CRUISING WITH CURIOSITY

PT Components Help Power NASA's Mobile Laboratory

Matthew Jaster, Associate Editor

Since arriving on Mars on August 5, 2012, the Curiosity rover has been methodically checking things off its lengthy two-year to-do list. This "Cadillac" of Mars rovers—fully loaded with robotic arms, cameras, laser beams and sensors—is currently examining rocks, scooping soil, taking photographs and trying to determine the habitability of the red planet. While these Mars trips aren't exactly breaking news at this point (*see Twitter*), it doesn't change the fact that scientists, engineers, manufacturers and even technology nerds are still very excited about sending a man-made machine to another planet. This isn't just another been there-done that trip into outer space, we're talking Mars (fourth planet from the sun, second smallest planet in the solar system, location of many a terrible science fiction film).

In order for Curiosity to function properly, the Jet Propulsion Laboratory (JPL) needed PT components that could withstand the harsh environment found on the planet's surface. Companies like Forest City Gear, Kaydon Bearing and Maxon Motors responded by creating parts that will help make the mobile laboratory's two-year mission a resounding success.

So what was it like being involved in a space exploration project of this magnitude? Being curious ourselves, we made a couple of phone calls.

Forest City Gear

2x the Pressure to Succeed

If you've ever visited Forest City Gear (FCG), located in Roscoe, Illinois, owner and operator Fred Young may have asked you to touch a gear in the lobby. Not an unusual request given that the gear shop produces a wide variety of products for military, medical, construction and aerospace projects. But it's not very often that the product in question is heading to another planet.

"I would have people come in and touch the gears and then I'd let them know that their DNA is going to Mars," Young said. "They were all very excited about the idea."

How could you not be?

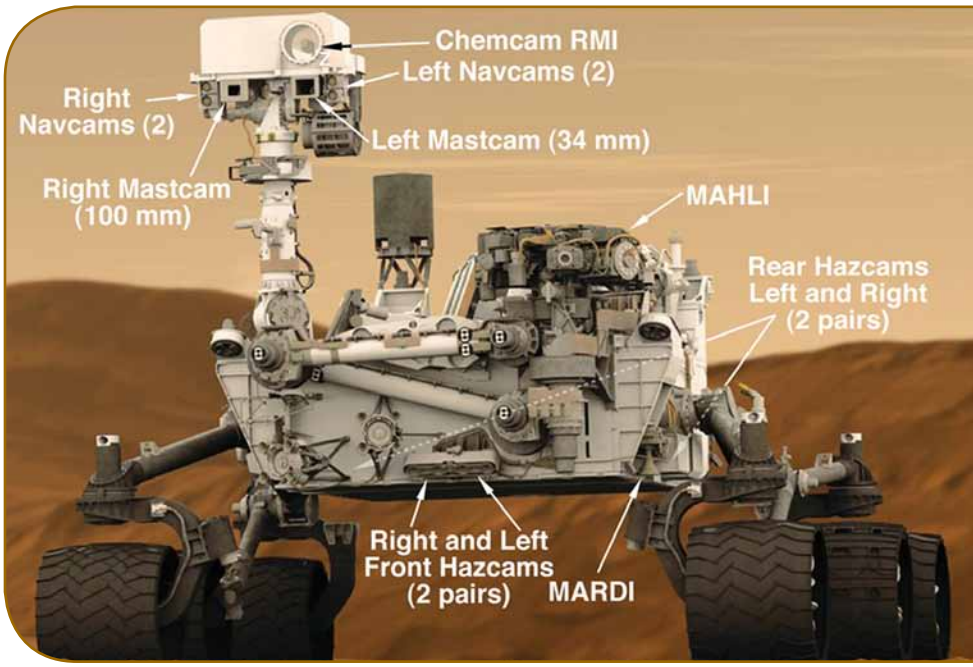
The gears manufactured at FCG have been utilized in home ice cream machines, basketball hoops in gymnasiums and space stations. After supplying gears for the Spirit and Opportunity Mars rovers, FCG was older, wiser, and more sophisticated. This was vital when the JPL requested 70+ gears for the Curiosity mission.

"They needed gears for different actuator arms, cameras, x-ray equipment, drilling equipment and lasers," Young said. "JPL was basically turning this vehicle into a mini mobile laboratory to determine the composition of the rocks and the granular structure. Given our experience with the other rovers, I knew our team could handle the request. It was an exciting job."

And one with its own unique set of challenges.

"JPL wanted 100 percent inspection of every dimension, documentation was necessary and all the gears needed to be serialized," Young said. "They tested all the actuators, drilling devices and laser beams under all kinds of strange conditions. There was serious pressure to make sure everything worked properly."

JPL, in fact, sent someone to Roscoe to help with the inspection of the gears since the timetable was so strict. "You basically have a two-week window to launch this thing and if



This graphic shows the locations of the cameras on NASA's Curiosity rover (all photos courtesy of NASA).

you miss the deadline, you've got to wait around another two years," Young added.

The magnitude of the project didn't really hit home until Young was watching Curiosity arrive on Mars six months after it had left Earth.

"This thing is going to land on another planet and it damn well better work," he said. To add more pressure, FCG had provided gears for the Sky Crane responsible for lowering the rover to the surface. "We basically had two opportunities to screw up big time if the gears didn't function."

Thankfully, the landing went flawlessly.

While Young jokes that he may be jaded on some of these space projects after participating in more than a few, he's thrilled at the level of excitement found in the FCG staff. Key members like lead gear inspector, Amy Sovina and hobbing set-up technician Kent Blatchford were proud of the work they accomplished. They even shared their stories for a short documentary web series entitled *Our City, Our Story* (*www.ourcityourstory.com*).

"It gives our staff confidence because it's such a high visibility project," Young adds, "It's exciting, it's challenging and most importantly it's a great learning experience. To imply that we had a major role in this project is a considerable leap of faith, but bottom line, the gears *had* to work and JPL had to select the best ones to make the trip."

Young credits the work done on Spirit and Opportunity as pivotal to the success of the latest Mars mission. "We were told that Spirit and Opportunity were supposed to last six months when, in fact, they lasted six years. The wealth of information they get from each mission is vital for planning the next one."

And is FCG ready if JPL calls on them for another mission to Mars?

"We're ready when they are," Young says. "Hopefully everyone at NASA and JPL remembers who we are and that we did a good job for them."

Kaydon Bearings
Meeting Incredibly High Expectations

Kaydon Bearings, located in Muskegon, Michigan, can't exactly shy away from extreme bearing applications. They've pretty much become the bread and butter of the company's work in the thin section bearing and slewing ring markets.

"We actively seek out the tough challenges such as space applications because they force us to push the envelope and make us a stronger engineering team," said Scott Hansen, vice president manufacturing planning. "Kaydon's first space application goes back to the 1960s Apollo program. Hamilton Standard had a contract to design a space suit and there were Kaydon Reali-Slim thin section bearings in the joints. The Apollo 15 Lunar rover built by Boeing used Kaydon Reali-Slims for wheel bearings since tapered roller bearings were too heavy."

Additionally, the company has provided bearings for classified government satellite applications, the Hubble Telescope and the International Space Station, rightfully earning its space credibility. After successful trips to Mars on Spirit, Opportunity and the Phoenix Lander, it was not surprising that Kaydon returned to supply bearings for the Curiosity project.

"Kaydon's Bearing Division was called upon to provide bearings for a variety of parts on Curiosity including the robotic arm, the steering actuators for the rover's wheels and in the deployment mechanism for the remote sensing

mast," said Robert Roos, senior product engineer. Since the rover boasted the largest, most advanced scientific payload of any Mars mission yet, it required a bearing capable of handling a multitude of harsh environment tasks—one like the Reali-Slim thin section bearing.

The Mars Hand Lens Imager (MAHLI) is one of the tools on a turret at the end of the rover's robotic arm.

One pair of duplexed Reali-Slim bearings is in the CHIMRA (Collection and Handling for In-Situ Rock Analysis), one of a number of devices mounted on a turret at the end of the rover's robotic arm. These angular contact bearings with a 3-inch O.D. are a key part of the thwack mechanism that must keep the primary sieve from clogging so that samples can reach the analytical instruments. The screens in the sieves have tiny holes—150 micron and 1 mm—to produce particles of the appropriate size; i.e. like a crushed aspirin. JPL engineers decided early on that thin section bearings were the best way to handle the load in the small space available, and built the design around them.

The other four sets of Kaydon bearings (7-inch O.D., 6-inch bore) support the steering actuators on Curiosity's four corners and relieve some of the load on them. This was critical during the landing. These bearings, like those in the CHIMRA, are angular contact with races and balls of 440C stainless steel and a built-in preload. JPL requested that all be shipped dry, including the phenolic separators, so they could add a space-rated lubricant.

Preparing for the Curiosity project was no different than other bearing applications back on Earth, according to Roos. "We start by looking at size and weight constraints. We try to utilize a standard size if at all possible. Then we discuss the various bearing features such as materials, separator or cage type, amount of preload or clearance and lubrication."

Kaydon then analyzes the loads and speeds to make sure the bearing meets the requirements of the application. "We also take a look at how the bearing fits to the shaft and housing. These can change significantly over the wide temperature range because of differential thermal expansion."

The most unique feature in the bearings used for Curiosity is the lubricant. "A special dry film lubricant was needed because of the extremely cold environment that the bearings need to operate in," Roos said.

Kaydon's engineering team was thrilled when called upon to work on another Mars project.

"I believe the Kaydon team derives a great sense of accomplishment and pride in taking on demanding applications such as space. Really, this is as close to exploration as most of us will ever get and it's really amazing to see the fruits of our work unfold on the surface of another planet," Hansen said.

"These are fun programs to work on," Roos agreed. "It is very rewarding to see something you have designed working exactly as you expected it would. In many applications you never hear back from the customer when everything is working fine. It's nice to actually *see* the results of your work!"

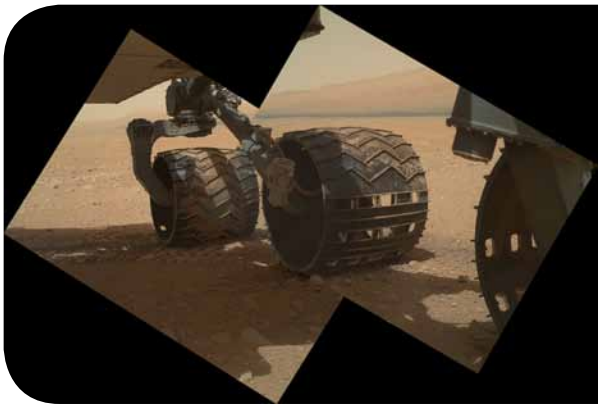
Maxon Motors

The Need for Advanced Encoder Technology

While Maxon motors were utilized on Curiosity's little brother, Opportunity, it was Maxon's encoder technology that was needed for the latest mission to Mars. The company realized some exceptions had to be made to participate in the project. The Swiss-based company normally does not sell, share or license its technology. "It's a closely held secret," said Robin Phillips, mmAG research and development. "But for a project of this importance, we made an exception."

"The environmental operating parameters that the JPL needed for the encoders were well outside of the normal range that Maxon works with," said Jeff Randall, sales engineer. "They had to be functional in very cold and very hot environments. Each part had to be "RAD hardened" or screened under tougher and tougher conditions. Many of the electrical components failed during this process. In the end, the parts that were still functional proved that they can survive the tough operating conditions required of them."

Mars applications differ from other encoder applications for several key reasons. "They require operation over a very wide temperature range (-130 to 130 degrees Celsius) since they have to survive both Martian nights and a sterilization cycle on Earth," Randall said. "Then there are the vibrations and shock from launch and landing. The biggest difference is that unlike an industrial application, it's not possible to replace a defective part. If something fails in a factory application we can send a replacement, if a motor fails on Mars it causes the loss of a multi-billion dollar mission!"



The view of the three left wheels combines two images taken by the rover's Mars Hand Lens Imager.

In contrast to the Opportunity and Spirit rovers, Curiosity can travel further distances on its six wheels and run longer without solar energy as a radionuclide battery gives energy for years. The plan is that the rover will explore the immense Gale Crater on Mars for signs of life. This is accomplished with some impressive onboard equipment including a gas chromatograph (to uncover organic compounds) a spectrometer (to analyze rocks) and a two-meter-long robotic arm (to collect the rocks).

The Maxon MR Encoder technology is built into the electro mechanic joints of the rover. The magnetic sensors are mounted on the drive shafts and are responsible for controlling the motors. Apart from that, Maxon's development services for the drive systems have also played a part in the 900 kilogram rover being able to carry out its Mars Mission successfully.

"There are 31 brushless motors on Curiosity that have encoder parts from Maxon," Randall said. "These are used for driving and steering the wheels, moving the science arm joints and moving the camera mast."

Looking back now, both Randall and Phillips reflected on the impact the assignment has had on the entire staff and how it will impact Maxon in the future.

"Maxon likes to take part in these well-known projects. It gives people that work at the factory some pride. There are rover models and displays everywhere at our headquarters in Switzerland. It's nice for the employees to see that their work helps the company support projects like Curiosity," Randall said.

"Applications like this require the latest technology in order to achieve the highest possible power density—meaning the maximum possible power out of the smallest volume and the lightest weight," Phillips said. "This is only possible by working closely with other high-tech suppliers so that we have the newest component designs and use the best production tooling for assembly."

Science and Progress

So what is Curiosity up to lately? The Mars rover has recently been digging up samples using its full array of analytical instruments to investigate a drift of sandy soil. While initial buzz had scientists down on Earth extremely excited, the rover has not detected any definitive evidence of Martian organics, according to a NASA press release. With Curiosity only four months in to its two-year mission, there's still plenty of time for breaking news stories.

Overall, NASA says the rover is exceeding expectations with all of its instruments and measurement systems performing well. This is a crowning achievement for Forest City Gear, Kaydon, Maxon and all of the other companies that took part in this historic science experiment.

"You never want to go overboard talking about a project like this. It's hard not to, though, given everything that needs to go right for it to be a success," Young said. "My wife occasionally threatens to send *me* up to Mars, if I don't pull back a little." **PTE**

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Not Just Curiosity

It may have taken hundreds of man hours to get certain Curiosity components approved by the JPL and NASA. This doesn't mean that engineers at Kaydon, Maxon and Forest City Gear have been locked in their basements for years focusing on Mars. Curiosity is but one project in a rather impressive list of applications that these companies have worked on.

Maxon, for example, has been developing motors for the commercial space industry. "We've had 10 motors on each of the SpaceX's Dragon spacecraft that has been pioneering commercial space cargo transport to the International Space Station," Phillips said.

Kaydon's Reali-Slim bearings are utilized in the hand pieces of the Intuitive Surgical da Vinci robot to transfer the movement of the surgeon's fingers to the robots arms. "We also redesigned the Honda robot ASIMO which uses nine catalog Reali-Slim bearings in inch and metric sizes," Hansen said.

Forest City provided the gears for the America's Cup racing yacht and has been incredibly busy in medical applications including heart pumps, kidney dialysis machines, x-ray positioning equipment and gears for a portable ventilator system. "We make a lot of gears and we have no idea where they actually end up," Young added.