Week 5

Akshay Harlalka

Linear Motion Module

Application for T- Base Lathe - To make a T- base lathe for machining custom made polycarbonate optical lenses

FRDPPARC Table for Linear Motion Module

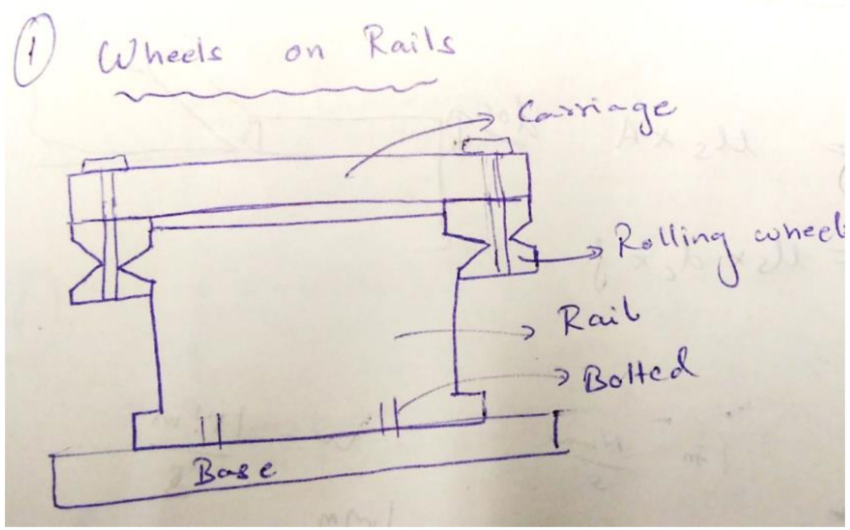
Sr. No	Functional Requirements	Design Parameters	Analysis	References	Risks	Countermeasures
1	High Stiffness in sensitive directions – (around 7 N/um) ability to bear cutting forces for polycarbonate (~70 N) while not deflecting more than 10 um.	Linear motion configuration Amount of preload Stiffness of the bearing pads Stiffness of set screws used to preload the bearing pad	Calculate the required size and stiffness for the bearing pads Deflection of the system under the effect of cutting forces Amount of preload required	Precision Machine Design – Chapter 8 – Sliding Contact Bearings	Too high preload can increase the friction between the rails and carriage	Add lubrication pathways in the bearing pads or use porous materials with inherent lubricity
2	Sufficient Range of Motion (60 mm)	Length of the rails Carriage length Amount of material stock available	Simple geometry – Size analysis	None	-	-
3	Carriage does not bind at any point	Keeper plates or elastic elements to allow for manufacturing errors Rail alignment L/D ratio Disk Spring washers	Stiffness of the keeper plates Jamming Analysis Force required to overcome manufacturing errors	Linear Bearing Spacing Spreadsheet Fundamentals Topic 10 – Linear Motion Slides	FR could cause the L/D ratio to increase – LM module size might increase	Budget for higher material stock requirement

FRDPPARC Table for Linear Motion Module

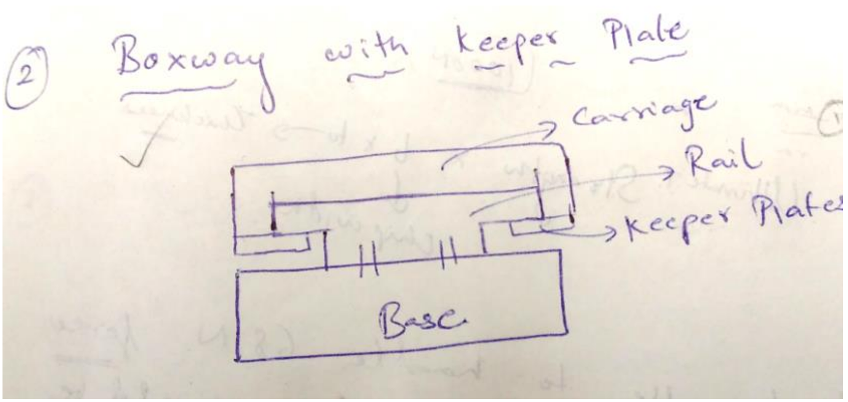
Sr. No	Functional Requirements	Design Parameters	Analysis	References	Risks	Countermeasures
4	Accuracy	Typical accuracy requirement for optical lenses Bearing pad wear Rail straightness Angular deviation of the carriage system stiffness's in angular and linear direction Structural loop	Calculation of roll, yaw and pitch stiffness Linear stiffness Prediction of manufacturing/assembly errors Can elastic averaging help?	Fundamentals Topic 10 – Linear Motion Slides	Inability to get the required accuracy with available materials and budget	Evaluate the feasibility of the application early in the design process
5	Easy to Manufacture	Material required Manufacturing equipment needed Time constraints Budget constraints	Check the available stock – resource assessment Check if the appropriate tools are available for the concept	Precision Machine Design – Chapter 8 – Sliding Contact Bearings	Design which I thought was easily manufacturable was not so in reality – example: Double V groove configuration which seems simple but needs management of 7 different manufacturing errors	Speak to Paul, Coby and Hayami for their suggestions on the choice of my design concept.

Concept Sketches

Both these concepts were selected for further analysis/sketch model prep

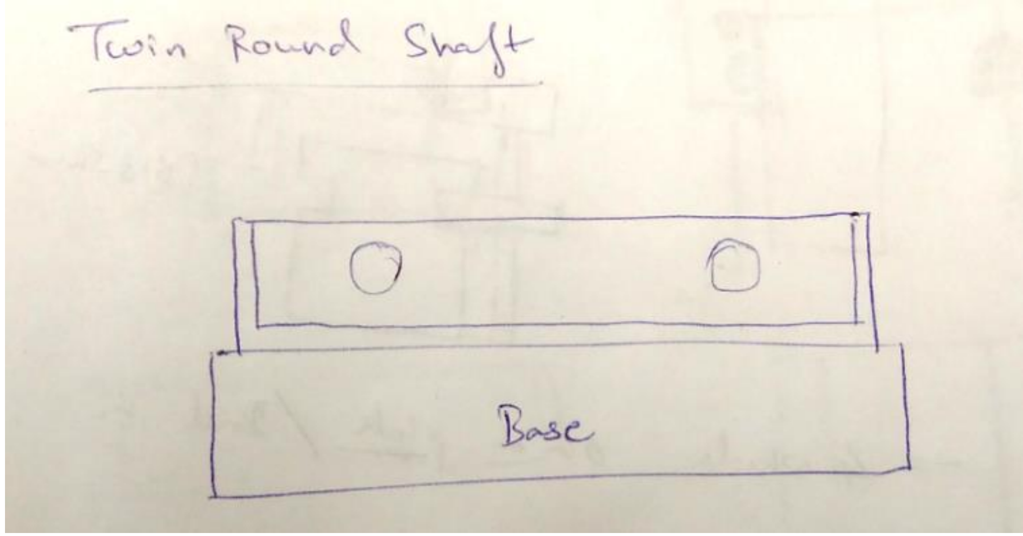


Pros	Cons
Good Stiffness [1]	Prone to edge loading if not assembled properly
Low Friction	

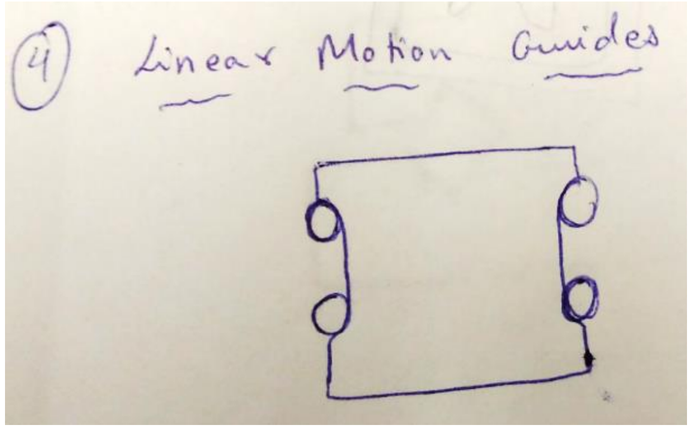


Pros	Cons
Easy to manufacture	High Friction/Need anti-friction element
Can be made of high stiffness	High Wear

Concept Sketches



Pros	Cons
Easy to manufacture using commonly available materials	Sensitive to shaft misalignment -Hard to align the shafts exactly

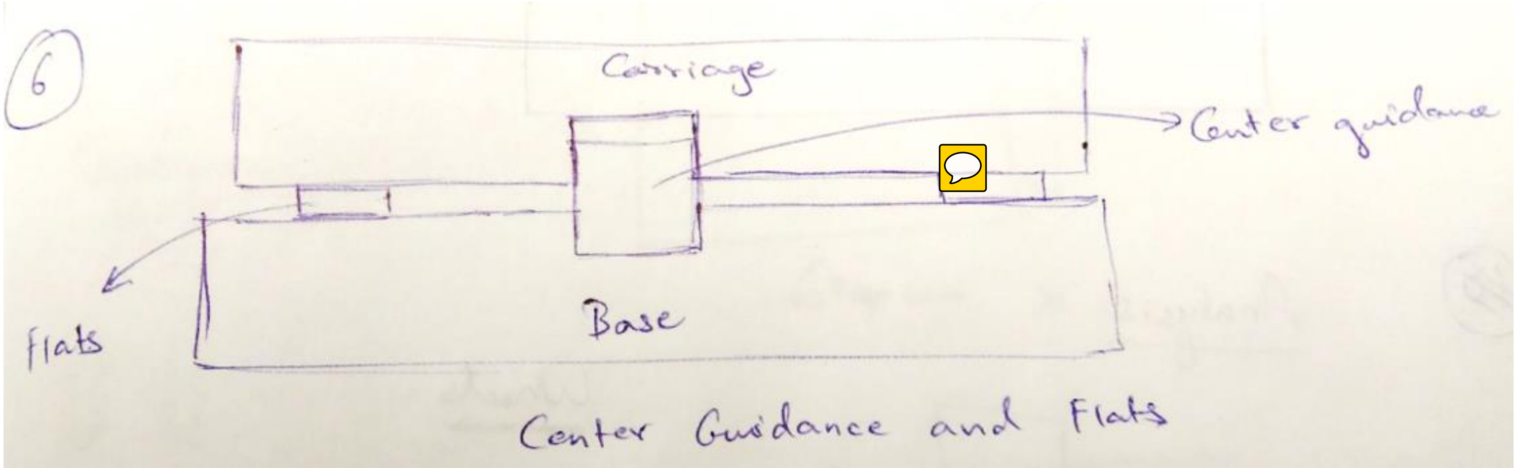


Pros	Cons
High Stiffness in roll, pitch and yaw	Hard to make the interface/ Difficult to recirculate the balls

Concept Sketches

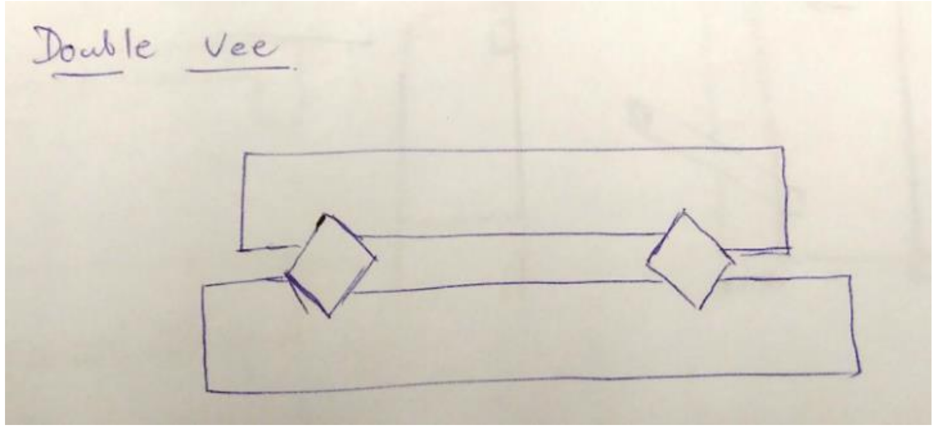
Dove Tail

Pros	Cons
High Stiffness	Difficult to manufacture the angled surfaces



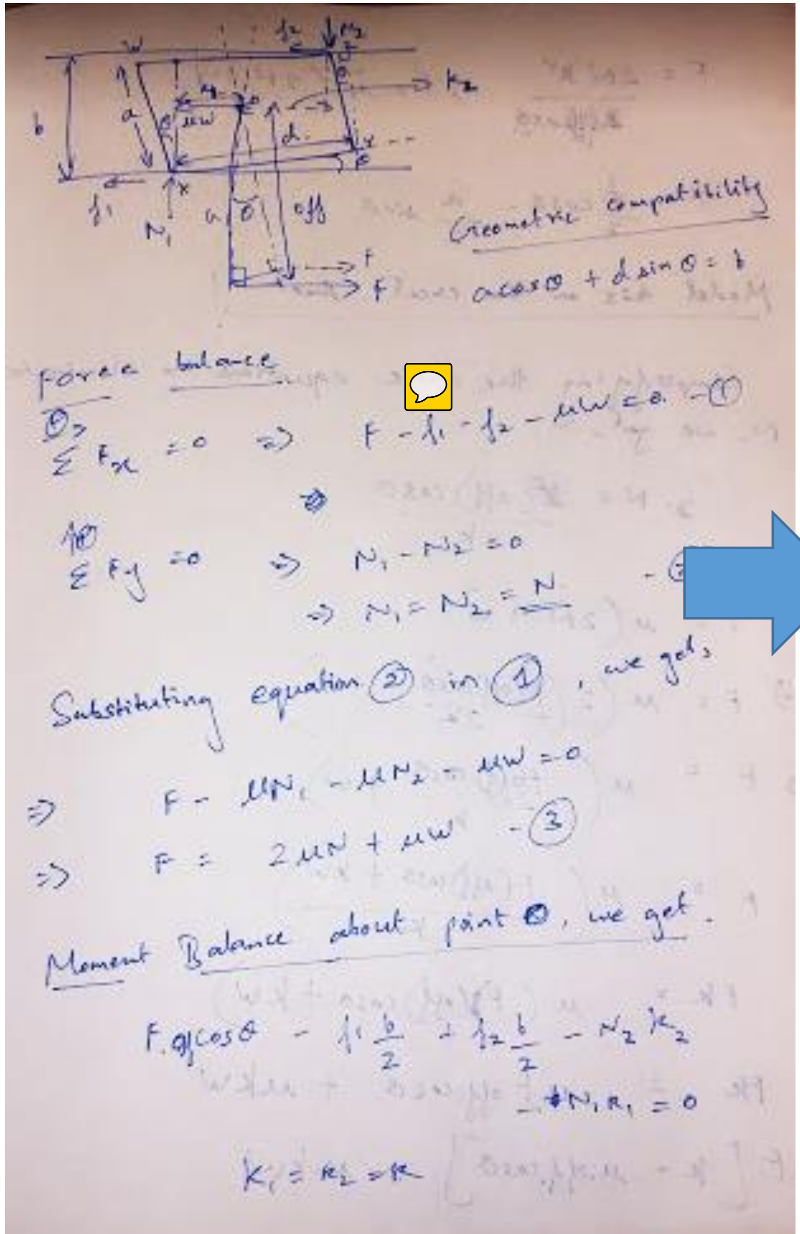
Pros	Cons
Simplicity of manufacture	Gravity preloaded – prone to walking problems
	Low Roll Stiffness

Concept Sketches



Pros	Cons
Quasi-Kinematic – Good accuracy and repeatability	Difficult to manage all the different possible manufacturing errors like center distance, rail parallelism etc.
	Low roll stiffness

Calculations for Box-way Concept



Geometric compatibility

$a\cos\theta + d\sin\theta = b$

Force balance

$\sum F_x = 0 \Rightarrow F - f_1 - f_2 - \mu W = 0$ — (1)

$\sum F_y = 0 \Rightarrow N_1 - N_2 = 0$

$\Rightarrow N_1 = N_2 = N$ — (2)

Substituting equation (2) in (1), we get,

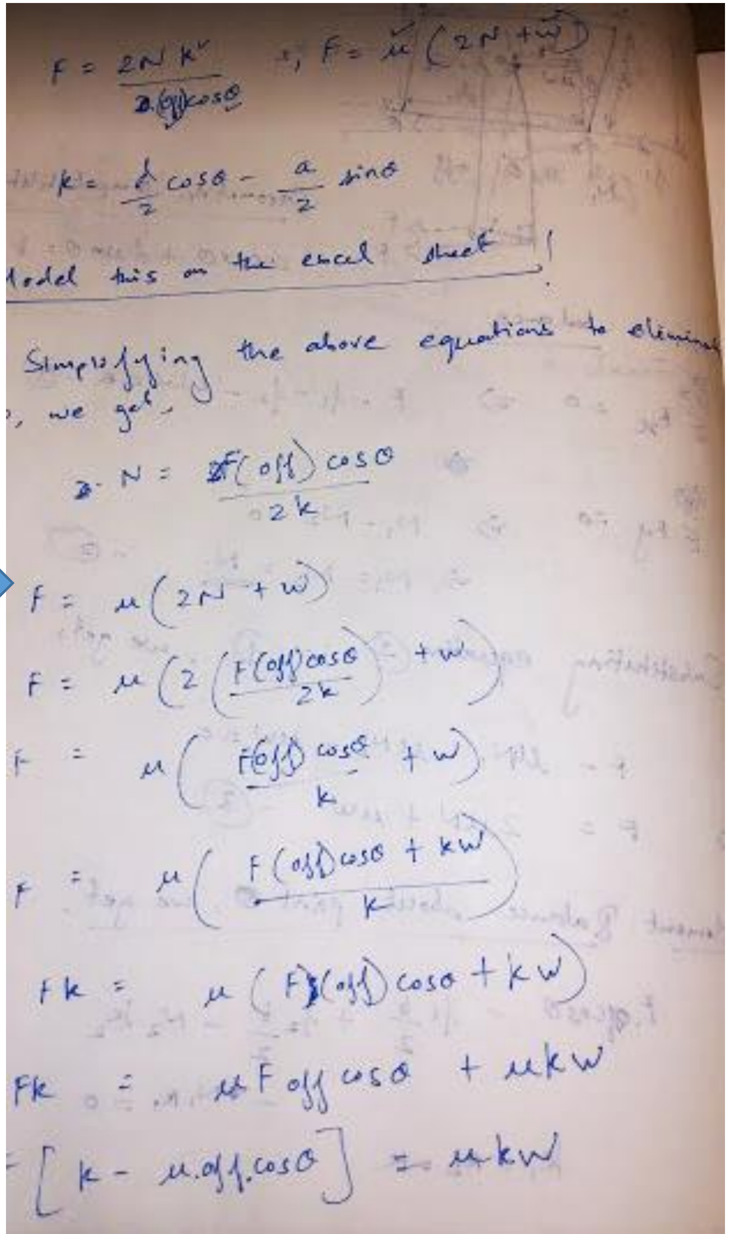
$\Rightarrow F - \mu N_1 - \mu N_2 - \mu W = 0$

$\Rightarrow F = 2\mu N + \mu W$ — (3)

Moment Balance about point O, we get.

$F \cdot off \cos\theta - f_1 \frac{b}{2} + f_2 \frac{b}{2} - N_2 k_2 + N_1 k_1 = 0$

$k_1 = k_2 = k$



$F = \frac{2N k}{2 \cdot off \cos\theta}$; $F = \mu(2N + w)$

$k = \frac{d}{2}\cos\theta - \frac{a}{2}\sin\theta$

Model this on the excel sheet!

Simplifying the above equations to eliminate, we get.

$N = \frac{F(off)\cos\theta}{2k}$

$F = \mu(2N + w)$

$F = \mu\left(2\left(\frac{F(off)\cos\theta}{2k}\right) + w\right)$

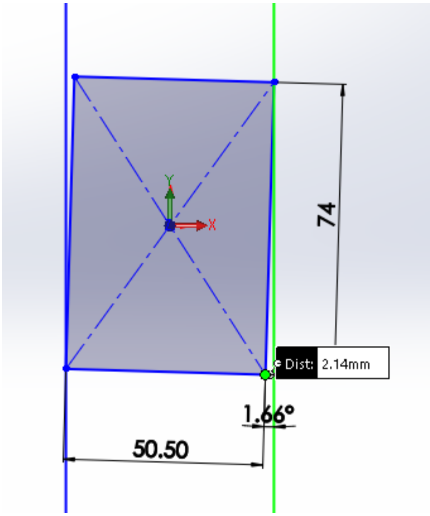
$F = \mu\left(\frac{F(off)\cos\theta}{k} + w\right)$

$F = \mu\left(\frac{F(off)\cos\theta + kw}{k}\right)$

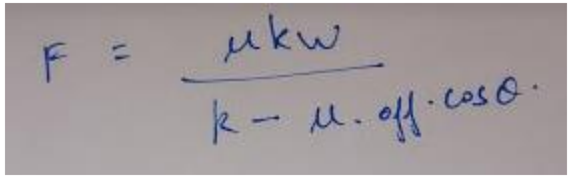
$Fk = \mu\left(F(off)\cos\theta + kw\right)$

$Fk = \mu F\, off \cos\theta + \mu k w$

$F\left[k - \mu \cdot off \cdot \cos\theta\right] = \mu k w$



CLEARANCE CALCULATION IN SOLIDWORKS



$$F = \frac{\mu k w}{k - \mu \cdot off \cdot \cos\theta}$$

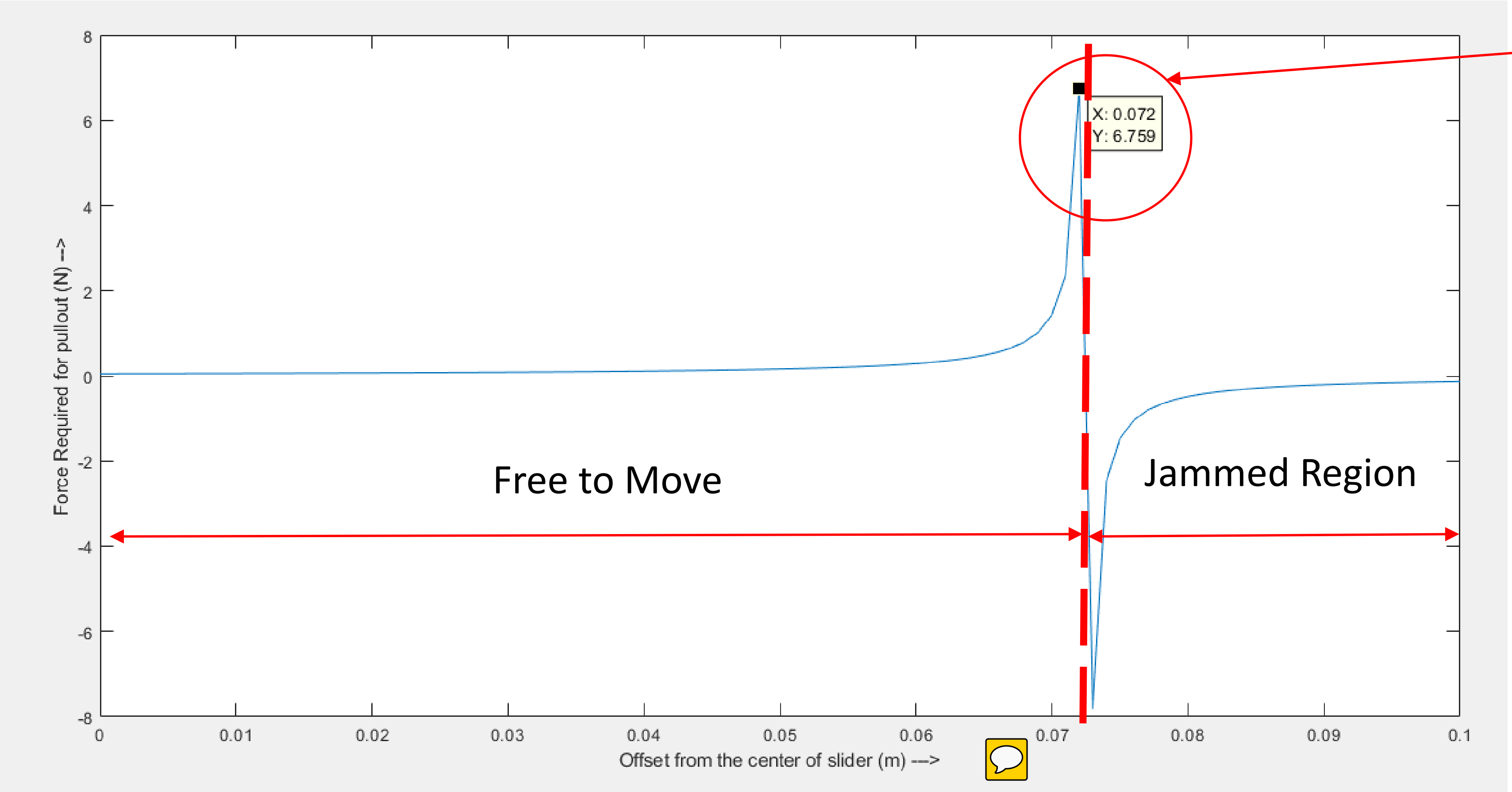
FINAL RESULT

```
a=0.0505
b=0.05261
d=0.074
theta=0.02897
off=[0:0.001:0.1]
k=(d/2)*cos(theta)-(a/2)*sin(theta)
mu=0.5
w=0.1
F=(mu*k*w)./(k-(mu.*off*cos(theta)))
plot(off,F)
```

MATLAB CODE SNIPPET

Box-way Concept Analysis

For a given length of slide, at which offset distance will it jam into the bearings?



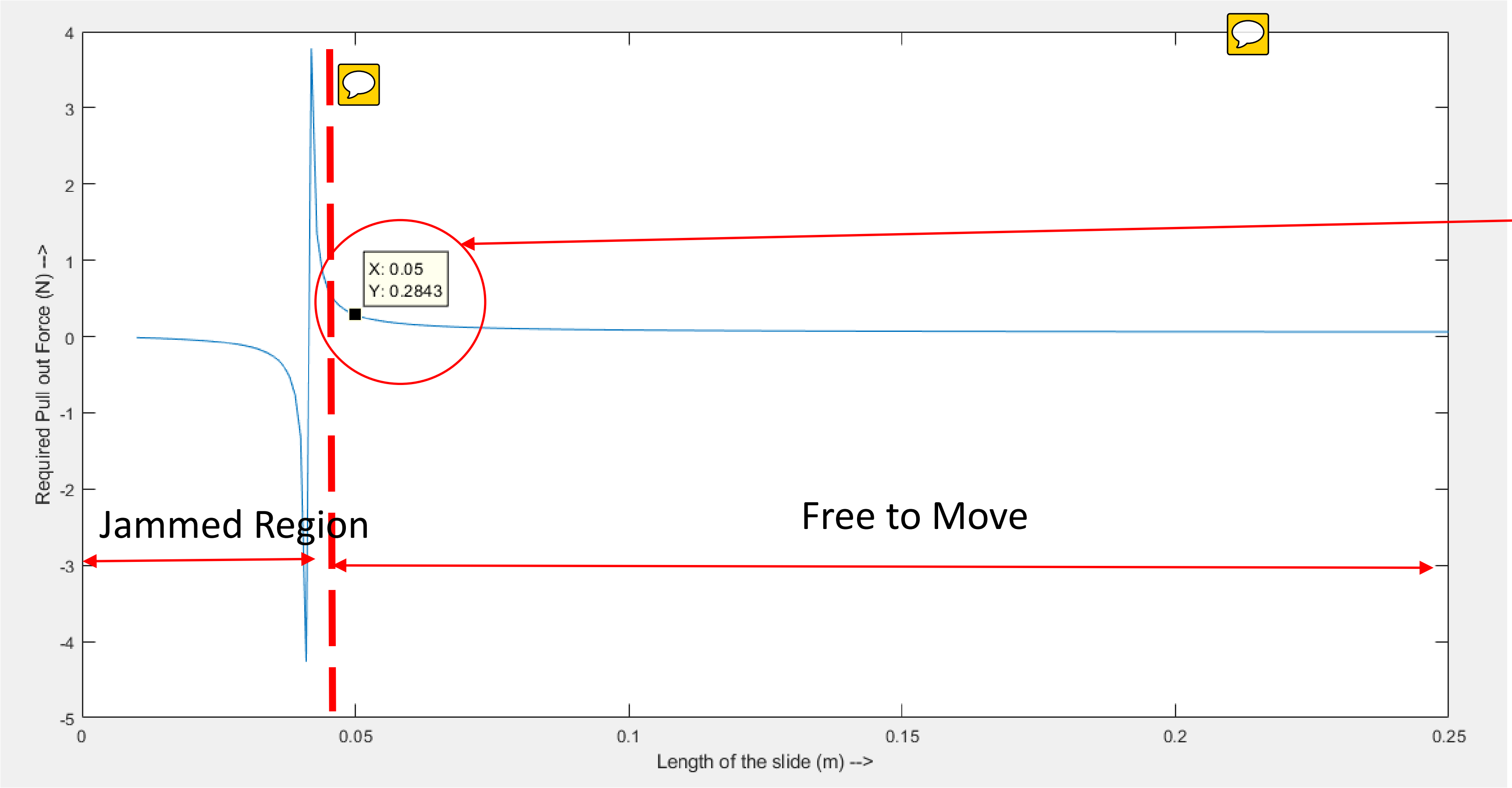
Jamming Point for the slide

- Based on the slide which I had made for my sketch model, the critical offset point at which it will get jammed is 72 mm
- The knee of the curve is near 68 mm approximately, so I have to ensure that the offset is less than that.

Beyond 72 mm, the normal reaction forces will keep increasing with the increase in F which will increase the friction forces proportionately. Therefore, the slide will not move in that case.

Box-way Concept Analysis

For a given offset distance from the load, what is the critical length of the slide to ensure that it will not jam?

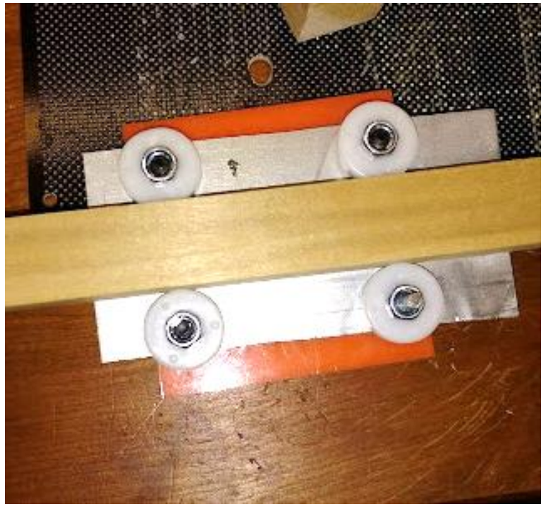


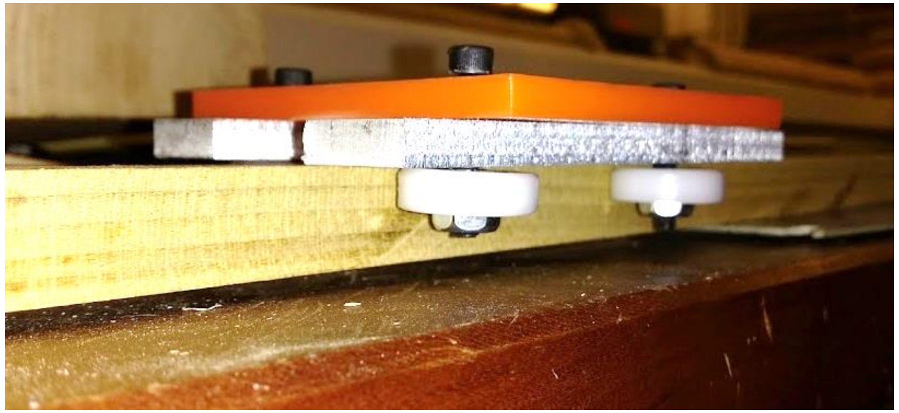
Knee of the curve

Corresponds to L/D ratio of 1!!! As width of the slide was 50.5 mm

- This graph tells us the minimum length of the slide which is needed to ensure that jamming does not happen.
- Unsurprisingly, the knee of this curve corresponds to L/D ratio of 1!!

Sketch Models





Wheel guide configuration

Box-way Sliding Contact Bearing

Testing and Learnings

Box-way Configuration

- Forces were applied at different offsets to check if they matched the prediction.
- For 40 mm offset, the predicted force required for pull-out was negligible. However, it was observed some minor rattle did occur and the pull out force in those cases was around 2N.
- It was noticed that the issue was with the wood glue residue which seeped into the inner lining of the bearings. The rattle was occurring at exactly those points where the glue seeped in.
- This made me realize the importance of keeping the inner lining of the bearings as clean as possible during the manufacturing stage.
- The actual jamming of the slider started to occur at an offset of 65 mm which was close to the predicted value of 72 mm.
- Straight line accuracy was measured using the laser which was projecting on the wall 8.6 m apart while pressing the slider against one side of the bearing as if it was preloaded.
- A max deviation of 5 cm was observed at a distance 860 cm apart which corresponded to an accuracy of 116 microns.


Jamming Test


Straight Line accuracy test

Testing and Learnings

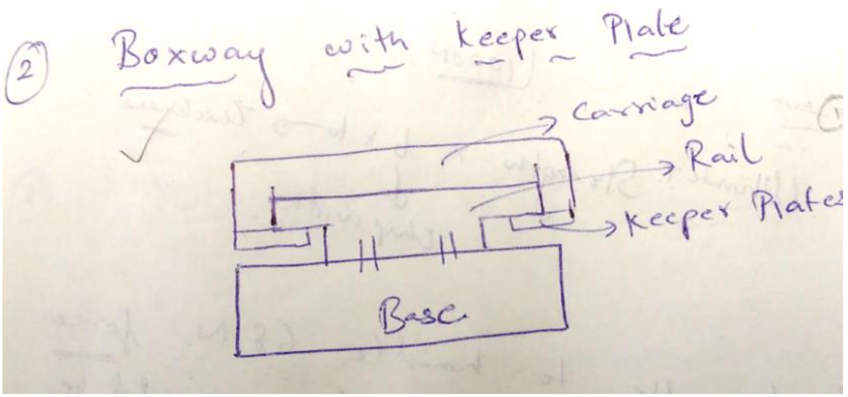
Wheel guide Configuration

- Wheel guide configuration was the second sketch model which was fabricated
- It was easy to manufacture but required extreme care that the wheels do not get edge loaded while pre-loading
- I wanted to learn from the wheel guide configuration, whether it could provide adequate amount of stiffness in yaw and roll direction.
- Testing was done on a preloaded wheel in slot variant of the configuration which gave higher stiffness in pitch and roll directions.
- Yaw Stiffness : A 30 N force caused a 28 micron deflection measured using laser pointer. Stiffness was approximately 1.07 N/um
- Pitch Stiffness: A 30 N force caused a 24 micron deflection measured using laser pointer. Stiffness was approximately 1.25 N/um
- Although, the stiffness was reasonable, it was far behind the required stiffness of 7 N/um
- Straight line accuracy was measured for wheel using the laser which was projecting on the wall 8.6 m apart. Wheels were pre-loaded. A max deviation of 3 cm was observed at a distance 860 cm apart which corresponded to an accuracy of 69 microns. Requirement was in the order of 10 microns.

Stiffness Testing

Straight Line Accuracy

Concept Selection



Pros	Cons
Easy to manufacture	High Friction/Need anti-friction element
Can be made of high stiffness	High Wear

After the sketch model testing, it was decided to go forward with the Box-way configuration because:

a) It was much simpler to manufacture than wheel guide
b) The bearing pads can be replaced easily in box-way whereas for the wheel guide, one will have to replace the wheels which are vey costly
c) Box-way configuration (once preloaded) will have higher stiffness than wheel guide as larger area of surfaces are in contact with each other. [1] (Stiffness test for box-way will be done the following week after preloading it)

Solid Model of the LM Module (in progress)