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▶ BY NORMAN MOAK

A balanced toolholder is essential when high-speed machining.

Balancing Act

The benefits of high-speed machining (HSM) have been well documented. But the elements required for maximizing the benefits while cutting costs have, to say the least, created a quagmire for many. When HSM, the forces at the cutting point decrease as cutter speed increases. Spindle speeds are increasing to exploit this phenomenon. The result is tighter-tolerance parts with improved surface finishes.

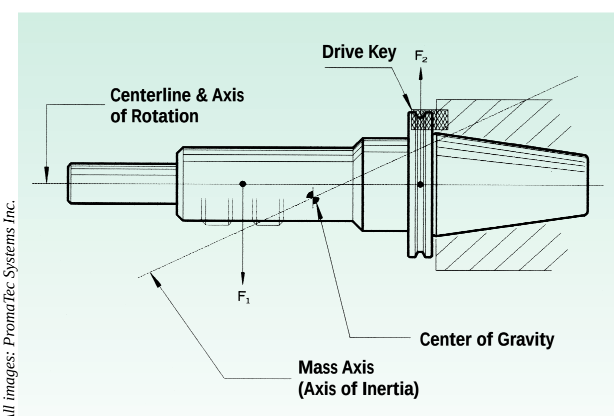
No Set Definition

Although there isn't a standard definition for HSM, experimental R&D programs have achieved spindle speeds of 500,000 rpm and production operations have machined at 100,000 rpm.

However, this article defines 8,000 rpm as the starting point for HSM. The reason why is that it's generally accepted that rotating parts need to be balanced to satisfy ISO 1940 when spindle speeds exceed 8,000 rpm. At speeds below 8,000 rpm, centrifugal forces produce negative results only when the toolholder is extremely asymmetrical.

With an ever-increasing number of machine tools featuring spindle speeds of 8,000 rpm or higher, the issue of balancing the tooling assembly confuses many end users. This assembly consists of the cutting tool and its holder. An unbalanced condition exists when the principle mass of a rotating holder (axis of inertia) does not coincide with the actual axis of rotation (Figure 1).

Since there are so many considerations when deciding whether it is necessary to balance a tooling assembly, many simply choose to ignore the issue until it becomes a time-consuming and expensive problem. Still, the downside of HSM with an unbalanced tooling assembly should not be ignored.



All images: PromaTec Systems Inc.

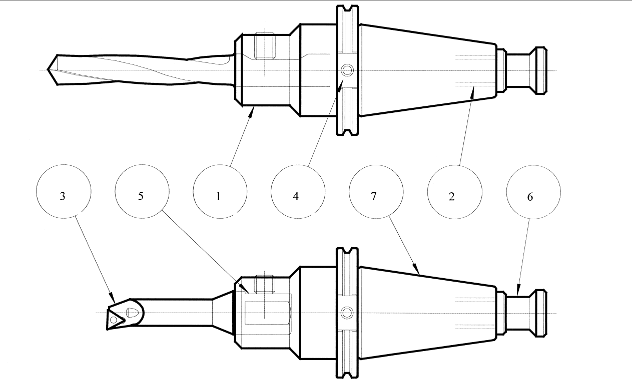
Figure 1: Dynamic (two plane) unbalance condition.

Undoubtedly, the most costly and time-consuming problem is damage to the spindle assembly. An unbalanced tooling assembly puts an additional load on the spindle bearings, causing premature bearing wear or failure and, possibly, damage to the spindle connection. Not only does the shop incur the cost of repairing or replacing the spindle assembly, but the production loss from machine downtime is usually significant as well.

In addition, an unbalanced tool assembly can dramatically reduce cutting tool performance and shorten tool life by increasing tool breakage. An unbalanced tooling assembly can also contribute to chatter, resulting in poor surface finishes.

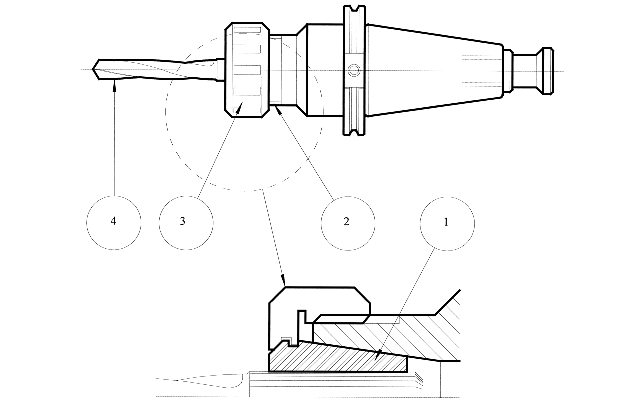
Cutting tools and toolholders, especially 7/24 steep-taper holders, have many potential sources of unbalance. As the spindle's speed increases, centrifugal forces cause it to expand minutely. The toolholder's taper cannot expand with the spindle. This causes the toolholder to separate from the spindle surface, which reduces rigidity.

Some sources of unbalance are correctable through design changes or careful choice of the tool and holder combination. This means that designing symmetry into the tools could eliminate unbalance. However, balancing systems are needed for adjustable toolholders with movable parts and asymmetrical cutting tools. Both design- and balance-correctable elements for steep-taper toolholders should be considered carefully when assembling tooling for HSM. When HSM, due diligence must also be applied to the selection of accu-



1. Unground, low-precision diameters.
2. Eccentric thread tolerances in the retention-knob threads.
3. Asymmetrical features in the cutting tool.
4. Unequal drive-slot depths and asymmetrical flange components.
5. Drive flats on tool shanks.
6. Nonprecision retention knobs or unpiloted threads.
7. Low-precision taper grade.

Figure 2: Design-correctable unbalance elements.



1. Moveable spring collet. Radial and axial position of the collet changes each time a tool is changed or moved.
2. Eccentric threads on the locknut and toolholder.
3. The moveable locknut changes position each time it's loosened and tightened.
4. Unequal flute depths in the cutter.

Figure 3: Balance-correctable unbalance elements.

rate and symmetrically round tools (Figures 2 and 3).

Taper Tolerance

The design and tolerance of the taper of a steep-taper toolholder has a considerable effect on the high-speed performance of the tooling assembly. The grade for taper accuracy of a steep-taper toolholder is generally guided by ISO 1947. The taper grade verifies the tolerance of both the spindle-socket and toolholder tapers, and significantly influences both toolholder balance and cutting-point runout. The machine spindles are manufactured to a grade of AT2 or better, with AT3 being the best taper grade that can be manufactured in a production environment.

In addition to the taper tolerance, consider the other allowable tolerances in the tooling assembly. Each allowable tolerance must be added together to arrive at the system eccentricity at the cutting point. Only then can the effects of unbalance be fully understood.

These other tolerances include, but are not limited to, cutting tool runout, length of the toolholder system and symmetry of the added components, such as the collet, collet nut, cutting tool and retention stud.

It's important for everyone involved in HSM to understand the many factors that contribute to an unbalanced condition and what can be done to minimize their negative effects. The one component impacting the tooling assembly's balance the most is the toolholder.

There are only two types of toolholders that should be considered for HSM: prebalanced and balanceable. The prebalanced holders are balanced by design and cannot compensate for any unbalance introduced by the other elements of the tooling assembly. The assumption is that any unbalance introduced by the other elements will be negligible. Unfortunately, this is not always the case. It's strongly recommended that the amount of unbalance be measured and, if necessary, corrected to an acceptable level for the desired spindle speed.

Balanceable toolholders also are balanced by design, but they can be adjusted to compensate for any unbalance introduced by the other components of the tooling assembly. Manufacturers have employed a number of different compensation methods to balance their toolholders. These include screws, steel balls, adjustable rings and adjustable segments.

A balanceable toolholder is limited in its ability to compensate for the unbalance of a tooling assembly. In some cases, the unbalanced mass is too large to bring the toolholder into balance and the machine can't operate at the desired

Applying short-taper toolholders for high-speed machining

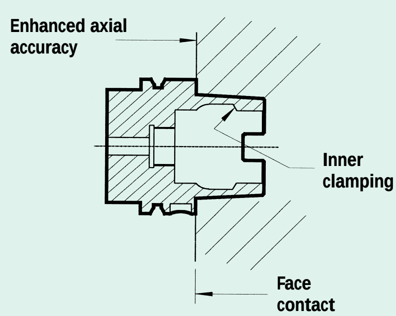
A number of toolholder designs are available that offer an alternative to the steep-taper spindle connection. The toolholders that have become the most popular for HSM offer a simultaneous fit on both the taper and the face at the front of the spindle.

These systems have been embraced by the metalcutting industry because of the increased rigidity of the joint and inherent reduction in size, compared to the equivalent steep-taper connection. With the emergence of high-speed spindles, the adoption of these toolholding systems has increased appreciably.

The 8° short taper with gage face contact and simultaneous taper interference was introduced in 1993 as HSK (DIN 69893), which became the published standard. HSK is a German acronym that translates as "hollow short taper."

In contrast to a steep-taper toolholder, an HSK toolholder provides high static and dynamic stiffness, high axial and radial repeating accuracy, a low mass and stroke, and inner clamping to allow higher rotational speeds.

—N. Moak



HSK toolholders offer numerous advantages when high-speed machining.

Balance requirements for rotating tools

The balancing process improves the mass distribution of a cutting tool and its holder, allowing the combination of the two to rotate with the minimum amount of unbalanced centrifugal forces. However, it's impossible to balance the tooling assembly to the degree where all unbalanced mass is accounted for, regardless of the process.

Any degree of unbalanced mass will create vibration. The toolholder, its mounting and the structure of the machine tool influence the characteristics of the vibration.

ISO 1940/1 and ANSI S2.19-1989 are the standards that define the degree of balance acceptable for specific applications. Both standards apply the "G" system of grading and make recommendations based on attainable limits and practical use.

For example, the G2.5 balance grade means that, at a minimum, the vibration velocity must not exceed 2.5mm/sec. These grades are being improved as performance goals increase, because of the availability of higher-quality machines, cutting tools and toolholders.

Balancing methods have also improved, further raising performance expectations. But if a specific balance grade cannot be achieved, then the spindle speed for the application needs to be reduced accordingly. —N. Moak

spindle speed. When this happens, reduce the spindle speed or reconfigure the tooling assembly, if possible.

Some other elements that can restrict HSM are the workpiece material, part overhang, fixturing, cutting tool configuration and required depth of cut.

The message here is not to discourage high-speed machining, but to encourage a close examination of every component of the machine tool system to allow successful HSM. △

About the Author

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