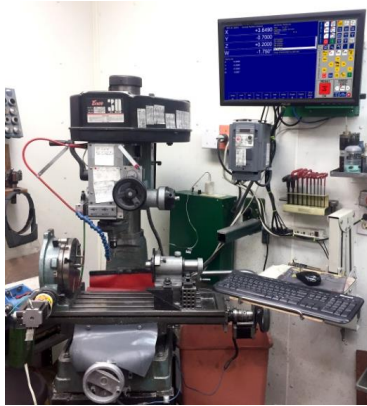# Centroid CNC12 Screw Mapping Using Gage Blocks, Version 2.2

By R. G. Sparber

Protected by Creative Commons.[1]

What excited me about having Screw Mapping as a Centroid CNC12 feature was the hope of improving the accuracy of my lead screw driven RF30 Mill/Drill.

My goal was to reduce lead screw errors to the point where they are insignificant compared to other sources of error like machine rigidity.

The Screw Mapping software is designed to work with a distance **measuring** device. I chose to use gage blocks as a distance **setting** device. The difference may seem minor but it turned out to have a major impact on how I calculate Correction factors.

My intended audience are people with a general knowledge of Computer Numerical Control (CNC) who own or are interested in Centroid's CNC12 with Acorn[2].

Many factors contribute to dimensional error on a machined part. Errors in position on each axis is just one source. Furthermore, screw mapping can only cancel error that is constant. Many of the numbers presented here are almost too good to be true. Keep in mind that this just means other errors then dominate.

After a little taste of my success, I will present machine set up and data collection. Then I will get into the theory that supports these procedures. Data from my mill will be presented last.

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[2] See http://www.centroidcnc.com/centroid_diy/acorn_cnc_controller.html

Contents

Sample Result

Here is a sample of what Screw Mapping did for me.
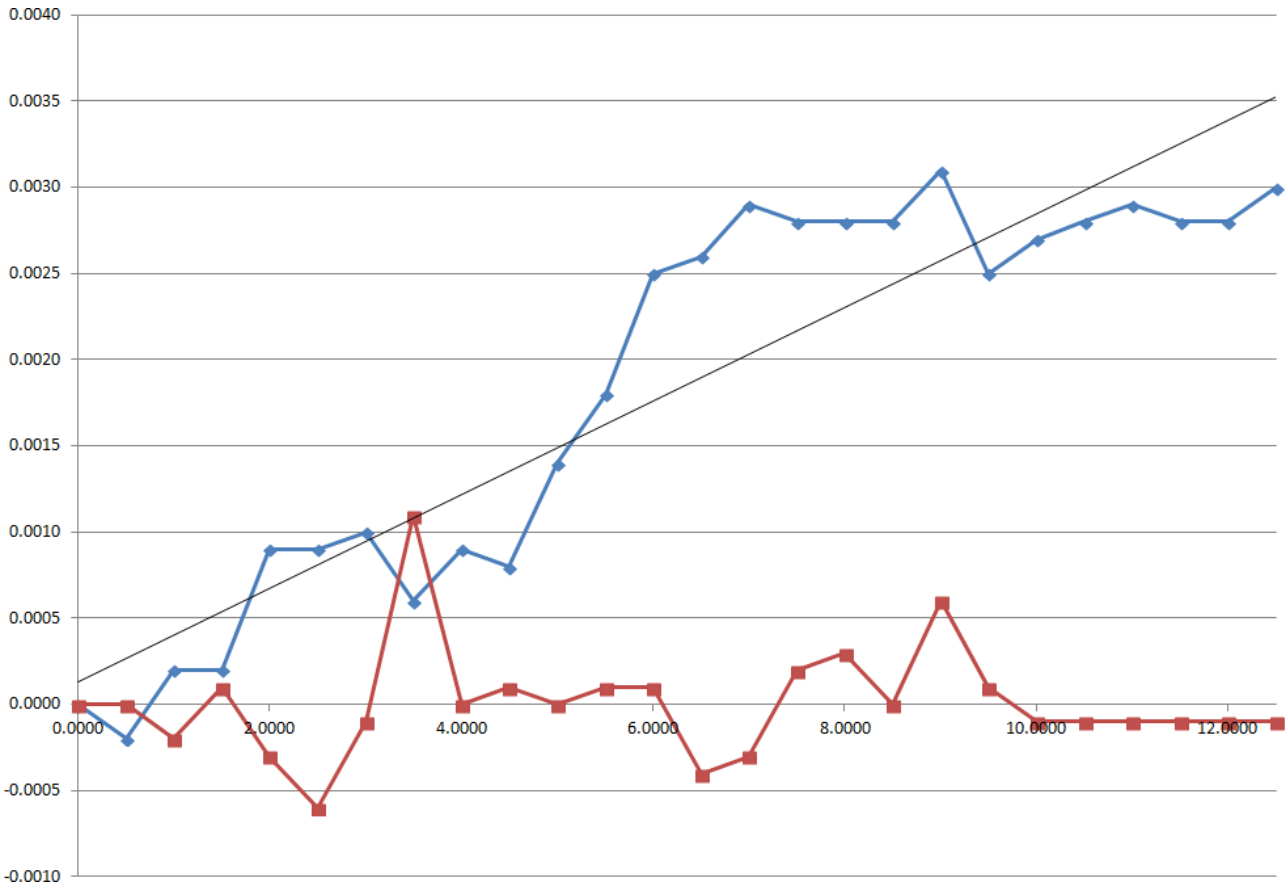
Valid data is at each square. I have drawn lines between data points to better see how these points relate. The horizontal axis is in inches of movement along the X axis. The vertical axis is error in inches. The blue line represents my uncompensated X axis feed error. The average slope[3] (black line) is due to error in setting the revolutions per inch. The red line is with Screw Mapping applied.

Worst case error after Screw Mapping is enabled is ± 0.001 inches. There is also error due to variation between correction points. This adds ±0.0005 inches to both Uncompensated and Compensated plots.

Notice the spike at 3.5000 inches on the red line. The error jumps up to 0.0011 inches while at all other positions it stays below 0.0007 inches in magnitude. This will be discussed later. It is not a bad data point but rather normal variation within my machine.

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[3] The slope is 3 tenths of error per inch of movement or 0.03% error.

Definition of Terms

All reference to position is in machine coordinates. Work Coordinate Systems are defined relative to the machine and are not used here.

X Axis Compensation Table					
Moving From Home			Moving Toward Home		
Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME 0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000

CNC12's Screw Mapping has a screen for each axis. The first line of the table on each screen identifies which axis is being represented. Here you see the top of the X Axis Compensation Table.

In this top view of my X axis, Home is defined as when the cutter is to the far left with respect to the table. Home means an X value of exactly 0. Note that all X values are positive.
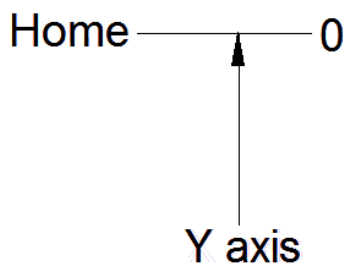
This is a top view of my Y axis. When the cutter with respect to the table is all the way forward, I'm Home and Y equals 0. Note that all Y values are negative.
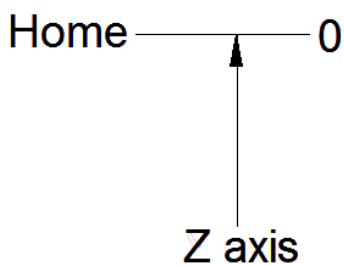
This is a side view of my Z axis. When the cutter with respect to the table is all the way up, I'm Home and Y equals 0. Note that all Z values are negative.

The "Position" column is the actual distance from Home and

		X Axis Compensation Table				
		Moving From Home		Moving Toward Home		
	Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000

includes a sign. For my X axis, all Positions are positive. For my Y and Z axes, all positions are negative.

Under "Moving From Home" we have "Measured Pos." (Measured Position). To the right of Measured Pos. is "Correction".

Next we have "Moving Toward Home" and the same two subheadings below it.

The last column is called "Difference". It is the absolute value of the difference between the two Corrections and represents the apparent backlash. This is the measured backlash after "Lash" has been populated. The Theory section will go into this in more detail.

Adapting To Using Gage Blocks

The software is designed to work with a measuring system. In order to use gage blocks and a finger Dial Test Indicator (DTI) which set position, a slightly different approach is needed. This essentially comes down to calculating Correction factors outside of the program and then directly inputting them. If we were using a measurement system, we could input Measured Positions directly.

		Moving From Home		Moving Toward Home		
	Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
	0.5000	0.50000000	0.00000000	0.51070000	-0.01070000	0.01070000
	1.0000	0.99940000	0.00060000	1.01010000	-0.01010000	0.01070000
	1.5000	1.49940000	0.00060000	1.51010000	-0.01010000	0.01070000

X Axis Compensation Table

In looking at this table, you may notice that

$$\text{Correction} = \text{Position} - \text{Measured Position}$$

For example,

$$0.0006 = 1.5000 - 1.4994$$

The adaption consists of changing the sign of Correction:

$$\text{-Correction} = \text{Position} - \text{Measured Position}$$

or

$$\text{Correction} = \text{-Position} + \text{Measured Position}$$

This change creates a problem because the new equation no longer matches what is shown in the table for Measured Position. Therefore, I will define new terms to use in place of **_Measured Pos._**:

DRO+ is the DRO reading while moving in a positive direction on a given axis.
DRO− is the DRO reading while moving in a negative direction on a given axis.

When all Position values are positive, use

$$\text{Moving From Home Correction} = \text{DRO}_+ - \text{Position} \qquad (1)$$

$$\text{Moving Toward Home Correction} = \text{DRO}_- - \text{Position} \qquad (2)$$

When all Position values are negative[4], use

$$\text{Moving From Home Correction} = -\text{Position} + \text{DRO}_- \qquad (3)$$

$$\text{Moving Toward Home Correction} = -\text{Position} + \text{DRO}_+ \qquad (4)$$

When these Correction values are put into the table, the resulting Measured Position values will *not* equal our DRO values.

---

[4] I chose to put "-Position" first in equations (3) and (4) because it was easier to do the math in my head. For example, When Position is -4.5 and DRO- is -4.5010, I think "4.5 - 4.5010".

Procedure Overview

	Position	X Axis Compensation Table				
		Moving From Home		Moving Toward Home		
	Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
	0.5000	0.50000000	0.00000000	0.51070000	-0.01070000	0.01070000
	1.0000	0.99940000	0.00060000	1.01010000	-0.01010000	0.01070000
	1.5000	1.49940000	0.00060000	1.51010000	-0.01010000	0.01070000
	2.0000	1.99890000	0.00110000	2.00970000	-0.00970000	0.01080000
	2.5000	2.49990000	0.00010000	2.51090000	-0.01090000	0.01100000
	3.0000	2.99940000	0.00060000	3.01040000	-0.01040000	0.01100000
	3.5000	3.49910000	0.00090000	3.51000000	-0.01000000	0.01090000
	4.0000	3.99870000	0.00130000	4.00970000	-0.00970000	0.01100000

On each linear axis we will move to predefined **Position**s and record the **DRO+** or **DRO−** values separate from the Axis Compensation Table. When done, equations (1), (2), (3), or (4) will be used to calculate the **Correction** values. These values are then put into the table.

Machine Setup For The X Axis

First Home the machine. Then put a finger DTI in the chuck. I used a Mitutoyo DTI that reads from -15 to +15 thou with a resolution of better than a tenth. Turn the bezel so the needle points to about -5. Be sure the finger moves back and forth parallel to the X axis and that the spindle does not rotate.

Secure a clean and smooth piece of aluminum angle[5] stock so it is parallel to the X axis. I used my vise which had previously been trued.

Loosely clamp a block to the right side with a sheet of paper[6] under it. Then stack up gage blocks to exceed the total movement of the table.
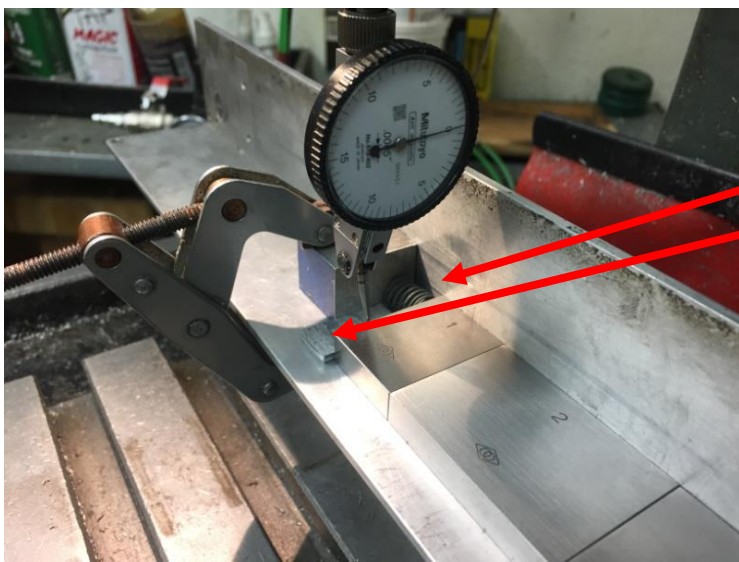
Slide the stack of blocks into the finger of the DTI until it reads 0 ±½. Tighten the clamp.

To insure repeatability of the stack, I attached a spring to a block of scrap aluminum[7]. A piece of scrap steel about ½ inch wide, 1 inch long, and 0.1 thick sits between the spring block and the reference surface. This insures a constant force[8] on the stack of gage blocks. I slide the spring block over until it almost touched the ½ inch wide spacer. Then I clamp the block.

Take care not to slam into the stack of gage blocks as this can move the clamped block.

Turn the bezel until the DTI reads 0. Jog forward a few thou and back to 0. Re-set 0 if necessary. I see less than a ½ thou of shift.

---

[5] The angle I used has no internal fillet. This made aligning the gage blocks easier.
[6] This reduces the change of the block sliding. Any such movement directly adds to error in the data.
[7] After having two springs shoot into the distance, I bolted the bottom of the spring to the block.
[8] Variation in force on the stack of gage blocks causes error.

Machine Setup For The Y Axis

This is almost identical to the X axis. The aluminum angle runs parallel to the Y axis and since I have chosen to set Home with the cutter all the way forward, all Position values are negative.

Machine Setup For The Z Axis

The gage blocks are stacked up on a 123 block which sits on the table. Fine adjustment of the DTI is done by sliding it up and down in the chuck which is then tightened. Since there is no spring to insure good contact between blocks, be sure to wring the blocks together.

I have chosen to set Home with the cutter all the way up[9] so all Position values are negative.

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[9] Notice that if I raise or lower the head, my distance from Home is unaffected. Had I referenced to the table, a new Screw Mapping table would have to be generated after each head move. Of course, I can set a Work Coordinate System with respect to the table.

General Advice
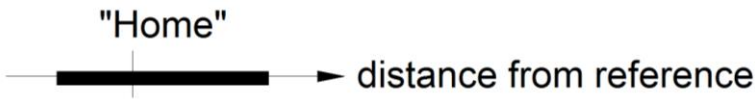
"Home"

The entire calibration process should be done in a single session to insure that all collected data is with respect to the same exact physical position called Home. If you set Home repeatedly and measured the exact position, you would see a range of values due to variation in the Home sensor.

By definition, my "distance from reference" is 0 once I Home the machine and prepare to take Screw Mapping data. Then all data is with respect to "Home". Do not re-Home the machine while taking this data or you will introduce unnecessary error.
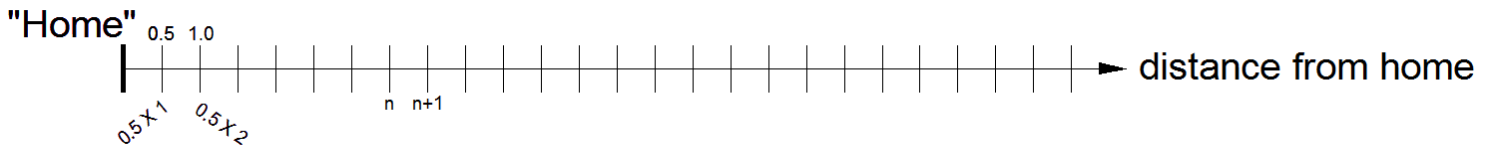
When the Screw Mapping data is later used, the location called Home will differ from the Home used to collect the data by the repeatability of the Home sensor. A Home sensor error of ± 0.005 inches is harmless[10] as long as the maximum change in adjacent correction values is less than ± 0.005 inches.

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[10] See http://rick.sparber.org/SMHE.pdf
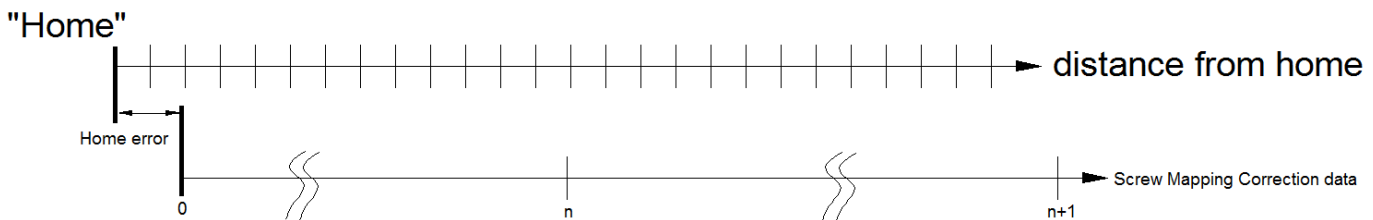
Setting Backlash At 0

X Axis Compensation Table					
	Moving From Home		Moving Toward Home		
Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
	0.5000	0.50000000	0.00000000	0.51070000	-0.01070000	0.01070000

By setting a good estimate of Backlash at Home, we increase our useful range of compensation. This is because the software requires that the Home entry in the Screw Mapping table be 0. That means backlash at Home is zero which is probably not true.

Since each of my X, Y, and Z Home positions is set at 0 which is the extreme of the range, I cannot move to a value on the other side of Home. Measuring Backlash requires this movement.

I know from past experience that my backlash on all axes is less than 0.02 inches. Therefore, I can move 0.0200 from Home and measure my backlash at this point. The backlash value will be a good estimate of backlash at Home. The number will go into the "Lash" box for each axis. Screw Mapping automatically includes this correction in all table movement.

Procedure

1. Estimate backlash on the given axis and round up to the nearest 10 thou.
2. Set Lash to 0 and disable Screw Mapping for this axis. See page 13 for details.
3. Home machine.
4. Move the DTI away from Home by a distance equal to your estimated backlash + 0.01 inches.
5. Slide the reference block over until the DTI reads 0.
6. Clamp the block.
7. Record the DRO reading as DRO_1.
8. Jog 2 thou more away from Home.
9. Jog toward Home until the DTI again reads 0.
10. Record the DRO reading as DRO_2.
11. Subtract DRO_1 from DRO_2, drop the sign, and call this value Lash for the given axis. It will be input before we start Screw Mapping.
12. Repeat procedure for each linear axis.

Example

1. I estimated my X backlash to be no more than 0.01 inches.
2. Set Lash to 0 and disabled X Screw Mapping.
3. Homed my machine.
4. Moved the DTI until the DRO reads 0.0200 inches.
5. Slid the reference block over until the DTI read 0
6. Clamped the block.
7. I recorded 0.0200 as my DRO_1.
8. Jogged 2 thou more away from home.
9. Jogged toward Home until the DTI again read 0.
10. I recorded 0.0096 as my DRO_2.
11. (0.0200 - 0.0096) = 0.0104 inches so this is my backlash at X Home.

Screw Mapping Preparation

Screw Mapping must be turned off in order to do calibration. This is done by going

 to Setup,

 Config,

 Mach,

 and Motor.

 Enter the Backlash (Lash) Compensation for each axis.
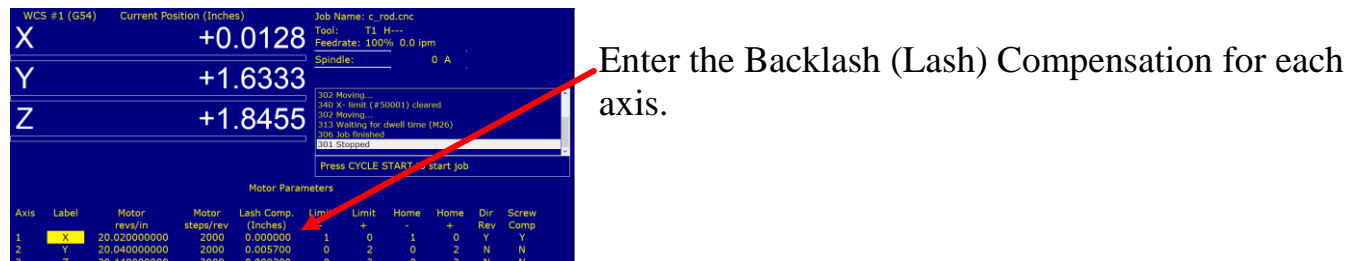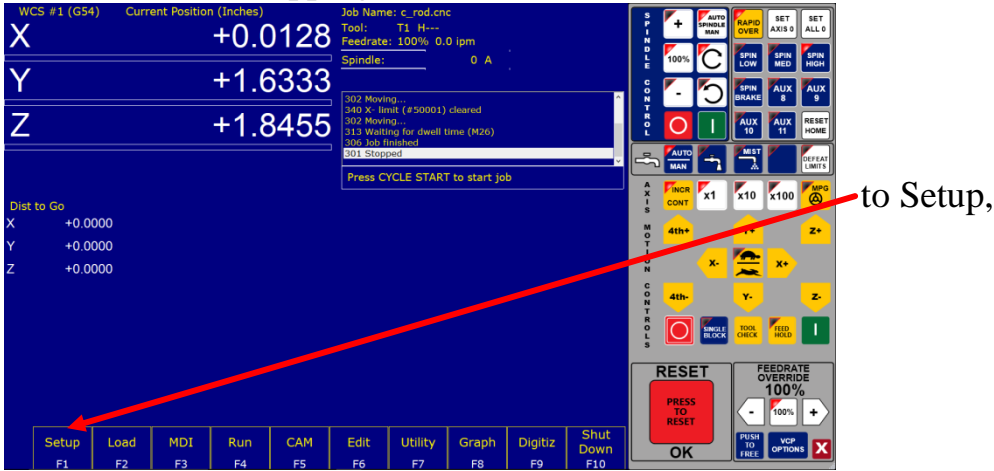
Lash can later be increased to account for *uniform* wear without generating a new table. If the wear is not uniform, the Screw Mapping data must be updated as needed.

Be sure Screw Comp is set to N. If it shows Y, click on Y and it will let you change it to N.

Do Save (F10). Then press Escape.

Selected M Comp and you will see the Screw Mapping screen.

The first entry in the table is a position of 0 which is, by definition, Home. CNC12 requires this row to be all zeros. The last entry in the table must have zero for both Corrections. My last entry is at 13 inches so is not visible on this screen. Use the up/down keyboard arrow keys to scroll the table.

I was doing a lot of DTI reading so decided to put a camera on the DTI and display the result on my monitor.

I use the jog function to position[11] the DTI. For closing a big gap, I use MDI or jog with 0.01 inch steps. When the needle starts to move, I change to 0.001 inch. When at or below 1 on the DTI, I use 0.0001 inch steps.

---

[11] When I say move the DTI, I mean to move it with respect to the table.

The Screw Mapping Procedure For Positive Positions

X Axis Compensation Table				
		Moving From Home		Moving Toward Home	
	Position	Measured Pos.	Correction	Measured Pos.	Correction
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000
	0.5000	0.50000000	0.00000000	0.51070000	-0.01070000

1. Home the machine.
2. For the Home position: 0.0000 inches
   a. Turn the DTI's bezel to read about -5 with the stack of blocks away from the finger.
   b. Move to Home so the DRO reads 0.0000.
   c. Slide the block stack on the aluminum angle in a negative direction until the DTI reads between -1 and +1. Clamp the block at the end of the stack.
   d. Turn the DTI's bezel to set the DTI to 0.
   e. Using jog, move the DTI in a positive direction until the DTI reads at least 2.
   f. Jog in a negative direction until you reach Home. Ideally the DTI reads 0.This might mean your Backlash value was set correctly and your repeatability error is 0. It could also mean you were just lucky. Jog forward about 2 thou and back to home 5 times and note DTI readings. Record the largest change in reading as your repeatability error[12]. If you decide the error is excessive, adjust the backlash value, Save, and re-home the machine.

3. For all other positions except the last one:
   a. Start at a location more negative than the target position.
   b. Move in a positive direction until the DTI equals 0. This is DRO_+.
   c. Calculate $(DRO_+ - Position)$ and save it for later input as "Move From Home: Correction" for this Position.
   d. Move until the DTI equals at least 2.
   e. Move in a negative direction until the DTI equals 0.
   f. Note DRO_-.
   g. Calculate $(DRO_- - Position)$ and save it for later input as "Move Toward Home: Correction" for this Position.
   h. Compare the new Correction values to the last few sets of data. If the change is not similar, something could have shifted. Return to the full stack and verify zero is still correct. Then return to the latest position and retake the data. You do not want to collect all of these readings only to find out that half of them are wrong.

---

[12] For example, say you read 0, -0.5,+1, +0.5, 0. The largest change is from -0.5 to +1 so the repeatability error estimate is $\pm \frac{1-(-.05)}{2} \approx \pm 0.8 \ thou$.

4. The last position has both correction values set to 0 as required by software.
5. Input all Correction values into the Screw Mapping table. Do a Save. It would also be a good idea to generate a Report in order to back up this data.
6. Enable Screw Mapping for this axis. See page 15 but this time change N to Y.
7. The machine is Homed and then we are ready to start using Screw Mapping on this axis.

The Screw Mapping Procedure For Negative Positions

		Y Axis Compensation Table				
		Moving From Home		Moving Toward Home		
	Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
	-0.5000	-0.50160000	0.00160000	-0.49510000	-0.00490000	0.00650000
	-1.0000	-1.00080000	0.00080000	-0.99400000	-0.00600000	0.00680000
	-1.5000	-1.50300000	0.00300000	-1.49550000	-0.00450000	0.00750000
	-2.0000	-2.00460000	0.00460000	-1.99650000	-0.00350000	0.00810000
	-2.5000	-2.50330000	0.00330000	-2.49500000	-0.00500000	0.00830000
	-3.0000	-3.00420000	0.00420000	-2.99610000	-0.00390000	0.00810000
	-3.5000	-3.50430000	0.00430000	-3.49610000	-0.00390000	0.00820000
	-4.0000	-4.00390000	0.00390000	-3.99650000	-0.00350000	0.00740000

1. Home the machine.
2. For the Home position: 0.0000 inches
   a. Turn the DTI's bezel to read about -5 with the stack of blocks away from the finger.
   b. Move to Home so the DRO reads 0.0000.
   c. Slide the block stack on the aluminum angle in a positive direction until the DTI reads between -1 and +1. Clamp the block at the end of the stack.
   d. Turn the DTI's bezel to set the DTI to 0.
   e. Using jog, move the DTI in a negative direction until the DTI reads at least -2.
   f. Jog in a positive direction until you reach Home. Ideally the DTI reads 0.This might means your Backlash value was set correctly and your repeatability error is 0. It could also mean you were just lucky. Jog backwards about 2 thou and forward to home 5 times and note DTI readings. Record the largest change in reading as your estimated repeatability error[13]. If you decide the average value is excessive, adjust the backlash value, Save, and re-home the machine.

3. For all other positions except the last one:
   i. Start at a location more negative than the target position.
   j. Move in a positive direction until the DTI equals 0. This is DRO_+.
   k. Calculate $(- Position + DRO_+)$ and save it for later input as "Move Toward Home: Correction" for this Position.
   l. Move until the DTI equals at least 2.
   m. Move in a negative direction until the DTI equals 0.
   n. Note DRO_-.

---

[13] For example, say you read 0, -0.5,+1, +0.5, 0. The largest change is from -0.5 to +1 so the repeatability error estimate is $\pm \frac{1-(-.05)}{2} \approx \pm 0.8\ thou$.

o. Calculate $(-\,Position + DRO_-)$ and save it for later input as "Move From Home: Correction" for this Position.

p. Compare the new Corrections to the last few sets of data. If the change is not similar, something could have shifted. Return to the full stack and verify zero is still correct. Then return to the latest position and retake the data. You do not want to collect all of these readings only to find out that half of them are wrong.

4. The last position has both correction factors set to 0.

5. Input all Correction values into the Screw Mapping table. Do a Save. It would also be a good idea to generate a Report in order to back up this data.

6. Enable Screw Mapping for this axis. See page 15 but this time change N to Y.

7. The machine is Homed and then we are ready to start using Screw Mapping on this axis.

Correction Touch-up

DRO$_+$ is the DRO reading while moving in a positive direction on a given axis.
DRO$_-$ is the DRO reading while moving in a negative direction on a given axis.

After testing, you may find some correction values are not good enough. Note the Position, DRO$_-$ or DRO$_+$, and the Correction value that is off. This procedure is done with Screw Mapping on.

When all Position values are positive, use

$$\text{Moving From Home Correction } \textbf{change} = DRO_+ \text{ - Position} \qquad (5)$$

$$\text{Moving Toward Home Correction } \textbf{change} = DRO_- \text{ - Position} \qquad (6)$$

When all Position values are negative, use

$$\text{Moving From Home Correction } \textbf{change} = \text{-Position } + DRO_- \qquad (7)$$

$$\text{Moving Toward Home Correction } \textbf{change} = \text{-Position } + DRO_+ \qquad (8)$$

In all cases, ***add*** the change value to the existing Correction values in the table.

Example

On my first pass of calibrating the X axis at a position of 12.5000 inches, I measured a DRO+ of 12.5030. Since Position is positive, I used equation (1) to find my Correction

Moving From Home Correction = DRO+ - Position   (1)

Moving From Home Correction = 12.5030 - 12.5000

Moving From Home Correction = 0.0030

During my first test of this data I measured a DRO+ of 12.4985.

Using (5)

Moving From Home Correction **change** = DRO+ - Position   (5)

Moving From Home Correction **change** = 12.4985 - 12.5000

Moving From Home Correction **change** = -0.0015

My original Correction was 0.0030 and my change is -0.0015. Adding them together gave me +0.0015 which was put into the table[14].

During the second test of this data I measured a DRO+ of 12.4999. I really doubt the error will remain this small but it does confirm that the equations are right. Drift in machine error will cause the compensated error to rise.

---

[14] You may wonder why a second iteration was needed. I have found that things can shift which moves all subsequent measurements. I also found that the clamped reference block can move from repeated bumps during the calibration process.

Protecting Your Investment

If you got this far, the data you have collected took a lot of time and effort. Now is the time to back it up. Go to the cncm folder and copy the files cnc-x.tab, cnc-y.tab, and cnc-z.tab. Then save them to a safe place that is not on the PC used to run your mill.

If you find that your screw mapping data is corrupted or missing, you can replace the existing 3 screw mapping files in your cncm folder with your backed up versions.
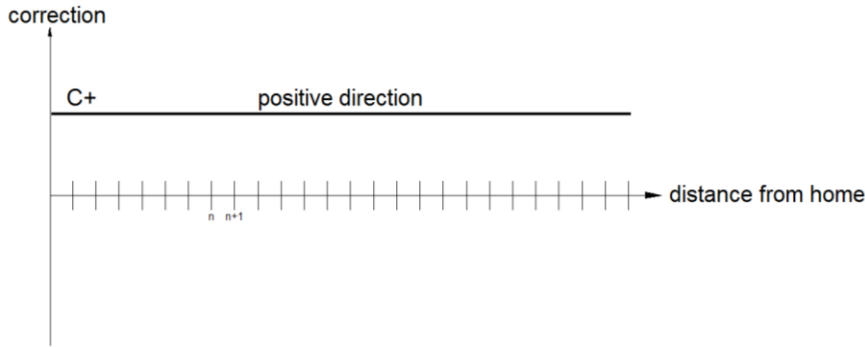
Screw Mapping Theory

Let's start with an ideal leadscrew, zero backlash, ideal nut, and perfect Home position.

At Home, the DRO reads 0.0000. Move 0.5000 inches in a positive direction and the DRO reads 0.5000. This means our correction is zero. In fact, I can move any positive distance up to the positive limit and all correction values will be 0. Moving back to 0.0000 and the DRO again reads 0.0000. This means the backlash is 0.
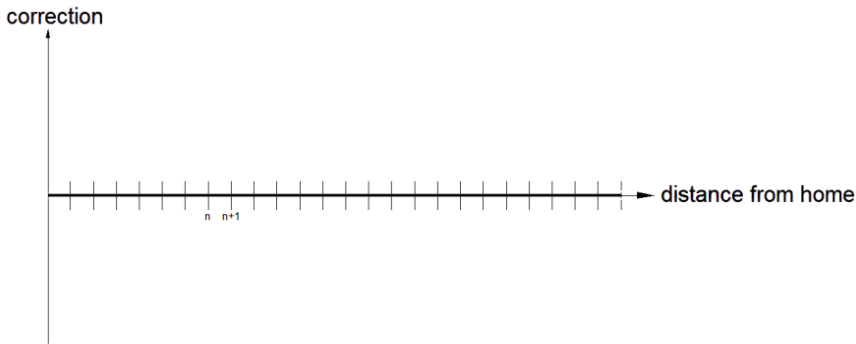
I can show this idea behavior as a straight line placed on the distance from home axis.

Next consider the effect of constant backlash.
As I move in a positive direction, the Screw Mapping data returns a constant value. Call this value C_+.
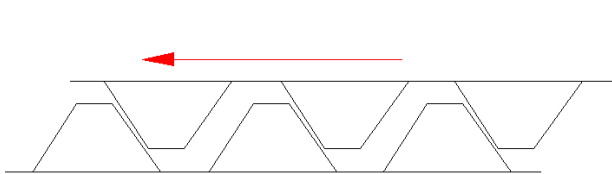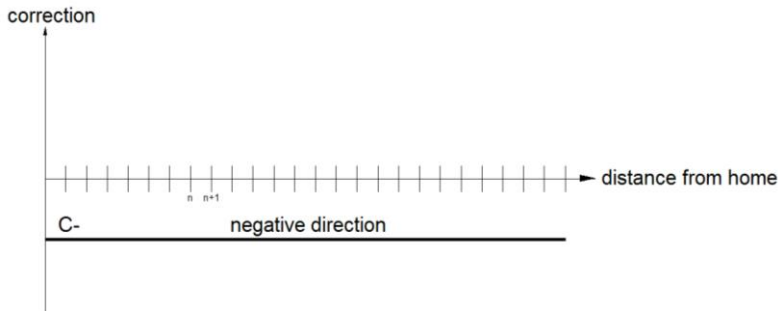

In order to calculate the correct DRO value, the software takes the raw position data which is based on counting pulses to the stepper motor and subtracts C_+. To reach the desired position, more pulses will be needed.
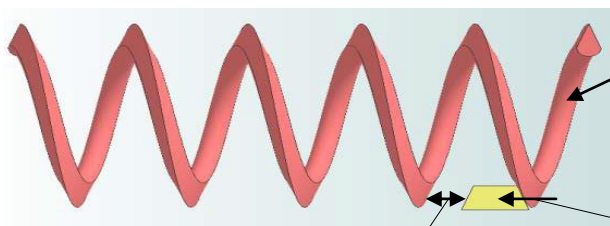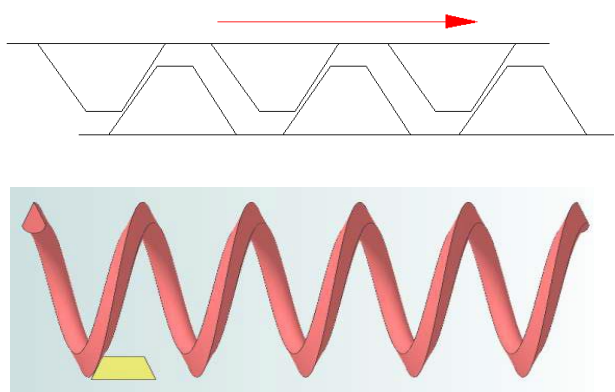

These pulses first move the leadscrew through

the dead zone called backlash. Then they start to drive the spindle relative to the table. The software stops when the raw position minus the correction equals our target value.

When the software moves the cutter relative to the table in a negative direction, the Screw Mapping data returns a constant C_-.

In order to calculate the correct DRO value, the software takes the raw position data which is based on counting pulses to the stepper motor and subtract C_-. In order to reach the desired position, more pulses will be needed. These pulses first move the leadscrew through the dead zone called backlash. Then they start to drive the cutter relative to the table.

Backlash is equal to the distance between positive and negative correction lines:
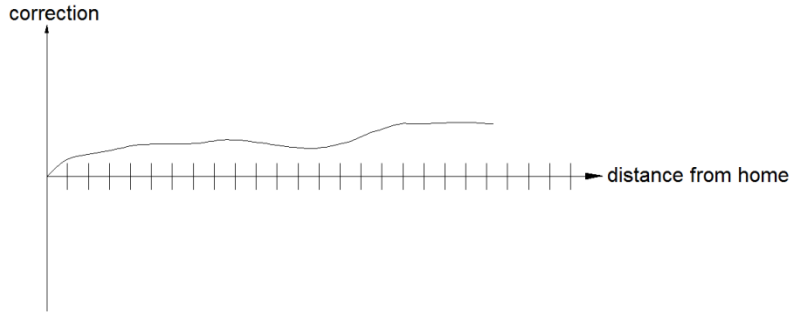
$$backlash = \; C_+ - \; C_- \quad (9)$$

My procedure attempts to set the correct backlash value at Home. Given that all Position values are positive, I set my DTI to 0 when at Home. Moving back to Home should bring us back to a DTI of 0.

Note that the Homing process is the only time that the spindle moves below home before going to Home.
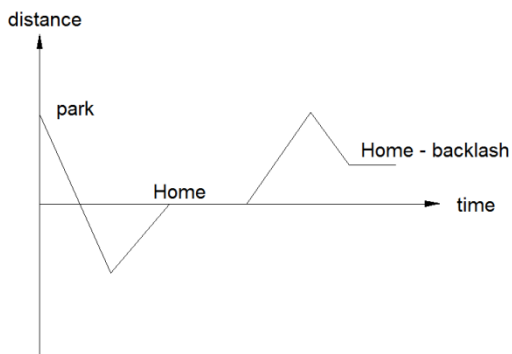
For example, after park, I will be at an X of +0.012 inches. When I home, we move in a negative direction until we are at about -0.012. Then we move in a positive direction to 0.0000. So when initially at Home, the previous direction was positive.

Subsequently, when we move to Home, all previous directions must be negative because *we* cannot go past Home to negative Position values. Without backlash set correctly at Home, we will land at a distance of Home minus backlash after the initial Homing is performed. *This means that it is essential that we get Lash correct at Home in order to avoid backlash error each time we go to Home.*

correction

distance from home

Next, consider the case of imperfect thread but constant backlash that has been perfectly canceled at Home. It might look like this. Correction starts out at 0 but then rises due to wear on the thread. Since we are assuming perfect backlash compensation, the direction of travel doesn't change the correction value.

correction

positive direction

distance from home

negative direction
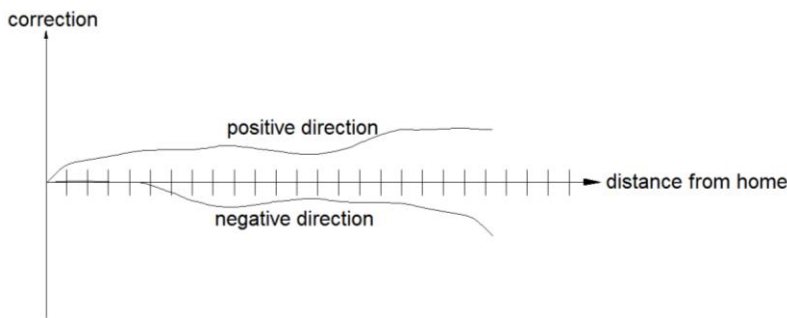
By letting backlash change with distance, we arrive at a non-ideal leadscrew and non-idea nut. However, this still assumes that changes between sample points are on a straight line. Note that backlash starts at 0 but eventually increases. This causes the positive and negative direction lines to separate.

Error Correction Theory
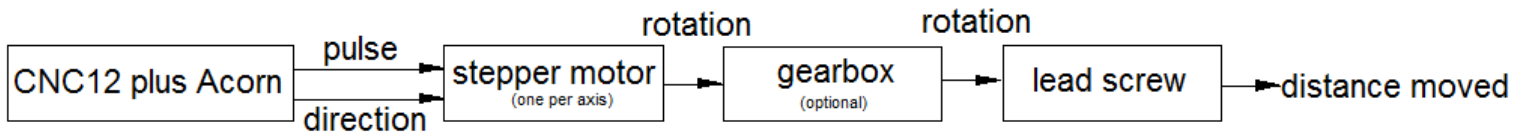
Consider what happens when CNC12 plus Acorn is told to move from Home to X = 1.000 inch.

Axis	Label	Motor revs/in	Motor steps/rev	Lash Comp. (Inches)	Limit -	Limit +	Home -	Home +	Dir Rev	Screw Comp
				Motor Parameters						
1	X	20.020000000	2000	0.000000	1	0	1	0	Y	Y
2	Y	20.040000000	2000	0.005700	0	2	0	2	N	N
3	Z	20.440000000	2000	0.000300	0	3	0	3	N	N

During machine set up for each axis, Motor revolutions per inch (revs/in) and Motor steps per revolution (steps/rev) are provisioned. Together they define the number of steps per inch for the given axis

$$\frac{revs}{inch} \times \frac{steps}{rev} = \frac{steps}{inch} \qquad (10)$$

Looking in the above table for my X axis we find

$$\frac{20.02\ revs}{inch} \times \frac{2000\ steps}{rev} = \frac{40,040\ steps}{inch}$$

So when the Acorn board sends 40,040 pulses to the stepper motor, it turns a pair of gears in my gearbox which turn my lead screw. The nut on the leadscrew is secured to the mill's table so, in the ideal case, it moves exactly 1.0000 inches.

Now, consider the non-ideal case where my revolutions per inch is slightly off at 1.0000 inches. Say it is low by 0.06%. This means that we only move 0.9994 inches when the software sends out 40,040 pulses. With Screw Mapping set up correctly, the software sees that when at 1.0000 inches on the X axis, it must add 0.0010 inches to the movement.

$$\frac{40,040\ steps}{inch} \times 0.0006\ inches = 24\ steps$$

The extra 24 pulses out of the Acorn board[15] brings us 40,064 pulses which moves the mill table to exactly 1.0000 inch.

The standard Centroid Screw Mapping table has corrections every 0.5000 inch. It interpolates between these points to generate corrections for any position within the range of the given axis.

Generating these correction values involves comparing actual movement to what the software thinks it moved. In the above example, the software initially thought it would move 1.0000 inch if it sent out 40,040 steps. But after consulting the Screw Mapping function, it learned that it must actually send out 40,064 steps. Populating the Screw Mapping table runs this logic backwards.

First consider what happens when we are using a distance ***measuring*** device. With Screw Mapping disabled, we tell the software to move from Home to 1.000 inches. It sends out 40,040 steps. As far as the software knows, the mill table is now at 1.000 inches.

The distance measuring device sees that the mill's table only moved 0.9994 inches. If we enter this number into the X Axis Compensation Table at a position of 1.0000 inches, the software calculates the Correction by:

$$\text{Correction} = \text{Position} - \text{Measured Position} \quad (11)$$
$$\text{Correction} = 1.0000 - 0.9994$$
$$\text{Correction} = 0.0006.$$

		X Axis Compensation Table				
		Moving From Home		Moving Toward Home		
	Position	Measured Pos.	Correction	Measured Pos.	Correction	Difference
HOME	0.0000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
	0.5000	0.50000000	0.00000000	0.51070000	-0.01070000	0.01070000
	1.0000	0.99940000	0.00060000	1.01010000	-0.01010000	0.01070000
	1.5000	1.49940000	0.00060000	1.51010000	-0.01010000	0.01070000

Then in operation, when the software is told to move to 1.0000 on the X axis it will send out enough pulses to move to 1.0000 + 0.0006 = 1.0006 inches. That will actually move the mill's table to 1.0000 inches.

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[15] If Screw Mapping was told that the revolutions per inch was 0.06% high, it would subtract 24 from 40,040 and only send the motor 40,016 pulses.

Now consider what happens in this example when we use a distance *setting* device like a stack of gage blocks[16] and a DTI.

The DTI is set to 0 at Home. Then a 1.0000 inch wide gage block is removed. The mill's table is manually driven until the DTI again reads 0. The mill's table is now at a *Position* 1.0000 inches from Home. The software says we moved 1.0006 inches. This is the *Measured Position*.

In order to generate the right Correction factor, we must multiply Correction in equation (11)

$$\text{Correction} = \text{Position - Measured Position} \quad (11)$$

by minus one:

$$- \text{Correction} = \text{Position - Measured Position}$$

or

$$\text{Correction} = \text{Measured Position - Position} \quad (12)$$

Where Measured Position is what the software displays and Position is what the gage blocks plus DTI say.

In this example, we have

$$\text{Correction} = \text{Measured Position - Position} \quad (12)$$

$$\text{Correction} = 1.0006 - 1.0000$$

$$\text{Correction} = 0.0006 \text{ inches}$$

Therefore, we arrive at the same Correction factor with either a distance measuring or distance setting device. However, the equations are different and the Measured Position as displayed in the table will not match what the software displays.

---

[16] We could use the gage blocks as a distance measuring device but it would require a lot more effort.

From a practical standpoint, both methods yield exactly the same result. From a purely theoretical standpoint, the Correction factor generated with the distance measuring device actually applies at 0.9994 inches and not at 1.0000 inches. Using the distance setting device, the generated Correction factor for 1.0000 inches is measured at 1.0000 inches.

Measured X Axis Results
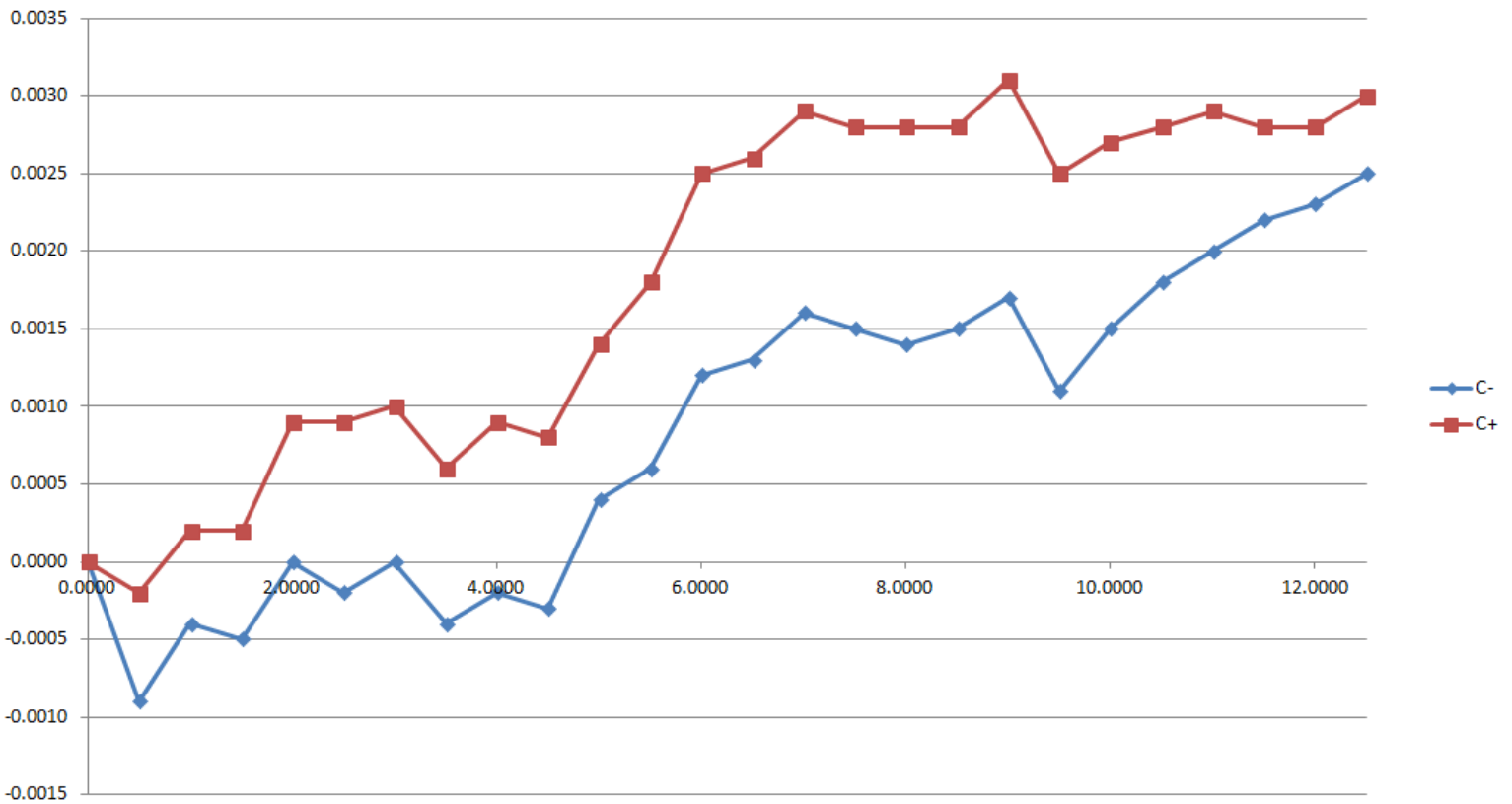
Here is measured X axis error data from my RF-30 Mill/Drill. My backlash at Home was set correctly so both Moving From Home (red) and Moving Toward Home (blue) are both 0 at Home. Both lines have an average slope of 3 tenths per inch. This is due to my revolutions per inch parameter being high by 0.03%.
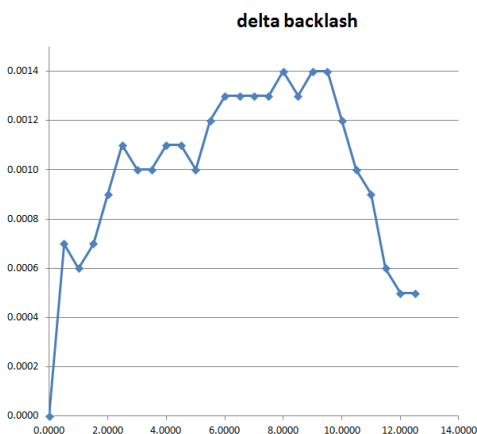
Looking at change in backlash, we can see the effects of wear on my X axis leadscrew.

At Home we have canceled all backlash so are at 0. Lots of machining took place between 2 and 9.5 inches so backlash is relatively large. Above 9.5 inches the backlash goes back down.

So how well did the Screw Mapping work on my X axis? Time to find out.

As a spot check, I measured at each calibration point along the X axis with Screw Mapping enabled. It is important to note that I am testing at the same locations used in calibration. This is a best case and ignores nonlinear[17] behavior between data points.
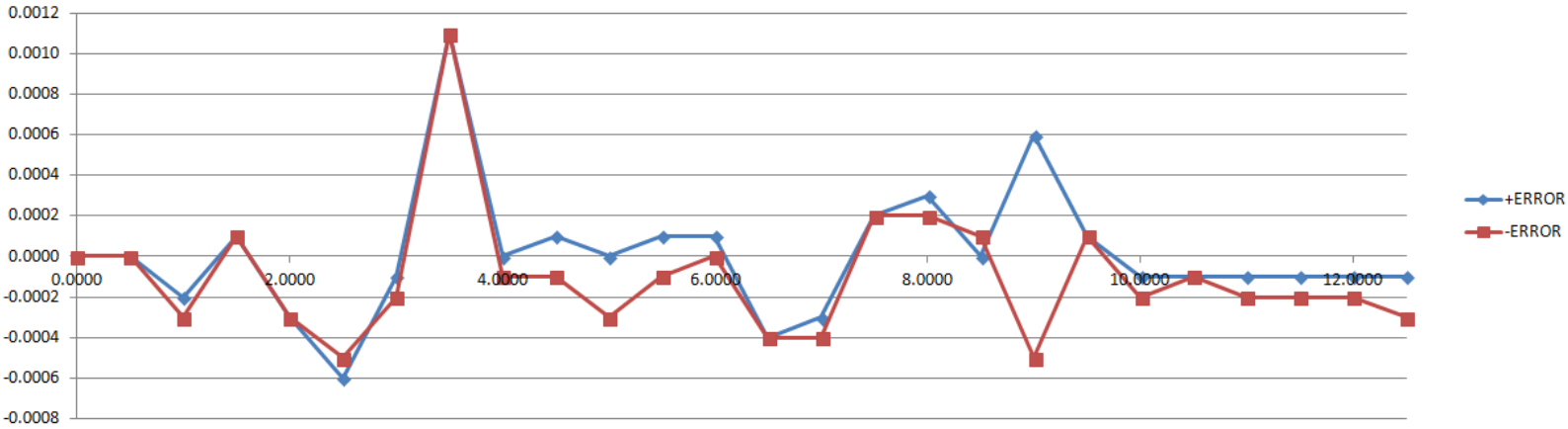
The most positive error was 0.0011 inches and my most negative error was -.0006 inches or 0.00025 ±0.00085 inches. I'll call this 0 ± 0.001 inches over the full range of the X axis.

Now come the really critical tests[18]. How does the error behave between 0.5000 inch calibration points? The software assumes linearity.

DRO-block
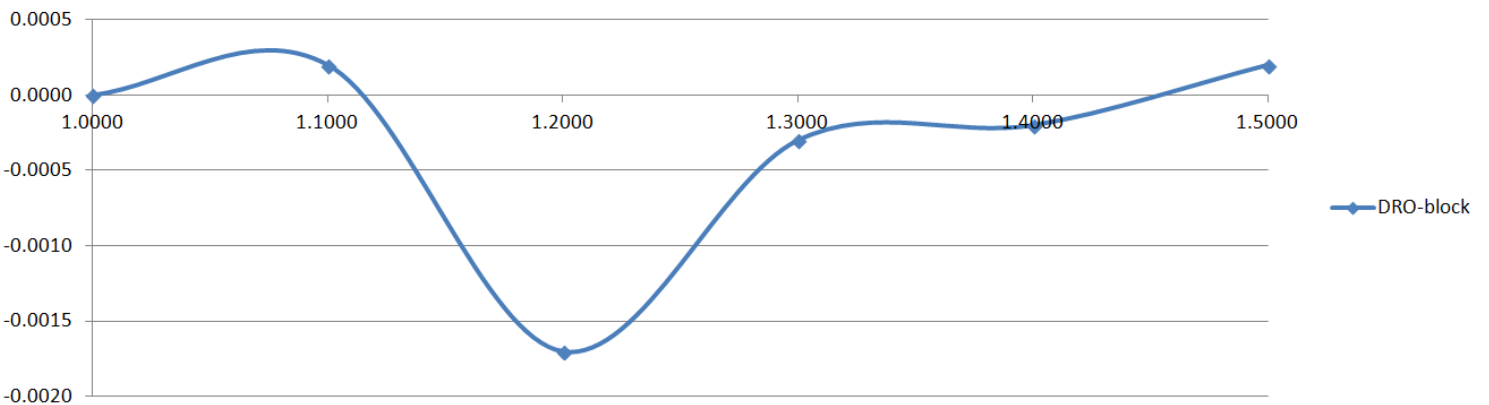
 Here is a closer look at compensated X axis movement from 1.000 inches to 1.500 inches. Data has been taken every 0.1000 inches. I fitted a curve just to make it easier to see the data points.

[17] Nonlinear - not on the straight line between 0.5000 inch Positions.
[18] This is data taken from previous runs so does not exactly match other graphs.

What is going on at 1.2000 inches? It is a sudden drop to -0.0017 inches of error. Is this a hint of more random error? Must look closer.

DRO-block
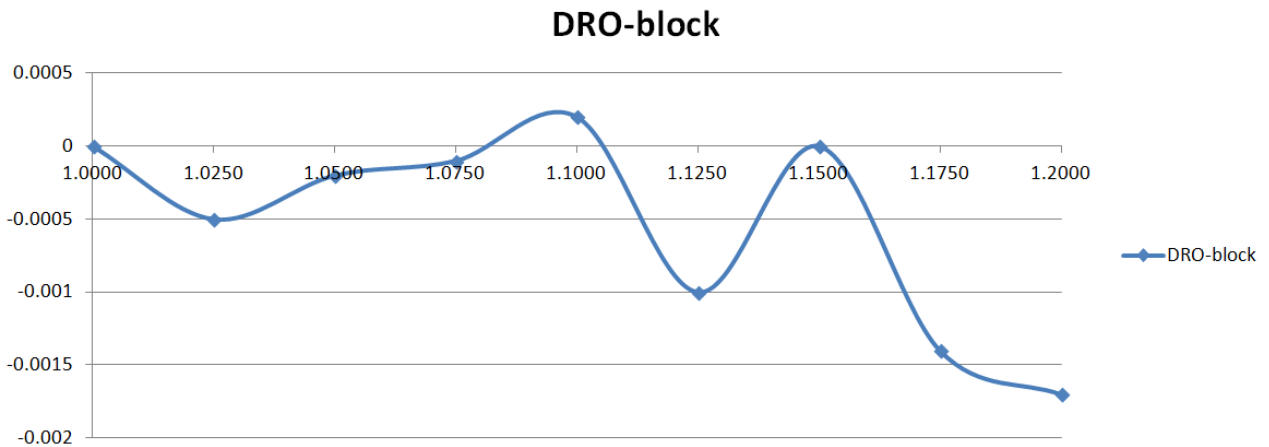
Taking data every 0.025 inches reveals more about error variation. Notice that our data point at 1.2000 inches is not a fluke. There is a negative going trend that starts at 1.000 inches plus variation that combine to produce this error of -0.0017 inches. This data tells me to look even closer.

I used my Grade B gage blocks to move 0.001 inches at a time. I also swept this range using my finger DTI to verify behavior between 0.001 points have no abrupt changes.
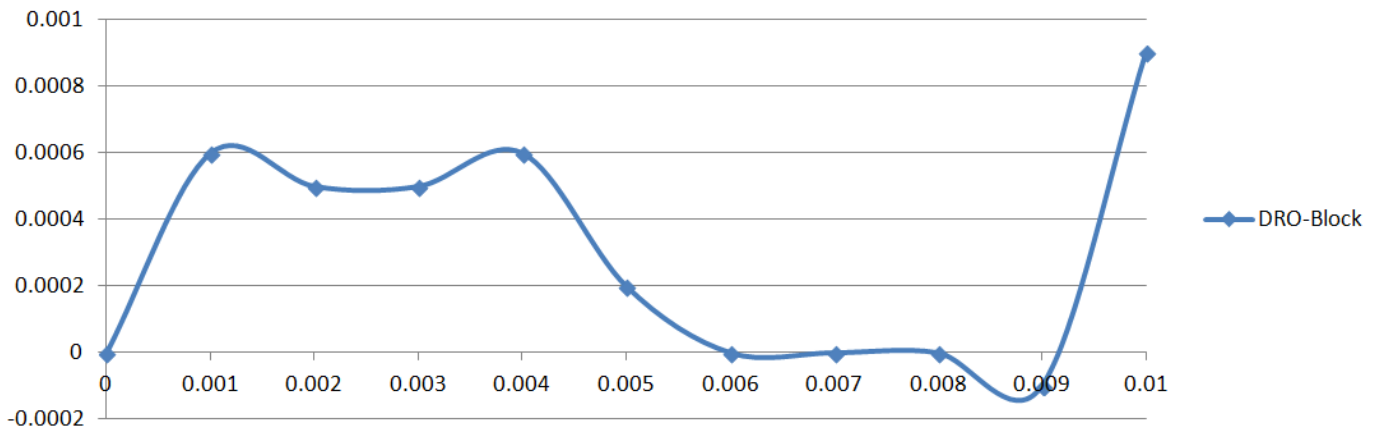

This data tells me that it is reasonable to say the error here is +0.0009 -0.0001 inches or 0.0004 ±0.0005 inches.

Going back to the variation in error at 0.5000 inch calibration points, we saw ±0.0007 inches. I can probably assume the variation at the 0.001 inch step size of ±0.0005 adds to this error. That means a total variation of ±0.0012. This compares well with my initial estimate of ±0.001.

Measured Y Axis Results

Next we have the Y axis with Screw Mapping disabled. This shows an error in revolutions per inch of about 0.01%.
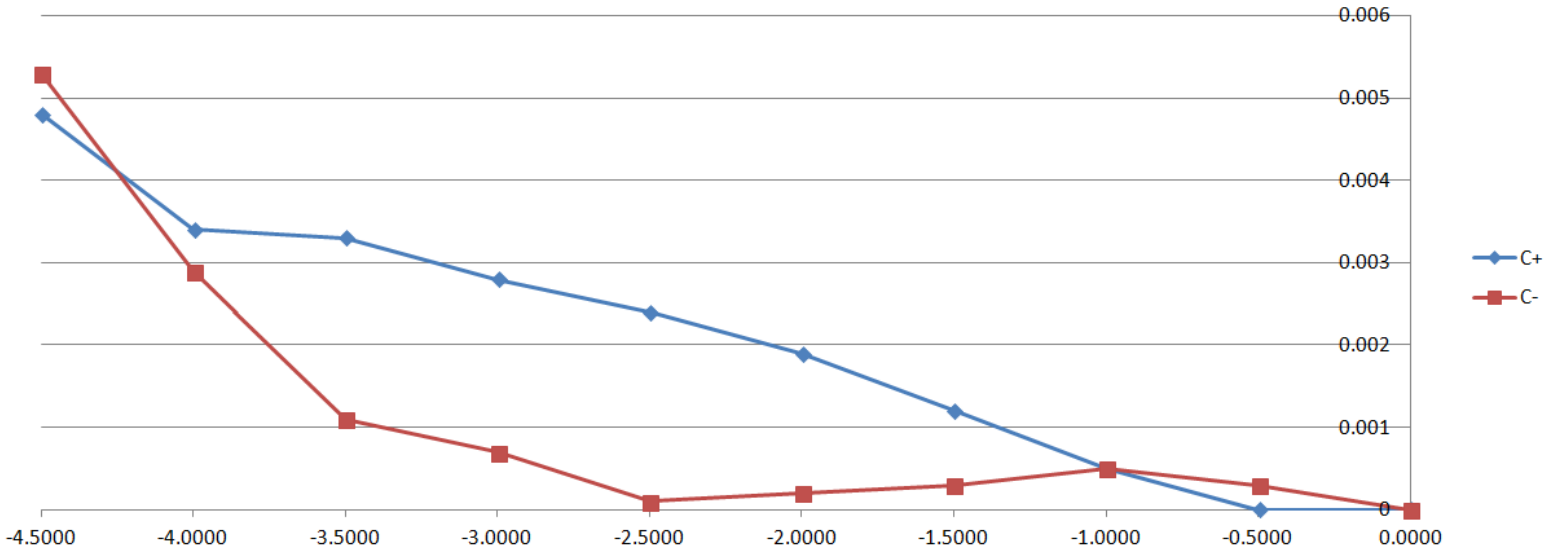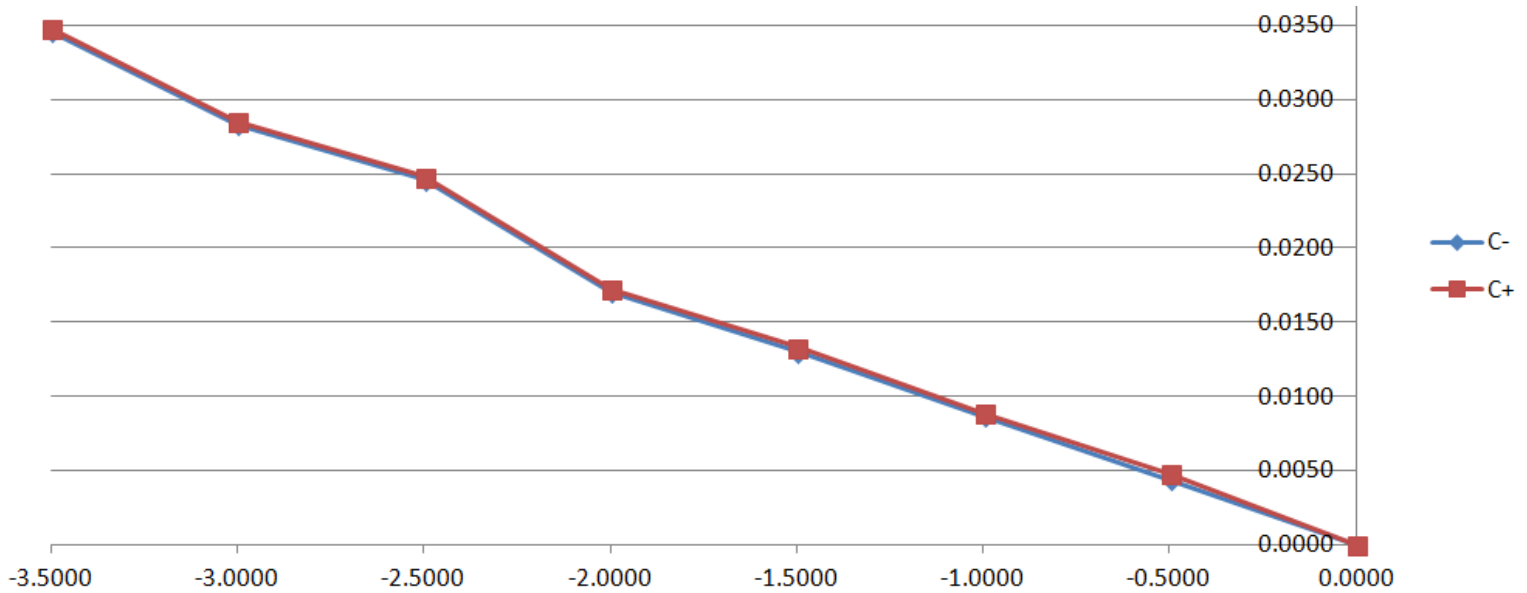
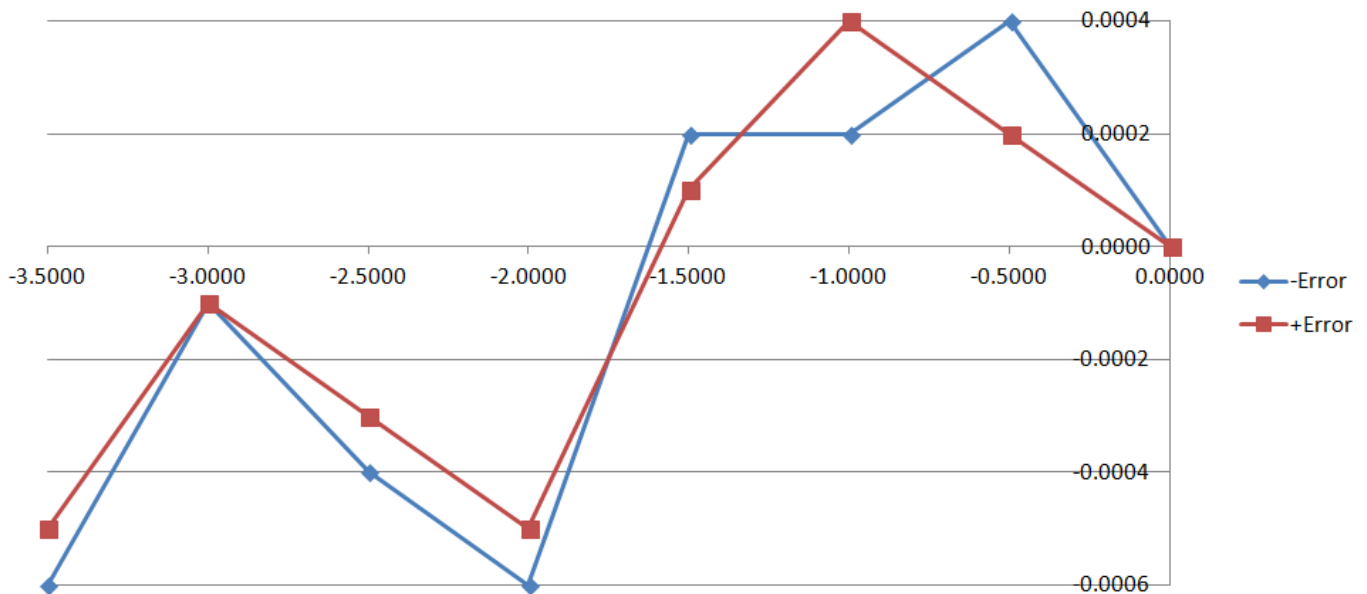

With Screw Mapping enabled this slope is removed.
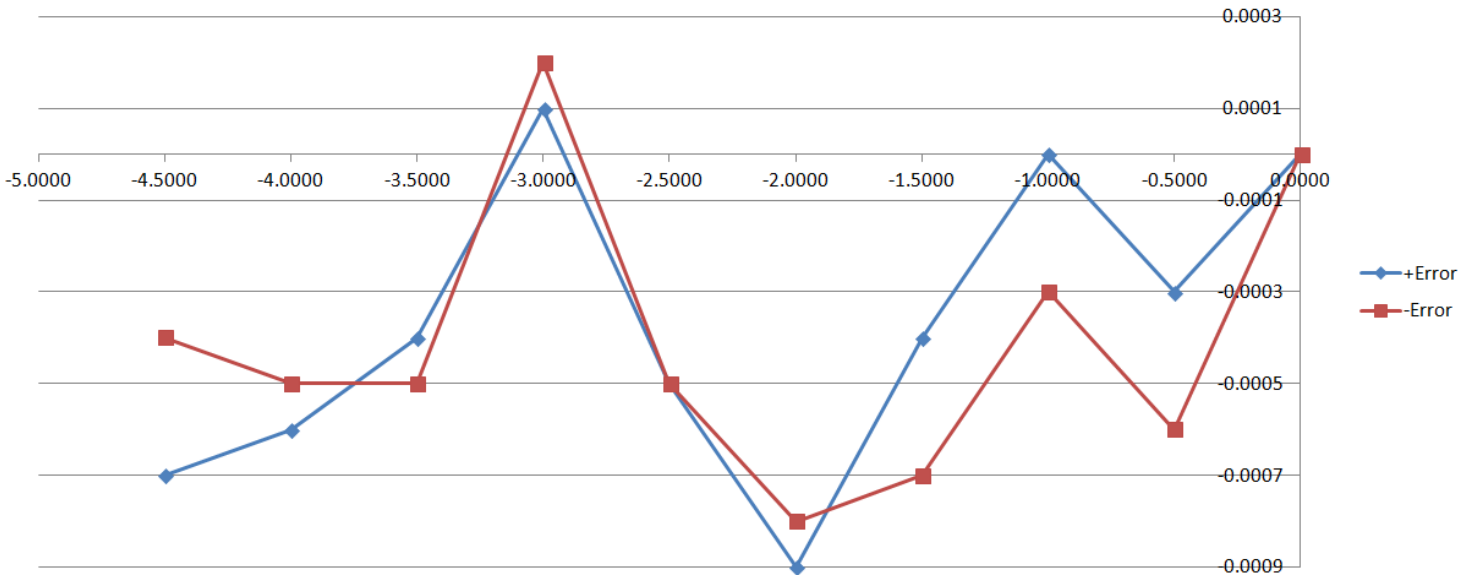
Worst case variation is +0.0002 to -0.0009 or -0.00055 ± 0.00035 inches. This just means other errors will dominate.

Measured Z Axis Results

Here is the Position error for the Z axis with Screw Mapping disabled. You can see a revolutions per inch error of about 0.5%.


With Screw Mapping enabled, things get a lot better.

There is a slope to this error but with a worst case error of -0.0001 ± 0.0005 inches, I know that other errors will dominate. Trying to improve this would be like chasing ghosts.
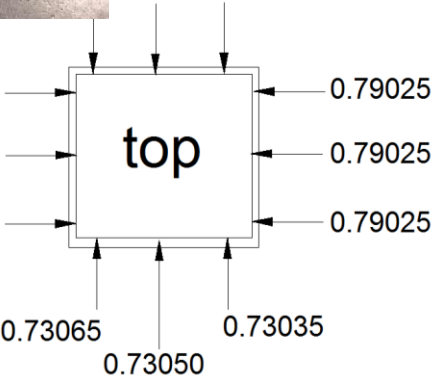
My First Test Cube

Doesn't look like much but this is my first test of the X and Y screw mapping. The G code says it should measure 0.790 inches along the X axis and 0.730 inches along the Y axis.
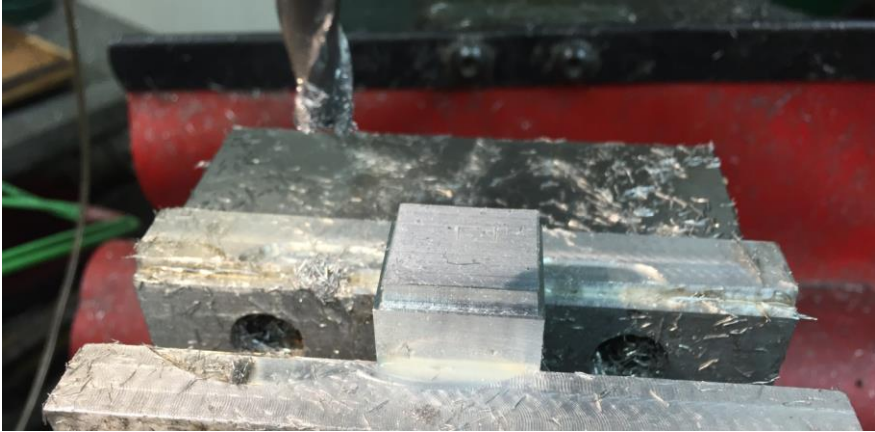
All measurements were taken with a Mitutoyo IP65 caliper.

In the X dimension, I measured 0.79025 inches in all three places. If repeatable over many test cuts, this would certainly be great news. It shows a consistent and small error of +0.00025 inches.

top
0.79025
0.79025
0.79025
0.73065   0.73035
0.73050

In the Y dimension there is a taper which starts at 0.73065 on the left and goes to 0.73035 on the right. This is a slope of approximately

$$\frac{0.73065 - 0.73035}{0.79025 - 0.250} = 0.6 \; thou \; per \; inch$$

I subtracted 0.250 to account for the diameter of the mic's anvil. This slope, if repeatable, is a substantial error. More study will be needed to determine the

source. At this time I can't say if it is related to my screw mapping data or a problem with the mill.

Acknowledgments

Thanks to Keith McCulloch of Centroid for enabling this feature. Thanks to Alan Hollerbach for his video:
https://www.youtube.com/watch?v=yMRqL8b0Orw&feature=youtu.be&t=4m19s
It helped me see the differences in approach.

I welcome your comments and questions.

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

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