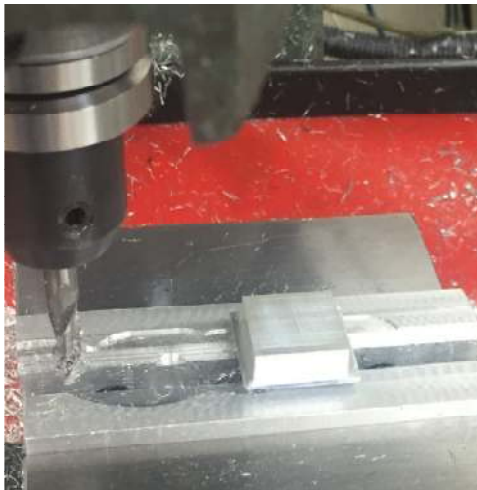


Performance Data After X and Y Backlash Reduction on a RF-30, version 2.0

By **R. G. Sparber**

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Conclusion



I CNC machined 41 dimensions of varying sizes. Thirty five of them were with the cutter diameter defined as 0.250 inches. This generated a constant offset in the data. I then changed the cutter diameter in the g-code to 0.248 inches and took 6 more data points.

The variation from expected was within ± 0.001 inches.

Background

My CNC system runs Mach3. In order to precisely run the mill, Mach3 needs to know how many steps to output in order to move exactly one inch along each axis.

First the number of steps per inch was precisely determined for the X and Y axes. I used the calibration method outlined in <http://rick.sparber.org/XSM.pdf> but did not use screw mapping. The resulting numbers were used in the Motor Tuning function.

Mach3 must also know the backlash on each axis so it can be canceled. However, any variation in this backlash is not canceled and directly reduces overall machine accuracy.

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Backlash on the X and Y axes was reduced to a minimum as was the variation in backlash.

For the X axis see <http://rick.sparber.org/XAA.pdf>.

For the Y axis see <http://rick.sparber.org/YAA.pdf>.

Doing static tests is necessary to see if backlash has been reduced and stabilized. But machining coupons takes into account dynamic forces and is much closer to how the machine will actually be used.

The Data

The end mill first cut a square with a depth of cut of 0.045 or 0.020 inches. Then it took a second pass at 0.005 inches followed by a final cut with no further advancement in order to take out any tool deflection.



I used a digital micrometer able to read down to the nearest 50 millionths of an inch.

X Axis Data

x	ideal	error	error - av
0.901750	0.900	0.00175	0.0004
0.801650	0.800	0.00165	0.0003
0.701300	0.700	0.0013	0.0000
0.600850	0.600	0.00085	-0.0005
0.501400	0.500	0.0014	0.0001
0.401050	0.400	0.00105	-0.0003
	Averages	0.0013	0.0000

The first column shows the measurements taken with my mic. The next column shows the values specified in the g-code. My error column is generated by subtracting the ideal from the measured value.

At the bottom of the error column is the average error. If only random variations

of the machine were involved here, the average would be zero. A non-zero average means there is a bias.

A simple way to remove this bias is to tell the program that generates the g-code that the end mill is smaller in diameter by this average error. That causes the software to move the cutter further into the stock by the prescribed amount.

It is equally valid for the sake of this analysis, to subtract the average error from each error value. The result is shown in the last column. As a check, the average was calculated and you can see 0.0000 in the lower right corner. This means the bias has been removed from the last column's numbers.

The worst case *variation* in measured values, rounded to the nearest thou, is ± 0.001 inches. This is true regardless of any constant added to any column of numbers.

Notice in the second column that I advanced in steps of 0.100 inches. These are valid data points but run the risk of missing cyclic variation caused by leadscrew rotation.

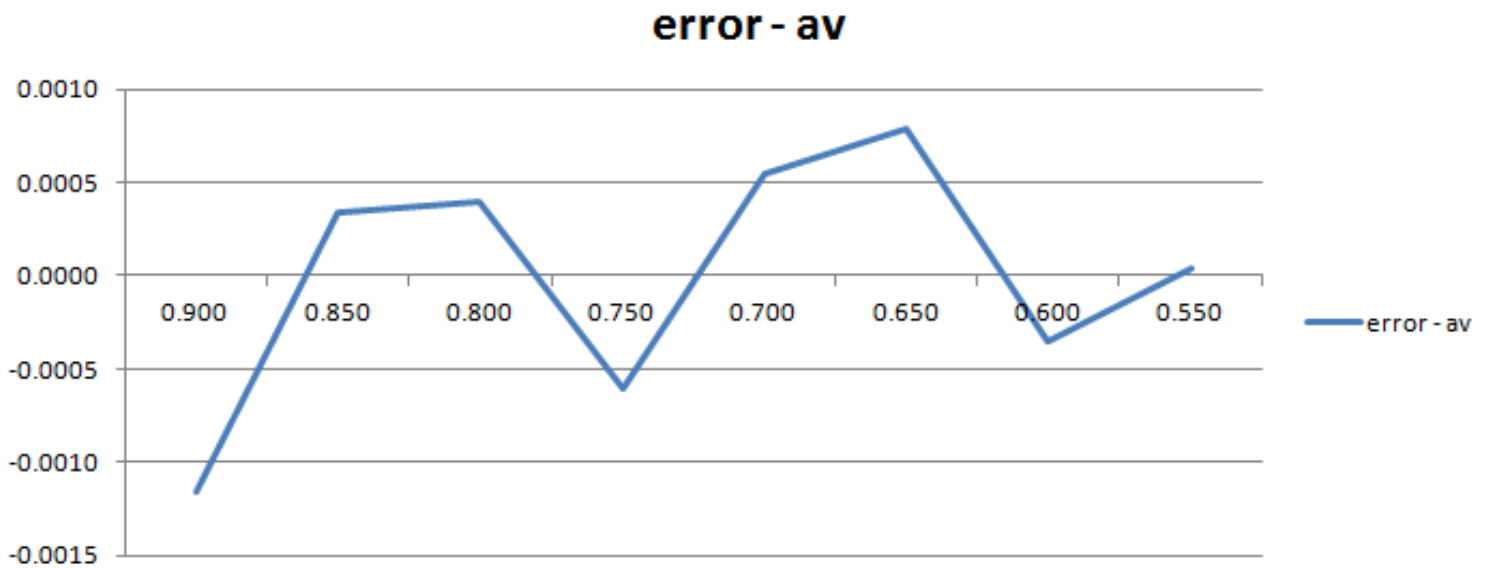
<u>x</u>	<u>ideal</u>	<u>error</u>	<u>error - av</u>
0.900300	0.900	0.0003	-0.0012
0.851800	0.850	0.0018	0.0003
0.801850	0.800	0.00185	0.0004
0.750850	0.750	0.00085	-0.0006
0.702000	0.700	0.002	0.0005
0.652250	0.650	0.00225	0.0008
0.601100	0.600	0.0011	-0.0004
0.551500	0.550	0.0015	0.0000
	Averages	0.0015	0.0000

I ran a second series of tests in steps of 0.050 inches.

My leadscrew pitch is 0.100 inches. If I advance the cutter in steps of 0.025 inches, I will get a reading every 90° of leadscrew rotation. This should improve my chances of seeing radial leadscrew error.

I cut in 0.025 inches on one side and 0.025 on the opposite side for a total of 0.050 inch steps.

I graphed the second series of coupons and the cyclic nature became evident.



If the error was due to the leadscrew, the cycle would repeat every 0.100 inches but it does not. I see minima at 0.900, 0.750, and 0.600. That is a period of 0.150 inches.

Feeding my leadscrew is a pair of gears with a 2.5:1 reduction. When the stepper motor turns one revolutions, the mill's table advances 0.040 inches. That doesn't fit the data either.

At least for now, the source of this periodic error is unknown.

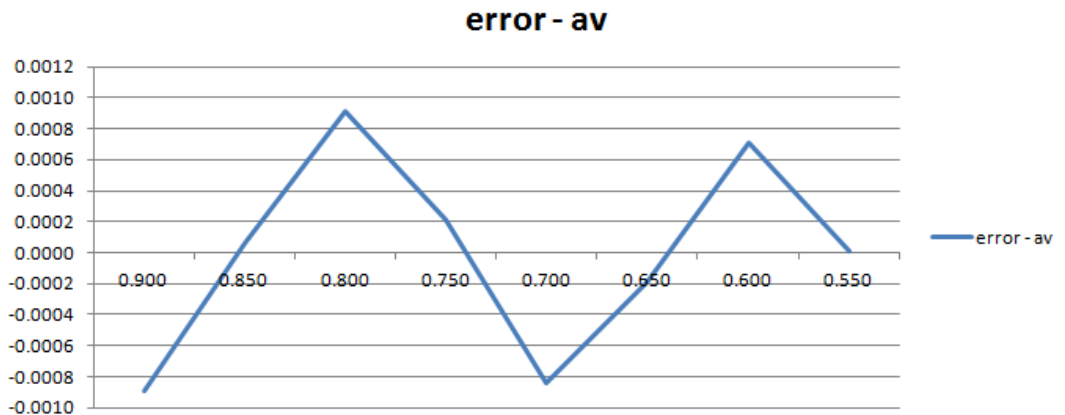
Y Axis Data

y	ideal	error	error - av
0.901400	0.900	0.0014	-0.0004
0.802450	0.800	0.00245	0.0006
0.701200	0.700	0.0012	-0.0006
0.602350	0.600	0.00235	0.0005
0.501550	0.500	0.00155	-0.0003
0.402100	0.400	0.0021	0.0003
	Average	0.0018	0.0000

This set of data is of Y axis readings. The worst case *variation* in measured values is ± 0.001 inches. This must also be the worst case variation of my last column.

Let's again look closer at the family of coupons cut in increments of 0.050 inches.

y	ideal	error	error - av
0.901100	0.900	0.0011	-0.0009
0.852050	0.850	0.00205	0.0001
0.802900	0.800	0.0029	0.0009
0.752200	0.750	0.0022	0.0002
0.701150	0.700	0.00115	-0.0008
0.651800	0.650	0.0018	-0.0002
0.602700	0.600	0.0027	0.0007
0.552000	0.550	0.002	0.0000
	Average	0.0020	0.0000



Worst case error is ± 0.001 inches.

There is a positive peak at 0.800 and 0.600 with a negative peak at 0.700. If this error was due to the leadscrew, I would expect to see the error cyclic with a period of 0.100 inches. The observed period is 0.200 inches. Doesn't look like the leadscrew is the source of this error. Nor can it be the stepper with its period of 0.040 inches.

At least for now, this data generates more questions than it answers.

A limitation of using the end mill diameter to correct for average error is that I only have one value. It will be used to correct both X and Y axis movement. But so far I have used the average X error to correct my X axis data and my average Y error to correct my Y data.

What if I used my average Y error to correct my X data? I will accept a shift in the error and the average value in that last column will not be zero. It will be shifted by 0.0005 inches. That is enough to push me out of the ± 0.001 inch band. The question is, how often will this occur?

I took the X axis data but use the Y axis average error of 0.002 inches:

<u>x</u>	<u>ideal</u>	<u>error</u>	<u>error - 0.002</u>
0.900300	0.900	0.0003	-0.0017
0.851800	0.850	0.0018	-0.0002
0.801850	0.800	0.00185	-0.0001
0.750850	0.750	0.00085	-0.0011
0.702000	0.700	0.002	0.0000
0.652250	0.650	0.00225	0.0003
0.601100	0.600	0.0011	-0.0009
0.551500	0.550	0.0015	-0.0005
	Averages	0.0015	-0.0005

When rounded to the nearest 0.001 inches, I got a variation of ± 0.001 inches in all but one data point. It is standard practice in metrology to drop the highest and lowest value so I will ignore that one case where the error was -0.0017 inches.

So if I had told the g-code generating software that my end mill was 0.248 inches in diameter rather than 0.250 inches, I expect to see close to zero average error and a variation of ± 0.001 inches. Time to try it!

<u>X</u>	<u>ideal</u>	<u>error</u>
0.900050	0.900	0.0000
0.849950	0.850	0.0000
0.799600	0.800	-0.0004

<u>y</u>	<u>ideal</u>	<u>error</u>
0.899700	0.900	-0.0003
0.850350	0.850	0.0004
0.800750	0.800	0.0007

This last set of data is with the end mill diameter actually reduced by 0.002 inches in my g-code generating software. This time I was cutting metal, not doing math.

It was no surprise that the error was within ± 0.001 inches based on the previous 35 readings. However, I knew it was "Murphy²" playing with me that the first few readings were extremely close to ideal. I know it is just random variation but experience has taught me that Murphy likes to mess with my head. I just took data until I finally saw the expected variation.

Acknowledgments

Thanks to Richard (edelec) for helping me clarify this article.

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.

Rick Sparber
Rgsparber.ha@gmail.com
 Rick.Sparber.org



² This is a corollary of Murphy's Law what when everything should be within known bounds, the first measurements come out near perfect.