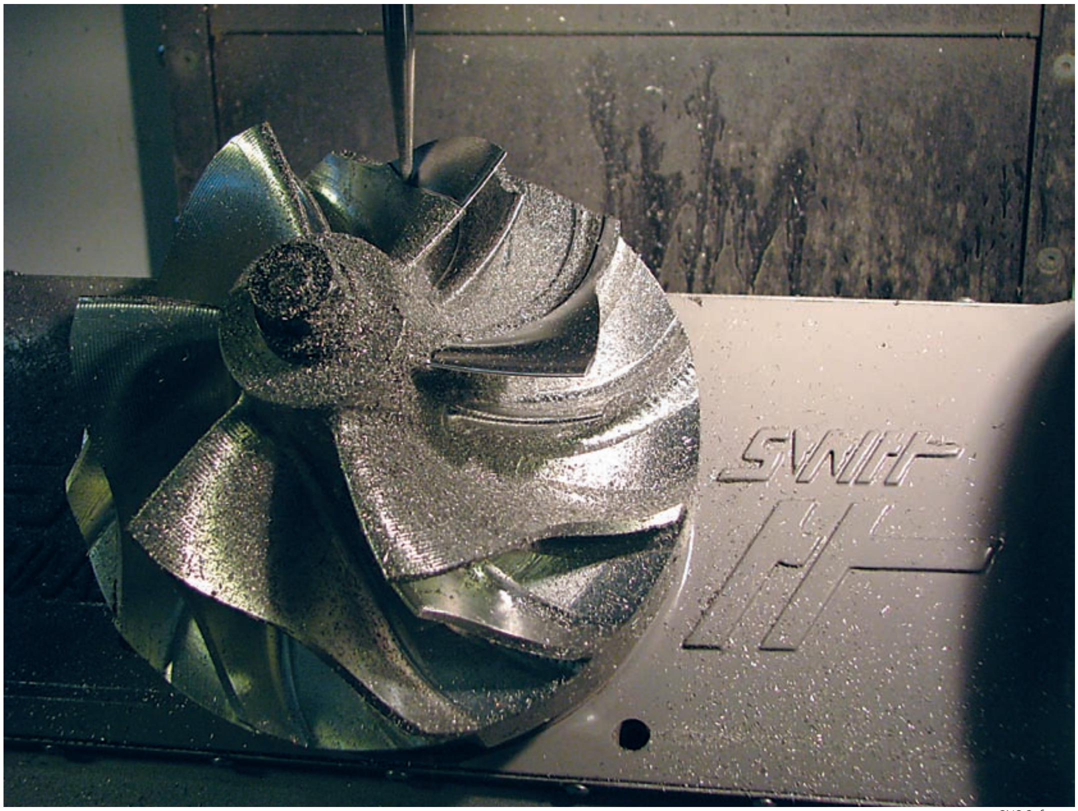
Multiaxis **Muscles Up**



CNC Software

Multiaxis finishing of a split impeller in progress. It was designed and cut at CNC Software's testing facility.

CAD/CAM strategies for increasing the efficiency of multiaxis machining.

By Karlo Apro, CNC Software Inc.

New research by Partners in THINC shows that many companies invest in multiaxis machine tools, but then fail to use them as efficiently as possible. One of the ways to measure efficiency is to monitor spindle output—the amount of time the machine is actually cutting metal during a 24-hour/7-day period. The study by Partners in THINC, a group of 30 companies that work together to improve manufacturing technology, shows the average U.S. spindle output is below 40 percent; yet some well-managed companies achieve 80 percent efficiency. That translates to a significant amount of "found" money.

There are many ways shops can improve efficiency (see sidebar on page 46). One of the most effective involves use of advanced CAD/CAM technology. CAD/CAM software developers use customer requests to build programs that improve machine efficiency. This cycle never ends because new machine tools are introduced that need software to efficiently drive them. Here are some ways CAD/CAM software can improve your multiaxis machine's spindle output:

1. Indexing multiaxis machining. Indexing work is the most basic multiaxis concept. It is an easy transition from multiple-setup, 3-axis work to a single-setup indexing method. Setups using indexing or indexed work are rigid and precise. Other common names for such setups are 2+3 machining or positioning and fixed rotary work. With indexing work, the rotary/pivoting axes are used only for positioning, and machining takes place with only three (or fewer) moving linear axes. The concept may be simple, but it allows for the precision manufacture of complex parts (Figure 1). This is a common stepping stone for companies that want to enter the multiaxis

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"Secrets of 5-Axis Machining," Industrial Press

Figure 1: Indexing work aids manufacturing of complex parts, such as this lever for an industrial robot.

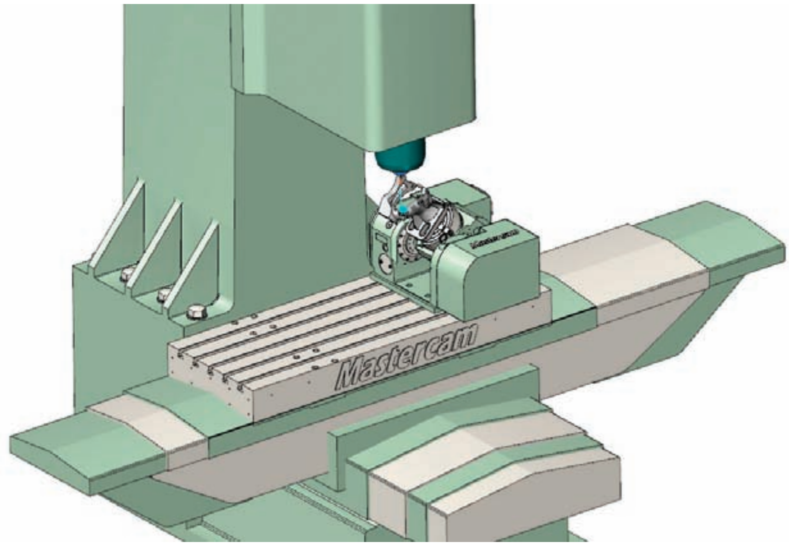

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Figure 2: Dual-rotary device mounted on a 3-axis machine.

realm. A shop can purchase an affordable dual-rotary device and bolt it on a 3-axis mill and get instant 5-axis manufacturing capability (Figure 2). Some CAM software packages, such as Mastercam, provide entry-level users with the ability to easily generate 3+2, 5-axis toolpaths.

This simple solution can dramatically improve efficiency. By reducing the number of setups, an operator can cut parts faster and more accurately. There is no need for elaborate, multiple fixtures and there is less chance of multiple-setup alignment errors.

2. Simultaneous multiaxis machining. Dedicated multiaxis machines handle more than indexing work—they are also capable of synchronized, accurate and simultaneous multiaxis motion. Many complex parts cannot be cut on a 3-axis machine, and instead require simultaneous multiaxis motion (Figure 3).

Technically, this part could be cut on a 3-axis machine in multiple setups, but such an attempt would be much less efficient than using a multiaxis machine. Naturally, you must have the ability to drive such a machine. Some CAD/CAM programs provide this capability. For example, Mastercam's multiaxis toolpaths provide the ability to control the cut pattern the tool should follow, the control of the tool axis as it follows the cut pattern and at the same time use collision and gouge protection to avoid any potential collisions. It also provides tools to generate G code.

Many people monitor spindle output only by measuring the actual time a machine is cutting material during a 24-hour/7-day period. Few people examine the actual efficiency of those cuts. Just because the spindle is busy cutting doesn't mean all is well. There might be too many deep cuts, or the spindle might be under a very light cut, which is just busy work. To remedy this, choose a CAD/CAM program that automatically adjusts the feed rate based on the amount of material removed. For example, a program might have a feature that allows the operator to take deeper cuts with trochoidal motion, allowing the choice of several dedicated, applications-specific multiaxis toolpaths that suit individual applications and can be customized to the capabilities of individual machines.

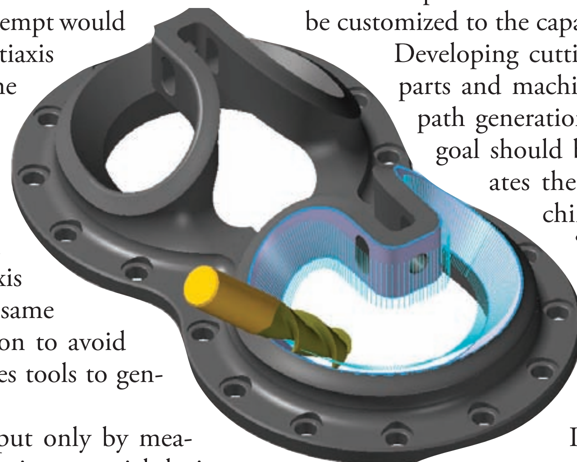

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Figure 3: A complex bracket, the machining of which requires simultaneous multiaxis motion.

Developing cutting strategies for these multiaxis parts and machines entails more than just toolpath generation—it is also about control. The goal should be to create a toolpath that creates the smoothest, most efficient machine motion inside the machine's "sweet spot" (the optimal work envelope), while avoiding near misses and collisions between machine tool components, fixtures and toolholders.

3. Designing for efficiency. In the early days of multiaxis machining, many parts were designed around motion instead of free-form CAD models. For example, one of my first jobs was on a team designing cam plates for a 12-axis screw machine. These cam plates work in a manner similar to the way camshafts work in your car's engine, but instead of moving the various internal parts of the engine, they move tools, collets and bar feeders.

There has always been a separation between design and manufacturing. Typically, part designers are not CNC programmers or operators. As a result, many of their designs don't take into account clean tool motion, or they include difficult-to-machine features that require additional operations. In well-run shops, designers and production engineers work as a team, from the design process through to manufacturing. Working together, engineers can reduce the time it takes to build tooling and fixtures and to manufacture parts. This is an ideal solution, but unfortunately it is not the norm.

4. Machine simulation is the safest and most cost-effective way to prove out multiaxis toolpaths, and CAD/CAM systems can provide this function (Figure 4). CAD/CAM systems generate 5-axis vector lines along 3-D paths. These 3-D paths represent tool motion as it follows the pattern being cut. The vectors represent the individual tool-axis directions (I, J and K vectors) as the tool follows the 3-D (X, Y and Z) pattern. (The toolpath pattern consists of a number of points in 3-D space, each of which has an X, Y and Z position in the orthogonal

Commonsense efficiency boosters

IN ADDITION TO USING EFFECTIVE CAD/CAM solutions, there are many other ways to increase efficiency, and most are common-sense solutions. For example, consider the following:

- Shops should be organized around reducing setup time.
- High-priced machines should not be used as verification tools, which wastes valuable machine time on prove outs.
- Do preventive maintenance instead of catastrophic repairs by routinely assessing machines.
- Monitor processes in detail by making sure to use all corners of inserts and by controlling chip shape.
- Keep your tools sharp. This includes the cutting tools *and* your manufacturing team.

There's a saying that the mark of a master is to make hard things look easy, and everything is easy when you know it. Know your machine. Know its limitations and capabilities. Know your CAD/CAM system and ensure that it is working in synch with your machine tool.

No matter what your place is in the manufacturing process, you can take the first step toward making your shop more efficient. If you are running the machine, you have an intimate knowledge of the sight, sound and feel of a healthy cut. You are the person best qualified to notice if machine performance is changing or to suggest ideas on how to improve the part-making process. If you are programming the machine, you have an opportunity to implement the operator's ideas and collaboratively develop innovative ways to hold and cut parts. If you design parts, you can work with the programmer to design them with manufacturing ease in mind. If you run a company, create an environment where teamwork and collaboration allow new ideas to come forth and flourish.

Examples of technology aimed at improving efficiency include the following:

- A preventive, built-in machine monitoring system that constantly measures thermal and vibration signatures to alert the operator to any performance changes.
- A measuring device that is wirelessly connected to the machine's controller. Have you ever stopped your CNC machine between operations, measured the part and found it to be near one of its tolerance limits? You must then adjust the tool offset for the next part. Care must be taken to adjust the right tool offset by the exact amount. This creates the potential for error, and the machine is idle during this time. A digital, wireless measuring device allows the operator to measure the part and simply press "transmit." This automatically and precisely adjusts the tool offset because the system constantly monitors the process.

Various probing devices and routines not only reduce setup times, but also make setup more precise. Probing routines can also monitor and react to cutting process changes.

—K. Apro

coordinate system and a directional vector represented by I, J and K directional values.) Every vector is represented by a line of code, and during toolpath creation a resolution of these vectors can be specified, either by defining the minimum angular differences or by defining the linear distances between vectors.

This information is written in a generic language. Depending on the CAD/CAM system, the generic language is called APT, CLS or NCI, among other names. Machine tool controllers do not speak or understand these generic languages, but they do understand many different CNC languages and dialects.

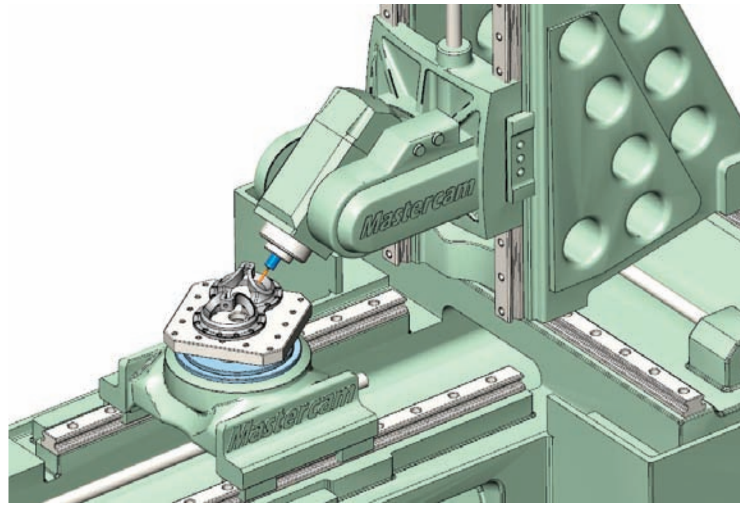
The generic CAD/CAM code must be translated into a machine-readable language, a process called post processing. A post-processor calculates the axis motions needed on a specific machine to reproduce the CAM vector sequence. The post-processor includes detailed information about the specific machine's physical properties and its controller's capabilities and properties that allow the post-processor to generate the required G code. This code, in turn, governs the axis movements of the machine needed to produce the part. A different post-processor is needed for every type of multiaxis machine in the shop.

Machine simulation provides a bridge between the virtual and the actual worlds. With machine simulation, a machine's virtual replica can be shown on the computer screen, where the cutting process can be safely simulated. This tryout ensures that the program contains the most effective cut, the part is located in the machine's "sweet spot" and that no fixtures, tools or machine components will meet unexpectedly.

Machine simulation is useful for more than just prove outs, which have the sole aim of finding code errors. It is also an additional tool to help develop clean, efficient and accurate programs.

With simulation, different approaches and different cutting strategies can be tested on different machines at a personal computer, and there is no need to waste machine time on prove outs. Nobody wants to see an expensive 5-axis machine sitting idle while programs are being tested.

Also, people make mistakes under pressure. Even small mistakes on multiaxis equipment can quickly add up to catastrophic damage to the part and machine, and cause downtime for costly repairs. Running a new, unproven, 5-axis program blindly on a machine is like playing Russian roulette. But with that said, nothing can substitute for real metalcutting. Even after simulation tests, the first run will always be exciting. The sights, sounds and feel of the cuts are irreplaceable.



"Secrets of 5-Axis Machining," Industrial Press

Figure 4: Simulation of cutting motion on a dedicated 5-axis machine.

Take the First Step

The goal of this article is to create awareness of existing technology that can help improve machine efficiency. The next step is for operators to use and comment on the technology available to them. After all, every tool in the world has evolved into its current configuration based on end user demands.

Regardless of your place in the manufacturing process, you can take the first step toward improving efficiency by demanding more from your machine, CAD/CAM system, tooling and yourself. Examine current problems as opportunities for great solutions. We have the technology; why not use it? CTE

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