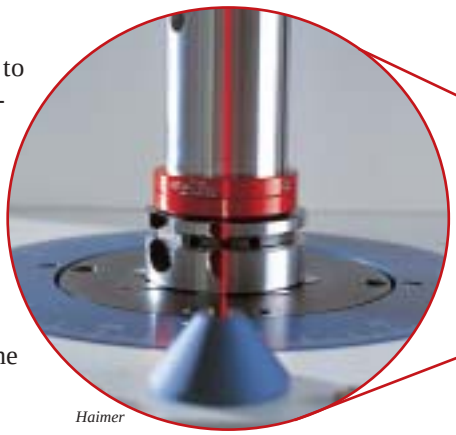
cover story

BY ALAN RICHTER, EDITOR

Considerations when deciding to run hard-balanced or balanceable toolholders.

EQUILIBRIUM Adjustment



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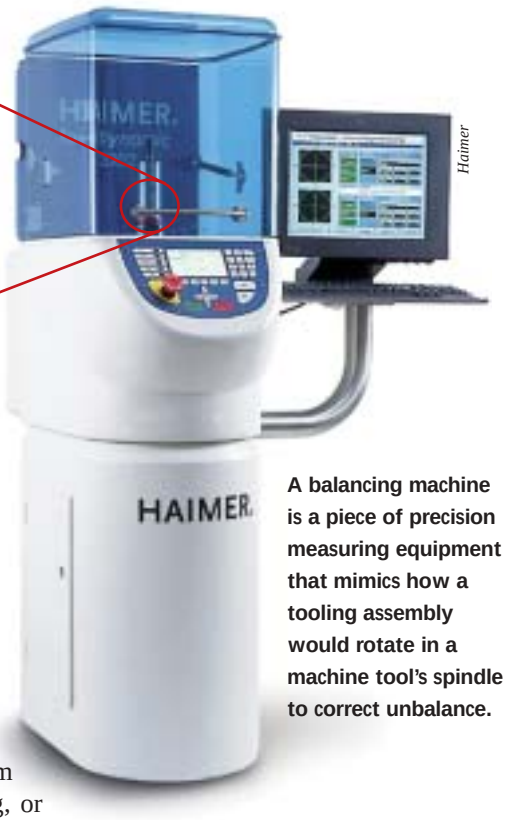
A laser on a balancing machine indicates the position a balancing ring needs to be in for the tooling assembly to be adjusted properly.



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A balancing machine is a piece of precision measuring equipment that mimics how a tooling assembly would rotate in a machine tool's spindle to correct unbalance.

When it comes to machining precision metal parts, what qualifies as balanced tooling is open to debate. As the spindle speed increases, any slight unbalance, which is a condition that exists when the mass centerline does not coincide with the geometric center, becomes accentuated.

One potential cause of unbalance in the toolholder, for example, is a flaw in the base material, such as voids, seams or porosity, according to Marty Trina, president of Manufacturer's Technologies, Algonquin, Ill., and manufacturing representative for Haimer USA LLC, Villa Park, Ill. Additional causes can include improper placement of through-holes; any machining performed on the toolholder that diminishes the absolute concentricity about the rotational axis; and an asymmetrical design, such as an offsetting weight that is not countered by equal, opposite forces. A cause of unbalance can be present even on the most precisely produced holder.

"Even though many toolholders are machined on a $400,000 grinder," Trina said, "the accuracy is not fine enough to pass some high-speed balancing requirements."

To meet those requirements, toolholders are needed that can be balanced on a balancing machine after the cutting tool and retention knob have been added. The primary methods for balancing include removing material from the holder via milling or drilling, or adding and redistributing weight with setscrews or balancing rings.

Prebalanced Holders

Toolholders that are "hard-balanced" at the factory are also available. "You can balance toolholders or buy toolholders that have inherent balance features in them. If you utilize balanced toolholders, you will extend the life of the spindle," said Preben Hansen, national sales manager of Lyndex-Nikken Inc., Mundelein, Ill., a manufacturer of both balanceable and hard-balanced toolholders.

He gave as an example a customer buying a toolholder that's prebalanced to run at 20,000 rpm with a G2.5 balance grade. "In a case like that, if the customer purchases a decent cutting tool that is balanced as well, meaning it is round and ground—there is no flat on it—he is going to be able to maintain that assembly balance after the cutting tool is

Increasing throughput through balancing

Not only did balancing a boring head assembly allow Rietschle Thomas Sheboygan (Wis.) Inc. to machine bearing journals using more aggressive cutting parameters, it also enabled the manufacturer of vacuum pump and compressor components to machine more parts per fixture.

The application involved OD turning, or hollow milling, on an Okuma MA40H horizontal machining center with a Komet M040 self-adjusting boring head, which has a roughing and finishing cartridge.

"It's like a reverse boring bar," said Pat Maigatter, manufacturing engineer for the company.

Maigatter explained that an ongoing capability problem prevented parts from being held in the top pockets of a tombstone fixture. Each side of the tombstone has four levels of two pockets each, for a total of 16 per tombstone. However, the parts could only be fixtured in the lower two levels. "As the tool got further away from the machine bed, the vibration from the tool would cause parts on the upper pockets to be out of round," Maigatter said. "So for years, we ran only the lower pockets and had all this wasted throughput potential."

Eventually, Maigatter spoke with Marty Trina, president of Manufacturer's Technologies, and a manufacturing representative for Haimer USA LLC. Trina recommended Haimer's Tool Dynamic 2002 balancing machine and a set of special 5"-dia. balancing rings. Distributor Engman-Taylor Co. Inc., Menomonee Falls, Wis., had one of the balancers and so Rietschle Thomas had Engman balance the boring head as a test.

Prior to balancing, the boring head had 199 g/mm of unbalance, which equates to 80.7 ft.-lbs. being displaced through the spindle when running at 3,000 rpm or 320 ft.-lbs. at 6,000 rpm. The impact on the spindle from that level of unbalance is equivalent to a 60-lb. ball-peen hammer hitting the spindle bearings 60 times per second, Trina said.

"After it was balanced, the boring head had only 5 g/mm of unbalance at 6,000 rpm," Maigatter said. "A G2.1 grade at 15,000 rpm is what we balance to."

The balanced boring head enabled Rietschle Thomas to increase the spindle speed from 2,037 rpm to 6,000 rpm and the feed rate from 10.2 ipm to 30 ipm, Maigatter said. "The out-of-round condition went away completely," he added, "so my throughput went up dramatically."

Rietschle Thomas

Purchasing a tool balancing machine enabled Rietschle Thomas to machine more parts per tombstone by balancing a self-adjusting boring head, which is applied for OD turning.

Once the benefits of tool balancing were quantified, Rietschle Thomas had to decide whether it was better to buy a TD2002 balancer, which costs about $32,000, or use a tool-balancing service. One of the advantages of ownership was avoiding the downtime associated with sending the tool to be balanced and waiting for its return. "The other thing was Engman-Taylor couldn't guarantee that they'd have a balancing machine on their floor at all times," Maigatter noted.

Having a balancer in-house not only allows Rietschle Thomas to conveniently rebalance the boring head, but it enables the manufacturer to balance other tooling assemblies. "We were amazed at how out of balance some of our tools were," Maigatter said. He noted that the balance for some tooling assemblies was adequate to run them at 450 rpm, but wasn't good enough to run them at the desired speed of 2,000 rpm.

Maigatter added that for those tooling assemblies, the toolcrib attendant measures the amount of unbalance and then either purchases the appropriate set of balancing rings or modifies the holder's weight distribution by milling away small portions of the holder or drilling holes into it to get it close to being balanced and then obtains the needed set of rings. "If there is way too much unbalance," Maigatter said, "he'll do that instead of putting on multiple sets of rings."

—A. Richter

changed," Hansen said. "So there is no need to rebalance, though you need to be careful to select balanced, high-quality cutting tools for that to be possible."

Another alternative to balancing a tooling assembly after a tool's cutting edges are worn and need replacing is to have an assembly hard-balanced at the factory that includes an indexable-insert tool body. "Changing the inserts would not change the assembly enough to put it out of balance," Hansen said.

The maximum spindle speed a pre-balanced toolholder can run at is also open to debate. "If you're running under 20,000 rpm, you probably wouldn't need to go with balanceable tooling," said Christ Gust, technical support for Briney Tooling Systems, Bad Axe, Mich., a manufacturer of hard-balanced holders. "You could probably get away with a [hard-balanced holder] without too much of a problem."

However, he noted that whenever weight is added to or removed from a toolholder assembly, the balance condition, or state of equilibrium in which rotational forces are countered by equal, opposite forces, changes. "If I balance a toolholder at 20,000 rpm without a cutting tool and retention knob in it, and then put a tool in that's sticking out 3" from the nose end and throw a retention knob in, the center mass has changed, so it's not going to be balanced, per se, at 20,000 rpm," Gust explained. "It might be at 17,000 or 18,000 rpm."

The reason a hard-balanced toolholder's balance changes after the rotary cutter has been added is that component is not entirely symmetrical.

"The industry-standard solid-carbide endmill is not completely symmetrical," said Steve Lovendahl, holemaking product manager for Command Tooling Systems, Ramsey, Minn. "It's primarily symmetrical, but not always completely symmetrical."

Sometimes, the cutting tool's impact on the assembly's balance is greater than others. Markus Keller, sales manager at Zoller Inc., Ann Arbor, Mich., recalled how one customer running at 25,000 rpm with a prebalanced HSK 63 shrink-fit holder required 35 spindle repairs over a couple months because the assembly was out of balance. "They tested the holder and it was balanced, but then the assembly with the drill in it was not balanced anymore," he said. "They couldn't even run at 9,000 rpm."

Even the lowly retention knob affects the balance of a toolholder assembly. Trina estimated that a 90 percent probability exists of not maintaining a G2.5 balance grade when a retention knob is placed into a previously balanced holder-and-cutter assembly. In other words, the complete assembly will require additional fine balancing 90 percent of the time. He added that even the use of a coolant tube in an HSK holder can throw the assembly out of balance.

Mike Ponsolle, product manager for tooling products, Schunk Intec Inc., Morrisville, N.C., concurred that the retention knob has an impact on an assembly's balance, but feels the effect is negligible once the cutting begins. "If you were to check a toolholder's balance with and without a retention knob, you may see some difference," he said. "But when you put that assembly all the way up into the machine's spindle itself, the retention knob has little impact."

Balancing Act

Depending on the G balance grade desired and the spindle speed the tooling is running at, Trina said hard-balanced tooling may be adequate. However, he noted that when balancing a tooling assembly on a balancing machine, the common and critical reference is grams per millimeter. This can be calculated manually or by using a balancing machine.

"What a balancing machine basically does is calculate g/mm for you," Trina explained. A balancing machine's software "takes that straight equation and puts it into usable information, telling you that not only is the tooling out of balance by 5 g/mm, but it happens to be 291° from [a specific] radial position. From there, you can make the necessary adjustments."

Although g/mm quantifies unbalance, a G balance grade is used to indicate a tooling assembly's degree of balance. "Balancing to G2.5, for example, is actually a balance specification for the balancing of electric rotors in electric motors," explained Command's Lovendahl. "It's not really the balance specification for tooling. The only reason it's become a much bigger deal in the last 5 years is because spindle speeds have increased."

The lighter components that enable newer spindles to rotate at higher speeds are not as durable as the ones in older, slower spindles. "Temperature-wise, ceramic bearings, which experience reduction deformation from thermal growth, are much more stable than steel bearings, but they can't take the abuse and banging that steel ones can," Trina said.

Therefore, builders of high-speed machining centers typically require an end user to run tooling assemblies that meet a specific balance grade to maintain the spindle warranty. It's not uncommon for a 40,000-rpm spindle to cost $30,000 or more, and running balanced tooling extends the life of the spindle, which machine builders generally source from dedicated spindle manufacturers.

"There are some machine tool builders that insist every toolholder be balanced or they will not warranty the spindle," Lyndex-Nikken's Hansen noted.

Calculating unbalance

As the spindle speed increases, the tolerance for allowable unbalance decreases. The equation for allowable unbalance is: U = G x 9,549 x W/rpm, where U is the permissible unbalance in g/mm, G is the standard for balance quality of rotating rigid bodies, W is the weight of the tooling assembly in kg, 9,549 is a constant and rpm is the spindle speed.

For example, the allowable unbalance for a 2.75kg tooling assembly rotating at 8,000 rpm to meet a G2.5 balance grade is 8.2 g/mm (2.5 x 9,549 x 2.75/8,000). The same tooling assembly run at 20,000 rpm to meet a G2.5 grade has an allowable unbalance of 3.3 g/mm (2.5 x 9,549 x 2.75/20,000).

Weight (kg)	10,000 rpm	15,000 rpm	20,000 rpm
0.5	1.19 g/mm	0.79 g/mm	0.59 g/mm
1.0	2.38 g/mm	1.59 g/mm	1.19 g/mm
2.0	4.77 g/mm	3.18 g/mm	2.38 g/mm
4.0	9.55 g/mm	6.36 g/mm	4.77 g/mm

Source: Haimer

Permissible unbalance to achieve a G2.5 balance grade as it relates to tooling assembly weight and spindle speed.

Balancing across the board

It's important to note that ISO 1940:1 balance-quality requirements cover a host of rotating products, from car wheels to gyroscopes. Although the number of G balance grades is theoretically infinite, the common ones for the metalcutting industry are G6.3, for a semibalanced tooling assembly, G2.5, for a well-balanced assembly, and G1.0, for new spindles such as ones with ceramic bearings—the lower the number, the finer the balance.

Here is a comparison of various products according to their G balance grades.

G40	Car wheels
G16	Drive shafts
G6.3	Fans
G2.5	Gas and steam turbines
G1.0	Spindles
G0.4	Gyroscopes

—A. Richter

Haimer

Balancing rings are sold in pairs, and as long as the amount of correction needed in g/mm is less than the g/mm value of the rings, the rings will be able to balance the tooling assembly.

Trina pointed out that requiring tool balancing to maintain the warranty can cause end users to come to the wrong conclusion about a spindle's durability. He said: "It's always been a Catch-22. If one machine tool guy talks about how important balancing is and another guy fails to, the customer perception has always been that the latter has a stronger spindle. It's a misperception, and only recently has the machine tool industry started to explain to customers tool balancing's importance to improving the longevity and the baseline general performance of the spindle."

Most machine builders require a G2.5 balance grade, but some ask end users to run tooling balanced to G1.0, which is 2½ times finer. "To protect the spindle warranty, some builders' requirements are more extreme than others," said Hansen.

Zoller's Keller said that depending on the total weight of the assembly, the spindle speed and the desired G balance grade, balancing a smaller tooling assembly, such as one incorporating an HSK 32 holder or smaller, can be problematic. "If the tooling is too small, you can't balance it to the machine tool builders' recommendation," he said. "You might have to balance it

Schunk

A toolholder can be hard-balanced by removing material.

Schunk

A balanceable shrink-fit toolholder accepts setscrews, which are used in connection with a balancing machine to correct an out-of-balance condition.

so that the toolholder only has 0.2 g/mm of unbalance to be within the G grade recommendation of the machine tool manufacturer, which is beyond the capabilities of toolholder balancing machines." Keller added that the highest level of accuracy for tool balancing machines is 0.5 g/mm.

"There is talk in the industry that if you truly want to get to G2.5 at 20,000 rpm on the very smallest tools, the only way to do that is to use a very expensive balancing machine," Hansen added.

It's important to note that high speed is not solely a function of spindle speed. For example, a ¼"-dia. endmill running at 5,000 rpm has a surface footage of 325 sfm (0.25 × 0.26 × rpm), whereas a 4"-dia. endmill running at 500 rpm has a 520 sfm. "High speed should be a function of surface footage," said Lovendahl.

Trina agreed. "With a smaller tool, you're generally going to run at a higher speed based on surface footage," he said.

In addition, "a smaller tooling assembly is harder to balance than a larger one," Trina said. This is because when balancing a low-weight assembly, the amount of weight that needs to be redistributed is significantly less than when balancing relatively heavy tooling. When redistributing the weight by drilling or milling the toolholder, time is consumed if not enough material is removed and additional cuts are needed. But if too much material is removed, a toolholder might need to be scrapped.

Balancing on the March

Whether for small tools or large ones, fast spindle speeds or slow, balanced tooling is a critical and growing issue for manufacturers striving to increase throughput while imparting finer surface finishes. Whether a hard-balanced or balanceable toolholder is needed to achieve those goals remains open to debate.

Toolholders for the highest-speed applications have evolved into perfect rotors, Trina explained, with even the inside surface being completely symmetrical. "But when you take these holders and run them at 40,000 rpm, it's still not fine enough," he said. "Under acceleration at 40,000 rpm, it's way off the map." Therefore, balancing is required.

However, Schunk's Ponsolle countered that "if you know you're going to be running the same type of tools all the time, it's less critical to get a balanceable holder than it is to buy a holder that's hard-balanced from a manufacturer."

"Personally, I think that prebalanced holders may grow a little more [in popularity] than the balanceable ones because of the cost of the balancing machine and the time to do the balancing," Hansen predicted.

Even so, many end users still feel they can increase profits by reducing tooling costs—a common but false economic model. "I find myself losing sales on high-end equipment for high-speed applications," he added. "Some customers are strictly looking for a cheaper tool. They may have a 30,000-rpm machine, but they think paying $20 extra is too much to pay for a good holder. If they took the time to evaluate the real cost, they would find it was well worth the investment to buy a

quality high-end toolholder."

Ultimately, deciding whether to run hard-balanced or balanceable toolholders depends on the application. "Our sister plant bought a balancer and runs balanceable tooling because they do die and mold work," Briney's Gust said. "Then there are customers who just happen to have a 20,000- or 18,000-rpm spindle and can get away with hard-balanced tooling because they're not going to run it at 20,000 rpm 80 percent of the time." △

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