Capitalizing on the Growing Demand for Micro-Milling

A Mold Maker's Guide

Micro-Milling Opportunities and Challenges

We are all familiar with the phrase "the world is getting smaller." However, it is not just that the world is getting smaller; practically everything we use is getting smaller.

Computers continue to get smaller, and monitors and TV displays get thinner and thinner. Advances in medical devices enable miniature appliances to be installed inside our bodies; even a tiny camera that can travel through it.

Not only are things getting smaller, they are packed with more components to provide added power and functionality. Mobile phones now function as a computer, video camera and GPS all in one compact unit. Micro-size components have a wide variety of applications in almost every industry, including aerospace, automotive, electronics, healthcare, information technology, and telecommunication.

All of these product and technology developments are increasing the demand for manufacturing of micro-scale components and products. These trends present mold makers with new and diverse challenges, ranging from the use of new materials to special mold coatings, milling parts with 0.1mm diameter tools, and achieving sub-micron-level accuracy.

At the same time, it is the inherent complexity of micro-components that brings about new opportunities for mold makers. At a time when production of simple and medium complexity molds is shifting to countries with low labor cost, US and European mold makers can turn to more advanced technologies such as micro-molds and micro-milling to maintain their competitive edge.

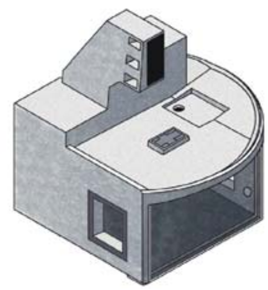
In this guide, we cover the key machining and software requirements for mold makers that are looking to capitalize on the micro-milling opportunity.

Micro-milling Machining Requirements

With multiple elements working in tandem, a machine is only as good as its weakest individual component. Less forgiving than traditional milling, micro-milling requires each machine component to be suitable for the unique requirements of the task.

Machine Geometry

Machine geometry plays an important role in the machine's overall performance. It determines the machine's stiffness, accuracy, thermal stability, damping properties, throughput, and ease of use. The most popular vertical machine geometry types are bridge and C-frame construction. With the spindle or Z-axis being the only moving axis, a C-frame construction offers the best stiffness qualities. Since stiffness directly affects accuracy, this design is highly suitable for micro-milling. Stiffness does decrease in C-frames as the length of Z-travel increases. Therefore, the ideal C-frame construction is one that balances the need to hold tight tolerances required for micro-milling and the length of Z-travel.



C-frame Machine

Machine Construction

One of the challenges when milling delicate and accurate parts is minimizing vibrations. Machine tools with greater damping will absorb more of the vibrations induced by cutting. Many machine frames are constructed using cast iron or steel weldments. Unfortunately, these types of materials are not suitable for micro-milling. The most suitable machine frame material for micro-milling is polymer concrete, which provides up to ten times higher absorption of vibrations than cast iron. Polymer concrete also provides superior dynamic and static rigidity and has substantially better thermal stability than cast iron, all crucial properties for small part accuracy.

Guide Way System

The machine tool way system includes the load bearing components that support and guide the movement of the spindle and table. The two most common guide way types are boxways (sometimes called hydrodynamic ways) and linear guides. Boxways are used on a large percentage of machines today, and are commonly found on large metal removal machining centers. However, boxways are problematic in applications that require frequent axes reversal and low friction motion for extreme accuracy. Linear guide ways offer low static and dynamic friction and are well-suited for high-frequency multi-axis and complex motions, thus are the better choice for a micro-milling machine.

Drive and Motion Technology

How small of a part you can successfully machine depends greatly on the drive and motion technologies built into your micro-machine. A ball screw driven by servo motor is the axis drive mechanism used in most machine tools, and is also the most suitable for micro-milling machines. Other technologies such as linear motors do not provide significant advantages for micro-milling. Most important, though, is how the drive and servo motor work together to provide precise and accurate motion in order to produce miniature size three-dimensional features.

Feedback devices such as glass scales and motor encoders are placed on machine tools to determine position. Many machine tool manufactures use rotary encodes to determine the position of an axis. However, rotary encoders only determine the distance or speed of travel; they do not account for backlash, wear, or thermal changes to the ball screw. Any such ball screw geometrical changes will cause errors in the calculation of the actual position. To ensure the most precise axis position, micro-milling applications require glass scales to be placed close to the guide ways in order to provide additional feedback to the control. Micro-milling applications will most likely necessitate the use of 0.1 micron glass scales rather than the commonly used 0.5 micron version.

Spindle

Spindle technology has come a long way over recent years. Many types of spindles are available, including air-driven, belt-driven, gear-driven, hydrostatic, and motorized. The most common high-RPM spindles are motorized, reaching up to 160K RPM. With that said, a 50K RPMs spindle would be quite adequate for most micro-milling applications, which use smaller size tools.

Motorized spindles come in two basic forms: open loop and closed loop (commonly called vector spindle). Open loop spindles are mostly used when cutting forces are relatively low, such as the case in micro-milling. They are also less expensive, but do have a number of drawbacks. Open loop spindles have no encoder feedback. Therefore, operations such as rigid tapping and spindle orientation are not supported. Furthermore, the range of supported spindle speed is limited.

The ideal spindle for micro-milling is a closed-loop or vector-controlled spindle, which supports a wide range of speeds and offers full torque at low speeds, rigid tapping capabilities, and consistent spindle orientation. A well-designed vector-controlled spindle on a micro-milling machine will offer great flexibility along with the ability to cut even the most difficult material.

Tool Holder and Spindle Interface

The most common tool holder interfaces are steep tapered such as CAT, BT, and ISO. These are used in the majority of milling machines and come in a variety of sizes. Another type of interface is HSK, which has been primarily adopted for high speed spindles used in high precision machining centers.

Tapered tool holders establish their axial position in the spindle through the mating of two tapers. One of the disadvantages of this interface is that as spindle speed increases, the spindle shaft tends to expand due to centrifugal force and thermal effects. When this occurs, the taper of the tool holder is drawn further into the spindle, causing inaccuracies in the Z-axis motion.

HSK tool holders offer a number of advantages for high RPM spindles and thus are the preferred choice for micro-milling machines. HSK tool holders are retained in the spindle by a set of internal grippers located inside the spindle. As RPMs increase, metal-to-metal contact between the tool holder and the spindle is maintained because centrifugal forces cause the internal grippers to expand within the tool holder, pressing it firmly against the inside of the spindle shaft. HSK tooling is also a dual contact interface. It locates on both a shallow taper and a flange creating a precision fit. This precision fit allows the interface to have superior run-out conditions compared to steep tapered tooling. When working with very small cutters, run-out inaccuracies can cause premature cutter failure. Excessive run-out can also reduce the life expectancy of the spindle. Therefore, run-out inaccuracies for micro-milling machines should be kept at 1 micron or less.

CNC Technology

Thanks to advances in both hardware and software, today's CNC controls are extremely fast and powerful. While adequately covering the topic of CNC technology is beyond the scope of this guide, two important aspects need to be pointed out:

- Control interface: packed with an ever growing number of features, the control interface can be quite overwhelming to the end-user, creating an intimidating work environment. The interface should be logically laid out and simple to use, yet flexible enough to handle even the most complex tool path output from any CAD/CAM system. Because micro-milling tool paths can be quite complex and contain thousands of blocks of information, it is important that the control is able to accept several types of storage media along with an Ethernet connection.

- Processing speed: motion control and feedback are crucial for precision micro-milling applications. The control must be able to quickly process high-density complex data and command the motion to the axis in a precise manner.

Auxiliary Components

Working with small parts and tools can be quite frustrating at times. Tools that can hardly be seen by the human eye are nearly impossible to measure mechanically. Using a laser measuring system, both the length and diameter of tools as small as 40 microns can be reliably and automatically measured.

Small parts and fixtures can also be rather challenging to set up. Setting up a micro-milling machine can be made easier with the use of a touch probe. Automatic centering, part zeroing, and part alignment can be used to quickly establish part orientation. Additionally, part measuring can be accomplished using many of the touch probe routines commonly found on controls that feature probing.

Machine Environment

The machine environment must have a controlled temperature and free from vibrations. If the machine is not properly isolated, even a heavy truck that passes outside the facility could generate enough vibrations to leave its marks on the surface.

Micro-milling CAD/CAM Requirements

It seems intuitive that milling machines, holders and tools are difficult to scale down to the microscopic dimensions and extreme accuracy needed for micro-milling. At first glance, software might seem to be an easier fit. After all, one might claim, working with a number like 0.0001 should be just as easy for the software as working with 1.0 or 10.

But there is more to it than meets the eye. Creating and modifying geometry with the right accuracy, smoothness, and continuity are just the entry points for a micro-component CAD and CAM solution. In order to have a functional solution for micro-milling, the CAD systems must be carefully tuned and optimized to support the following requirements.

Data Translation

A translation error resulting in a 0.005 gap between two surfaces might not be problematic in a large part, because the part can be polished. However, polishing is typically not an option in miniature molds or micro components, so a gap of the same size in a micro-milled part would be clearly visible. Therefore, the CAD/CAM software should be capable of reading native format files from other CAD systems to keep the integrity of the geometry. Data translation issues between separate CAD and CAM packages can also adversely affect machining accuracy, and these inaccuracies are exacerbated in micro-milling. An integrated CAD/CAM package eliminates the need for data translation and minimizes the risk of introducing such inaccuracies.

Tight Tolerances

Working with tight geometric tolerances of 0.1-0.01 microns when generating parting surfaces and creating geometry for slides, lifters, and ejectors is essential in order to prevent gaps between surfaces and keep C1 and C2 continuity. The software should support tool path calculation with tolerances down to 0.01 micron while considering the constraints of the machine used. Such tight tolerances require special tool path algorithms with greater accuracy and better point distribution in order to achieve a polish-free surface. For instance, the CAM system should enable corner rounding techniques to generate smooth tool path even while using a tool diameter as small as 0.1mm and a side step of 0.005mm or smaller.

Machining Strategies

The software should support machining strategies optimized for micro-milling, such as maintaining a constant chip load for the rough and re-rough procedures. With dimensions that can be smaller than 1mm, the roughing tools used in micro-milling are very sensitive to the chip load and could easily break. Therefore, the ability of the software to support efficient roughing strategies with constant chip load and varying feed rates is critical for micro-milling. When it comes to micro-milling finishing, two or more cutters of different lengths are often used. To generate a smooth tool path, the software should support the use of multiple cutters with different spindle speeds, feed rates, and cutting parameters in a single finishing operation.

Special strategies may be required when machining tall, thin walls or bosses on miniature parts. Following the roughing operation, the wall may become too thin to support the finishing operation, causing the walls to vibrate, damaging and possibly even fracturing the surface. In such instances, the software should be able to generate tool paths with layers combining roughing and finishing in a single operation.

Tool Motion

When creating a tool path, there are certain similarities between high speed machining (HSM) and micro-milling, such as the need for rounding corners in order to avoid sharp tool motions. However, rounding can become a challenge in micro-milling, which commonly features very small stepovers. Rounding smaller than the stepover will likely create a sharp motion, while round corners larger than the stepover could create ridges and gaps between sequential passes and generate excessive scallops.

To prevent such gaps and ridges and ensure high surface quality, support for tool motion techniques such as CBP (Clean Between Passes), CBL (Clean Between Layers), and Ridge Machining is a key requirements for micro-milling success.

Multi Axis

A growing number of micro-milling applications require multi-axis machining, such as the use of 5-axis machining for miniature impellers. 5-axis machines enable the utilization of small tools with tilt options that result in better surface quality while eliminating the need for multiple tools. Compared to conventional 5-axis applications, micro-milling applications require greater flexibility in controlling the tool orientation, as well as the ability to track the stock model across multiple dimensions.

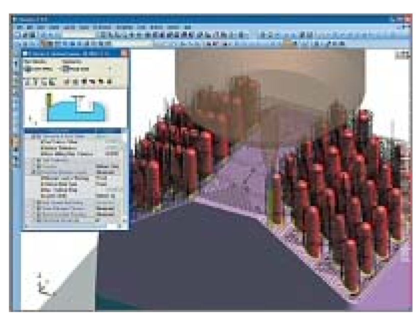
Knowledge of Remaining Stock

Knowledge of actual remaining stock throughout the entire process allows the software to adjust the feed rate to actual tool load, in order to shorten machining time while protecting the delicate tools from breaking. As the work piece shape dramatically changes during the roughing operation, the software simulates the remaining stock after each layer. This enables the tool to go into locations that were cleaned by previous layers, thus allowing shorter tools to cut into deep areas.

Accurate calculation of remaining stock is especially critical when dealing with tight tolerances, such as in finishing or re-machining operations. To reduce tool load during the finishing passes, the software should be able to address re-rough operations within the re-machining procedure, while utilizing the remaining stock knowledge.

Geometry Mending

Almost every CAM programming job requires some geometry mending procedures. In many cases, only during the programming process does it become clear that a certain geometry modification is required. For example, when making a mold, cooling and ejector holes are typically capped to prevent the cutting tool from machining into them. Surfaces must be extended to protect the areas that will be machined in another setup, and a draft angle should be applied. CAM software that includes built-in CAD capabilities and provides the assisting geometry (e.g., capping, extending surfaces) with the appropriate accuracy and tangency enables this design-for-tooling mending to be performed by a toolmaker who understands the machining process, such as the NC programmer.



Summary

Micro-system, micro-molds and micro-milling are new and exciting technologies for the mass manufacturing of miniature parts. With sub-micron tolerance and tool tips that can hardly be seen by the naked eye, this emerging and fast-growing field presents numerous challenges to mold makers and vendors.

On the bright side, micro systems and micro-milling bring about new opportunities for mold makers who are seeking to differentiate themselves, generate business in an emerging and lucrative market segment, and be better positioned against lower-wage competitors. New materials, new machining capabilities, and innovative CAD/CAM software are available now to help mold makers step up to these challenges and capitalize on the growing demand for micro-milling.

About Cimatron

Cimatron is a pioneer in micro-milling software and was the first vendor to bring to market a commercial NC application for milling micro-components.

With over 25 years of experience and more than 40,000 installations worldwide, Cimatron is a leading provider of integrated, CAD/CAM solutions for mold, tool and die makers as well as manufacturers of discrete parts. Cimatron is committed to providing comprehensive, cost-effective solutions that streamline manufacturing cycles, enable collaboration with outside vendors, and ultimately shorten product delivery time.

The Cimatron product line includes the CimatronE and GibbsCAM brands with solutions for mold design, die design, electrodes design, 2.5 to 5 axes milling, wire EDM, turn, Mill-turn, rotary milling, multi-task machining (MTM), and tombstone machining. Cimatron's subsidiaries and extensive distribution network serve and support customers in the automotive, aerospace, medical, consumer plastics, electronics, and other industries in over 40 countries worldwide.

Cimatron is publicly traded on the NASDAQ exchange under the symbol CIMT. For more information, please visit http://www.cimatrontech.com.

About Kern Precision

KERN Precision, Inc., is a subsidiary of KERN Micro- und Feinwerktechnik GmbH & Co. (Germany) and a pioneer in micro and ultra precision machine tools, with a 45 year track record of delivering state of the art machining centers. The company's product line includes three multi-axis machining centers that are designed to provide positioning accuracies down to 0.3 µm and can machine a variety of materials, from aluminum to titanium. For more information, visit http://www.kernprecision.com.