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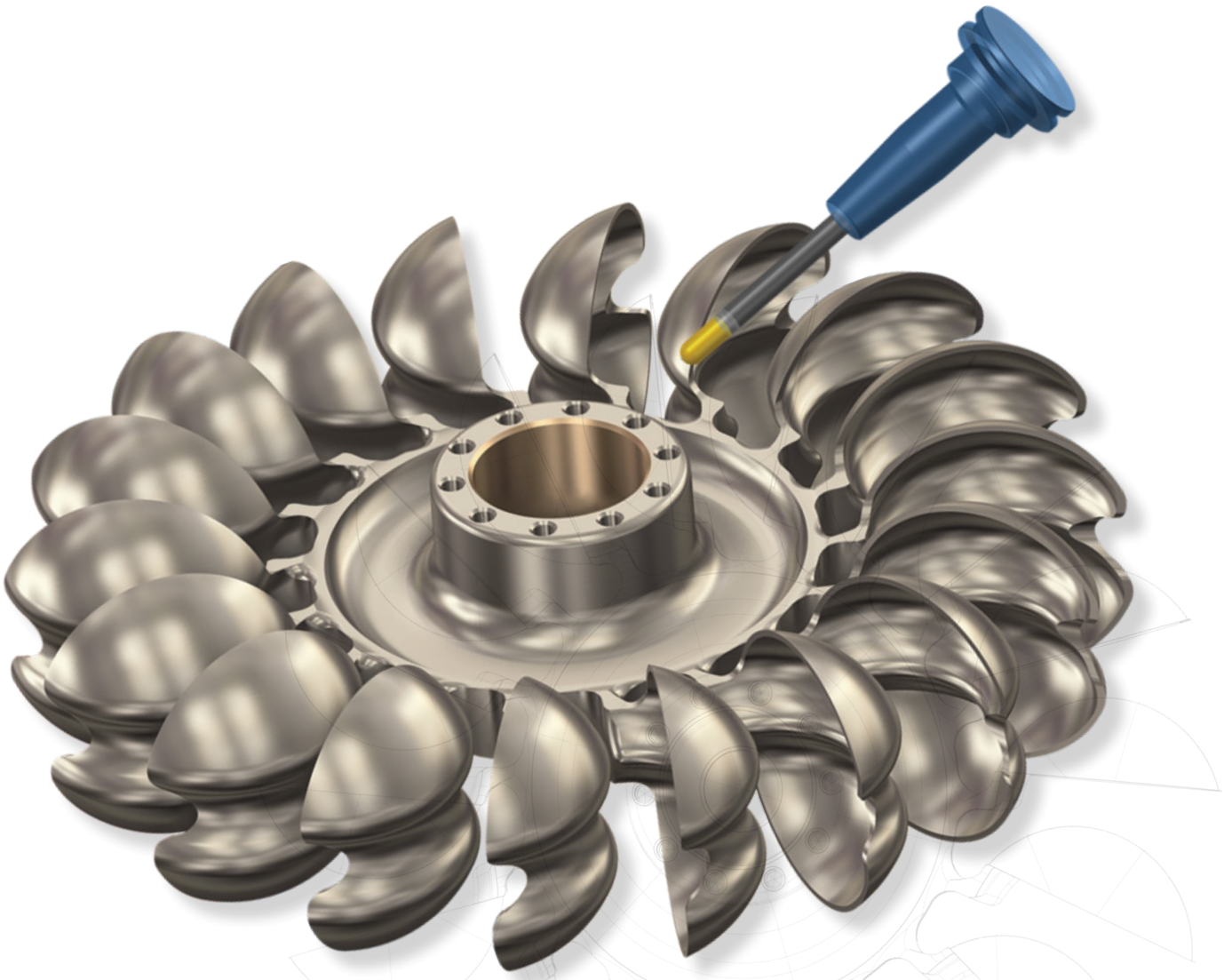
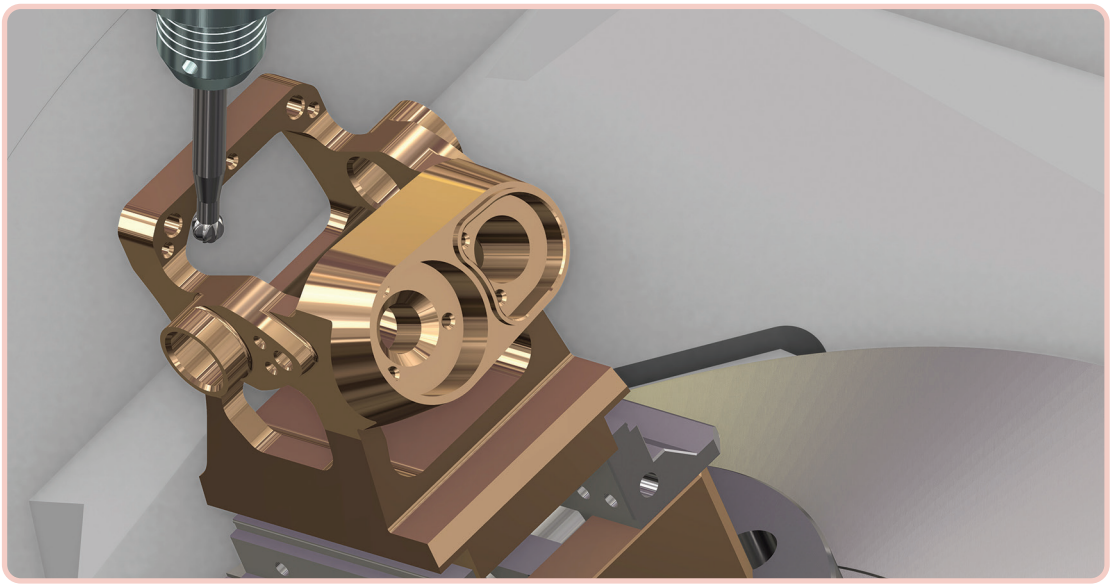
Transitioning from 3-Axis to Multiaxis Machining



Transitioning from 3-Axis to Multiaxis Machining

Multiaxis machining is less complicated and more affordable than one might imagine. Despite its high-tech image, this precision machining strategy sparks individual creativity and provides manufacturers with a host of production options and project opportunities. For those who assume that the technology is beyond their capabilities and budgets, it may be time to take a fresh look at multiaxis machining. With time and proper training, virtually any shop could benefit from these manufacturing techniques.

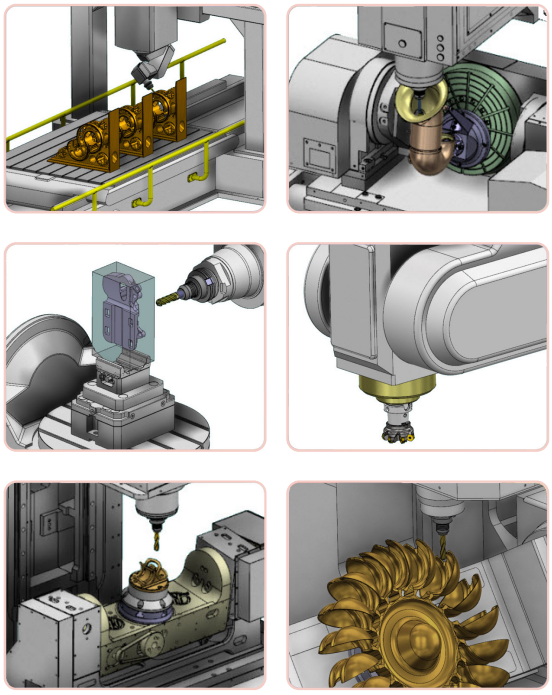
As manufacturers seek ways to compete in a global market — and against cheap labor — multiaxis machine sales continue to climb. Machine builders offer a variety of configurations, capabilities, and pricing, making multiaxis machining attainable for most companies, regardless of size. Whether it produces simple or highly complex parts, an organization that invests in this technology will gain more consistent, efficient, and precise machining practices.



The Basics

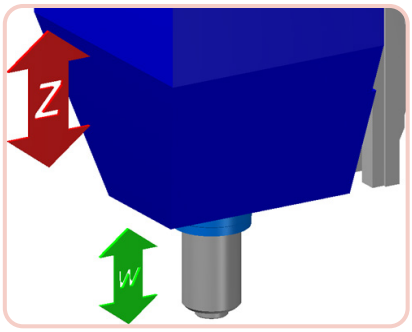
Before delving into the intricacies of multiaxis machining, it is important to note that there is no such thing as a standard multiaxis machine. The arrangements illustrated in **Figure 1** are popular configurations, but none are considered standard.

Figure 1



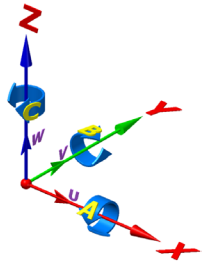
Any motion controlled by the NC controller, either linear and/or rotational, is considered an axis. For example, in **Figure 2**, both the spindle head and the quill can move in the same direction but are controlled by two separate commands. Movements of the head are controlled by Z and those of the quill by W.

Figure 2



The terms "multiaxis" and "5-axis" are often used interchangeably, which can be confusing. Though widely recognized in the industry, the term "5-axis" is misleading because 9-axis standard possibilities exist, without adding additional subsystems. Also, a 4-axis machine is considered a multiaxis machine. For the purposes of this paper, we will use the term "multiaxis."

The following list provides the industry standard nomenclature for the basic 9-axis designations and directions.



- XYZ are the linear axes where Z is aligned with the spindle of the machine.
- ABC are rotary axes rotating round XYZ respectively.
- UVW are parallel linear axes along XYZ respectively.

Most multiaxis machining is performed with simple indexing and positioning, also known as the 3+2 machining method. A steppingstone to multiaxis machining, this strategy is achieved when the part is attacked from different orientations using 3-axis milling techniques. The machine rotates the part; once the part is rotated into position, rotary brakes are applied, and 3-axis machining commences in this preferred rigid mode.

Multiaxis machining yields several major benefits. The first is reduced setup work. Most parts can be manufactured in one or two setups, eliminating the need for extra fixturing and time, which saves money. Second, improved accuracy is achieved through use of indexing rotary tables or dedicated multiaxis machines because multi setups are eliminated. More aggressive cuts with higher RPM and feed rates can be made while precise movement of short, rigid, high-speed cutters yield optimum cutting engagement. Third, better surface finishes are achieved through use of shorter tools, minimizing tool deflection, machine vibration, and extending tool life. The fourth benefit of multiaxis machining lies in the possibility of taking on parts that cannot be cut on a 3-axis machine.

Adopting simultaneous multiaxis machining will bring new job opportunities to your shop. Before adopting any new technology, clearing up possible misconceptions is essential and will pave the way to manufacturing success.

Benefits of multiaxis machining

- Reduced setup work
- Improved accuracy
- Better surface finishes
- Ability to machine new, complex parts

Common Misconceptions

Misconception #1: 5-axis CAD/CAM is too expensive and hard to use.

This statement was true in the past, but not anymore. If you currently own a CAD/CAM system, it is likely that you already have 5-axis positioning capabilities. Most CAD/CAM systems include these capabilities in their base packages. In many cases, training is all that is needed to get up and running.

When shopping for a CAD/CAM system, seek a reputable company with a proven commitment to training and support. A CAD/CAM system is just another tool in your toolbelt. A plethora of fancy, capable tools are available, but tools are worthless if you do not know how to use them. Quality, local support may be the most important feature of your new software.

> The cost will be offset because you can charge nearly double for hourly machine time.

The price of your chosen CAD/CAM system is just a small part of your simultaneous multiaxis investment. Additional training will be needed; however, the cost will be offset because you can charge nearly double for hourly machine time.

Misconception #2: Multiaxis machining is too complicated and unattainable.

One of the most common misconceptions of multiaxis machining is that it is a highly complex, unattainable technology. When people think of multiaxis machining, many assume it entails complicated techniques and programming like those used to machine the induction pump illustrated in **Figures 4 and 5**.

Figure 4

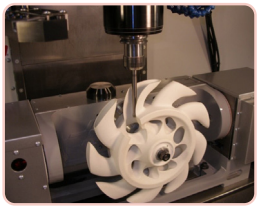
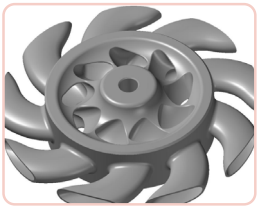


Figure 5



Tradeshow exhibitors and company websites tend to feature the high-end results of what their machines and software can produce. Showcasing machining propellers, turbines, and other intricate parts is an eye-catching way to demonstrate the powerful capabilities of CAD/CAM systems and CNC machines, but 3-axis users who attend these shows and view websites will likely conclude that multiaxis machining is extremely complicated. The visuals reinforce the perception that this technology is beyond them.

The good news? These high speed, high-end examples do not represent the entirety of multiaxis machining or its users. In fact, the majority of multiaxis users never make impellers or racing engine cylinder heads. Most users machine parts with simple 3-axis drilling, contouring, and pocket milling while rotating the part occasionally in a rotary indexing mechanism (see **Figures 6 and 7**).

Figure 6

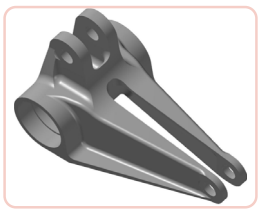
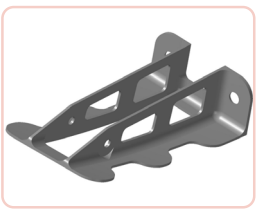


Figure 7



More elaborate parts can be machined by applying 3D surfacing toolpaths and engaging the part from different angles by indexing a rotary table (see **Figures 8 and 9**).

Figure 8

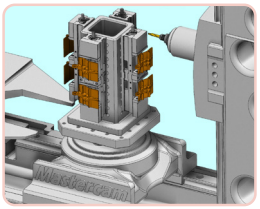
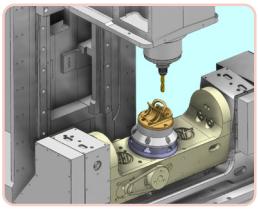


Figure 9



If your shop has 3-axis capability and you are performing multiple setups on your machines, you could eliminate those multiple setups and multiple fixtures simply by installing a rotary device in the machine. Many 3-axis machines come equipped with rotary devices; some shops have these devices but have never used them. Putting rotary devices in service and using indexing can save a lot of time and, ultimately, money.

If you own a CAD/CAM software package, you already have indexing capabilities.

Indexing is virtually cost free because it is included in CAD/CAM software systems. If you own a CAD/CAM software package, you already have indexing capabilities. You will need to learn how to use the technology, but, fortunately, it is not complicated and requires just one program input, made simple with CAD/CAM software.

This major misconception of multiaxis machining — that it is too complex and unattainable — is easily debunked. The many advantages of the technology make it a worthwhile investment.

Multiaxis machines simplify required motions, programming effort, and the amount of fixturing needed for machining complex workpieces. Every shop could benefit from these machining techniques.

Misconception #3: I don't do enough 5-axis work to warrant a 5-axis machine.

Currently, many shops are machining parts by manually moving them to different fixtures on 3-axis machines. Compared to this manual procedure, production can increase greatly without much effort by using a 4- or 5-axis machine. Adding a single- or dual-rotary indexing table would require only minor edits to the CNC-code files. (See Figures 10 and 11.)

Figure 10

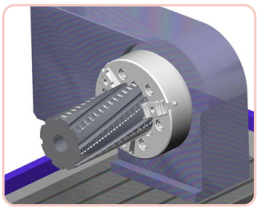
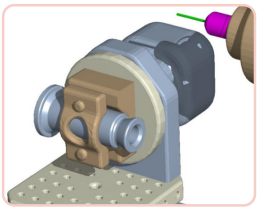


Figure 11



While transitioning to multiaxis machining requires thinking in 3D space rather than a flat plane, many find themselves comfortable with it much more quickly than expected.

When determining if multiaxis machining is right for your organization, consider the following concepts.

As soon as your shop enters the multiaxis realm, new opportunities will arise. Your manufacturing team will quickly become more adept and able to tackle increasingly complex work. In time, your shop will be able to accept more jobs, and, possibly, need to expand.

Five Key Multiaxis Machining Concepts

1. Part Placement

Before investing time or money in the selection or design of fixturing, a multiaxis machinist must first determine part placement and toolpath strategies. This shift in approach sparks creativity and yields optimal results. Learning to use machine simulation is an essential part of this process as it is the saftest, most cost-effective means to prove out multiaxis toolpaths.

> Design the fixture around the cutting strategies.

When considering a multiaxis machining strategy, some programmers may look at a new part and think, "How can we hold this part?" Workholding and tooling are then determined. However, a more effective approach is to ask, "How should I place this part in space so that I have access to all features in different operations?" This feat is accomplished by levitating the part virtually in a virtual machine simulation and then experimenting with different cutting strategies. Lastly, design the fixture around the cutting strategies when possible. This process is a departure from 3-axis machining and from traditional thinking.

2. Tooling

For successful multiaxis machining, the use of shorter tools is preferred and proves beneficial when it comes to part location and getting into places and angles unreachable with a 3-axis machine. Shorter tools provide better fitting and reduced deflection. In addition to determining tooling options for multiaxis applications, tool holders must be carefully considered. Creating precise simulation models allows programmers to see if tooling will collide with any part of the machine or fixture.

The importance of viewing the tool holder and assembly cannot be overstated. Simulation helps programmers make better decisions, and they can make them at their desks. Using multiaxis CNC equipment as a verification system is much more costly than using simulation. Simulation keeps valuable machines from being tied up with testing and allows potential issues to be addressed before parts are ever cut.

3. Machine Tools

Once tool choice is finalized, it is important to become familiar with machine tools. Keep in mind that some machines are best suited for a certain family of parts. With so many machine configurations available, choosing the right one for your specific application requires time and research. A variety of cutting strategies are available for different machines, so equipment options will depend on specific machining processes.

For example, imagine a table/table machine with a part that is bolted to the table and the part and/or fixture must be rotated. If the part and fixture are large, a huge mass must be rotated. Be conscious of where the center is to ensure that the part is not out of balance, which could present a daunting challenge.

For a machine on which the part is stationary—like a gantry-type machine—only the head of the machine is rotated. Machining strategy is based on machine type. With multiaxis machining, it is critical to understand all of the capabilities of the machine, much more so than with 3-axis machining.

4. Toolpath Controls

A quality CAD/CAM system provides enough control to drive any multiaxis CNC equipment. Familiarity with toolpath controls — cut pattern, tool axis control, and collision control — is essential.

Cut pattern is the tool's motion along the part. Cut patterns guide the tool along specified paths. They can be simple 2D or 3D wireframe, solid primitives, or complex multi-surface grids. Examples include zig zag, straight line, circle, and parallel cuts. The pattern you choose depends on the part you cut. The cut pattern must be married to the part or feature that is cut on that part.

Figure 12

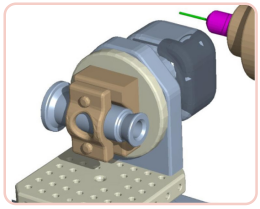
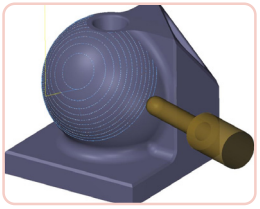


Figure 13



Tool axis control refers to the orientation of the tool's center axis in 3D space as it follows the cut pattern. It is controlling the direction from where the tool is attacking because the 2-axis is locked to a plane. You can rotate your plane and attack it from a different plane, so the tool axis is controlled by the planes.

Many methods exist in a simultaneous multiaxis set up, including staying normal to a surface. For example, for a cylindrical surface, staying normal would cause the tool to always point to the center of the cylinder. For an open-type organic surface (normal to that surface), the tool axis will remain perpendicular or normal to that surface. The patterns vary from part to part and are dependent on programmer preferences.

Figure 14

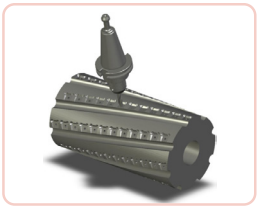
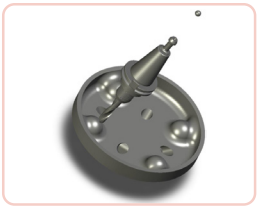


Figure 15



Be sure to take time to set up collision controls. Not all CAD/CAM systems are designed to automatically avoid collisions or gouges because, at times, it limits needed flexibility, as in the case of engine head-porting. Collision control permits monitoring of the cutter's engagement with the surface while ensuring that the tool features—shank, holder, etc.—do not come in contact with surfaces. A good CAM system allows ways to avoid collisions yet permits "near miss" distances to be set for various parts of the tool.

A note of caution: Generally speaking, automatic toolpaths are not always precise. For example, automatic toolpaths are not the most efficient way to rough out one part quickly, but they will do the job. If you are making many parts that require short cycle times, machining efficiency, and quality surface finishes, you need to be in control of the entire process. Toolpaths cater to both scenarios; research your options then decide which is best for your specific application.

The 4 most important aspects of multiaxis machining

- Part placement
- Tooling
- Machine tools
- Toolpath controls

It takes time and a bit of back and forth to discover the best multiaxis machining method for each job, but as jobs are completed, you will gain the experience and confidence to take on more complex parts. The key to mastering machining methods is training. After all, the sharpest tool in the toolbox is useless if you do not know how to use it. Learning these controls will change your manufacturing experience and machining results.

Taking the Multiaxis Plunge

Once you are ready to enter the multiaxis world, resist the temptation to start with a complex, simultaneous job. If you already own a 3-axis machine, begin with a single- or dual-rotary table and apply indexing techniques. You will make more accurate parts at a faster pace, allowing for an investment in more equipment.

The building blocks of multiaxis machines

- Physical properties of the machine
- CNC drive system
- CNC controller capabilities

When buying new equipment, consider bundling a CAD/CAM purchase with the machine purchase order. Most CAD/CAM systems offer both design and manufacturing capabilities, however, be aware that few excel in both CAD and CAM. Also, this a good time to make sure that your CAD/CAM system speaks your specific machine's language—in other words, it has the correct post processor.

Purchasing equipment with a turn-key solution ensures that a specific job will run on the machine upon delivery from the manufacturer. Many machine tool builders employ applications engineering teams that work closely with CAD/CAM developers. Together, the teams determine the most efficient way to machine a specific part based on material, quantity, tolerance requirements, tooling availability, and more.

To truly harness the power of multiaxis machining, it is not recommended that multiaxis programmers be self-taught. Training is a critical aspect of maximizing your software purchase. The most effective training is hands on and occurs throughout the entire process. It should include importing geometry, creating toolpaths, post processing, and simulating toolpaths on a virtual machine.

The next step in training is to learn how to set up a real machine, find its Rotary Zero Point, set tool locations, load the toolpath into the machine controller, and then cut a part. Online and on-site training courses are beneficial as well. Find out what type of programming training your CAD/CAM supplier offers. The supplier you choose should also provide application support after training completion, as well as update training to keep current with ever-evolving software.

The timetable for transitioning from 3-axis to mulitaxis machining varies between companies. A machinist who launches his own company, for example, may purchase one machine and perform full multiaxis machining from the start. With only one machine, the new company owner may want to get the most out of the machine and take on more complex jobs, which in turn allows him to charge more for services.

To truly harness the power of multiaxis machining, it is not recommended that multiaxis programmers be self-taught.

In contrast, some organizations could take much longer to make the full jump to multiaxis machining. A progressive company may make the transition in months if it is willing. Once 3-axis positioning and indexing are mastered, jobs can be completed faster.

What's Next?

Multiaxis machines are available at vastly different prices. Depending on what parts you plan to manufacture, when choosing machine capabilities, the sky is the limit. Before buying a CNC machine, consider the following questions and possible answers:

What do you see yourself doing in three to five years?

- Mass production.
- Unique parts, prototypes, challenging parts.

Do you want to make bigger parts than those you are currently making?

- Yes. (If you are planning to make bigger parts, you should purchase a bigger machine now.)

Are you satisfied with your current work envelope?

- No. I would like to be able to work on long, thin parts.
- No. I am planning to do some work for the heavy mining industry.

These simple questions will help determine the best machine for your company.

Any manufacturing company can benefit from multiaxis machining. For those that attempted it in the past without success, it is important to understand what happened. Often, the reason is operator error. While learning the ins and outs of multiaxis machining, crashes can occur, which can be discouraging. If this scenario sounds familiar, seek out a CAD/CAM software Reseller or approach a colleague experienced in multiaxis machining. Ask for opinions on machines and CAD/CAM systems.

If speaking to a software Reseller, describe the parts you are making to determine if multiaxis machining would work for that application. Look for a manufacturing partner that wants you to succeed, not simply sell you the highest level of software right off the bat.

The advent of multiaxis machining is one of manufacturing's biggest evolutionary events since the introduction of CNC machining. Technology is a constantly evolving dynamic process, and although it grows more efficient, there is still much to learn.

As multiaxis technology evolves, CNC machines become more accessible and more capable. Likewise, CAD/CAM systems are much more powerful, simpler, and enjoyable to use. What has not changed is the fact that technology is a mere tool. The art of machining is still dependent on the user. Ultimately, it is our job to make sure that the use of technology is creative and beneficial to humankind. Automation should make manufacturing easier and enhance our capabilities, not force us to lose our enthusiasm for making products. No matter what type of machines or CAD/CAM software you choose, be sure to use technology as a creative tool.

Points to consider when evaluating CAD/CAM software companies

1. Can you start small then increase functionality as your business grows?
2. Where is your local Reseller located? Try to meet someone from the company to discuss training, support, post processors, etc. Make sure you are comfortable with the Reseller.
3. How established is the software manufacturer? Find a reputable company with a large user base and support network. How easy is it to find employees who already know how to use your selected software?

For more information, reach out to your local Mastercam Reseller or visit www.mastercam.com.

Source: Apro, K. (2008). Secrets of 5-Axis Machining. South Norwalk, CT. Industrial Press, Inc.

About Us

CNC Software, LLC provides state-of-the-art software for CAD/CAM markets. Our single focus is to provide superior solutions based on our users' needs to solve simple to complex design and manufacturing problems.

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