DECEMBER 2001 / VOLUME 53 / NUMBER 12

▶ BY BILL KENNEDY, CONTRIBUTING EDITOR

cover story

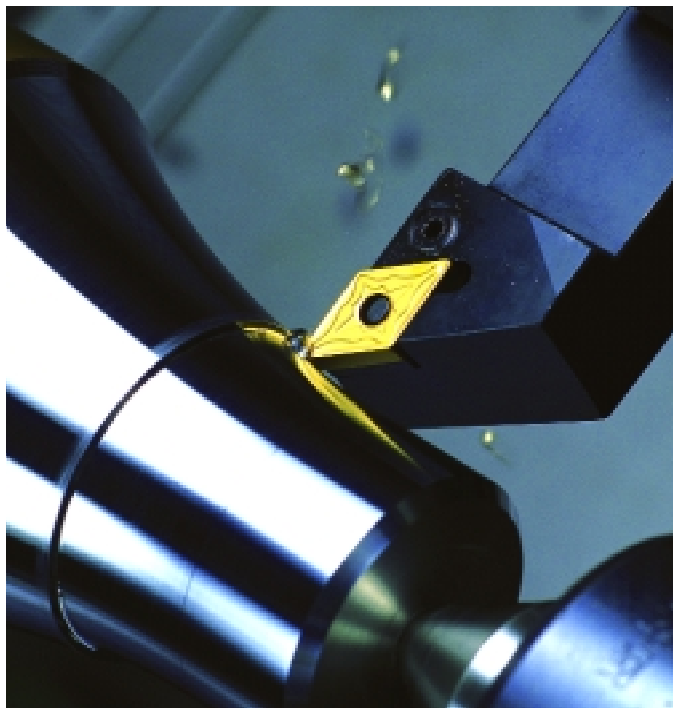
Complicating Matters

Factors that complicate—and fixes that simplify—turning operations.

Life rarely gets simpler. The same is true for manufacturing. Customers are demanding increasingly complex components and ever-shorter lead times. And, new, difficult-to-machine workpiece materials just add to the complexity.

In response, manufacturers continually seek more economical and efficient ways to produce complex parts, including those that are turned. Advancements in CNC technology have helped by allowing nearly any conceivable tool path to be programmed. But as the cutting tool follows these increasingly elaborate paths, the relationships between it and the part—angle of attack, feed, speed and depth of cut—continually changes.

Handling those relationships is both science and art—and the key to turning complex parts in the most efficient, economic way possible.



Sumitomo Electric Carbide

What is Complex?

A complex turning operation can be described as one in which the tool feeds both radially and axially, enabling the creation of varying part contours. In other words, a profiling cut.

Beyond the shape of the part, other complicating factors include the machinability of the workpiece material, the expected production volume, the available machine tool capabilities and—as always—deadlines and budgets.

It should be noted, too, that a part considered complex by one shop may be thought routine by another, and a part's complexity (or lack thereof) isn't always apparent.

John Campbell, CNC supervisor at specialty component-maker Voss Industries Inc., Cleveland, pointed out that a simple-looking part might pose a greater machining challenge than one with an intricate shape. He compared turning a relatively uncomplicated flange made of a 718 nickel alloy with the machining of a convoluted titanium coupling (Figure 1).

Although the coupling requires 10 times the setup effort and two dozen operations, the process is straightforward once the job is up and running. The 718 alloy flange, on the other hand, requires that constant adjustments be made during machining to compensate for material spring back and shrinkage, and tool wear.

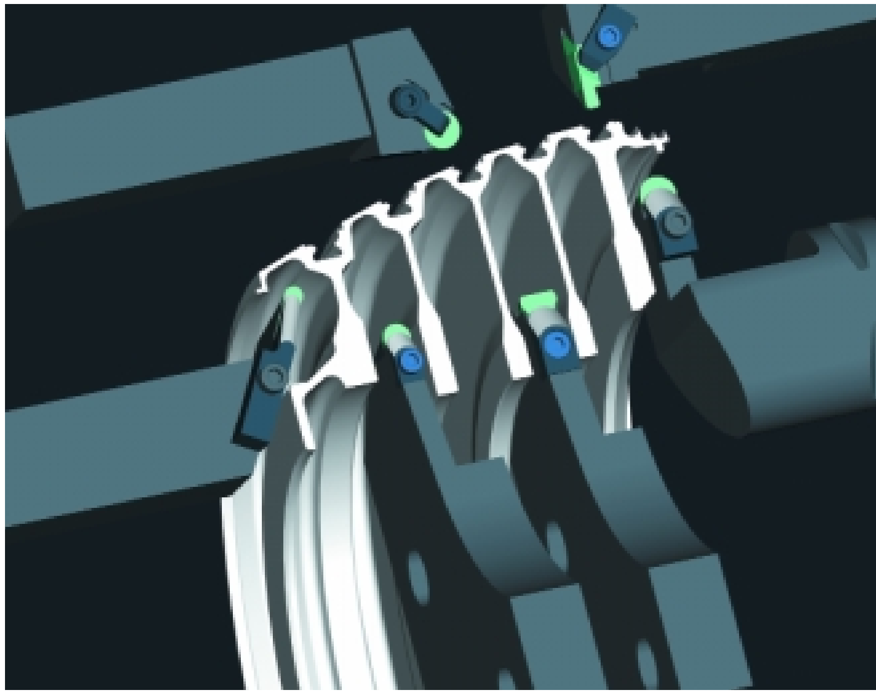
Furthermore, identical workpieces made from different raw-material lots may react differently to cutting forces. Using the flange as an example, Campbell said, "Nickel- and chrome-content variances allowed within the material specification is such that cutting conditions can vary greatly from one lot of material to another, or even from part to part."

Assessing the Situation

Manufacturing consultant Gerald Murray, president of Raleigh, N.C.-based Advanced Manufacturing Technology Sales & Consulting, said the first step in processing a complex part is identifying the kinds of cuts needed and determining which machine tool in the shop can perform them at the lowest cost. For example, a manual lathe can face, turn, bore, groove and cut off. If the part requires no other processing, a manual machine with an overhead rate of perhaps $25 an hour is obviously preferable to a more technologically advanced machine with a burden rate 10 to 25 times higher.

After determining which machine can perform the required cuts most cost-effectively, the next step is planning the sequence of operations. Then, Murray said, it's time to consult with two or more tool suppliers for suggestions regarding tool shape and geometry, cutting tool material and application parameters, such as feed, speed and DOC.

"You'll hear what's the latest and greatest from each one," Murray said, adding that you'll also probably get some good recommendations on the part-processing sequence.

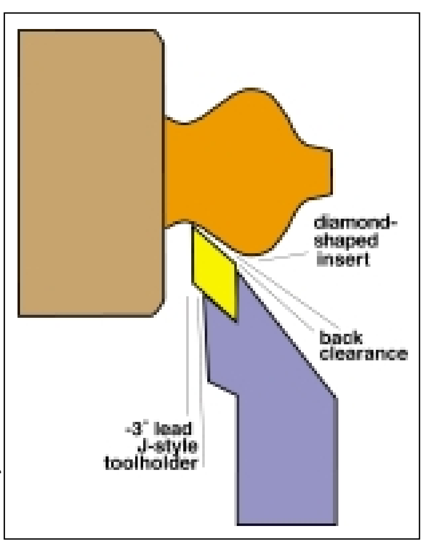


Greenleaf

Figure 3: Simulation software allow trials—and errors—to take place on a computer screen, not on the shop floor with real parts. The software is especially helpful for lowering the design time needed to produce a special.

B. Kennedy

Figure 1: Looks can be deceiving. Voss Industries says this complex-appearing, titanium coupling is easier to machine than a nickel-alloy flange that it also manufactures.



B. Kennedy

Figure 2: For complex profiling, a J-style toolholder with a diamond-shaped insert will provide the necessary back clearance.

Production volume is another major consideration. "If you're going to make less than 20 pieces," said Murray, "you may want to simply give the part print to a machinist—as opposed to a machine operator—and say, 'Make this.' But if it's going to be 500 pieces, then you'll want to go to the trouble of programming the part."

Just-in-time-delivery schedules also could factor into the decision of whether or not to write a part program. According to Murray, "These days, 500 pieces may mean setting up 10 runs of 50 parts. The greatest amount of time in processing a complex part is spent setting up." Therefore, having a part-program stored and ready to be called up will significantly speed changeovers between parts, he said.

Access is First

The first requirement in turning a complex part is obvious: The cutting edge must be able to reach the area(s) on the raw stock where the part contours are to be located. That necessitates choosing the best possible insert shape for the job and determining the lead angles, rake angles, and face- and back-clearance angles that will allow the cutting edge to do its job without interference.

Strength is usually the first consideration when choosing an insert's shape, with round ones being the strongest. For nonround styles, the larger the point angle the stronger the insert. However, clearance issues often require profiling operations to be performed with a 35° or 55° diamond-shaped insert.

Brent Godfrey, turning specialist at Sandvik Coromant Co., Fair Lawn, N.J., said insert choice "really depends on what kind of accessibility you need. If you're going to do complex profiling, you'll probably need to use a J-style toolholder with a diamond-shaped insert that provides a great deal of back clearance (Figure 2). As far as how much clearance is needed, that's determined by the specific workpiece configuration."

An insert's point angle, combined with the lead angle of the toolholder, determine whether a tool can access a contour. Clearance between the workpiece and the insert's cutting edge, back side and heel is crucial. Until recently, determining accessibility and clearances involved estimates, experience, trial and error, and—oftentimes—luck.

Today, CAD drawings and metalcutting-simulation software allow the trials (and errors!) to take place on a computer screen, not on the shop floor with real parts.

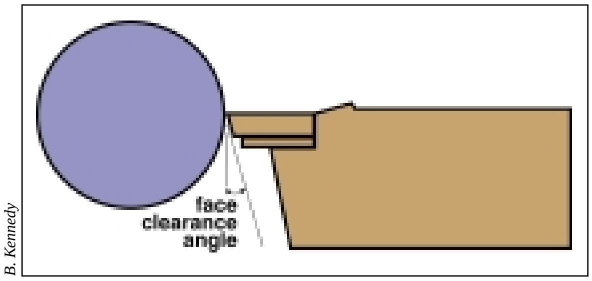


Figure 4: An insert's front and side rakes determine the clearance between the flank face of the insert and the workpiece.

Dale Hill, application engineer at Greenleaf Corp., Saegertown, Pa., said his company designs tools directly from customer-supplied CAD drawings. "Our tool engineers use computer simulations to find the right tools to machine a part (Figure 3). For example, they can see if the back of the tool is clearing a radius where it needs to or if it can reach into a deep groove area."

For truly complex contours, standard tools often don't work. A simulation speeds the process of designing a special. "Standards can't get into those nooks and crannies that a lot of complex parts have," Hill said, adding that design assistance from a toolmaker can be a lifesaver for a smaller shop that lacks simulation capabilities. "That's a free service we offer as part of our overall way of doing business."

Standard Differences

An insert's front and side rakes determine the clearance between the flank face of the insert and the workpiece (Figure 4). For machining steels, the standard rake—and resulting face clearance—is 5°. Other workpiece materials have different clearance requirements.

For example, more-ductile materials, particularly nickel-based alloys, exhibit spring-back tendencies when machined. These alloys bulge ahead of the cutting edge, then spring back once it passes. The rebounding workpiece can rub the insert flank face and generate heat. Additional heat develops due to the workhardening characteristics of nickel-based materials, causing the tool to eventually experience thermal failure.

According to Gary Baldwin, director of Latrobe, Pa.-based Kennametal University's metalworking training program, the failure mode may appear to be chipping, but thermal expansion of the cutting edge actually causes it to fracture.

"Materials like titanium may spring back as much as 0.002" or 0.003"," Baldwin said. As a result, cutting this type of material could require 14° to 15° of clearance between the insert's flank face and the workpiece to prevent thermal failure.

Surprisingly, titanium and plastic exhibit similar spring-back tendencies. While insufficient clearance when machining titanium can cause thermal failure of the insert, the same forces and heat caused by spring back will melt a plastic workpiece. Gummy materials, such as aluminum, will also melt and smear when insufficient clearance causes the workpiece and cutting tool to rub.

Baldwin said a positive-rake insert might offer sufficient flank-face clearance but may lack the strength necessary for edge security. A negative-rake insert has adequate strength but must be seated in a negative-rake toolholder to produce sufficient clearance. Use of a positive chip-control geometry with a negative-rake insert can provide both effective cutting action and the needed insert strength.

Controlling Forces and Chips

The changing relationships among the workpiece, tool and other components of a complex turning operation can negate the effectiveness of chip-control geometries. For example, as the insert moves out from the center of the workpiece in a profiling operation, the chip thins, the DOC increases and chip control deteriorates. One solution is to break the tool path into two passes, replacing the outward feed with one that moves toward the center of the workpiece to achieve the final contour.

When a part is long, has thin walls or is difficult to fixture, cutting forces can cause deflection and an unacceptable surface finish, which could result in the part being scrapped. An insert with a chip-control geometry designed to reduce cutting forces can minimize deflection and its unwanted effects.

Greenleaf offers a carbide insert for finishing called TurboForm (Figure 5). It features a high-positive, molded chip-breaker. Hill said, "This chip form is specifically designed to produce very low tool forces, and it also provides good finishes because it has a precision-ground periphery."

One of the company's customers, an aerospace manufacturer, was experiencing tool chatter that chipped inserts and degraded the surface finish while turning a thin-wall (0.045") titanium seal for a jet engine compressor. Switching to TurboForm inserts eliminated the vibration and deflection while increasing tool life.

If the machinability of a workpiece material contributes to the complexity of a turning operation, a part consists of two different materials can be doubly complicated. The solution when cutting a multimetal part is to select a cutting tool grade engineered for a variety of workpiece materials.

Rich Maton, applications engineer for Sumitomo Electric Carbide Inc., Mount Prospect, Ill., described an oil-field part that consisted of Inconel pressed inside 4340 steel. To machine the part, the manufacturer had to program a pause to allow a second insert grade to be applied to the cut. Despite switching grades, tool life was poor.

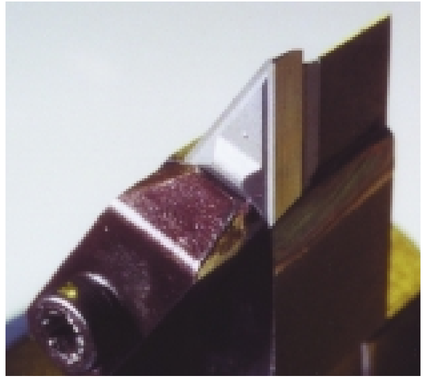
Sumitomo recommended altering the program's feeds and speeds and suggested applying its AC2000 CVD-coated carbide grade, designed to cut both materials productively. The new grade eliminated the mid-program tool change and, at the same time, significantly increased tool life.

Figure 5: Finishing inserts, like Greenleaf's TurboForm, are specifically designed to produce very low tool forces, making them good choices for machining thin-walled and/or long parts.

Grind Away the Problem

Some contours simply can't be cut with the inserts a shop has on hand. In a plunge cut with a J-style negative-rake toolholder, for example, the heel of a 35° diamond insert can strike the workpiece and cause the tool to fracture. A way to avoid the problem is to modify the insert by grinding away the portions of it that disrupt the cutting action (Figure 6).

Jeff Carver, vice president of Willoughby, Ohio-based Duke Mfg. Inc., a maker of components for gas-turbine fuel systems, said, "We use some pretty sharp-pointed tools to machine parts. Many times, there's no standard tool to do what we want to do, so we have to take something and modify it to make it work."



B. Kennedy

Figure 6: The heel of this insert was ground to provide clearance so it could be used for a complex profiling operation.

While some manufacturers would rather stock standard inserts and modify them for particular jobs, modified tools are also available directly from cutting tool manufacturers. And, as mentioned earlier, toolmakers also tailor inserts shapes and geometries to specific part requirements.

When a modified cutting tool can't achieve what's desired in a single pass, the only choice is to stop the machine, change to a different style tool and complete the cut. That, unfortunately, takes time, and interrupting a pass often leaves a mark on the workpiece that must be removed during a secondary operation.

Machine Builder Contributions

Machine tool builders and developers of CNCs continually introduce technology to simplify the turning of com-

Manufacturer takes 'team' approach to machining complex parts

Voss Industries Inc. makes a lot of complex parts. To complete them as efficiently as possible requires the Cleveland company to work in a concerted fashion.

Voss manufactures fasteners, couplings and other components for the aerospace, medical, marine, petrochemical and food-processing industries. And although it employs 210 at its 237,000-sq.-ft. facility, it maintains a "job shop" mentality, said company president Dan Sedor.

It focuses on smaller lot sizes and specialized products. The company rarely sees long runs of parts, meaning it seldom has the luxury of gradually refining a manufacturing process to achieve the greatest efficiency. To maximize productivity quickly, Voss uses a team approach.

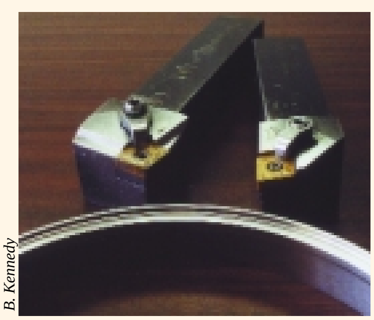
For example, before estimating or preliminary part programming begins, most jobs, especially new items, are presented to a preproduction review committee made up of representatives from affected disciplines.

"A cross-functional team—product development, toolroom, engineering, sales and purchasing—work together to determine what it will take to make the part," Sedor said.

Voss Operations Vice President Mark Schodowski added, "First, we determine whether we have the right engineering and machining capabilities, then we start to work from there regarding pricing, materials and the customer's needs."

Even seemingly peripheral issues, like the packaging of the completed parts, may be discussed. "Little things can give you headaches," Schodowski said.

The teamwork concept extends beyond the company, too. "Our vendors have a great willingness to work with us," said Sedor. "We'll ask our materials suppliers to meet the high or low side of a particular specification, and they are happy to help."



B. Kennedy

Stellram's SP4036 insert, with the new 3J chipbreaker geometry, helped Voss simplify the machining of a tough aerospace alloy.

Voss CNC Supervisor John Campbell added that the company works very closely with its tooling suppliers. For example, Voss had been machining a 718 nickel-alloy flange with the 80° corner of a CNMG insert. But tool life was only one or two pieces per edge. "The 718 alloy responds to a shearing action rather than cutting, and if you don't have the right tool geometry, it pushes instead of shears," explained Campbell.

Ron Milicia, the representative for toolmaker Stellram, La Vergne, Tenn., offered a solution to the flange-machining problem. He brought Campbell Stellram's SP4036 insert, which incorporates the new 3J chipbreaker geometry, in the CNMG style.

Campbell recalled: "We roughed the part with the 100° corner and left 30- to 50-thousandths on the diameter. We got six or eight pieces from it. Then we finished the part with the 80° edges, and got 30 pieces from each. Not only did we use all eight edges and get much better tool life, but the lead angle of the holder and the 100° edge thinned out the chip and improved the shearing action."

Just as Voss looks to its suppliers for assistance, the Cleveland company often reciprocates. It lets suppliers test tools in its plant, said the company's tool analyst/buyer, Ken Rupert. While the tests may not immediately benefit Voss, Rupert sees it as a mutually beneficial way to do business.

It takes a team to meet the challenges of producing a complex part. Sedor said, "There are so many things you don't know, and we're fortunate to have a team of talented people, both inside our company and out, who have that base of knowledge and expertise."

—B. Kennedy

To contact Stellram, call (800) 232-1200, or visit the company's Web site (www.stellram.com).

plex parts. An example of the former is the Integrex series of multitask, turn/mill machines available from Mazak Corp., Florence, Ky.

These machines resemble a machining center with a turning spindle on either end of the table. The machining-center head, or B-axis, can move the tool 225° radially around the part during a turning operation. That makes it possible to keep the tool's nose radius tangent to the cut, and enables one tool to do the work of two or more.

This advance in metalworking science, as well as those mentioned earlier, certainly make the turning of complex parts easier. But most will agree that producing such parts as efficiently and economically as possible will always require an artistic element.

Following is contact information for the companies that contributed to this article:

Advanced Manufacturing Technology Sales & Consulting
(919) 539-9000

Duke Mfg. Inc.
(440) 942-6537

Greenleaf Corp.
(800) 458-1850
www.greenleafcorporation.com

Kennametal University/ Kennametal Inc.
(724) 539-5000
www.kennametal.com

Mazak Corp.
(859) 342-1700
www.mazak.com

Sandvik Coromant Co.
(800) 726-3845
www.sandvik.com

Sumitomo Electric Carbide Inc.
(847) 635-0044
www.sumitomo.com

Voss Industries Inc.
(216) 771-7655
www.vossind.com