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cover story

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Calming Chatter

B. Kennedy

Strategies for minimizing tool chatter.

Boosting speed and feed rates helps maximize the productivity of milling operations. But doing so can lead to chatter, which negatively affects surface finish, tool life, machine tool longevity and cycle time.

Chatter and its undesirable consequences are an outgrowth of vibration. To some degree, all milling tools vibrate as their teeth bite into the workpiece.

Each vibrating tooth leaves a wavy surface. When the wave left by Tooth No. 2 matches the one made by its predecessor, Tooth No. 1, chip thickness is constant and a smooth cut results. If the waves are out of sync, though, chip thickness varies and regenerative vibration—chatter—develops.

The key to controlling chatter is maintaining a constant chip thickness or absorbing, or redirecting, the energy that generates vibration. The entire cutting system—from the structure of the machine tool to the geometry of the cutting edge—affects the level of chatter that develops.

Bigger Not Always Better

A large mass absorbs vibratory energy better than a small mass. That's why, historically, machine tools have been heavy and featured massive columns and box ways.

The current trend of milling at higher speeds and feeds, however, requires machines with near-instantaneous acceleration and deceleration capabilities.

Today, "weight is the enemy," said Alan Hollatz, proposal engineer for Makino Inc., Mason, Ohio. The linear guide ways used in the current generation of machine tools are accurate and fast, but they are not as heavy or capable of absorbing vibration as box ways.

In response, Hollatz said, Makino installs moderately oversized guide ways and trucks that ride on them, and places the guides at different heights to maximize rigidity.

During the design process, finite-element-analysis software, which simulates the machine's dynamic behavior, enables the builder to minimize mass while maintaining stiffness.

"Ideally, you want a column that has zero mass and infinite rigidity," Hollatz said.

Spindle stiffness also is a factor in whether or not chatter develops during milling. The higher a spindle's bearing preload, the greater its rigidity. But because preloads can change as spindle temperatures rise during machining, the preloads for cold bearings are normally set lower than what is optimal.

Some machines feature oil-chilled spindle bearings. A sensing system keeps spindle temperature constant by circulating oil through the center of the spindle and bearings. A separate circuit cools the jacket of the spindle. Because spindle temperature is constant, a higher bearing preload is possible.

An adjustable-preload feature maintains spindle rigidity over a range of applications. SKF Precision Technologies, Grafton, Wis., markets GHS spindles. The spindles' bearing preloads can be adjusted hydraulically via a solenoid in the machine tool control.

Chris Hetzer, head of engineering and assistant general manager at SKF, said spindles can be set to respond to specific levels of speed or load.

According to one company, the spindle's role in helping control chatter may depend on more than mechanical factors.

Spindel Corp., Grand Rapids, Mich., designs and manufactures adjustable-speed, AC motor drives (inverters) for machine tools. The drives supply the spindle with precisely balanced, 3-phase, sinusoidal current. According to Spindel, a better-balanced current reduces motor-torque pulsations that may contribute to tool chatter.

Company president Boris Polic said, "People usually think of chatter mainly from the mechanical side ... everything else but the three wires that come to the motor."

He added that spindles designed for higher speed and greater power are more sensitive to imperfections that arise in the drive's waveform. An imperfect drive may work satisfactorily with a relatively low-speed, 10-hp spindle, Polic said, but with a high-speed, 30-hp spindle, "big time vibration" can result.

Sandvik

This milling adapter consists of an encased, heavy-metal bar. The cavity holding the bar is filled with oil that helps absorb and modify a machine tool's harmonic frequencies.

Tooling Solutions

Increasing tool rigidity and reducing runout minimizes chatter during milling. Modular tooling systems and toolholding interfaces designed to provide the requisite levels of rigidity and accuracy include Capto, from Sandvik, Kennametal's KM system, Innofit from Ingersoll and HSK-style tooling, as well as screw-on systems for integral endmills.

Bruce Carter, milling products manager for Sandvik Coromant Co., Fairlawn, N.J., cited a test in which cuts were made with two long-edged milling cutters. One was arbor-mounted and the other was Capto modular tooling. The cutters were run at exactly the same radial and axial depth, feed and speed.

"Using the modular system resulted in a smoother-running cutter, due to increased rigidity and near-zero runout," Carter said. "You almost couldn't hear the Capto run, while the arbor-mounted cutter chattered severely."

Sandvik's senior product specialist for tooling systems, Andy Pitsker, recommends placing a damping adapter between the spindle and cutter in applications involving long overhangs. "The traditional solution is to reinforce a long overhang with a carbide bar," he

The following organizations contributed to this report:

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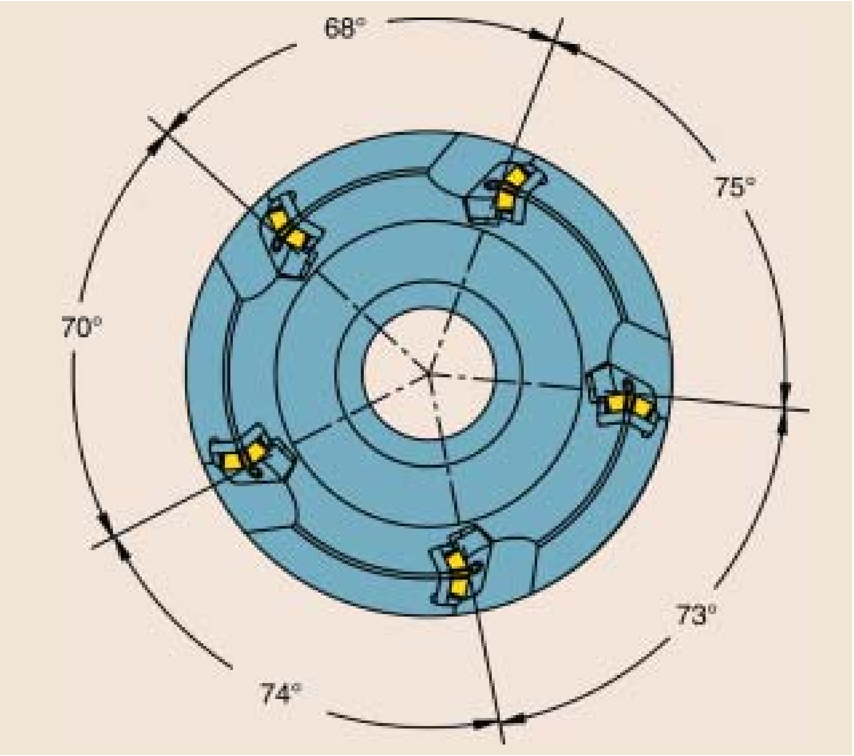


Kennametal

Differential pitch—a staggered spacing between inserts—interferes with the regenerative vibration that creates tool chatter.

said, but solid-carbide tools can microfracture and crack when subjected to vibration.

So Sandvik and its partner, Teeness ASA, Trodheim, Norway, developed an adapter that encases a heavy-metal bar supported between centers. The cavity holding the bar is filled with oil that helps absorb and modify a machine's harmonic frequencies. The heavy-metal mass moves in response to vibration and counteracts it.

Konrad Forman, marketing manager for milling products at Ingersoll Cutting Tools, Rockford, Ill., said another way to overcome chatter is to create a bimetal structure within the milling cutter. Inserting a carbide rod in the middle of the cutter body, he said, "will give you some of the benefits of carbide, as far as stiffness, but also changes the harmonic characteristics of the cutter. If you've got a long extension, it can help avoid chatter."

The geometry and arrangement of the cutting inserts play a key role in chatter control, too.

Positive-rake inserts generate lower cutting forces and decrease vibration because they tend to shear material instead of push it. Inserts with up-sharp edges or those with minimal or variable hones can also reduce cutting forces and, thereby, vibration.

Often, applying a cutter with a coarser pitch—i.e., fewer inserts—eliminates chatter. Differential pitch also can be effective.

Dr. Scott Smith, professor in the Department of Mechanical Engineering at the University of North Carolina at Charlotte, explained that staggering the spacing between inserts works because it interferes with regenerative vibration.

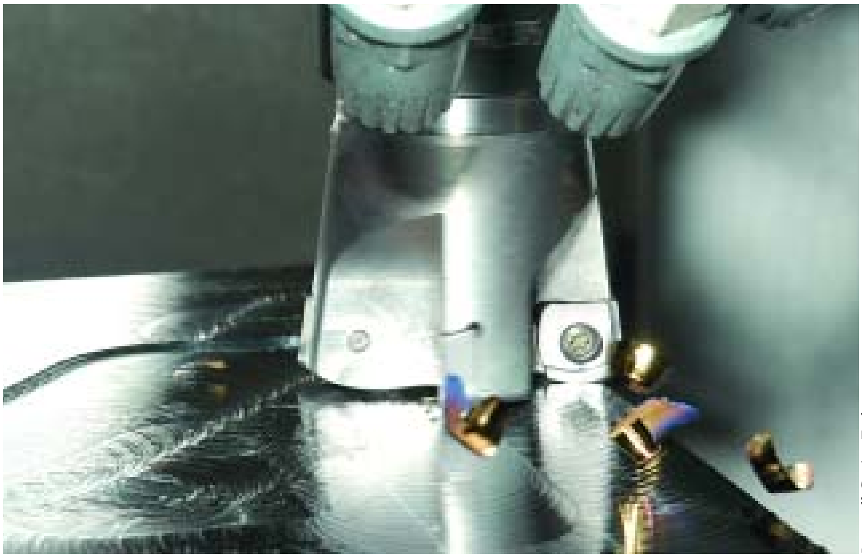
However, he added, sometimes there are drawbacks to the differential approach. Because the inserts are spaced unevenly, chip thickness varies. Therefore, some of the inserts do more work than others.

"I think many people who are using a nonproportionally spaced tool miss that," Smith said. "They see they can cut a little deeper than with proportional spacing, but they may have to slow down the feed or the tools will wear out quick."

Forman said feed adjustments may be necessary in extreme cases, but relatively small differences in spacing significantly limit chatter without unduly affecting chip load. "For instance," he said, "on many of our standard tools over 2" in diameter, we employ small differences in spacing that affect chip thickness by less than 0.0008 ipt.

"We do not recommend lowering the feed rate."

Variably spacing a tool's cutting edges is not limited to inserted tools. Some solid endmills are manufactured with a waveform on the cutting edge of each flute that is out of phase with the form on the previous flute. This results in a continuously variable pitch that


Ingersoll Cutting Tools

With a large edge radius and drafted periphery edge, Form-MasterSpeed high-feed inserts applied at a shallow DOC when milling can help control chatter by redirecting forces into the machine spindle.

breaks up regenerative vibration.

Phil Bell, R&D manager of Technicut Ltd., Sheffield, England, said HSS waveform cutters have been available for many years. Tool manufacturers now are grinding this type of form on solid-carbide cutters, such as Technicut's Gator tool. It can be run at a heavier DOC and higher feed rate on tough alloys like titanium.

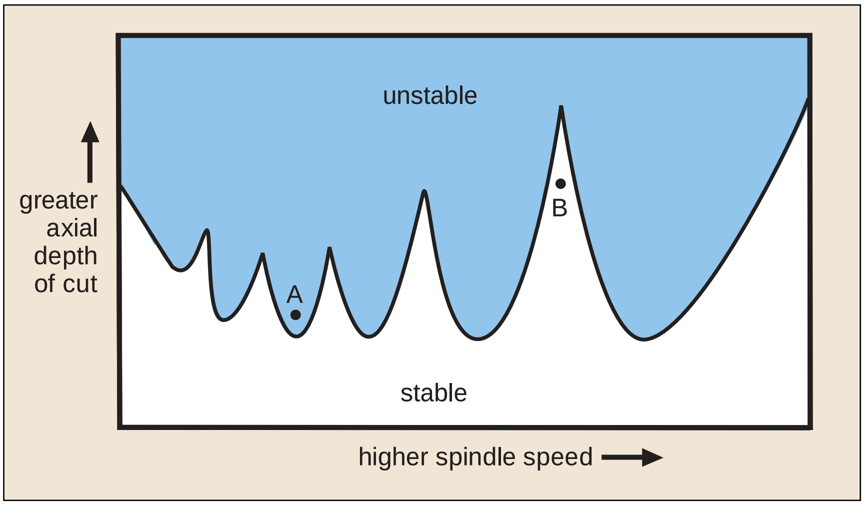
Bell said Gator parallel cutters feature a constant-diameter cutting edge—the diameter does not decrease at the troughs in the waveform. This results in good surface finishes and enables the cutter to be used for both roughing and finishing.

Special insert geometries can also help control chatter. Forman said Ingersoll and a number of other cutting tool manufacturers have begun to offer high-feed milling cutters, which are designed to run at high feed rates and very light DOCs.

Ingersoll's Form-MasterSpeed insert is engineered to minimize radial forces and direct the energy axially, into the spindle of the machine.

Ingersoll Milling Product Manager Don Yordy said the light DOC enables a user to take advantage of higher speeds because the cutting action is more stable.

"Where you can really hit a home run is when the length-to-diameter ratio of the cutter is extreme," said Yordy, "and you're down to 30 ipm and picking away with a back-draft cutter, and you can't make any gains without chatter. These high-feed tools redirect the load toward the spindle so the cut is efficient and stable and you can raise the rpm and feed rate."



The continually changing relationship of tool vibration characteristics to cutting parameters can produce instability when machining at a relatively low-speed with a shallow DOC (A) while a deeper, faster cut (B) remains in a stable zone.

Tool Tuning

A longstanding tradition in machining has been to rely on the machine operator's experience to control chatter. When an experienced machinist hears chatter, he adjusts the feed- or speed-override control until the sound halts.

Scott Etling, manager of Global Machining Technologies at Kennametal Inc., Latrobe, Pa., said this method usually works. But tools and parts can be damaged prior to the adjustment, "and, for sure, the machinist is not optimizing his operation." Etling said computerized analysis tools are available that enable users to stop chatter while maximizing productivity.

One example is the Harmonizer software package from Manufacturing Laboratories Inc., Las Vegas. The user loads the software on a PC and inputs the spindle speed and number of cutter teeth. A microphone records the sounds emitted by the machine as it operates. The software distinguishes between the sound of teeth hitting the workpiece and the sound emitted when vibration occurs. The software then recommends a cutting speed that will stop chatter.

Other software systems offer predictive analysis of an operation's tendencies for chatter by analyzing the vibration characteristics of the tool that will be making the cut. A hammer fitted with special instrumentation strikes the tool and a sensor measures the vibration at the tool tip. The software generates what is known as a "stability lobe diagram," which charts the combinations of speed and DOC that will produce chatter-free cutting.

Because a tool vibrates differently at different speeds, stable lobes appear and disappear as parameters change. Some stable areas exist at higher speeds and deeper DOCs than might be expected.

The benefits of these technologies become more apparent as cutting speed rises. At low speeds, simply remaining below a certain DOC will ensure a stable process. But as spindle speed increases, the software can identify parameters that are both chatter-free and more productive.

"In one of those stable zones, a 10 percent change in the spindle speed can mean the difference between a beautiful part and breaking the tool," said Smith.

These analytical tools provide maximum benefits when the user records the information in a database, allowing it to be applied to similar operations in the future. Smith said, "Some large companies have the data stored on intranet sites, so when programmers are going to use a certain tool, the information about speed and DOC is available."

To use such data effectively, setups must be repeatable. "The tradition and practice in small shops goes against this," said Smith. "Tools are set up on an ad hoc basis, as they are needed." However, "if you can set tool length the same every time, then the data repeats very well over long periods of time."

Dr. Tony Schmitz, assistant professor at the University of Florida's Machine Tool Research Center, Gainesville, described a predictive modeling approach to tool tuning. As opposed to examining the stiffness of each separate component of the machining system, predictive modeling provides the user with data on the dynamic stiffness of the overall system.

This approach, Schmitz explained,

allows the natural frequency of a tool to be lowered to match the spindle's frequency. When tool vibration matches that of the rest of the system, a longer tool can take a deeper cut and remain stable. The energy dissipates throughout the structure instead of just at the tool/workpiece interface.

Schmitz said that although analytic tools do a good job of predicting and compensating for chatter, "they are not bullet-proof. They are right most of the time. The thing that's stopping them from being used in every shop across the land is the data that you have to have. If you change the length of your tool by 3mm, things can change significantly. That's what's tricky about this whole business. If I change tools but use the same machine and same holder, I get a new diagram. So that makes it very difficult to do turnkey chatter control."

Still, that is the goal of Schmitz and his fellow researchers. "Everything we do is to try to make this more useful," he said. "I am interested in making this technology accessible to the people running machines."

Another goal is to control chatter without slowing machines. That isn't being competitive, according to Smith. "With the trend of manufacturing jobs moving offshore, it's not just how much the wages are somewhere else, it's how productive we are.

"My experience has been that most people in the U.S. are under-utilizing their machines by a factor of two—easily. I think most people who figure out what their machines can do are surprised at how good their machines are," said Smith.