

High-Speed Machining with Micro Tooling

This paper outlines the benefits of using ultra high speeds when machining non-ferrous metals and plastics with micro tooling. The topics covered include the definition of both micro tooling and high speed machining, the challenges of machining with micro tooling, the available technology, superior solutions and the maximized feeds and speeds that result from these given solutions.

Micro tooling and high-speed machining defined

Micro tooling involves mills and drills with a diameter of 0.250" or less. It is required for very intricate or detailed machining and works best with high-speed spindles.

High-speed machining has no set definition or absolute parameters, but one workable definition is machining with spindle speeds of 25,000 RPM or more.

The challenges of machining with micro tooling

With a trend towards miniaturization in manufacturing, work piece sizes are decreasing and part versions are increasing. So, the use of micro tools is becoming more and more prevalent. However, efficient and cost-effective use of these small tools requires both the foresight to employ equipment specifically designed for them and a willingness to deviate from standard machining practices. This is primarily due to the fact that the spindles on conventional CNC equipment cannot achieve the higher RPM speeds required for small diameter tools. Even if they can, it puts undue stress on the equipment by constantly red-lining their spindles. As an example, a conventional CNC machining center running tools smaller than 1/2" in diameter at 10,000 RPM or less will result in unfavorable feed rates and costly tool breakage.

Often this tool breakage is blamed on operator error, incorrect machining parameters, or worse yet, simply the nature of small tools. The reality is that it's due to the force of a conventional machine's heavy spindle and it's inability to reach the high RPM speeds required to effectively evacuate chips from the cutting channel.

Available technology

The best approach to efficiently machine with small tooling is a three-fold process. The three interrelated elements are: 1) high-speed machining technology, 2) optimized micro-tool design, 3) low-viscosity coolant.

High-Speed Machining Technology. The smaller the tools, the higher the spindle speed you will need to efficiently machine quality parts and avoid tool breakage. High-frequency spindles with speed ranges up to 60,000 RPM are ideal for milling, drilling, thread milling and engraving using micro tools.

High-speed machining technology uses high RPM rates, taking a smaller stepover, but with significantly increased feed rates. Move your hand through the flame of a burning candle. If you move too slowly, there's enough time for the flame to cause damage. But if you sweep your hand swiftly through the flame, there's insufficient time for the fire to damage your skin. The same principle applies to high-speed machining with micro-tooling. Move fast, and there's insufficient time for heat to feed back into the part and cause issues.

During the machining process, the tool continually carves a chip out of the work piece. The generated heat develops approximately 40% from friction on each side of the tool, and 20% from the deformation (bending) of the chip. Therefore, about 60% of the heat is inside of the chip. High-speed machining tries to evacuate the bulk of the heat with the chip, providing for a cleaner cut. The better machining quality is based on cooler tooling, lower machining forces, and therefore less vibration.

The high spindle speed reduces the chip load to less than 0.005". Such a low chip load significantly reduces the forces between the tool and the material. High-speed/low-force machining yields less heat, reduces tool deflection, and allows machining of thinner walled work pieces. This all results in cooler machining, superior surface and edge quality, better accuracy and, as a by-product (of low force), easier workholding — since modular vacuum tables can be employed for quick set up and job changeover (particularly with thin flat substrates).

Optimized Micro-Tool Design. Scaling down the tool geometry of larger diameter tools to a smaller format yields unacceptable feed rates and unsatisfactory finishes. Tooling requirements change when tool diameter is decreased and spindle speed is increased. Conventional tooling using inserts is not appropriate for micro-tooling applications. This is primarily due to the high RPM rates rather than the tool diameter. Increased RPM rates require properly balanced tools with significantly increased chip room to assure proper chip removal and to prevent chip burn up. Efficient machining with small tools requires the tools to be optimized specifically for high-speed machining applications. The proper geometry of micro-tooling, together with high-speed spindles and the ideal coolant, can totally eliminate de-burring and de-greasing as secondary operations.

Low-Viscosity Coolant. While high-speed machining inherently reduces heat, the task of cooling a rapidly moving micro tool often requires coolant. Those dedicated solely to high-speed machining with small tools understand that coolant used with conventional CNC equipment is not optimal — and this is a perfect example of where thinking "out-of-the-box" is necessary when undertaking applications that require high-speed machining .

A small tool with intricate geometry turning at an extremely high RPM calls for a cooling and lubricating agent with a lower viscosity than water. Lower viscosity is needed because the coolant needs to make it to the cutting edge of the tool despite the high spindle speeds involved. Emulsion-based coolants have a higher viscosity than water, and thus are ineffective as a lubricant for high-speed machining with micro tooling.

But some micro-volume coolant spray systems can use ethanol, a form of alcohol which occurs naturally in the sugar fermentation process and exhibits a lower-than-water viscosity. The low evaporation point of ethanol makes it an extremely efficient cooling and lubricating agent for high-speed machining operations. Plus, while conventional flood coolant is petroleum based and needs to be properly disposed of, ethanol simply evaporates. This eliminates the costs associated with disposal. In addition, ethanol as a coolant does not leave any residue on the machined parts, thus eliminating the costly secondary operation of de-greasing parts.

Note: Ethanol coolant should only be used for machining of non-ferrous materials and not for machining steel-based materials.

Machine Dynamics

Using small micro tools just isn't as easy as finding an adapter to hold a tiny tool in a 40 Taper spindle on a conventional CNC machine. Because that spindle was designed for large tools like a 3 inch fly cutter intended to "hog" out deep cuts in dense substrates. As such, it has so much torque and force that it just breaks small tools which is both inefficient and very costly over the long haul. The only option an operator has in this situation is to slow the RPM and feed rates down to a crawl — and this isn't efficient either because it results in unacceptable cycle times.

A vivid, and perhaps comical, analogy is the Hemi-powered pick-up truck vs. the sports car. The reality is that you wouldn't compare the two or even consider racing them against one another. Why? Because the truck was designed with the power and force to haul or tow enormous mass, while the sports car was designed for speed and maneuverability. In essence, conventional CNC manufacturers who tout the ability to run micro tools are like an auto manufacturer putting a spoiler and racing stripes on a clunky SUV and claiming that it now possesses the same qualities as a Porsche. Well, just like you can't put a spoiler and racing stripes on an SUV and expect it to perform like a sports car, you can't retrofit a high-speed spindle onto a clunky conventional machine and expect it to efficiently accomplish high-speed machining with micro tooling.

When designing a machine, you can go in one of two directions. You can build your machine with a big motor and heavy mass to provide the force and torque to drive large tools. Or you can build a lighter machine with a high-speed, low-force spindle specifically designed for micro-tooling. Certainly both types of machines can be multi-purpose and perform a variety of functions — like milling, drilling, tapping and routing. But that's where multi-function ends. In the end, if efficiency and quality are important to you and you need to produce both large and small parts, you'll end up with both types of machines working side by side on the same shop floor. While this may seem like a duplication in terms of equipment expenditure, the costs are quickly recouped through the R.O.I. associated with efficiency and versatility. You'll produce better parts, quicker, at a lower cost.

The Solution

In consideration of high-speed machining centers exclusively, the best means of tackling micro tooling applications is to employ equipment that exhibits the key attributes detailed above (high-speed machining technology, optimized micro-tool design and low-viscosity coolant) all working together synergistically. If applied together this three-fold process can provide you with breathtaking manufacturing speeds and improved product quality. But the benefits don't stop there. In addition, this process can totally eliminate secondary operations like de-burring and de-greasing.

Examples

Here are two examples of high-speed machining, as done on Datron machines. A ¼" single flute cutter in 6061 aluminum, going 1/8" deep. The machining runs at 45,000 RPM and is cooled by Ethanol. The feed rate is 250"/min.

Secondly, using a 1/8" double flute high-speed cutter (HSC+) with low helical angle to machine through a 1/8" 6061 aluminum sheet. The machining runs at 50,000 RPM and is cooled by Ethanol. The feed rate is 200"/min.

There are certain rules of thumb for high-speed machining. First of all, avoid red-lining your spindle, as this increases wear and tear on it and significantly reduces its lifetime. Machine with maximum half the tooling diameter in Z. Machine with a smaller step-over but with higher feed rates. And finally, move fast and evacuate the heat with the chip.

Conclusion

It all comes down to the right tools for the right job. A golfer wouldn't use a driver on the green, nor tee off with a putter. Conventional machines with low-speed, high-force spindles can't meet the criteria for efficiently machining with small tools. Only a machine built from the ground up, for the sole purpose of high-speed machining with micro tooling, will deliver the efficiency and quality needed to manufacture most intricate, small parts.

High-speed machining with micro tooling offers lower force, less tool breakage, no thermal growth, better surface finish, elimination of de-burring and de-greasing operations and less tool vibration. Spindle speeds between 25,000 and 60,000 RPM result in efficiency with small tools, better part quality and improved cycle times. Datron's line of machines offer the features and advantages mentioned above and can help manufacturers to achieve efficiency and quality in small part production with micro tools. We offer machining systems with a typical working volume of 40" x 27" x 8"; and other sizes are available.