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SMALL DOSE

Machine shops scale down to make micro medical devices

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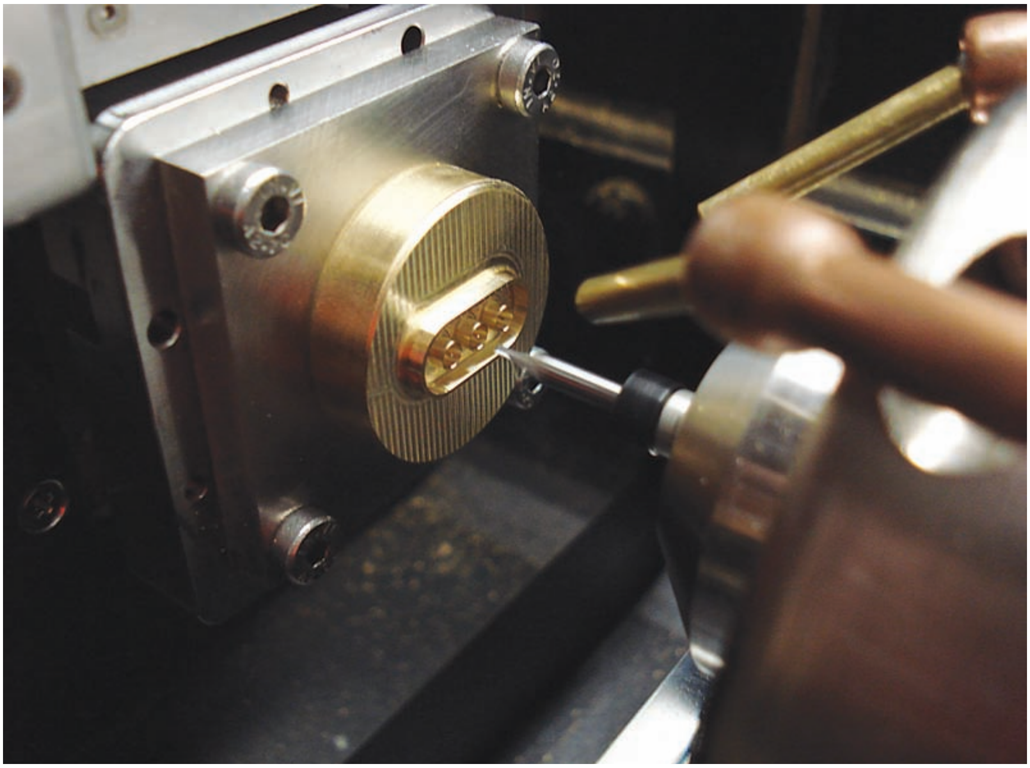
First-Place Finish

Imparting fine surface finishes when micromilling

By Bill Kennedy, Contributing Editor



Microlution

As milling tools shrink in diameter, a number of factors loom large in generating fine surface finishes.

As milling tools shrink, several factors loom large in generating fine surface finishes. The productivity and surface finish a tool achieves depend on specific combinations of cutting speed, feed rate, tool runout and coolant application. In micromilling—involving tools 0.020" in diameter and smaller—the size of the tool often dictates strategies to maximize performance and surface finish.

There are several key milling practices that help impart fine surface finishes. They include running at ultrahigh spindle speeds, carefully monitoring chip load, employing climb milling when possible and using CAM software to develop toolpaths that enhance surface finishes. Researchers also point to promising developments that can improve surface finishes in areas as diverse as using atomized cutting fluids and milling ultrafine-grain workpieces.

Perhaps the most important factor is the need to run micromills at high rpms to achieve optimal cutting speeds. With rpm determined by the formula sfm × 3.82 diameter, the smaller the tool diameter, the faster it must turn to generate recommended cutting speeds.

To generate the 220 to 250 sfm recommended for machining stainless steel, Jim Libby, owner of medical partmaker JLP Machine and Welding, Kingston, Mass., recommends running a 0.015"-dia. endmill at 56,000 to 64,000 rpm, and a 0.010"-dia. endmill at 84,000 to 95,500 rpm. "To get a nice finish, you need to spin that tool fast enough that the geometry and chip loading will work and the tool will shear the metal properly," he said. Libby, who also is application engineer for toolmaker Microcut Inc., Kingston, Mass., pointed out that when running too slow and cutting stainless steel, built-up edge occurs, ruining surface finish and breaking the micromill.

Ferdinand Krall, senior CNC programmer at Protofab Inc., Petaluma, Calif., said, "Most machines will never reach the recommended surface footage for these small tools." Protofab, a CNC shop, uses aftermarket spindle speeders (air turbines) up to 50,000 rpm on some applications. "We ran a job on an older machine that only had an 8,000-rpm spindle. It was just not getting anywhere timewise, and there was a problem with poor surface finish and burrs. As soon as we picked up the rpm closer to what it's supposed to be, it made a tremendous difference," Krall said.

Of course operating factors other than spindle speed affect surface finish. Chip load is one. Performance Micro Tool, Janesville, Wis., manufactures tools as small as 0.0002" (5μm) in diameter. PMT President Dave Burton said, "The bigger the chip load you take, the bigger the potential for a poor finish, but the faster you can produce your part and the longer the tool life. With a bigger chip, more heat stays in the chip and stays out of the tool."

Regarding surface finish, he said: "It's always going to be a trade off between productivity and finish. I know of a customer cutting copper and running tools from 0.004" to 0.009" in diameter who takes 8 hours to cut a part, even though he has a 100,000-rpm spindle. He could probably do it in one-fifth of the time, but he has a surface finish requirement." Chip load equals feed rate ÷ rpm × the number of cutting flutes, so a faster feed rate will boost chip load and speed throughput.

However, too low a chipload also can be a problem. "When you reduce the feed rate to a certain level, you end up using the tool more like a grinder than a cutting tool," Burton said. Most tools have a positive rake to shear the workpiece. "If you use less than the suggested chip load, only a percentage of the tooth bites in and you start to wear a little radius on the cutting edge. Then that radius kind of just bumps the material around, smearing the surface." That smearing can actually produce a smooth surface, but "as you can imagine, tool life goes way down," Burton said. "If you applied a 0.010"-dia. endmill with a 0.000001" chip load, you would end up honing your tool and would have a cut that might be 0.10" long before the tool snapped."

Libby said tools down to 0.010" in diameter can be run as slowly as 10,000 rpm,

JLP Machine

JLP Machine employed a 0.015"-dia. Microcut ball mill to machine features, including a 0.015"-wide slot, on a tiny medical component made of polyetheretherketone (PEEK) polymer.

but the shop must be willing to accept the long cycle times and frequent tool changes that result from the low feed rates required to generate the correct chip load. At high or low rpm, he noted, the correct combination of speed and feed will impart fine finishes. He added that JLP Machine regularly achieves finishes of 0.4μm R_a and better with microtools.

Climb preferred

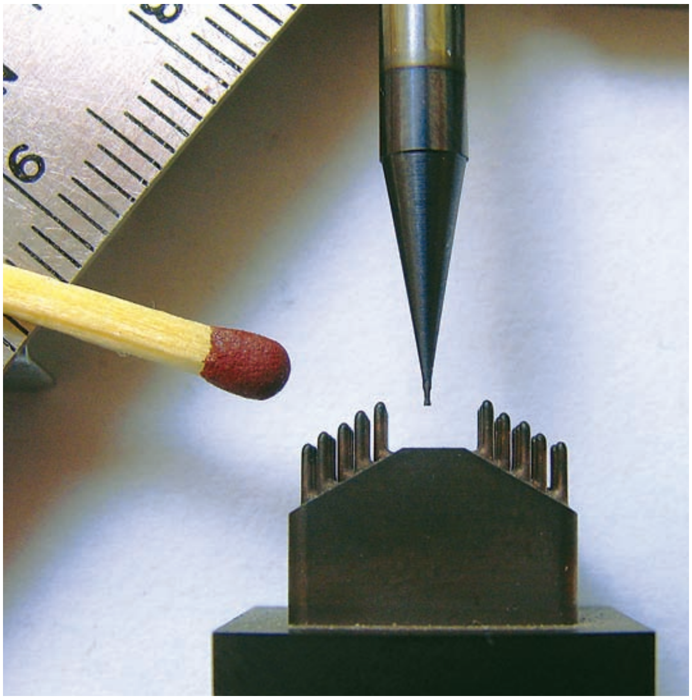
Maintaining a constant chip load is essential to obtaining a fine surface finish. As a result, climb milling is typically preferred over conventional milling. In climb milling, the cutter tooth enters the work at full depth, then cuts a progressively thinner chip as it exits. In conventional milling, the tooth begins the cut at essentially zero depth and exits the work at full depth. As such, Libby said, tool loading in conventional milling is not as predictable as in climb milling, and may be influenced by workhardened material on the part surface. Climb milling, on the other hand, is more stable and thereby imparts a finer surface finish, especially in workhardening materials like stainless steel.

However, conventional milling might be necessary in certain applications. "Sometimes, if you are having chatter, you can eliminate it by changing to conventional milling," he said. "It's an antivibration technique. If you are having chatter, the forces you are putting on the part may be more inclined not to vibrate if you conventional-mill." However, he noted that conventional milling typically does not impart as fine a surface finish as climb milling.

Another way to control surface-degrading vibration is by using shorter endmills. "With micromachining, you always want to use the shortest-possible tool to maintain rigidity," Libby said. "If you have a 0.020"-wide slot that is 0.010" deep, try to get a 0.020"-dia. endmill that has a 0.010" length of cut." The feed rate or chip load a tool can handle without vibrating, and in turn the best surface finish it can produce, can be related more to the length and rigidity of the tool than the recommended chip load.

Chips that are recut or clog the flutes in a micro-endmill also can damage surface finishes. One solution is flushing the chips with coolant. Again, however, the small size of the tools and chips involved may require a different approach than simply applying flood coolant.

Dr. Richard DeVor, college of engineering distinguished professor of manufacturing in the Department of Mechanical Science and Engineering at the University of Illinois, and his colleague Prof. Shiv Kapoor have performed extensive research in micromachining. In some

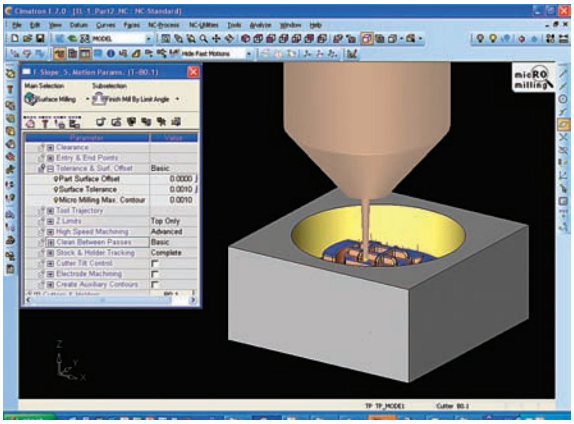


Cimatron

When micromilling, the size of the tool itself often dictates the strategies required to maximize performance and surface finish.

micromilling scenarios, DeVor said, “when we applied the coolant as you would with flood coolant, we found that we weren’t getting much of an effect. That’s when we began to realize that, probably because of the size of the cutting zone and the viscosity and surface tension associated with the cutting fluid, we weren’t penetrating very well.”

As a result, the researchers applied atomized cutting fluid, “where we could get the droplet sizes down to 10µm to 15µm.” The technique produced multiple benefits, DeVor said. “Not only were we getting good penetration and good lubrication, with much better tool life and significant improvement in tool wear, but,



Cimatron

Software developer Cimatron says its CimatronE Micro Milling CAM software can create toolpaths capable of producing tolerances as tight as 0.000004", using cutting tools as small as 0.004" in diameter and smaller and running at 150,000 rpm or faster.

due to evaporative cooling, the temperature actually went below ambient during cutting.”

On the same subject, PMT’s Burton said some shops have found that the low viscosity of WD-40 lubricant enables it to flow freely between tiny tool flutes and act as an effective coolant in micromilling operations.

Precision toolpaths

Toolpath development is another critical part of creating fine surface finishes. To produce tolerances and surface finishes commensurate with their size, micromilling tools require higher accuracy toolpaths. “Micromilling is kind of a puzzle; the tooling, the software and the machine have to work together,” said Hari Sridharan, vice president of engineering for CAD/CAM software developer Cimatron Ltd., Novi, Mich. Addressing the software puzzle piece, Cimatron collaborated with the Fraunhofer Institute for Production Technology, Aachen, Germany, to develop the algorithms used in the company’s CimatronE Micro Milling CAM software. The software directs toolpaths capable of producing tolerances as tight as 0.000004" using cutting tools 0.004" in diameter and smaller and running 150,000 rpm or faster. The algorithms break the toolpaths into a larger number of individual points and locate those points with higher accuracy than macroscale CAM programs.

Sridharan noted that most standard machine controls can faithfully reproduce toolpath accuracies up to four or five decimal places, but to take full advantage of the enhanced accuracy the software provides, new micromilling machines feature controllers that can handle accuracies of six or seven decimal places (see MICROmanufacturing, Winter 2009 and Spring 2009).

Sridharan pointed out that micromills are subject to breaking if they encounter an unanticipated excess of workpiece stock. As a result, CimatronE Micro Milling software stores data from prior cuts and monitors remaining “microstock” in real time. Sridharan said micromilling is usually preceded by roughing and semiroughing passes with larger tools, and the smaller tools used for finishing “have to know exactly where the larger tools have left the material.”

Protofab’s Krall agreed that the amount of workpiece material remaining for the finish pass is critical when micromilling. The remaining material, which he calls “leave allowance,” has to be calculated as a percentage of the tool diameter. “It can no longer be an arbitrary ‘couple of thousandths of an inch,’ which may work with a larger tool,” he said. A rule of thumb is to leave stock amounting to between 3 and 8 percent of the finish tool’s diameter for the finish pass (axial and radial step-over). “I use the lower percentage for harder materials and the higher percentage with softer material,” Krall said.

"A large finish allowance will increase the chance for a poor surface finish." He noted that care must be taken during the roughing process to leave a uniform thickness of material for the finish tool.

Material factors

Researchers have found that, in some cases, altering the grain structure of the workpiece material can improve surface finish when micromilling. The Manufacturing Engineering Centre at Cardiff University and the University of Strathclyde (Glasgow, Scotland), working with representatives of the Warsaw University of Technology and the University of Science and Technology (Kraków, Poland), micromilled an Al-5083-series aluminum alloy with metallurgically and mechanically modified grain microstructures. The study compared micromilling of annealed and strain-hardened alloys with an ultra-fine-grained (UFG) alloy processed via severe plastic deformation. SPD turns a coarse-grained metal into a fine-grained one by a mechanical process. An example of such a process would be to push a billet of metal through a channel that turns at a 90° angle. The plastic deformation is accumulated by repeating the action until a fine-grain microstructure, with high-angle grain boundaries, is produced in the bulk of the billet.

After a 150µm-dia. endmill machined channels and pockets in the three versions of the alloy at identical machining parameters, the average roughness of the UFG samples was approximately 3.1 and 3.6 times better than that achieved on strain-hardened and annealed samples, respectively.

Andrzej Rosochowski, senior lecturer at the University of Strathclyde, has performed research into UFG metals produced by SPD, and supplied the samples for the milling experiments. Rosochowski said most SPD processes are laboratory scale and suitable for producing small samples for subsequent metallurgical or mechanical testing. However, he is developing an SPD process called Incremental Equal Channel Angular Pressing (I-ECAP), which involves a split reciprocating die that minimizes friction during feeding of the material. The process permits processing of longer bars, plates and sheets, enhancing the possibility of industrial applications. Rosochowski said he cannot readily offer a proven physical reason for surface finish improvement in micromilling, but speculates that it may have "something to do with the milling tool interacting with a larger number of grain boundaries and a higher frequency vibration caused by that."

Protofab's Krall agreed that workpiece choice is critical to achieving fine surface finishes. However, he said if the proper tool with the proper geometry is selected, a good surface finish can be achieved over a wide range of materials. In plastic, particularly, the surface finish depends on the cutting tools.

As an example, he cited a tool custom-made to mill a special blend of PEEK for a medical implant. The 0.015"-dia., single-flute endmill features a 0.045" length of cut and a shank necked back to 0.095" in diameter. "With this tool, we are roughing a full slot at 0.045" DOC and were able to increase tool life three times over standard tooling, while we decreased the run time dramatically."

Protofab's approach to imparting fine surface finishes and productively milling tight-tolerance parts with microfeatures is to use the best equipment available. "Micromachining can be done with a low-end machine, cheap toolholders and a bargain-price endmill, but it will not be pretty," Krall said. "The smaller the tools, the harder it is to troubleshoot problems. My rule is to eliminate as many potential problems right at the start to achieve good and predictable results—and keep the few hairs I have left on my head." µ

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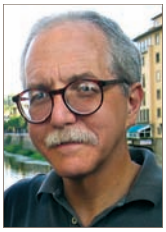

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