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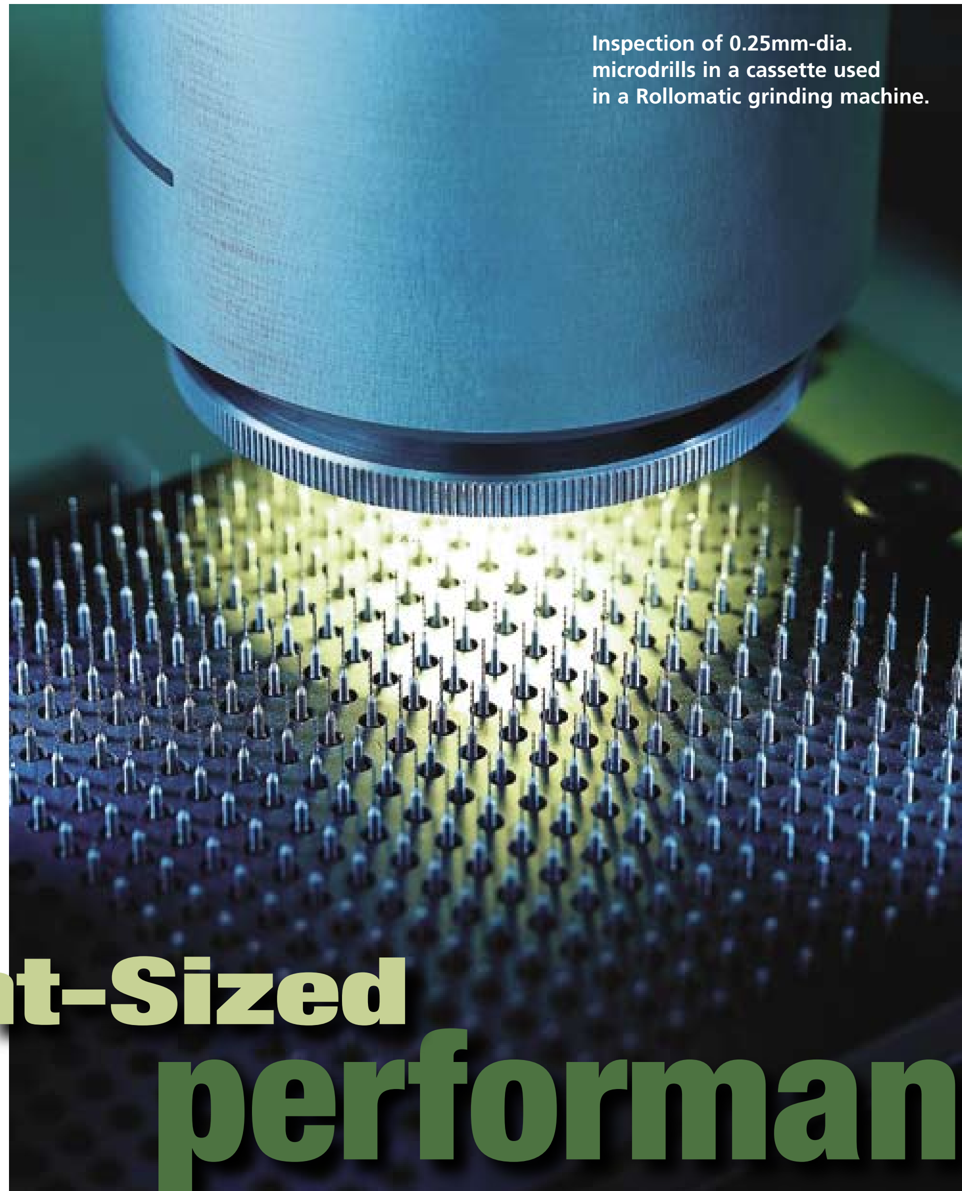

Inspection of 0.25mm-dia. microdrills in a cassette used in a Rollomatic grinding machine.

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Pint-Sized performance

Micromachining involves a lot more than just using scaled-down tools.

Consumers are demanding ever smaller, more complex and smarter products. Cell phones, laptop computers and PDAs all have micro operational modules, such as tiny electronic devices and mechanical motors, which allow them to do more in less space. User interfaces are also becoming finer, as seen in the titanium casings, keyboards and color screens on new cell phones.

Some tiny devices are obvious but many are hidden inside larger ones. For example, the latest seats in high-end BMWs contain 30 or more small stepper motors. Modern automobile braking systems are loaded with small motor systems. New fuel injectors are complex structures with many microfeatures.

Manufacturing these miniature products is a major challenge. Drilling and milling must meet the associated demands of miniaturization and accuracy. It is not enough to simply scale down the processes and geometries that work well for larger tools. Toolmakers must rethink factors such as force, vibration and temperature to develop tools that are appropriate for machining microfeatures.

This article summarizes key microtool issues, starting with the production of parts, molds and dies with microfeatures. Also analyzed are the demands on machine tool builders and the associated demands in achieving geometric accuracy when producing microtools. These demands can only be met by marrying production processes and quality control suitable for microtools.

Working with Microtools

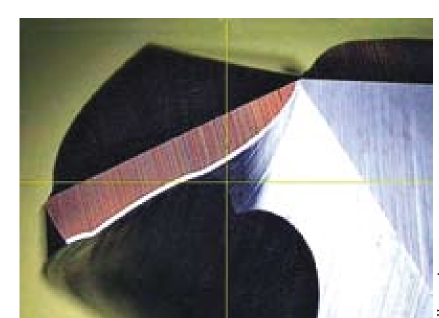
One of the major differences in using smaller tools is visually evident. An operator often cannot even see what size they are without visual aid. That means tool storage must be more disciplined, using correct labeling so tools can be readily identified.

Microtools ranging in size from 0.1mm to 3mm.

Rollomatic

And the tools are fragile. While capable of running at 100,000 rpm in some cases, microtools are generally made of very fine carbide grain to produce their delicate dimensions. The slightest uncontrolled lateral force can cause breakage. If you chip a macrotool, it may not adversely affect cutting, but a 5µm chip on a 100µm tool radically changes the tool's cutting geometry and performance. This may cause the tool to break during machining or damage the part being machined. Precise handling of microtools is also vital to prevent tool damage.

What does "micro" mean? It is generally accepted that any tool less than ⅛" in diameter is in this range, but some companies talk about micro as starting at ¼". And don't forget that big tools can also have microgeometry, such as a small corner radius or small features on a step or form tool, so much of what is summarized here is also applicable to larger tools with such features.



A 30µm chamfer, which is a critical form for evacuating chips effectively, on a 12mm drill is an example of a microgeometric feature on a standard tool.

Rollomatic

The size of the part or the feature being machined helps determine the accuracy needed to ensure that components fit together without friction or jamming. If a radius is only 100µm, then a 5µm form error is major in relation to the total size and can cause a part to malfunction. As a result, microtools must be more accurate than macrotools. Form and dimension tolerances of 5µm are now "normal." Most importantly, microtools must have minimum runout. This factor—in both the tool itself and the spindle rotation—is probably the single most important factor influencing machining quality.

Tool dimensions must be tight but also constant from tool to tool in order to deliver consistent cutting parameters. Modern tool grinding systems have excellent inherent process stability—differences of just 0.1µm to 0.3µm between consecutive tools from the best grinding machines are common. That's why it is not a good idea to buy microtools one at a time. Insist that they come from the same production run, which should ensure the tools' forms will be nearly identical and will behave the same way in the machining center. Incoming inspection must ensure the rejection of tools that do not meet these criteria.

Machine Demands

Once you have an accurate tool, the other components of the machining system must also be accurate. With parts that require high accuracy being made on large machining centers, the parts become subject to dimensional changes due to temperature changes—internally and externally. Environmental and machining fluid temperatures must be carefully controlled to ±2° C. The fluid should be kept clean to maintain its heat dissipating properties. Therefore, the fluid's filtration system should remove particles down to 3µm. Running machines as long as possible with similar parts—24/7 operation is best—provides stable process conditions.

In micromachining, spindle rotation must be faster to avoid excessive force on the cutting edge, which may break the tool. If the maximum spindle speed is only 5,000 rpm, you will need to add a miniature air spindle that can run at the 80,000 to 100,000 rpm required for microdrilling. Operators can use some tricks to increase the feed rate on a slower spindle—such as applying tools with more cutting edges. However, the reduced flute volume that results may cause other problems.

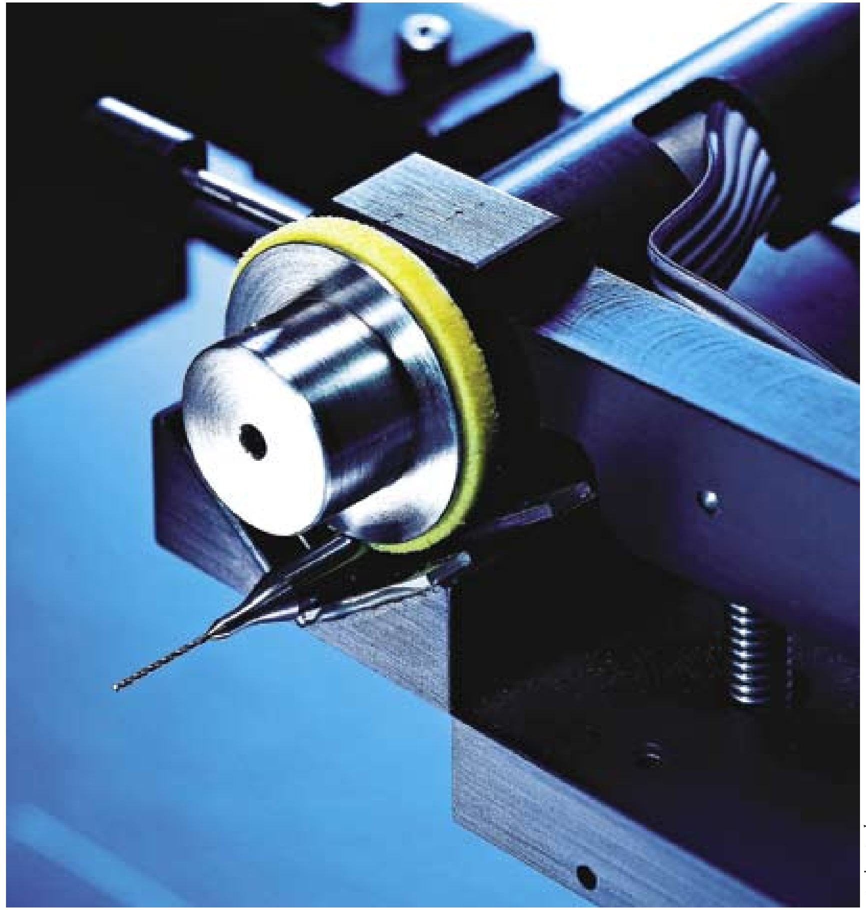
The slightest vibration at the tool/workpiece interface will produce significant proportional error due to the size of the features being machined. Vibration can emanate from the surroundings, such as other nearby machines or poor damping due to the machine base or the factory floor. But vibration can be inherent in the machining center itself, caused by play in an axis, poor spindle runout or defective collets. Regular machine maintenance helps impart a finer surface and improved dimensional accuracy.

A machine's axis system is vital for micromachining accuracy. Axes must be vibration-free to a level less than 1µm. The feedback system between the CNC and axes only works correctly at this level if the resolution is about 0.1µm. Both axes and the measurement system must be free of backlash. An encoder is one option, but a measurement system with glass or magnetic scales is preferred. Worn spindles driving the axes create positional error or vibration. This can sometimes be minimized by moving the axes in the same direction, which is sometimes called "unidirectional machining."

What is Best for My Machining System?

As with larger tools, the way a part is micromachined determines its quality. The appropriate feed rate and chip load (feed rate per cutting tooth) can generally only be found by trial and error and will differ from machine to machine, for the same machine when cutting different materials and even from tool to tool. To reduce the number of differences, try machining a particular part with the same type of machining center and with tools that are as similar as possible. With this combination of tool and machine, operators can find the optimal feed rate to reduce vibration and get the best surface quality and accuracy.

Chip evacuation in micromachining must be smooth to obtain high-quality parts. Tool manufacturers design their flutes and web geometries to optimize chip removal, but the machinist also has a major influence. Depending on how he operates the machine tool, chip removal can be good or bad. This can be detected through sensor systems, such as an acoustic one, on the part or spindle, which can show whether the process is stable. Also, microtool breakage can be difficult to recognize, but a high-speed video camera or tool monitoring system can identify breakage before it becomes a production problem. It is frustrating—and costly—to find, after 8 hours of machining, that the tool broke several hours earlier!



mt microtool

Measuring a microtool in a rotary V-block with zero runout.

Factors for the Toolmaker

Everyone involved in micromachining—from researchers to machinists—identifies runout as the single most important success factor. The reason, again, is tool size. If one cutting edge is 1µm further away from the tool center than the other, meaning there is 1µm of runout, then the feed rate on that tooth will be around six times higher than on the first tooth. One edge will also be cutting 1µm deeper, which produces asymmetric forces, or vibration, on the tool and even visible "furrows" in the part's surface. It will probably destabilize chip formation, with detrimental effects on cutting quality or even tool breakage.

As the surface finish of microparts cannot easily be improved by following a process, the tool must be capable of imparting a surface finish finer than 1µm the first time. To help achieve the required finish, runout on the toolmaker's tool grinding system must be minimal. This can only be achieved by a production-proven shaft-guidance system, which is capable of less than 1µm runout.

The tool grinding system must also have an axis/controller system with 0.1µm resolution. Any form or runout error will not only produce poor surface finish and accuracy problems, it will also produce more wheel wear—which increases tool cost and breakage.

The outer profile of a microtool often cuts the required part dimension in a single pass. The profile must therefore have excellent form geometry. Here, the tool grinding system is affected by the same factors discussed previously for the machine tool, including vibration, runout on the chucking system, temperature fluctuations and cleanliness of the grinding fluid.

Because cutting edge geometry is more critical on microtools than standard tools, chip size must not exceed the tool's edge radius or the edge will effectively cut with a negative rake, producing excessive force and heat. This causes poor-quality cutting or even tool breakage. If the chip size is 2µm (a normal order of magnitude for micromills), there will be a negative rake if the edge radius is 1µm. This means microtool edges must be much sharper than those on standard tools. This also means that if the tool is coated, the coating thickness must be kept to a minimum so as not to produce excessive corner rounding.

Tool grinding systems are not absolutely accurate—they need external control because they are subject to temperature changes and grinding wheel wear. To be sure that form, runout and edge quality on microtools are optimal, they must be checked on a tool measurement system with high magnification. A magnification greater than 1,000× is needed to view small radii, tool edges and surface quality.

Measurement systems must have toolholders capable of rotating the tool with near-to-zero radial and axial runout. Because microtool form tolerances cannot be greater than 5µm, even 1µm of toolholder runout movement is too much. This cannot be compensated for by software because the movement is erratic. The 2µm to 3µm of runout provided by normal chucking systems is not acceptable. V-block systems are ideal because they can be used quickly and have no collets to change.

There is no real secret to successful micromachining. It takes good work practices and quality control in each step, whether grinding the tool or setting up and running the machining center. Micromachining is simply a matter of scale—any small error on a microtool creates a proportionally large defect on the part. In micromachining, there is no substitute for accurately grinding, inspecting and applying microtools. △

About the Author

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