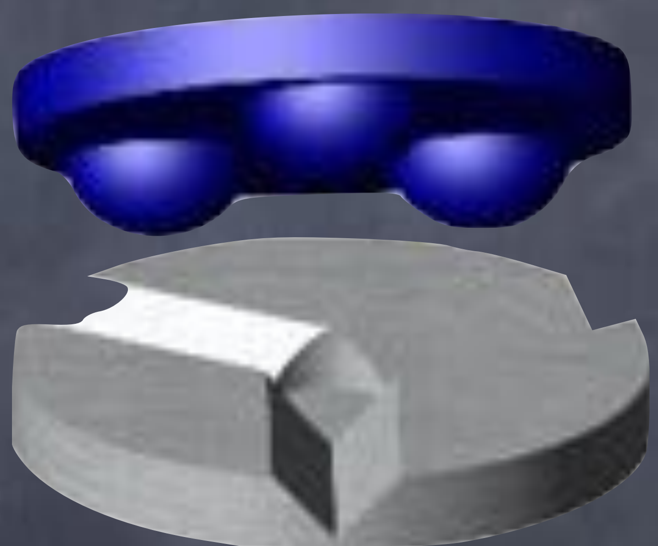
Kinematic coupling

Week 2



2.70/2.77 FUNdaMENTALS of Precision Product Design

Fernández Galiana, Álvaro

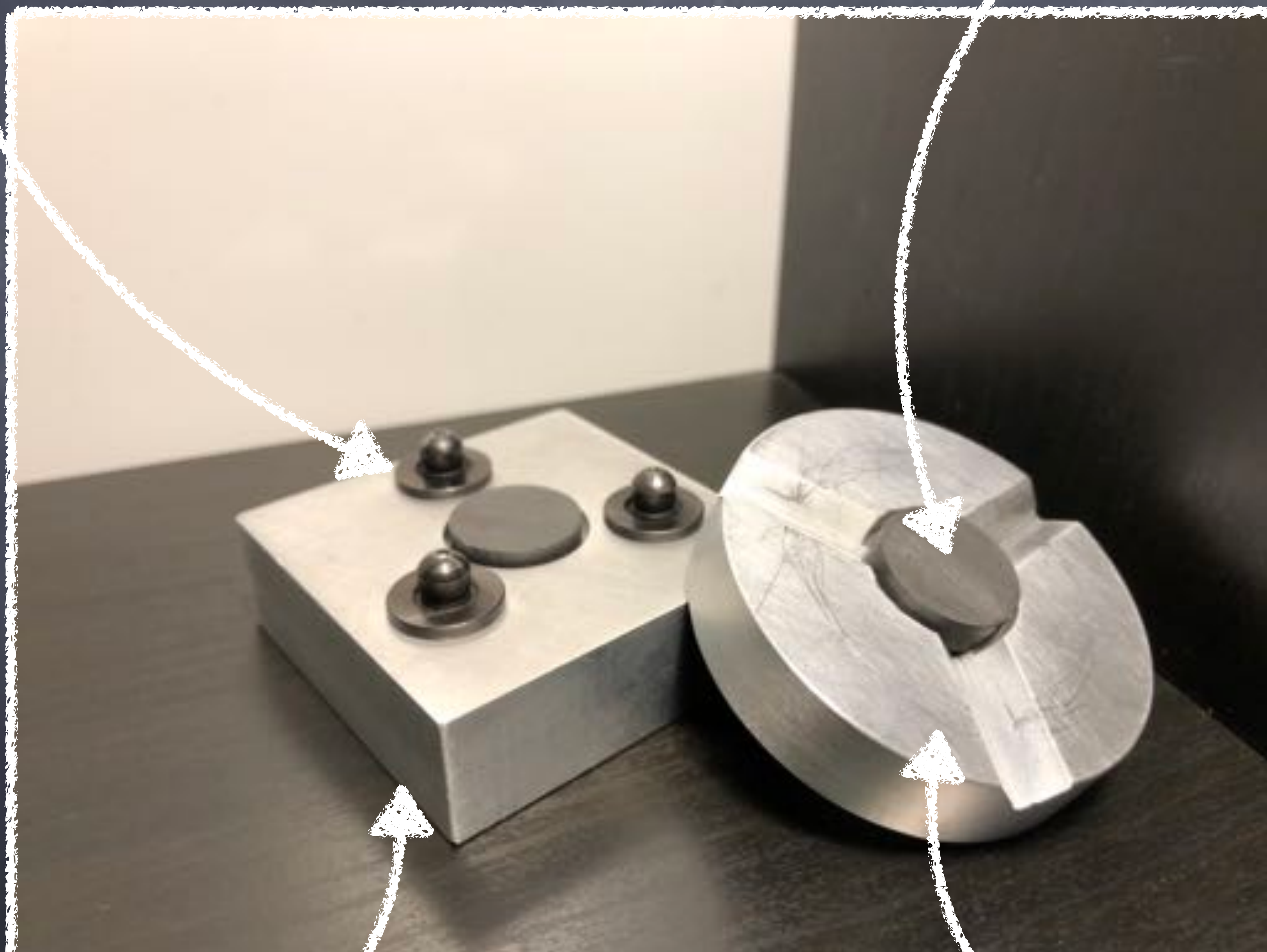
Motivation

- It is common in optics laboratories to have to take out optical elements for cleaning or inspection for damage. This elements, such as mirrors or lenses, are usually aligned with other elements are the realignment process might be tedious. Therefore, we decided to design a kinematic coupling that could allocate an optical element.

Overview

Mating pins

Magnets



Lower body

Upper body

FRDPARRQ

KINEMATIC COUPLING

FUNCTIONAL REQUIREMENTS	DESIGN PARAMETERS	ANALYSIS	REFERENCES	RISK	COUNTER-MEASURES
Repeatable	<2 mrad	Estimated number to be determined during the next week	FUNdaMENTALS book and experience	Too loose of a constraint; useless	Review the constraints for the system
Materials easy to procure	Less than a week to procure all the elements	It is due in a week	2.70 Syllabus	Won't be done on time	Use spare materials from the machine shop
Within budget	< 30$	Total amount to be spent in 2.77 / number of hardware assignments	Budget spreadsheet	Lack money left for the upcoming tasks	Increase the budget for this class
Can be machined in the Hobby shop	Mill (CNC)	Personal knowledge of the machining equipement and experience	Experience	Too simple design to be adapted to the current machining capabilities (i.e. have not CNC in a while)	Ask for help with the CNC
Compact	<10 cm per side	Estimated number to be determined during the next week	Previous KC	Will not be adaptable to any system	Analyze the final use of this KC
Capability to support a lens/mirror	On the top part	Necessary to check repeatability	2.70 Syllabus	Not possible to validate design and compare with expected performance	Tape it (can induce errors)
Preload	Not very strong/maybe just gravity	It is to support an optical element that should be easy to remove and reinstlall	Previous KC used in my lab	Too sensitive to motions/external loads	Magnetic preload
Stiffness	Enough to withstand 50g of lateral load	The KC is not going to have yo carry any load, it is for pure positioniong	Previous KC used in my lab	Too sensitive to external loads	Magntic preload

Note: Red indicated variations from week 1 FRDPARRQ

FRDPARRQ

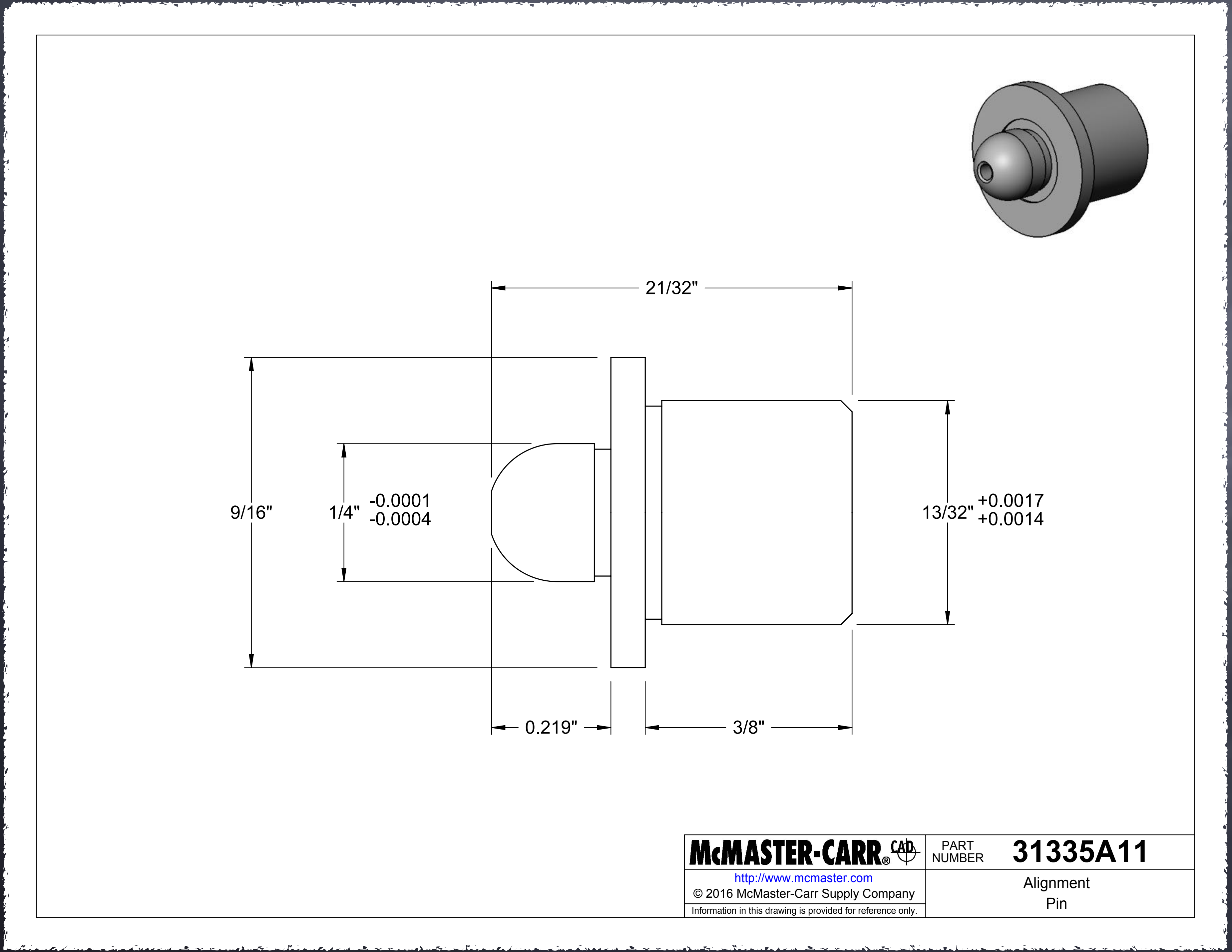
- Essentially the functional requirements are related with the function of the KC, which is to potentially carry an optic, and the machining techniques and material available
- Initially the gravity preloading was considered but finally a magnetic preload was selected due to the need of some stiffness
- Wood was used in the first week KC but was not considered this time since it is hard to be cleaned and produces dust that is not desirable

Design

- The selected design is an aluminum two body KC with magnetic preload and press fit mating location pins as balls
- Its dimensions and final design are presented in the next slides, which correspond to the final design

Balls

- Instead of balls, we have bought mating pins from McMaster because they are easy to preocupe and easy to install (press-fit)



- Ball diameter: 1/4"

Balls

- The press fit calculation, made to define the tolerances on the KC part to be machined is presented below:

Calculation of fits according ISO 286 (2010)

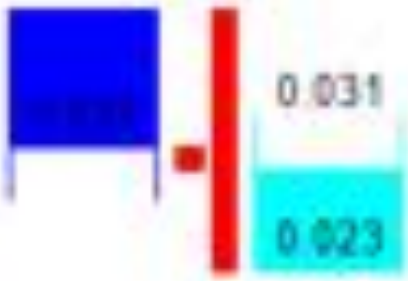
The dimensions of a fit are calculated using the tolerances according to ISO 286 (2010). In additio
These online calculations are provided free of charge by MESYS AG. The software is tested and no

Nominal size	D	10.32	mm
Tolerance hub		EF 5	
Upper limit deviation	ES	0.031	mm
Lower limit deviation	EI	0.023	mm
Tolerance shaft		u 6	
Upper limit deviation	es	0.044	mm
Lower limit deviation	ei	0.033	mm

Calculate

Interference fit

Minimum interference	imin	0.002	mm
Maximum interference	imax	0.021	mm



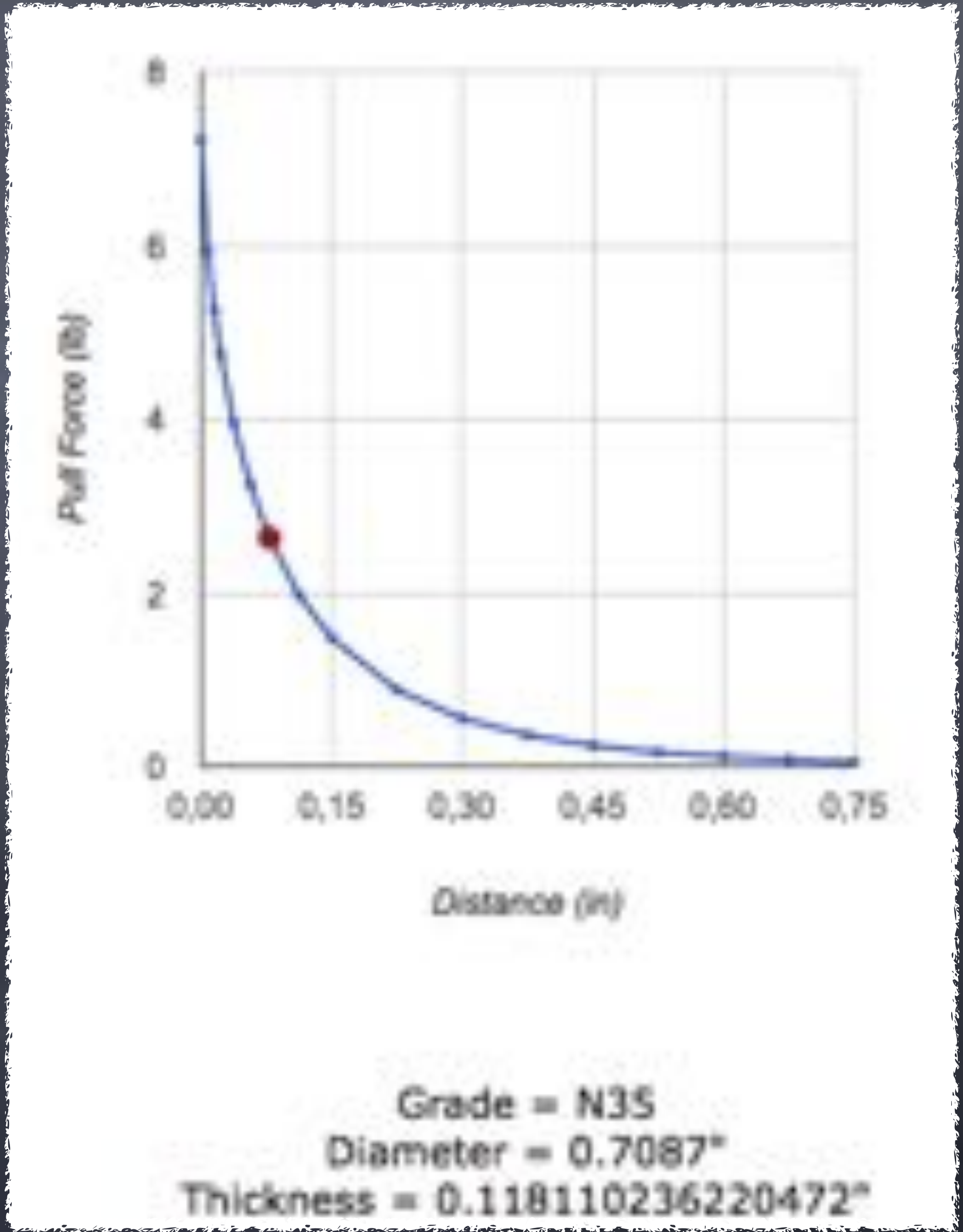
Source: https://www.mesys.ch/calc/tolerances.fcgi?lang=en

Preload

- The weight of the optic is not enough to provide minimum stiffness with gravity. Therefore, magnetic preload was chosen since it provides a quick easy way to interchange optics, as opposed to screws, for example.
- Given the pull force curve presented, we decided to have the magnets at at distance of 2mm, providing a pulling force (i.e. preload) of:
- PRELOAD: 12N (aprox.)

Pull Force curve

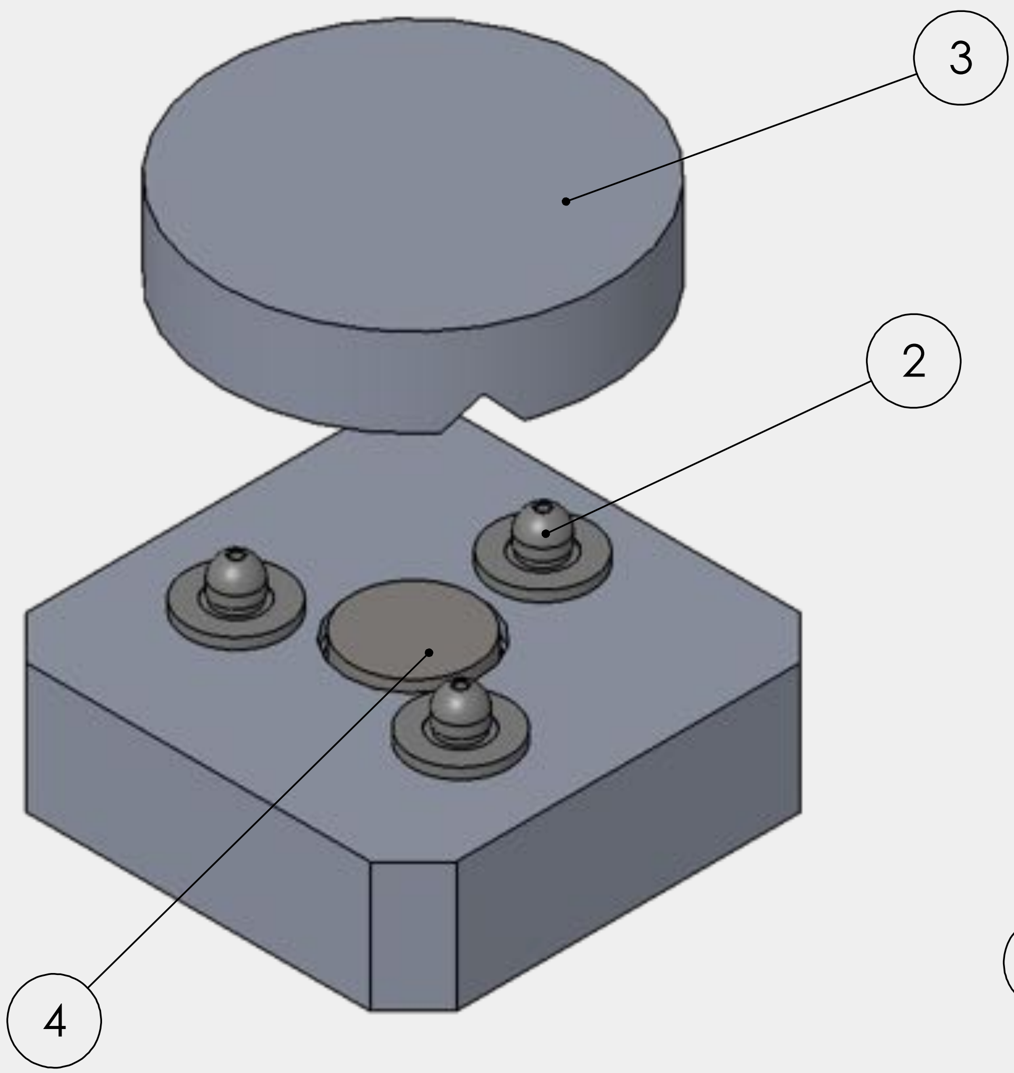
(for the selected magnets)

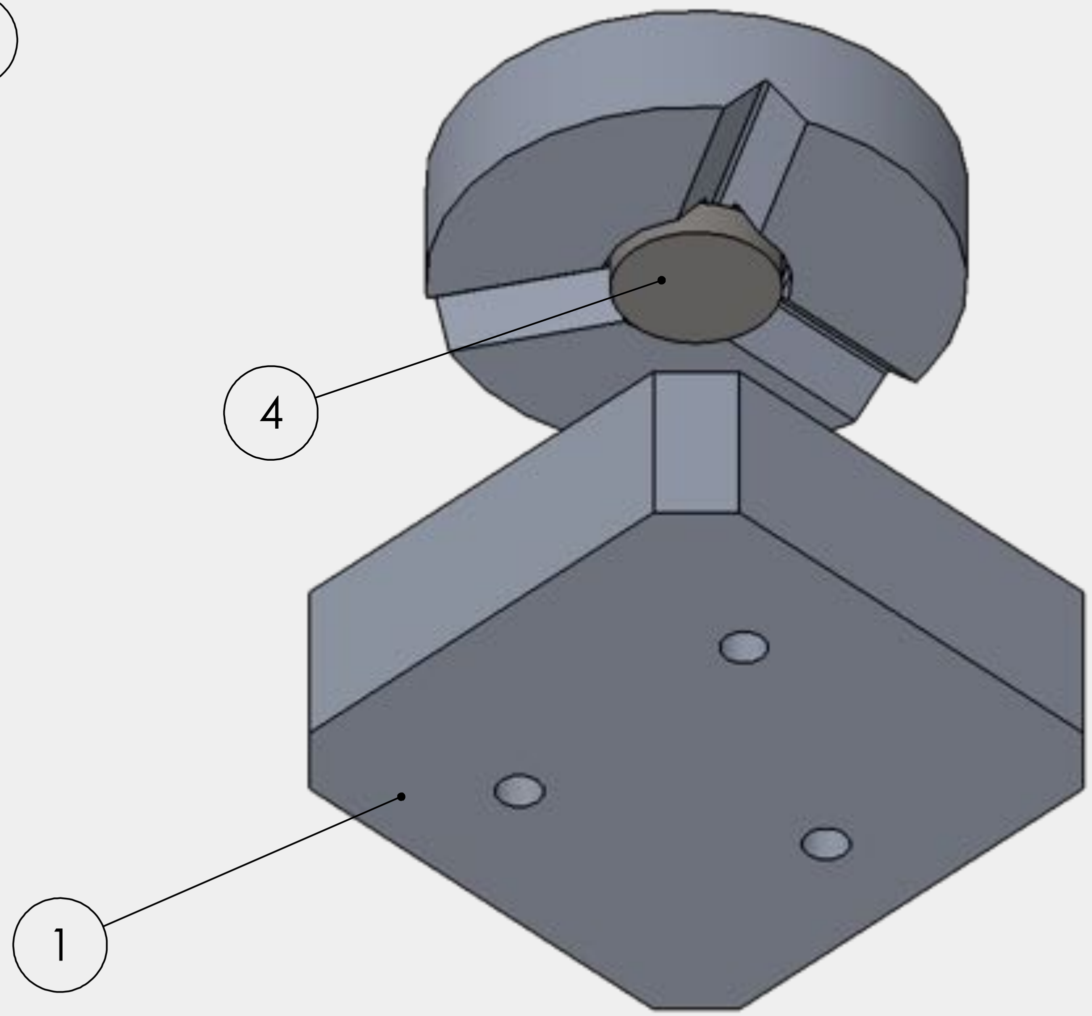


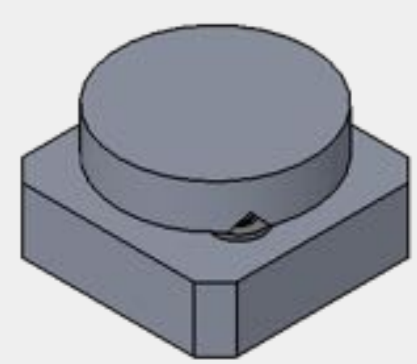
Source: https://www.kjmagnetics.com

Main bodies

- The next slides present the drawings for the parts that compose the KC
- All these parts were made out of scrap material to stay within budget and were machined using CNC milling and a lathe







ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	REQ	TOTAL
4	Cutequeen 27PCS	KC_Magnet	Ferrite Magnet	2	2
3	2.77-18-KC-1	KC_Top	6061-T6 (SS)	1	1
2	McMaster_31 335A110	KC_Ball	N/A	3	3
1	2.77-18-KC-2	KC_Bottom	6061-T6 (SS)	1	1

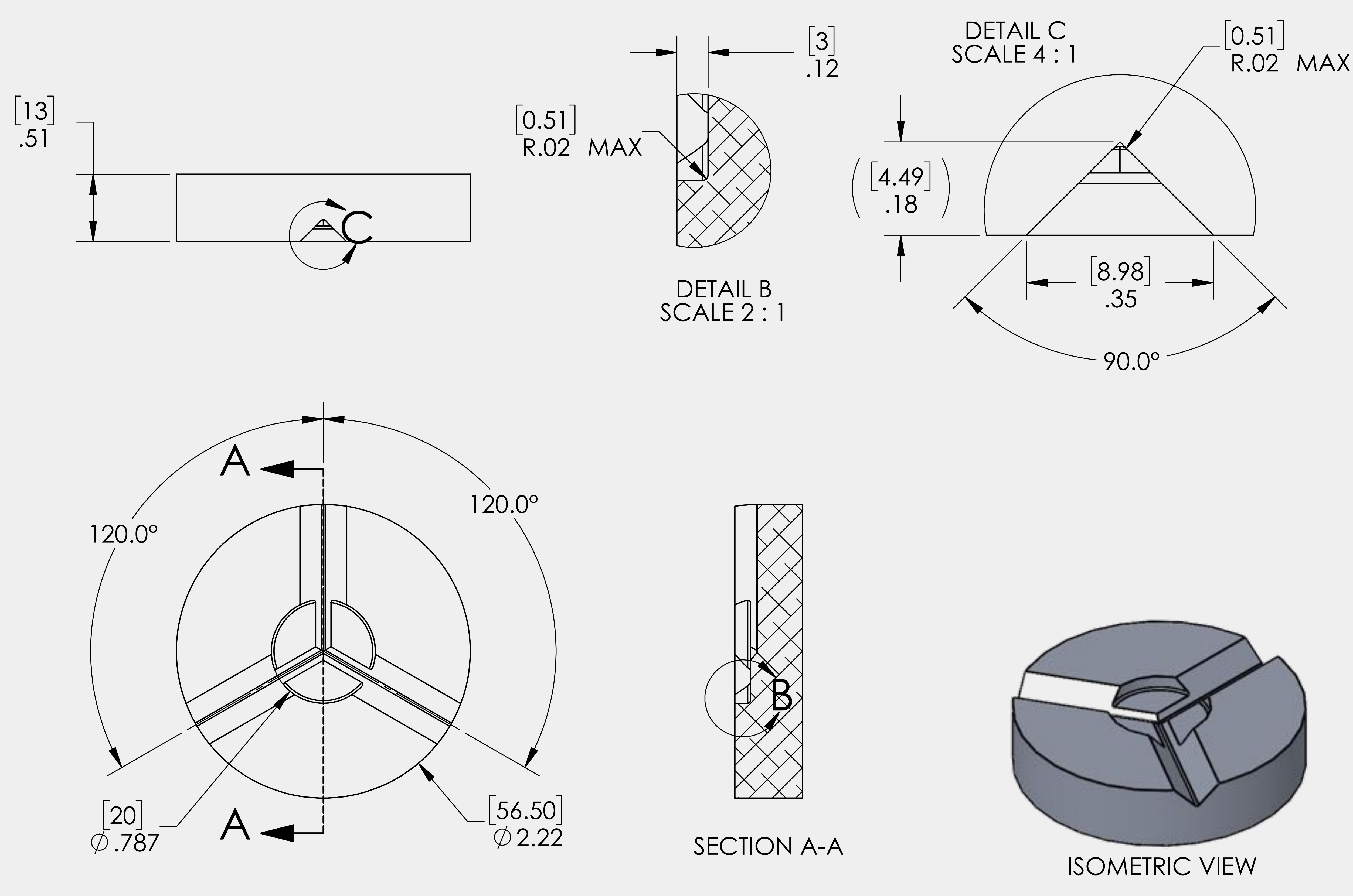
PARTS LIST

LIGO CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SIZE A | DWG. NO. 2.77-18-KC-3 | REV. v1

SCALE: 1:1 | PROJECTION: | SHEET 1 OF 1

KC_Assembly, PART PDM REV: , DRAWING PDM REV:



NOTES AND TOLERANCES: (UNLESS OTHERWISE SPECIFIED)

DIMENSIONS ARE IN INCHES

TOLERANCES:
.XX ± .015
.XXX ± .005

ANGULAR ± 0.5°

1. INTERPRET DRAWING PER ASME Y14.5-1994.
2. REMOVE ALL SHARP EDGES, .005-.015. FOR MACHINED PARTS. ROUND ALL EDGES APPROXIMATLEY R.02 FOR SHEET METAL PARTS.
3. DO NOT SCALE FROM DRAWING.
4. ALL MACHINING FLUIDS MUST BE FULLY SYNTHETIC, FULLY WATER SOLUBLE AND FREE OF SULFUR, SILICONE, AND CHLORINE.

MATERIAL: 6061-T6 (SS)
FINISH: µinch

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

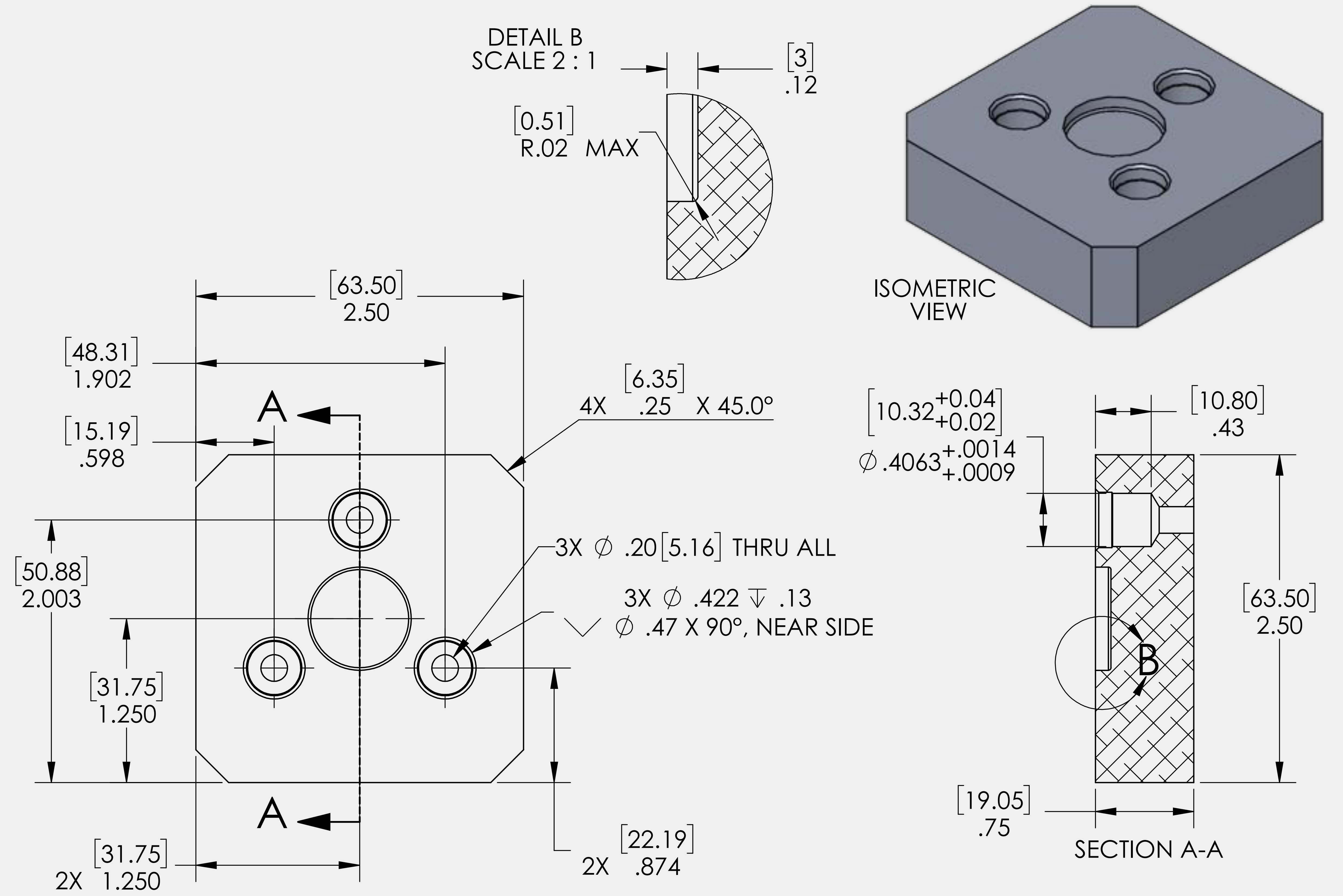
SYSTEM:
SUB-SYSTEM:
NEXT ASSY: KC_Assembly

PART NAME: KC_Top

DESIGNER	A. Fernandez	14 FEB 2018
DRAFTER		
CHECKER		
APPROVAL		

SIZE: A
DWG. NO. 2.77-18-KC-1
REV. v1
SCALE: 1:1
PROJECTION:
SHEET 1 OF 1

KC_Top, PART PDM REV: , DRAWING PDM REV:



NOTES AND TOLERANCES: (UNLESS OTHERWISE SPECIFIED)

DIMENSIONS ARE IN INCHES

TOLERANCES:
.XX ± .015
.XXX ± .005

ANGULAR ± .5°

1. INTERPRET DRAWING PER ASME Y14.5-1994.
2. REMOVE ALL SHARP EDGES, .005-.015. FOR MACHINED PARTS. ROUND ALL EDGES APPROXIMATLEY R.02 FOR SHEET METAL PARTS.
3. DO NOT SCALE FROM DRAWING.
4. ALL MACHINING FLUIDS MUST BE FULLY SYNTHETIC, FULLY WATER SOLUBLE AND FREE OF SULFUR, SILICONE, AND CHLORINE.

MATERIAL 6061-T6 (SS)

FINISH N/A µinch

2.77 FUNdaMENTALS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SYSTEM

SUB-SYSTEM

NEXT ASSY KC_Assembly

PART NAME KC_Bottom

DESIGNER	A. Fernandez	14 FEB 2018
DRAFTER		
CHECKER		
APPROVAL		

SIZE A **DWG. NO.** 2.77-18-KC-2 **REV.** v1

SCALE: 1:1 **PROJECTION:** SHEET 1 OF 1

KC_Bottom, PART PDM REV: , DRAWING PDM REV:

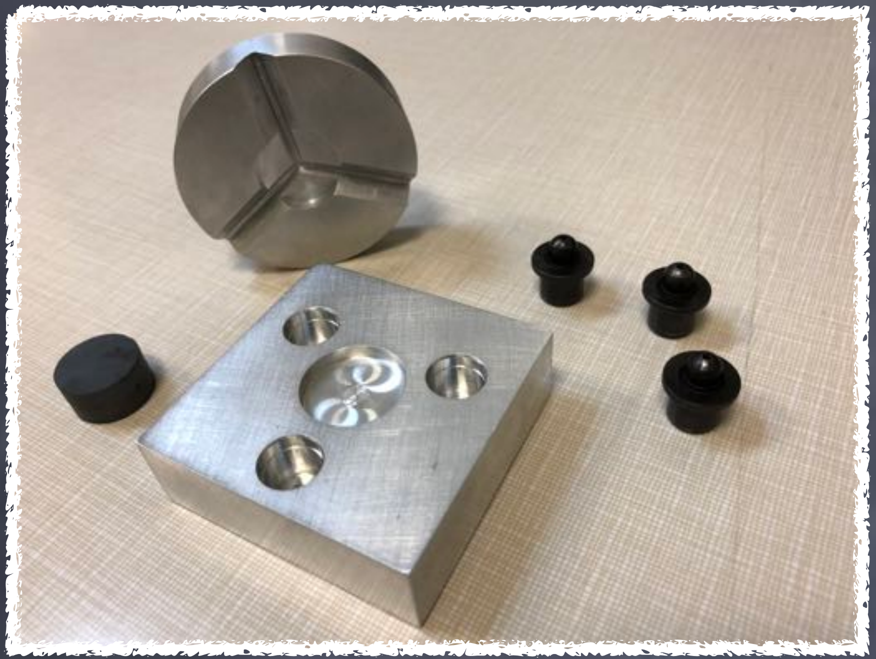
Calculations

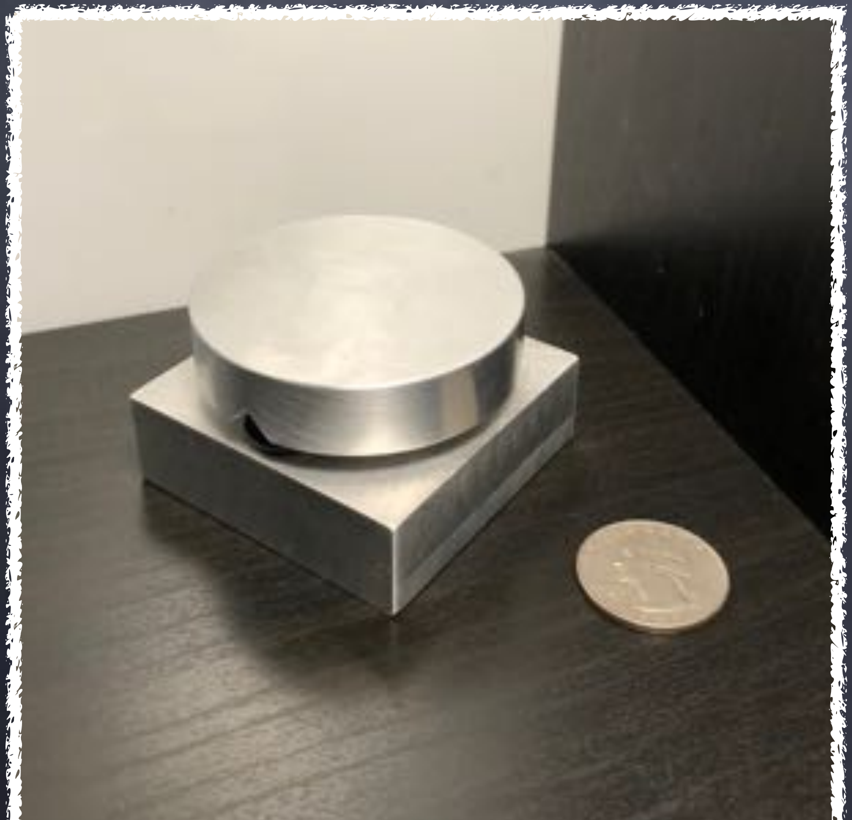
- The expected performances for this system were measured using Prof. Slocum spreadsheet and the results are presented:

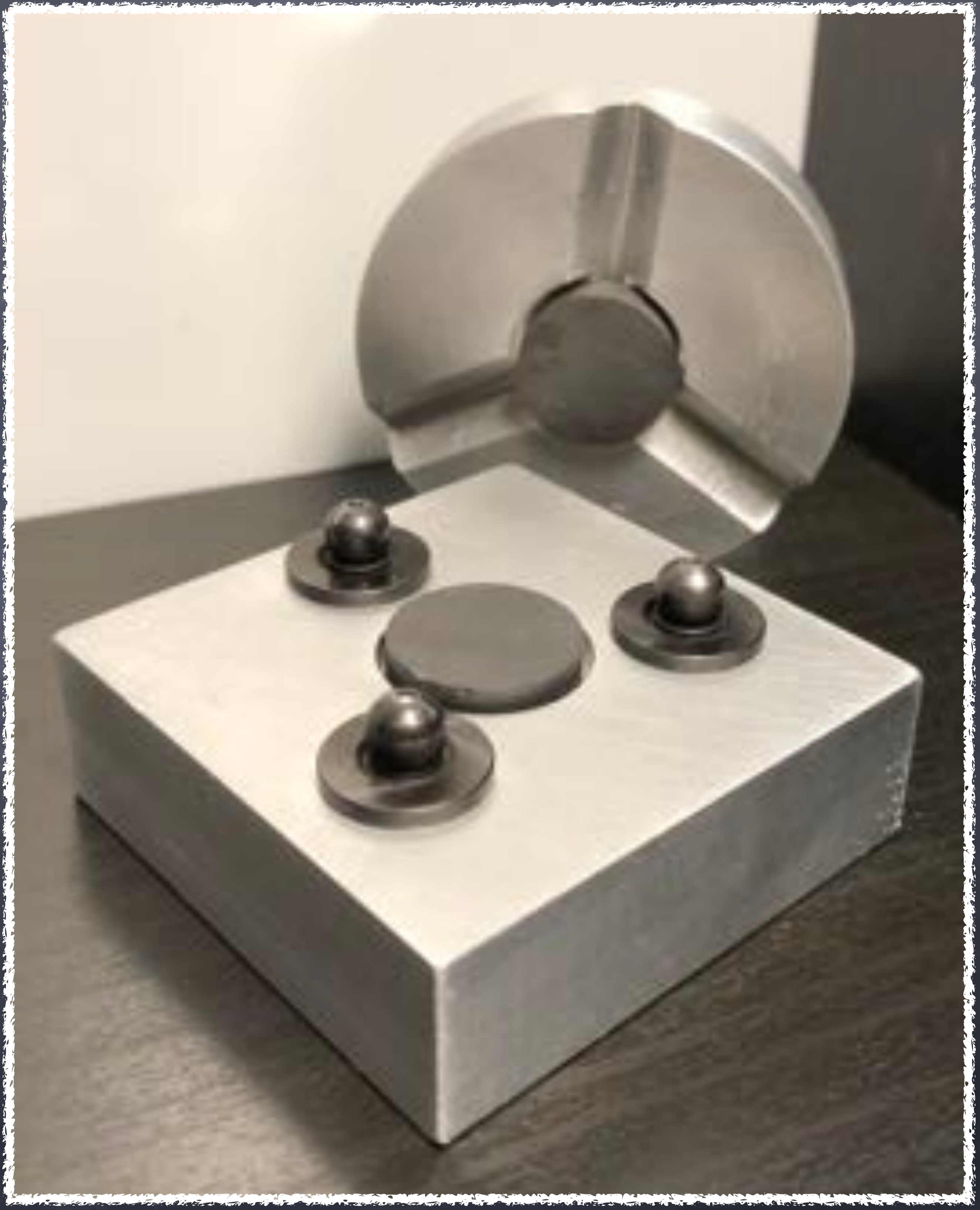
Results: Error motions			**Xerr**	**Yerr**	**Zerr**	
Error motions are at X,Y,Z coordinates (m)			6,000	0,000	0,000	
deltaX	0,00E+00		RMS	3,21E-07		
deltaY	-2,14E-07		*Homogenous Transformation Matrix:*			
deltaZ	-2,39E-07		1,00E+00	0,00E+00	0,00E+00	0,00E+00
EpsX	-1,46E-05		0,00E+00	1,00E+00	1,46E-05	-2,14E-07
EpsY	0,00E+00		0,00E+00	-1,46E-05	1,00E+00	-2,39E-07
EpsZ	0,00E+00		0,00E+00	0,00E+00	0,00E+00	1,00E+00

- The results show that even for a load of 2N in the edge of the equilibrium triangle resulted error motion at 6m is imperceptible (1/50 of a mm). This is a promising result since given the weight of the element it is unlikely to get more nominal load that that. Stiffness at this point is not a problem since, should a force >2N move the lens, the operator can reposition it

Result





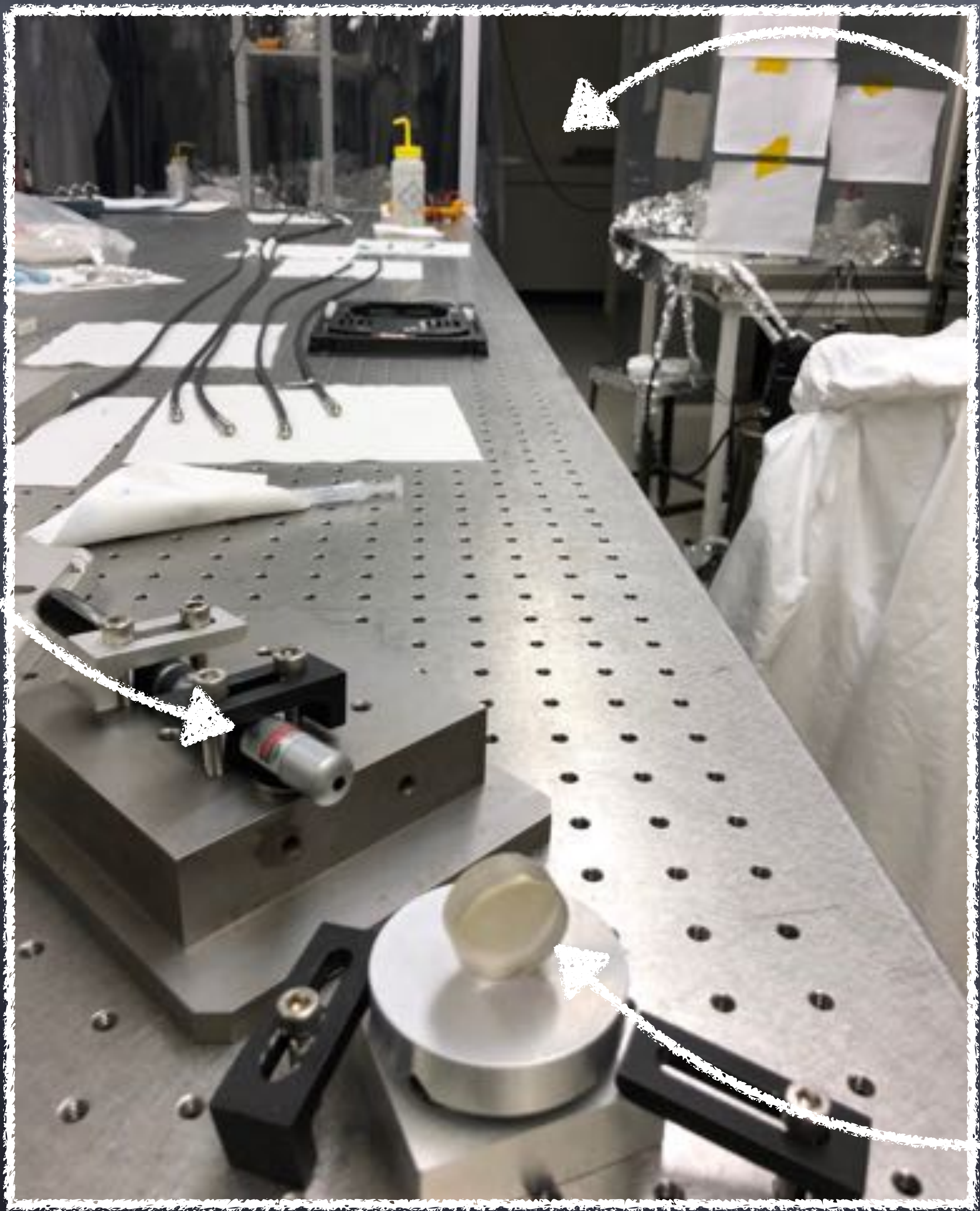


Testing

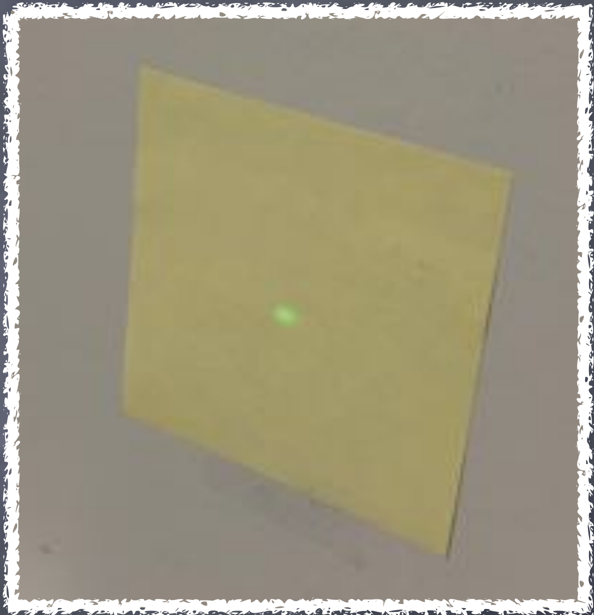
- We tested the repeatability of the position of a mirror glued to the KC. We traced a laser that was reflecting from the mirror at a distance of 6m
- On a second test, we simulated an external load by hanging weights from the top element of the KC to try to get an insight about stiffness

Test setup

Laser



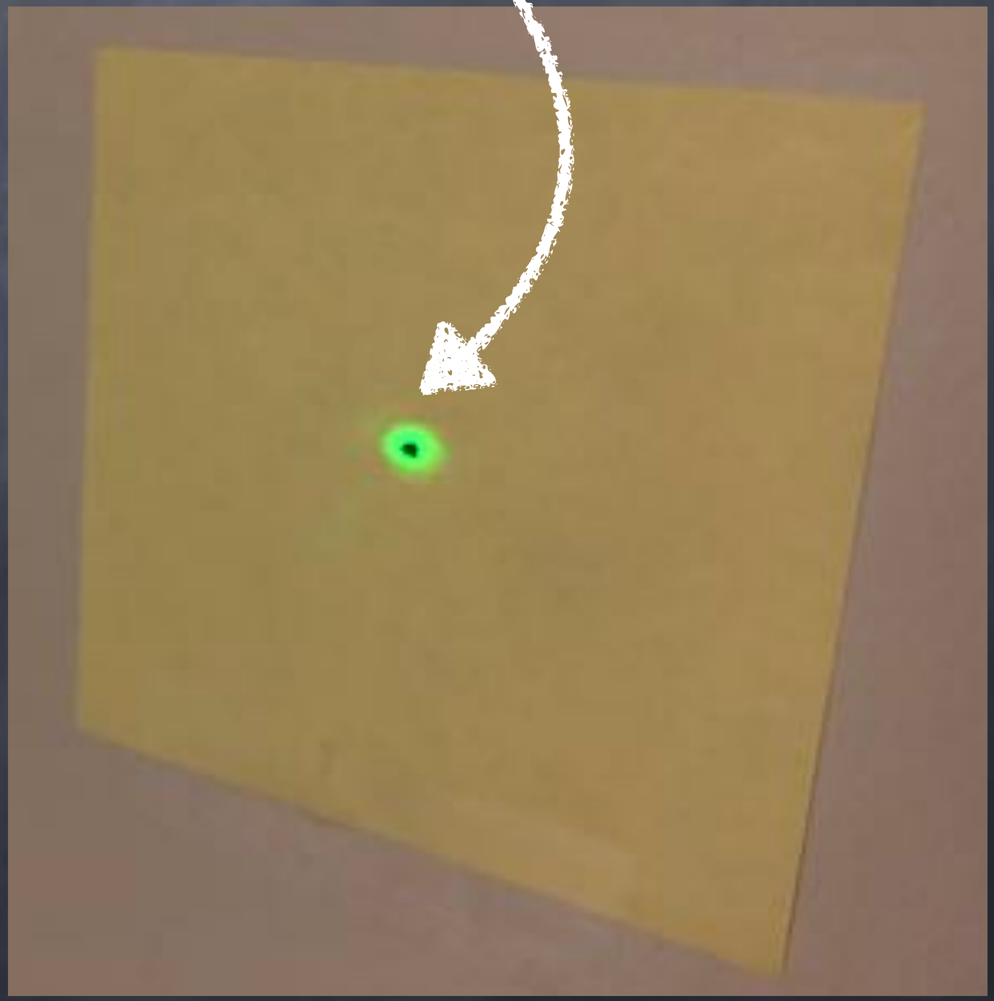
Post-it in the wall



Mirror on KC

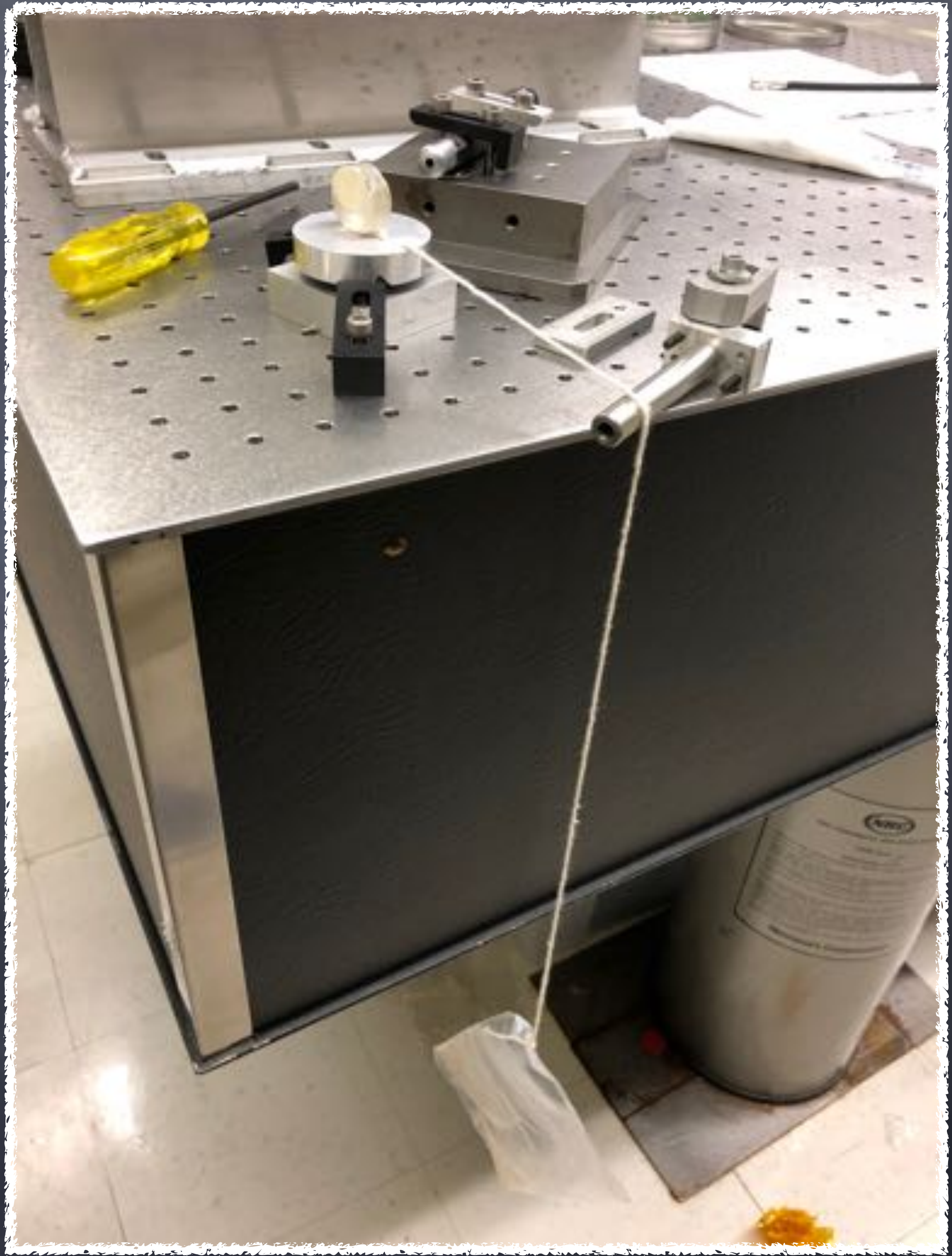
Repeatability

- We took out and back in the mirror more than 20 times and the repeatability was perfect, i.e. not displacement could be detected
- In future testing we are going to use a Quadrant Photo Detector (QPD) to increase the resolution and/or a more focalized laser



Stiffness

- To measure the stiffness we added weights thru small rope and measured at which level there was a perceptible difference in the laser position in the post-it. The result is that at least 150g needed to be added for a motion of about 1/2 mm, which is in the same order of magnitude as the calculations



Conclusions

- We have built a highly repeatable, relatively low stiffness kinematic coupling small enough to be potentially used to hold optics
- It is easy to use since the magnetic preload eases the in/out procedures
- Future versions should contemplate to have a more adapted height (i.e. to the laser's height) and an adapted holder for the lens
- The theoretical calculations are in general agreement with the performances tested