Toolholder Balance in Practice

The concept of balance is straightforward, but the standards applied to toolholder balance are not well known and are often misinterpreted. The current balance standard used by machine tool builders relates a "G" value to a spindle speed. This standard originated in the 1940s, long before current high-speed spindle options and microtooling were even considered. Use of this standard is generally well accepted for larger tools, but does not reflect the needs of smaller tools running at high speeds.

The G value for a toolholder can be calculated based on three known factors: unbalance (mass x radial distance), total tool mass, and operating speed. The G tolerances are numbered based on the requirements of a specific application. These numbers range as high as G4000, but G6.3 and G2.5 are most often associated with cutting tools. For example, G6.3 is used for machine tool and general machinery parts, while G2.5 is specified for machine-tool drives. In some cases, a machine-tool builder will specify that all tools must be balanced to a G2.5 value at the machine tool's maximum operating speed.

The true purpose of balancing is to reduce the influence of centrifugal forces induced by the toolholder's inherent unbalance. Centrifugal forces are an exponential function of the rotational speed of a tool, and therefore become a larger factor in tool life, surface finish, and part accuracy as operating speeds increase. For example, a tool with 100 g-mm of unbalance running at 6000 RPM will induce one-fourth of the centrifugal force that it will generate at 12,000 RPM.

$$F = \frac{U}{10^6} \times \left[\frac{2 \times \pi \times n}{60}\right]^2$$

$U = \text{Unbalance } (g - mm)$
$n = \text{Speed } (rpm)$
$F = \text{Force } (\text{Newtons})$

The most accurate toolholder balancing machines have resolutions of 0.1 g-mm, but a measuring accuracy of 0.5 g-mm of unbalance. This means that they have the capability to display a value under 0.5 g-mm, but will not be able to measure a lower value accurately. If we use 0.5 g-mm as a minimum U value and add a machine-tool builder's requirement of G2.5, we are left with rpm and tool mass as our only variables. If the tool mass, in grams, is less than 0.021 x rpm, the tool cannot be certified to be within the G2.5 tolerance. This is not a problem for 40- or 50-taper tools, but when applied to a 30-taper or small HSK tapers, the tools become too light to balance accurately to the G tolerance at high speeds.

Solving for Mass
$U = \text{Unbalance } (g - mm)$
$M = \text{Mass } (g)$
$G = \text{Tolerance Grade}$
$\omega = \text{Rotational Velocity (radians)}$

$$U = \frac{G \times M}{\omega} \rightarrow U = 9.5\left[\frac{G \times M}{rpm}\right]$$

Solving for Minimum Mass

$$0.5 = 9.5 \times \left[\frac{2.5 \times M}{rpm}\right] \rightarrow M = \left[\frac{0.5 \times rpm}{9.5 \times 2.5}\right]$$

$$M = 0.021 \times rpm$$

As tools become smaller and machine spindles become faster, a different approach to quantifying permissible unbalance is required. The relationship between toolholder mass and unbalance mass must also be taken into consideration. ISO standards also use an "e" value for mass-axis displacement. This takes the unbalance and divides it by the total mass of the assembly. The result is a measurement of how far the center of balance is removed from the axis of rotation. This value can then be related to the accuracy of the tool change. If a machine tool change is repeatable to 0.002mm, a 500-g tool would need to have less than 1 g-mm of unbalance.

Given all the possible options for quantifying toolholder unbalance, we must always keep in mind what we are trying to achieve. Each tool in a process should be evaluated to determine if the application justifies close-tolerance balancing. If a tool is found to require balancing, common sense and engineering principles should be a guide to how to make adjustments. In some cases, the amount of unbalance may be so large that getting the tool into tolerance will so weaken the tool that it will not perform as well as an unbalanced tool. Also, any changes to the tool set-up will require re-balancing.