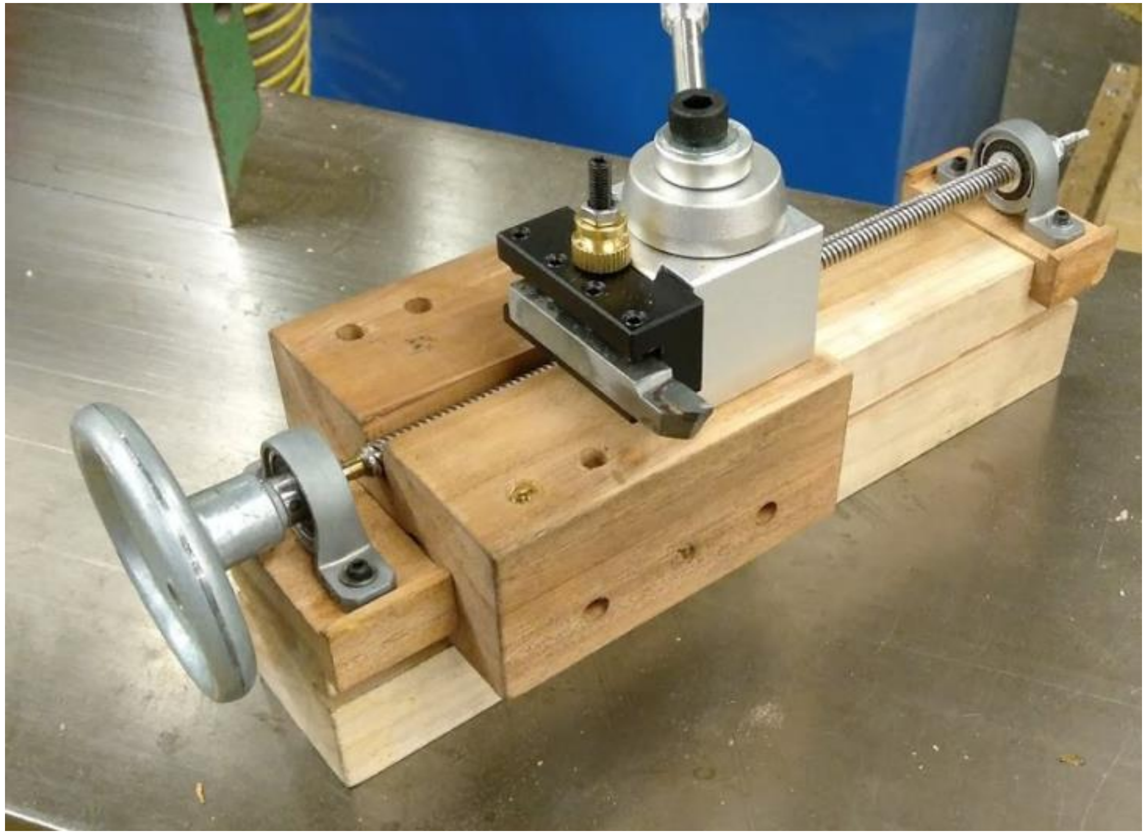
Week 11 and 12

Overview of the Work Completed

Following work was done for previous 2 weeks:

a. Manufacturing of the Rotary Motion Module
b. Testing of the Rotary Motion Module
c. Manufacturing of the Spindle Mount, Base
d. Prediction of Tool Point Error using Error Budget Spreadsheet
e. Assembly and Test of Lathe

Manufacturing of the Rotary Motion Module



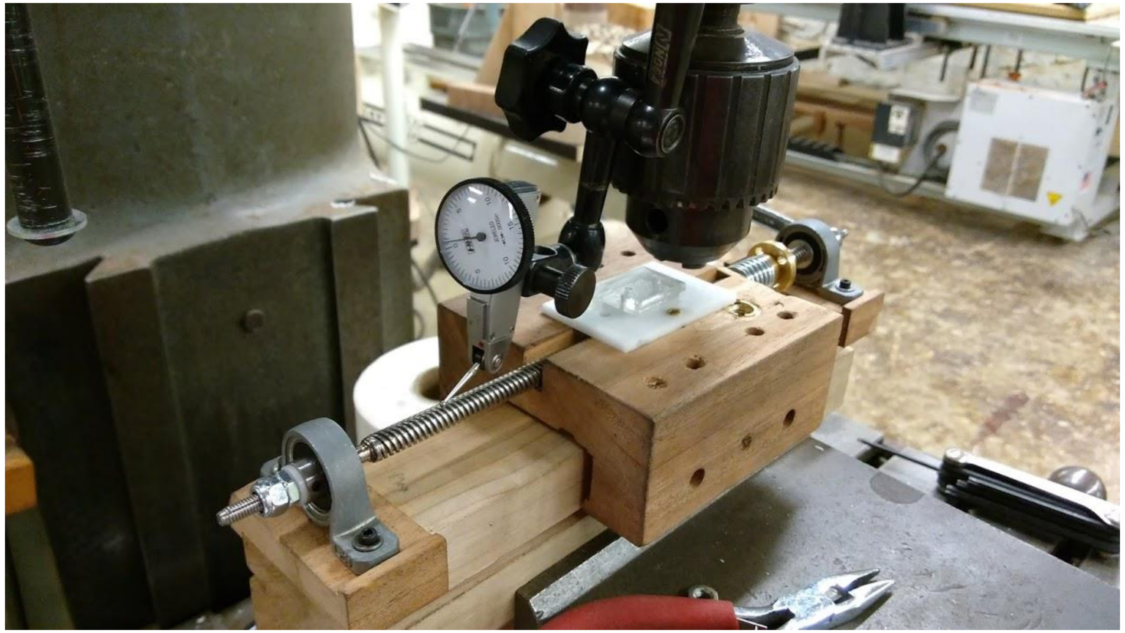
Manufacturing of the rotary motion module was completed

Testing of the Rotary Motion Module

The following tests were conducted on the Rotary Motion Module:

a. Leadscrew Misalignment
b. Required Torque to Move the Carriage
c. Stiffness Tests – Axial, Yaw, Linear Stiffness (Vertical, Lateral)
d. Accuracy Test – Yaw

Leadscrew Misalignment Measurement

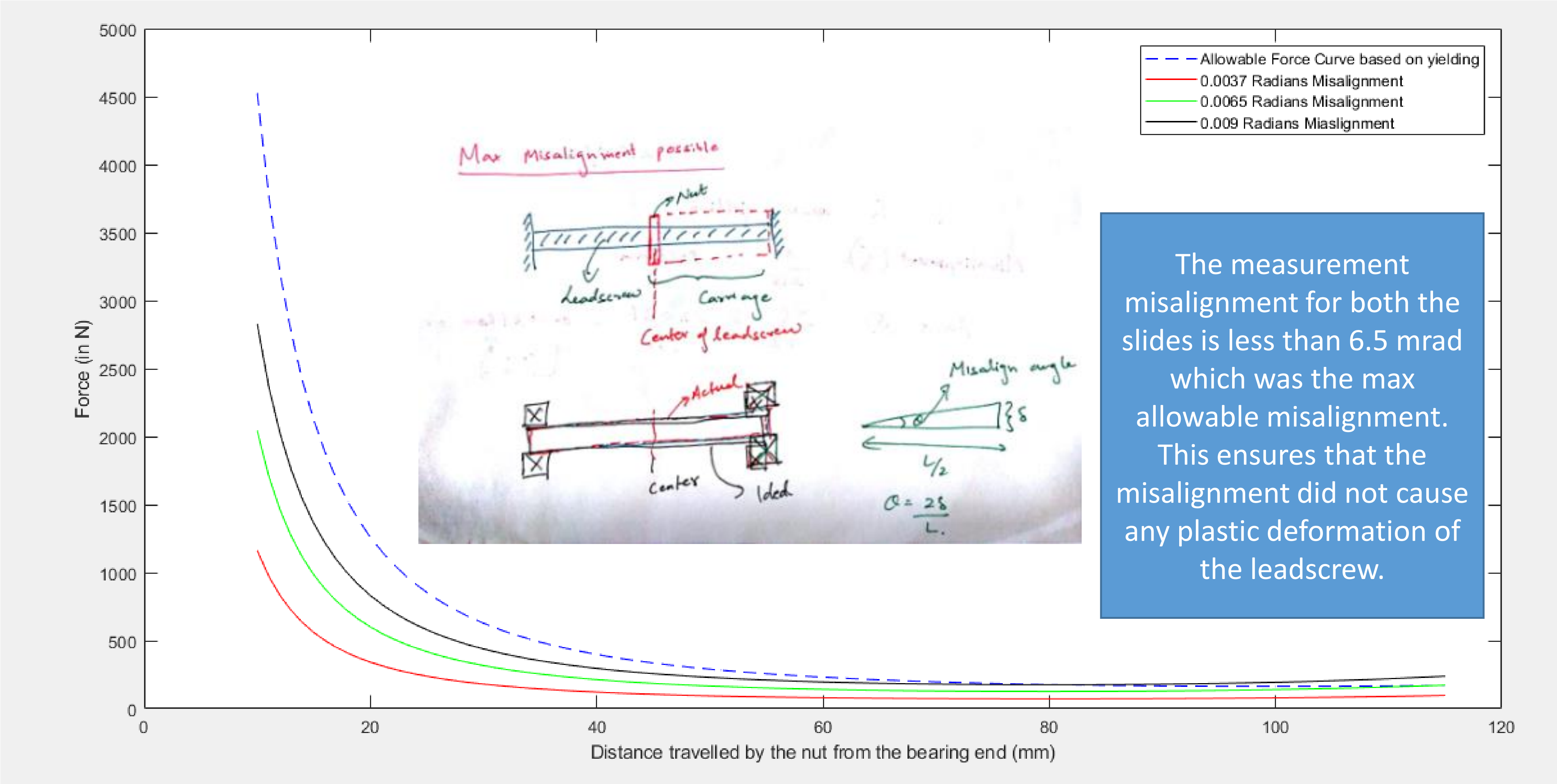


Measurement Results

1^{st} Slide (Tool)	**2^{nd} Slide (Spindle)**
0.0127 mm over 18 mm	0.0127 mm over 3.6 mm
Misalignment angle = **0.7 mrad**	Misalignment angle = **3.5 mrad**

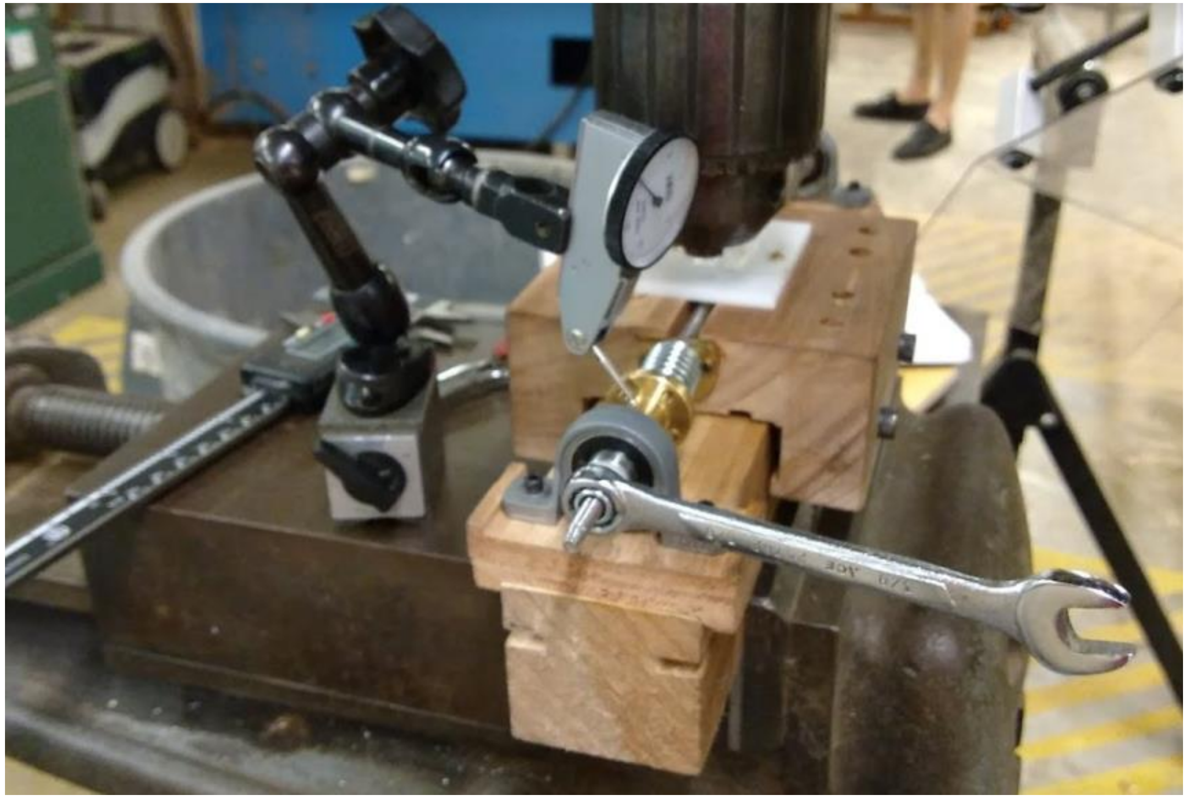
Procedure: The LM module was mounted on the mill ensuring that the rail was resting flat on the parallels. The leadscrew was rotated by 1 revolution for each such rotation, the resulting movement in the dial indicator was monitored. Care was taken to ensure that the measurement was being taken on the flat part of the thread of the leadscrew.

Comparing Measured results to Misalignment Budget



The measurement misalignment for both the slides is less than 6.5 mrad which was the max allowable misalignment. This ensures that the misalignment did not cause any plastic deformation of the leadscrew.

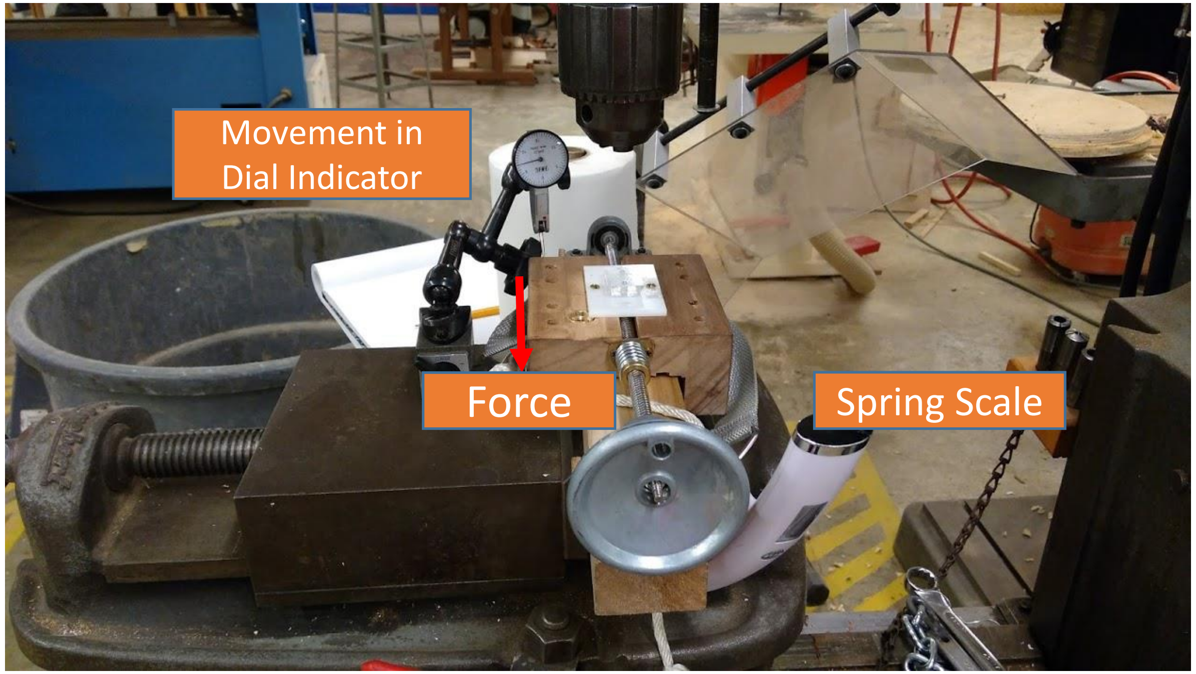
Attempt to measure the runout of the Leadscrew



Procedure: An attempt was made to measure the runout of the leadscrew by inserting a nut on the leadscrew. However, during measurement, it was found that the surface of the nut was uneven and the measurement that I was making involved significant component of the error from the nut itself.

I thought of subtracting the curvature of the nut from my measured values to get the runout of the leadscrew. However, the method did not give me significant results.

Axial Stiffness Testing



In the direction of Preload

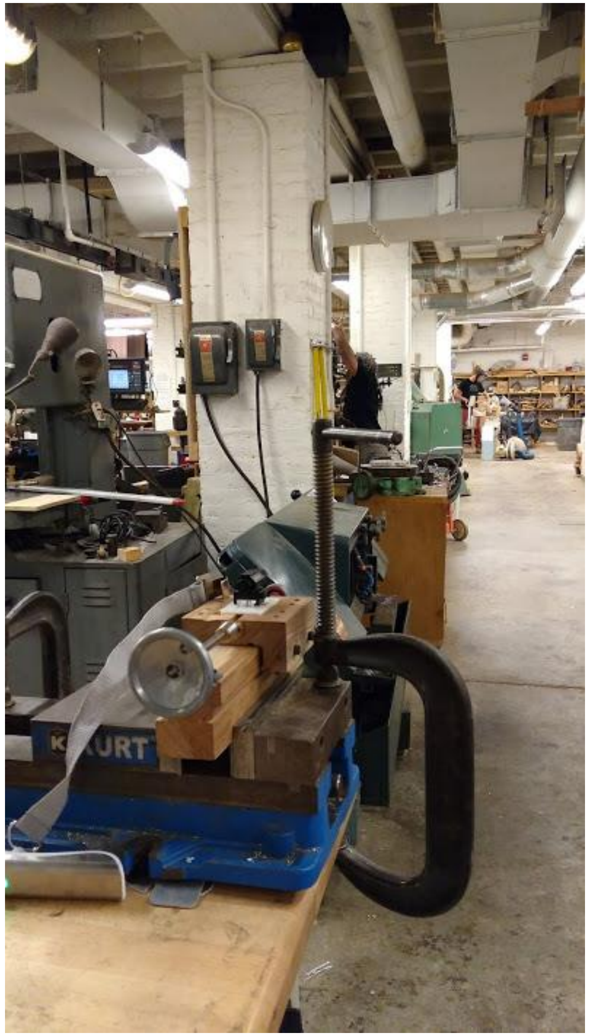
Force	Deflection	Stiffness
85 N	0.0005 in	6630 N/mm

Opposite to the direction of Preload

Force	Deflection	Stiffness
57 N	0.0005 in	4446 N/mm
82 N	0.001 in	3198 N/mm
108 N	0.0015 in	2808 N/mm

The axial stiffness values are far away from those predicted in the design spreadsheet. I later realized that the axial stiffness here is not the true stiffness. A significant amount of force that I applied will be utilized in countering the friction between the slide and the rail. The force is in the order of magnitude of 50 N. Therefore, the actual axial stiffness would be in the range of 1000 N/mm which is closer to the predicted value

Stiffness Tests – Yaw



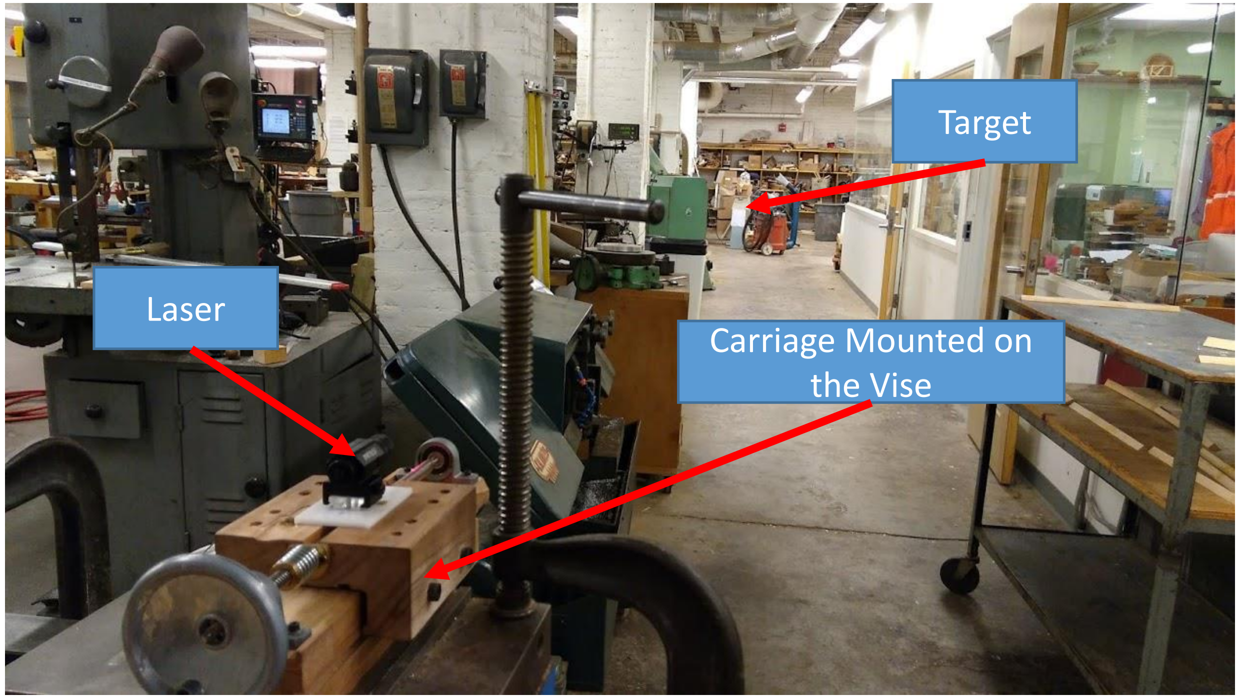
Load	Moment Arm	Moment	Deflection on paper	Distance from target	Angular Deflection	Yaw Stiffness
50 N	35 mm	1750 Nmm	7 mm	14.5 m	0.55 mrad	3645 Nm/rad

This was an additional test which was performed just to verify if the stiffness did not change drastically after the addition of the rotary motion module.

The value of Yaw stiffness was close to what had been measured earlier.

Testing Pitch Accuracy

Distance of the target from laser pointer = 14.5 m



Sr. No	Distance from Edge	Movement of the Laser	Angular Deviation
1	10	12 mm	0.82 mrad
2	20	12 mm	0.82 mrad
3	30	8 mm	0.55 mrad
4	55	10 mm	0.69 mrad

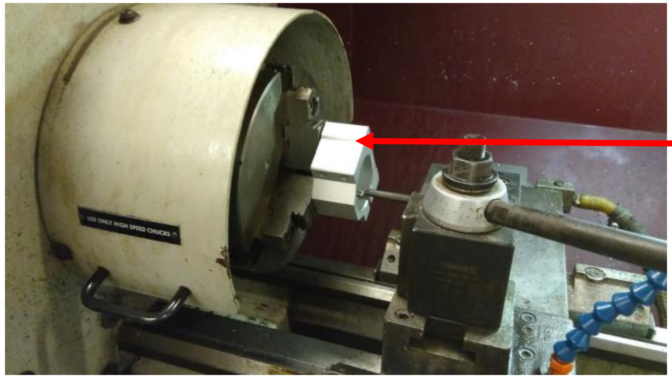
Average: 0.72 mrad

Pitch

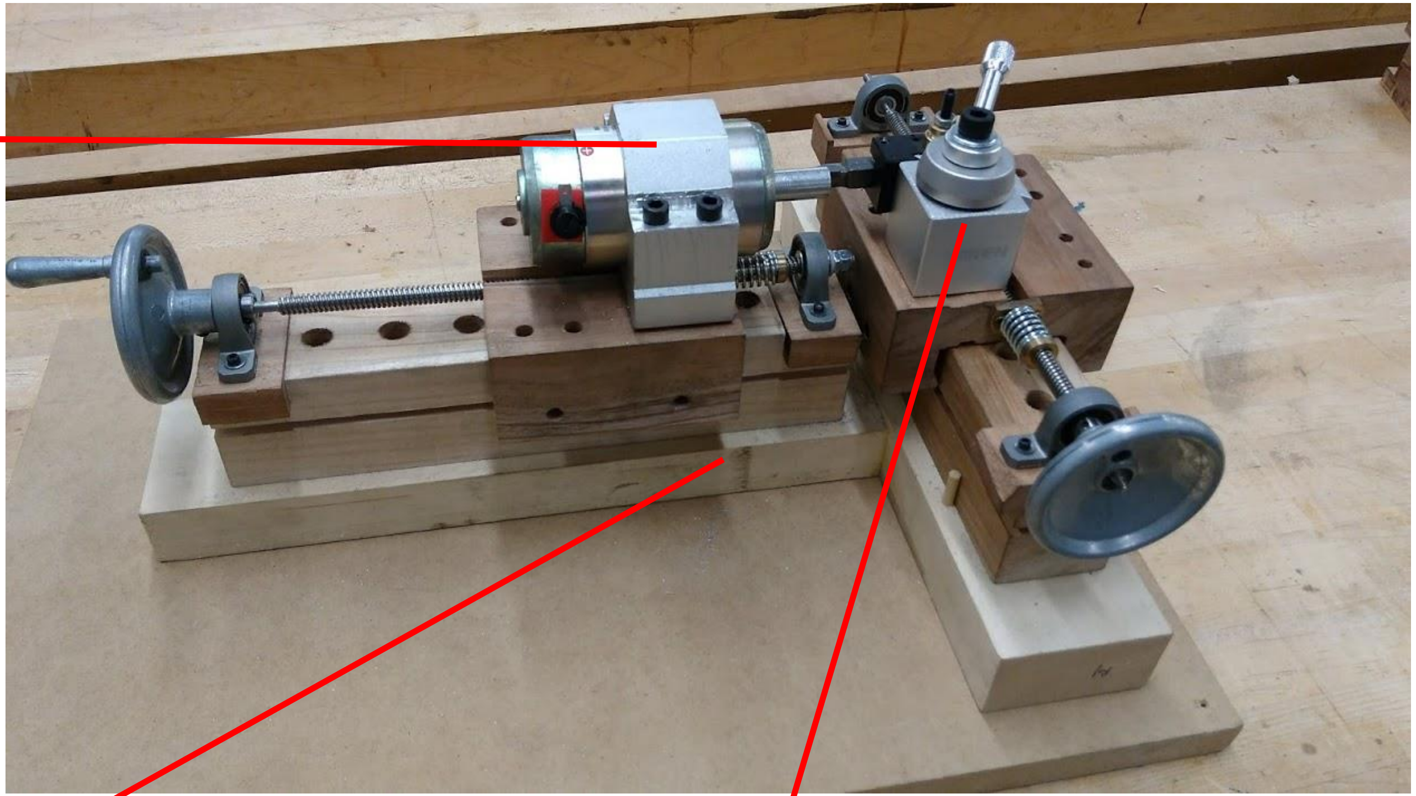
Previously Predicted: Pitch = 1.88 mrad, Yaw = 0.94 mrad
Previously Tested: Pitch = 1 mrad, Yaw = 0.44 mrad

The measured pitch accuracy seems to be better than before. However, this could also be due to the reduced travel of the carriage with the addition of the anti-backlash nut assembly. The pitch errors could be more near the ends of the travel range.

Manufacturing Details



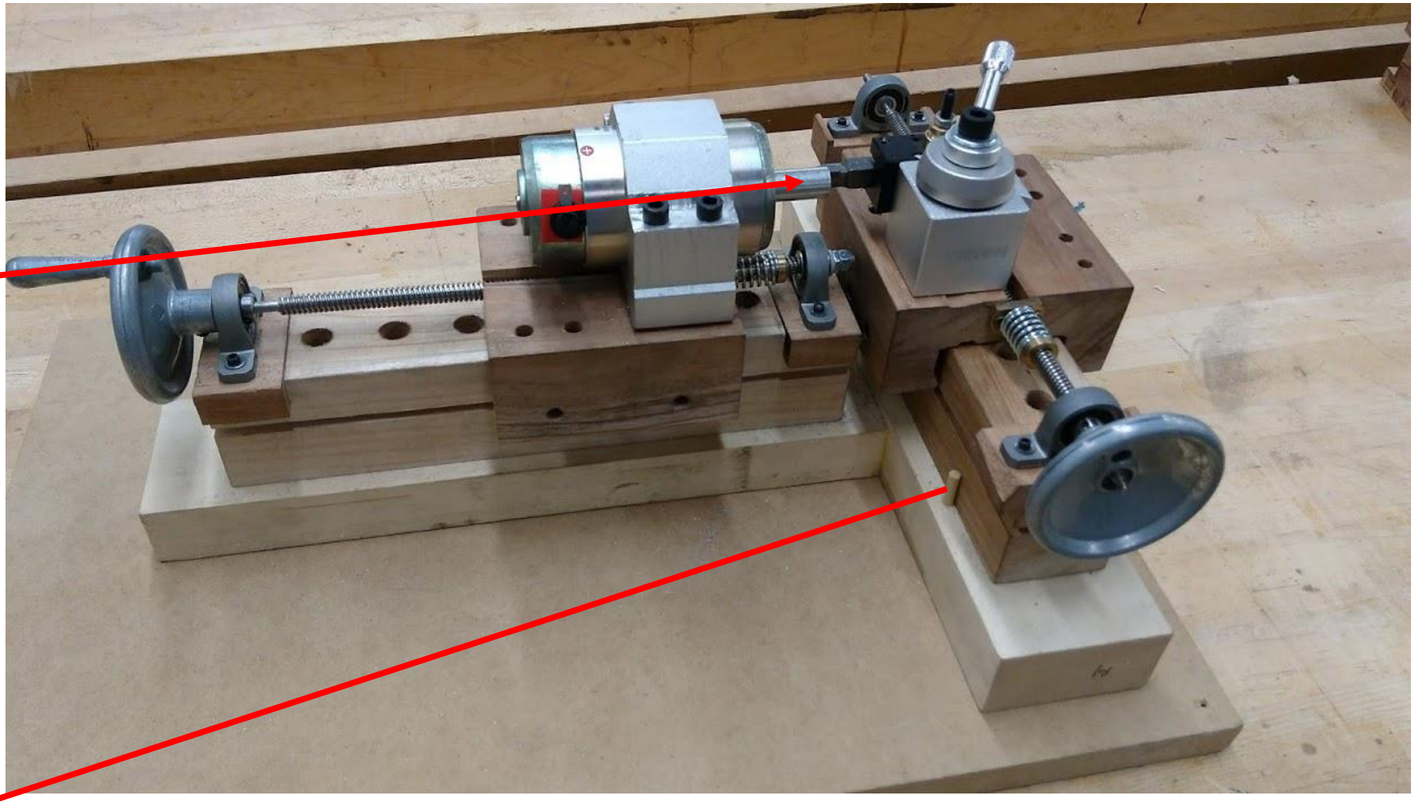
Spindle Mount: I found a cheap Aluminium Spindle Mount online. The bore was not of the right dimensions, so I decided to clamp the piece on the lathe and use the boring tool to enlarge the hole.



Base: The base is made in 2 parts as it was too big to machine in a mill. After cutting the pieces, the mating surfaces were milled flat to ensure perpendicularity.

The tool holder was bought off the shelf and then attached to the carriage using a threaded brass insert.

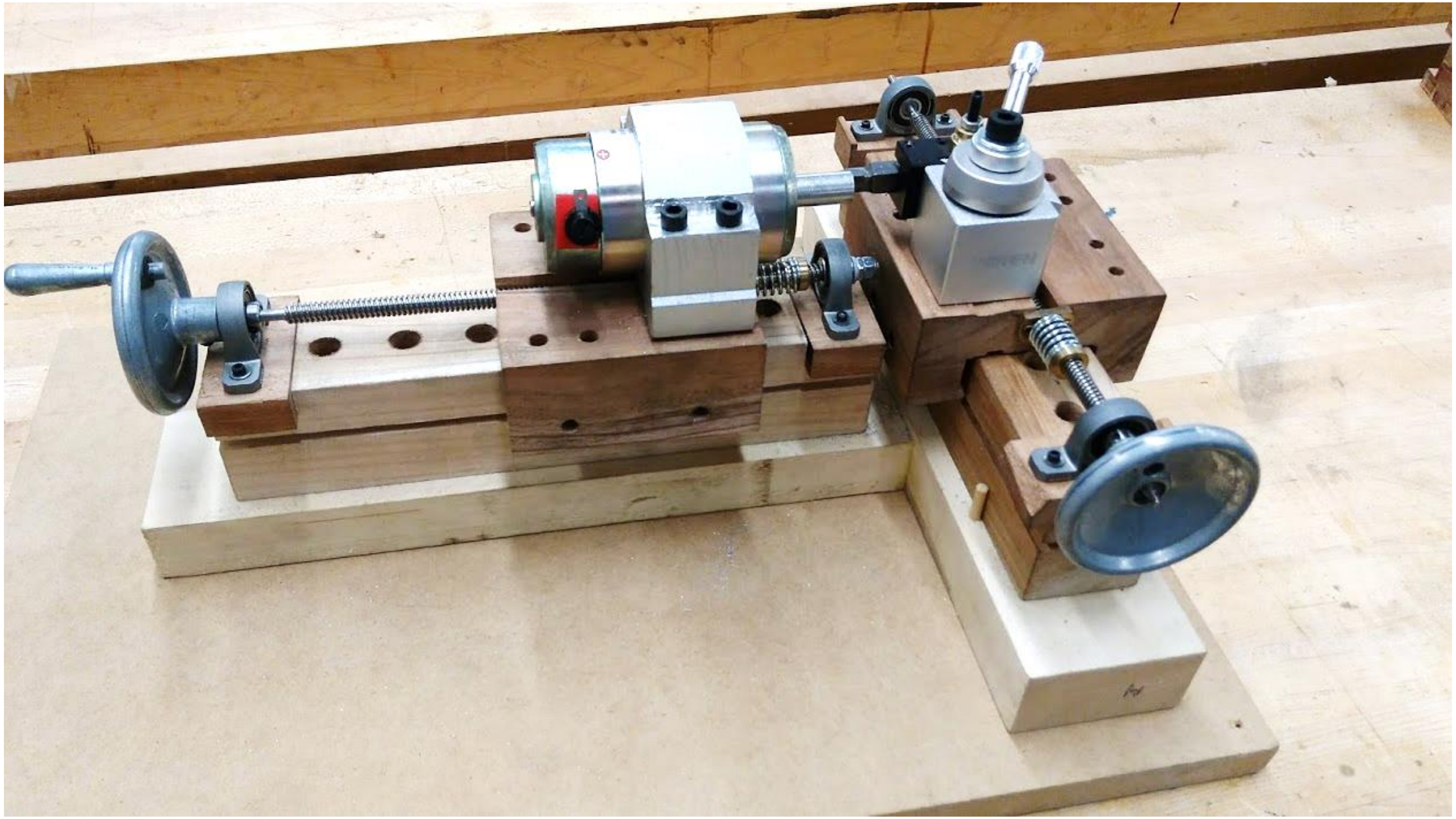
Manufacturing Details



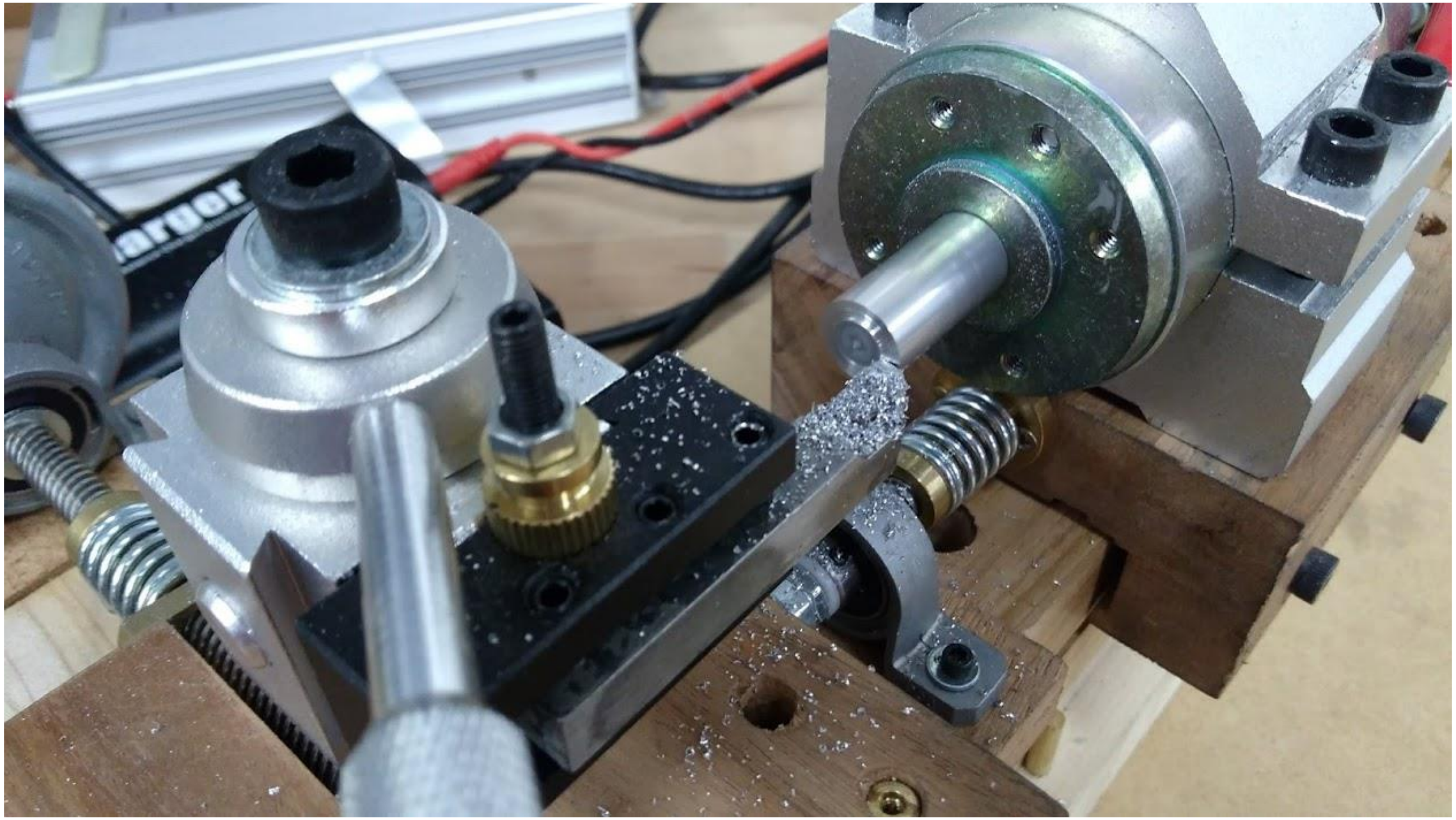
Attachment of the Workpiece to the Motor Spindle: The workpiece was an Aluminium Spacer which was attached to the spindle of the motor using hot glue. Hot glue used to solidify very quickly, so a hot air blower was used to keep it in semi-solid state while assembly

Dowel Pins: The dowel pins helped in placing and adjusting the yaw tilt of the individual slides to ensure that the workpiece and the tool are perpendicular to each other

Final Assembled Lathe



Cutting the Part on the Lathe



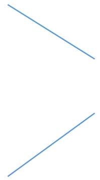
1 div = 0.0005 in = 12.7 microns

Closing the Loop on Tool Point Errors

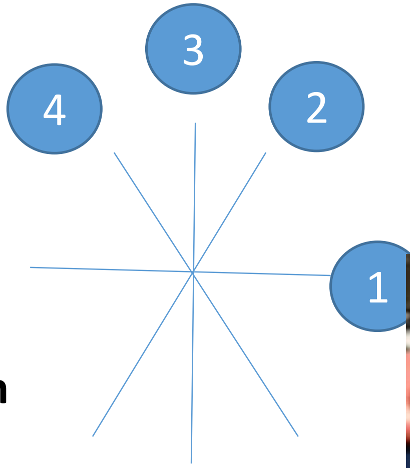
Sr. No	Distance	1	2	3	4
1	0.4 mm	-2	0	1	1
2	0.8 mm	-1	1	0	0
3	1.2 mm	-1	2	0	0
4	1.6 mm	0	2	2	0
5	9.2 mm	-3	1	0	-4
6	9.6 mm	-3	1	-4	-4
7	10 mm	-3	0	-4	-5
8	10.4 mm	-4	0	-4	-6
9	10.8 mm	-4	-1	-4	-9

Average Deviation = 6 divisions = 76.2 um

Profile of the cut workpiece is similar to this:



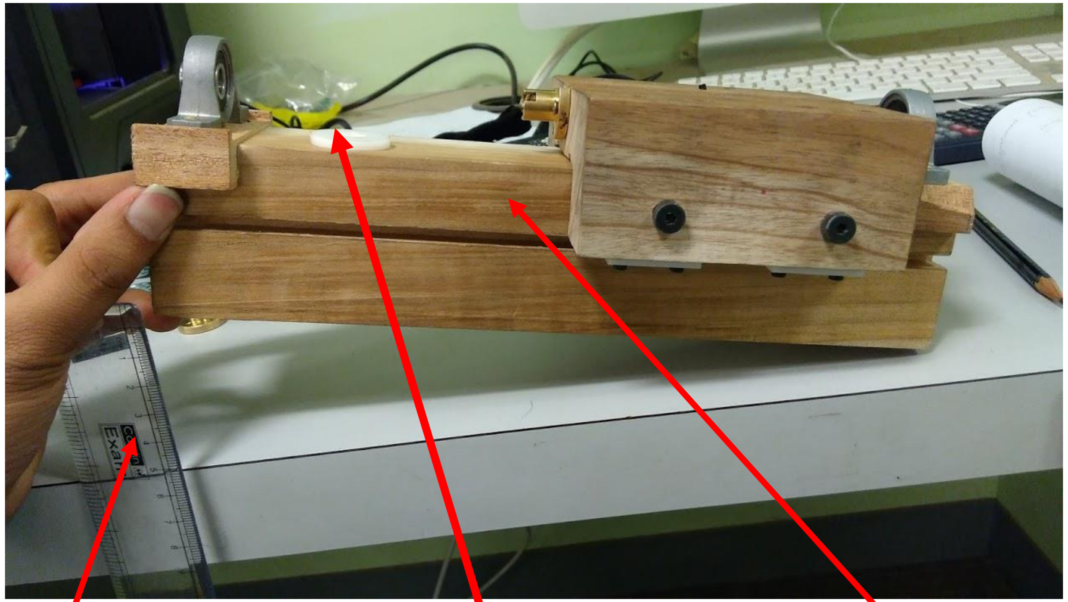
Lesser value of the critical dimension at the edges and higher near the center



Predicted Error in the sensitive direction as per error budget sheet = **108 microns**
Error measured on the part = 6 divisions = **76.2 microns**

Appendix

Measuring the friction coefficient b/w waxed wood and Delrin



Delrin Piece

Top Surface is waxed

Scale to Measure the height

The friction coefficient between waxed wood and delrin was not easily available online. So, this quick test was done to estimate the friction coefficient.

Measured friction coefficient was 0.39