Elastic Averaged Coupling

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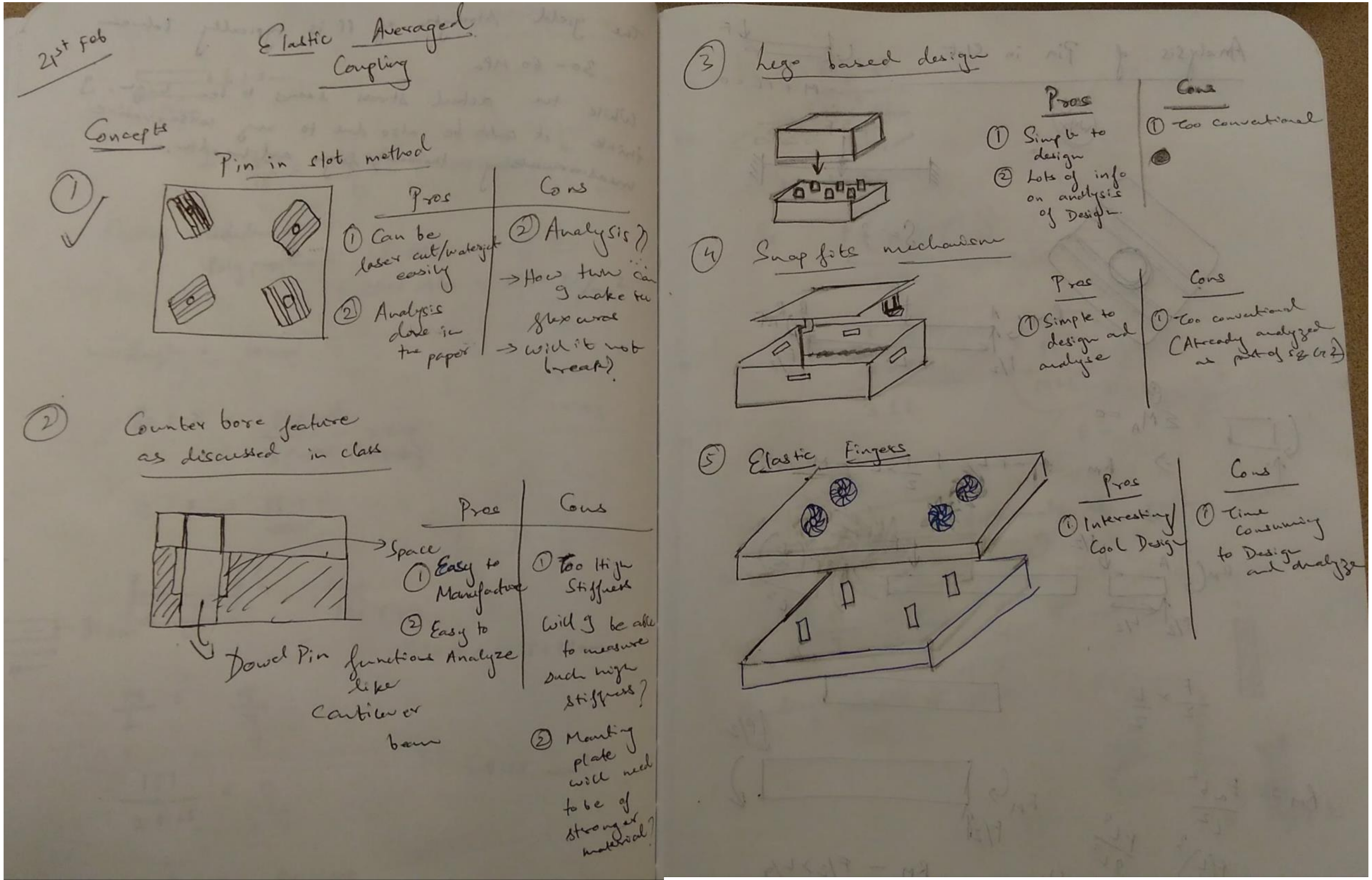
FRDPARRC

Sr. No.	Functional Requirements	Design Parameters	Analysis	References	Risks	Counter Measures
1	Ability to bear reasonable moment loads without failure	Yield Strength of the mounting plate Moment of Inertia of the beam elements Thickness of the beams	Bending stress calculations for the beam elements	Mechanics of Materials Textbook	The elastic beams may fail under excessive moment loads	Limit the amount of allowable moments or design a stop which does not allow the moments to exceed a limit
2	Accuracy	Manufacturing errors Number of elastic contacts needed to average out the errors	Performance Ratio (PR) = Manufacturing error/desired accuracy Number of elastic contacts = sqrt(PR)	A.H. Slocum, T.J. Teo, “Principle of elastic averaging for rapid precision design”	Too few elastic contacts for desired accuracy	Do the calculations for accuracy
3	Stiffness	V, W, Slot width, beam element properties, material properties, angle of orientation	Young's Modulus of the materials Slot width, Dowel Pin diameter, thickness, width and length of the beam elements	Paper, "Principle of elastic averaging for Rapid Precision Design" Mechanics of Materials Textbook	Too high stiffness which I cannot measure	Deterministic Design of the beam elements to get the stiffness I want
4	Ease of Manufacture	What do I have? Time/Budget Constraints Accessibility of Machines	Resource Assessment Bank Balance Machine Shop Schedules	MW Website, Hobby Shop site	I may not finish the EAC by the deadline. --Bad	Work fast and use readily available materials
		Pull out force	Force on each beam		The EAC is very difficult to insert and remove.	Design the beam elements such that the

Concept Generation



Analysis – check for local yielding of elastic elements

Elastic Averaging Spreadsheet - Check for yielding of the eleastic beam elements				Acrylic	
			Yield Strength of the Material	70	Mpa
Pin diameter	3.2	mm	Tensile Modulus	3102	Mpa
Slot diameter	3	mm	Flexural Modulus	3100	Mpa
Displacement of beam element due to Dowel Pin offset	0.1	mm			
Total deflection to be borne by a flexure	0.2	mm			
Length of the flexure	20	mm			
Thickness of the sheet	6.2	mm			
Width of the flexure	1.65	mm			
Moment of Inertia	2.3	mm4			
Stiffness of each flexure	172.8	N/mm			
Force on each beam	34.6	N			
Bending Stress	30.7	N/mm2			
Bending Stress Ratio	0.44				

Number of contact points needed:

Manufacturing error = 100 um

Desired Accuracy = 10 um

Number of contact points = $\sqrt{\frac{100}{10}} = 3.16\ or\ 4\ contact\ points$

Analysis – MATLAB code for predicting the System Stiffness

```
% 2.77 Precision Machine Design 2018
% Akshay Harlalka - 23rd Feb, 2018
%Reference for Calculations:
%% EAC Calculations

% Defining the number of elastic contacts needed
% deltaa=input('Enter the desired accuracy of the system in um')
% deltam=input('Enter the expected manufacturing error in the parts in
% perratio=deltam/deltaa;
% n=ceil(sqrt(perratio))%
thetai=[pi/4 (pi/4+pi/2) (pi/4+pi) ((pi/4)+(3*pi/2))]

%Geometry
V=2.3*10^-3
W=0.675*10^-3
r=0.05176 % coupling radius
%Orientation Matrix
G1=[cos(thetai(1)) cos(thetai(1)+pi/2) 0 ; sin(thetai(1)) sin(thetai(1)+pi/2
G2=[cos(thetai(2)) cos(thetai(2)+pi/2) 0 ; sin(thetai(2)) sin(thetai(2)+pi/2) 0 ; 0 0 1]
G3=[cos(thetai(3)) cos(thetai(3)+pi/2) 0 ; sin(thetai(3)) sin(thetai(3)+pi/2) 0 ; 0 0 1]
G4=[cos(thetai(4)) cos(thetai(4)+pi/2) 0 ; sin(thetai(4)) sin(thetai(4)+pi/2) 0 ; 0 0 1]
%Jacobian
Ji1=[1 0 0 ; 0 1 r ; 0 0 1]
Ji2=[1 0 0 ; 0 1 r ; 0 0 1]
```

Key Highlights

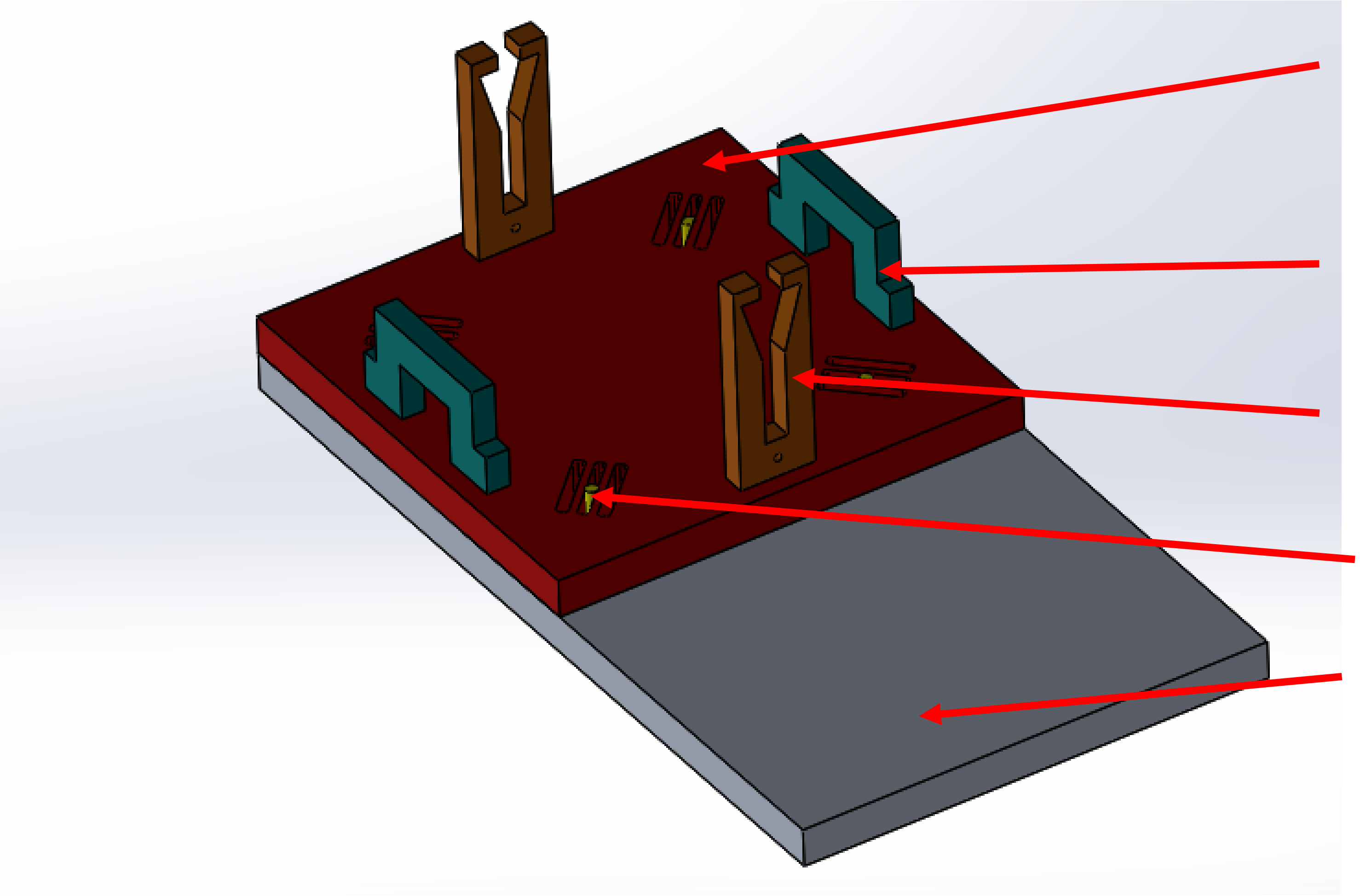
Ignores the effect of body stiffness. Assumes body has infinite stiffness

Uses the calculation strategy outlined in the paper titled, “Principle of elastic averaging for rapid precision design”

Final System Stiffness Predicted = 3730 Nm

Code is uploaded in the Dropbox folder too!

Design - CAD



Mounting plate

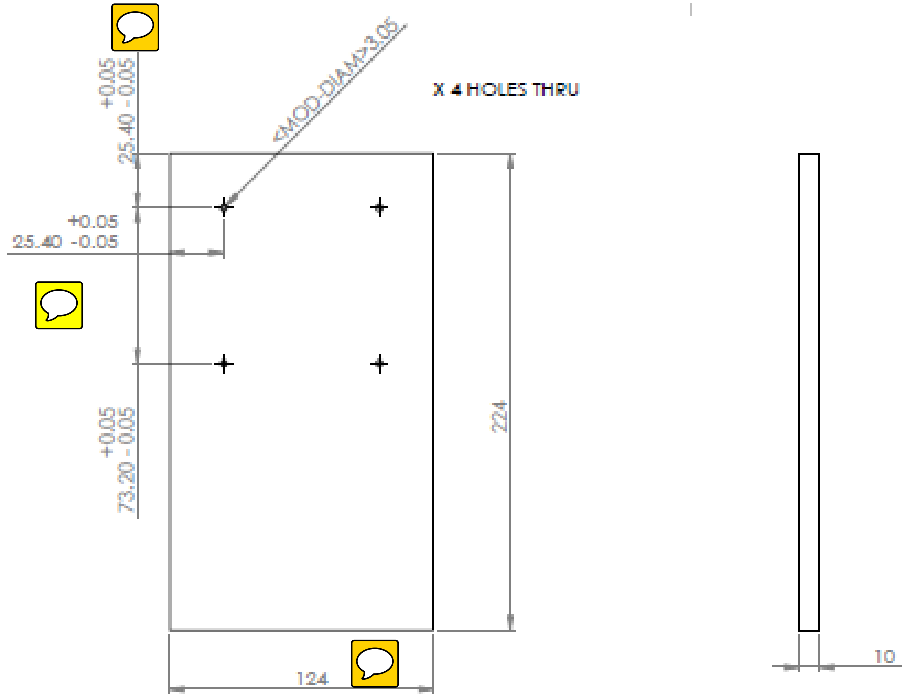
Handle for easy insertion and removal of the mounting plate

Mounts for the laser

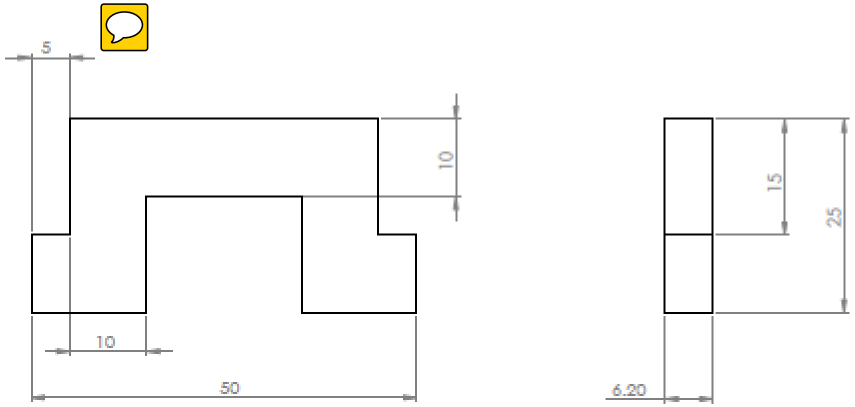
Dowel Pins

Base plate (Extra space for clamping)

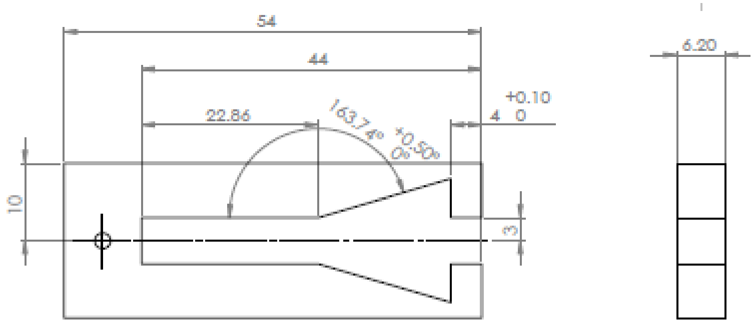
Drawings



Base Plate



Holder



Snap Mounts

Individual drawing files will full details are available in the folder. This is folder representational purposes only.

Fabrication

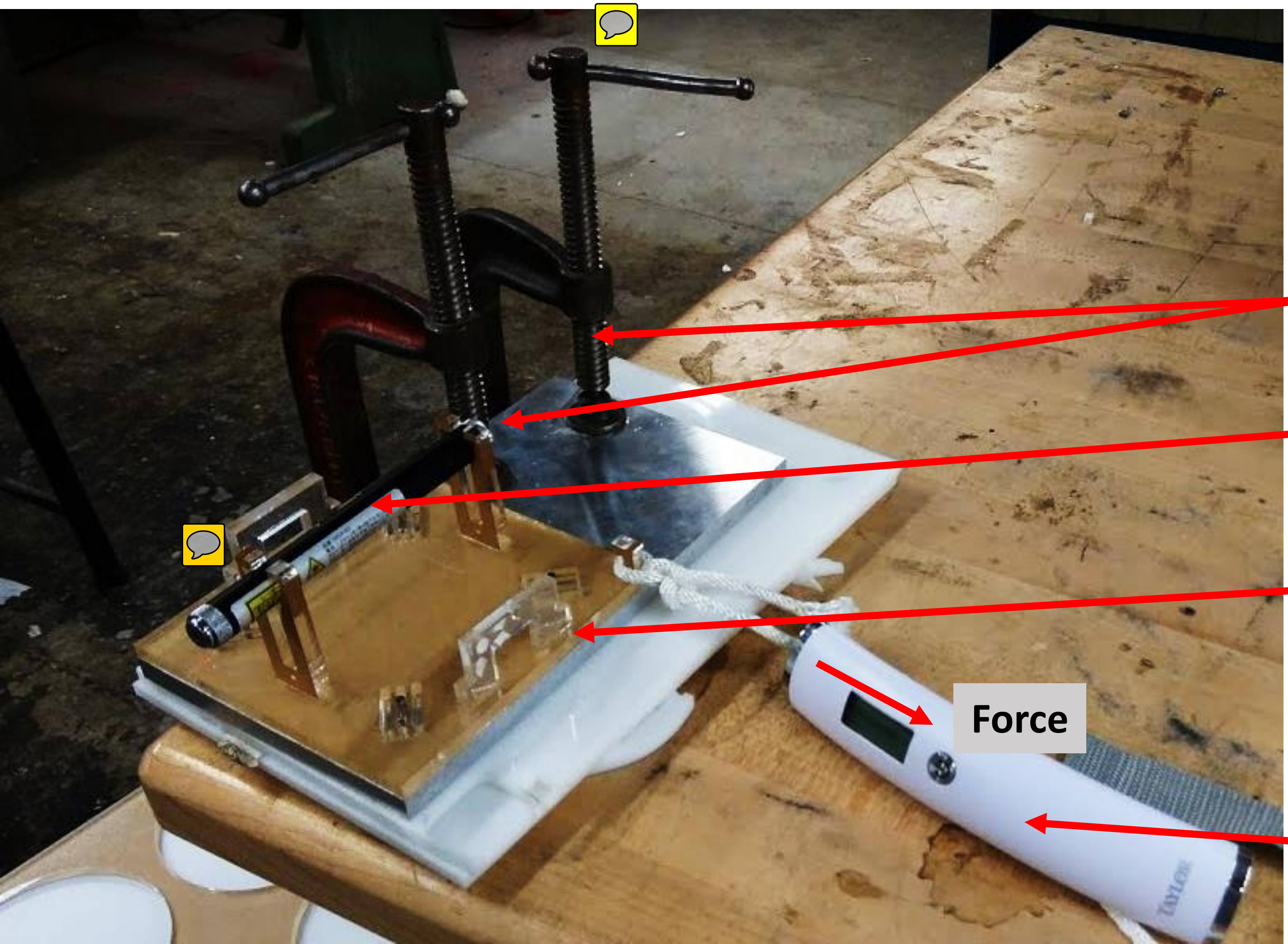
Materials and Manufacturing :

- **Mounting Plate, Laser Mounts, Holder** – All fabricated by laser cutting Acrylic 6.2 mm thick sheet

- **Base Plate** – Aluminium 10 mm thick plate – Took original stock size = 124 * 224 * 10 mm – Drilled 4 holes using 0.12 inch drill, followed by 1/24 '' inch reamer (through) and 1/26 inch reamer (upto 1mm depth) to allow the pins to stand straight while press-fitting dowel pins to plate

- **Dowel Pins** – Stainless Steel – Available off the shelf

Test Setup



Objective: To find the moment stiffness of the EAC

Used two C clamps to fix the base plate to a stiff table *(Could not find a fixed Vise which could hold 124 mm wide Al plate)*

Laser was mounted firmly on the mounts

The mounts and the handle were attached to a laser-cut acrylic plate using acrylic solvent

Digital scale for load measurement

Testing Results - Stiffness

Sr. No	Weight (in Kg)	Deflection on paper (m)	Distance (m)	Theta (radians)	Force (N)	Arm length (m)	Moment (Nm)	Stiffness (Nm)
1	2.54	0.00479	14	0.000342	24.892	0.062	1.543304	4510.701
2	3.5	0.01072	14	0.000766	34.3	0.062	2.1266	2777.276
3	4.17	0.0101	14	0.000721	40.866	0.062	2.533692	3512.048
4	4.8	0.01486	14	0.001061	47.04	0.062	2.91648	2747.693
							Average	**3386.93**

Need to check this reading again

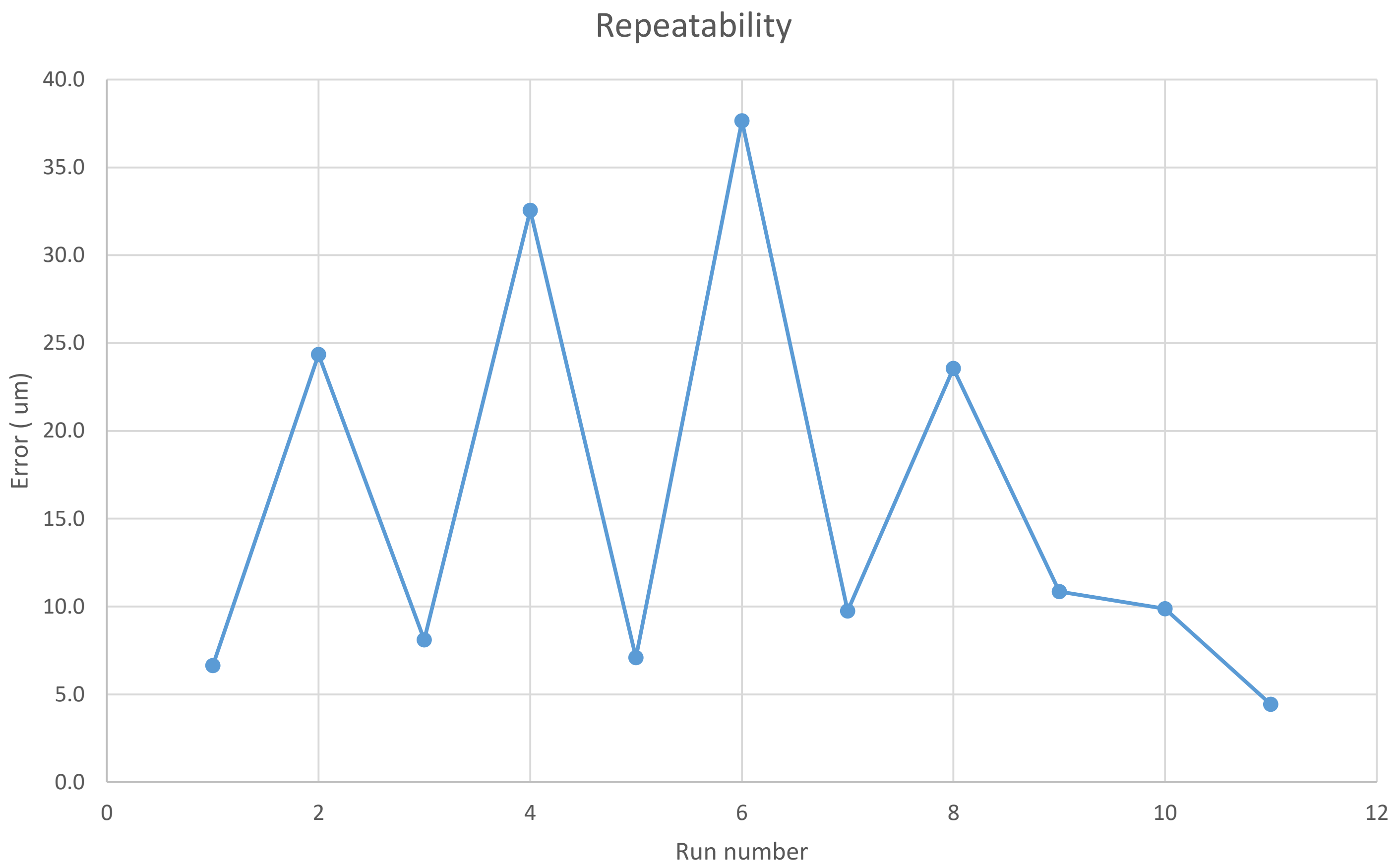
Distance of laser pointer from paper = 14 meters

Predicted Stiffness was 3730 Nm

Probable reasons for difference in the theoretical and experimental Stiffness Values:

1. Theoretical Stiffness does not take the body stiffness into consideration. Therefore, actual stiffness will be slightly lower than predicted.
2. Movement of the laser could have messed with the values of stiffness I am getting. Plan to make a kinematic mount for this design and redo the testing

Testing Results - Repeatability



As per recent literatures, the theoretical repeatability for an elastically averaged design can be loosely approximated as 1/√n = ½ =0.5 um. This confirms my hypothesis on the movement of the laser

Key Observations

1. Since the pull out and insertion force of the mounting plate is high, every time, I pull out the plate, it seems that the laser moves a bit within the mount. This causes drastic variation in the repeatability results. **At this point, I realized that a kinematically mounted laser would be been a better design choice!!**
2. **The reason why I had chosen the snap mounts for laser holding** was so that I could have an option of clamping the coupling at 90 deg with a Vise because I wasn't able to clamp the coupling horizontally (exceeded the range)