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▶ BY RICH DZIERWA, EDITOR

Cutting CGI PDQ

A rotary cutter permits high-speed machining of compacted graphite iron.

High-speed boring of cylinders in engine blocks made of compacted graphite iron used to be impossible. CGI's fatigue strength is 180 percent that of cast iron (gray iron)—the material that's been used for automotive engines since Henry Ford's time—and its tensile strength and modulus are 180 percent and 140 percent, respectively, of gray cast iron.

But CGI can help manufacturers of diesel engines—for automobiles as well as trucks—produce more horsepower and less emissions. And while boring, and milling, the material is possible with conventional cutters, it has been only accomplished at slow speeds and high feeds, and tool life has been poor. That's fine for low-volume production—for example, many NASCAR race car engines are made of CGI, but they're essentially produced as one-offs—but such parameters are not conducive to manufacturing hundreds of thousands of engines. As recently as 3 years ago, numerous machining experts did not believe there was any way to high-speed-machine the material.

Well, the experts have been proven wrong. They have the rotary cutter to thank for their correction. Conceptualized for milling by aerospace giant Lockheed Corp., Bethesda, Md., in the 1970s, refined by Rotary Technologies Corp., Rochester Hills, Mich., and adapted to boring CGI by UNOVA's Lamb Technicon, Warren, Mich., the double-negative, circular, rotating cutter, with its ability to shed friction and heat, is carving out new paths that seemingly will change automotive design in the years to come.

The rotary boring tools are fitted with rotating cartridges, each of which holds a 1.062"-dia. round insert. The number of inserts a cutting tool has depends on its diameter. A 3"-dia. cutting tool has four inserts, for example.

Lamb Technicon

A simulation of a facemilling operation using a rotary cutter that normally would be performed on head decks of diesel engines made of CGI. Officials with Rotary Technologies, which fine-tuned the rotary cutter's design over the years, believe its application in CGI could lead to its use by aerospace parts makers machining titanium.

Peter Pasienza, Rotary's vice president of sales and marketing, said that, contrary to common assumptions, the tool does not require bolstered power from a machine tool. "We were brought up in this business to think that a big, round insert creates a lot of tool pressure. Actually, with this design, less horsepower and tangential forces are required than with a standard milling cutter, and the reason is the insert rotates."

Typically, the inserts are made of silicon nitride, but carbide versions have also been applied for high-speed CGI applications. A Si_3N_4 insert with a 10° by 0.010" land on the

insert edge has worked best.

Until recently, the rotary tool did not have a lot of proponents. Installed first on a mill, the design of the bearings and grease within the cartridge subjected the system to overheating. Those issues have been worked out, said Peter Pasienza, vice president, sales and marketing, Rotary Technologies. And, then, along came Lamb.

In the late '90s, the machine tool builder supplied three CNC machining centers to a European automotive components manufacturer attempting to switch to CGI from gray iron.

"They programmed conventional cutters for feeds and speeds associated with gray iron, but tool life fell apart extremely fast," said George Georgiou, engineering manager, machining systems, Lamb Technicon.

To make production requirements, Lamb supplied—free-of-charge—a fourth CNC machine. "We learned an $800,000 lesson," Georgiou said. "It was one of the things that kick-started our research into CGI."

Soon after, Lamb identified the applicability of the rotary cutter to machining CGI, with the rotating nature of the insert, continuously supplying a "new" tool edge, being the key. Heat is dissipated over the insert's entire circumference.

Not surprisingly, the points where a conventional cutter meet the surface of a CGI part and where chips rub along its rake face are highly abrasive. Temperatures there are usually higher than at the shear plane—up to 900° F vs. 300° F, respectively. The high temperature quickly softens the substrate of a conventional cutter, coated or not.

When chips hit a rotating insert, though, they're expelled from the cutting zone, eliminating heat buildup due to chip rubbing.

"You basically eliminate that friction/heat zone," Georgiou said. "There is still some rubbing, because you need friction to propel the insert, but it is negligible compared to what you have with a conventional tool."

On CGI engine blocks supplied by German automaker The Audi Group, Lamb found that, when machining the blocks with conventional cutters at 800 m/min. at a depth of cut of 1.5mm with a 0.2mm chip load per tooth, the tool failed immediately. With the rotary tool cutting at the same parameters, inserts suffered only 0.15mm (maximum) of edge wear in 15 minutes.

Rotary Technologies

Lamb Technicon

A rotary cutter mill (left) and boring tool (right). The number of cartridges/inserts capable of being assembled into a tool body varies, for example, 4 in a 3" body and 6 in a 12" cutter. But Lamb Technicon is near completion of the development of a downsized cartridge that will allow more inserts to be loaded onto a tool body. Unlike the original cartridge, the smaller version will not have rolling element bearings and, therefore, no maintenance requirements.

Worth the Cost

DaimlerChrysler Corp.'s Trenton, Mich., engine plant is not machining engine blocks out of CGI, but it is enjoying the benefits of the rotary cutter on gray iron blocks. It is being employed on mills on a transfer line to machine 500,000 blocks per year for Chrysler minivans. The areas dry-milled with the rotary cutter are the top and bottom of the block. (Tests are underway to apply the tool to the front and back of the block.) Speed is approximately 2,050 sfm. Feed is 121 ipm. The number of tool changes has decreased to 46 from 697 per year.

Doug Roberts, one of the Trenton factory's tool engineers, told CUTTING TOOL ENGINEERING the only drawback to applying the rotary cutter is the insert's 1.062" diameter. It requires special adjustment within existing workstations.

"When you have a 14" effective-cut rotary mill, the OD of that mill is 15"," he said. "A lot of the equipment here was not designed to afford that much room."

The facility's maintenance department is modifying the transfer line to accommodate the milling of the rear and front faces of blocks. Whatever the time and cost of the retrofit, as well as the $40 price tag on the inserts and $225 cost of the cartridge, Roberts said it is worth it.

"My job and the job of my associates is to save money while producing a quality part," Roberts said. "We were running in the neighborhood of 500 pieces per cutter. Today, we hit tool life somewhere between 5,000 and 7,000 parts."

The DaimlerChrysler plant has employed the rotary cutter since early 2000. But that was not the first time engineers at the factory were exposed to it. It was evaluated several years earlier but deemed subpar because of issues with the cartridge's bearing life.

"The fact that we had problems with heat in the bearings and the grease as little as 9 years ago probably scared people off," said Rotary Technologies' Pasienza.

"With the advent of new bearing materials and greases," he continued, "we solved the problem of heat within the cartridges for machining gray iron."

He admitted that the tougher job of machining CGI still poses a small heat problem within the cartridge. Georgiou

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Tough engines

In Europe, where fuel is expensive and emission standards are very tight, car and truck makers are keenly interested in using CGI to cast their diesel engine blocks and heads. The material, which on a scale of toughness and machinability falls between cast gray iron and the infrequently machined nodular iron, provides the capability to design lighter-weight, improved-fuel-efficiency diesel engine blocks with thin structural walls and cylinder walls that do not expand under the significant compression of pistons firing. DAF Trucks NV, the Dutch diesel truck manufacturer, found that the CGI version of its 6-cylinder, 12.6-l. engine block produces 530 hp, 50 hp more than the same block made of gray iron.

"CGI is so much stronger than gray iron in that when you fire off the piston, all the power stays on top of it" instead of some dissipating along the sides, said George Georgiou, the lead engineer who has studied high-speed-machining techniques for CGI for Lamb Technicon.

Many North American diesels, if cast in CGI today, would meet 2005 emission standards. Due to the CGI cylinder walls' resistance to expansion, there is a greatly reduced occurrence of "blowby," or unfired gas flowing past the piston rings.

Automaker Audi has been producing as many as 10,000 CGI V-8 engine blocks per year in flexible manufacturing cells with conventional cutting tools. The company has high tooling costs, which are insignificant because the engines go in upper-end vehicles that sell for some $80,000 in the U.S.

However, the company will soon produce 200,000 V-6 CGI engines per year for other models—as will Ford U.K. for Jaguars and SUVs. The manufacturing efficiencies high-speed machining offers will become even more important as these two leaders ramp up production.

—R. Dzierwa

said that can be countered somewhat in milling by using the up (conventional) milling method.

Up milling calls for the tool to enter the cut at a slight angle—15°, for example. Chip thickness starts at zero and gets thicker thoughout the cut. This is the opposite of down (climb) milling, the more standard approach to milling engine blocks that calls for the tool to enter the cut at a severe angle—90°, for example—and take a maximum depth of cut. As the cut continues, the chip gets thinner, until it reaches zero at the end of the cut.

Up milling is bad for tool life in standard cutters. Because of the forward progression and the forward rotation of the cutter, the heel of the insert is rubbing on the workpiece all the time, creating heat, friction and wear.

Up milling is good for the rotary cutter, as it increases the cutter's bearing life. In addition, Georgiou said this process is critical to machining complex features inherent in an engine block, including thin-wall sections. "It helps reduce impact vibrations on the part, which translates into a better finish."

The softer entry angle is also important, given Si_3N_4 inserts are mostly used on the rotary cutter and they are more prone to fracture than carbide ones.

A Small Improvement

Lamb engineers are addressing bearing life as they work to downsize the cartridge. Following 10 months of work, the company has nearly completed the design of a cartridge that will have been shrunk to about 0.600". This new configuration, obviously, will also allow more inserts per tool body.

"With the boring tool we created and the original cartridge design, the smallest job possible was just under 3"," Georgiou said. "So you couldn't use it for anything other than boring a cylinder. With a smaller cartridge, we can get smaller bores."

On the milling side, Georgiou said that a cartridge about half the size of the original—he won't talk specifics until the new design is officially unveiled—should allow more teeth on the same body. "An OEM could increase its feed rate across the part."

Georgiou said the new cartridge could open up opportunities in non-engine-block applications.

"The aerospace sector machines a lot of titanium," he said, "and they love running endmills. By developing a smaller-diameter cartridge, we can get it into an endmill as small, perhaps, as 1½"."

Pasienza said he'd like to take the redesign a step further. "If we could somehow get this cutter configured with positive rake or a pos.-neg. design, that could open the door to its use in steel and a lot more aluminum applications than the few we participate in today."

Rotary Reliability

DaimlerChrysler's Roberts cautions potential adopters of the rotary cutter of one thing: "Even though this is a fixed-pocket cutter and the company says there is no adjustment, that is not the case. To me, no adjustment means you throw the stuff in, you put it on the machine and away you go. We've not experienced that."

This dictates, according to Roberts, dedicated supervision. "You need a reliable person to set this thing up. You don't want 10 different people going about that."

Critics of the rotary tool have said you also need a dedicated person to perform cutter upkeep. Pasienza discounts those claims. "My competitors talk about how big a maintenance project this is," he said. "Actually, there's no maintenance at all as long as you clean the cartridge. The only thing you have to remember to do after indexing the insert and cleaning the cartridge is to regrease it through a tiny hole in the back. I can index and set up a 10" milling cutter with 13 teeth in less than half an hour."

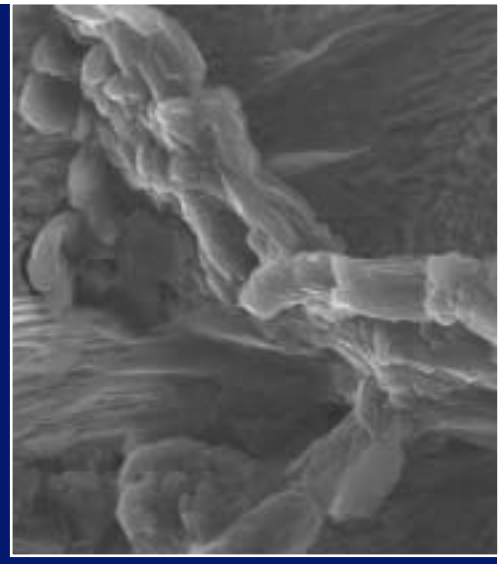
As optimized as the cutter system may already seem, Georgiou said Lamb will continue to improve the cutter. For example, there is no grease required in the new design. Plus, the company intends to address slight thermal cracking that occurs to inserts during high-speed CGI milling. "Historically, when a milling insert entered a material at ba-

sically ambient temperature, it saw its temperature jump to as much as 900° F then quickly cool via air or coolants, and cracks would occur. Insert manufacturers have supposedly developed thermally resistant carbide and Si_3N_4 inserts. With the rotary insert running at high speeds in the tough CGI, the thermal issue remains."

If all this information piques your interest to the point you want to investigate the rotary cutter, you should know that the material you intend to machine will determine who you should contact. Rotary Technologies maintains rights for non-CGI projects, including engine block machining. Lamb, in assisting Rotary in advancing the use of the rotary cartridge system, holds exclusive worldwide rights to new and retooled application of the tool for milling and boring CGI. Thus, you'll only see the cutter machining CGI on Lamb machine tools.

Georgiou explained an exception to this, however. He said that if a good customer has a non-Lamb machine suited to cutting CGI, Lamb will help it apply the rotary cutter. "We'll make sure the machine can handle the rigidity requirements of these operations."

If the machine can, Lamb seems bent on rounding up the right people, circling the wagons, even jumping through some hoops to help you correctly apply the rotary cutter.



Lamb Technicon

At the microstructure level, CGI (shown) maintains some of the graphite characteristics of cast (gray) iron that make the latter so easy to machine. Although CGI's graphite content is vermicular, or coral shaped, not flake-like as in gray cast iron, it is similar in that it still allows a cutting action based on breaking from graphite pocket to graphite pocket. However, to continue the shear and breaking to the next pocket requires 20 to 30 percent more load than cutting gray iron. While nodular iron, known for its very difficult machinability, also contains graphite, the graphite components are present in nodules, not flakes or coral-shaped forms, so, when cutting, the tool rarely breaks into graphite components.