



## Zoom Lens Barrel Design

Final Design Review

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## Abstract

This is a design review of a zoom lens barrel with variable focus. The manufacturing and assembly are described, but since this is an educational project that will not be physically implemented, these steps may be incomplete. Furthermore, the design cannot be physically tested. The basic requirements were also arbitrarily assigned, so they may be unrealistic or too loose.

The goal of this project is to design a zoom lens mounting system. A pre-existing optical design will be used and built upon. See the following website for the entire lens patent:

(<http://www.kenrockwell.com/nikon/18-55-ii/patent-7277232.pdf>) The methods for adjusting zoom and defocus will need to be clearly specified and discussed.

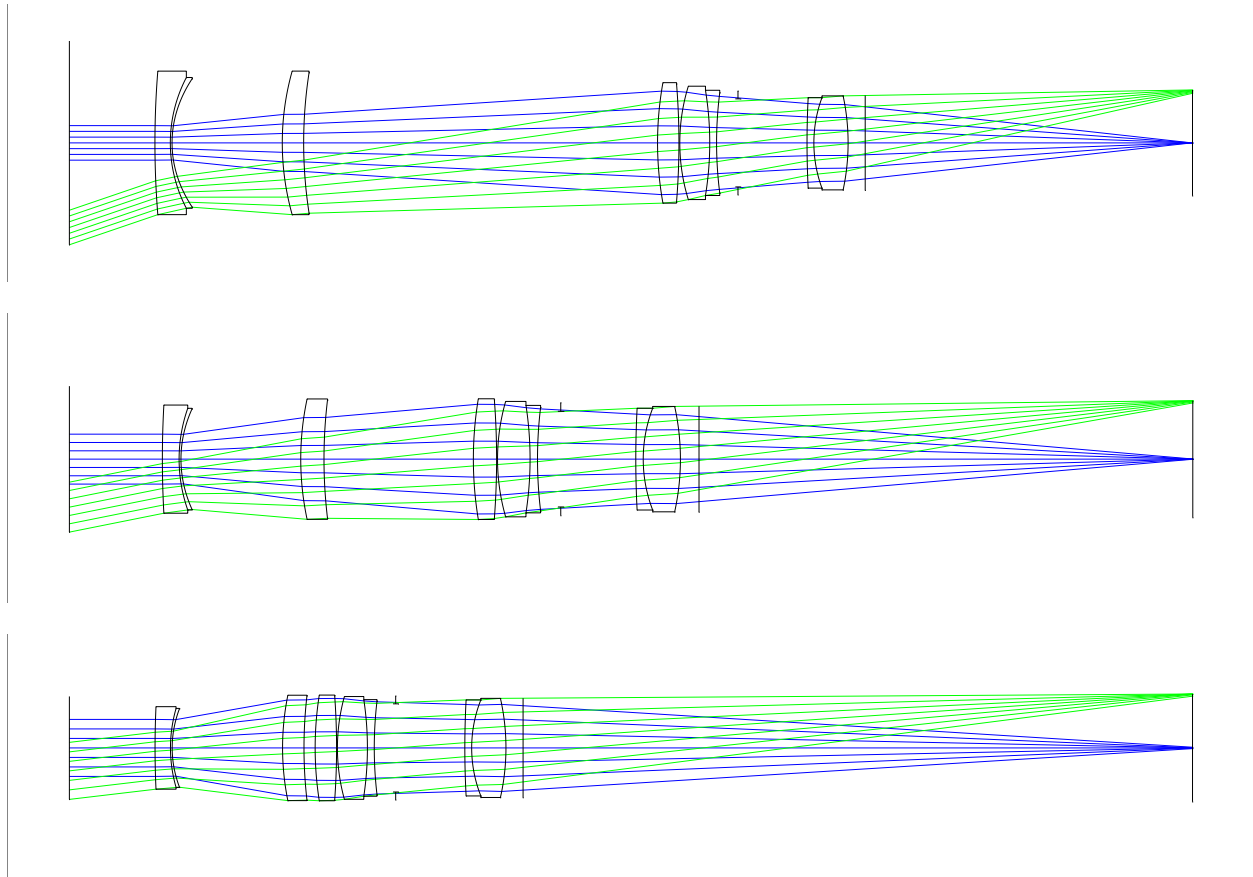
## Requirements

- Operational Temperature: 20° +/- 15°
- Shock Loading: 20G
- Volume of production: 1
- Schedule: Flexible
- Lens Spacing:  $\pm 100\mu\text{m}$
- Lens Group Spacing:  $\pm 200\mu\text{m}$
- Lens Decenter:  $\pm 50\mu\text{m}$
- Lens Tilt:  $\pm 20\text{arcmin}$
- **Defocus Range: >1in**
- Mount Type: C

## Lens Prescription

Surf	Type	Comment	Radius	Thickness	Glass	Semi-Diameter	Conic
OBJ	Standard		Infinity	Infinity		Infinity	0.000
1	Standard		Infinity	10.000		6.000	0.000
2	Standard		104.620	1.800	1.77, 49.6	4.808	0.000
3	Standard		16.500	0.200	1.55, 38.7	4.606	0.000
4	Standard		12.539	12.885		4.583	-0.479
5	Standard		30.943	2.500	1.81, 22.8	6.143	0.000
6	Standard	D5	53.571	1.303		6.088	0.000
7	Standard		39.679	2.500	1.64, 55.4	6.159	0.000
8	Standard		-84.183	0.100		6.102	0.000
9	Standard		22.469	3.500	1.52, 64.1	5.990	0.000
10	Standard		-37.953	0.800	1.80, 46.6	5.630	0.000
11	Standard		46.568	2.500		5.464	0.000
STO	Standard		Infinity	8.072		5.140	U 0.000
13	Standard		104.913	0.800	1.83, 37.2	5.598	0.000
14	Standard		15.211	4.000	1.52, 64.1	5.592	0.000
15	Standard		-26.189	2.000		5.777	0.000
16	Standard	D15	Infinity	78.142		5.794	0.000
IMA	Standard		Infinity	-		6.284	0.000

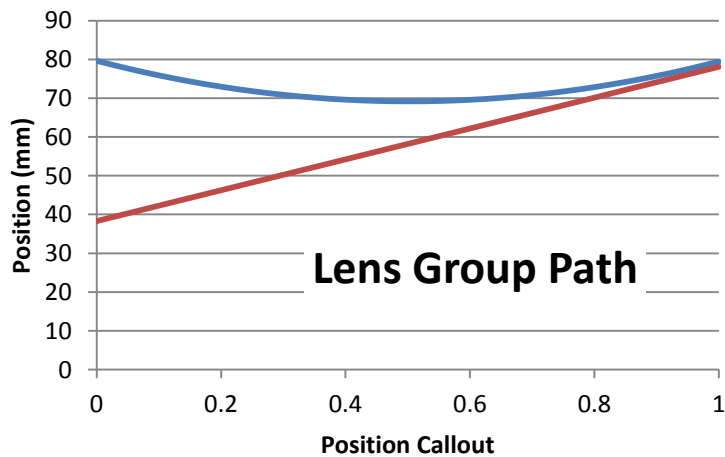
## Zoom Configurations



Lens Group Path (specified in mm)

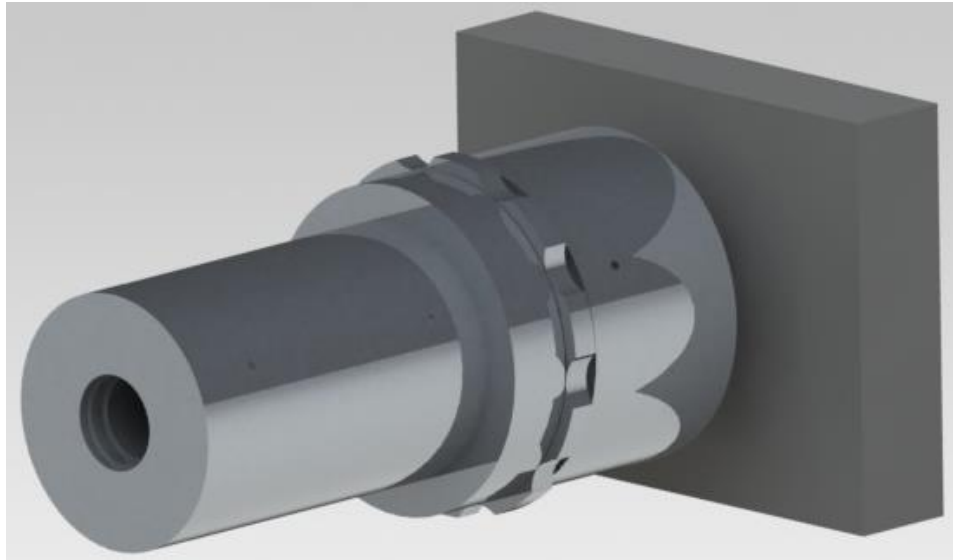
Group 1 (Spacing 1, D5): Quadratic from  $x=0$  to  $x=1$ :  $\text{Position}(x)=41.412x^2-41.588x+79.621$

Group 2 (Spacing 2; D15): Linear from  $x=0$  to  $x=1$ :  $\text{Position}(x)=39.8x+38.3$



## Design Concept

The design for this zoom lens is shown below. The geometry of this design is based on functionality alone- no aesthetic features have been added. In addition, there are not any indicators on the zoom lens that can be referred to when it is being used. It is assumed that the user will have access to the image and be able to refer to the image when making adjustments. The outer barrel was made thinner than the inner part to reduce extra weight, but an extra outer feature could easily be added if desired.



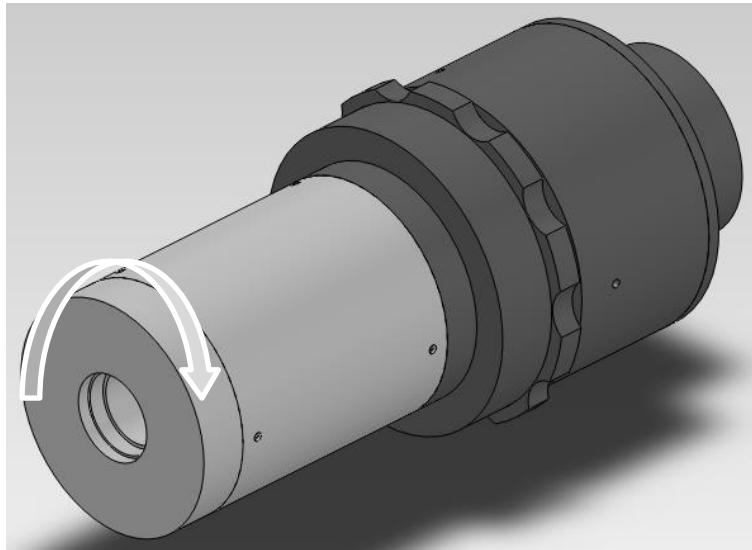
## Design Details

### External Functions

The following sections describe the mechanisms used in the design to adjust both focus and zoom. For additional detail, the assembly procedure in the appendix can be referenced.

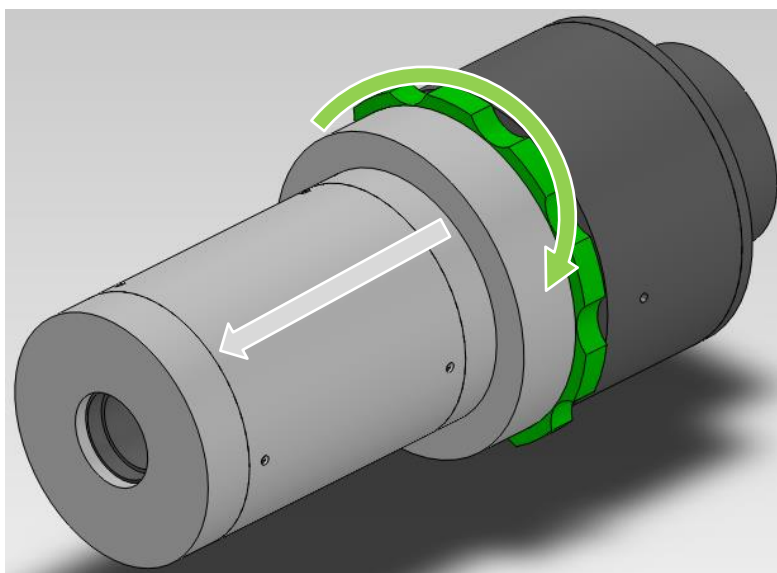
## Zoom Adjustment

In order to adjust the zoom, the front barrel section is moved clockwise or counter-clockwise. The entire range of zoom can be adjusted by twisting the front barrel ninety degrees. As previously mentioned, there is no reticle or other reference in this design that can be used to quantify the zoom position. This is particularly an issue for the zoom adjustment, since the movement of the lens cells cannot be seen externally.



## Focus Adjustment

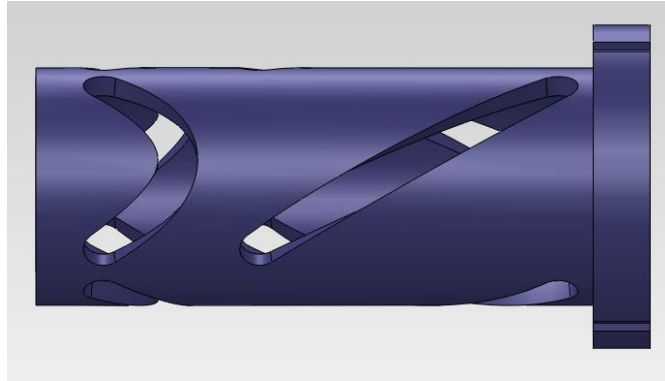
In order to adjust focus, the ribbed dial in the middle of the barrel is twisted. The front barrel section will move laterally without spinning. The entire range of focus can be achieved by turning the focus adjustment handle approximately 360 degrees.



## Mechanism Details

### Zoom Adjustment

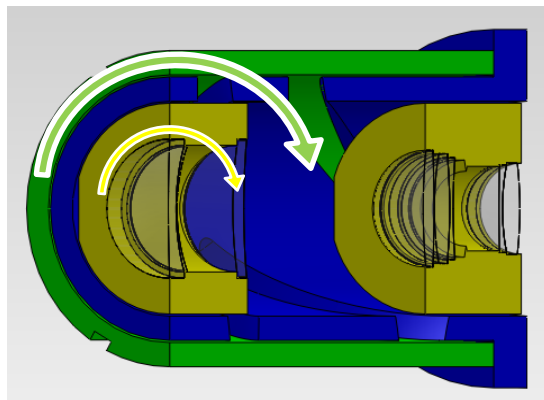
The front section of the barrel consists primarily of a cylinder with the lens paths cut into the sides of the barrel (referred to as the cam shaft). This cut is repeated twice more around the diameter of the shaft, with a high level of precision required (see Drawings section for additional detail).



A secondary cylinder (referred to as the cam guide) fits around the cam shaft. This shaft has vertical holes cut into its diameter that will be used in conjunction with the cam shaft to guide the lens cells along the correct zoom path.

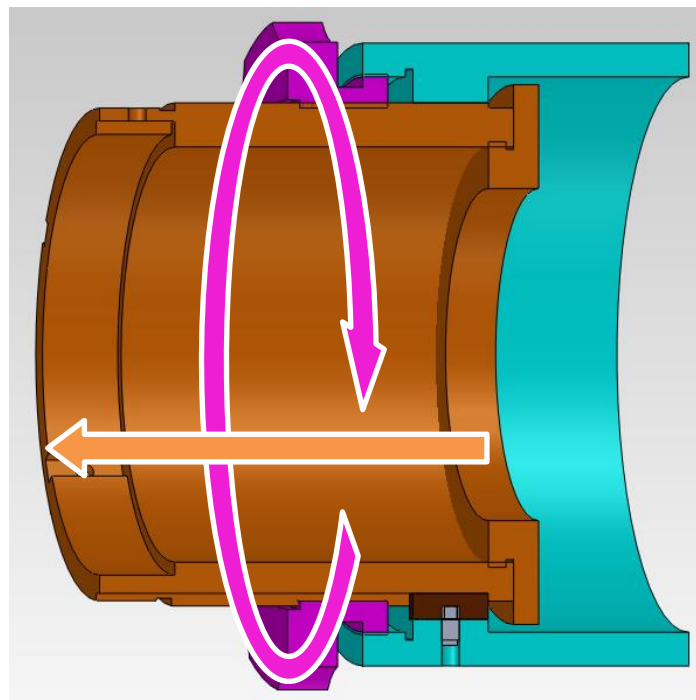
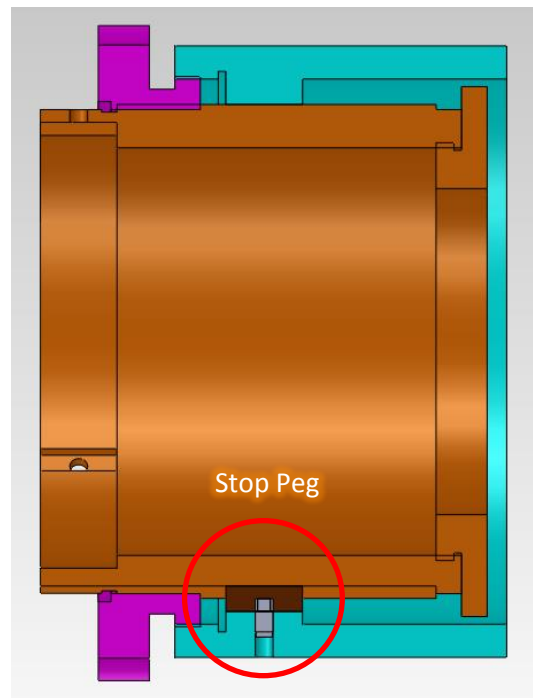


As the guide (green) is twisted, the lens cells will rotate in the same direction and move along their individual paths specified by the cam shaft (blue). The cam shaft will be held in place by the rest of the assembly.



## Focusing Mount

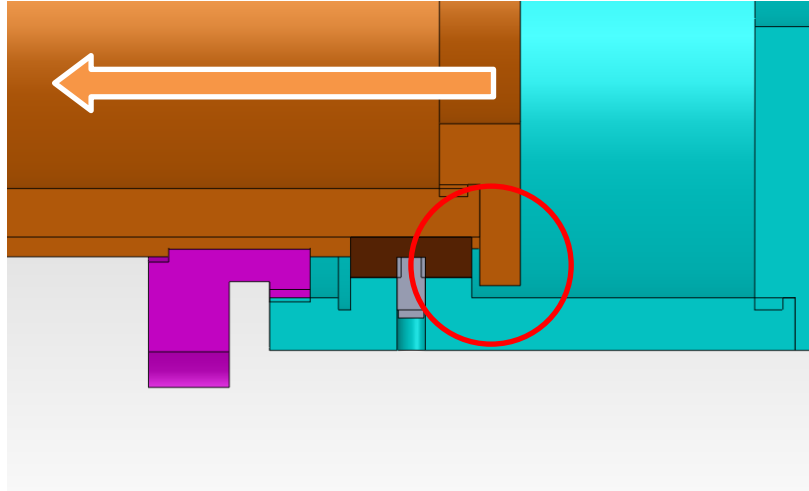
By twisting the focus adjustment handle (pink), the main focusing mount will move to the left relative to the focus attachment (teal). Three stop pegs will prevent the two elements from rotating relative to one another. The reason that the adjustment handle does not bind with the attachment is that the inner threads are much more aggressive than the outer threads. By the time the focus has been fully extended, the handle has only moved a few tenths of an inch relative to the attachment.



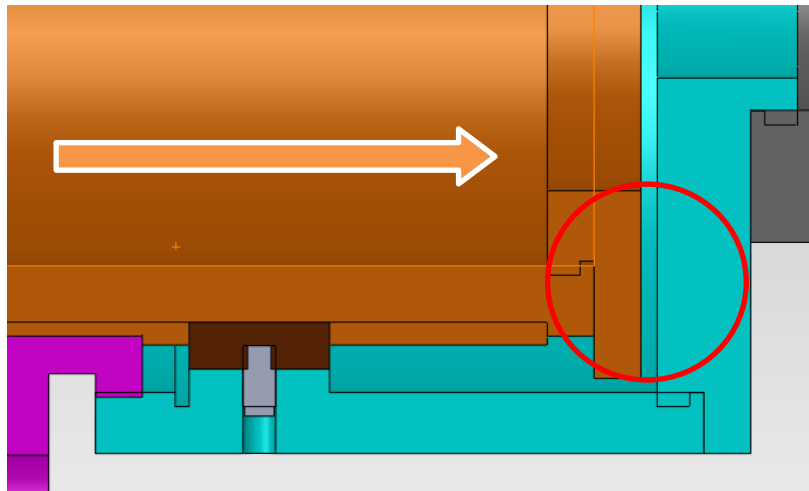
## Boundaries

### Focusing Mount

When the focus has been fully extended, the focus adjustment stop comes into contact with the attachment and prevents further movement. The stop must be sufficiently tightened, but not much tightening is necessary to prevent the assembly from coming apart.

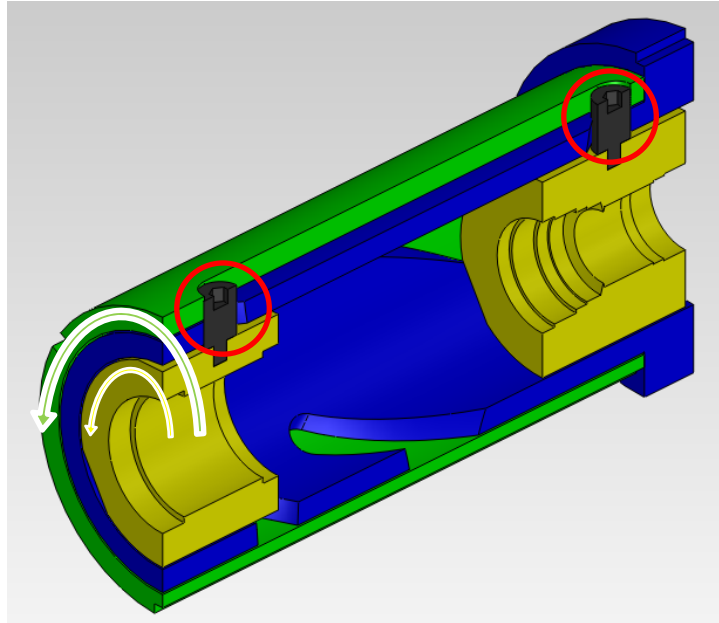


When the focus has been fully contracted, the stop will come into contact with the mount interface. In this case, the mount interface is threaded. If this is not the case, the stop peg will also come into contact with the end of its track.



## Zoom Adjust

When the zoom has been fully extended (or contracted), the geometry of the components will not allow the assembly to rotate further. The strength of the material will prevent any damage from occurring.



## Requirements Checklist

Requirement	Value	How Satisfied
Operational Temperature	20° +/- 15°	Cell Tolerances, Similar Material
Shock Loading	20G	Epoxy, Thread Grease
Lens Spacing	±100µm	Cell Tolerances
Lens Group Spacing	±200µm	Cam Shaft Tolerances
Lens Decenter	±50µm	Cell, Cam Shaft Tolerances
Lens Tilt	±20arcmin	Cell, Cam Shaft Tolerances
Defocus Range	>1in	Focusing Mount
Mount Type	C-Mount	Mount Interface

## Fabrication Plan

### Component Fabrication/procurement

#### Minimum Tolerances

Part	Tolerance (milli inches)	Purpose
Peg Stop	1	Small dimensions
Peg Screw	1	
Cam Shaft	5	Cylindricity of zoom adjustment
Cam Guide	5	
Adjustment Handle	5	
Cell G1	5	Placement of Cell Pegs
Cell G2	5	
Focusing Mount	5	Focus Adjustment
Focusing Handle	5	
Cell Peg	5	Cell Peg Placement
Compensator Fastener	10	Thread match
Focusing Attachment	20	General
Compensator Stop	20	
Cap	20	
Mount Interface	20	

## System Assembly

### Material List

Machined Parts: Aluminum Alloy 6061 (Anodized) – dimensions in drawings are intended to be after anodization.

Lubricant: LAMONS Thread Lubricant/Anti-Sieze (GP 450)

<http://www.lamons.com/products/thread-lubricant.html>

Epoxy (for mounting lenses): Sil-Bond RTV 4500 Aluminum Industrial

<http://www.industrialproducts.com/Sil-Bond-RTV-4500-Aluminum-Silicone-Sealant-p/rtv4500aluminum.htm>

## Assembly Steps

1. Mount Lenses to Cells – this step should be done prior to other assembly steps, since it is the most time-consuming part of the assembly. Each of the lenses will be placed into the shaft after a thin layer of epoxy has been placed around each corresponding ring that the lens will be placed into.
2. Attach cell to cam guide and shaft with cell pegs – before the parts are put together, a thin layer of thread lubricant is applied to both sides of the shafts. Care should be taken to prevent lubricant from getting onto the lenses. Once each of the cells have been placed (make sure to put them in the right direction!), the three pegs should be inserted and screwed into the base.
3. Mount stop pegs into focusing attachment – At this point, the stop pegs should be mounted into the focusing attachment part. Each of these pegs is secured into place by screwing the peg screws into the peg. This will be a tight fit, and may need to be carefully hammered into place.
4. Attach Focusing Attachment & Handle – The focus attachment is then slid onto the focusing mount from the right side (where the notches are cut all the way to the edge). It is slid all the way to the left side so that the focusing handle can be screwed onto the attachment before it is threaded onto the focusing mount. It should not be over-tightened at this point, though. Enough slack is needed so that it does not bind when the focus is adjusted.
5. Secure Focusing Mount with Compensator Stop – The compensator stop is attached to the focusing mount in order to prevent the attachment from coming off during use.
6. Insert Pegs, Attach Compensator Fastener – Pegs are inserted into the focusing mount prior to mating the two assemblies. In this step, the peg screws cannot be kept in the assembly due to spatial constraints. Therefore, the screws can only be used to mount the pegs. Once the pegs are mounted and the cam shaft has been placed into the focusing mount, the screws will not be needed.
7. Attach Pegs to Zoom Adjustment Handle – The zoom adjustment handle will allow the user to adjust the zoom without getting grease on their hands. It needs to bring the cam guide along with it, so the six pegs must be attached to the inside of the adjustment handle and screwed into place.
8. Attach Adjustment Handle and Cap – Once the pegs have been mounted, the adjustment handle is placed onto the cam guide and the cap is attached and screwed into place.
9. Attach Mount interface, attach to C-Mount

## System Test Plan

The system can be tested by rotating the correct parts and observing their movement. Additional testing can be performed by attaching the assembly to a camera mount and observing the zoom and defocus.

## Risks

### Focusing Mount Exposed Thread

When the focus is extended, some parts of the focusing thread will be exposed. This part has thread lubricant on it, which should not get everywhere. On the other hand, depending on the usage of the camera, there is risk of dirt getting into the thread and causing the focus adjustment to jam up. This risk can be mitigated by keeping the camera covered when not in use and avoiding dusty environments.

### Thread tightening

Almost all of the parts in this assembly are attached with threaded screws. This makes the assembly versatile and easy to put together, but adjusting focus and zoom can cause this to be an issue. It is important that the assembly threads are tightened with more force than the force necessary to make adjustments. If this becomes an issue, the parts can be glued together when they are tightened.

### Thread Lubricant Outgassing

At high temperatures, some thread lubricants will release gases that can end up coating the lenses. This will essentially ruin the system. To avoid this, a thread lubricant should be used that has known outgassing properties. If the system is used in higher temperatures, a different thread lubricant should be used. Additionally, high temperature environments should be avoided even when the camera is not in use.

## Error Budget

### Temperature Expansion-Lens Mounting

The lenses will not expand at the same rate as the barrels inside which they are mounted. This will be accommodated with using RTV epoxy, which has an appropriately large CTE as well as a low elastic modulus (see previous design).

### Temperature Expansion-Lens Spacing

The spacing of the lenses will increase with temperature expansion. This expansion is acceptable because it stays within the requirements:

$$\Delta L = L * \Delta T * \alpha = 1.5in * 15^{\circ}C * \frac{23ppm}{^{\circ}C} = 0.5 \text{ millinches} = 13\mu m$$

### Temperature Expansion-Cam Alignment

As long as the components that are involved in zoom movement are made of the same material, temperature fluctuations should not affect the alignment of the components.

### Shock Loading- Lens Mounting

These lenses are somewhat larger than the previous lens designs in this class. However, the bond strength of the epoxy used should be enough to prevent 20G shock loading from damaging the lens mounting. As long as the contact area is greater than the required surface area to prevent movement at 20G, the lenses will meet the requirement.

Mass of larges lens: 1.22 grams

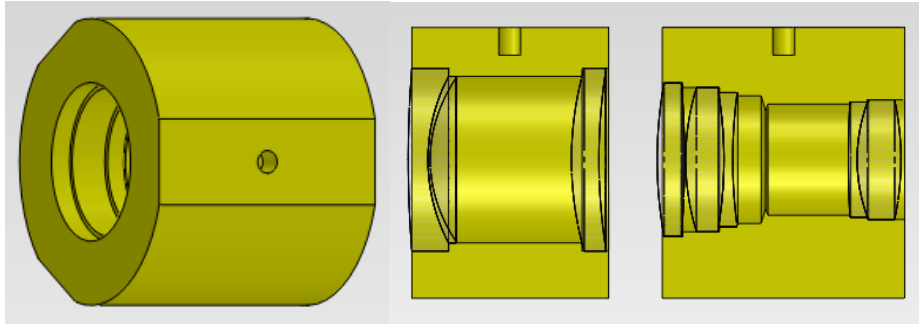
Maximum force from shock loading: 0.239N

Tensile Strength of Epoxy: 310 lb/in<sup>2</sup>=2MPa

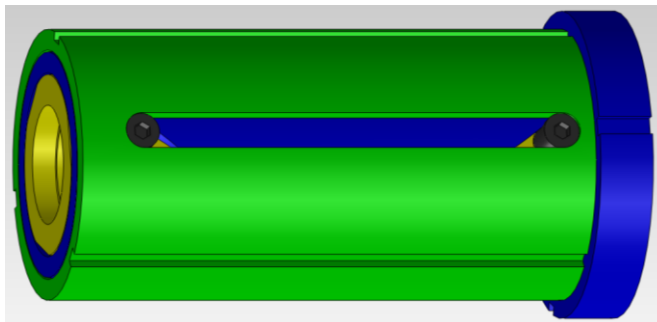
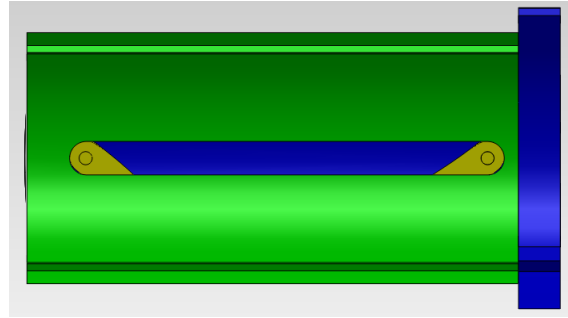
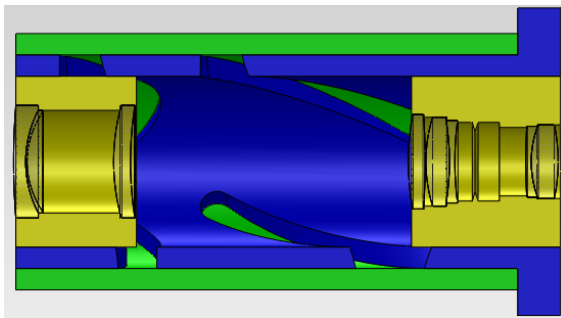
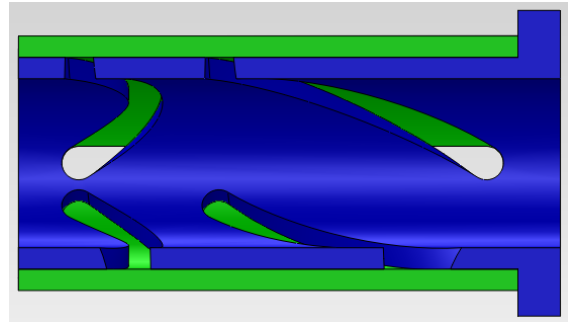
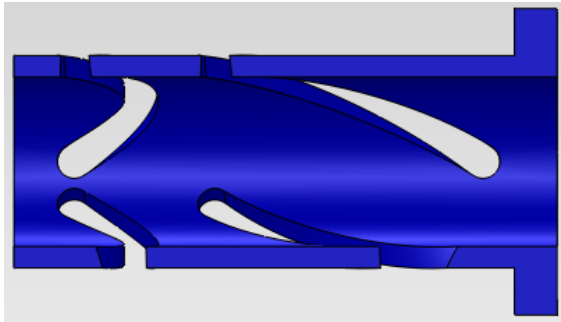
Minimum Contact Bond Area: 0.12mm<sup>2</sup>

## Assembly Procedure

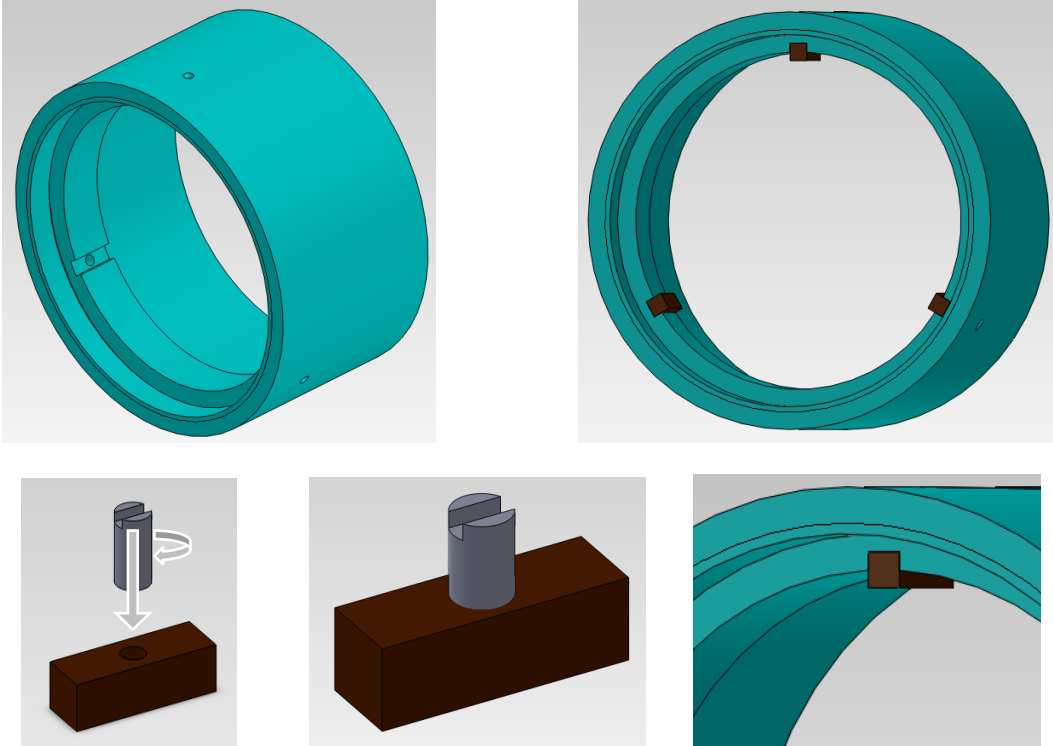
1. Mount Lenses to Cells (only gluing step)



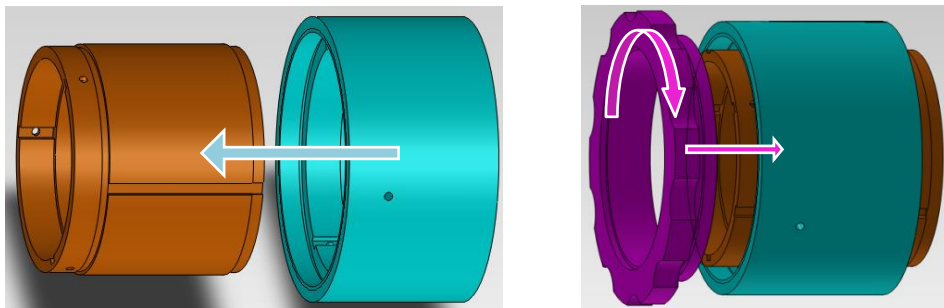
2. Attach cell to cam guide and shaft with cell pegs (lubricate threads, moving parts)



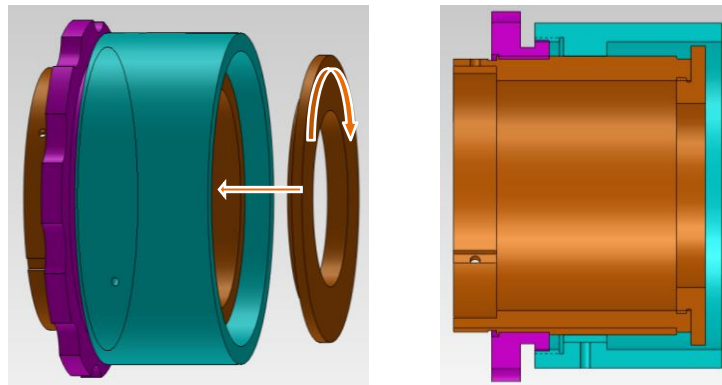
3. Mount stop pegs into focusing attachment



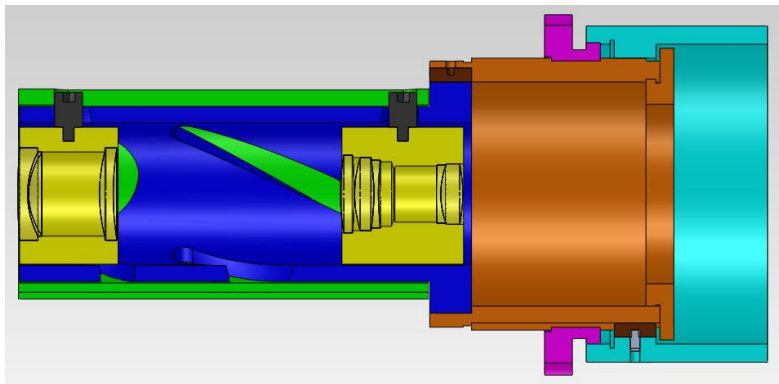
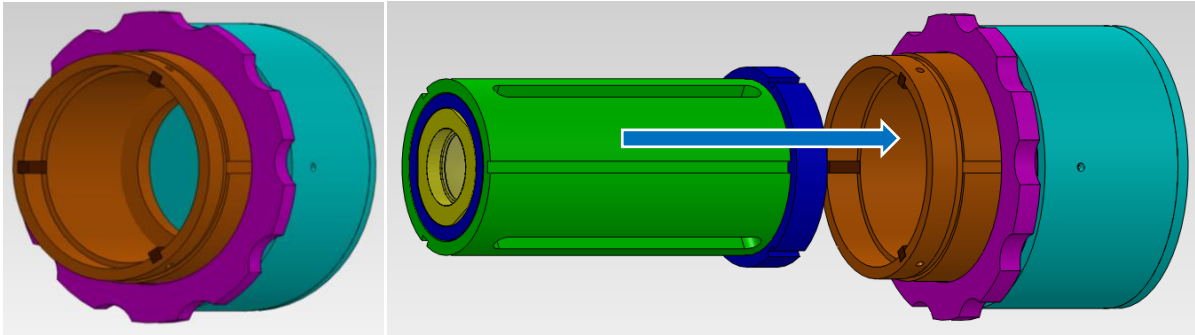
4. Attach Focusing Attachment & Handle (don't overtighten or it won't be able to defocus)



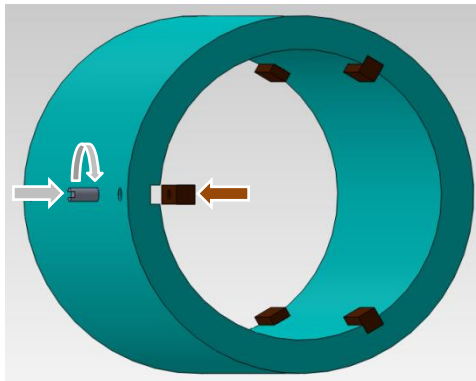
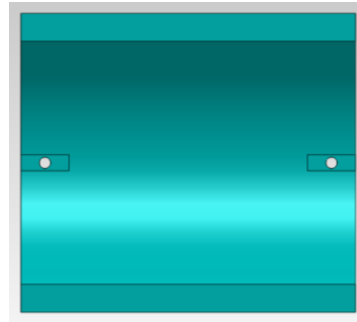
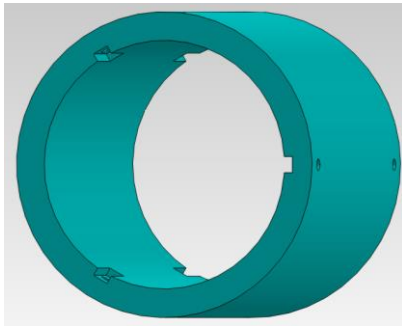
5. Secure Focusing Mount with Compensator Stop



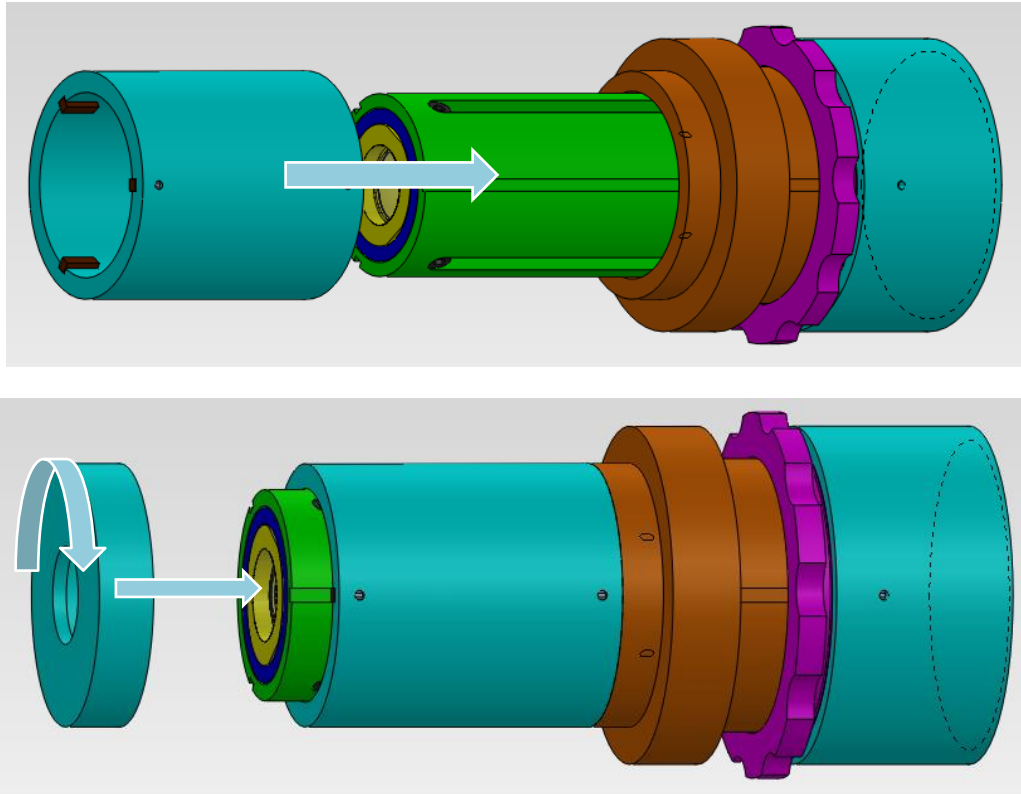
6. Insert Pegs, Attach Compensator Fastener



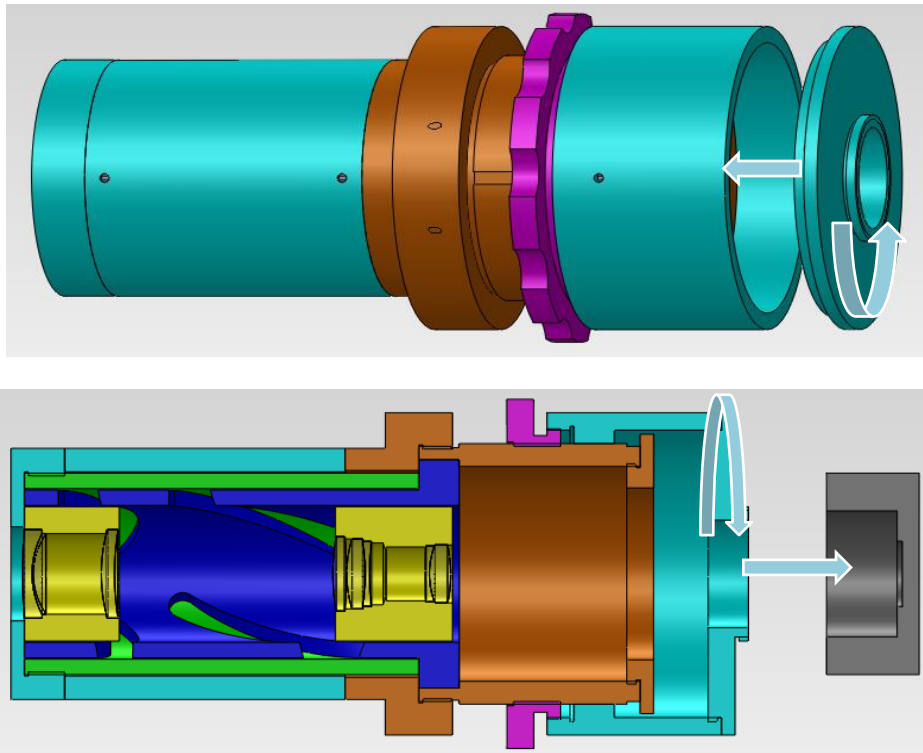
7. Attach Pegs to Zoom Adjustment Handle

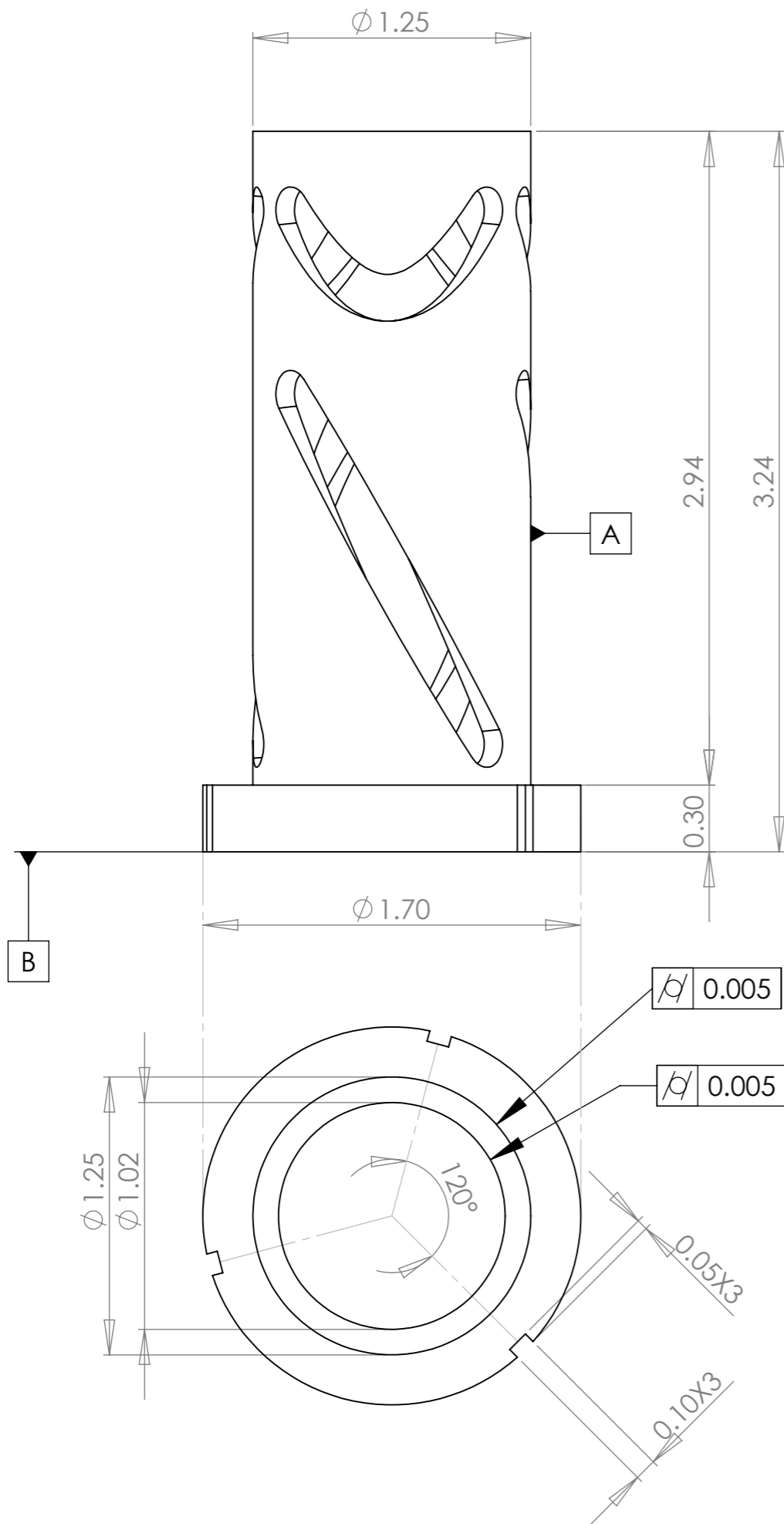


8. Attach Adjustment Handle and Cap



9. Attach Mount interface, attach to C-Mount



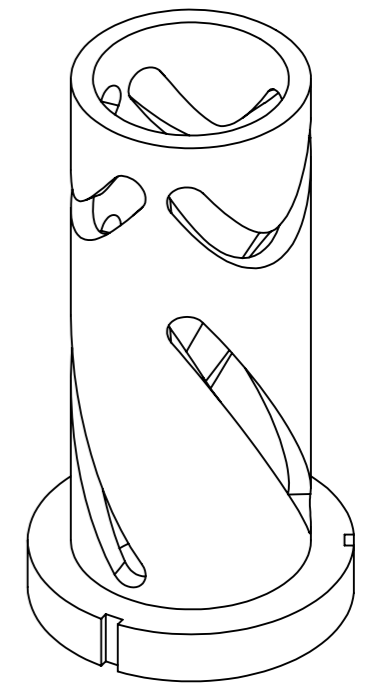
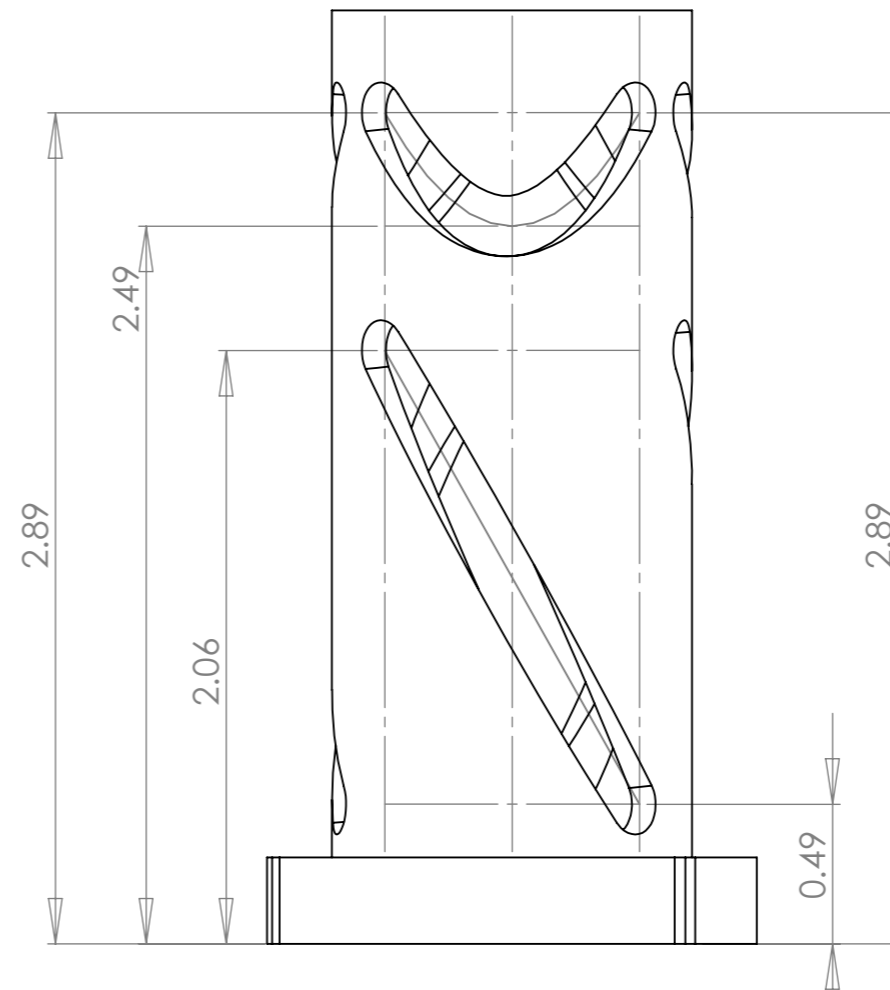


### Track Path for Slot Cuts

Each of the three cuts is a 0.21" cylindrical swept cut that spans 90 degrees relative to datum A. The position in the equation below gives the central position relative to datum B. The dimensional profile tolerance must be within 0.005".

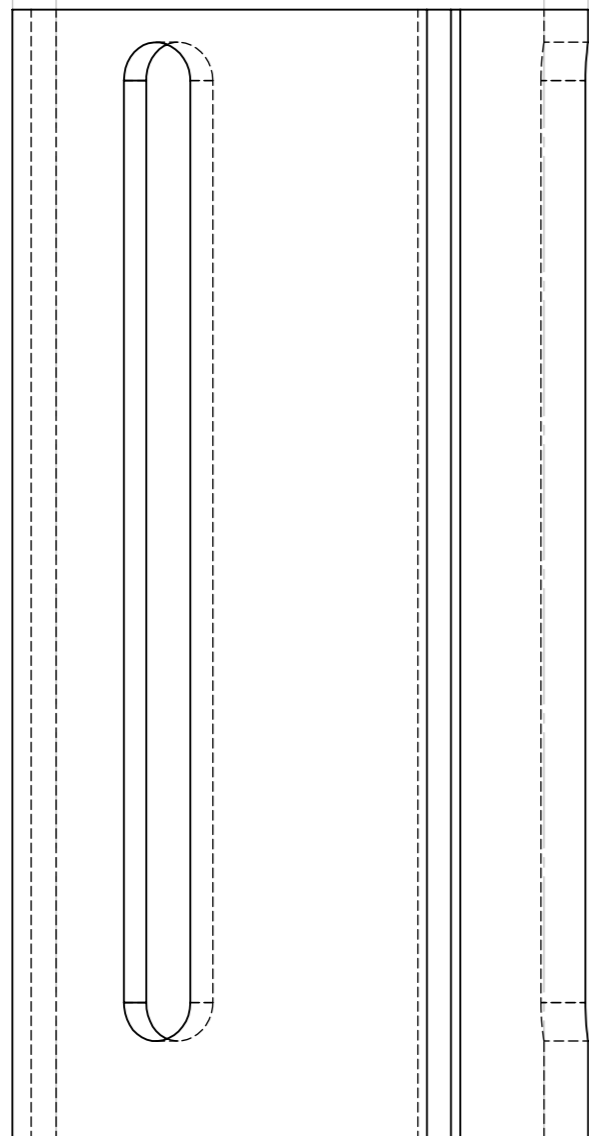
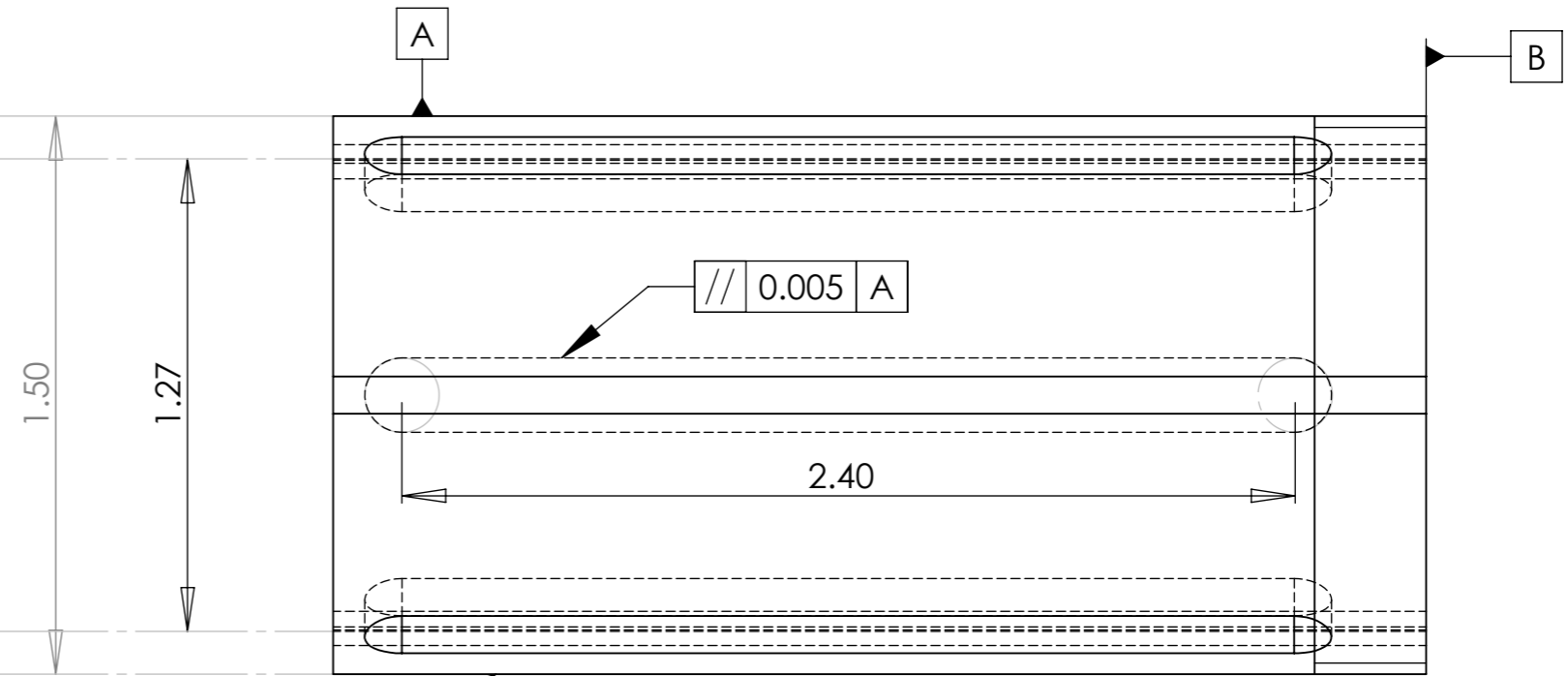
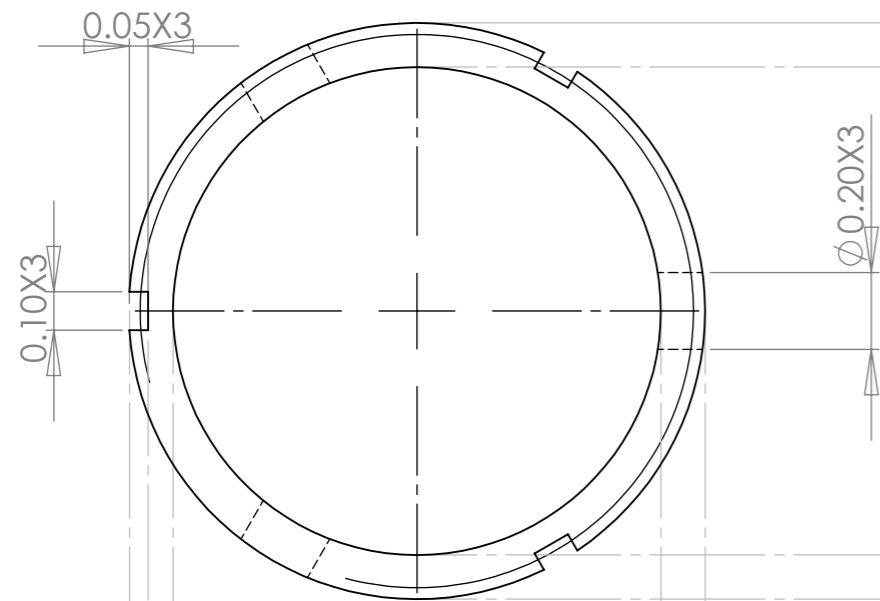
$$\text{Cut1}(x)=0.000193x^2-0.018192x+2.89$$

$$\text{Cut2}(x)=0.01741x+0.49$$



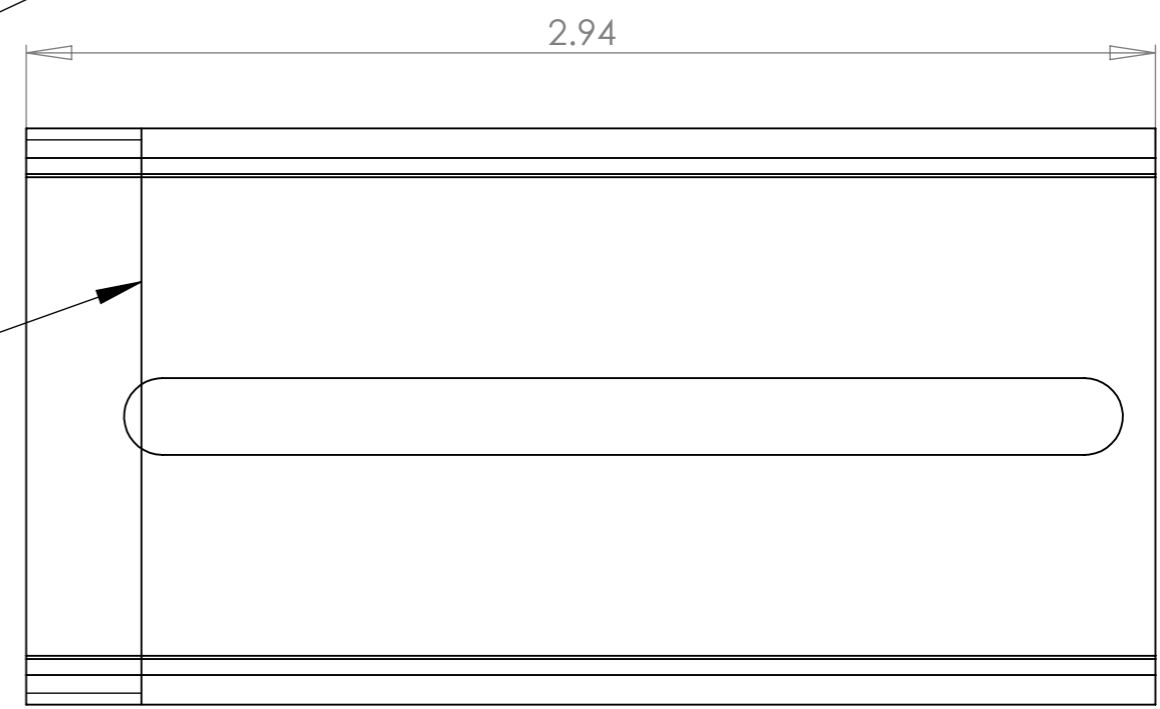
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DRAWN				NAME		SIGNATURE		DATE		TITLE:	
CHK'D											
APPV'D											
MFG											
Q.A								MATERIAL:		DWG NO.	
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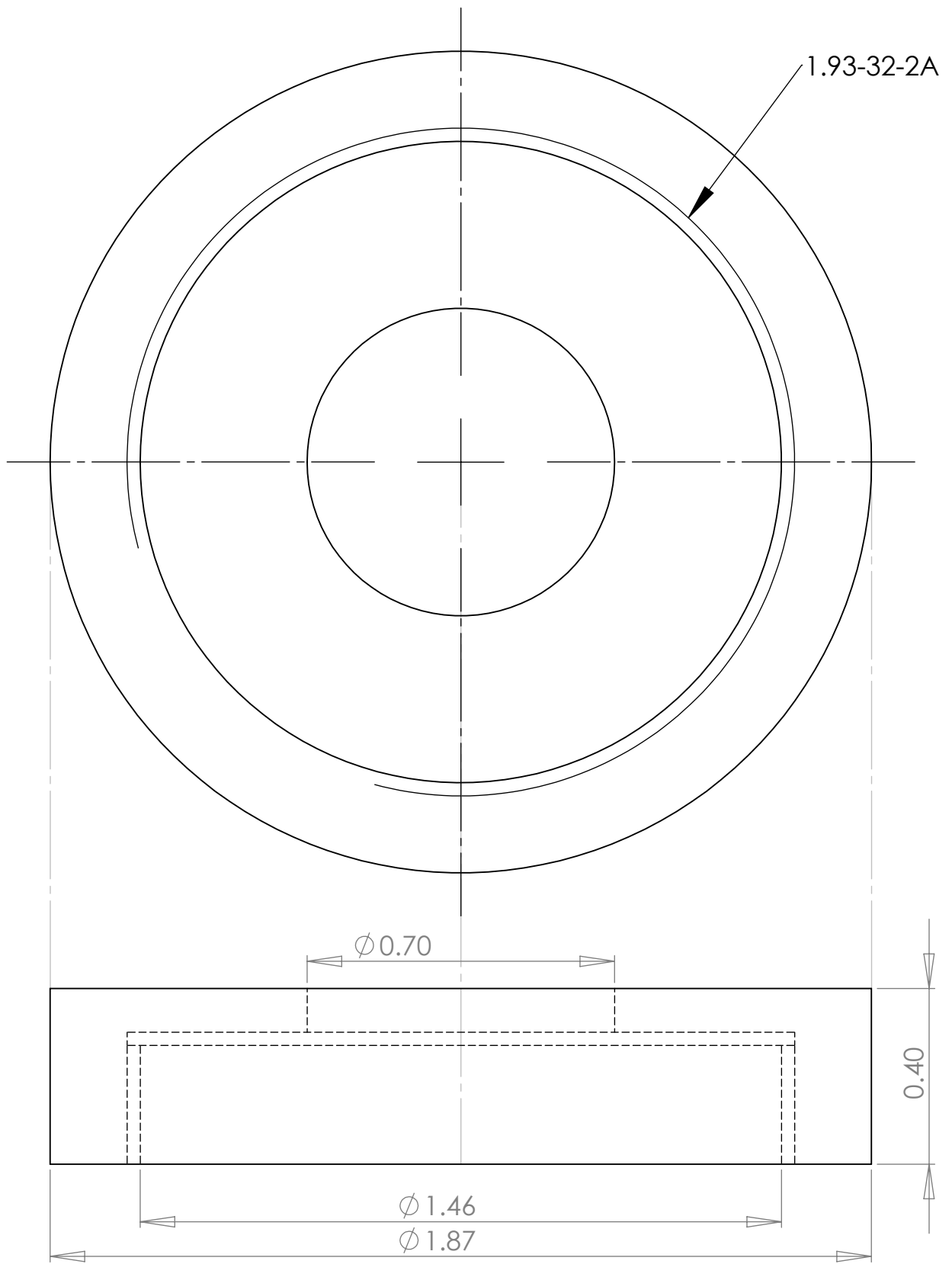


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APPV'D											
MFG											
Q.A								MATERIAL:		DWG NO.	
										Cam Guide	
								WEIGHT:		SCALE:1:1	
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										A3	



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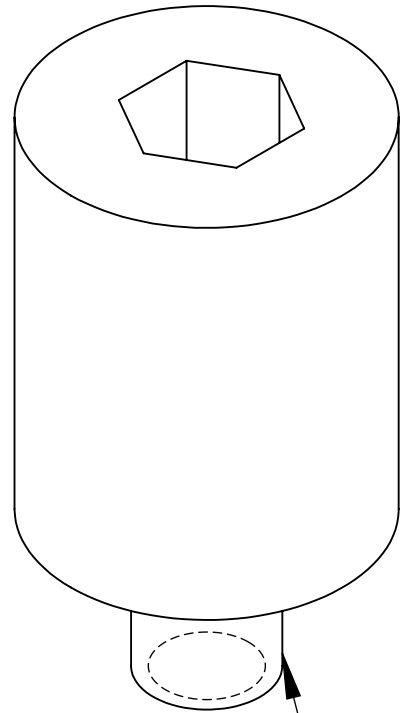
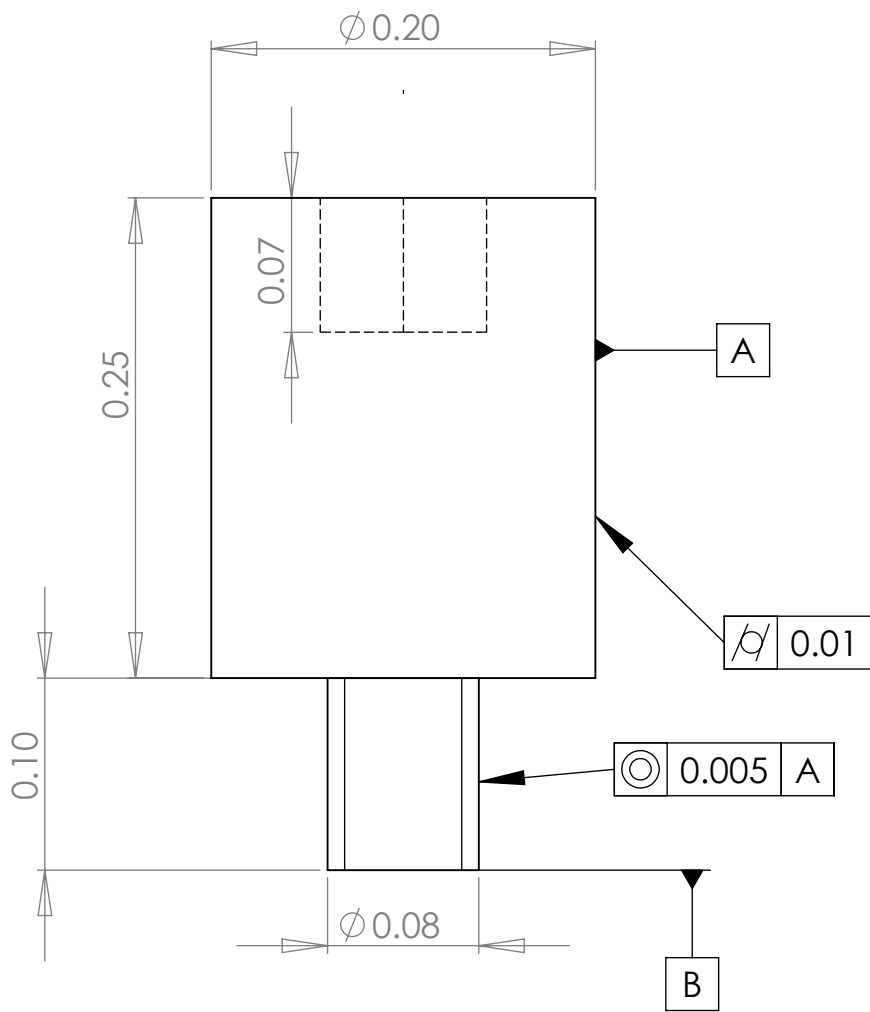
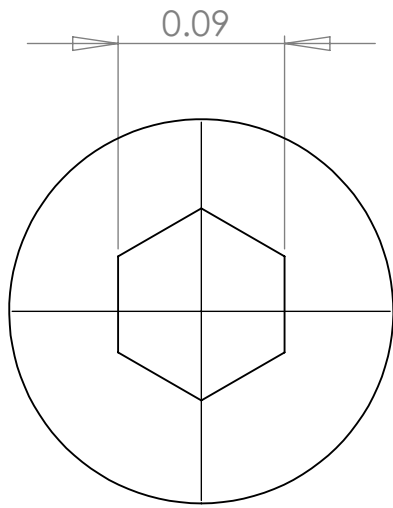
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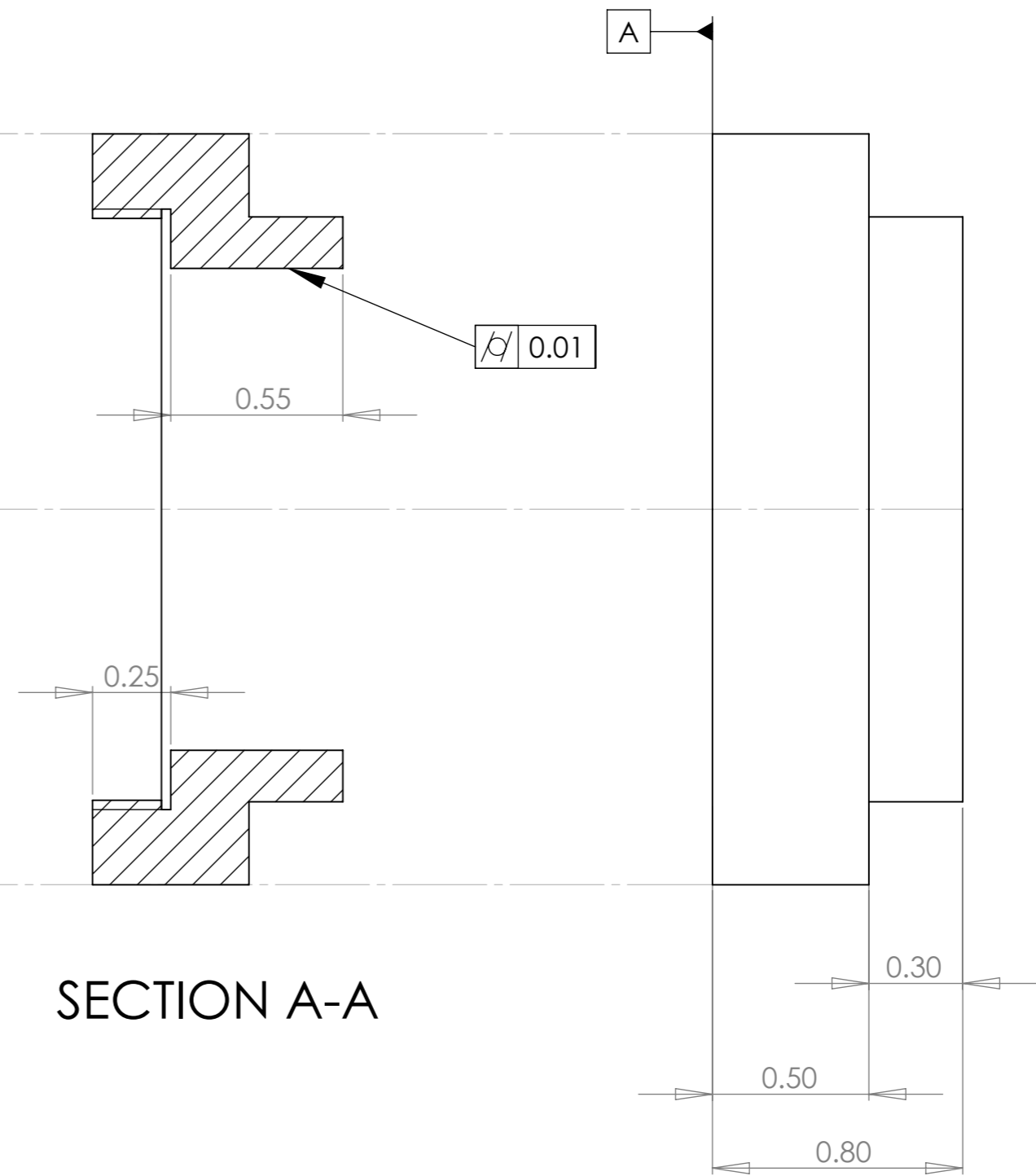
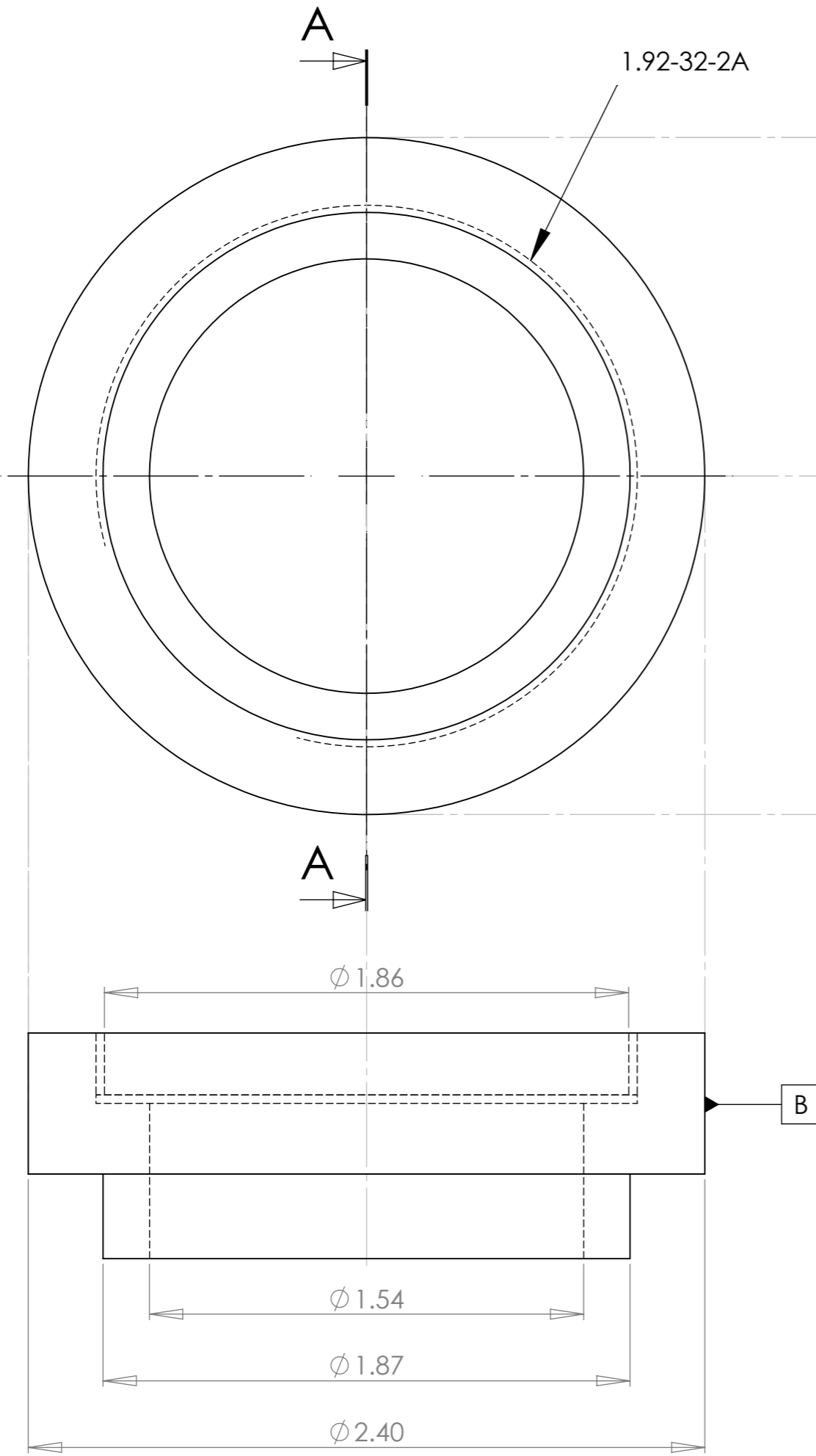
DEBUR AND  
BREAK SHARP  
EDGES

DO NOT SCALE DRAWING

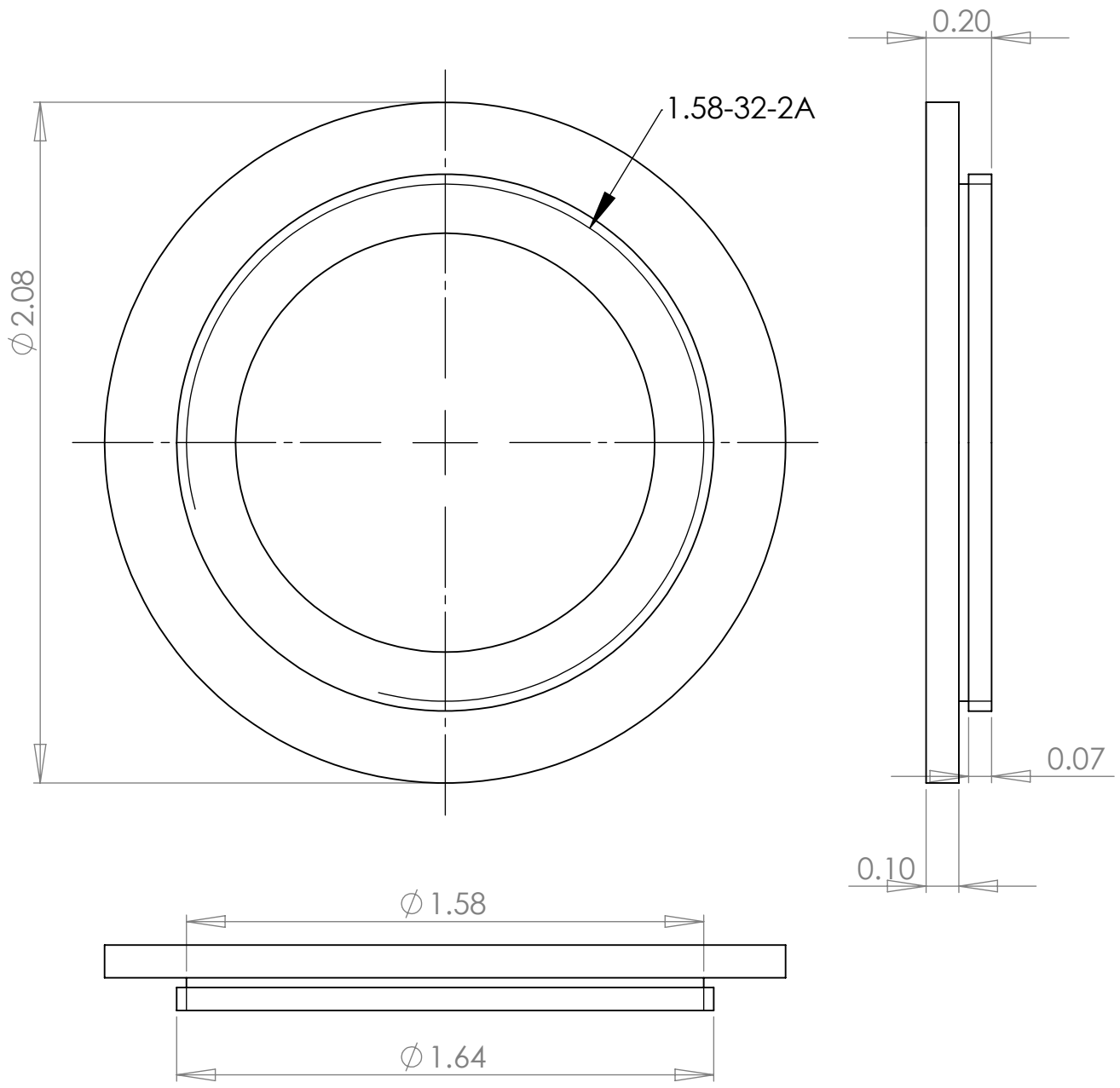
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	NAME	SIGNATURE	DATE		
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CHK'D					
APPV'D					
MFG					
Q.A					
				MATERIAL:	
				WEIGHT:	

TITLE:	
DWG NO.	Cell Peg
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SHEET 1 OF 1	



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DRAWN				NAME		SIGNATURE		DATE		TITLE:	
CHK'D											
APPV'D											
MFG											
Q.A								MATERIAL:		DWG NO.	
										Compensator Fastener	
								WEIGHT:		SCALE:2:1	
										SHEET 1 OF 1	



UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN MILLIMETERS  
 SURFACE FINISH:  
 TOLERANCES:  
 LINEAR:  
 ANGULAR:

FINISH:

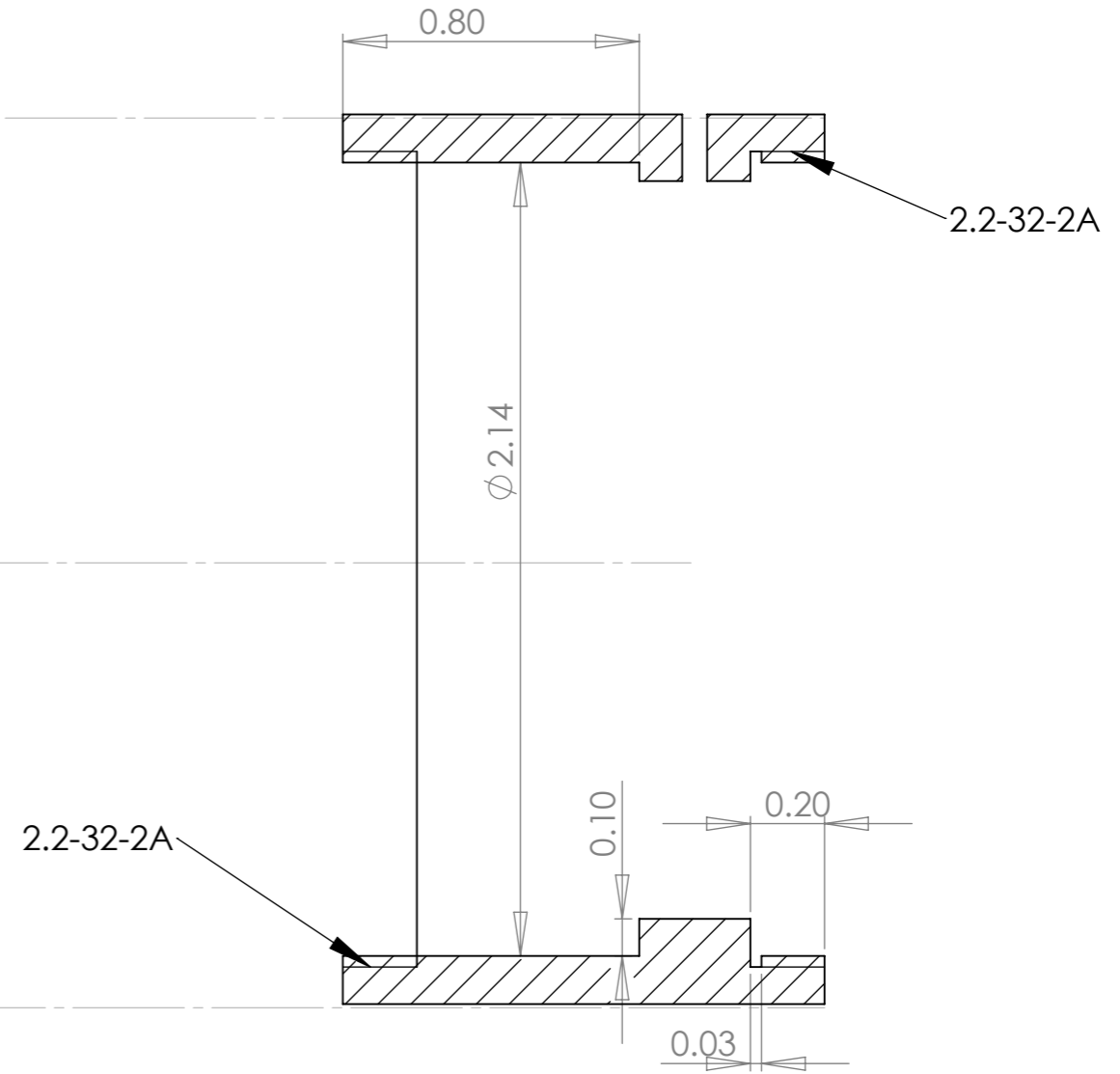
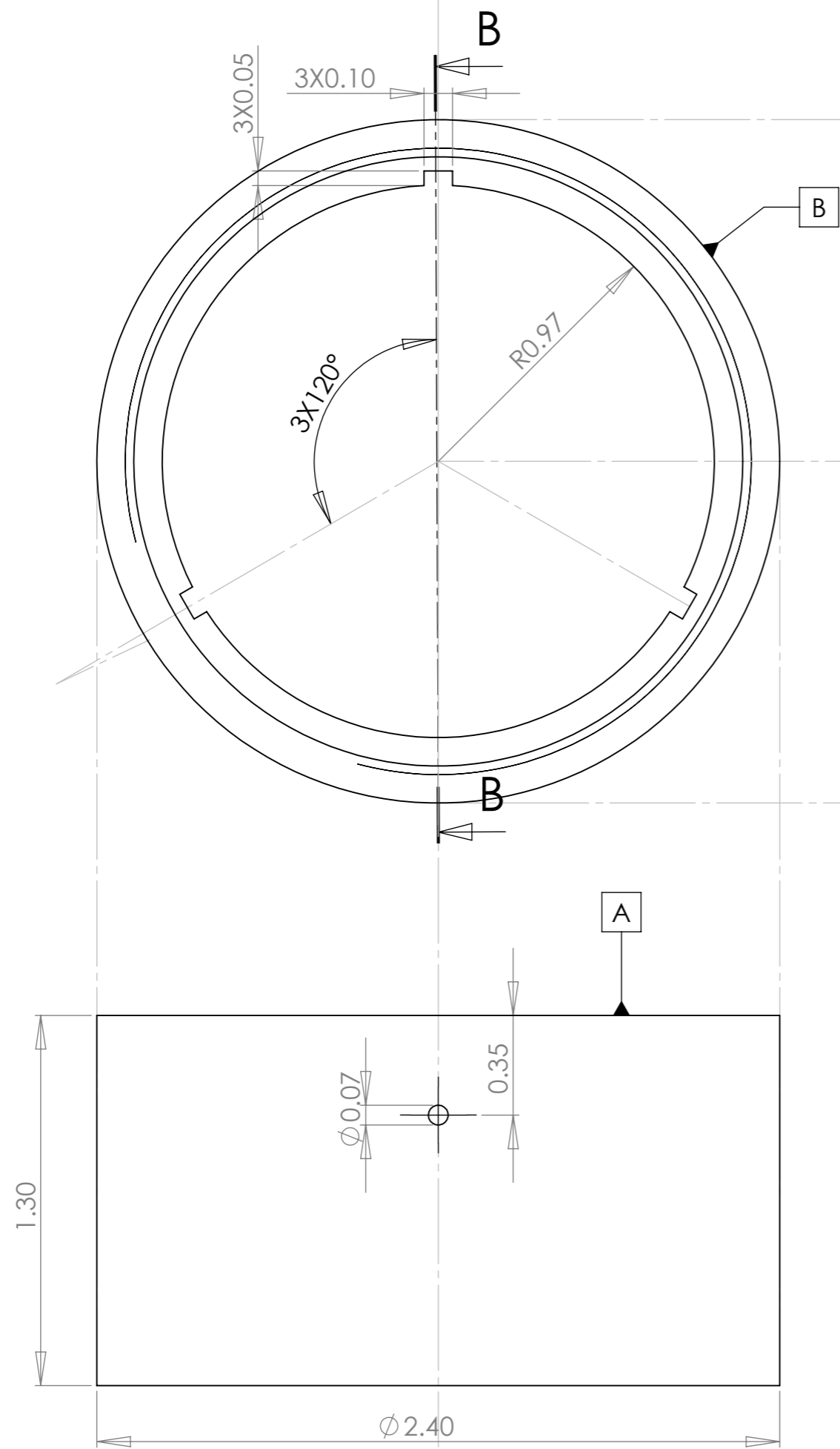
DEBUR AND  
 BREAK SHARP  
 EDGES

DO NOT SCALE DRAWING

REVISION

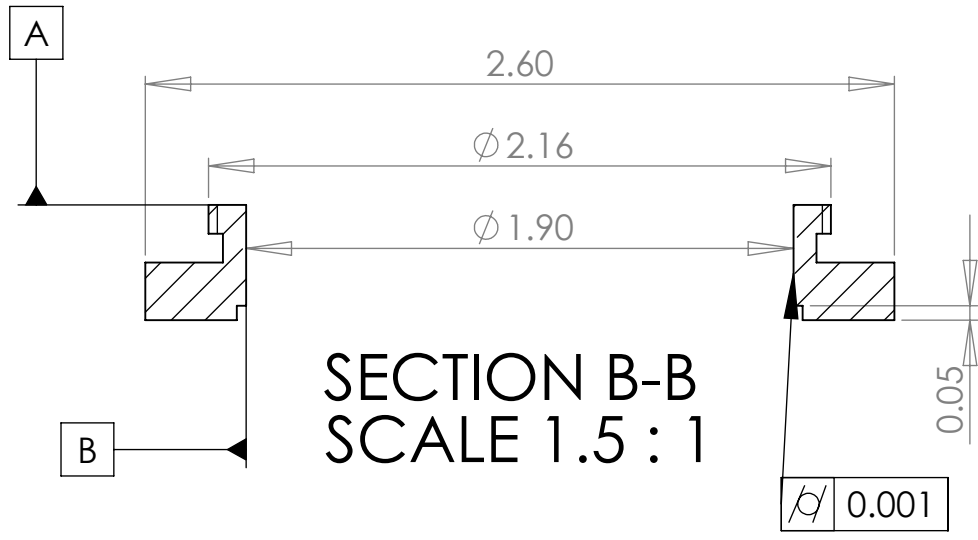
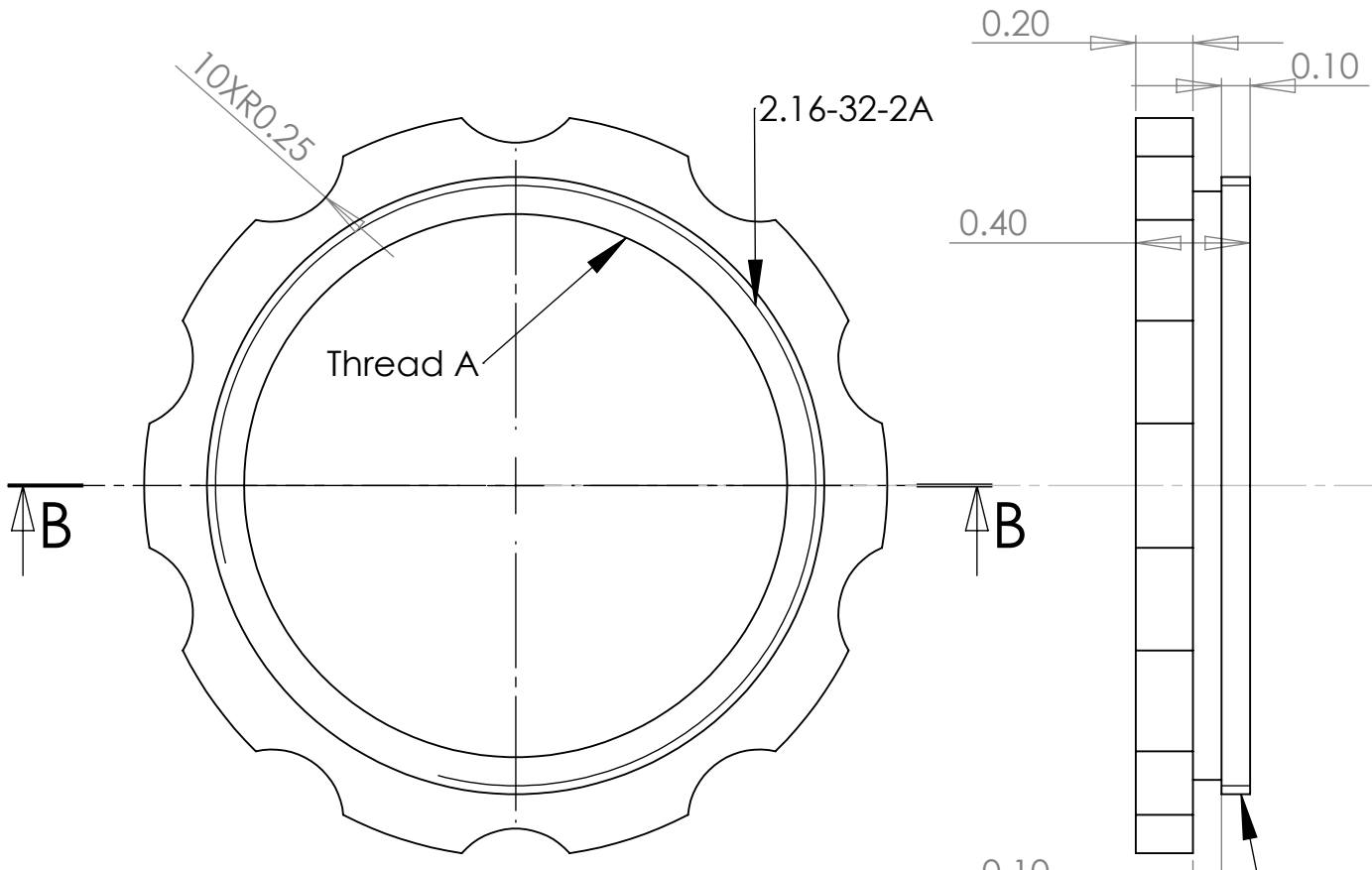
	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	
				WEIGHT:	

TITLE:	<h1>Compensator Stop</h1>	A4
DWG NO.		
SCALE: 1:1		SHEET 1 OF 1



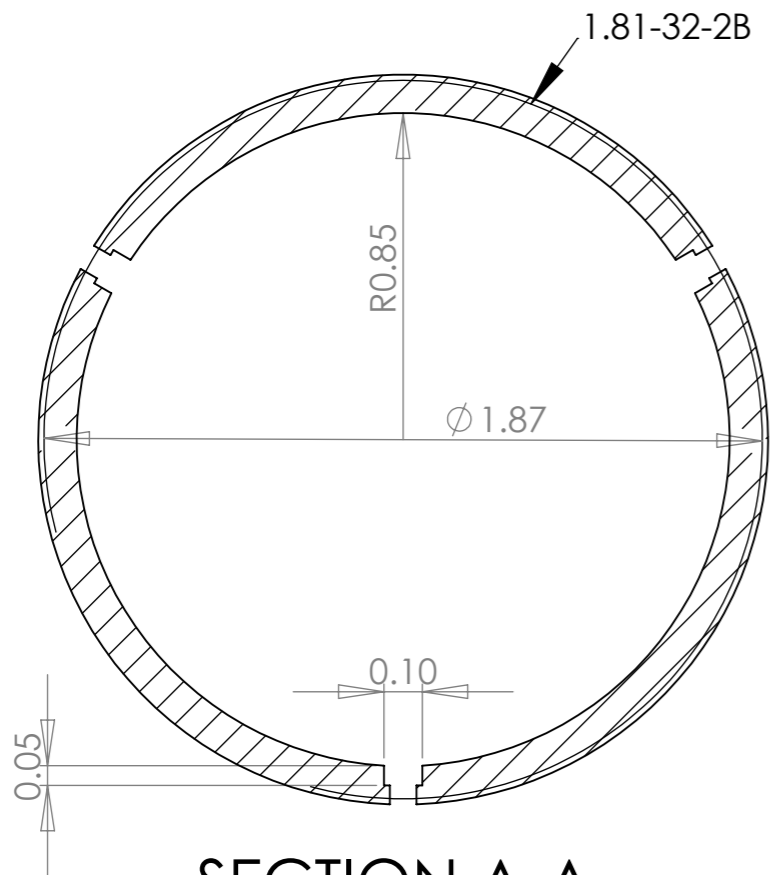
SECTION B-B  
SCALE 2 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION	
DRAWN	NAME	SIGNATURE	DATE					TITLE:			
CHK'D											
APPV'D											
MFG											
Q.A						MATERIAL:		DWG NO.		Focusing Attachment	
						WEIGHT:		SCALE:1:1		SHEET 1 OF 1	

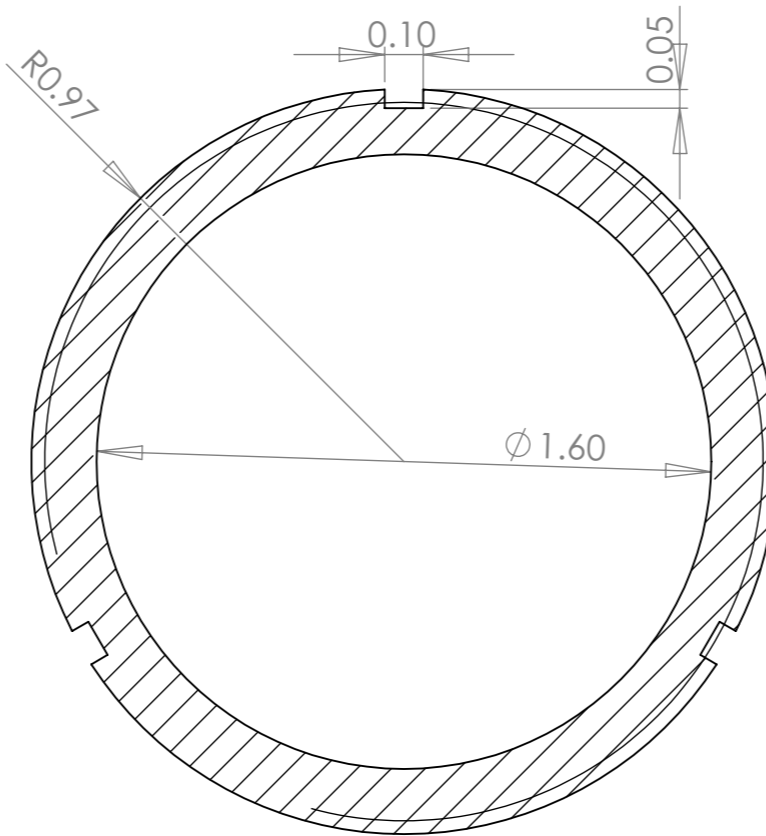


Thread A is aggressively threaded- 0.03in pitch @1in per revolution

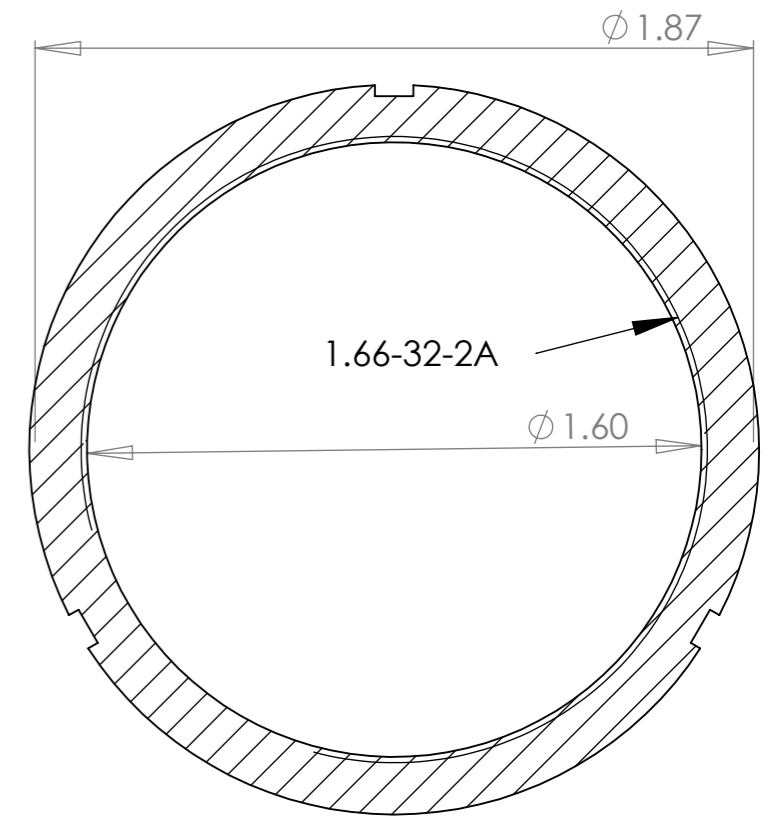
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION
NAME	SIGNATURE	DATE				TITLE:	
DRAWN							
CHK'D							
APPV'D							
MFG							
Q.A				MATERIAL:		DWG NO.	<b>Focusing Handle</b>
				WEIGHT:		SCALE:1:1	A4
						SHEET 1 OF 1	



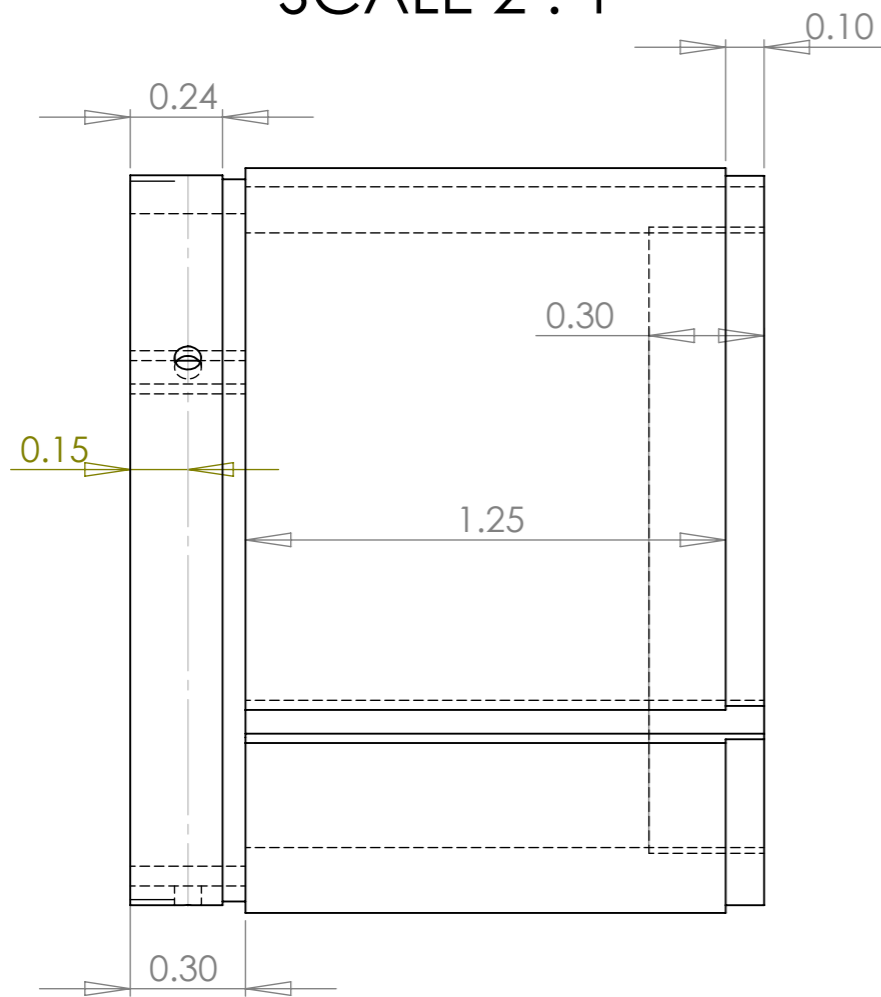
SECTION A-A  
SCALE 2 : 1



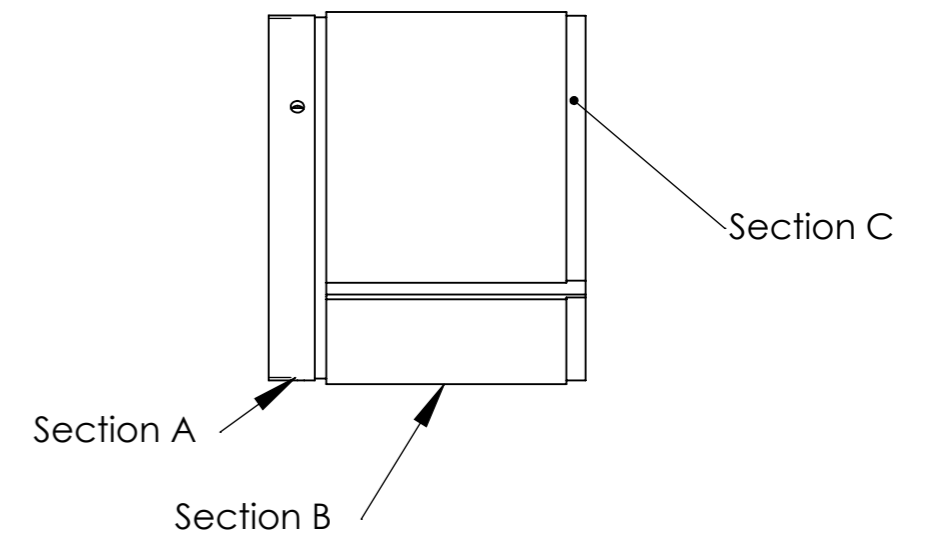
SECTION B-B  
SCALE 2 : 1



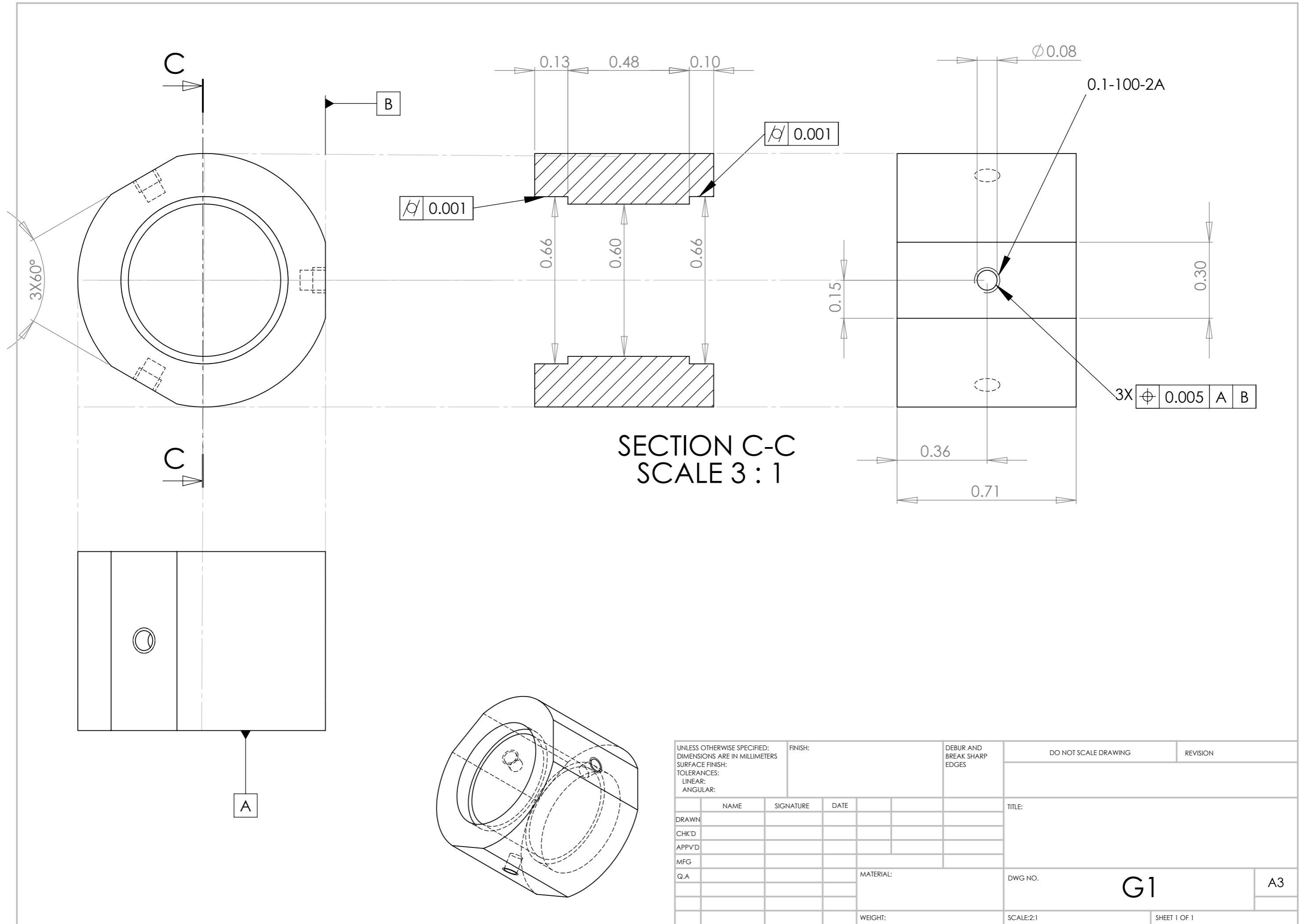
SECTION C-C  
SCALE 2 : 1



Section B is threaded aggressively;  
0.03in pitch @ 1 inch per revolution

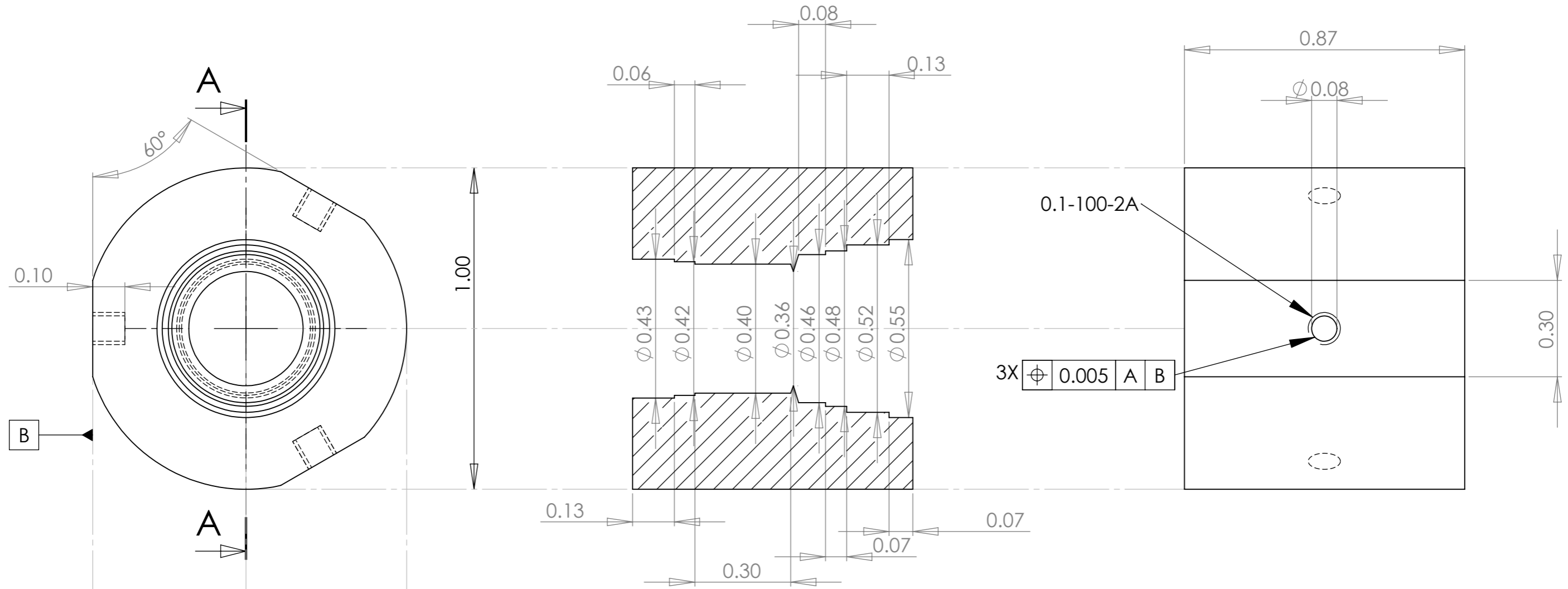


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION	
DRAWN				NAME		SIGNATURE		DATE		TITLE:	
CHK'D											
APPV'D											
MFG											
Q.A								MATERIAL:		DWG NO	
										Focusing Mount	
								WEIGHT:		SCALE:1:1	
										SHEET 1 OF 1	

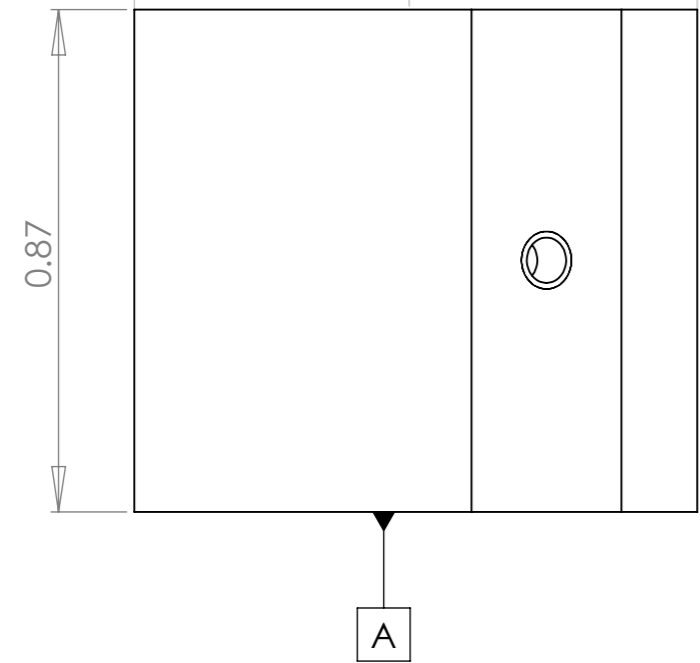
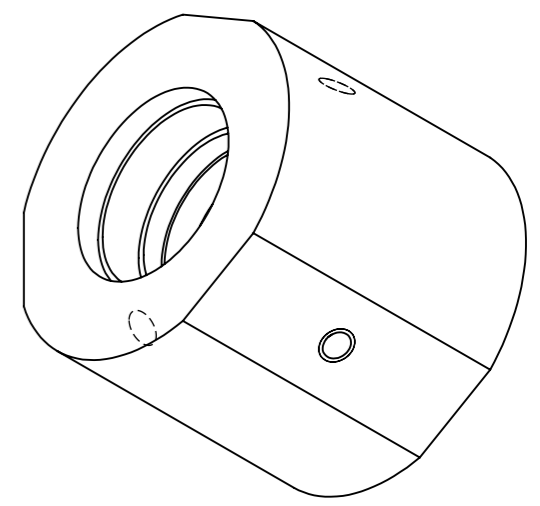


SECTION C-C  
SCALE 3 : 1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS				FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION	
SURFACE FINISH:											
TOLERANCES:											
LINEAR:											
ANGULAR:											
DRAWN		NAME		SIGNATURE		DATE		TITLE:			
CHK'D											
APPV'D											
MFG											
Q.A								MATERIAL:		DWG NO.	
										G1	
								WEIGHT:		SCALE:2:1	
										SHEET 1 OF 1	
										A3	



SECTION A-A  
SCALE 3 : 1



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:				FINISH:		DEBUR AND BREAK SHARP EDGES		DO NOT SCALE DRAWING		REVISION	
DRAWN				NAME		SIGNATURE		DATE		TITLE:	
CHK'D											
APPV'D											
MFG											
Q.A								MATERIAL:		DWG NO.	
										G2	
								WEIGHT:		SCALE:2:1	
										SHEET 1 OF 1	

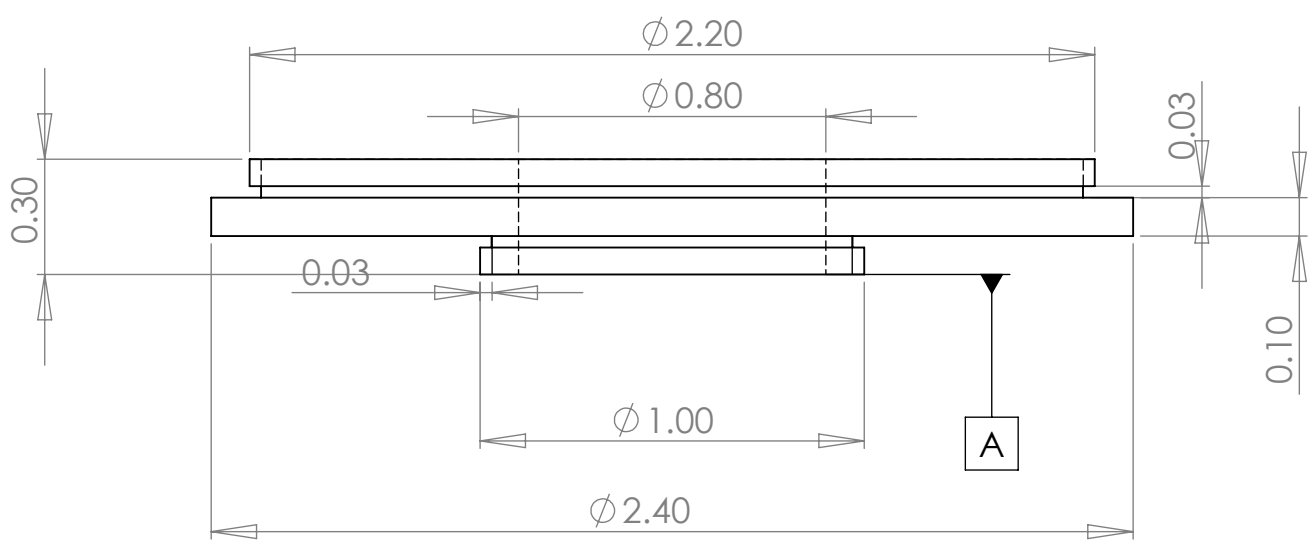
A3

2.14-32-2B

1-32-2B

B

A



UNLESS OTHERWISE SPECIFIED:  
DIMENSIONS ARE IN MILLIMETERS  
SURFACE FINISH:  
TOLERANCES:  
LINEAR:  
ANGULAR:

FINISH:

DEBUR AND  
BREAK SHARP  
EDGES

DO NOT SCALE DRAWING

REVISION

NAME	SIGNATURE	DATE			
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A					

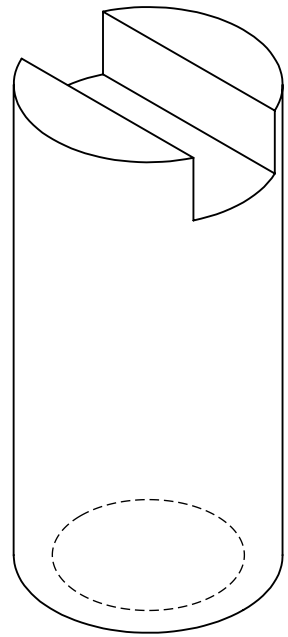
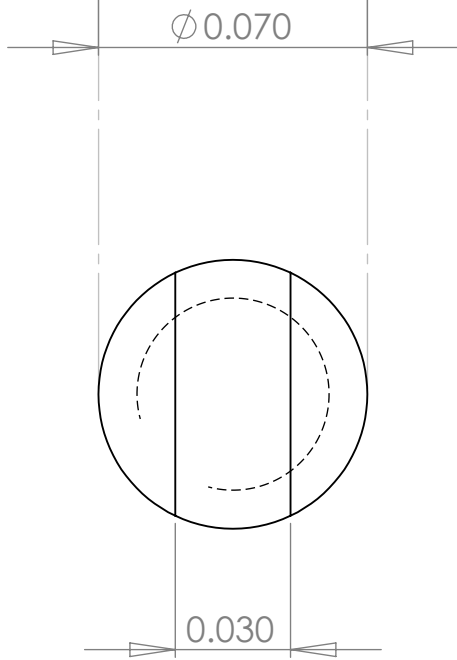
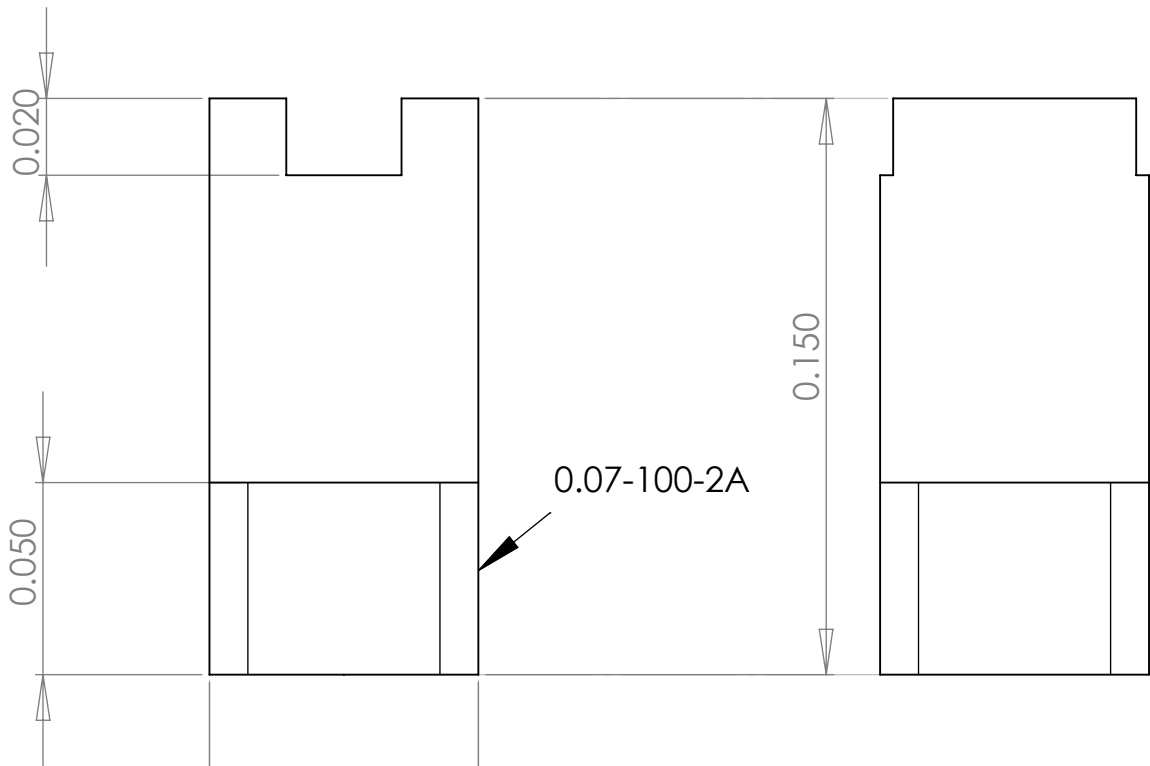
TITLE:

DWG NO. **Mount Interface** A4

SCALE:1:1 SHEET 1 OF 1

MATERIAL:

WEIGHT:



UNLESS OTHERWISE SPECIFIED:  
DIMENSIONS ARE IN MILLIMETERS  
SURFACE FINISH:  
TOLERANCES:  
LINEAR:  
ANGULAR:

FINISH:

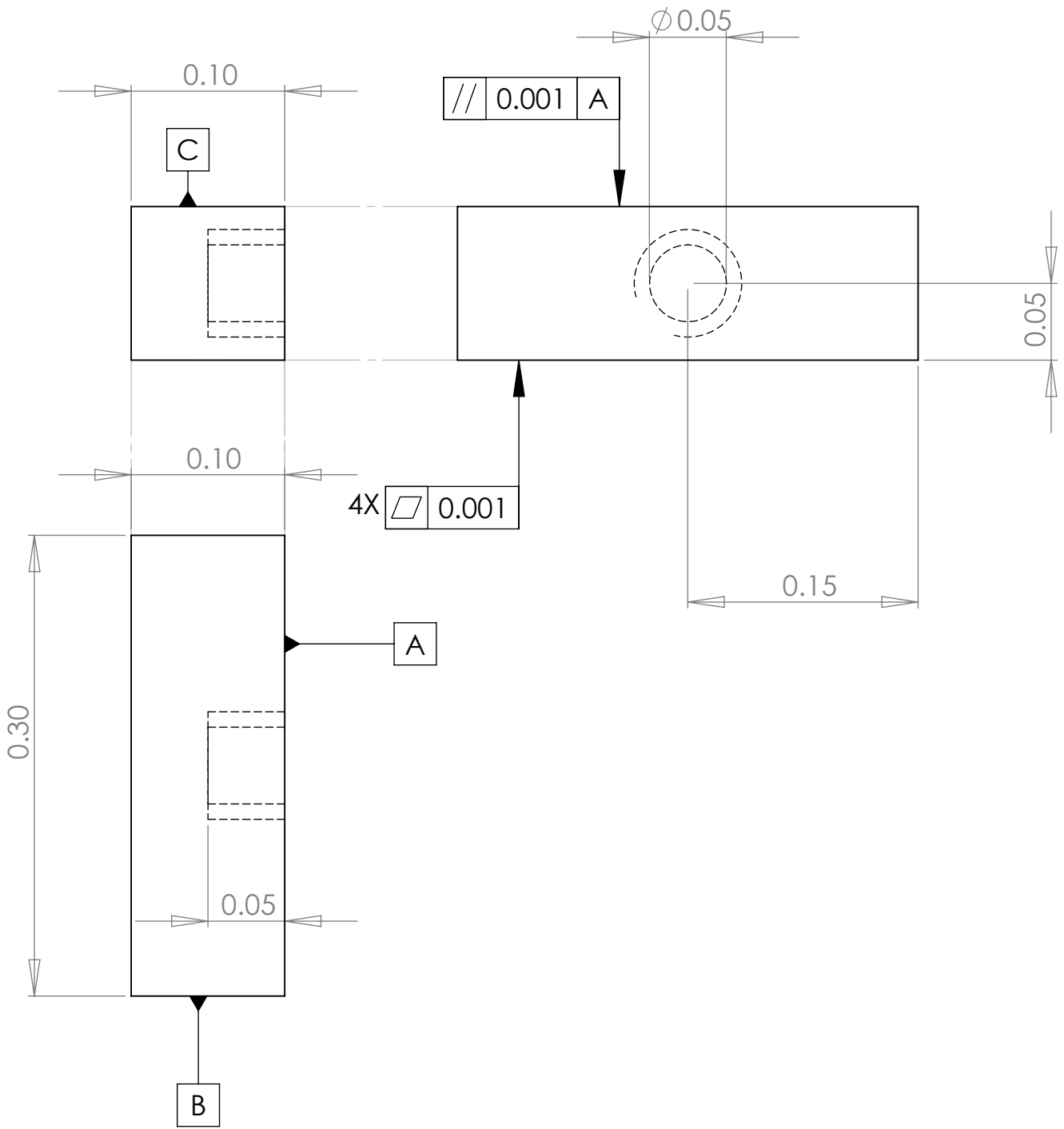
DEBUR AND  
BREAK SHARP  
EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	
				WEIGHT:	

TITLE:	
DWG NO.	<b>Peg Screw</b>
SCALE:20:1	A4
SHEET 1 OF 1	



UNLESS OTHERWISE SPECIFIED:  
 DIMENSIONS ARE IN MILLIMETERS  
 SURFACE FINISH:  
 TOLERANCES:  
 LINEAR:  
 ANGULAR:

FINISH:

DEBUR AND  
 BREAK SHARP  
 EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE		
DRAWN					
CHK'D					
APPV'D					
MFG					
Q.A				MATERIAL:	
				WEIGHT:	

TITLE:	
DWG NO.	Peg Stop
SCALE:10:1	SHEET 1 OF 1
	A4