


PRECISION MANUFACTURING

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SPINDLECHECKING MACHINES

to Prevent Unexpected Failures and Identify Problems

By Don Martin and Mark Kretschmar



Figure 1: A system of three noncontact displacement sensors measuring dynamic error motions of a spinning precision target pin.

All of the samples from that run of 400 parts failed on two dimensions on the CMM. They're probably all scrap. Who gets to tell the boss? Better yet, who gets to tell the customer? "We've been making these parts every month for a year without a failure," says the operator. Maintenance says, "We just had the machine lasered two months ago!" As it turns out, the laser was right (they always are)—the machine can precisely position the X, Y, and Z axes.

Did anyone test the spindle rotation and location? X, Y, and Z aren't the only axes on the machine; what about the spindle? If the spindle has a problem, precision parts will fail—those are usually the expensive ones.

"Spindlechecking" a machine measures spindle error motions at full operating speed. Spindle error motions are any motion other than going around in a perfect circle, including shifts in position. These motions cause failures in feature location, roundness, and surface finish. Measuring a machine's rotating spindle with noncontact instruments secured to the table tells you what is happening where it really counts—at the "point of machining" (Figure 1). That's what else you need to know and track over time to prevent and analyze quality problems.

A spindlecheck measures dynamic errors in the tool position in X, Y, and Z (Axial) axes, at real operating speeds and under real thermal conditions. That's the only way to know what's happening. A simple dial-indicator runout measurement only reveals the grossest of error motions; it's the more subtle, full-speed error motions that create your headaches.

A variety of troubles lurks in your machine tool as a whole that can be revealed only by a measurement of the dynamic spindle behavior relative to the machine table.

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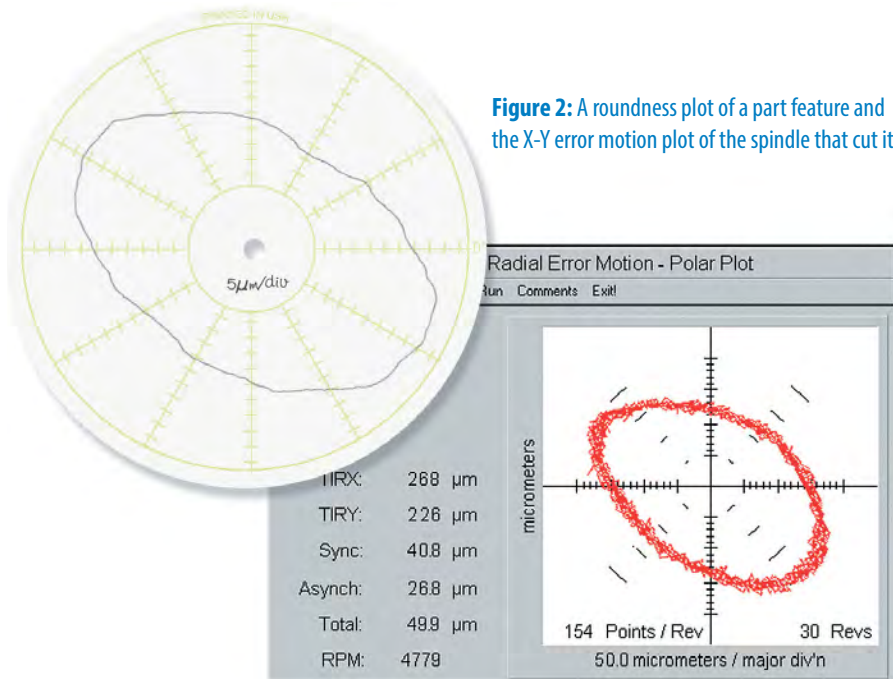


Figure 2: A roundness plot of a part feature and the X-Y error motion plot of the spindle that cut it.

Roundness

A round feature fails a roundness measurement even though a ball-bar test indicates that the tool can be moved in an accurate circle. The likely problem is that the spindle rotation is not round. **Figure 2** shows the roundness plot of a round feature and the X-Y polar plot of the motion of the spindle that was used to cut the part. The similarity is not coincidental.

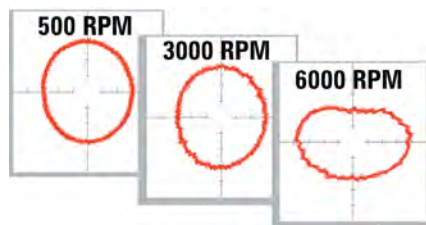


Figure 3: X-Y error motion plots of a spindle at three different speeds showing significant increases in error motion as speed is increased.

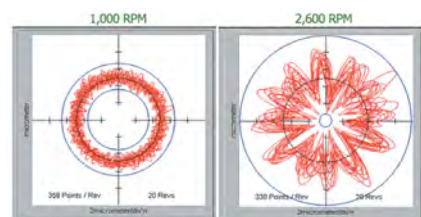


Figure 4: A resonance problem shows as significantly higher error motions at 2,600 RPM.

Roundness and RPM

Your spindle accuracy has a relationship to speed. **Figure 3** shows an obvious speed-related problem. A static measurement with a dial indicator would show the spindle in good condition. This one turned out to be a tool holder problem.

Resonant Frequencies

Figure 4 shows the X/Y motions of a spindle at 1,000 and 2,600 RPM. There is a resonance problem at 2,600 RPM, making it a poor choice for an operating speed.

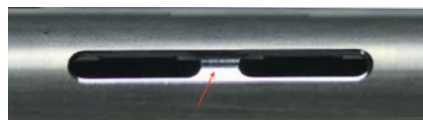


Figure 5: A surface finish problem resulting from a resonant vibration in the Z axis at a 12,000 RPM.

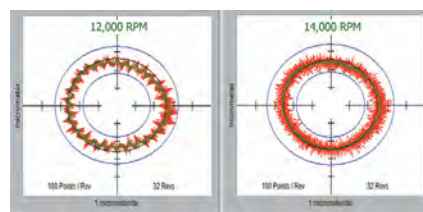


Figure 6: Undulations in the average position (green line) at 12,000 RPM which cause surface finish failures. The problem is not present at 14,000 RPM.

Results of resonance problems depend on the axis in which the error motion is taking place. In **Figure 5**, the pictured surface finish problem was created by a resonant oscillation in the Z axis during a face milling operation. Great but fruitless efforts had been made to solve the surface finish problem in a part produced by the millions. Finally, a spindlecheck was performed. It revealed a resonance at 12,000 RPM which is seen in the regular undulation of the green “average position” plot (**Figure 6**). This is a similar pattern to “chatter,” but it is happening whether or not the tool is engaged with the workpiece. At 14,000 RPM the resonance is gone. Contrary to the typical response of slowing speeds to address problems, the simple solution was to increase the speed allowing for higher feed rates and faster throughput in addition to better surface finish.

Thermal Errors – The Great Enemy of Precision

It’s well known that changes in temperature are the greatest source of precision machining errors. They are hard to solve if you cannot determine what is moving which way under what conditions. Things as simple as warm-up time can have a real impact on productivity. How long does the machine take to stabilize? Wait too long, and you drop productivity. Not long enough, and you make bad parts. **Figure 7** shows the first 60 minutes after this particular spindle starts turning. As expected, most of the movement is in the Z axis (red line). After 60 minutes it does not yet appear stable enough for precision machining.

Qualified Machine Acceptance

A precision machine shop ordered a \$1 million gantry-style mill with exacting specifications. Before accepting

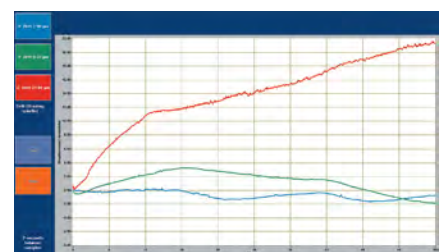


Figure 7: Significant Z-axis thermal drift (red line) during the first 60 minutes of spindle operation.

delivery, they went to the manufacturer to measure the machine including a spindlecheck. The spindlecheck revealed a significant change in the Y axis during warm up (a tilt problem). The apparent problem was that the drive motor was not centered on the cross beam of the gantry. As the motor heated up, an asymmetrical expansion of the cross beam caused a significant tilt in the Y axis (parallel to the cross beam). In that condition, the machine would be incapable of making the parts for which it was being purchased. The machine was rejected—a far better outcome than discovering the problem once it's on the shop floor and the \$1 million check has been cashed.

There simply isn't space here to talk about all the other problems solved through a spindlecheck discovery of error sources such as forklifts driving by, pump induced vibration, and chiller cycling causing repeated ball screw expansion/contraction at five minute intervals.

Why Spindlecheck Your Machine?

There are four primary reasons to include spindlecheck measurements in your toolbox of machine measurement:

1. Prevent unnecessary spindle rebuild/replacement. It's too expensive to guess.
2. Preventive Maintenance. You'll know when the spindle performance is dropping and can schedule appropriate maintenance without the risk of suddenly losing production abilities. You'll also spot other changes threatening machine performance and part quality. You'll be empowered with knowledge.
3. Analyze performance issues. When parts aren't meeting spec, a measurement of the point of machining can be the quickest way to see what exactly is happening.
4. Machine qualification. High-precision machine tools are expensive and yet they don't come with a certification of performance like a simple gage block set does. Ask for spindle measurements of new machine tools or make them yourself.

In the 21st century, there are so many great tools for measuring machine tool performance. Dynamic spindle measurement must become a vital piece in the machine tool measurement arsenal to take us to the next level of quality and productivity. [PM](#)



DON MARTIN is the president of Lion Precision. He can be reached at don@lionprecision.com.