizes and this can be a significant challenge for gear shops."

There's also the perception that a job shop simply won't be able to afford the kind of automation and robotic upgrades you might find within OEMs.

"Return of investment (ROI) is so important to consider when discussing these upgrades. Several of our integrators start with an entry-level system—maybe a robot, a feeding device and a fixture table. There are cost-effective ways to make these shop floor upgrades feasible," Dawson said. "At the end of the day, you want a system that will be able to support *your* products and equipment."

In order to better prepare the next generation of manufacturers for robotics and automation, FANUC continues to emphasize training and educational programs. The company works with community colleges, trade schools and universities on programs where they receive robots for their labs and a curriculum that FANUC provides. This allows these institutions to better prepare the next workforce.

"Some still say that robots take jobs, but there's some pretty good data out there that suggests robots sustain jobs and make companies more competitive. Instead of going offshore, many organizations have invested in automation and robotics to remain competitive which allows them to keep a facility open, having the solid, well-rounded, qualified employees in place to accomplish what they need," Dawson said.

Information is key to one of FANUC's pioneer programs with the automotive industry known as its Zero Down Time (ZDT) Application. This analytics system (in collaboration with Cisco) identifies potential failures so that manufacturing equipment can be maintained and repaired in scheduled downtime rather than breakdown during critical production. The application was recognized with a GM Innovation Award in 2016.

"General industrial is part of this initiative (including gear manufacturing) where we'll be able to work with our customers and provide services so they don't lose production time due to maintenance issues. It's about being proactive instead of reactive," Dawson said.

Intelligent technologies will be the crux of FANUC's focus for the foreseeable future. "Our servomotors are at the heart of everything we do," Dawson said. "Whether it's a CNC or a robot, our goal is to continue to develop solutions for the next generation of users."

IIoT: The Promise of Big Data

What does Industry 4.0 or the Industrial Internet of Things (IIoT) really mean to gear manufacturing? The whole concept, according to Marco Kampka, program manager at the Gear and Transmission Technology Group, Fraunhofer CMI, is based on the availability of information.

"This means that every element along the process chain has the right information to complete the given task in the most economical way. It may be a machine tool having the tool and workpiece data to machine the next part, or a human, who needs additional information to make the best decision, solving a given problem," Kampka said.

The main difference from the past is that this is supposed to happen in real time, and in a way that every piece of information is available to everyone from a single source. Kampka said that in this framework, it is important to differentiate between information and data.

"Information is formatted and often filtered data to be easily understood by either machine or human. The transfer of data to information can either happen using very generic approaches of analyzing data, which would make it a big data problem, or by using sophisticated models or rule sets," Kampka said. "Gathering data is easy. Producing information can be difficult."

This FANUC R-1000iA robot can handle magnetic bin picking operations (courtesy of FANUC).

Essentially, every piece of information gathered along the process chain is a first step to Industry 4.0/IIoT. In reality, Kampka said there are currently not many *real solutions* in our field yet. "Those big terms like 'Industry 4.0' or 'IIoT' are often widely used without reaching the level of a true solution. Even though, a lot of products show promising approaches," Kampka added. One of the challenges is to collect the right data and derive the most important information from it. Modern machine tools and the controls create much more data than gets used or collected on an average basis.

"Blindly adding more and more sensors into the machine tools will create more data, but not necessarily more information. The challenge right now is identifying the right data to collect and the right analytics to turn that data into information. But time can't be turned back and all the data not collected may be a drawback later on. So it is kind of a guessing game at the moment," Kampka added.

Obviously, conversations need to continue between the manufacturing industry and academia to discuss how to make the most out of these strategies.

"I suggest contacting the universities who do research in gear manufacturing, get involved in discussions on how these solutions might assist your organization and try the software solutions that are available," Kampka said. "Most of those solutions are not perfect, but they improve much less than they could, because of little feedback provided from the gear industry. The machine tool manufacturers should do their part, and participate in finding a common data standard to simplify communication and data management."

The right simulations and software tools can help a job shop employee to set up a process by proposing tools and the necessary parameters. This could shorten setup times and increase the process knowledge of the employee. This is a great way for new employees to gain experience on the shop floor, but you'll still need skilled workers on hand that know the ins and outs of every machine they operate which enables them to optimize the output.

"With our partners at WZL and IPT in Germany, we constantly try to improve manufacturing simulation capabilities to be able to offer digital shadows and digital twins of the most common gear manufacturing processes in the future," Kampka said. "Besides that, we will be happy to help establish these solutions by offering consultant and training services."

For more information:

FANUC America Corporation
Phone: (888) 326-8287
www.fanucamerica.com

Fraunhofer CMI
Gear and Transmission Technology Group
Phone: (617) 353-0067
www.cmi.fraunhofer.org

NASA
Jet Propulsion Laboratory
Phone: (818) 354-4321
www.jpl.nasa.gov