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cover story

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Decisive Deburring

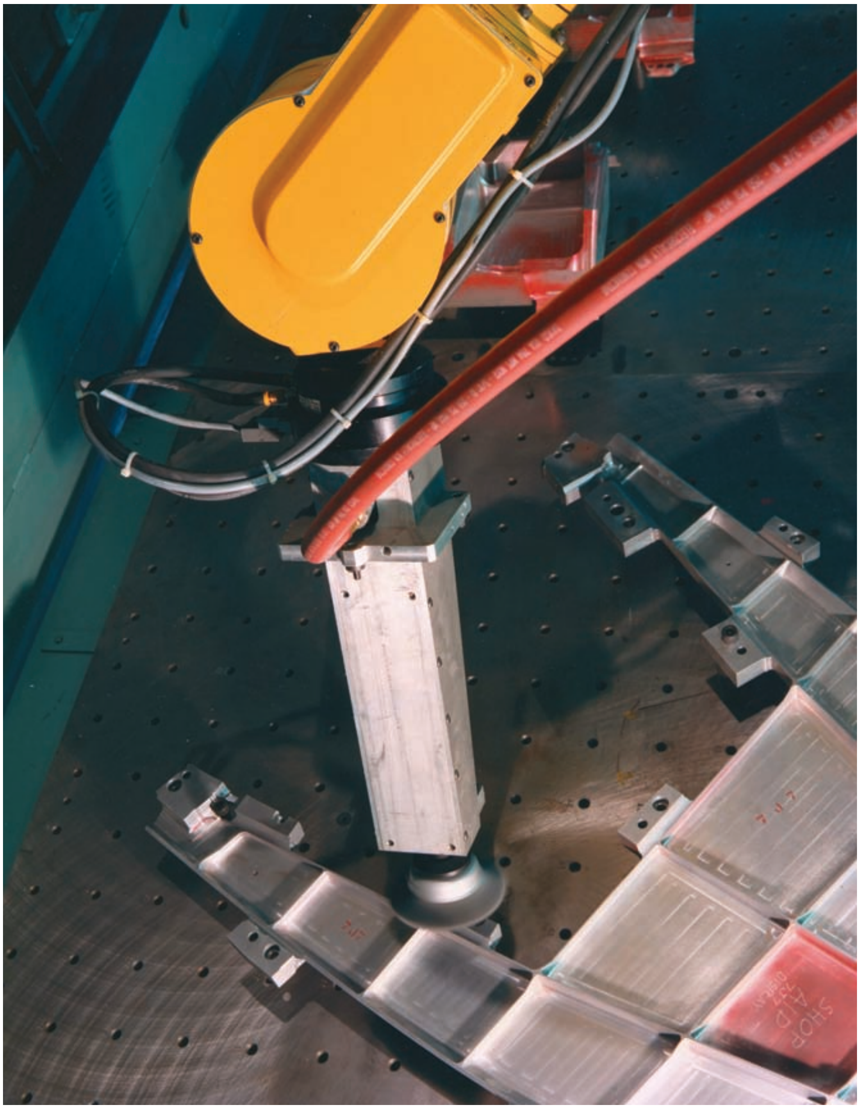
Robotic deburring eliminates part inconsistencies that occur when deburring by hand.

Two steps forward, one step back. A component is machined on a CNC lathe or mill, then put in front of a guy with a hand grinder to remove burrs. The part's final quality is in jeopardy, the time required to deburr the part varies, and the shop worker is exposed to grinding dust, tedium and, perhaps, repetitive-motion injury.

One way to maximize part quality and consistency, speed part finishing and reduce workplace hazards when deburring is through robotic automation. Although not the answer in every situation, advances in robotic technology, tooling and programming are widening robotic deburring's range of effective application, as well as its acceptance in industry.

The most obvious benefit of robotic deburring is the elimination of repetitive and inconsistent handwork. Robert Little, product manager at ATI Industrial Automation Inc., Apex, N.C., pointed out that parts that are candidates for robotic deburring are most often being deburred by hand, not by mass finishing processes such as vibratory tumbling. "Shops are deburring by hand because they are trying to deburr just certain areas and not let any other material be knocked off," he said.

Hand deburring is labor-intensive and, therefore, makes a good candidate for robotic automation. However, production volume is an important


Acme

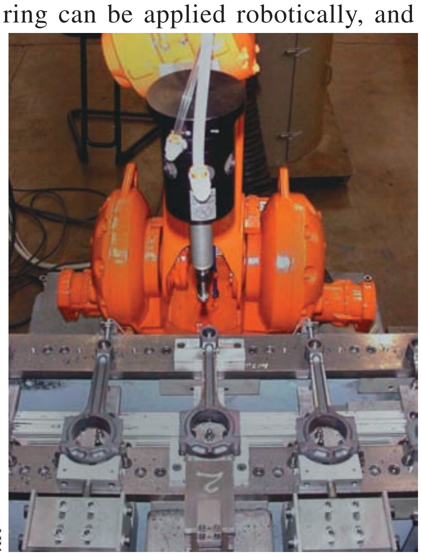
A deburring system assembled by robot integrator Acme Manufacturing processes an aluminum airframe component.

consideration, too. If a shop deburrs just a few parts once in a while, it's hard to justify investing in a robot. Keeping the robot busy is crucial, whether with long production runs or multiple families of parts. Joe Saad, director of sales for robot integrator Acme Manufacturing Co., Auburn Hills, Mich., said robots can operate continuously and "we promote running 20 to 24 hours a day. If you have a one-shift operation, it's probably not going to justify a robot. You have to run at least two shifts."

Burr location is a factor in choosing robotic automation as a deburring method. Ron Jech, general manager of custom deburring systems provider Online Services Inc., Cleveland, said a small burr on a flat part often can be removed in a pass-through situation, where a conveyor takes the part through a brush. If a burr appears in multiple places, such as a larger burr on each tooth of a gear, "then the robot often works well because it can go around the whole part," he said.

How Big a Burr

Virgil Wilson, senior engineer for material removal at Fanuc Robotics America Inc., Rochester Hills, Mich., said that determining the size of the burr is the first step in deciding how to remove it. "Determining the size is not going to tell you absolutely the solution, but it will eliminate certain solutions," he said. Many of the tools that have been developed for manual deburring can be applied robotically, and classifying the size of the burr can help determine which tool to choose.



ATI

A radially compliant Flexdeburr tool deburrs connecting rods.

Wilson uses a burr classification system developed by brush and abrasive maker Weiler Corp., Cresco, Pa. The system categorizes burrs in five classes, with Class 1 being the smallest. An example of Class 1, he said, is "a microburr that would occur in a grinding operation. You may have to use a magnifying glass to see it, but it is there."

A Class 2 burr breaks off the parent material fairly easily. "It's just kind of hanging there," he said. "I've seen people use the No. 2 pencil lead test. If you can remove it with a No. 2 pencil lead without the lead breaking, then it is a Class 2 burr." With Class 2, "an impact actually removes the burr," he said, so the use of softer media, such as Nylox nylon abrasive filament brushes, may be appropriate.

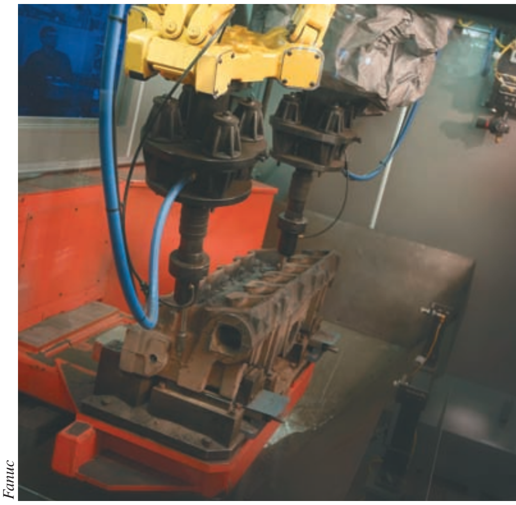
A Class 3 burr is well-attached. "It is going to take more energy to remove it," Wilson said. "That's when you start getting into coated abrasives, burs and things of that nature."

A Class 4 burr is heavier yet, and a Class 5 burr is a major outcrop such as overflow gates on gray iron, for which, according to Wilson, "you are going to take a grinding wheel with a lot of horsepower and just grind it off."

Who Moves First?

A robot can expedite deburring in different ways. It can carry the deburring tool and move around the part, or it can carry the part to the deburring tool or tools. Leif Britting, senior project manager at ABB Automation Robotic Products, Auburn Hills, Mich., said carrying the part to the tool has advantages. "Number one," he said, "you don't have to fixture the part. The gripper or end-of-arm tool becomes the fixture." In addition, the robot can present the part to multiple deburring tools quickly, such as several belt sanders with different grits. "You can take the part from belt to belt. It takes longer to have toolchangers and carry the tools to the part," Britting said.

According to Saad: "If the part is large and we are trying to do edge deburring and we have one media required, then we will pick up the tool. If the part is smaller and we have multiple media requirements, then we like to pick up the part and take it through the various sequences. I'd say it's about a 60-40 split. We generally like to pick up the part, but about 40 percent of the time, we'll pick up the tool."



Fanuc

A Fanuc F-200iB robot equipped with air hammers and custom chisels processes a cast-iron diesel engine head.

Typically, a robot is programmed for deburring by stepping through the intended toolpath point-by-point and teaching it to the robot controller. Deburring programs can also be created offline using 3-D CAD files. For example, the Roboguide simulation package from Fanuc enables a user to create a virtual workcell using IGES files of the robot, the fixture and a 3-D model of the part. After the workcell is designed on the computer, Wilson said, "you select an edge on the part that you want to deburr, set certain parameters, and click and trace a path."

The program creates a toolpath that can be downloaded to the robot and run from its controller. In many cases, this method is faster and more accurate than the point-by-point technique. It also permits running a simulation of the deburring operation before any hardware is put into place.

Acme's Saad said many shops have an exaggerated view of the complexity of robot programming. "They say, 'I don't have the educated people to be robot programmers.' I say give me one of your polishing guys or deburring guys, we'll teach him how to run the robot. It's much easier to teach a polisher or deburring guy to run a robot than it is to teach a robot programmer to be a finisher," he said.

Compliant Tooling

Even the most rigid and accurate robot is not as stiff or precise as a CNC machine tool. Positioning the part in a fixture adds another level of variability. When deburring with a hard tool, such as a bur or grinding wheel, programming the controller to follow a complex part can be time-consuming, and the relatively low rigidity of the system can promote chatter. ATI's Little said compliant tooling provides a way to minimize chatter and reduce programming time. A compliant tool yields to irregularities in the part, enabling programmers to space teach points further apart, which speeds the programming process.

ATI offers both radially and axially compliant end-of-arm tools that allow the deburring bit to follow the part profile and compensate for surface irregularities while maintaining a constant, settable force. ATI's air turbine-driven Flexdeburr tool is radially compliant; its rotating spindle is supported in the X and Y axes by pneumatic pressure. Changing the pressure changes the amount of force needed to deflect the spindle. The tool is available in three sizes with air motors capable of 30,000 and 60,000 rpm. For the largest unit, compliance at the collet is ±0.35", and air pressure from 10 to 60 psi creates a compliance force of 2.1 to 10.2 lbs. The tools use standard burs made for rotary applications.

ATI's axially compliant deburring tool, called Speedeburr, is compliant in the Z-axis for edge deburring and chamfering and features a special 45° cutting bur. The tool, also air-driven, operates at 18,000 to 25,000 rpm and provides ±0.31" axial compliance at a force of 0.23 to 5.77 lbs. The radially compliant tool can deburr a range of part contours, ATI says, while the more specialized axially compliant unit is better for edge deburring and chamfering.

Air pressure, and resulting compliance force, can vary according to the material being deburred. "Aluminum might require lower stiffness than steel,

Blade runner

Darrell Guthrey is a senior process development engineer at McCauley Propeller Systems, Columbus, Ga., a division of Cessna Aircraft Co. Previously, he worked for a manufacturer of turbine engine components, and was involved in deburring and radiusing titanium compressor blades after a broaching operation. Radiusing is common in aerospace applications to relieve stress and prevent cracking. The radius required, he said, "was 0.005" minimum to 0.040" maximum, but we wanted to give them 0.015" to 0.025".

After a blade was broached, a worker deburred and broke its edge by hand with an Al_2O_3 grinding wheel. "The broach could typically run faster than that person could deburr," Guthrey said. "So they would start getting behind and taking shortcuts. We had a lot of inconsistencies."


Weiler

A robot carries a turbine blade to be deburred by a nylon abrasive filament brush from Weiler.

After deburring and edge breaking, the operator carried the part to another machine where the corners were buffed to the final radius. The machine had four buffing heads with cotton wheels and employed a dry abrasive compound. The blade was rotated sequentially through the heads until all corner radiuses were buffed. "It was a pretty complex machine," Guthrey said. "It was expensive, messy and dirty." In addition, each different blade required unique fixturing, so new workholding had to be installed with every new part number that was processed.

Guthrey was part of a group that put together a robotic cell to improve the process. The cell was assembled by Hammond Machinery Inc., Kalamazoo, Mich., and featured a Fanuc M710i robot with an RJ3 controller. The robot carried each blade to an electric deburring tool with a ⅛"-dia. carbide bur. The tool had pneumatic passive compliance, which Guthrey said was "key. Without some kind of compliance, you really cannot do this type of work."

The deburring unit featured a toolchanger that automatically replaced the bur after a certain number of cycles. After the bur created an edge break of 0.008" to 0.015" on the blade, the robot took it to a machine employing a nylon abrasive filament brush from Weiler Corp. Guthrey said Weiler representatives developed a brush specifically for this application. He said one brush buffed thousands of parts, compared to about 800 for each cotton wheel.

A major benefit of the robotic cell was consistency. "Either all of them were going to be good, or all of them were going to be bad," Guthrey joked. The setup also reduced manpower requirements by two positions, as deburring and buffing operators were no longer needed. Buffing with brushes also eliminated the dust and debris generated previously. Finally, because the robot carried each part through the cell, no special fixturing was required.

Guthrey created programs for each part number. "I would teach the robot to pick up the part and deburr it," he said. "Even though the deburring tool was compliant, it took substantial amount of time." Guthrey had a "recipe" for each part number in which he'd control spindle speed for the tool and the amount of compliance.

A later version of the cell incorporated a camera to identify each part. It changed the program in seconds and ran it automatically, enabling different part numbers to be run back to back.

Guthrey pointed out a distinction between burr removal and edge finishing. Removing burrs alone involved simply brushing the part, but "we were actually creating geometry on the part by breaking the edge to a certain size, then rounding that edge with a brush."

—B. Kennedy

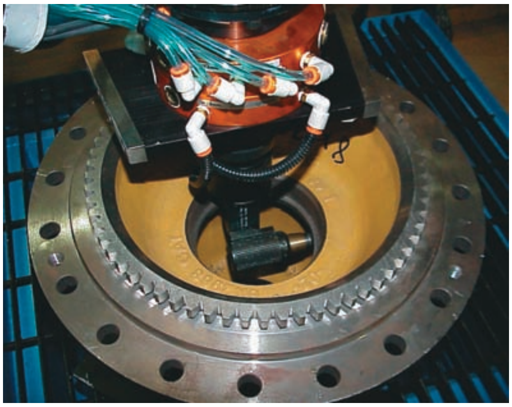
depending on the type of part and how much the user wants to take off," Little said.

Another pneumatically compliant deburring tool, the UltiBurr from Robotic Accessories Div. (RAD), Tipp City, Ohio, provides compliance in X, Y and Z axes directions of ±1.06" at the collet. Air pressure of 10 to 90 psi produces a compliance force of 5 to 33 lbs. RAD says the unit should be pressurized to a level that assures that the spindle is deflected out of zero position when deburring, and the tool should be applied in climb milling mode. The tool uses standard burs.

Beth Van Haaren, RAD design engineer, said that in addition to providing a way to adjust the tool for material and desired removal rate, compliance can also compensate for tool position. The force the tool exerts on the part changes if the robot is operating from above, below or the side of the part. "If you are going to change positions during your work cycle, then you might want to get a programmable regulator and vary the amount of pressure," she said. "When you're in one orientation and move to a different orientation, you need to change the pressure to get the same amount of compliance."

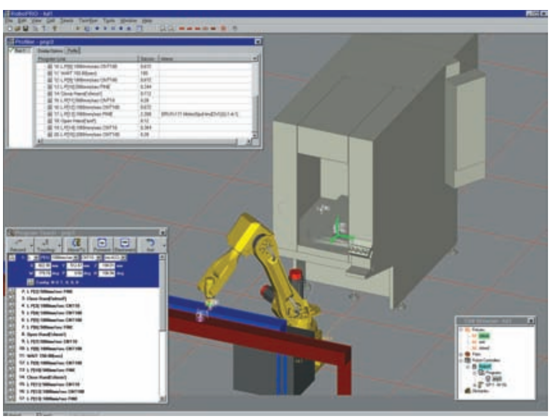
Brian Connaly, senior applications engineer at ABB, said the use of compliant tooling can help extend the life of deburring media. For example, when a robot takes a part to a brush on a fixed toolpath, the force the brush exerts declines as the brush wears. By using compliant tooling, he said, "we're always maintaining that force on the part, compensating for the wear of the brush and extending tool life," he said. "Without the adjustment provided by compliance, you might use that brush for 1,000 parts and throw the brush away." Compliant tooling, on the other hand, might extend brush life to 5,000 parts.

Rick Sawyer, manager of applications engineering for Weiler, said that even with compliance, hard tooling must be programmed carefully to avoid unwanted changes in part geometry. On the other hand, "with abrasive filament brushes, we're not following every step, every notch, every edge," he said. "We are just plunging the part into the brush, so programming is much simpler."


ATI

An axially compliant Speedeburr tool deburrs the hub of a large gear.

Brushes do have their own programming requirements. To conform to a part but still deburr it, the brush must be run just fast enough. "If you run the filaments too fast across an edge, they start to bounce off the surface," Sawyer said. For deburring applications, "we're generally around 2,500 to 3,000 sfm," he added.


Fanuc

Robotic deburring simulation packages enable shops to construct and test a virtual deburring workcell offline.

An Accurate Conception

Connaly feels many shops have misconceptions about the accuracy that can be achieved with robotic deburring. "When they go robotic, they automatically assume that they are going to be holding tolerances that they could never hold before. That's not true," he said. It is true that manual deburring can be "all over the map," he added, and "with a robot, you're going to get close, you can hold some tolerance, but you can't hold in the tenths."

ABB's Britting noted that "the quality is consistent. Not necessarily better than a human, but it is consistent. With the robot, it doesn't matter what time of the day or day of the week it is."

Sawyer said that what happens upstream of a robotic cell plays a role in its accuracy. "The cell repeatability is only as accurate as what comes in. If your window coming in, meaning min. burr to max. burr, is quite large, an automated cell can't compensate for that," he said. "When burrs vary within a certain limited range, then the system is very repeatable."

Accuracy can also be an issue in heavy deburring applications where rigidity of the robotic system is a consideration. A typical serial-link industrial robot resembles a human arm and torso, with joints along its length that give it its axes of flexibility. In general, a serial-link robot has sufficient rigidity to handle light to medium deburring on parts, but might have a problem with heavy deburring.

A parallel-link robot provides greater rigidity than a serial-link unit. Fanuc's F200iB parallel-link robot, for example, features six linear ballscrews pivoting on a base on one end, while a face plate to hold the part or deburring tools is mounted on the ballscrews' other ends. The framework of ballscrews provides excellent rigidity as well as permitting movement in six degrees of freedom.

Force Control

When a worker deburrs by hand, he applies more or less force depending on the size of the burrs. Depending on variations in the part contours and the size of the burrs, robots also need to have some form of force control. There are two basic approaches: "through the arm" control and "around the arm" control.

In through-the-arm control, a force

RAD

The Ultiburr deburring tool is compliant in the X, Y and Z axes.

sensor sends feedback to the robot controller, which dynamically adjusts the toolpath. Around-the-arm control utilizes a device between the robot and the tool that operates independently and maintains a programmed force by the tool on the part.

Not DIY

The complex interaction of robot, abrasive media, fixturing and part features make it clear that adopting robotic deburring is usually not a do-it-yourself situation. More and more, robot OEMs or integrators set things up. ABB's Connaly said few customers do it on their own any more, and it may cost more or even be dangerous for the ones that do. For example, "if you take a 6"-dia. grinding wheel that's turning at 1,000 rpm and jam a part against it with about 20 lbs. of force, you need some force to retain the part or it is going to take off," he said. "We have a lot of expertise with how to grip parts to make sure they are properly contained, so that you don't lose it during the deburring process."

Acme's Saad said, "Certainly anyone can buy a robot and anyone can buy a deburring tool, but you have to know the recipes to put it together. That's where a robotic integrator plays a major role."

Increased ease of use and accuracy, as well as lower costs, have increased the acceptance of robotic deburring. Saad noted that like computer equipment, "the cost of robotics has really come down, and that has made it much more affordable."

He pointed out that the flexibility and adaptability of robotic technology fits with industry's trends toward small lot sizes and cellular manufacturing processes. "From our perspective, we're a machine builder. We replaced a lot of our inline hard automation machinery with robotic integration, because we're trying to accommodate the current mode of manufacturing," Saad said. △

The following companies contributed to this report:

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