DIAL DOWN OR DIAL UP

Modern Machine Shop Magazine Cover Story March 2010 Issue

Vibration analysis may be the machining center's missing piece. If you haven't performed this analysis on your high speed machine, you probably don't know what the machine can do.

By Peter Zelinski
Senior Editor

Experienced machinists and NC programmers cultivate a particular response when it comes to the loud, ugly shriek of a poorly performing milling pass. Confronted with this evidence that the chosen parameters of the cut are not ideal, they reduce something. That is, they dial down some aspect of the process.

The specific parameter they reduce might be the depth of cut, the combination of speed and feed rate, or the length-to-diameter ratio of the tooling. Whatever the parameter, "down" is strategy for achieving better performance. Indeed, the more experienced machining personnel are practiced at reducing these parameters to just the extent necessary to achieve acceptable cutting. And in most shops, this reduction—this compromise—is likely to be the right response.

However, the very essence of high speed machining is found in a departure from this practice. Beyond a certain spindle speed, the reduction is liable to be the wrong response.

The key parameters remain the same—depth of cut, spindle speed and the length of the tooling. Yet reducing any of these parameters in response to chatter at high spindle speeds can be counterproductive, if not downright wasteful. Many shops using high speed machining centers routinely waste capacity in this way without realizing what they are doing.

In high speed machining, the way up might still be down. However, the way up might also be "up." In the case of both spindle speed and tool length, there are times when the best answer to chatter is actually to increase one of these parameters. As counter-intuitive as it seems, there are cases in which a higher spindle speed and/or a less rigid tool can actually allow the machine to handle more aggressive depths of cut, simply because of the ways that these changes bring the vibration tendencies of the system into greater harmony.

In high speed machining, the machine tool enters a realm of spindle speed where it is no longer possible to determine from intuition or experience just where the ideal cutting conditions are likely to be found.

One shop that knows this is part of Warner Robins Air Force Base in Georgia.

Robins Air Force Base services both cargo and fighter aircraft. The machine shop supports that mission. The technician seen here installs a newly machined part into an aircraft wing section.

Military Milling

The fast-response machine shop here is part of the 573rd Commodities Maintenance Squadron of the Air Force's 402nd Maintenance Wing. The shop's mission includes machining replacement parts for the military fighter and cargo aircraft that fly to this base for service from locations all over the world. Because of the frequent need for these planes to return to action quickly, the shop often has to produce complex and critical parts in tiny quantities according to narrow lead-time demands.

Programmers David Devore and Mike Estes say that when this shop first began to use high-speed machining centers, the shop unknowingly used them in a sub-efficient way. The shop broke tools frequently on these machines, including 3/4-inch end mills used for roughing. The shop's response was to slow down on certain cuts—breaking tools less often.

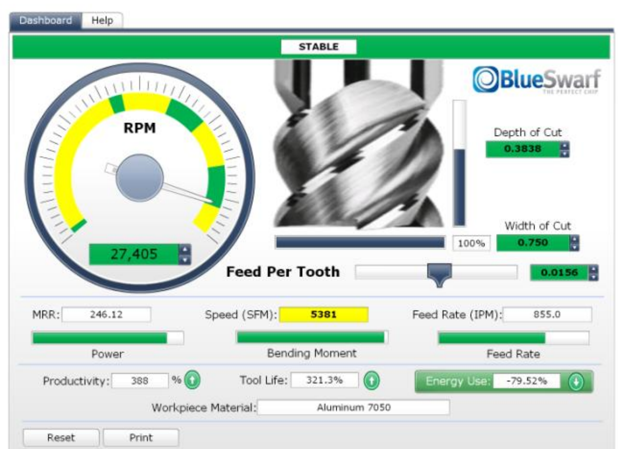
But when the shop installed its fastest machining center (a 30,000-rpm MAG 3 machine from Makino), the shop had this machine "tap tested." That is, the shop measured the machine's vibration characteristics, using a sensitive hammer to ring the tool in the spindle like a bell.

This analysis specifically aims to find stable cutting speeds for each of the tool/toolholder sets that the shop plans to use on a particular machine. Once these stable parameters were found and put to use on the new machine, part quality, productivity and tool life all were superior to the shop's experience of high speed milling to that point. The difference was great enough that the shop determined to perform the same analysis on the existing high speed machines as well. On these machines, the shop discovered that many tools were more stable and productive at speeds that were not slower than where the shop had run, but instead considerably faster. The shop turned up the speed in line with these optimal parameters, and immediately began to run quieter, cut heavier and make better parts—no longer routinely breaking tools.

Now, the shop is committed to running high speed machines using parameters that are based on vibration analysis. Beyond a certain speed, the shop has seen that this analysis is practically essential for realizing the machine's full efficiency. Within the higher reaches of milling spindle speed, every particular combination of machine, toolholder and cutting tool has specific stable speed values that permit the deepest cuts and heaviest metal removal. There is no way to infer from experience where these speed values might be. Given all the tools Warner Robins uses, there was also no practical way to find the stable parameters through testing in the cut. Instead, the shop contracted with a source who could measure all of the machines' vibrations, devoting the relatively small amount of time necessary to determine the best speeds and depths of cut for all the tool/toolholder combinations used on each of the high speed machining centers.

Tool Dashboard

Cutting performance couldn't be more different now. The very environment of the shop has changed. With less chatter, machining is quieter. With the high speed machines capable of heavier depths of cut at higher speeds without tool breakage, the machines are now more productive. And with the information that is now available about optimum machining parameters, even the programmers are more productive. One of the resources now available to them is a "Tool Dashboard" that allows the programmers to precisely anticipate the performance and productivity of any set of cutting parameters chosen for a particular tool in a particular high speed machining center.



On the "RPM" dial of the Tool Dashboard, green zones represent the stable cutting areas for this particular tool. The Tool Dashboard makes it easy for the programmer to manipulate speed, depths of cut and chip load, and predict the effects of these changes based on the dynamics of the machine.

Now, when a particular tool and toolholder are chosen for one of the high speed machines, optimum parameters based on the vibration analysis load into Catia automatically. Still, these parameters might not be right for the particular cut. The programmer might need to tailor the depth of cut, for example. In these cases, the programmer can manipulate slider bars in the Tool Dashboard to adjust axial and radial depth of cut, finding an efficient set of parameters just shy of where chatter would set in. Even the feed rate can be adjusted this way—testing it against the bending moment of the spindle.

The tap test can find the spindle speed and depth of cut that will maximize metal removal rate for a particular combination of machining center, toolholder and milling tool.

Warner Robins contracted with the company BlueSwarf both to perform the tap-test analysis and to provide the shop with resources including the Tool Dashboard. BlueSwarf is a firm specializing in machine-tool vibration analysis. The company sells a "Metalmax" analysis kit, including hardware and software, allowing shops to perform this analysis internally. However, BlueSwarf also performs the on-site analysis itself for shops that want to contract for this work. The actual testing involves simply striking the tool while it's in the machining center, hitting it with a sensitive hammer so that a sensor on the tool tip can capture the response. Because different combinations of tool and toolholder have to be tested separately, however, the complete work might span hours or days. Certain tool details such as corner radius don't matter, so the actual number of tools tested is not as large as all the mill varieties in a given shop, but the shop at Warner Robins had about 300 different tool setups to be tested in each high speed machine.

Specific Speeds

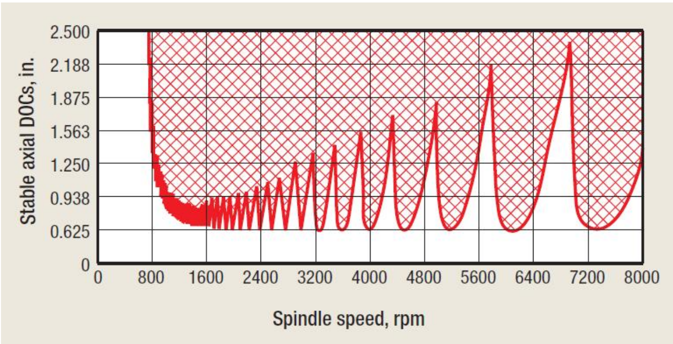
Why do high-speed machining centers behave like this? That is, why do they sometimes perform better with particular speeds and/or particular tool lengths? The answer has to do with resonant frequencies.

Every mechanical system has some set of natural frequencies at which it inherently wants to vibrate. Any system of machining center, toolholder and tool has these natural frequencies, and to at least some tiny extent, the machine is vibrating at these frequencies while it cuts. The vibration leaves microscopic waviness in the machined surface.

The machine tends to fight against this waviness. The waviness produces a varying depth of cut, and the load on the tool fluctuates as a result of this variation. To be sure, the fluctuation is often minute, and so is the machine's fight against it. However, in aggressive cuts, when the extent of the variation becomes more pronounced, the fluctuation actually feeds on itself. Tool deflection produces more extreme waviness, which further exaggerates the variation in depth of cut. This self-exciting vibration is chatter. Tool life and part quality suffer—and the sound can be insufferable.

Still, at spindle speeds higher than about 10,000 rpm, a different possibility sets in. At these higher speeds, it becomes possible for some rate at which the cutting edges are hitting the workpiece to be in harmony with a natural frequency of the system.

When this happens, the machine is still vibrating, but the tool tip essentially moves in unison with the waviness. The cutting load becomes consistent. The cut is smooth. The result is this very phenomenon that is so strange to many shops. Namely, at high speeds, certain very specific spindle speeds permit dramatically higher depths of cut.



This example of a stability diagram shows the increased depths of cut that are possible within specific, narrow bands of spindle speed across the entire speed ranges. Tap testing is aimed at finding these stable speeds.

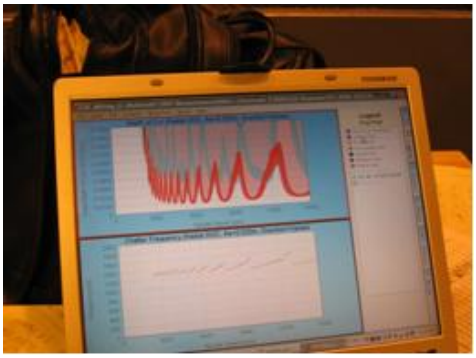
The above diagram illustrates this. Across the range of spindle speeds seen here, the peaks show where this particular machine and tool setup is capable of more productive cutting. Above the curve is the area where chatter sets in. Thus, a particularly large depth of cut is possible around 12,000 rpm, even though nothing like that same depth would be possible if the machine ran just a little faster or slower than this speed. The shop that wasn't aware of this magic speed would have no idea what its machining center actually could do.

In fact, the shop might also have no idea what its tools can do.

Tool Strangeness

Differences in tool performance at high speeds reveal one more potentially surprising aspect of knowing the nature of a machining center's vibration. When BlueSwarf tap-tested Warner Robins' oldest high speed machining center, it made the discovery illustrated in the photo on this page. Typically, shorter tooling provides for more stable milling—but not always. On this particular machine, the system was actually found to be more stable, and capable of heavier depths of cut, when using the longer of the two tool setups shown in the photograph. The "floppier" tool therefore permits higher metal removal rates on this machine.

The shop used the machine for years without knowing this. The machine performed well, but still—the information certainly would have helped. For those years, the machine could have performed better. Running without this valuable information was like running, for all this time, with that machine's potential quality and output both dialed down.



Almost any machining center user would expect to cut more aggressively—to cut with less chatter—using the shorter of these two tool setups. On one machine in the Robins shop, the longer tool is actually more stable, and capable of deeper cutting. The computer display from the test, just minutes after it was performed on Robins' shop floor, shows the difference. The red peaks show the possible depths of cut with the shorter tool, while the blue peaks behind it show the larger depths of cut the longer tool will allow.

For More Information

Learn more about BlueSwarf® and the Tool Dashboard™ system at www.blueswarf.com