Lakehead University
Department of Mechanical Engineering

Mechanical Engineering Design I, EMEC-4130

Design Project:

BENCH-MODEL PRESS

By:
Gareth Lawton (1148194)
Zachary Michalski (1149176)
Zachery MacNabb (1131531)
Dennis Prost (1130629)

Instructor: Dr. H.T. Saliba

Due: March 29, 2021

Table of Contents

List of Figures

List of Tables

1.0 - Introduction

1.1 - Background and Problem Statement

A press is a versatile machine that can be used for a variety of operations from force fits to bending shafts. The size and model of press will determine the tasks it can perform. Basic tasks that do not require a high force such as force fitting small components can be performed with a hand operated press. Hand operated presses are simple, inexpensive, and compact. For jobs that require high forces, it is advisable to use a hydraulic press. These types of presses are more complicated with a higher price as a result.

1.2 - Objective and Goals

The objective is to design a rugged hand operated press capable of pressing for general purpose work such as force fits and bending. Workpieces expected to be used in the press include gears, pulleys, sprockets, couplings, bushings, dowels, shafts, rods, and tubes. This press will be appropriately sized to fit on a workbench, and designed with simplicity in mind, ensuring practicality, affordability, and reliability. Ideally, the finished assembly will consist of buyout parts with minimal manufactured parts to reduce cost. The parts that are required to be manufactured must be simple and easy to machine. Additionally, the final assembly should consist of low to mid-grade materials with minimal moving pieces and loose tolerances wherever possible. It is not desirable to design a press that costs more than necessary.

1.3 - Design Specifications

The press must be designed to meet the following parameters:

- 2.5 Ton (5000 lb) Capacity
- Clearance from ram to base plate: Max 20 in, Min 6 in
- Throat clearance: 10 in
- Hand wheel diameter: Max 18 in, Min 10 in

2.0 - Preliminary Design

2.1 - Ideation

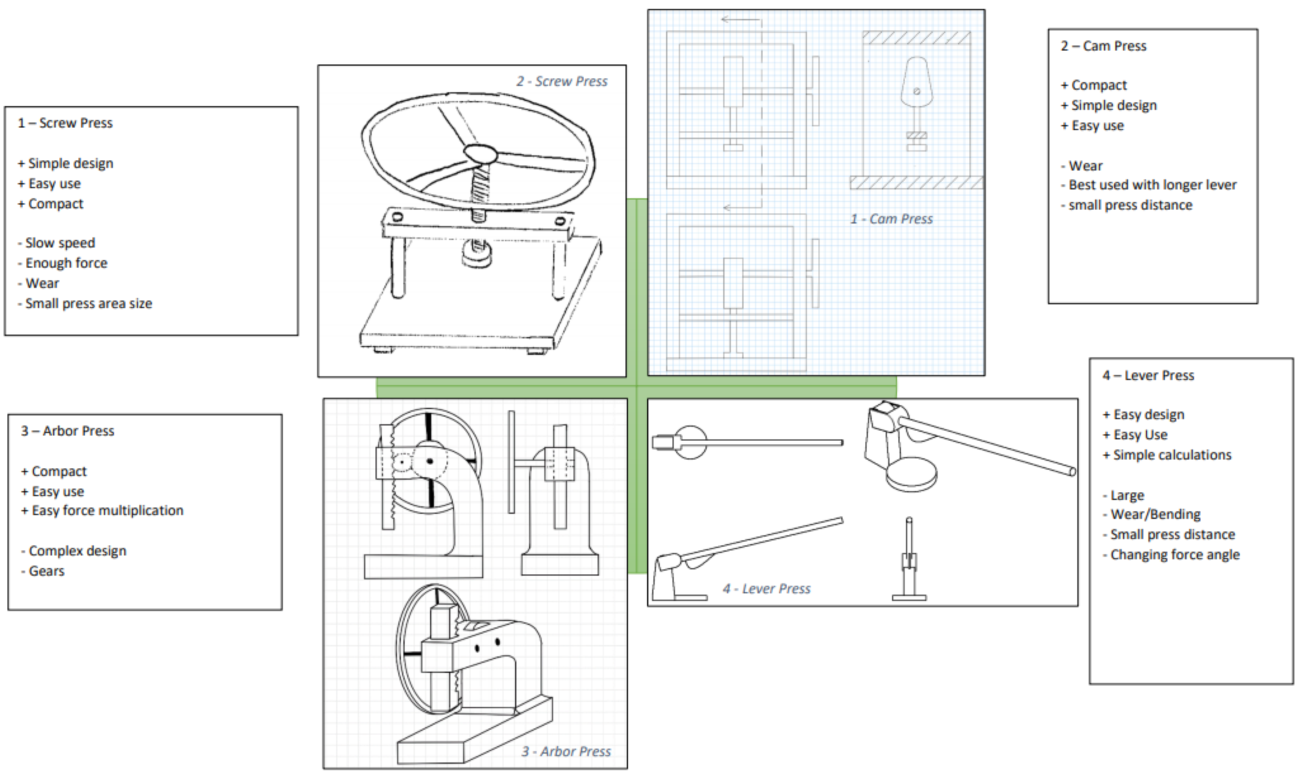


Figure 1 - 4-Blocker

2.1.1 - Design Concept 1 – Screw Press

The screw press design uses a threaded rod to transmit rotational torque to linear force. One main advantage is the simple and compact design, which will result in straightforward operation and assembly. The force generated will depend on thread pitch, lubrication, and materials. A notable benefit for this design is the ram clearance is highly flexible and can easily be changed to meet the design specifications. Unfortunately, the output force is not linearly related to the input force provided by the operator due to the frictional resistance of the threads increasing as output force increases, making this press slightly less user friendly. Using an appropriate thread pitch will allow the operator to transmit the necessary 2.5 tons of output force, however it is not possible to adjust the ram quickly with a fine thread pitch.

2.1.2 - Design Concept 2 – Cam Press

This design utilizes the use of a cam to transmit rotational torque into linear force. As the camshaft rotates the ram will move up and down, with the direction determined by the position of the cam. Unfortunately, the cam press has limited travel due to the limited range the cam lobe presents. To achieve the minimum required 6 inches of clearance, the radius of the cam would have to vary by 6 inches to fully utilize the stroke. It may also be difficult to generate 2.5 tons of force with this design due to the rotational friction. The output force would also vary with the position on the cam, which is not desirable.

2.1.3 - Design Concept 3

The third design to be considered is the arbor press. Some benefits of the arbor press are ease of use, simplicity, and a linear correlation between input and output force. The overhanging arm is ideal when designing for throat and ram to plate clearance. The most prominent characteristic of the arbor press is the use of a rack and pinion to transmit force. The gear ratio creates a mechanical advantage for the operator which is easy to calculate. The input force needs to be multiplied to attain an output force of 2.5 tons, and according to CCOHS, workers are only safely capable of delivering 50lbs of force. As a result, a gearbox must be used in conjunction with the rack and pinion to amplify the force enough to make the maximum pressing force achievable. While the gearbox presents advantages in accurately calculating output force, it is disadvantageous in that a level of complexity is added with the additional moving parts. Increasing the number of moving parts increases cost and wear points, which is something to be considered in the desirability of this design.

2.1.4 - Design Concept 4

The lever press is a simple design that is easy to construct and maintain. This press uses simple mechanical advantage to increase the output pressing force of the lever. The problem with this design is that to generate a force of 2.5 tons the lever will need to be extremely long. Unfortunately, it is not possible for the design parameters to be met using this design due to the large output force required and the limit on handwheel size. Furthermore, the stroke of this press would be very limited, and it is not capable of pressing linearly.

2.2 - Design Selection

From the decision-making model seen in Appendix 1 it was found that the best design concepts were the Screw and Arbor type press. The output values for these concepts were very close, so it was decided that the best attributes from both models would be utilized in the final design. To determine which components were better, the press needed to be broken down into individual sections. Firstly, the mechanism needed to convert the input force into clamping force. After careful review it was found the screw type would be a better choice for this component. The Arbor press uses a series of gears to multiply the input force to obtain the required clamping force. This gear train would result in an overcomplicated press with unnecessary components. Where with the screw concept the same mechanical advantage could be reached by using a shaft with an ACME thread. The screw type mechanism would allow for a much simpler and compact design that would require fewer moving parts which in turn would produce a superior press. For the base section, a design similar to the arbor press was selected. The arbor press concept has a single arm that extends above the lower platform to where the ram will be located. This concept gives the user more room to work when compared to the screw press design concept. From a reliability standpoint a base with a homogenous frame would be more reliable than a base that is constructed from numerous pieces bolted together.

3.0 - Final Design

3.1 - Refinement

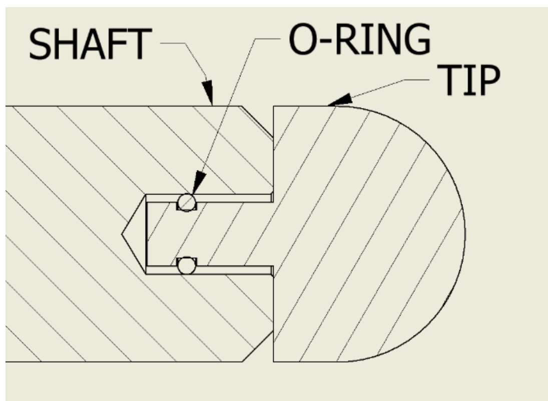


Figure 2 - Assembly of the Tip

For the final design, some small changes were made to improve functionality. One change was the addition of a rotating tip. This removable tip is attached to the end of the shaft and held in place with a pressure fit O-ring. Figure 2 shows a cross section of the shaft and outlines the fit of the O-ring and tip inside the shaft. Several advantages are associated with the removable tip. Firstly, when the press is clamping down on an object with the shaft rotating, the tip will remain stationary. This will prevent damage caused by friction between the press and object. Instead of replacing the entire shaft when the bottom wears out the user will only need to replace the tip. Furthermore, the tips can be made using different materials to suit different applications. Three different shapes of tips have been made for this press, making the applications more versatile. The general-purpose tips designed for this press can be seen in the drawing packing (Appendix 2).

The shaft refinements include adding a woodruff key as well as a step in the shaft for the handwheel to ride on. Initially a square key was selected for this design, but upon further investigation it was determined that the key had the potential to slide out of the keyway. This problem was resolved by switching to a woodruff key, which does not allow the key to escape once assembled. Previously the hand wheel was only held up with a ¼" 20UNC set screw, as a safety precaution, the 1/16” step was added for the wheel to rest on.

In the initial design of the base, two high stress locations were located during the stress analysis. The spine along the arc, and the base connection. To reduce these stresses, a heavy fillet was added which distributes the stress concentrations. The arm received a widening crown as it approached the base to distribute the stress concentration and expand the cross-sectional area, which ultimately reduced the overall stress. Figure 3 denotes the stress analysis simulation when 2.5 tons of force is applied to the press. This figure is for visual representation only and was not used as a formal calculation method.

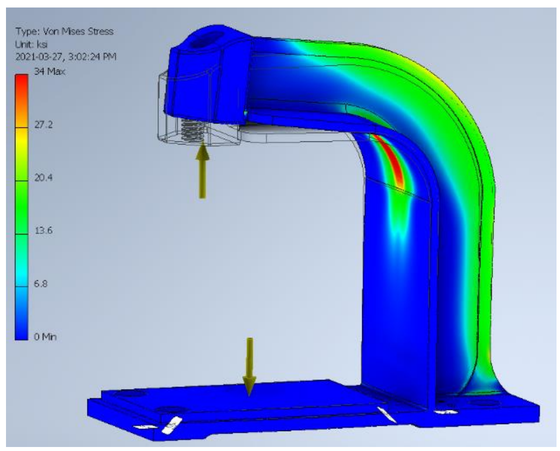


Figure 3 - Stress Concentrations

3.2 - Drawing Package

A full drawing package for this assembly can be found in Appendix 2. The drawing package includes all the necessary dimensions, tolerances, and buyout part numbers needed to build this press. It consists of detail and assembly drawings, which depict the fit and function of all components.

4.0 - Analysis and Results

4.1 - Design Calculations

All necessary stress calculations have been calculated to ensure the safety and functionality of the design. These calculations are based on an input force of 50lb; this value was taken from the Canadian Occupational Health and Safety Website. The calculations for each component are stated below and can be seen in Appendix 3.

- Shaft
    - Torque required
    - Axial Stress
    - Thread bearing and shear
    - Rod torsion

- Main Body
    - Curved and linear bending in key areas
    - Thread bending and shear
    - Mounting screw calculations
- Hand Wheel
    - Bending and shear
    - Key bending and shear

4.2 - Tolerances

The following tolerance table depicts how the components will fit together. Most of the parts do not require tight tolerances due to the low operating speed and low precision needed. This keeps costs low and increases ease of assembly. The tolerances can be seen below in Table 1

Tolerances				
Lactation	Fit Type	Nominal Size	Tolerance	
Shaft (Hub to shaft location)	LC4 (h9)	1.000	+0.000	-0.002
Hud (Hub to shaft location)	LC4 (H10)	1.000	+0.0035	-0.000
O-Ring Groove Diameter	Standard	0.188	+0.003	-0.003
Tip Hole	RC6 (H9)	0.313	+0.0014	-0.000
Tip Shaft	RC6 (e8)	0.250	-0.001	-0.002
Tip Hole Depth	RC8 (H10)	0.500	+0.0028	-0.000
Tip Shaft Height	RC8 (c9)	0.500	-0.0035	-0.005
Shaft Keyway Depth	Standard	0.1513	+0.005	-0.000
Hub Keyway Depth	Standard	0.0997	+0.005	-0.000
Key Width	Standard	0.1875	+0.002	-0.000

Table 1 - Tolerance Table

4.3 - Cost Estimate

A direct material cost estimate was fabricated for this design, this can be seen in Appendix 5. The estimate includes all the materials required to build the Bench-Model press, which includes the raw materials for the manufactured parts as well as the buyout parts from McMaster-Carr. A complete cost estimate was considered but due to constantly changing markets it is near impossible to determine labor costs for this design.

5.0 - Manufacturing Considerations

5.1 - Material Selection

Table 2 provides an overview of the manufactured parts and materials.

Manufactured Parts		
Part Name	Part No.	Material
Base	3001	Cast Iron
ACME Shaft	3002	A36 Steel
Hand Wheel	3003	A36 Steel
Round Tip	3004	A2 Tool Steel
Flat Tip	3005	A2 Tool Steel
Point Tip	3006	A2 Tool Steel

Table 2-Manufactured Parts List

The materials were selected with considerations such as safety, cost, and availability driving the decision-making model. The main casting is a crucial component to this design, and it is important to select a material that will be able to handle the stresses involved, while keeping the overall size as compact as possible. With this in mind another decision-making model was constructed to determine the best material, this can be seen below in Table 3. From the results, it is evident that cast iron should be selected for the base material. This selection is mainly due to the ease of manufacturing with a Cast Iron part and that will be covered in Section 5.2 - Manufacturing Methods.

		Desirability		Probability	
#	Factor	Machined Steel	Cast Iron	Machined Steel	Cast Iron
1	Cost	0.2	0.8	1	1
2	Complexity	0.3	0.9	1	0.7
3	Safety	0.9	0.8	0.8	0.8
4	Availability	0.6	0.8	0.7	0.9
5	Appearance	0.8	0.5	0.8	0.8
			(1/Σ Probability)->	0.2326	0.2381

Normalized		Products	
Machined Steel	Cast Iron	Machined Steel	Cast Iron
0.2326	0.2381	0.0465	0.1905
0.2326	0.1667	0.0698	0.1500
0.1860	0.1905	0.1674	0.1524
0.1628	0.2143	0.0977	0.1714
0.1860	0.1905	0.1488	0.0952
	SUM->	0.5302	0.7595

Table 3- Material Decision Making Model

For the ACME Shaft and Hand Wheel, a basic A32 steel was selected. This is because of its low cost, accessibility, and safety under operating conditions. Lastly a tool steel needed to be selected for the removable tips, after some precise examination, A2 Tool Steel was selected. This steel is for general purpose applications and has great wear resistance properties. A2 tool steel is also readily available with relatively low cost compared to other tool steels.

5.2 - Manufacturing Methods

Because there are multiple manufactured parts that make up this assembly, a process plan was constructed (see Appendix 4). The process plan outlines all the required raw stock and machining operations needed to manufacture the Bench-Model Press. This guide was precisely thought out and has all operations necessary to ensure correct manufacturing.

5.3 - Assembly and Quality Control

The assembly drawings in Appendix 2 depicts how to properly assemble the Bench Model Press, with an exploded view to ensure all parts are made fully visible. Detailed drawings outline the tolerances and nominal dimensions of each manufactured part, which ensures a level of quality is met upon manufacturing. For this design it is recommended that two quality control inspections take place. The first inspection should take place at the machine shop where parts are originally manufactured, and a second inspection should be performed upon assembly. This process is appropriate if the press is a one-off design, however this process is not practical should mass production occur.

6.0 - Conclusion

The objective of the design was to create a bench model press capable of applying 2.5 tons of force with a throat of 10 inches and a ram clearance of 6 to 10 inches. The design also required the use of a hand wheel to apply the necessary force. Initial design options included antique style screw and lever presses, industrial style cam press, and consumer level arbor press. The arbor and screw press designs were the most desirable, therefore a hybrid design encapsulating the benefits of both presses was chosen.

The press is intended to be an affordable, robust, and an effective means to meet the given design specifications. Affordability has been ensured by using low to mid-grade materials such as grey cast iron and simple carbon steel. As this press is a stationary, indoor piece of equipment, higher grade material is not necessary. Furthermore, the cast main body has been intentionally designed to require minimal machining operations, which has been outlined by the process plan in appendix 4. Other components such as the shaft and handwheel are also designed to be as simple as possible to keep costs low. The main assembly comprises just seven parts, resulting in minimal wear points, ease of use, and straight forward assembly. This design has been made possible by using the decision-making model, planning phases and design process.

7.0 - Recommendations

Should this design go into production, it will require review and approval by a licensed professional engineer. During this process, the press may undergo slight refinement to increase production efficiency, reduce cost, and improve functionality. It is recommended that the potential manufacturers of this product are consulted to ensure all machining operations are possible with the equipment at their disposal. If a larger clamping force is required, it would be advisable to substitute a gear rack and pinion with square cut teeth. This would present a more linear relationship between force in and force out.

8.0 - References

Boresi, A. P., & Schmidt, R. J. (2003). *Advanced Mechanics of Materials* (6th ed.). Wiley.

Budynas, R. G., Nisbett, J. K., & Shigley, J. E. (2020). *Shigley's Mechanical Engineering Design* (11th ed.). Mcgraw-Hill Education.

Dandong Foundry - Gray Iron, Ductile Iron, Steel Castings in China. (n.d.). Www.iron-Foundry.com. Retrieved March 27, 2021, from http://www.iron-foundry.com/index.html

Giesecke, F. E., Mitchell, A., Spencer, H. C., Hill, I., Dygdon, J., Novak, J., Loving, R., Lockhart, S., Johnson, C., & Goodman, M. (2016). *Technical drawing with engineering graphics* (15th ed.). Prentice Hall.

Government of Canada, Canadian Centre for Occupational Health and Safety (2017, April 3). *Pushing & Pulling - General : OSH Answers*. https://www.ccohs.ca/oshanswers/ergonomics/push1.html

McMaster-Carr. (2015). https://www.mcmaster.com/

Metals Depot (2019) *Metals Depot® - Buy Metal Online! Steel, Aluminum, Stainless, Brass*. https://www.metalsdepot.com/

Mott, R. L., & Untener, J. A. (2017). *Applied Strength of Materials* (6th ed.). Crc Press, Taylor & Francis Group.

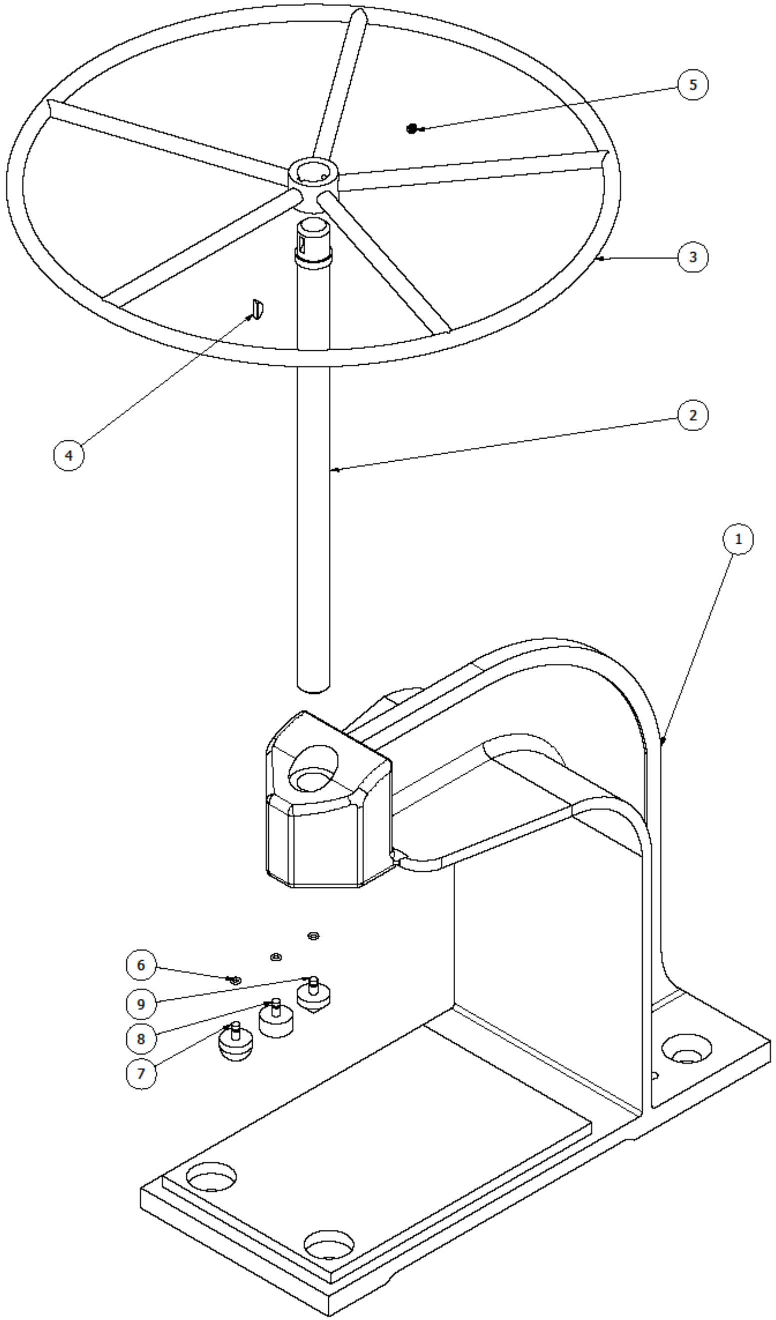
Oberg, E., Jones, F. D., Holbrook Lynedon Horton, Ryffel, H. H., & Mccauley, C. J. (2016). Machinery's handbook : a reference book for the mechanical engineer, designer, manufacturing engineer, draftsman, toolmaker, and machinist (30th ed.). Industrial Press.

APPENDIX

Appendix 1 - Decision Making Mo

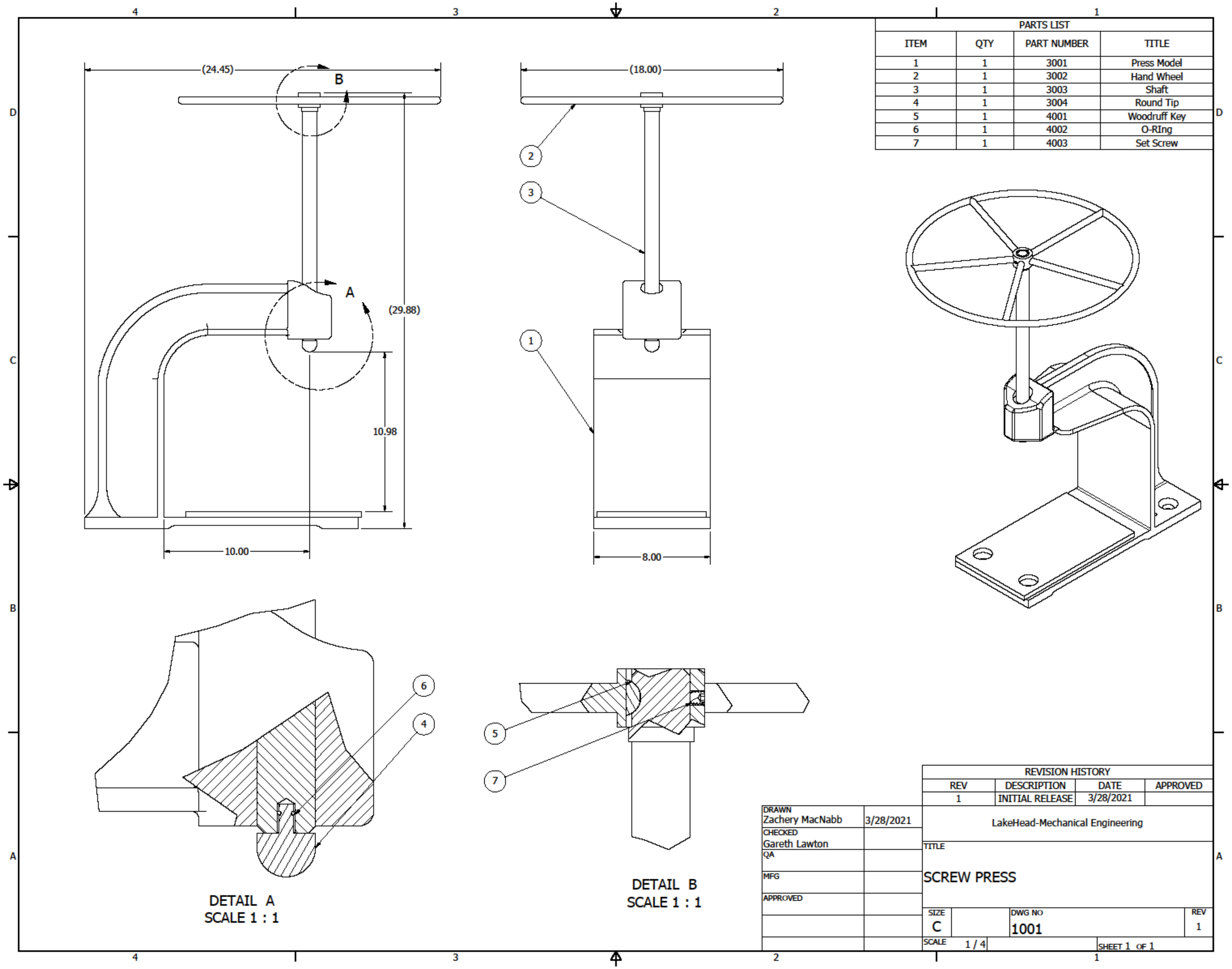
		Desirability				Probility			
#	Factor	Abor Press	Screw Press	Cam Press	Leaver Press	Abor Press	Screw Press	Cam Press	Leaver Press
1	Cost	0.5	0.7	0.8	0.7	0.75	0.75	0.9	0.9
2	Complexity	0.3	0.9	1	0.7	1	1	1	1
3	Efficiency	1	0.7	0.4	0.4	1	0.6	0.6	0.7
4	Maintenance	0.4	0.7	0.8	0.8	0.5	0.8	0.9	0.85
5	Construction	0.6	0.6	0.9	0.8	0.8	0.8	1	1
6	Ease of use	0.8	0.7	0.2	0.4	1	0.8	0.5	0.7
7	Weight	0.5	0.8	0.7	0.6	0.9	0.7	0.8	0.75
8	Size	0.6	0.8	0.4	0.4	0.5	0.7	0.8	0.75
9	Clamping force	1	0.7	0.5	0.6	1	1	0.8	0.9
10	Clamping Percisoin	1	0.6	0.7	0.7	1	1	1	1
11	throat clearance	1	1	0.2	0.3	1	1	0.7	0.8
12	Ram travel	1	1	0.3	0.2	1	1	0.8	0.9
					(1/ΣProbility)->	0.0957	0.0985	0.1020	0.0976

Normalized				Products			
Abor Press	Screw Press	Cam Press	Leaver Press	Abor Press	Screw Press	Cam Press	Leaver Press
0.0718	0.0739	0.0918	0.0878	0.0359	0.0517	0.0735	0.0615
0.0957	0.0985	0.1020	0.0976	0.0287	0.0887	0.1020	0.0683
0.0957	0.0591	0.0612	0.0683	0.0957	0.0414	0.0245	0.0273
0.0478	0.0788	0.0918	0.0829	0.0191	0.0552	0.0735	0.0663
0.0766	0.0788	0.1020	0.0976	0.0459	0.0473	0.0918	0.0780
0.0957	0.0788	0.0510	0.0683	0.0766	0.0552	0.0102	0.0273
0.0861	0.0690	0.0816	0.0732	0.0431	0.0552	0.0571	0.0439
0.0478	0.0690	0.0816	0.0732	0.0287	0.0552	0.0327	0.0293
0.0957	0.0985	0.0816	0.0878	0.0957	0.0690	0.0408	0.0527
0.0957	0.0985	0.1020	0.0976	0.0957	0.0591	0.0714	0.0683
0.0957	0.0985	0.0714	0.0780	0.0957	0.0985	0.0143	0.0234
0.0957	0.0985	0.0816	0.0878	0.0957	0.0985	0.0245	0.0176
			SUM ->	0.7565	0.7749	0.6163	0.5639



PARTS LIST			
ITEM	QTY	PART	DESCRIPTION
1	1	PRESS BASE	3001
2	1	ACME SHAFT	3002
3	1	HAND WHEEL	3003
4	1	98481A110 WOODRUFF KEY	STEP AP203
5	1	94105A533 SET SCREW	STEP AP203
6	3	9452K160 O-RING	STEP AP203
7	1	ROUND TIP	3004
8	1	FLAT TIP	3005
9	1	POINT TIP	3006

DRAWN Zachary Michalski	2021-03-26	
CHECKED Gareth Lawton		TITLE
QA		Exploded View
MFG		
APPROVED		
		SIZE C	DWG NO Assemb.	REV
		SCALE 4/10	SHEET 2 OF 2



PARTS LIST			
ITEM	QTY	PART NUMBER	TITLE
1	1	3001	Press Model
2	1	3002	Hand Wheel
3	1	3003	Shaft
4	1	3004	Round Tip
5	1	4001	Woodruff Key
6	1	4002	O-RIng
7	1	4003	Set Screw

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	3/28/2021	

DRAWN Zachery MacNabb	3/28/2021
CHECKED Gareth Lawton	
QA	
MFG	
APPROVED	

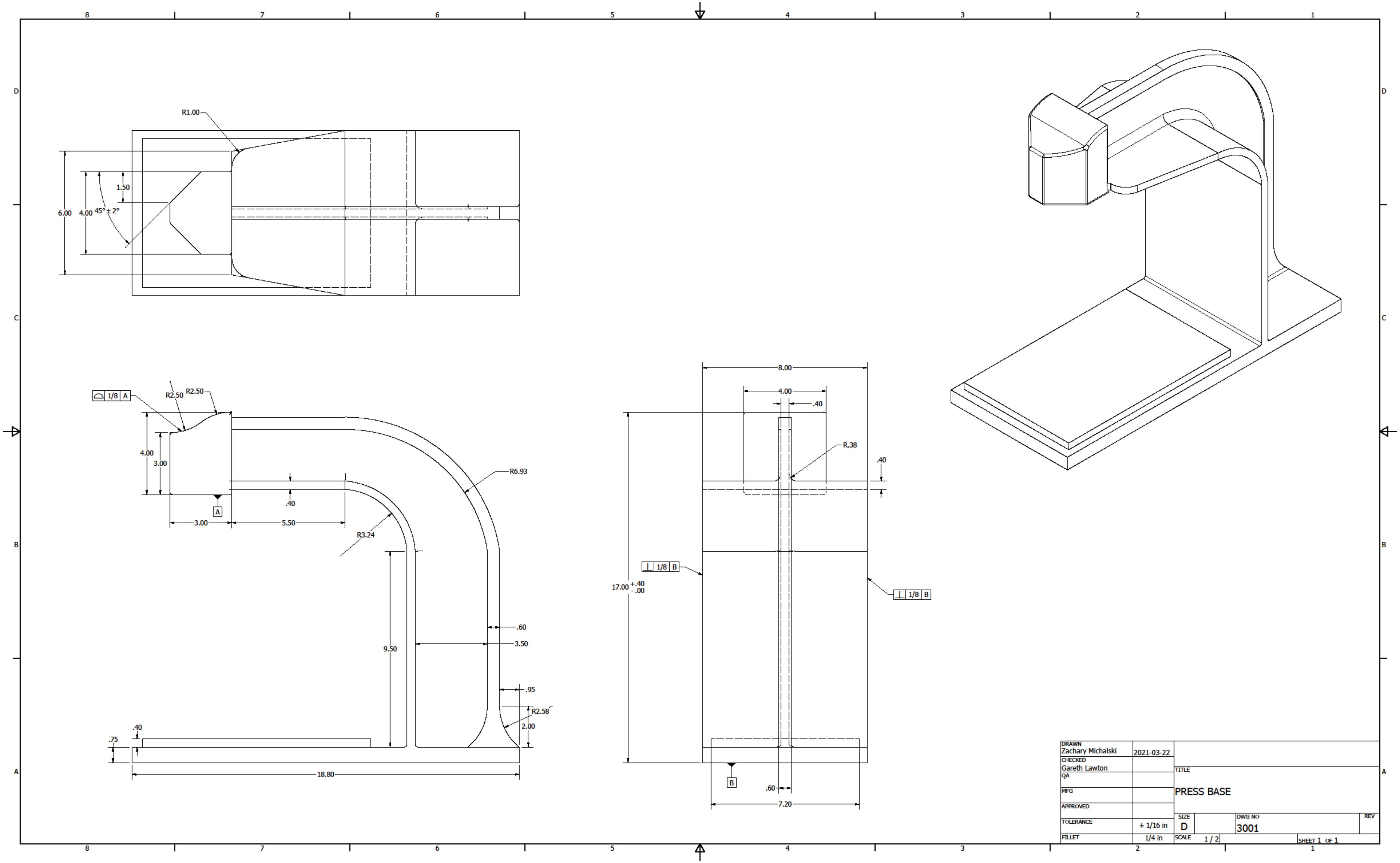
LakeHead-Mechanical Engineering

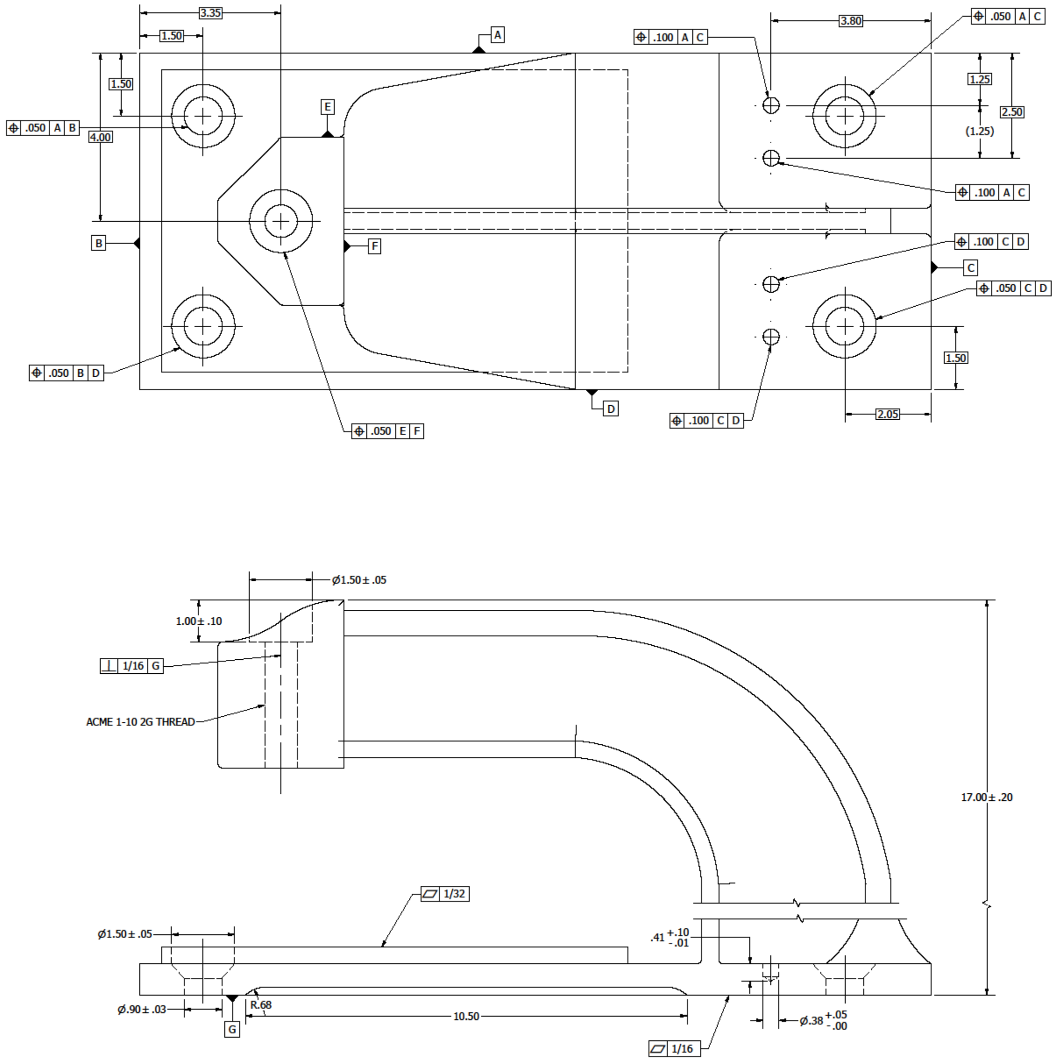
TITLE

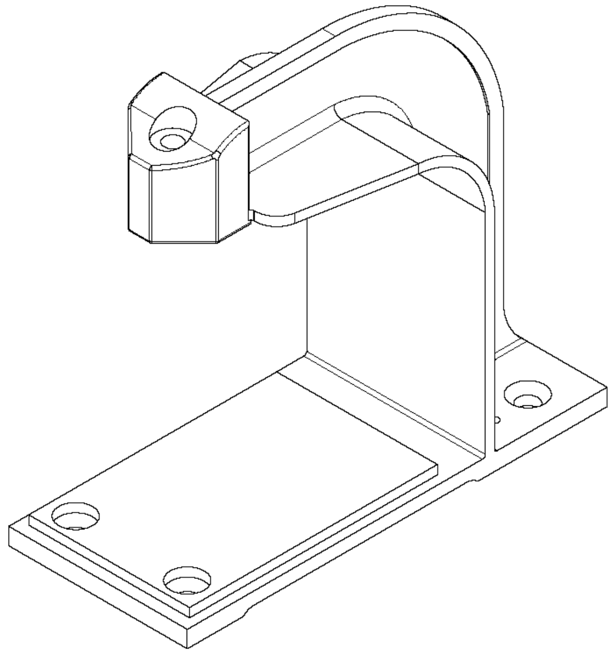
SCREW PRESS

SIZE	DWG NO	REV
C	1001	1

SCALE 1 / 4 SHEET 1 OF 1


R1.00
1.50
6.00
4.00
45° ± 2°
1/8 A
R2.50
R2.50
4.00
3.00
A
.40
3.00
5.50
R6.93
R3.24
9.50
.60
3.50
.95
R2.58
2.00
.40
.75
18.80
8.00
4.00
.40
R.38
.40
1/8 B
17.00 +.40 -.00
1/8 B
B
.60
7.20
DRAWN
Zachary Michalski
2021-03-22
CHECKED
Gareth Lawton
QA
MFG
APPROVED
TOLERANCE
± 1/16 in
FILLET
1/4 in
TITLE
PRESS BASE
SIZE
D
DWG NO
3001
REV
SCALE
1 / 2
SHEET 1 OF 1

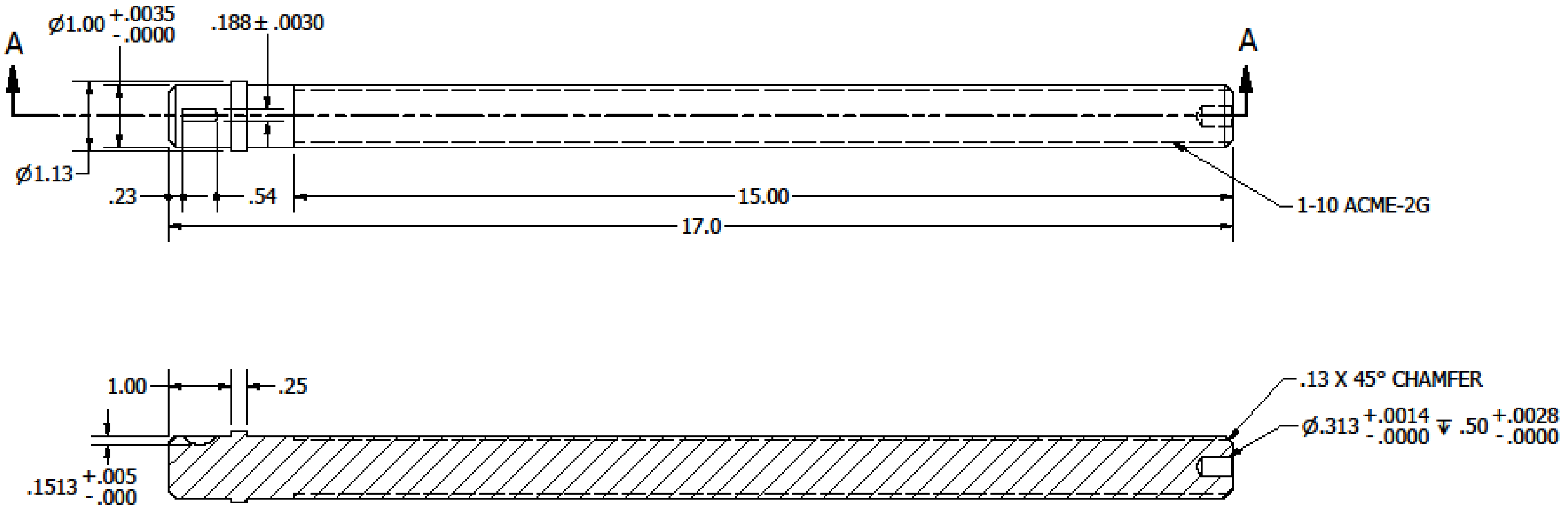




DRAWN		
Zachary Michalski	2021-03-26	
CHECKED		
Gareth Lawton		TITLE
QA		
MFG		BASE MACHINED
APPROVED		

SIZE D | DWG NO 3001 | REV

SCALE 2/3 | SHEET 1 OF 1



SECTION A-A

Note:
1: FAO
2: MAT'L IS A36 STEEL

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	3/25/2021	

DRAWN Zachery MacNabb	3/25/2021
CHECKED Dennis Prost	
QA	
MFG	
APPROVED	

LakeHead-Mechanical Engineering

TITLE
Shaft

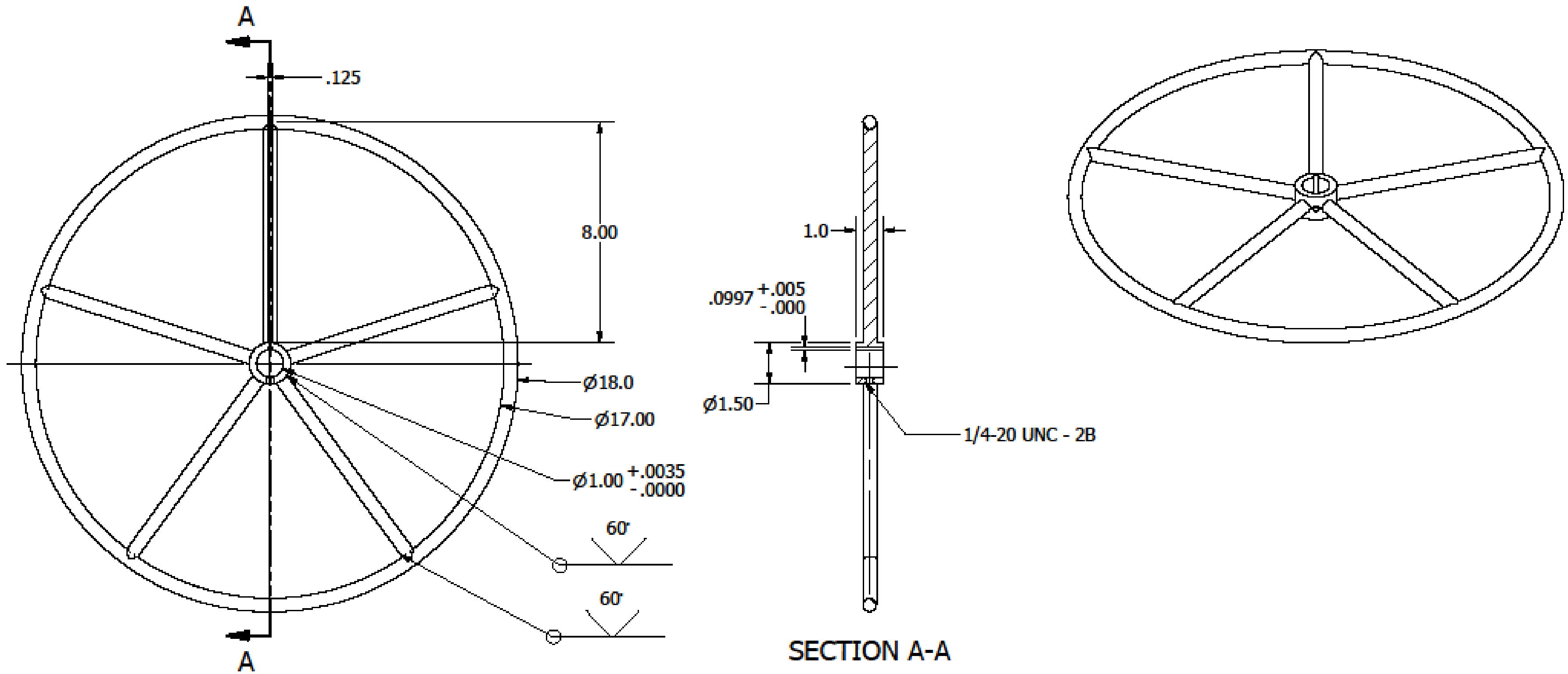
SIZE	DWG NO	REV
B	3002	1

SCALE 1 / 2 SHEET 1 OF 1

TOLERANCES UNLESS OTHERWISE SPECIFIED

.X	±.015	FRACTIONS:	± 1/32
.XX	±.010	ANGLES:	± 1/2°
.XXX	±.005		

(ALL DIMENSIONS IN INCHES)



NOTE:
1: MAT'L IS A36 STEEL

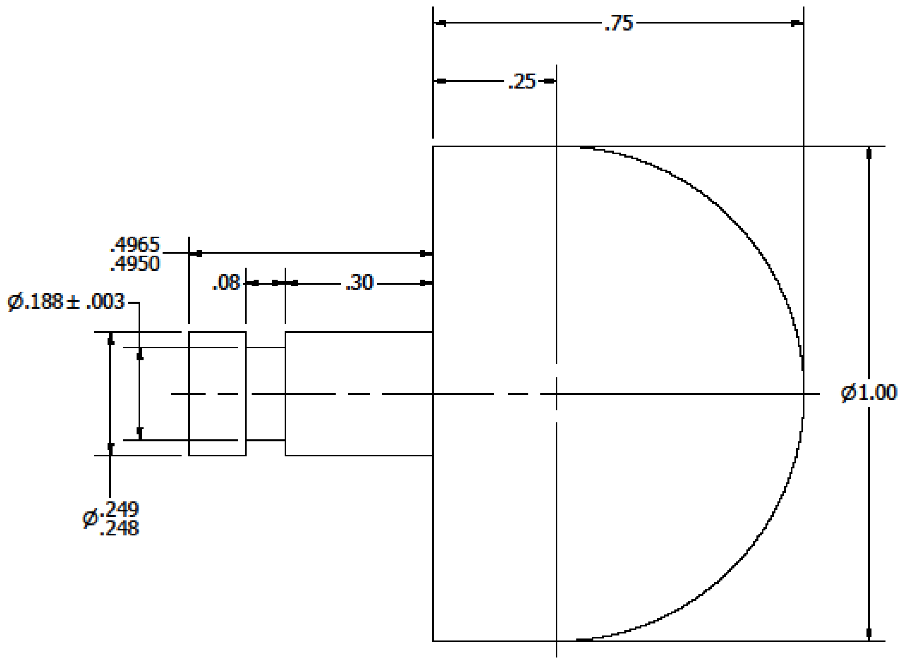
REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	3/25/2021	

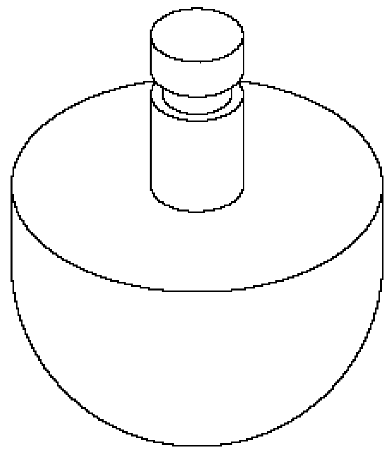
DRAWN Zachery MacNabb	3/25/2021	LakeHead-Mechanical Engineering
CHECKED Dennis Prost		TITLE HAND WHEEL
QA		
MFG		
APPROVED		SIZE B / DWG NO 3003 / REV 1
		SCALE 1 / 4 / SHEET 1 OF 1

TOLERANCES UNLESS OTHERWISE SPECIFIED

.X ±.015 FRACTIONS: ± $\frac{1}{32}$
.XX ±.010
.XXX ±.005 ANGLES: ± $\frac{1}{2}$°

(ALL DIMENSIONS IN INCHES)



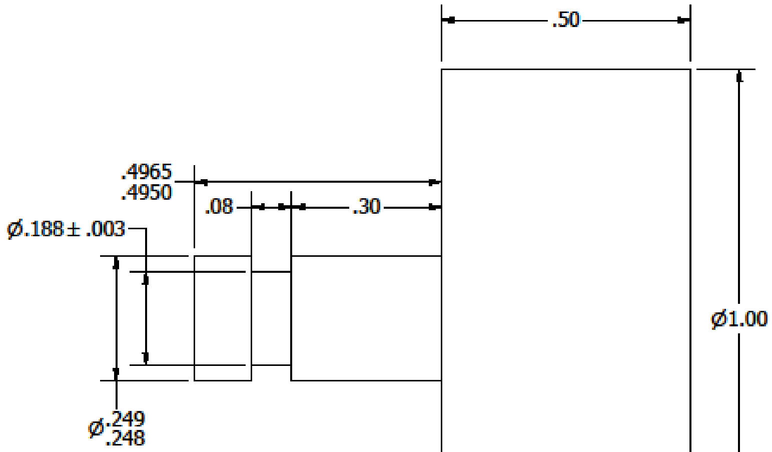


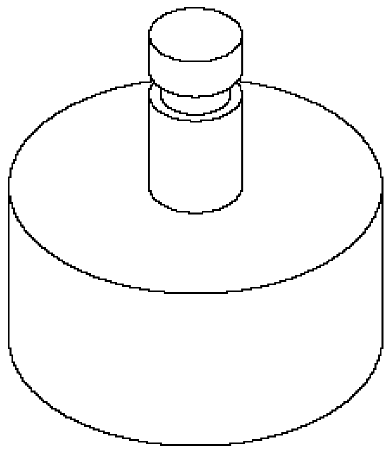
Note:
1: FAO
2: MAT'L IS A2 TOOL STEEL

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	3/24/2021	

DRAWN Zachery MacNabb	3/24/2021	LakeHead-Mechanical Engineering
CHECKED Gareth Lawton		TITLE
QA		Round Tip
MFG		
APPROVED		SIZE B — DWG NO 3004 — REV 1
		SCALE 4 : 1 — SHEET 1 OF 1

TOLERANCES UNLESS OTHERWISE SPECIFIED
.X ±.015 FRACTIONS:± $\frac{1}{32}$
.XX ±.010 ANGLES: ± $\frac{1}{2}$°
.XXX±.005
(ALL DIMENSIONS IN INCHES)





Note:
1: FAO
2: MAT'L IS A2 TOOL STEEL

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	3/25/2021	

DRAWN Zachery MacNabb	3/25/2021
CHECKED Gareth Lawton	
QA	
MFG	
APPROVED	

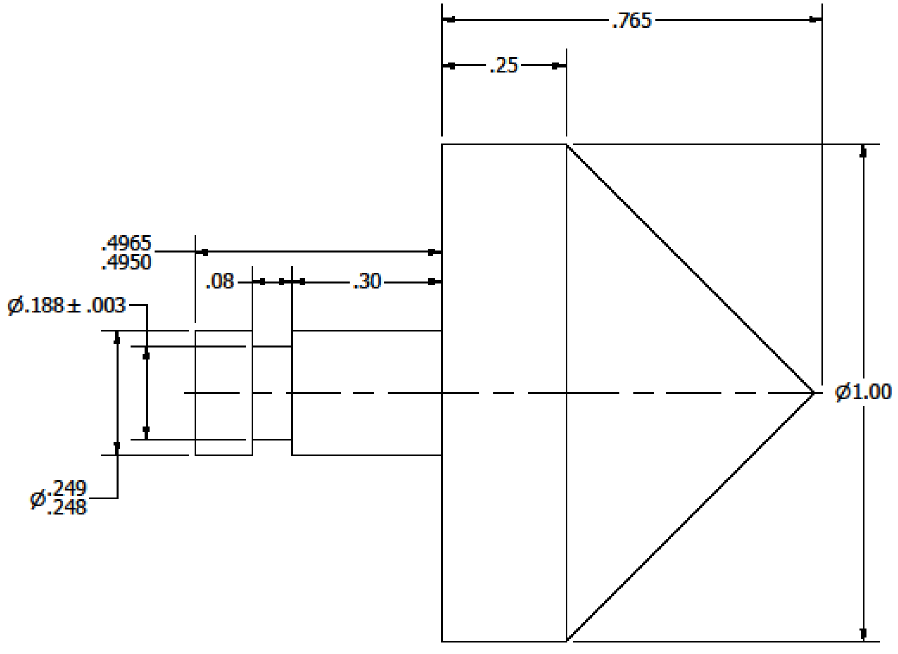
LakeHead-Mechanical Engineering

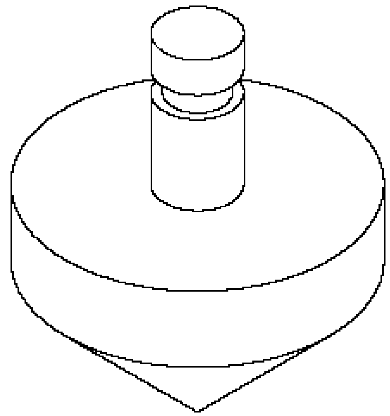
TITLE
Flat Tip

SIZE	DWG NO	REV
B	3005	1

SCALE 4 : 1 SHEET 1 OF 1

TOLERANCES UNLESS OTHERWISE SPECIFIED
.X ±.015 FRACTIONS: ± $\frac{1}{32}$
.XX ±.010
.XXX ±.005 ANGLES: ± $\frac{1}{2}$°
(ALL DIMENSIONS IN INCHES)





Note:
1: FAO
2: MAT'L IS A2 TOOL STEEL

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	3/25/2021	

TOLERANCES UNLESS OTHERWISE SPECIFIED

.X ±.015 FRACTIONS: ± $\frac{1}{32}$
.XX ±.010 ANGLES: ± $\frac{1}{2}$°
.XXX ±.005

(ALL DIMENSIONS IN INCHES)

DRAWN Zachery MacNabb	3/25/2021	LakeHead-Mechanical Engineering
CHECKED Gareth Lawton		TITLE Point Tip
QA		
MFG		
APPROVED		SIZE B · DWG NO 3006 · REV 1
		SCALE 4 : 1 · SHEET 1 OF 1

Appendix 3 - Calculations

Shaft Calculations

Known:

Thread Specs:	
Ext Acme 1-10 - 2G	
Major Diameter	
Max	1.0000
Min	0.9900
Avg	0.9950
Minor Diameter	
Max	0.78
Min	0.7509
Avg	0.76545
Pitch Diametor	
Max	0.892
Min	0.8726
Avg	0.8823

Table 8–5

Coefficients of Friction f for Threaded Pairs

Source: H. A. Rothbart and T. H. Brown, Jr., *Mechanical Design Handbook*, 2nd ed., McGraw-Hill, New York, 2006.

Screw Material	Nut Material: Steel	Bronze	Brass	Cast Iron
Steel, dry	0.15–0.25	0.15–0.23	0.15–0.19	0.15–0.25
Steel, machine oil	0.11–0.17	0.10–0.16	0.10–0.15	$\boxed{0.11–0.17}$
Bronze	0.08–0.12	0.04–0.06	—	0.06–0.09

$p = 0.1\ inch$

$F = 2.5\ Ton = 5000\ lbf$

$f = 0.14$

$S_{y,rod} = 53000\ psi$

$SF = 2$

$$\sigma_{design} = \sigma_d = \frac{S_y}{SF}$$

$$\sigma_d = 26500\ psi$$

$$\tau_{design} = \tau_d = \frac{(0.5)S_y}{SF}$$

$$\tau_d = 13250\ psi$$

Torque Required

$$T_R = \frac{F d_m}{2}\left(\frac{l + \pi f d_m}{\pi d_m - f l}\right) \qquad (8\text{–}1)$$

$$l = \pi d_m \tan(\lambda)$$

$$l = \pi \times 0.8823 \times \tan(2.86°)$$

$$l = 0.13847$$

$$Tr = \frac{5000 \times 0.8823}{2}\left(\frac{0.13847 + \pi(0.14)(0.8823)}{\pi(0.8823) - (0.14)(0.13847)}\right)$$

$$Tr = 421.95\ lb - in$$

According to CCOHS, operators are capable of supplying 50lbs of force, the handwheel radius is 9 inches (18in diameter) therefore the maximum output torque available is 450 in-lb, meaning the operator is capable of providing enough torque to achieve 2.5 tons of force.

Axial Stress

$$\sigma = \frac{F}{A} = \frac{4F}{\pi d_r^2} \qquad (8\text{–}8)$$

$$\sigma = \frac{4(-5000)}{\pi(0.76545)^2}$$

$$\sigma = -10865.42\ psi$$

Acceptable - Less than σ_d

Thread Bending

$$\sigma_b = \frac{M}{Z} = \frac{Fp}{4}\frac{24}{\pi d_r n_t p^2} = \frac{6F}{\pi d_r n_t p} \qquad (8\text{–}11)$$

$$n_t = \frac{Threads}{Inch} \times\ Inches\ of\ threads$$

$$n_t = 10 \times 3$$

$$n_t = 30\ threads$$

$$\sigma_b = \frac{6(5000)}{\pi(0.76545)(30)(0.1)}$$

$$\sigma_b = 4158.5\ psi$$

Acceptable - Less than σ_d

Thread Shear

$$\tau = \frac{3V}{2A} = \frac{3}{2}\frac{F}{\pi d_r n_t p/2} = \frac{3F}{\pi d_r n_t p} \qquad (8\text{–}12)$$

$$\tau = \frac{3(5000)}{\pi(0.76545)(30)(0.1)}$$

$$\tau = 2079.2\ psi$$

Acceptable - Less than τ_d

Rod Torsion

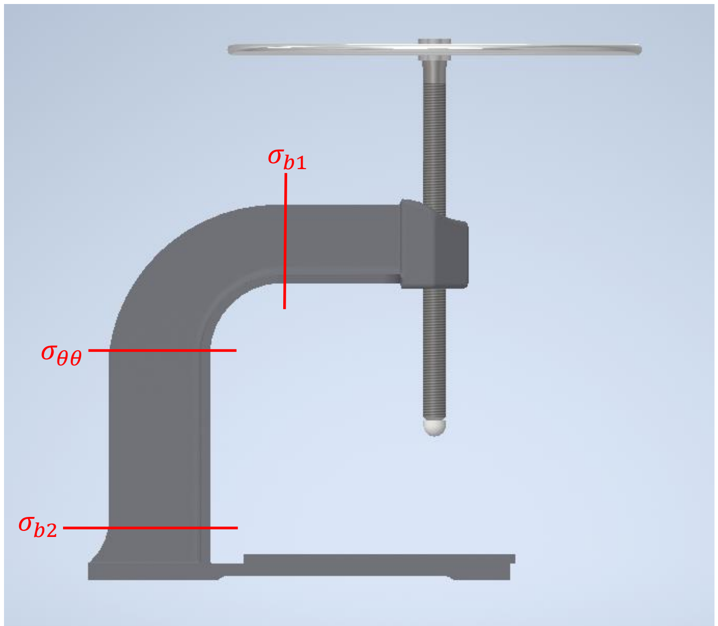
$$\boxed{\tau_{MAX} = \frac{16T}{\pi d^3}}$$

$$\tau = \frac{16(450)}{\pi(0.76545)^2}$$

$$\tau = 4791.6\ psi$$

Acceptable - Less than τ_d

Main Body Calculations

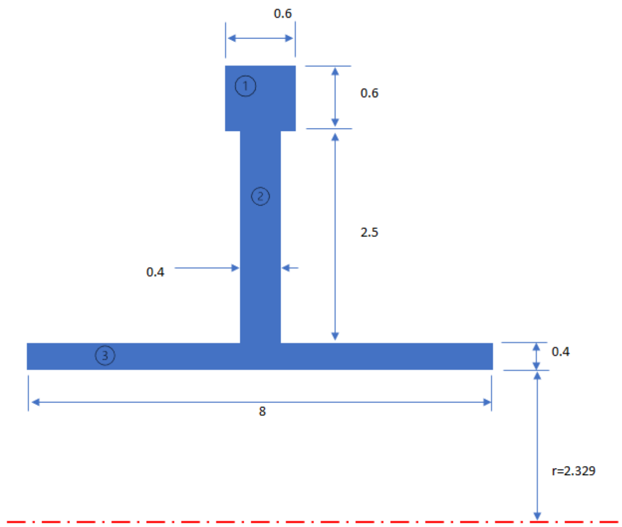


Known:
Material: ASTM 50 Gray Cast Iron
$S_y = 52500\, psi$
$SF = 2$
$$\sigma_{design} = \sigma_d = \frac{S_y}{SF}$$
$$\sigma_d = 26250\, psi$$
$$\tau_{design} = \tau_d = \frac{(0.5)S_y}{SF}$$
$$\tau_d = 13125\, psi$$

Curved Bending for $\sigma_{\theta\theta}$

Known:

Distance from shaft/force to centerline is $6.769\ in$



$$\sigma_{\theta\theta} = \frac{N}{A} + \frac{M_x(A - rA_m)}{Ar(RA_m - A)} \tag{9.11}$$

$A_1 = 0.6 \times 0.6$

$$A_1 = 0.36\ in^2$$

$A_2 = 2.5 \times 0.4$

$$A_2 = 1.00\ in^2$$

$A_3 = 0.4 \times 8$

$$A_3 = 3.20\ in^2$$

$A = 4.56\ in^2$

$$A_{m_1} = (0.6)\ln\left(\frac{2.329 + 0.4 + 2.5 + 0.6}{2.329 + 0.4 + 2.5}\right)$$

$$A_{m_1} = 0.0651$$

$$A_{m_2} = (0.4)\ln\left(\frac{2.329 + 0.4 + 2.5}{2.329 + 0.4}\right)$$

$$A_{m_2} = 0.260$$

$$A_{m_3} = 8\ln\left(\frac{2.329 + 0.4}{2.329}\right)$$

$$A_{m_3} = 1.268$$

$$A_m = A_{m_1} + A_{m_2} + A_{m_3}$$

$$A_m = 1.593$$

$$R_1 = 2.329 + 0.4 + 2.5 + \frac{0.6}{2}$$

$$R_1 = 5.529\ in$$

$$R_2 = 2.329 + 0.4 + \frac{2.5}{2}$$
$$R_2 = 3.979\ in$$
$$R_3 = 2.329 + \frac{0.4}{2}$$
$$R_3 = 2.439\ in$$
$$R = \frac{R_1A_1 + R_2A_2 + R_3A_3}{A}$$
$$R = \frac{(5.529)(0.36) + (3.979)(1) + (2.439)(3.2)}{4.56}$$
$$R = 3.021$$

$$M = (6.769 + 3.021) \times 5000$$
$$M = 48948.33\ in - lb$$

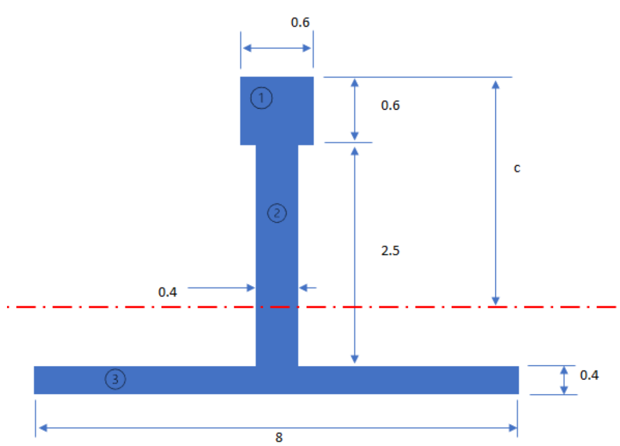
$$\sigma_{\theta\theta} = \frac{5000}{4.56} + \frac{48948.33\big(4.56 - (2.329)(1.593)\big)}{(4.56)(2.329)\big((3.021)(1.593) - 4.56\big)}$$
$$\sigma_{\theta\theta} = 16586.47\ psi$$

Acceptable - Less than σ_d

Linear Bending for σ_{b_1}

Known:

Perpendicular distance from shaft/force to axis of bending is 7 in



$$\sigma_{\max} = \frac{Mc}{I} \qquad (3\text{–}26a)$$

$$c = \frac{(A_1)(\overline{y_1}) + (A_2)(\overline{y_2}) + (A_3)(\overline{y_3})}{A}$$
$$c = \frac{(0.36)\left(\frac{0.6}{2}\right) + (1)\left(0.6 + \frac{2.5}{2}\right) + (3.20)\left(0.6 + 2.5 + \frac{0.4}{2}\right)}{4.56}$$

$$c = 2.745$$

$$I = \frac{b_1 h_1^3}{12} + A_1 d_1^2 + \frac{b_2 h_2^3}{12} + A_2 d_2^2 + \frac{b_3 h_3^3}{12} + A_3 d_3^2$$

$$I = \frac{(0.6)(0.6)^3}{12} + (0.36)(2.445)^2 + \frac{(0.4)(2.5)^3}{12} + (1)(0.895)^2 + \frac{(8)(0.4)^3}{12} + (3.20)(0.555)^2$$

$$I = 4.513\ in^4$$

$$M = F \times d$$

$$M = 5000 \times 7$$

$$M = 35000\ in - lb$$

$$\sigma_{b_1} = \frac{35000(2.745)}{4.513}$$

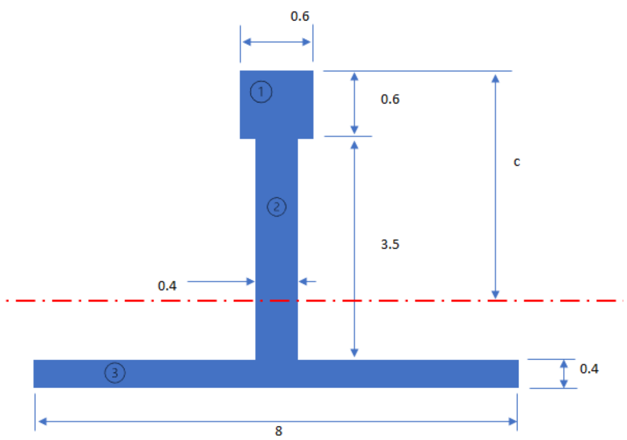
$$\sigma_{b_1} = 21288\ psi$$

Acceptable - Less than σ_d

Linear Bending for σ_{b_2}

Known:

Perpendicular distance from shaft/force to axis of bending is $10\ in$ (Throat distance)



$$A_1 = 0.6 \times 0.6$$

$$A_1 = 0.36\ in^2$$

$$A_2 = 3.5 \times 0.4$$

$$A_2 = 1.40\ in^2$$

$$A_3 = 0.4 \times 8$$

$$A_3 = 3.20\ in^2$$

$$A = 4.96\ in^2$$

$$c = \frac{(A_1)(\overline{y_1}) + (A_2)(\overline{y_2}) + (A_3)(\overline{y_3})}{A}$$

$$c = \frac{(0.36)\left(\frac{0.6}{2}\right) + (1.4)\left(0.6 + \frac{3.5}{2}\right) + (3.20)\left(0.6 + 3.5 + \frac{0.4}{2}\right)}{4.96}$$

$$c = 3.460$$

$$I = \frac{b_1 h_1^3}{12} + A_1 d_1^2 + \frac{b_2 h_2^3}{12} + A_2 d_2^2 + \frac{b_3 h_3^3}{12} + A_3 d_3^2$$

$$I = \frac{(0.6)(0.6)^3}{12} + (0.36)(3.16)^2 + \frac{(0.4)(3.5)^3}{12} + (1.4)(1.11)^2 + \frac{(8)(0.4)^3}{12} + (3.20)(0.84)^2$$

$$I = 9.06\ in^4$$

$$M = F \times d$$

$$M = 5000 \times 10$$

$$M = 50000\ in - lb$$

$$\sigma_{b_2} = \frac{50000(3.460)}{9.06}$$

$$\sigma_{b_2} = 19094\ psi$$

Acceptable - Less than σ_d

Thread Bending

Known:

Thread Specs:	
Internal Acme 1-10 - 2G	
Major Diameter	
Max	1.0400
Min	1.0200
Avg	1.0300
Minor Diameter	
Max	0.81
Min	0.8
Avg	0.805
Pitch Diametor	
Max	0.9194
Min	0.9
Avg	0.9097

$$\sigma_b = \frac{M}{Z} = \frac{Fp}{4}\frac{24}{\pi d_r n_t p^2} = \frac{6F}{\pi d_r n_t p} \qquad (8\text{–}11)$$

$$n_t = \frac{Threads}{Inch} \times\ Inches\ of\ threads$$

$$n_t = 10 \times 3$$

$$n_t = 30\ threads$$

$$\sigma_b = \frac{6(5000)}{\pi(1.0300)(30)(0.1)}$$
$$\sigma_b = 3090\ psi$$
Acceptable - Less than σ_d

Thread Shear

$$\tau = \frac{3V}{2A} = \frac{3}{2}\frac{F}{\pi d_r n_t p/2} = \frac{3F}{\pi d_r n_t p} \qquad (8\text{–}12)$$

$$\tau = \frac{3(5000)}{\pi(1.0300)(30)(0.1)}$$
$$\tau = 1545\ psi$$
Acceptable - Less than τ_d

Tensile strength of bolts required to secure base

Known:

$M_{max} = 50000\ in - lb$ and 2 bolts are used to secure the base, offset $2.050\ in$ from the base

$$\sum M = 0$$

Therefore

$$50000 - [2(F_{bolt})](2.050) = 0$$
$$F_{bolt} = \frac{50000}{2(2.050)}$$
$$F_{bolt} = 12195$$

$A_{bolt} = 0.606\ in^2$ (Bolt size used = 1-8 UNC)

$SF = 3$

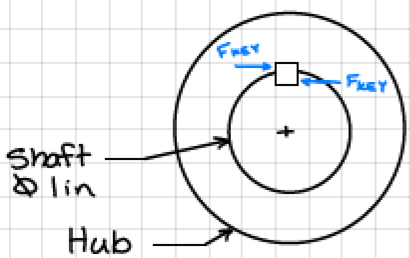
$$S_{y_{min}} = SF \times \frac{F_{bolt}}{A_{bolt}}$$
$$S_{y_{min}} = 3 \times \frac{12195}{0.606}$$
$$S_{y_{min}} = 60371.3\ psi$$

Therefore, bolts used to secure the base must be **grade 5** (proof load 74 000 psi)

KEY CALCULATIONS

Hand wheel $\phi = 18in$
Input Force $F_{IN} = 50lb$

$$T = F\frac{D}{2}$$
$$= (50lb)\left(\frac{18in}{2}\right)$$
$$= 450\ lb{\cdot}in$$



$$F_{KEY} = \frac{T}{D/2}$$
$$= \frac{(450\ lb \cdot in)}{(1in/2)}$$
$$= 900lb$$

1045 CARBON STEEL KEY

$S_y = 77\ ksi$

Safety factor $N = 3$

$$\tau_d = \frac{0.5\,S_y}{N}$$
$$= \frac{(0.5)(77000\,psi)}{3}$$
$$= 12833.33\,psi$$

$$\sigma_d = \frac{S_y}{N}$$

$$= \frac{77000\,psi}{3}$$

$$= 25666.67\,psi$$

REQUIRED AREA FOR SHEAR

$$\tau_d = \frac{F_{KEY}}{A_s}$$

$$A_s = \frac{(900\,lb)}{(12833.33\,psi)}$$

$$= 0.07013\,in^2$$

REQUIRED AREA FOR COMPRESSION

$$\sigma_d = \frac{F}{A_c}$$

$$A_c = \frac{(900\,lb)}{(25666.67\,psi)}$$

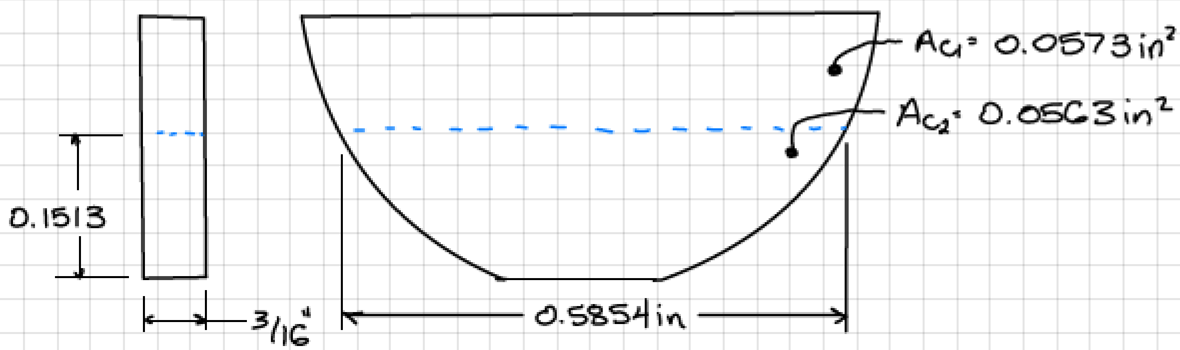
$$= 0.03506\,in^2$$

KEY SELECTION

* Woodruff key selected to ensure it does not fall out during operation

* Based on shaft size a 3/16" wide key is needed

3/16" x 5/8" Woodruff key



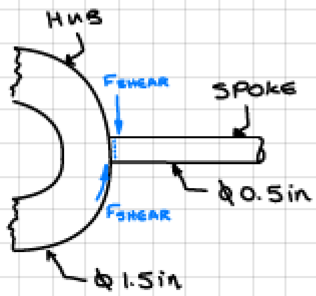
$A_s = (0.5854\,in)(0.1875\,in)$
$= 0.1098\,in^2$

$0.1098\,in^2 > 0.07013\,in^2$ ✓ GOOD FOR DESIGN

$A_{c1} > A_{c2}$
$0.0563\,in^2 > 0.03506\,in^2$ ✓ GOOD FOR DESIGN

— HAND WHEEL CALCULATIONS —

SHEAR ON SPOKES



* 5 spokes total

$$T = (50\,lb)(9\,in) = 450\,lb\cdot in$$

$$F_{SHEAR} = \frac{(450\,lb\cdot in)}{1.5\,in} = 300\,lb$$

$$A_{SHEAR} = \left[\left(\frac{\pi}{4}\right)(0.5\,in)^2\right](5)$$

$$= 0.9817\,in^2$$

$$\tau_d = \frac{F}{A} = \frac{300\,lb}{0.9817\,in^2}$$

$$= 305.58\,psi$$

$$\tau_d = \frac{S_y}{2N}$$

$N = 4 \longrightarrow$ Repeated torsion
(Table 4-1, Robert L. Mott)

$S_y = (305.58\ psi)(2)(4)$

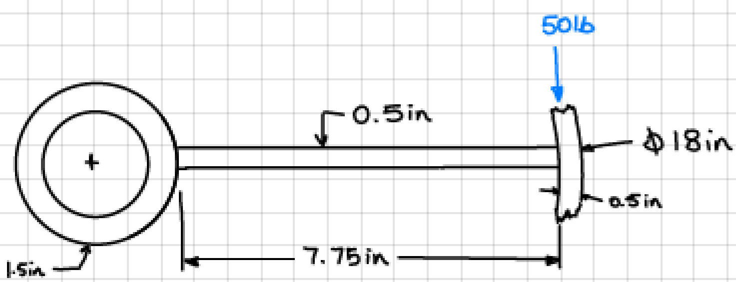
$= 2444.6\ psi = 2.44\ ksi$

$S_y = 36\ ksi \longrightarrow$ A36 Steel (metals depot)

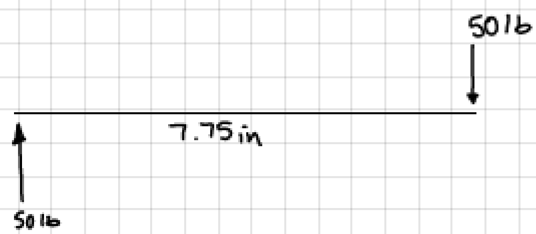
$36\ ksi > 2.44\ ksi$ ✓

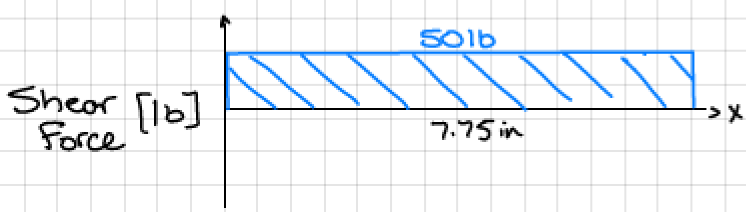
GOOD FOR DESIGN

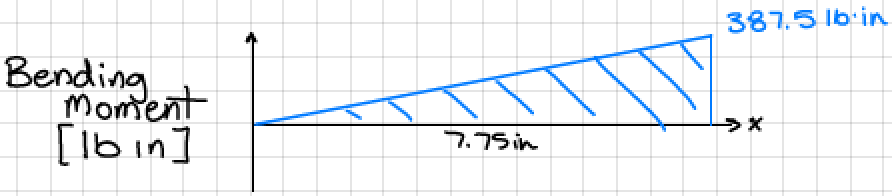
BENDING ON SPOKES



FBD SPOKE







$M_{max} = 387.5\ lb \cdot in$

$$\sigma_d = \frac{Mc}{I}$$

$$I = \frac{\pi D^4}{64} = \frac{\pi (0.5in)^4}{64} = 0.003068\ in^4$$

$$\sigma_d = \frac{(387.5 lb \cdot in)(0.25in)}{(0.003068\ in^4)}$$

$= 31575.94\ psi$ ← Divided amongst 5 spokes

$$\frac{(31575.94 psi)}{5}$$

$= 6315.19\ psi$

$\sigma_d = \frac{Su}{8}$ ⟶ Table 7-1 Bending stress Repeated loading (Robert L. Mott)

$Su = (6315.19 psi)(8)$

$= 50521.51 psi = 50.5 ksi$

✓ $50.5\ ksi < 58.0\ ksi$ ⟶ Su for A36 steel

GOOD FOR DESIGN

Appendix 4 - Process Plan

EMEC-4130 DESIGN PROJECT PROCESS PLAN

RAW STOCK		PART NAME	QUANTITY
SEE SPECIAL INSTRUCTIONS		BENCH-MODEL PRESS	1
DRAWING / PART NO.		**DATE**	**WORK ORDER**
1001		29-Mar-21	A1234-56
REVISION NO.	1		

PROCESS NUMBER	DESCRIPTION	DEPARTMENT	MACHINE TOOL
1A	CAST BASE PART	CASTING	N/A
2A	MOUNT AND FACE BOTTOM SURFACE OF BASE	MACHINING	CNC MILL
3A	FLIP PART AND MOUNT ON FIXTURE	MACHINING	CNC MILL
4A	FACE PRESS SURFACE AND DRILL MOUNTING HOLES	MACHINING	CNC MILL
5A	FACE/ SPOT DRILL/ DRILL/ THREAD ACME THREADS	MACHINING	CNC MILL
6A	DEBURR AND INSPECT	MACHINING	N/A
1B	CUT RAW STOCK TO REQUIRED LENGTH	CUTTING	BANDSAW
2B	MOUNT/ FACE/ OD TURN/ SPOT DRILL/ DRILL	MACHINING	CNC LATHE
3B	FLIP PART AND MOUNT IN CHUCK	MACHINING	CNC LATHE
4B	FACE/ OD TURN/ TURN ACME THREADS	MACHINING	CNC LATHE
5B	DEBURR AND INSPECT	MACHINING	N/A
1C	CUT RAW STOCK TO REQUIRED LENGTH	CUTTING	BANDSAW
2C	MOUNT/ FACE/ OD TURN/ SPOT DRILL/ DRILL/ PART OFF	MACHINING	CNC LATHE
3C	DEBURR AND INSPECT	MACHINING	N/A
4C	CUT RAW STOCK TO REQUIRED LENGTH	CUTTING	BANDSAW
5C	DEBURR AND INSPECT	MACHINING	N/A
6C	CUT RAW STOCK TO REQUIRED LENGTH	CUTTING	BANDSAW
7C	DEBURR AND INSPECT	MACHINING	N/A
8C	RUN PIECE THROUGH ROLLER UNTIL FULL CIRCLE	BENDING	ROLLER
9C	TAKE PIECES AND ARRANGE THEM IN CORRECT ORIENTATION	WELDING	N/A
10C	WELD PIECES TOGETHER	WELDING	WELDER
11C	CLEAN UP AND INSPECT	WELDING	GRINDER
1E	CUT RAW STOCK TO REQUIRED LENGTH	CUTTING	BANDSAW
2E	MOUNT/ FACE/ OD TURN/GROVE/ PART OFF	MACHINING	CNC LATHE
3E	DEBURR AND INSPECT	MACHINING	N/A
1F	FINAL ASSEMBLY AND INSPECTION	QA/QC	N/A

PROCESS NUMBER	SPECIAL INSTRUCTIONS
1D	1" DIAMETER A2 TOOL STEEL CUT INTO 2" LENGTHS **3 PIECES REQUIRED** (TIPS)
10C	SPOKES NEED TO BE WELDED TO HUB AND OUTTER WHEEL, OUTTER WHEEL NEEDS TO BE WELED ON SEEM
9C	PIECES MAY NEED TO BE GROUND DOWN TO ACHIEVE PROPPER FITMENT
8C	AFTER BENT INTO FULL CIRCLE EXCESS WILL BE CUT OFF
6C	1/2" DIAMETER ROUND STOCK CUT INTO A 57" LENGTH (OUTTER WHEEL)
4C	1/2" DIAMETER ROUND STOCK CUT INTO 8" LENGTHS **5 PIECES REQUIRED** (SPOKES)
1C	1-1/8" DIAMETER ROUND STOCK CUT INTO A 1-1/4" LENGTH (HUB)
1B	1-1/8" DIAMETER ROUND STOCK CUT INTO 17-1/4" LENGTH (ACME SHAFT)

Appendix 5 - Cost Estimate

Direct Material Cost					
Manufactured Parts					
Name	Part No.	Material	Cost/Volume	Raw Stock Volume	Cost
Base	3001	Cast Iron	$0.21/in^3	260.32in^3	$54.67
ACME Shaft	3002	A36 Steel	$0.84/in^3	17.1468in^3	$14.40
Hand Wheel	3003	A36 Steel	$0.84/in^4	10.7949in^3	$9.07
		A36 Steel	$0.84/in^5	7.6085in^3	$6.39
		A36 Steel	$0.84/in^6	1.7671in^3	$1.48
Round Tip	3004	A2 Tool Steel	$9.13/in^3	1.5708in^3	$14.34
Flat Tip	3005	A2 Tool Steel	$9.13/in^4	1.5708in^4	$14.34
Point Tip	3006	A2 Tool Steel	$9.13/in^5	1.5708in^5	$14.34
					$129.04

Buyout Parts			
Name	Part No.	Manufacture Part No.	Cost
O-Ring	4001	9452K16	$4.66
3/16" X 5/8" Woodruff Key	4002	98481A110	$16.68
1/4"-20 Set Screw	4003	94105A533	$13.53
			$34.87
		Total Cost	**$163.91**

*Cost of steel from MetalsDepot
*Cost of cast iron from Iron-Foundry
*Cost of buyout parts come from McMaster Carr
*All Costs were converted to $CAD

Appendix 6 - Buyout Parts

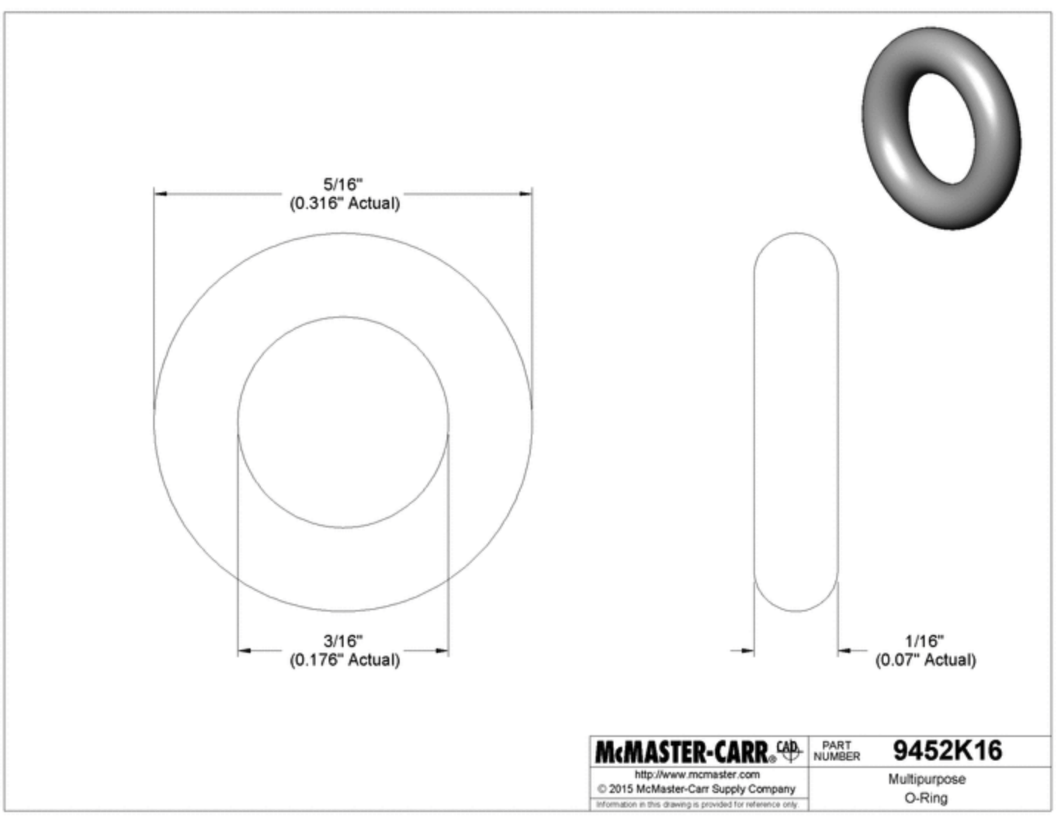
Oil-Resistant Buna-N O-Ring

1/16 Fractional Width, Dash Number 008

	Vegetable Oils Water
Specifications Met	ASTM D2000, SAE AS568, SAE J200
Temperature Range	-20° to 250° F
Color	Black
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/19/2021, 211 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	Peoples Republic of China or Vietnam
Schedule B	401693.0000
ECCN	EAR99

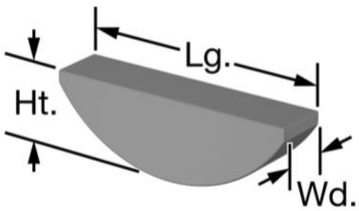
Made of Buna-N, these O-rings resist grease, hydraulic oil, and motor oil—plus mild chemicals and water. However, Buna-N is not for use with brake fluid. These O-rings are commonly used to create multidirectional seals between two parts in power transmission assemblies, hydraulic cylinders, and pneumatic cylinders. With a round profile, they resist compression and tearing to keep their shape over time, so they're reusable. All have shelf life, cure date, and a traceable lot number printed on the bag. Many meet ASTM D2000 and SAE J200, international standards for rubber products.

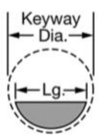
Inch O-rings have a dash number and are sized to the SAE standard AS568.



Woodruff Key

1018-1045 Carbon Steel, Key Number 61, 3/16" Wide





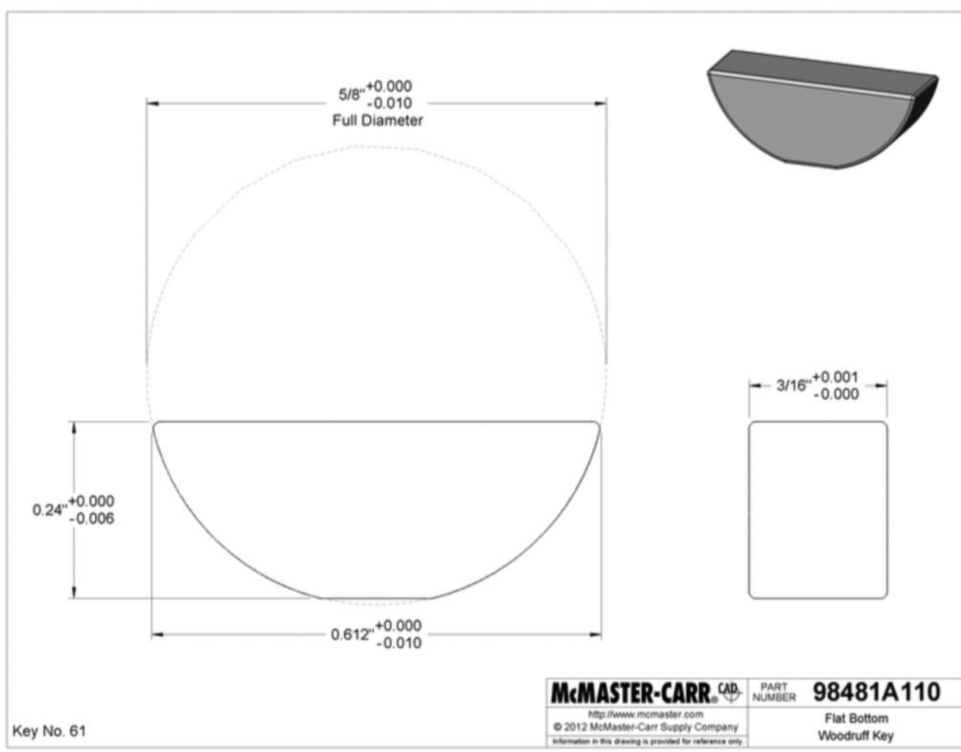
Side View

Length	-0.010" to 0.000"
Minimum Hardness	Not Rated
Specifications Met	ANSI B17.2
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (06/25/2020, 209 SVHC) Compliant
DFARS	Specialty Metals COTS-Exempt
Country of Origin	United States
USMCA Qualifying	No
Schedule B	731824.0000
ECCN	EAR99

Woodruff keys work well near shaft shoulders, where a standard open keyway would create too much stress. They are also often used on tapered shafts. These keys have a rounded shape that makes them easy to remove when parts need to be taken apart frequently, such as for maintenance or prototyping. Because they're usually shorter than standard machine keys, they work best in light duty applications. Use them to connect gears and other components to shafts. Also known as half moon keys.

Steel keys offer good strength.

Inch keys conform to ANSI B17.2 standards for dimensions and tolerances.



Alloy Steel Flat-Tip Set Screws

Black Oxide, 1/4"-20 Thread, 1/4" Long

Packs of 50

ADD TO ORDER

In stock
$10.76 per pack of 50
94105A533

CAD 3-D Solidworks Download

Material	Black-Oxide Alloy Steel
Thread Size	1/4"-20
Length	1/4"
Drive Size	1/8"
Screw Size Decimal Equivalent	0.250"
Hardness	Rockwell C45
Specifications Met	ASME B18.3, ASTM F912
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 3A
Thread Direction	Right Hand
Drive Style	Hex
Tip Type	Flat
Head Type	Headless
System of Measurement	Inch
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/19/2021, 211 SVHC) Compliant
DFARS	Specialty Metals Compliant (252.225-7009)
Country of Origin	United States
USMCA Qualifying	No
Schedule B	731815.9000
ECCN	EAR99

The tip makes good contact on flat surfaces and allows you to make frequent adjustments with minimal surface damage. Length listed is the overall length.

Black-oxide alloy steel set screws resist corrosion in dry environments.