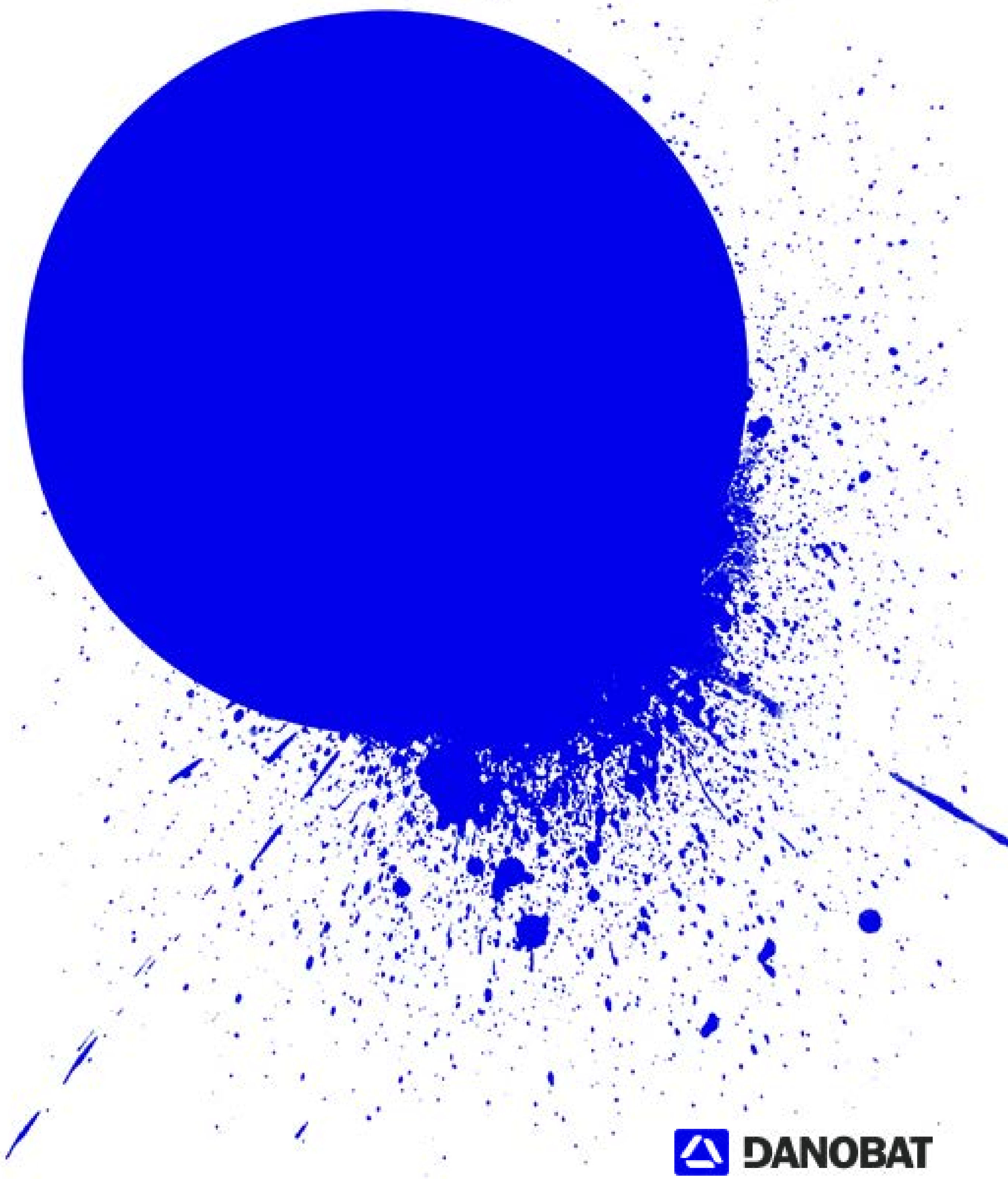
Elements of precision in grinding and turning machines



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Precision is not simply the ability to machine a part accurately, but the capability to repeatably manufacture parts to exacting specifications over time. It is important to remember that no one feature will make a machine capable of precision manufacturing, but rather a variety of factors working in harmony will enable a machine to consistently produce parts within the most exacting tolerances. These are some of the most important elements of a CNC machine that buyers should consider when evaluation machining solutions.

With its Danobat, Overbeck and Hembrug companies, Danobat has over 70 years of experience in building precision grinding and turning machines. With deep technical experience in designing every component of a machining system, Danobat explains the technology most important to precision machining.

MACHINE STRUCTURE

While there are many motion control technologies that can be employed to render a machine tool more accurate and repeatable over time, true precision begins with the machine structure itself. Without getting this right, the fundamental accuracy of the machine will be limited in ways that motion control technologies – CNCs, servomotors, feedback devices and more – cannot fix. Critical elements of a machine structure include:

- Symmetry

How accurately a machine tool executes axis movements obviously impacts the precision of the machine. What most vendors report in specs are the accuracy and repeatability on an axis-by-axis basis. But the true precision scenario is much more complicated, particularly when machining with variable cutting forces due to workpiece mass or more aggressive machining rates. Under these conditions even very small degrees of misalignment between axes or deflection of major machine components under load will result in a less accurate machine across its entire working envelope. As for machine deflection, or stiffness, the rule is that the farther the load is concentrated away from the axis drive the greater the likelihood of machine component deflection, and the greater the load and speed of the axis, the more severe that potential becomes. A way to counter this problem is with symmetrical machine design that centers loads on each axis. For example, a ballscrew should be located at the center of a table, or two ballscrews should be used on either side of a table to minimize or eliminate the cantilever effect of off-center loads in machining.

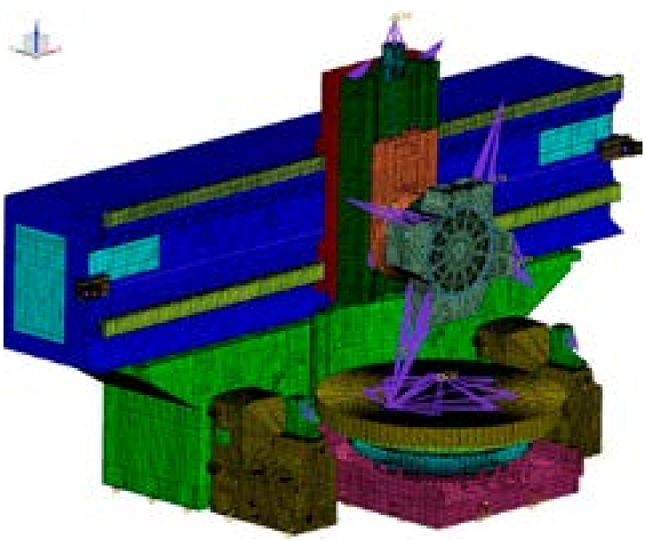
Symmetry can also play an important role when a machine tool is in a state of thermal expansion. Machinists know that as a machine warms up it "grows" larger. That alone can impact accuracy, but a machine will typically expand in an asymmetrical manner, and different machine components will expand or contract at different rates. The greater the symmetry of the machine design, the less impactful these thermal effects will be.

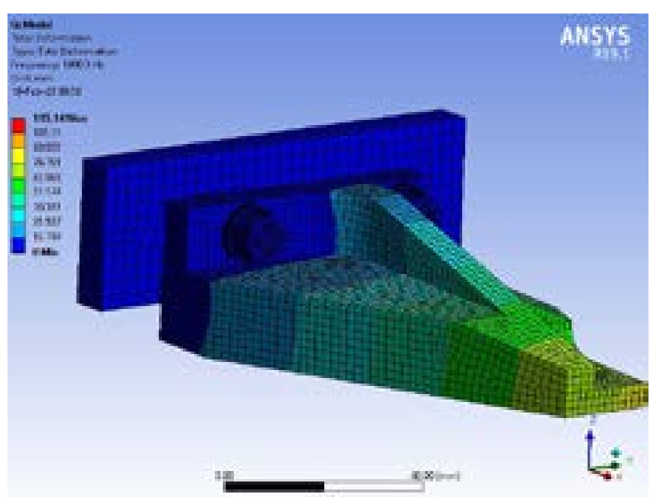
- Rigidity

Machine tool builders have been talking about rigidity almost since their invention, and for good reason. The engineering term for this is stiffness, which means how resistant to deflection and vibration the machine and its components will be under load. Even with balanced loading, machine deflection can still be a problem, particularly when attempting to maintain perfect alignment from one axis to another. The stiffer the machine, the less dynamic deflection can occur. A stiffer machine is also less inclined to transmit vibration from one machine element to another, which results in the ability to machine more aggressively, generate better surface finishes and improve tool life. But high performance machining is not just about stiffness. The key is to find to right combination of stiffness and vibration damping in the machine structure.

Machine tool builders have for many years talked about the massiveness of their castings as evidence of superior rigidity, and that can indeed be true. More, a machine base and other component castings play an important role in absorbing, or damping, vibration to enable a more steady state at the edge of the tool. But in today's world of higher speed machining processes, increasing casting mass is not the answer. Casting designs should be optimized to deliver the best stiffness at the lowest weight to lower the inertial forces of machining.

Machine bases are particularly important. While bases made of weldments have their place, particularly among larger machines, iron castings offer comparatively superior stiffness and vibration damping characteristics. This is why most machine tools today use cast iron bases. But for precision applications that are sensitive to vibration and thermal distortion, more builders today are moving to bases made of polymer concrete and natural granite stone. Both have superior damping and thermal stability in comparison to cast iron, with natural stone being the most stable of all.





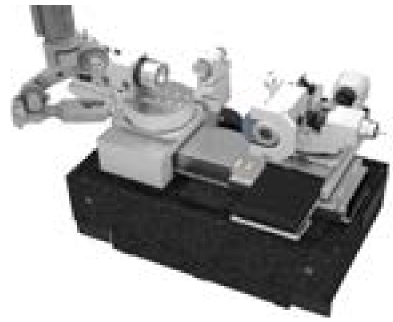
- Thermal Stability

Another argument for natural stone bases is their high degree of thermal stability. Iron castings are more prone to react to the thermal effects of process induced or ambient temperature variations. Simply, as it heats up cast iron “grows” and often not entirely symmetrically. This induces reduced and variable levels of accuracy as the machine encounters differing thermal conditions. This can be minimized by use of auxiliary cooling techniques such as chilled fluid circulating through critical machine elements.

But it is better if major machine components are more resistant to thermal expansion in the first place. This is one of several reasons why Danobat uses natural granite bases for its most demanding applications. Granite offers the highest performance in stiffness, vibration damping and thermal stability. The thermal conductivity granite is a small fraction compared to cast iron and the thermal expansion rate is about half that of cast iron. Simply, granite bases are much less inclined to heat up, and even when they do, they are much more dimensionally stable. Moreover, granite bases are roughly twice as stiff as cast iron, and five times more effective in damping vibration.

MOTION CONTROL

There is a wide range of technologies available to execute motion on a machine tool and to measure the accuracy of that motion through a variety of feedback devices. The baseline standard for this is to use servomotors driving ballscrews to move linear axes with feedback provided by a rotary encoder on the servo motor or, more accurately, linear scales mounted somewhere on the axes of the machine. Linear scales are more accurate because they are directly measuring movement on the machine as opposed to rotary encoders that simply tell you how far the servo motor has turned.



This fundamental approach to motion control has served the general machine tool industry well for many years and is perfectly appropriate even in many high precision applications. But there are still major differences in machine capabilities due to how these technologies are applied, and newer technologies are being used in high speed and hyper precision applications. The key to which technology to apply where is deep understanding of the requirements of the application.

First off, there are differences in the resolution of linear feedback devices and how those devices are mounted is critical to establishing true position of an axis under a range of machining conditions. More basic “exposed” linear scales use graduated steel tape and a reader head to measure axis position. More precise “enclosed” linear scales use etched glass that is finely graduated for high precision. Glass is extremely thermally stable so errors that might be introduced by expansion of steel tape and/or the machine itself are eliminated. Across the range all types of linear scales the real measuring accuracy can range from 10 to 1 microns.

As for the mounting, glass scales are fixed on one end, essentially establishing an origin point for the axis. Though secured inside a housing, the free end of the scale is allowed to float so that when the machine and housing grows around it, the true position as indicated by the reader head is unaffected.

Where and how the scale is attached to the machine can be extremely consequential to the performance of the feedback device over time and across range of machining conditions. Placing a scale in the wrong place can actually amplify an error factor in the machine. Also, it is important to isolate the scale as much as possible from vibration which can have a significant impact on accuracy.

As for axis actuation deciding where to position the driving mechanisms is also extremely important. As said above, placing a ballscrew, for example, as near to the center of balance for an axis will be the most accurate. In many applications, however, the servo-and-ballscrew mechanism is being replaced altogether with a linear motor that runs the entire distance of an axis travel.

When linear motors first came on the scene for machine tools about 20 years ago it was all about speed. They were considered an enabling technology to processes such as high speed machining with the ability to deliver high feed and rapid travers rates, as well as better acceleration/deceleration profiles, that were beyond the capabilities of conventional axis drives. While those capabilities are still important there are other benefits of linear motors that today have them applied in grinding and turning machines, even in some EDMs.

By eliminating the conventional drive mechanism, linear motors are inherently more accurate, and free of backlash inaccuracies that come with any geared drive. They are also more space efficient and require less maintenance than ballscrew drive systems.

AXIS BEARINGS

The mechanism that supports axis movements is extremely important. It should lower inertia, that is, resistance to movement of a resting axis or to velocity changes when an axis is in motion. And it must provide as stiff an interface from stationary to moving components as possible. This interface can also be a significant source of heat, so reducing friction is also a primary design goal.

Box ways have been the traditional technology, with an axis moving on a film of oil across a wide linear contact surface. With heavy mass and a large contact area, box ways provide excellent stiffness and damping capability. The primary limitations of box ways are high speed capabilities and inertial issues, which are interrelated, and the generation of heat through friction.

As machine tools have grown faster, box ways have largely given way linear slides, or guides, which use prepackaged rolling element “trucks” that ride across a rail mounted on a way-like surface on the machine structure. Rolling element linear guides substantially lower inertia in axis movement. This makes them deal for higher feed and rapid travers rates and the ability to move axes more quickly with much lower force. They are also easier to assemble on to a machine tool, all of which is why most machines today use them. However, linear slides do sacrifice some rigidity for these benefits.

The next level is the hydrostatic way which combines some of the benefits of box ways and linear slides into a single engineered system. In a hydrostatic system, the guideways use a pressurized film of oil, with pockets in the way system distributing the oil to center the moving element. Without the surface-to-surface contact, the slides can operate virtually frictionless and without wear. Because the moving element is suspended by fluid, the impact of vibration is reduced which makes hydrostatic ways ideal for a range of grinding applications. Reduced vibration results in better surface finish and significantly improved tool life. Moreover, hydrostatic ways exhibit even less inertia than rolling element bearings and can handle heavier loads, also in some high force applications with repeated passes that can result in lower cycle times.

SPINDLES

Spindle technology is a broad topic all on its own. Here, we will focus on the relative benefits of belt driven vs direct drive spindles. Belt or gear-driven spindles have been the traditional choice in machine tools. As implied, the motor and spindle are separate, and linked through a speed reduction transmission mechanism. While these drives are used less today, particularly in higher speed applications, they are still the best solution for lower speed, high torque applications.

The downside of belt and gear drives is they aren't accurate enough for precision C-axis movements and can sacrifice concentricity since the belt is unevenly preloading the spindle axially. A belt drive can even induce an asynchronous error which can degrade the roundness of a part. Belt driven spindles will also typically take longer to ramp up to full speed, or ramp down. This can affect part cycle times.

Direct drive spindles are increasingly used today. Here the motor and spindle are combined into a single unit. Because direct drive spindles eliminate the transmission, they run smoother and much more accurately in C-axis applications. Direct drive spindles generally are capable of higher speeds and provide better acceleration/deceleration performance. Elimination of the drive train also enables greater concentricity, less vibration, and longer life.

Many machine tools today use standard spindle cartridges which are designed to serve a broader range of applications. But because Danobat considers spindles to be such a critical component in machine, it builds its own spindles, specially designed to the individual machine applications.

Bringing it all together

As said earlier, no one feature will make a machine capable of precision manufacturing, but rather a variety of factors working in harmony will enable a machine to consistently produce parts within the most exacting tolerances. This is the principal by which Danobat designs and builds its machines.

It takes a great deal of expertise to get the right balance of all components to build a machine, or a system, that performs accurately, productively and reliably over time. The key is understanding the application, and then using the technologies that best get the job done.

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