Lead Screw Backlash and Mach3, version 2

By R. G. Sparber

This article looks closely at backlash and then explains how to measure it. The resulting numbers are used in Mach3, a Computer Numerical Control (CNC) program, to cancel a lot of the backlash[2]. An excellent treatment of backlash can be found at http://liutaiomottola.com/Tools/Backlash.htm but I will give it a try too.

Lead screws are commonly found in milling machines and lathes. Turn the lead screw and something moves along a ways.

Depending on how tightly the lead screw is fitted to the nut, there will be a dead zone when you turn the lead screw in the ***opposite*** direction. This dead zone is called backlash. From an accuracy standpoint, it does not matter how much backlash is present. What matters is how much the backlash changes over the full range of conditions including position and machining forces.

My mill has about 0.040" of backlash which doesn't worry me in the least. The nut is tightly secured to the mill but is rather worn after over 25 years of use. As I crank the handles, I know to ignore the backlash. When I converted to a Digital Read Out, backlash was no longer important because the scales measured actual table movement, not lead screw rotations.

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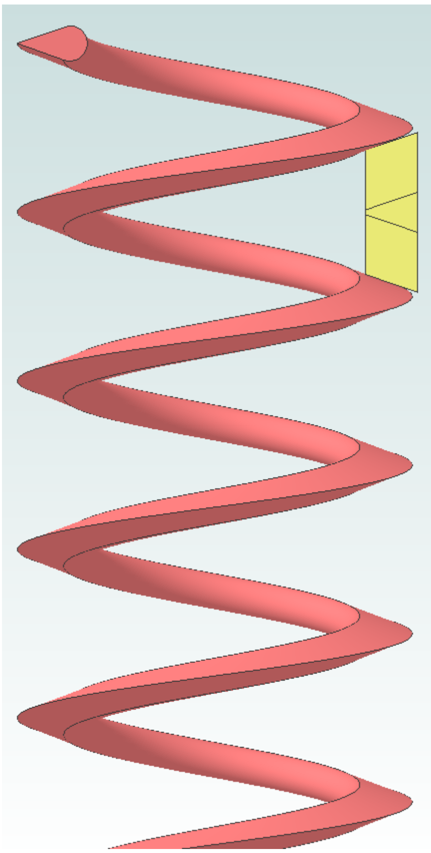
[1] You are free to distribute this article but not to change it.
[2] I am using Paul Thompson's CNC hardware which drives the existing lead screws in the RF-30.

This blissful ignorance of backlash was broken when I converted my mill to CNC. Mach3 tracks lead screw rotation so must compensate for backlash.

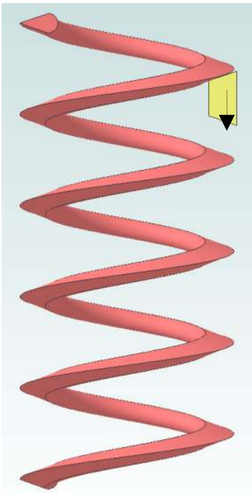
A closer look at backlash is in order.



The orange helix is the thread of the lead screw. The yellow block is part of a nut. In this case, the nut is a snug fit to the thread. Assuming both thread and nut are perfect, there is constant contact between them as the thread is turned in either direction.

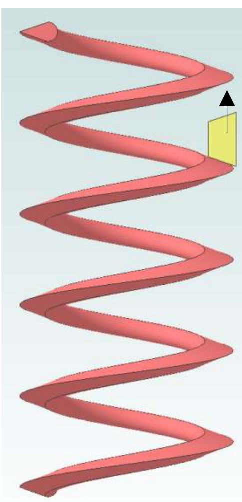
Backlash is zero. A close approximation to this arrangement is the ball recirculating lead screw. At least one manufacturer claims zero backlash.

If either thread or nut are not perfect, they will bind up as the thread is turned relative to the nut. This binding is avoided by changing the geometry of the nut so only one face is in contact with the thread at a time.

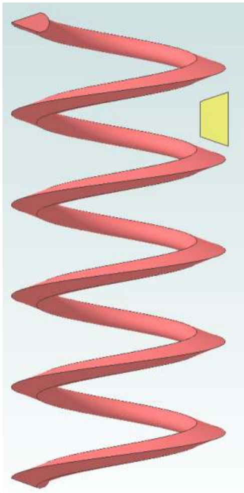


When this helix is turned counterclockwise as viewed from the top, the yellow nut is pushed down. As long as there is contact between thread and nut, the nut will move down at a rate entirely determined by the rotation of the helix.

In some cases the nut is secured to the mill's table causing the table to move. The lead screw is secured to the base so it does not move. In the rest of the cases the nut is secured to the base and the lead screw moves which causes the table to move.



Turn the helix in the opposite direction and the yellow nut will rise.

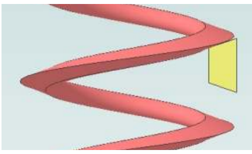


Look what happens when we change the direction of rotation of the lead screw. The threads move away from the nut and they are no longer in contact. As you turn the lead screw crank, there is almost no resistance. The table stops moving. Keep turning and eventually the thread will again contact the nut. Over some number of degrees of rotation, nothing happened.

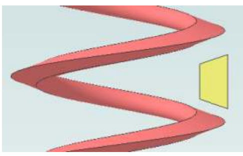
If you look at the graduated collar connected to the lead screw, you will see that it is marked in distance, not degrees. So while backlash is really a dead range of degrees, we refer to it by how much movement was lost.

Watching the collar's movement and feeling the range of no resistance, you can get a rough idea of the backlash. But for CNC use, this is not good enough. Fortunately, precisely measuring backlash is rather easy if you have a finger Dial Test Indicator (DTI).

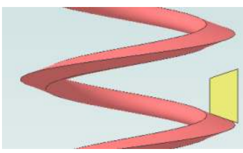
First a word about how Mach3 handles backlash. For each axis, there is a backlash value specified by the user. Say you are moving the cutter (relative to the table) in a positive direction. This means that the nut is in contact with the thread. You then reverse direction. Mach3 sees this reversal and injects the corresponding backlash value to the amount you wish to move.



For example, say you just moved from zero to + 0.100" on the X axis.



Then you decide to change direction and go 0.001" back towards zero for a final value of +0.099". As the lead screw is turned, you no longer are in contact with the nut and the cutter does not move.



Once you have traversed the backlash zone, the opposite face of the nut comes in contact with the thread. An additional bit of rotation is applied to move you that 0.001" back towards zero.

If the backlash value is correct, the cutter will have moved from +0.100" to +0.099".

If the backlash value is 0.0005" too small, the cutter will only move from +0.100" to 0.0995". The lost 0.0005" was absorbed into the backlash movement.

If the backlash is 0.0005" too big, the cutter will go past the target and land at +0.0985". The gained 0.0005" came from moving the full backlash distance and having 0.0005" left over.

Time to put this into practice.

I set up my finger Dial Test Indicator (DTI) so the base was supported by the mill's table. The finger rested on the lower spindle bearing housing.

To minimize the force on the DTI support, rotate the outer ring of the DTI so total needle movement from non-contact to zero is just a few thou.

Movement between table and spindle bearing housing was measured by the DTI.

I set up Mach3 to be in step jog mode with a step size of 0.001". I set the X axis backlash value to zero.

After moving the cutter two ***positive*** steps, I knew the nut was on one side of the lead screw.

At this point, I zeroed the X axis Digital Read Out (DRO) in Mach3 plus zeroed the DTI.

I next jogged one ***negative*** step at a time while monitoring the DTI. As soon as the DTI dial moved, I stop pressing the step button. In my case, the dial moved about +0.0005". That is enough to tell me I am through the backlash zone plus went 0.0005" over.

I read the DRO. This value was -0.0390". Add the DRO reading to the DTI reading: -0.0390" + 0.0005" = -0.0385". That is our first guess at the correct backlash value. Ignore the sign and write +0.0385" into Mach3 as the X axis backlash. Then I retested by first jogging a few positive steps, zeroing the DRO and DTI. I jogged one positive step followed by one negative step. The DRO was at 0.0000", then 0.0010" and finally back to 0.0000". The DTI read +0.0005" meaning my backlash is still 0.0005" too large. I changed the X axis backlash from 0.0385" to 0.0380. A second retest gave me a final DTI value of 0. Repeated the test 10 times and noted the worst case movement of the DTI. That gave me a rough idea of how well the backlash compensation works. In my case, I hit within ± 0.0001" every time.

Do not assume that this is the correct backlash value for the full range of the lead screw. The lead screw is not perfectly ground. Its pitch probably does vary a little over its length. The thread's contact area with the nut probably changes with distance too. On top of this, cutting forces can change backlash since more pressure is exerted between thread and nut. In other words, a lot more goes into overall machine accuracy than just setting the backlash to a fixed value.

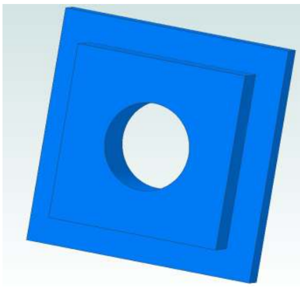
I next repeated the test on the Y axis. My first pass gave me a DRO value of -0.0350" and DTI reading of +0.0005". This gives me -0.0350" + 0.0005" = -0.0345". I then set my backlash to +0.0345". I jogged a few positive steps, zeroed the Y DRO, and zeroed my DTI. After jogging one positive step and one negative step I read + 0.0002" on my DTI. Although I doubt this small error matters when all other errors are included, I decided to tweak my backlash and go from 0.0345" to 0.0343". Jogging up one step and down one step gave me 0 on my DTI every time. I know, I know, this is wishful thinking. But it was fun to see.

The Z axis is different from X and Y axes because there is a spring that lifts the quill. This ideally eliminates backlash. But there is still backlash in the drive mechanism. Using the procedure, I found a backlash value of 0.0014" worked.

With reasonably good backlash values loaded into Mach3, I can start to assess accuracy and repeatability along each axis.

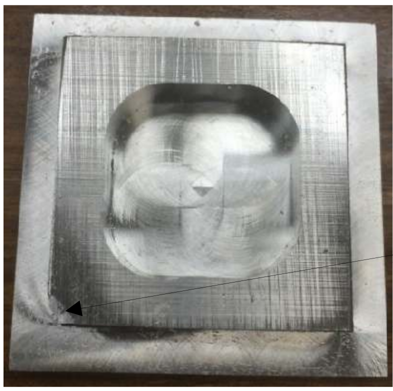
By the way, it would be good for you to write down the backlash values and put them in a safe place. Do not trust that your computer will preserve them forever.

Dynamic Testing



So far we have been addressing just the first "layer of the onion". The second layer includes actual cutting forces. An elegant test was suggested by Steve "pilotltd". A square perimeter is side milled followed by a hole in the center. By comparing the lengths of the sides of the square, we can see how well cutting along the X axis compares to cutting along the Y axis.

The diameter of the hole is selected to be a close fit on a piece of drill rod. In my case, I had some 0.750" rod.

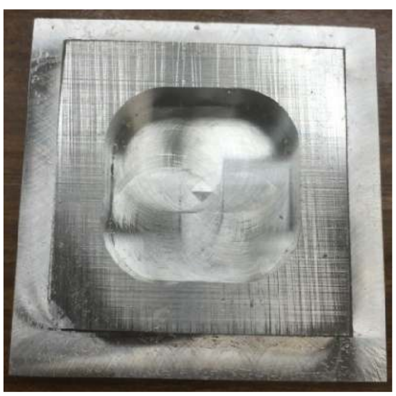


Due to various false starts, I ended up making this test coupon a half at a time. One coupon has the perimeter of a 1-1/2 x 1-1/2" square milled correctly. The other had the hole.

I milled off the corner of the square to mark the corner closest to the origin. First I put my digital caliper on the sides of the square parallel to the Y axis and then zeroed it. Then I put the caliper on the sides parallel to the X axis. It read 0.0000". The caliper is good to about ± 0.001" near zero so I can claim that the two sides of this square are within a thou of each other. I then directly measured one dimension and read 1.5000". The caliper's error in this range is ± 0.002". So this is a spot check of the linear accuracy.

Here you see that the 0.750" diameter drill rod does fit into the milled hole. It is not possible to see even in this magnified view, but there are two crescent shaped slivers of light showing between hole and rod. One is about 0.0005" at its peak and the other is about 0.001". Now that I have the rod in the hole, it is stuck.

These two tests imply that my backlash is set about right for the X and Y axes. However, this is far from an exhaustive test.



In the first test coupon, I milled a pocket 0.300" deep. Using my best mic, I zeroed it on the face of the square. Then I moved the mic into the pocket and read -0.30775". This is an error of 8 thou! Clearly there is more work needed on the Z axis.

Time to go back and do a closer static study of the Z axis linear accuracy.

Acknowledgments

Thanks to Paul Thompson and Dan Benoit. They are my primary guides as I learn Mach3. The Mach3 documentation is excellent but it saves a lot of time and frustration to be able to ask an expert. Thanks to Steve for suggesting the test coupon.

I welcome your comments and questions.

If you wish to be contacted each time I publish an article, email me with just "Article Alias" in the subject line.

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