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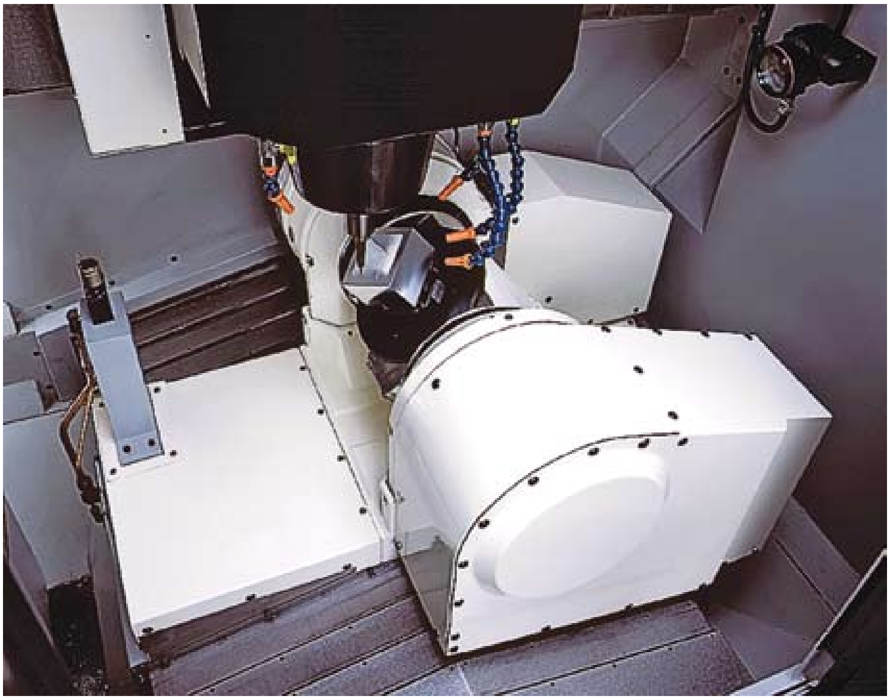
2+3: Greater Than 5

2+3 machining of die and mold components is more accurate and often faster than full 5-axis machining.

By Bill Howard, Makino Inc.



All Images: Makino

Using 2+3 machining techniques, this Makino 5-axis vertical machining center is able to machine deep cavities while retaining the accuracy of 3-axis machining.

Many manufacturers are considering the benefits of 5-axis machining—specifically the ability to reduce setups, part handling and work-in-progress, use shorter, rigid cutting tools and obtain better surface finishes.

Almost everywhere in the manufacturing industry, 5-axis machining seems to be the hot topic, growing in popularity among virtually every market segment. Most machine tool builders are introducing 5-axis machines or updating their current 5-axis machines. To support this trend, software companies are developing new, easier to use and more powerful 5-axis programming tools.

Moving beyond the traditional X, Y and Z axes may be generating a substantial amount of news, but many manufacturers are unaware of the nuances involved in 5-axis machining and are unsure how or when it should be used. Outside of the aerospace industry, 5-axis is still a somewhat untested method of machining.

While 5-axis machining is required for certain applications, such as blisks for jet engines, the machining technique is challenged by the precision required for die and mold applications. Die and mold makers can achieve the highest precision by not running five axes simultaneously, but instead using the two rotational axes to position the part and machining with the other three axes.

Yes, 2+3=5

Five-axis machining refers to the simultaneous motion of all five axes on a machine tool: the linear X, Y and Z axes and two rotary axes. When many people think of 5-axis machining, they associate it with complex aerospace parts manufacturing, specifically the production of structural components and turbine blades with leading edges or curved, flowing shapes requiring full 5-axis techniques for machining.

However, 5-axis machining has

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accuracy problems derived not only from the simultaneous movement of the axes, but also the number of axes themselves. When dealing with three axes, there's a chance for error. When a 4th axis is added, like a tilting A-axis or tilting worktable, the extra axis increases the potential for inaccuracies. The A-axis' additional motion, when combined with the X, Y and Z axes, can adversely affect the machine tool's ability to correctly position its spindle relative to the part during production. Obviously, addition of a 5th axis can create even more inaccuracies in part positioning.

Like 5-axis machining, 2+3 machining requires a full 5-axis machine and uses all five axes, but without simultaneous movement of the two rotary axes with the three linear ones.

As a result, Makino developed a 5-axis application technique known as 2+3 machining. In contrast to typical 5-axis machining, 2+3 machining is a more practical approach to 5-axis machining that allows for accuracy levels found in 3-axis machines.

Like 5-axis machining, 2+3 machining requires a full 5-axis machine and uses all five axes, but without simultaneous movement of the two rotary axes with the three linear ones. (See sidebar on page 92.) The 2+3 technique uses the secondary, rotary A and C axes, the least accurate axes, to move and hold a part in position and then uses the more accurate X, Y and Z axes to machine the part. This technique offers all of the capabilities of 5-axis machining, but with the greater accuracies typically found in high-performance 3-axis machines.

Also, 2+3 machining allows die and mold shops to produce parts at a faster rate with increased accuracy than either 3-axis or true 5-axis machining.

2+3 for Dies & Molds

Applying full 5-axis machining can be beneficial for aerospace parts, but we encounter an immediate problem when applying it to dies and molds. Many aerospace parts have tolerances wider than those associated with die and mold components, as well as many parts made via general parts production.

For example, an aerospace structural component, usually a 2-axis profile part, will have tolerances ranging from 0.007" to as much as 0.025", with a typical part often having a tolerance of 0.015". It's not uncommon, however, to deal with die and mold parts that require tolerances of 0.0005", much tighter than 5-axis machining can deliver. Given the current technology, most 5-axis machines would average about 0.0010". There's little room for error in linear positioning accuracy, repeatability, parallelism, squareness and straightness. Therefore, mold parting lines, blends and radii, and surface shut-off areas of core and cavities—requiring 0.0002" to 0.0005" tolerances (or better)—would pose a significant challenge to most current, state-of-the-art 5-axis machines.

Visualize a typical 12"×12"×6" die and mold part. If the worktable is tilted up to position the part in the A-axis, the table could be "high" by as much as 4 arc-seconds, the rotary axis' positioning accuracy. As the table is repositioned down in the A-axis, it could become off by an additional 4 arc-seconds. That's a total positioning error band of 8 arc-seconds. Any part feature has plus and minus accuracies of positioning. Errors—due simply to machine positioning accuracies and repeatabilities—could range anywhere from 0.0002" to 0.0015".

The error band becomes wider because a repetitive machining operation will also have a repeatability band on each side of the positioning accuracy. The most accurate machines would achieve an error

The Makino V33-5XB provides access to tight geometries in this steel mold.

keywords

FLASH: Thin web or film of metal on a casting that occurs at die partings and around air vents and movable cores. This excess metal is due to necessary working and operating clearances in a die. Flash also is the excess material squeezed out of the cavity as a compression mold closes or as pressure is applied to the cavity.

CUTOFF: Step that prepares a slug, blank or other workpiece for machining or other processing by separating it from the original stock. Performed on lathes, chucking machines, automatic screw machines and other turning machines. Also performed on milling machines, machining centers with slitting saws, hacksaws, bandsaws or abrasive cutoff saws.

—CTE Metalworking Glossary

band of 9µm. However, a typical 5-axis machine has an error band of 24µm, and some machines have a 41µm error band when dealing with this size part. Obviously, the error band associated with the angular axes is a significant issue when manufacturing a part that demands exacting tolerances.

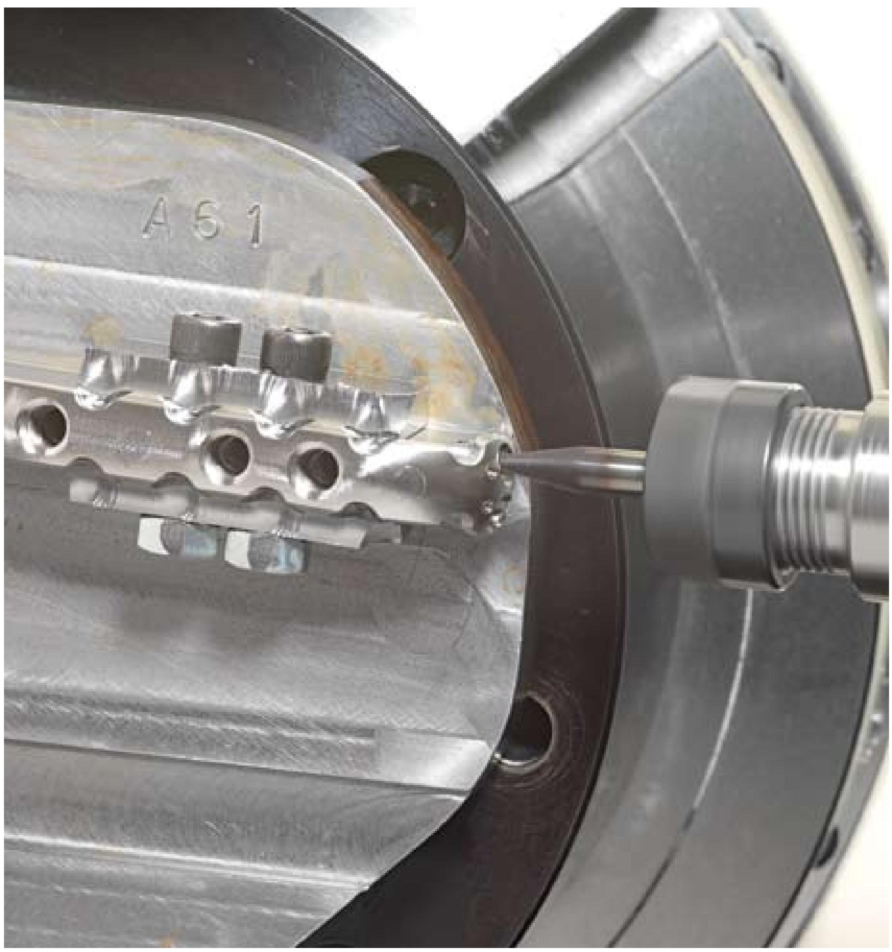
Another key aspect of rotary axes is: The larger the part, the farther it extends from the center of rotation. As part size increases, it may become more negatively affected by potential rotating axis positioning accuracy and repeatability errors at its outer edge.

For instance, a 24"×24"×6" part has twice the radius of a 12"×12"×6" part, so the larger part will be open to error bands twice as wide as the smaller part. That wider error band would range from 18µm on the most accurate 5-axis machines to 82µm on the least accurate. Die and mold parts, however, require an average error band of 12µm.

2+3 Machining: An Alternative

2+3 machining permits moldmakers to eliminate manual relief, scraping and fitting of molds. Hand scraping and fitting a mold core and cavity are labor intensive methods (requiring hand tools) of finishing the final blend and match-points as well as parting lines and shut-off surfaces. The 2+3 method allows for tighter geometries in pocketing, and key details can be created in mold areas where there is minimal room for movement. Moldmakers can achieve part surface and mold shut-off accuracy of 12µm or less, which ensures excellent part release from the mold.

They can also achieve accuracy in cavities to zero stock and cores to negative stock of 10µm/257µm. They can machine parting surfaces that don't require relief from the edges; the precision and



This medical part was produced using 2+3 machining on a Makino a61 with a rotary table to handle the free-flowing surfaces, varying angles of holes and thread tolerances of 0.002".

accuracy assures the entire parting surface will match. These improvements not only allow for more accurate parting surface alignments, but also reduce the potential for flashing.

Although the accuracy of 2+3 machining is equivalent to that of a traditional 3-axis approach, the A and C axes allow easy accessibility on all sides of the part, giving 2+3 machining the advantage of multisided machining, fewer

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and quicker setups and less handling. The utilization of 2+3 machining enables manufacturers to use shorter tools and holders that increase accuracy and tool rigidity, enable machining at higher speeds and feeds and minimize chatter.

By utilizing this technique, manufacturers can use adjustments in the A and C axes to improve surface finishes on draft angles and flat-tapered surfaces. In addition, since the A and C axes are not in simultaneous motion with the other three axes, they can be used to correct part position and more accurately locate the part relative to the machine axes, permitting simpler and less costly fixtures and reduced dependence upon operator skill for part loading.

5-Axis vs. 2+3

A series of tests were conducted to compare the total error bands, surface finishes, toolpaths and cycle times of 2+3 machining and 5-axis machining. Two sample parts, a core and a cavity, were machined, one using 2+3 machining and the other using 5-axis machining. Once completed, eight points on each side of the part were measured using a coordinate measuring machine. Along with

Typical 5-axis configurations

THE MACHINE TOOL used for 2+3 machining is a full 5-axis machine; only the technique is different from simultaneous 5-axis machining. No matter which method manufacturers employ, they are still using a 5-axis machine.

Machine tool builders have many approaches to 5-axis machining. Vertical machining centers with linear X, Y and Z axes can be equipped with a tilting trunnion table, which is usually a rotating C-axis over a tilting A-axis. Another configuration employs a tilting A-axis and a rotating B- or C- axis. In the metalworking industry, it's typical to see positioning accuracies measure about 8 arc-seconds, and repeatability ranges from 2.5 to 3 arc-seconds.

Another way to accomplish 5-axis machining is with an articulating spindle on a vertical machining center. Many of these machines are bridge- or ram-type machines. The rotation of the spindle head itself is a C-axis, and the spindle's angle position is on the A-axis. This configuration typically provides 10 to 20 arc-seconds of positioning accuracy and 4 to 8 arc-seconds of repeatability on the A and C axes.

Manufacturers can also use an articulating spindle on a horizontal machine to have five axes available for machining. Another articulating spindle configuration uses an A-axis on the spindle and a C-axis under the workpiece. This setup provides positioning accuracy of 4 to 20 arc-seconds and 2 to 8 arc-seconds of repeatability.

The best average positioning accuracy possible is 4 arc-seconds and the worst is 20 arc-seconds. The average is about 12 arc-seconds. Repeatability ranges from 2 to 8 arc-seconds, with the average being approximately 4.5 arc-seconds.

— B. Howard

2+3 Greater Than 5 *(continued)*

these points, the corner radii were also checked. In total, 44 points were measured to test the proficiencies of both machining methods.

The total error band of the parts milled using 2+3 machining was 6.8µm, the total error band of the 5-axis method was 28.1µm. The 2+3 method imparted a surface finish of 18.7µm, while the 5-axis method produced the best finish at a 16.5µm. The 5-axis method imparted a slightly better surface finish, but the difference wasn't much.

Toolpaths were 13.5 percent shorter when using the 2+3 method as compared with the 5-axis approach. The longer toolpaths reduce tool life. Likewise, the total cycle time was 62 minutes on the 2+3 approach and 72 minutes on the 5-axis approach—a 16 percent increase.

Faster throughput is another advantage of 2+3 machining. Besides a faster cycle time, it takes less time to program for 2+3 machining than it does for 5-axis machining. Many conventional programming systems may be limited in their support of full 5-axis machining, but nearly all support 2+3 machining. As a result, it will be quicker to get up and running with the 2+3 approach compared to the full 5-axis contouring approach. Another factor manufacturers need to think about is the availability of full 5-axis programmers who have worked in die and mold vs. programmers who can perform 2+3. Also, any optimizations or changes are much more difficult to support in a full 5-axis mode than in a 2+3 mode.

From the testing, it's evident that 2+3 machining is often superior to 5-axis machining when making dies and molds.

In addition, on the full 5-axis approach, hand finishing is often needed in the blend, match and critical parting line and shut-off surface areas to minimize surface imperfections and flashing. The 2+3 method, however, has the best potential for bench-free machining. It also has the advantage of much tighter control in small details and shut-offs, making 2+3 machining suitable for die and mold applications. This tighter dimensional control ensures the precision of key working elements of the core and cavity—such as blend lines—and eliminates flashing due to mismatches between elements.

Moldmakers will also notice better control over the pattern and cusp variations and reduction in blending or matching of lines between a mold's geometric features. Moldmakers can also achieve smaller, finer increments of surface finish and sharper details, as noted above.

Thus, 2+3 machining delivers what the die and mold industry demands—high accuracy—with the added benefits of minimized setups, faster cycle times, longer tool life, limited bench work and easier programming. While full 5-axis machining definitely has its place and is a valuable technology for producing complex components, especially for the aerospace industry, 2+3 machining offers a better alternative for the die and mold industry. CTE

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