MET Senior Design Project Spring 2016

Final Report

Pallet Support Fixture

April 24, 2016

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Introduction

This is the final report to be submitted for our senior design project proposed by the team of John Fisher, Rachael Klopfenstein, and Michelle Gilruth. We would like to take this opportunity to thank PDQ Workholdings in Columbia City, Indiana for sponsoring our project. We did not have the opportunity to follow through with our project to the end because required design changes requested by the customer pushed back our timeline. At this time some materials have been ordered; however, by the time we were ready to order the main piece of material, so that we could have enough time to build and test our project, our sponsor informed us that there were too many customer orders scheduled to allow for the use of necessary machines to complete the project. In the following sections of this progress report, we will discuss the purpose and specifications of the project, design of our project, FEA analyses done on our project, how we would have fabricated our project, how we would have tested our project, overall project costs, and our conclusions.

Purpose

PDQ presently uses a fixture for their op10 sequence that is time-consuming to set-up. The current op10 fixture holds a piece of workable material (usually cast iron) and faces the top and one of the sides as well as completing the center bore. The fixture is riddled with numerous bolt holes that are no longer needed as well as blocks that require being bolted and unbolted when they need to be moved. The object of this project was to improve upon the original op10 fixture by creating a whole new fixture for the op10 sequence. The new op10 fixture will continue to perform the facing and center bore, but more efficiently. The features that were improved upon are:

- Reduce fixture set-up time
- Remove sporadic bolt holes that have no use
- Eliminate most of the blocks with bolts
- Replace crowders with adjustable sliders and grippers

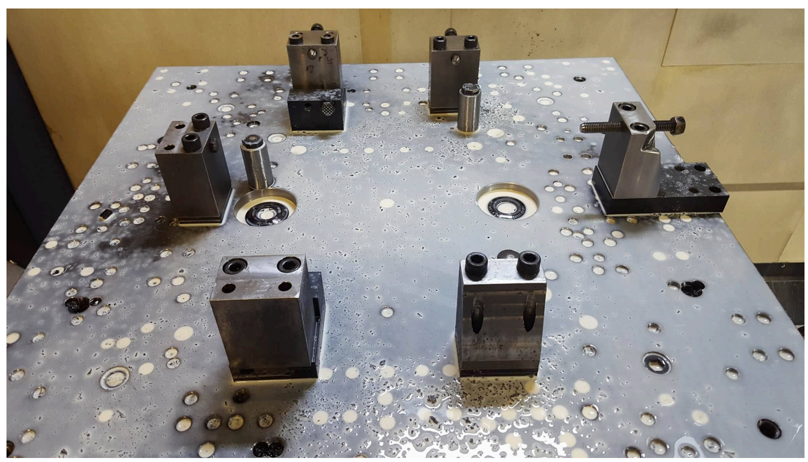


Figure 1: A photo of the current op10 fixture. Note the many bolt holes and static blocks that add to the set-up time.

Specifications

The fixture needs to be able to hold the workable material static as the mill goes through its sequences. The following specifications were required to ensure that the fixture would perform as needed:

- Material for fixture is hot-rolled steel
- Material for crowders and sliders is cold-rolled steel
- Material for datums and grippers is hardened tool steel
- Needs to hold workable material size up to 800 mm x 1000 mm
- Components need to hold the material static
- Components should not warp, bend or break

Design

SolidWorks was the chosen program used to design our project, as that is the program that is currently in use at PDQ. One of the project specifications was that the fixture hold material up to a size of 800 mm x 1000 mm, so to begin with, the team chose a circular design over a square one because it can hold the required material size, while saving on weight, material cost, and increasing table travel in the machine. One of the needed changes was to reduce the number of bolt holes. Some are no longer used and removing them would give the fixture a cleaner look, so in the new design, the bolt holes have been reduced by about one-third. Another needed change was to eliminate some of the static blocks that need to be bolted down. Some were removed, while others have been replaced with sliding blocks that are held in place with pins. Finally, one of the most important changes was the requirement to reduce set-up time. The team planned for at least a 20% decrease in this area. We have no doubt that the use of pins over bolts will certainly help reduce set-up time making the op10 sequence more efficient.

Finite Element Analysis (FEA)

Using SolidWorks, the team was able to analyze some components of the newly designed fixture as well as forces on the material as it is loaded in the assembly. Looking at the FEA of the assembly for displacement and stress (Appendix E, pg 25), the lone pink arrow pushing against the material in the assembly represents a force of 1000 lbs. This value was used because the force that the spindle puts on the material being machined was calculated to be 1070.1 lbs. (Appendix A, pg 7). The other pink arrows represent a force of 3000 lbs applied against the components holding the material, while the green arrows represent a static hold. This value was chosen because the largest amount of force the machine can apply is about 2400 lbs. We chose to go beyond that to show the strength of the components. For the displacement, at 3000 lbs the largest displacement was 3.692×10^{-2} mm. For stress, at 3000 lbs the largest value was 7.086×10^{-7} N/m^2. During this analysis, the tertiary datum, showed signs of deflection so more material was added to reduce this deflection. Subsequent analysis of the crowder sliders and the datum sliders showed largest displacements of 1.591×10^{-2} mm and 2.77×10^{-2} mm, and largest stresses of 6.687×10^{-7} N/m^2 and 1.350×10^{-8} N/m^2.

Fabrication

Even though we did not have the opportunity to fabricate our fixture, this was our plan to complete this part of our project.

- To start, the DMU 100 milling machine at PDQ will be used. No program needs to be written because PDQ uses iMachining to translate drawings into machining program language.
- The base plate would be loaded into a fixture and the top and sides would be milled.
- Grooves will be cut.
- All holes will be drilled and/or tapped.
- After those operations, the smaller DMU 400 milling machine would be used. No program needs to be written because PDQ uses iMachining to translate drawings into machining program language.
- Each slider will be mounted onto a fixture to perform surfacing opposition.
- The supports will then be turned on the lathe and threads will be added.

Testing Plan

The plan for testing the limitations of our project was a simple one:

- Use the DMU 100 P duoBlock milling machine at PDQ. This machine offers 5-axis machining capabilities, is equipped to handle challenging materials and high surface quality standards.
- Set-up the new fixture paying attention to set-up time. The material being tested is cast iron because this is the type of material that is usually worked with at PDQ.
- Load the existing op10 program with some modifications such as material height. Because there is already a program available, no programming was needed.
- Begin the face milling sequence. We are looking for the components to hold the material static and at the same time, hold their shape in that they should not warp, bend or break.

Figure 2: The DUM 100 is the machine that we were planning to use to test our project.

Costs

In our proposal, we estimated the cost to build our fixture at around $2000. Table 1 shows that the actual cost for all the components came out to $2279.61. However, the items highlighted in yellow are those that were available at PDQ at no cost to the project, so that brings the total to $1616.50, which is 19% below our budget.

Table 1: Costs for the fixture components.

Part	Description	Quantity	Cost
Base Plate 40.6" x 40.6" x 2.875"	Hot-Rolled Steel	1	$775.00
Blanchard to 2.875"	Grind base plate to required thickness	1	$200.00
Liner Bushings		2	$48.02
Speedloc Bolts		2	$177.26
Sliders	Datum and Cylinder	4	$40.00
T-Nuts		8	$55.44
Pull Pins		4	$34.42
Gripper Bolts		3	$26.52
Cylinder		3	$245.25
SAE4 Port Plug		1	$1.50
Manual Decoupler		1	$517.50
Gauge		1	$84.00
¾-10 x 1-¾ Hex Head Cap Screw		1	$12.44
¾-10 x 1-$^{3}/_{8}$ SHCS		4	$38.68
$^{3}/_{8}$-16 x 1-½ Low Pro SCHS		2	$23.58
Total			**$2279.61**
Actual Cost	without highlighted items		**$1616.50**
Estimated Cost			**$2000.00**

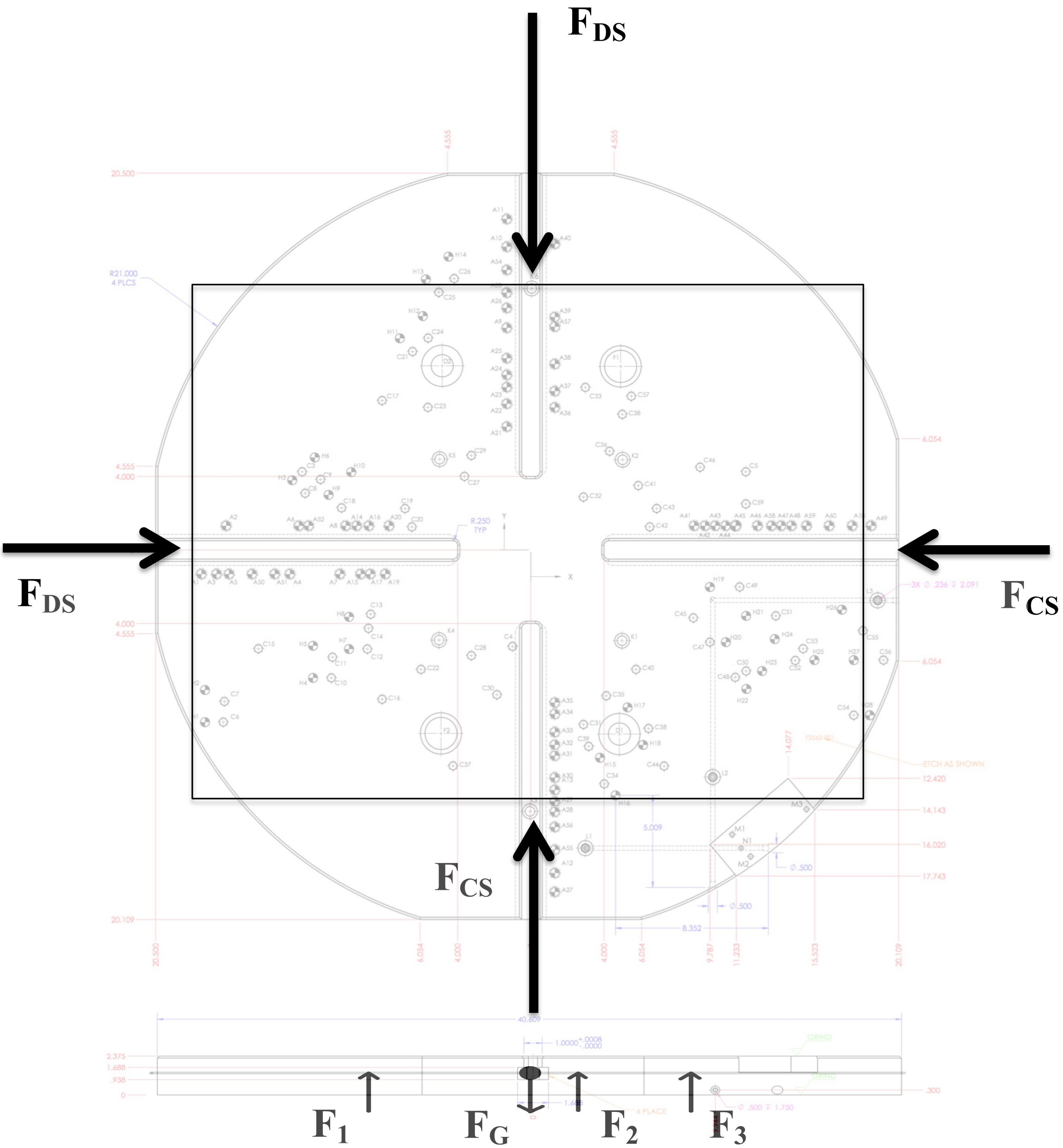
Conclusion

While we did not finish our project, the analysis shows that the assembly and its components are sound and would have held the material with no issues. We did not have the opportunity to measure set-up time, but by reducing the number of bolts used to hold the material and by replacing some of the static blocks with sliders and pins, we have not doubt that this process will see some reduction in set-up time. The plan was to reduce set-up time by at least 20%. With the current set-up time at about 45 minutes, if the new design can be set-up in at least 30 minutes that would be a 34% time savings, which far exceeds our goal of 20%.

Appendix

Appendix A

F_{DS} = Force of the Datum Slider
F_{CS} = Force of the Cylinder Slider
These forces are applied to the material to keep it static while it is being face milled. These forces need to overcome the force of the facing tool to keep the material from moving.



Face Milling with High Shear Cutters - High Feed Mill			
Input Data			
Nomenclature	Symbol	Value	Unit
Ultimate Strength	σ_{ts}	125000	PSI
Effective Cutting Diameter	D	3	in
Number of inserts in the cutter	Z	6	
Cutting Speed	V_c	650	sfm
Axial Depth of Cut	d	0.055	in
Radial Depth of Cut	W	2.1	in
Required feed per tooth (chip load) at the cutter	h_r	0.055	in
Machinability Factor (from Table 1 - Appendix A)	C_m	1.15	
Tool Wear Factor (from Table 2 - Appendix A)	C_w	1.3	
Machine Efficiency Factor (from Table 3 - Appendix A)	E	95	%
lbs to N		4.44822	
ft-lb to Nm		1.3558	
hp to KW		0.7457	
Calculated Data			
Nomenclature	Symbol	Value	Unit
Spindle Speed = $\frac{12\times\frac{V_c}{\pi}}{D}$	n	827.6	rpm
Feed Rate* = if $W \geq \frac{D}{2}$, then $F_p = F$ and if $W < \frac{D}{2}$, then $F_p = \frac{Z\times n\times h}{\sqrt{\frac{((D-W)\times W)}{D\times 2}}}$	F_p	273.1	ipm
Program chip load* = $\frac{\frac{F_p}{Z}}{n}$	f_z	0.0550	in
Feed Rate = Z × n × h	F	273.1	ipm
Actual chip load at cutter = if $W \geq \frac{D}{2}$, then $h_a = h_r$ and if $W < \frac{D}{2}$, then $h_a = \sqrt{\frac{((D-W)\times W}{D\times 2}} \times \frac{(\frac{F}{n})}{Z}$	h_a	0.055	in
Metal Removal Rate = d × W × F	Q	31.5	in^3/min
Metal Removal Rate* = $d \times W \times F_p$	Q_p	31.5	in^3/min
Cross-sectional Area of the Chip = $d \times h_r$	A	0.003	in^2
Number of Inserts in the Cut = $Z\times \frac{\sin^{-1}(2\times W-D)}{D} + \frac{\sin^{-1}(1)}{2\times\pi}$	Z_c	1.893	
Ratio of Radial Width of Cut to Cutting Diameter	$(\frac{W}{D})$	0.700	
Tangential Cutting force = $\sigma_{ts} \times A \times Z_c \times C_m \times C_w$	F_T	1070.1	lb
Tangential Cutting Force = $(\sigma_{ts} \times A \times Z_c \times C_m \times C_w) \times 4.44822$	F_T	4760.0	N
Torque at the Cutter = $F_T \times \frac{D}{2}$	τ	1605.1	in-lb
Torque at the Cutter = $\tau \times \frac{1.3558}{12} \times 1000$	τ	181353.3	Nmm
Torque at the Cutter = $F_T \times \frac{(\frac{D}{2})}{12}$	τ	133.8	ft-lb
Torque at the Cutter = $\tau \times 1.3558$	τ	181.4	Nm
at the cutter: Machining Power = $\frac{F_T \times V_c}{33000}$	P_c	21.08	hp
at the cutter: Machining Power = $P_c \times 0.7457$	P_c	15.7	KW
at the motor: Machining Power = $\frac{P_c}{E} \times 100$	P_m	22.2	hp
at the motor: Machining Power = $P_m \times 0.7457$	P_m	16.5	KW

*When the centerline of the face mill is not on the workpiece

Face Milling with High Shear Cutters - Face Mill			
Input Data			
Nomenclature	Symbol	Value	Unit
Ultimate Strength	σ_{ts}	125000	PSI
Effective Cutting Diameter	D	4	in
Number of inserts in the cutter	Z	8	
Cutting Speed	V_c	525	sfm
Axial Depth of Cut	d	0.155	in
Radial Depth of Cut	W	2.8	in
Required feed per tooth (chip load) at the cutter	h_r	0.0182	in
Machinability Factor (from Table 1 - Appendix A)	C_m	1.15	
Tool Wear Factor (from Table 2 - Appendix A)	C_w	1.3	
Machine Efficiency Factor (from Table 3 - Appendix A)	E	95	%
lbs to N		4.44822	
ft-lb to Nm		1.3558	
hp to KW		0.7457	
Calculated Data			
Nomenclature	Symbol	Value	Unit
Spindle Speed = $\frac{12\times\frac{V_c}{\pi}}{D}$	n	501.3	rpm
Feed Rate* = if $W \geq \frac{D}{2}$, then $F_p = F$ and if $W < \frac{D}{2}$, then $F_p = \frac{Z\times n\times h}{\sqrt{\frac{((D-W)\times W)}{D\times 2}}}$	F_p	72.995	ipm
Program chip load* = $\frac{\frac{F_p}{Z}}{n}$	f_z	0.0182	in
Feed Rate = Z × n × h	F	72.995	ipm
Actual chip load at cutter = if $W \geq \frac{D}{2}$, then $h_a = h_r$ and if $W < \frac{D}{2}$, then $h_a = \sqrt{\frac{((D-W)\times W}{D\times 2}}\times\frac{(\frac{F}{n})}{Z}$	h_a	0.0182	in
Metal Removal Rate = d × W × F	Q	31.7	in^3/min
Metal Removal Rate* = $d \times W \times F_p$	Q_p	31.7	in^3/min
Cross-sectional Area of the Chip = $d \times h_r$	A	0.003	in^2
Number of Inserts in the Cut = $Z\times\frac{\sin^{-1}(2\times W-D)}{D}+\frac{\sin^{-1}(1)}{2\times\pi}$	Z_c	2.524	
Ratio of Radial Width of Cut to Cutting Diameter	$(\frac{W}{D})$	0.700	
Tangential Cutting force = $\sigma_{ts} \times A \times Z_c \times C_m \times C_w$	F_T	1330.6	lb
Tangential Cutting Force = $(\sigma_{ts} \times A \times Z_c \times C_m \times C_w) \times 4.44822$	F_T	5918.7	N
Torque at the Cutter = $F_T \times \frac{D}{2}$	τ	2661.1	in-lb
Torque at the Cutter = $\tau \times \frac{1.3558}{12} \times 1000$	τ	300663.7	Nmm
Torque at the Cutter = $F_T \times \frac{(\frac{D}{2})}{12}$	τ	221.8	ft-lb
Torque at the Cutter = $\tau \times 1.3558$	τ	300.7	Nm
at the cutter: Machining Power = $\frac{F_T \times V_c}{33000}$	P_c	21.17	hp
at the cutter: Machining Power = $P_c \times 0.7457$	P_c	15.8	KW
at the motor: Machining Power = $\frac{P_c}{E} \times 100$	P_m	22.3	hp
at the motor: Machining Power = $P_m \times 0.7457$	P_m	16.56	KW

*When the centerline of the face mill is not on the workpiece

MACHINABILITY FACTORS, TOOL WEAR FACTORS, AND MACHINE EFFICIENCY FACTORS FOR FACE MILLING

Table 1. Machinability Factors, C_m

Most Common Workpiece Materials	C_m at W/D ratios:		
	W/D < = 0.66	**0.66<W/D<1.0**	**W/D = 1.0**
Aluminum alloys	1.0	1.05	1.1
Carbon and alloy steels	1.0	1.15	1.3
Cast irons	1.0	1.15	1.3
Titanium alloys	1.0	1.20	1.4
Stainless steel, High-temperature alloys	2.0	2.15	2.3

Note: *W = Radial width of cut, inches,*
D = Effective cutting diameter, inches,
W/D = Ratio of radial width of cut to cutting diameter.

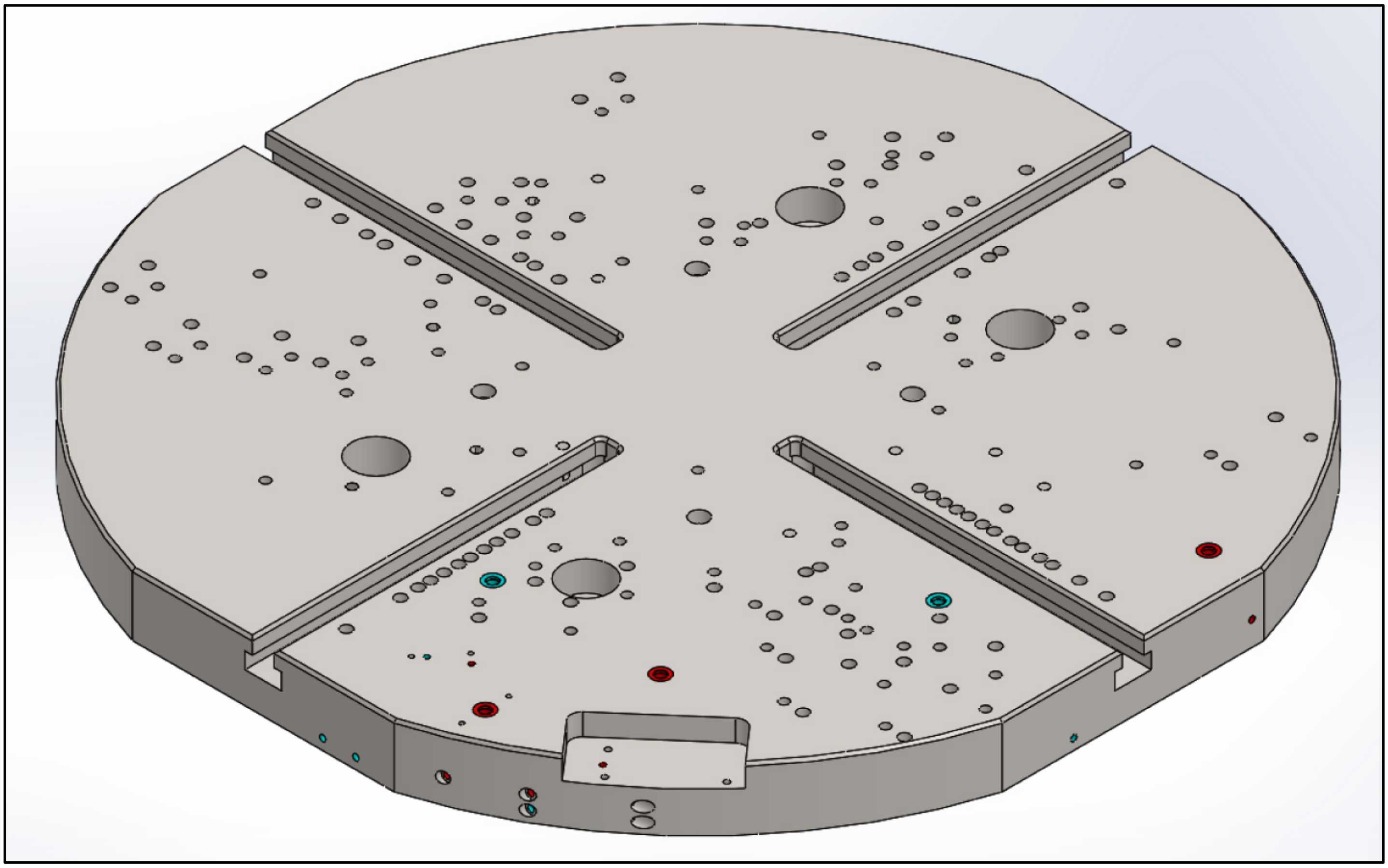
Table 2. Tool Wear Factors, C_w

Milling Category	Depth of cut (min-max), in.	Chip load (min-max), ipt	C_w
Light	0.020-0.100	0.003-0.006	1.1
Medium	0.100-0.200	0.006-0.010	1.2
Heavy duty	0.200-0.400	0.010-0.020	1.3

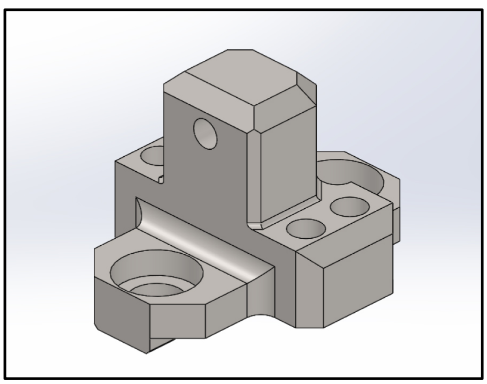
Table 3. Machine Efficiency Factors, E

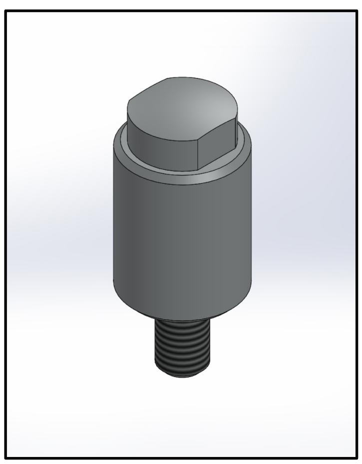
Type of Drive	E, %
Direct Drive	95
Direct Belt Drive	90
Back Gear Drive	75
Geared Head Drive	70-80
Oil - Hydraulic Drive	60-90

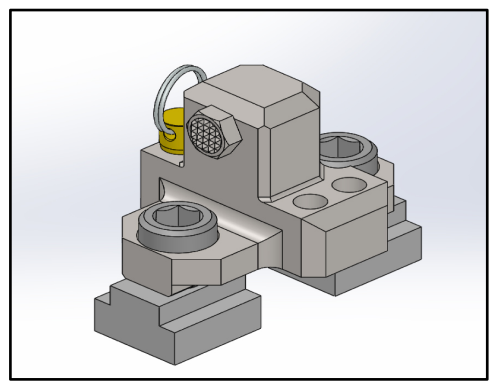
Appendix B

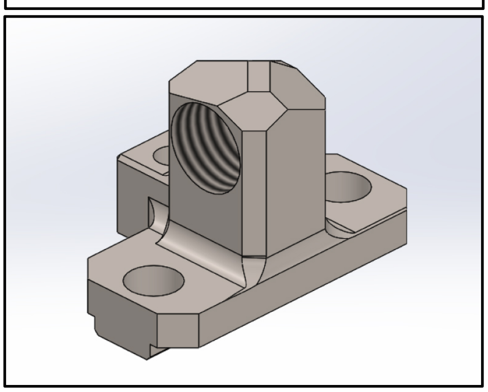


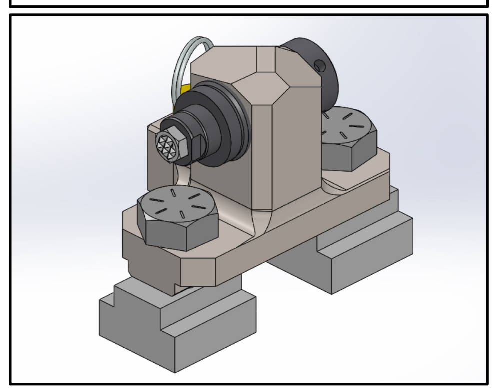
Rendering of the baseplate











Renderings of datum slider (top left), a riser (center), datum slider assembly (top right), cylinder slider (bottom left) and a cylinder slider assembly (bottom right).

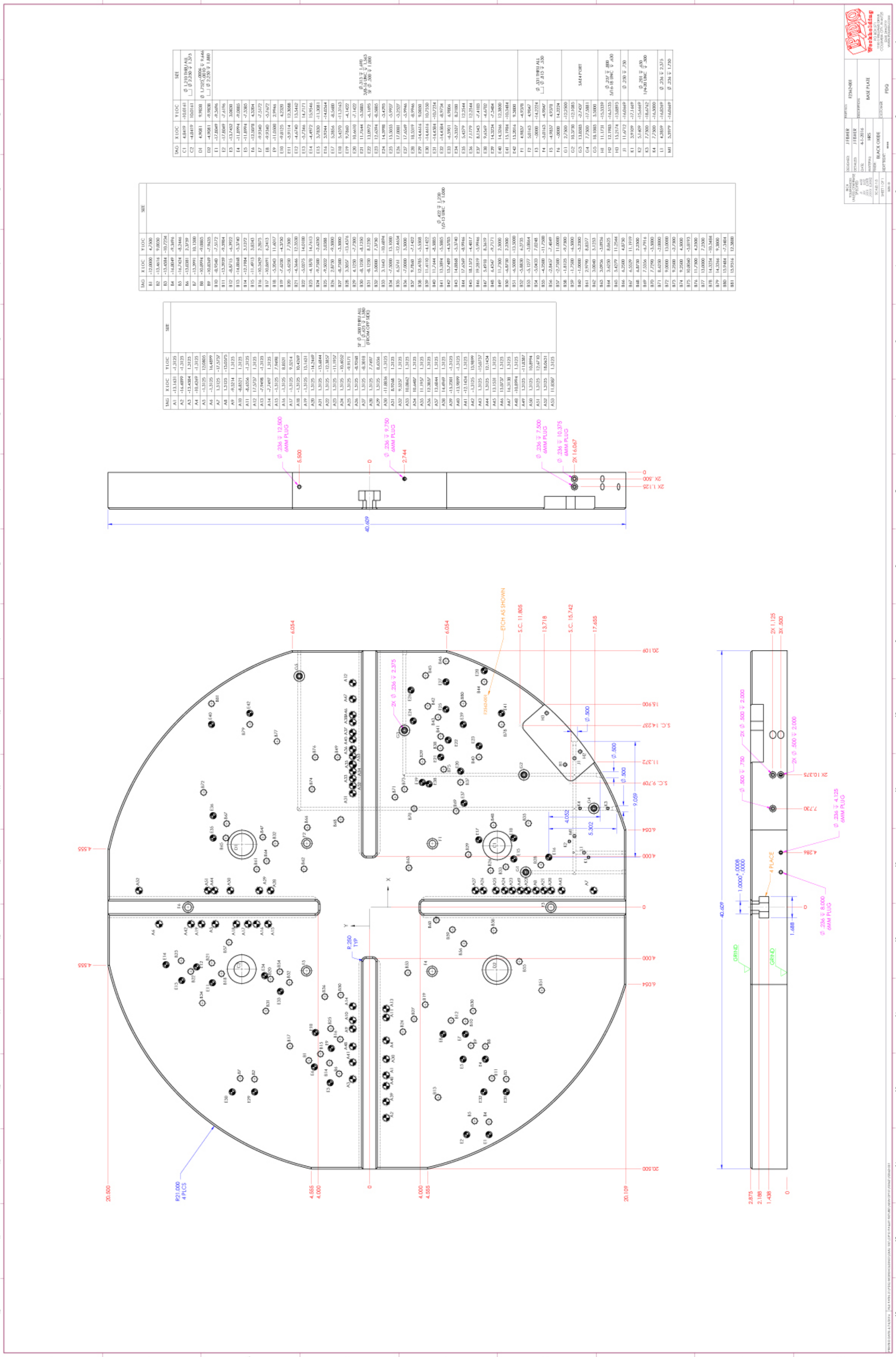
A riser component part.

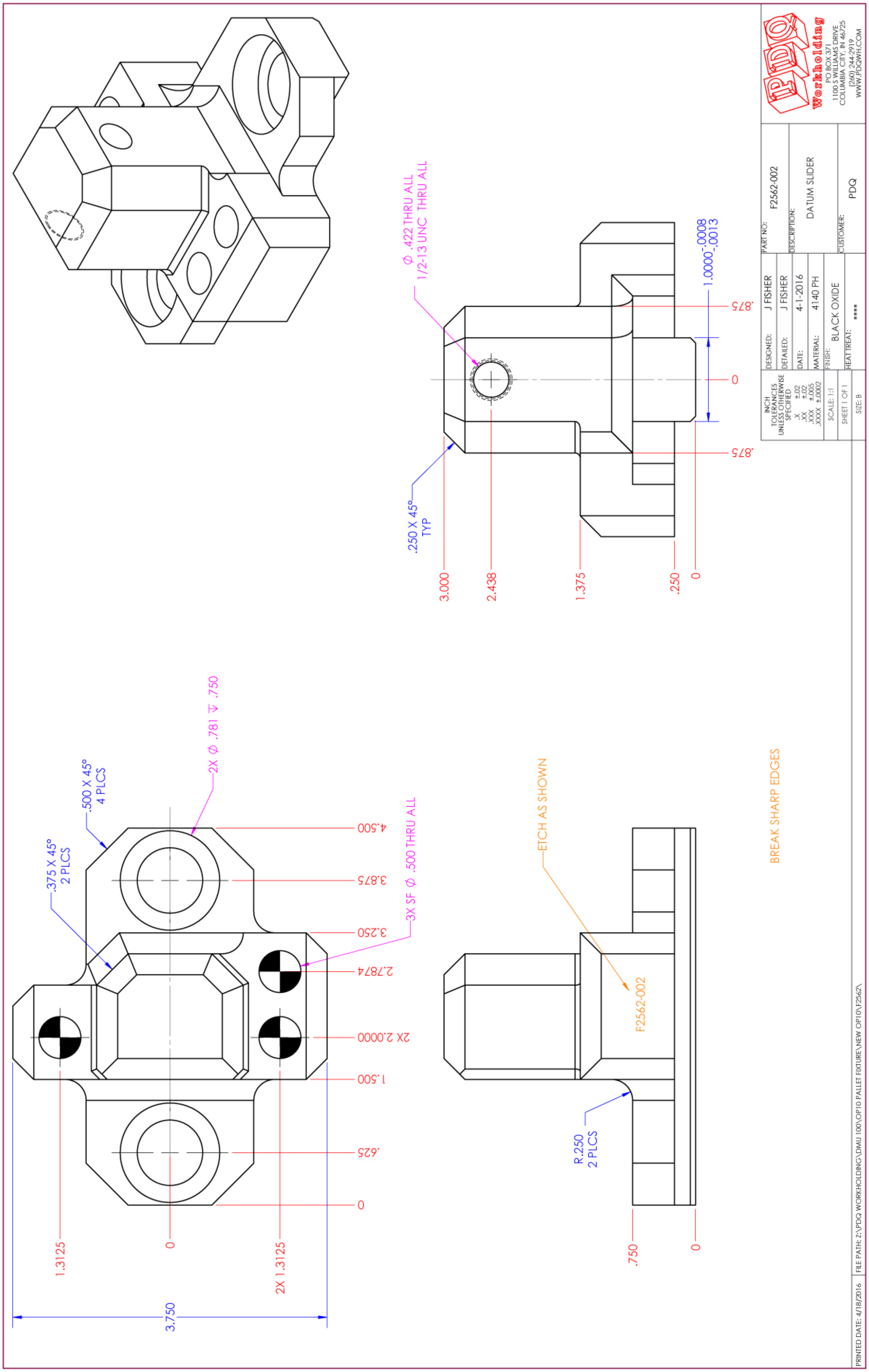
A Z-Datum component part.

A Z-Datum component part.

Originally, we were going to incorporate springs with our sliders but decided to use pull pins instead.

Appendix C





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COLUMBIA CITY, IN 46725
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CUSTOMER: PDQ
DESIGNED: J FISHER
DETAILED: J FISHER
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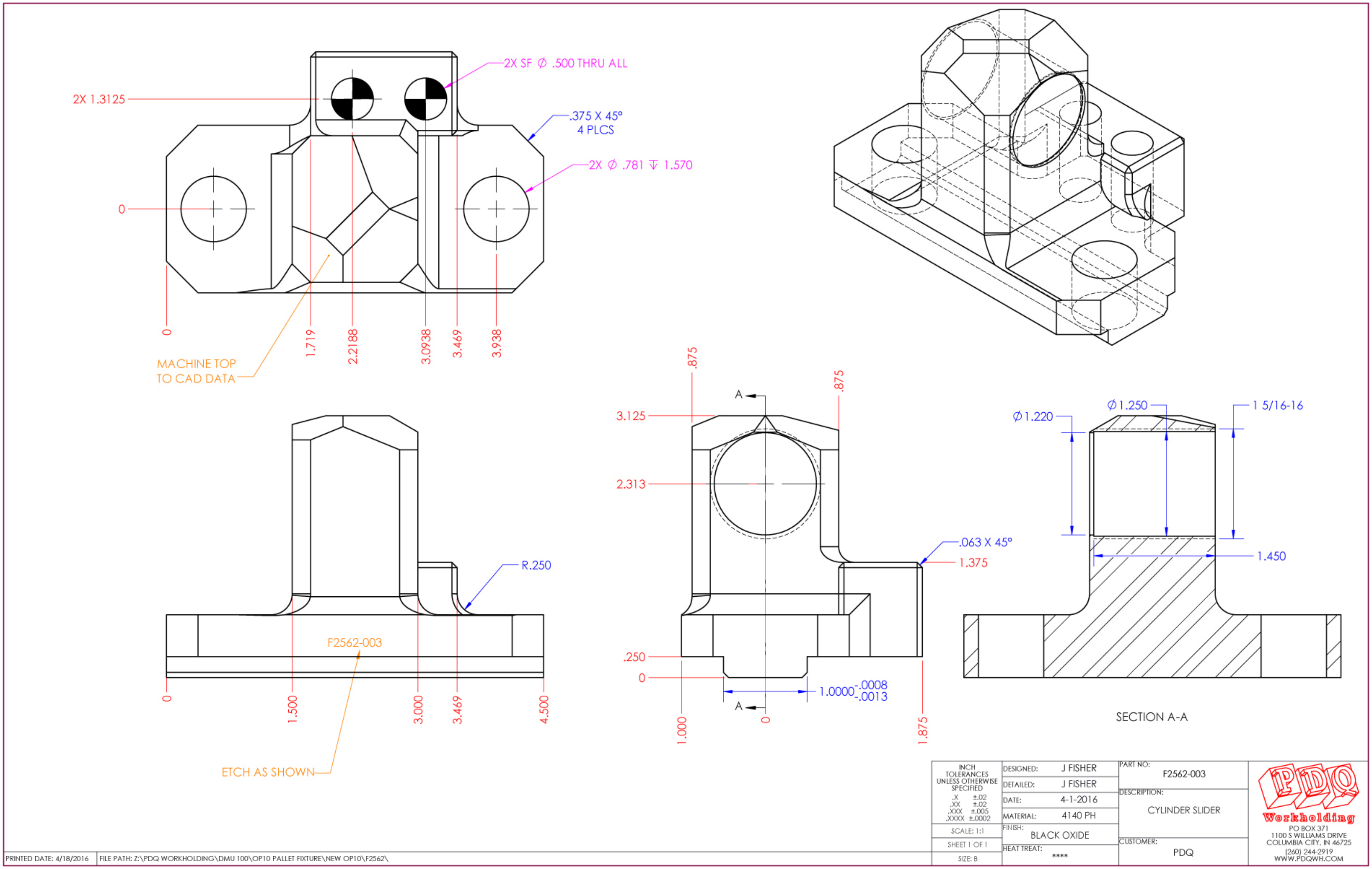

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DETAILED: J FISHER
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HEAT TREAT: ****
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DESCRIPTION: CYLINDER SLIDER
CUSTOMER: PDQ
PDQ
Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
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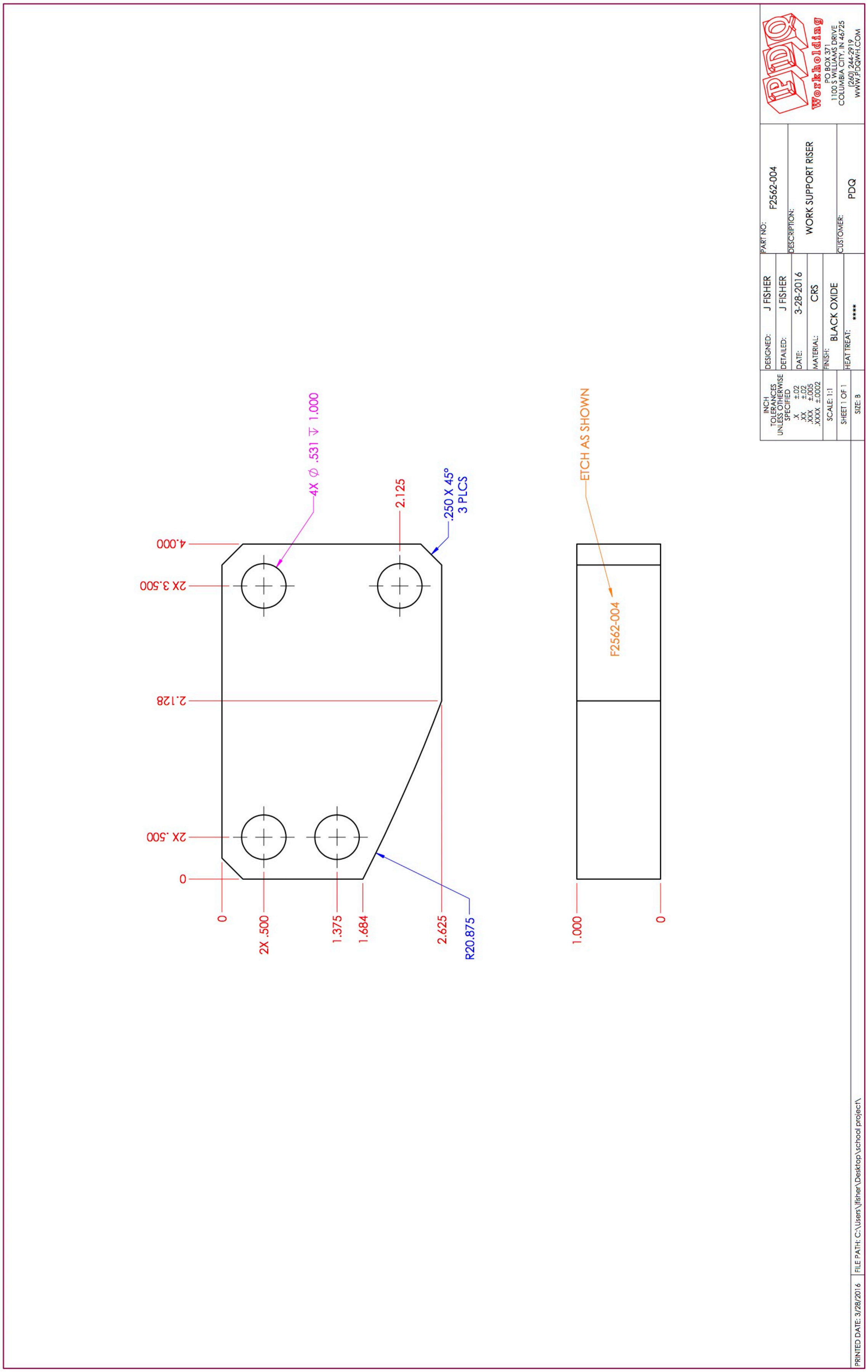
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UNLESS OTHERWISE
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HEAT TREAT: ****
PART NO: F2562-004
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CUSTOMER: PDQ
PDQ Workholding
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1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
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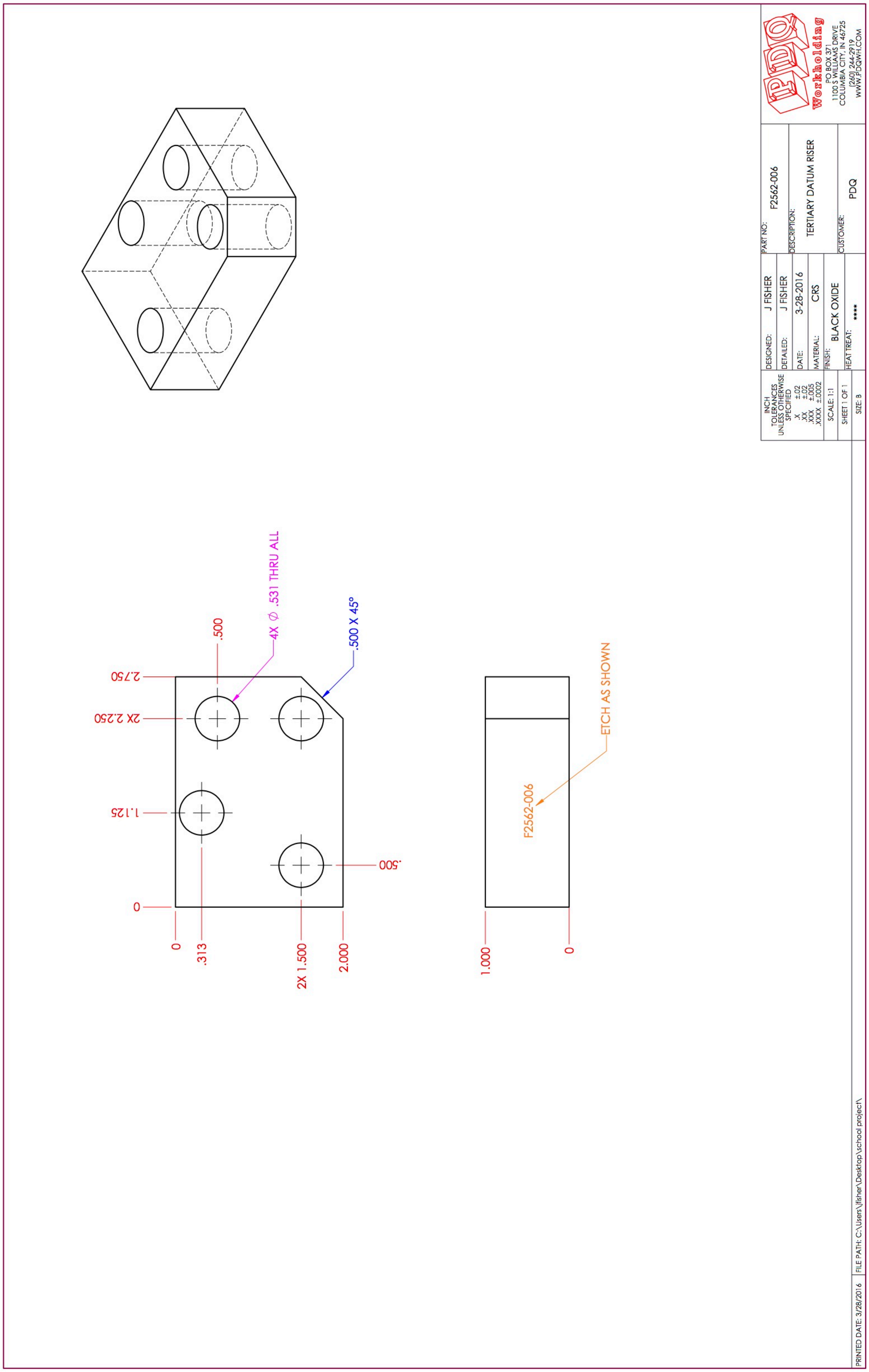
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PDQ Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
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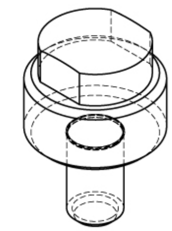

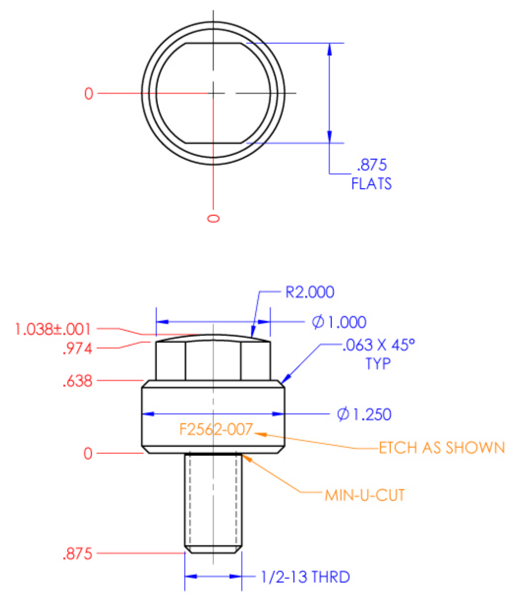

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	MATERIAL: A-2			
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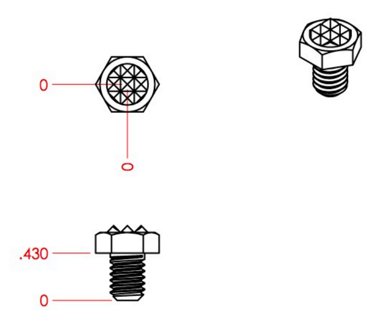
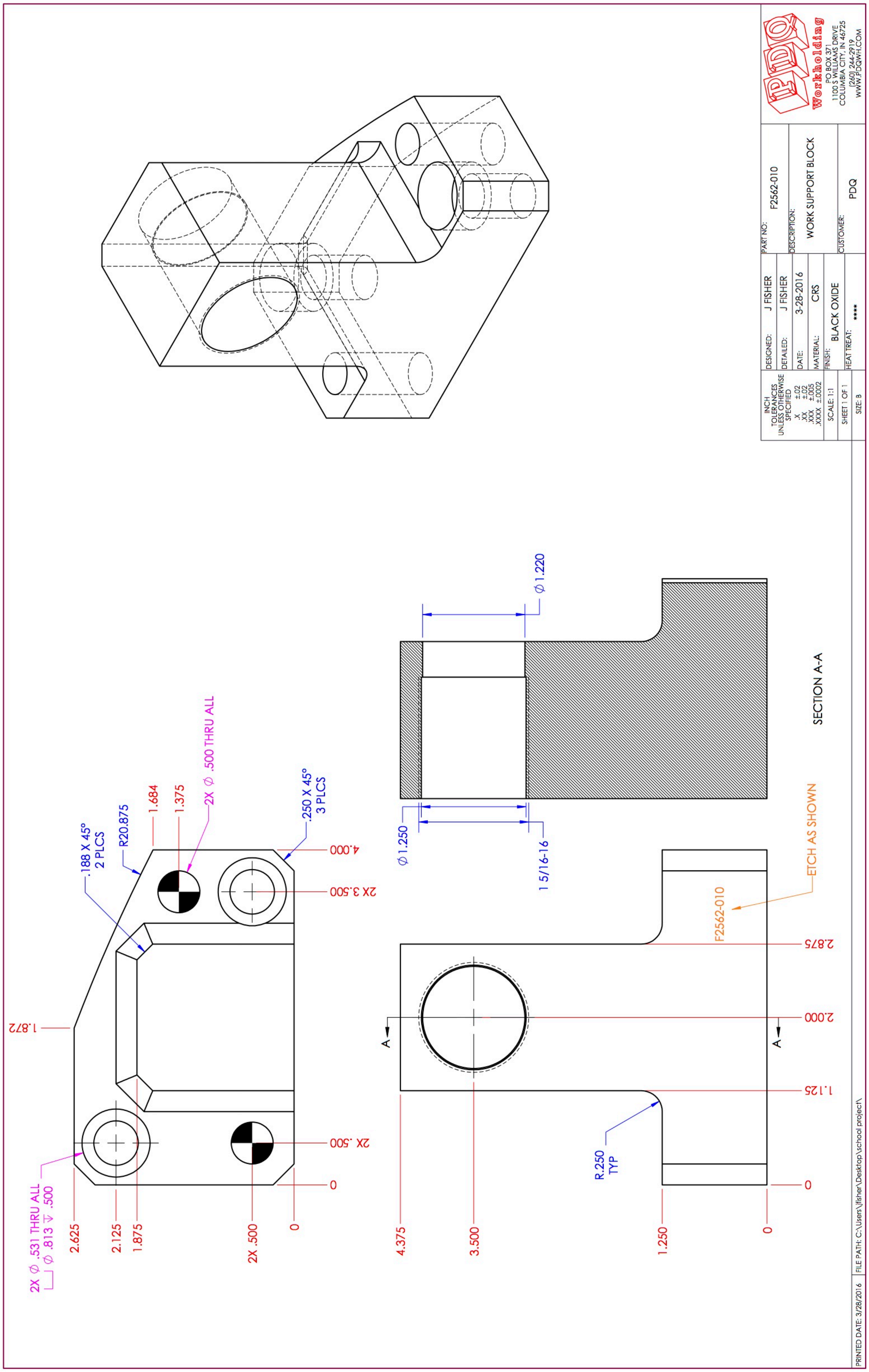
SHEET 1 OF 1	HEAT TREAT: Rc 54-56			
SIZE: B				

PRINTED DATE: 4/18/2016 | FILE PATH: Z:\PDQ WORKHOLDING\DMU 100\OP10 PALLET FIXTURE\NEW OP10\F2562\

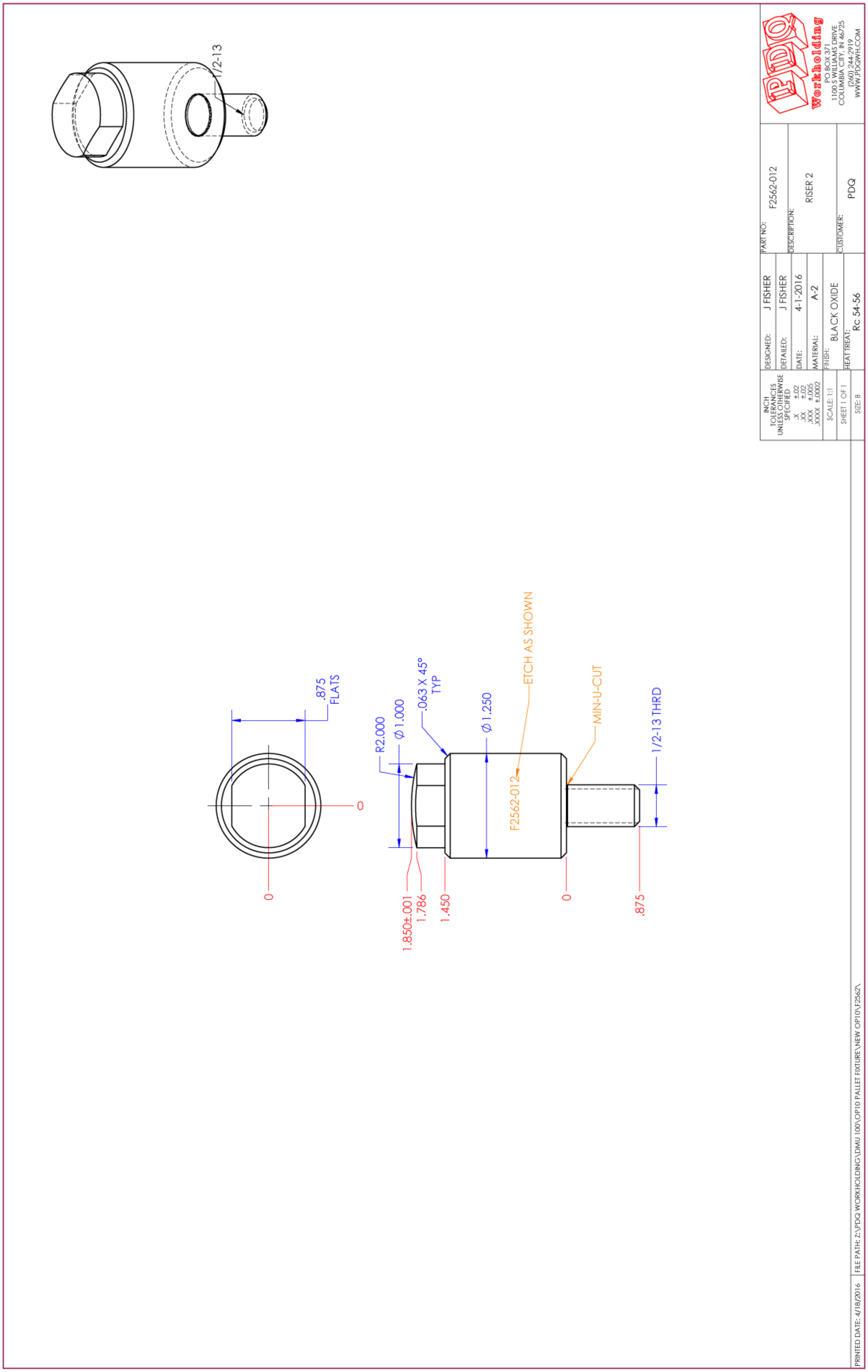


INCH TOLERANCES UNLESS OTHERWISE SPECIFIED .X ±.02 .XX ±.02 .XXX ±.005 .XXXX ±.0002	DESIGNED: J FISHER DETAILED: J FISEHR DATE: NONE MATERIAL: PUR/ALT	PART NO: F2562-009(CL-505-GCB) DESCRIPTION: GRIPPER BOLT	PDQ Workholding PO BOX 371 1100 S WILLIAMS DRIVE COLUMBIA CITY, IN 46725 (260) 244-2919 WWW.PDQWH.COM
SCALE: 1:1 SHEET 1 OF 1 SIZE: B	FINISH: NONE HEAT TREAT: ****	CUSTOMER:	

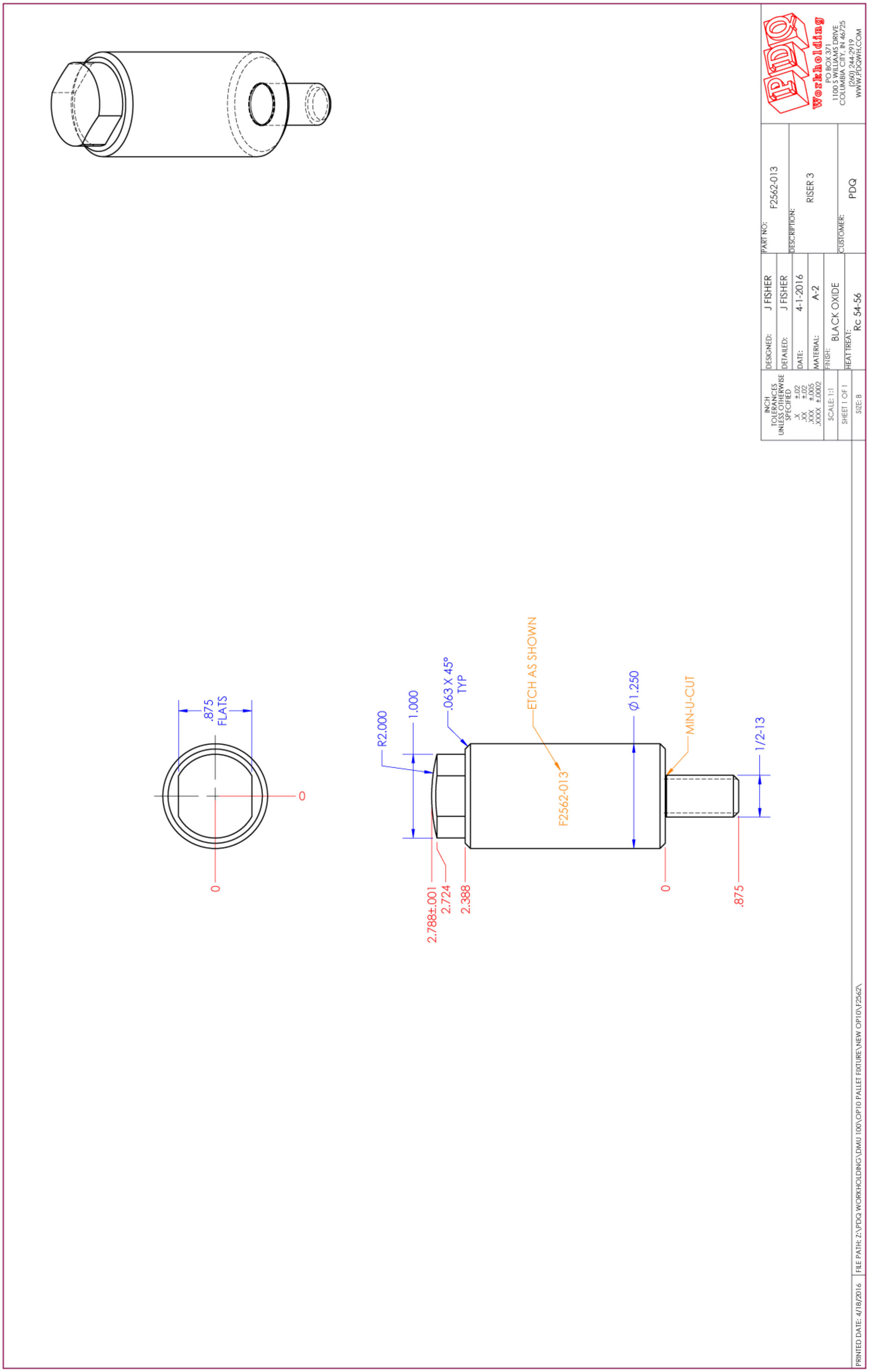
PRINTED DATE: 3/28/2016 | FILE PATH: C:\Users\jfisher\Desktop\school project\



INCH TOLERANCES UNLESS OTHERWISE SPECIFIED
.X ±.02
.XX ±.02
.XXX ±.005
.XXXX ±.0002
SCALE: 1:1
SHEET 1 OF 1
SIZE: B
DESIGNED: J FISHER
DETAILED: J FISHER
DATE: 3-28-2016
MATERIAL: CRS
FINISH: BLACK OXIDE
HEAT TREAT: ****
PART NO: F2562-010
DESCRIPTION: WORK SUPPORT BLOCK
CUSTOMER: PDQ
PDQ Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
PRINTED DATE: 3/28/2016
FILE PATH: C:\Users\jfisher\Desktop\school project\
2X ∅ .531 THRU ALL
⌴ ∅ .813 ↧ .500
.188 X 45°
2 PLCS
R20.875
2X ∅ .500 THRU ALL
.250 X 45°
3 PLCS
1.684
1.375
4.000
2X 3.500
2X .500
0
1.872
2.625
2.125
1.875
2X .500
0
∅ 1.220
∅ 1.250
1 5/16-16
SECTION A-A
ETCH AS SHOWN
F2562-010
2.875
2.000
1.125
0
A
A
R.250
TYP
4.375
3.500
1.250
0



1/2-13
.875
FLATS
R2.000
⌀1.000
.063 X 45°
TYP
⌀1.250
ETCH AS SHOWN
F2562-012
MIN-U-CUT
1/2-13 THRD
0
0
1.850±.001
1.786
1.450
0
.875
INCH TOLERANCES UNLESS OTHERWISE SPECIFIED
.X ±.02
.XX ±.02
.XXX ±.005
.XXXX ±.0002
SCALE: 1:1
SHEET 1 OF 1
SIZE: B
DESIGNED: J FISHER
DETAILED: J FISHER
DATE: 4-1-2016
MATERIAL: A-2
FINISH: BLACK OXIDE
HEAT TREAT: Rc 54-56
PART NO: F2562-012
DESCRIPTION: RISER 2
CUSTOMER: PDQ
PDQ Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
PRINTED DATE: 4/18/2016
FILE PATH: Z:\PDQ WORKHOLDING\DMU 100\OP10 PALLET FIXTURE\NEW OP10\F2562\


PDQ Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
PART NO: F2562-013
DESCRIPTION: RISER 3
CUSTOMER: PDQ
DESIGNED: J FISHER
DETAILED: J FISHER
DATE: 4-1-2016
MATERIAL: A-2
FINISH: BLACK OXIDE
HEAT TREAT: Rc 54-56
INCH TOLERANCES UNLESS OTHERWISE SPECIFIED
.X ±.02
.XX ±.02
.XXX ±.005
.XXXX ±.0002
SCALE: 1:1
SHEET 1 OF 1
SIZE: B
.875 FLATS
0
0
R2.000
1.000
.063 X 45° TYP
ETCH AS SHOWN
Ø1.250
MIN-U-CUT
1/2-13
F2562-013
2.788±.001
2.724
2.388
0
.875
PRINTED DATE: 4/18/2016
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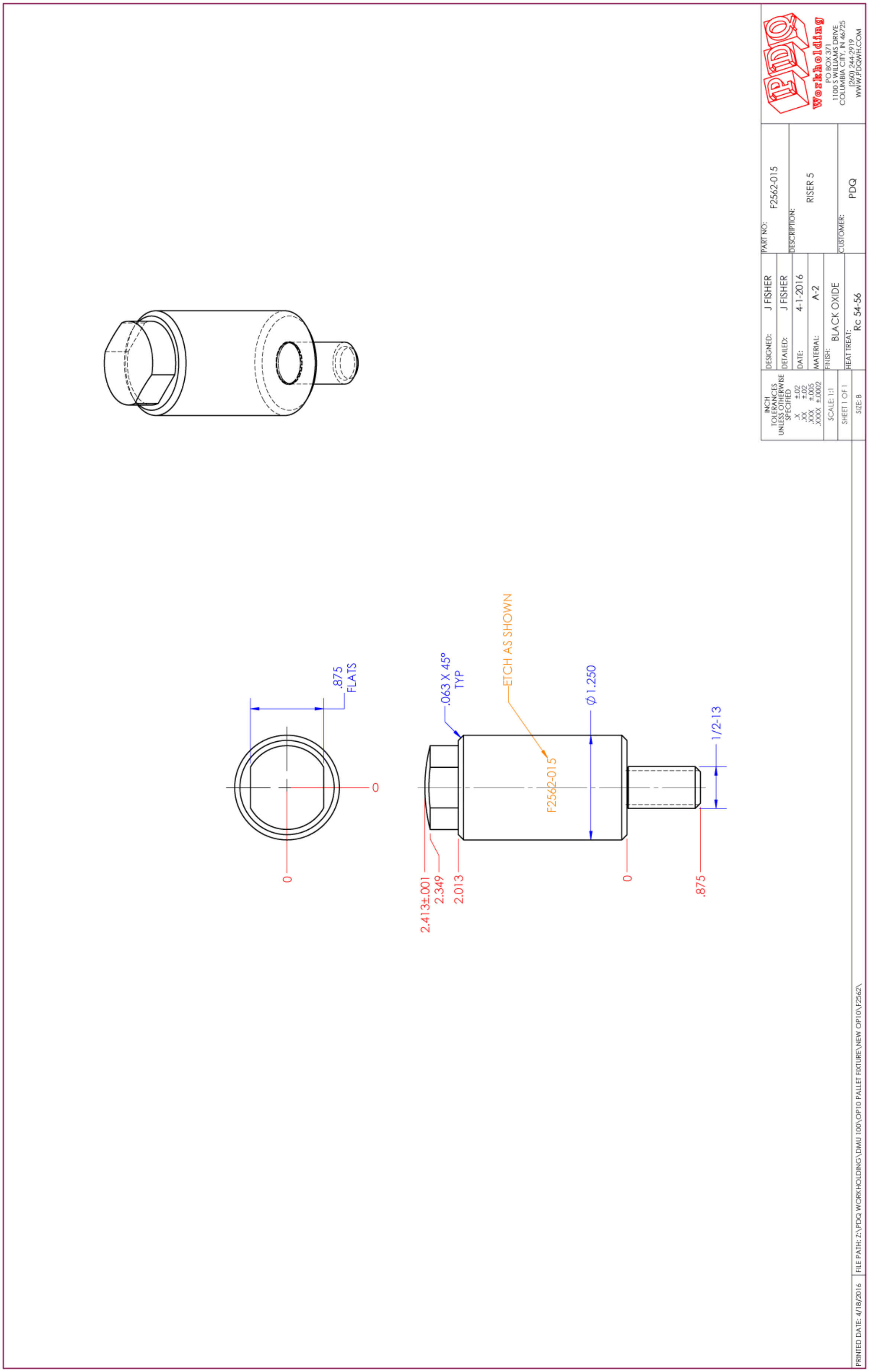

PDQ Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
PART NO:
F2562-015
DESCRIPTION:
RISER 5
CUSTOMER:
PDQ
DESIGNED: J FISHER
DETAILED: J FISHER
DATE: 4-1-2016
MATERIAL: A-2
FINISH: BLACK OXIDE
HEAT TREAT: Rc 54-56
INCH TOLERANCES UNLESS OTHERWISE SPECIFIED
.X ±.02
.XX ±.02
.XXX ±.005
.XXXX ±.0002
SCALE: 1:1
SHEET 1 OF 1
SIZE: B
.875 FLATS
.063 X 45° TYP
ETCH AS SHOWN
Ø 1.250
1/2-13
F2562-015
0
0
0
2.413±.001
2.349
2.013
.875
PRINTED DATE: 4/18/2016
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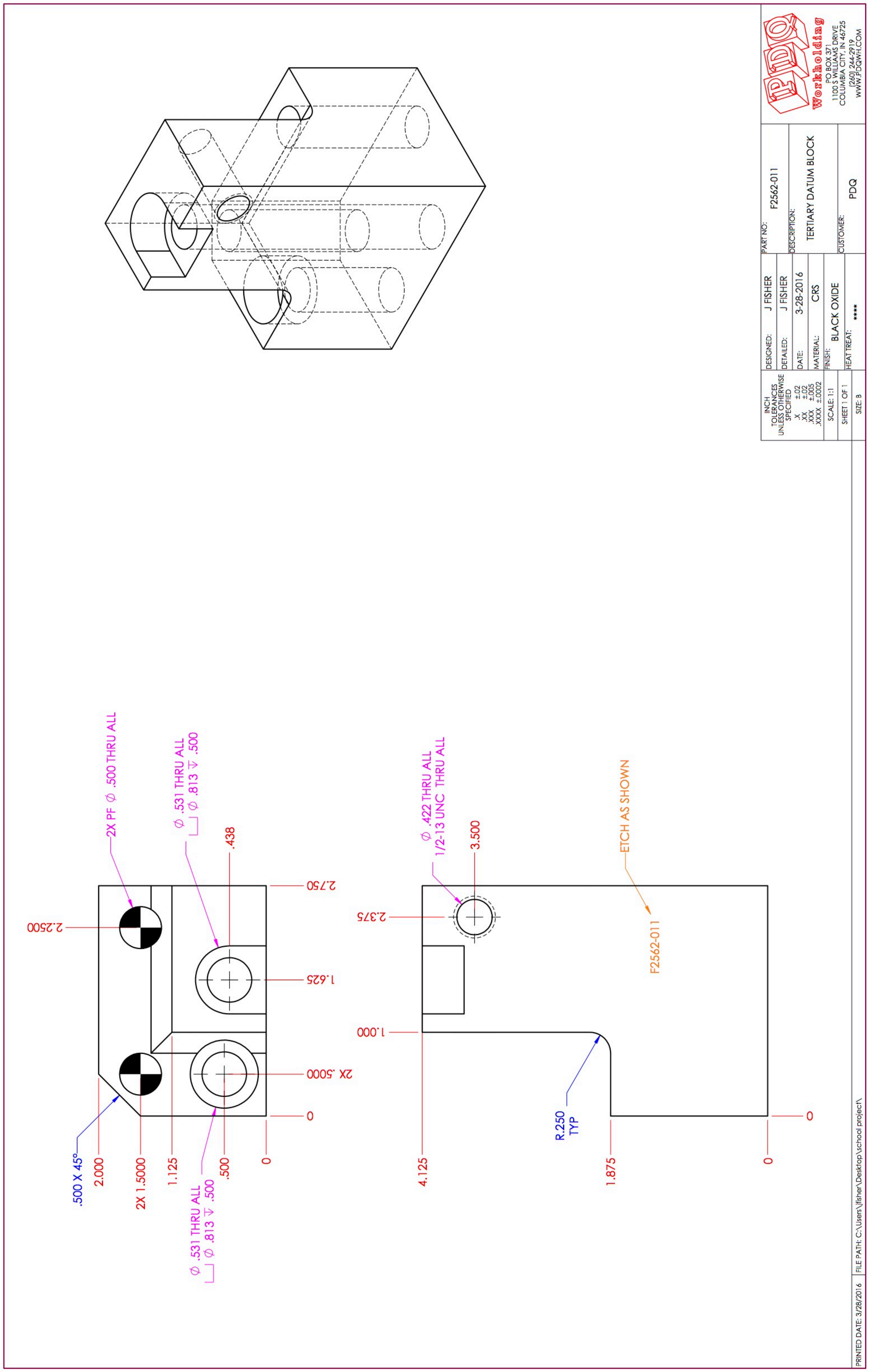
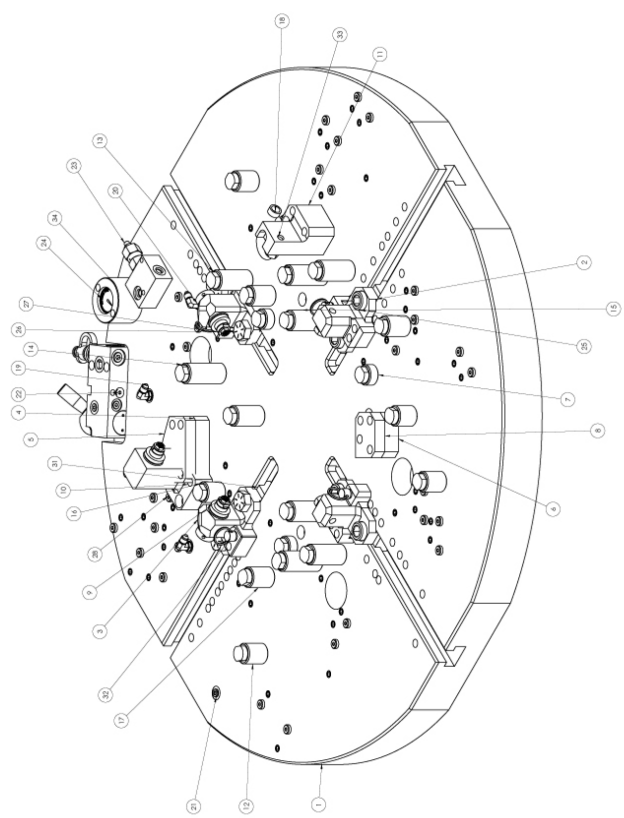
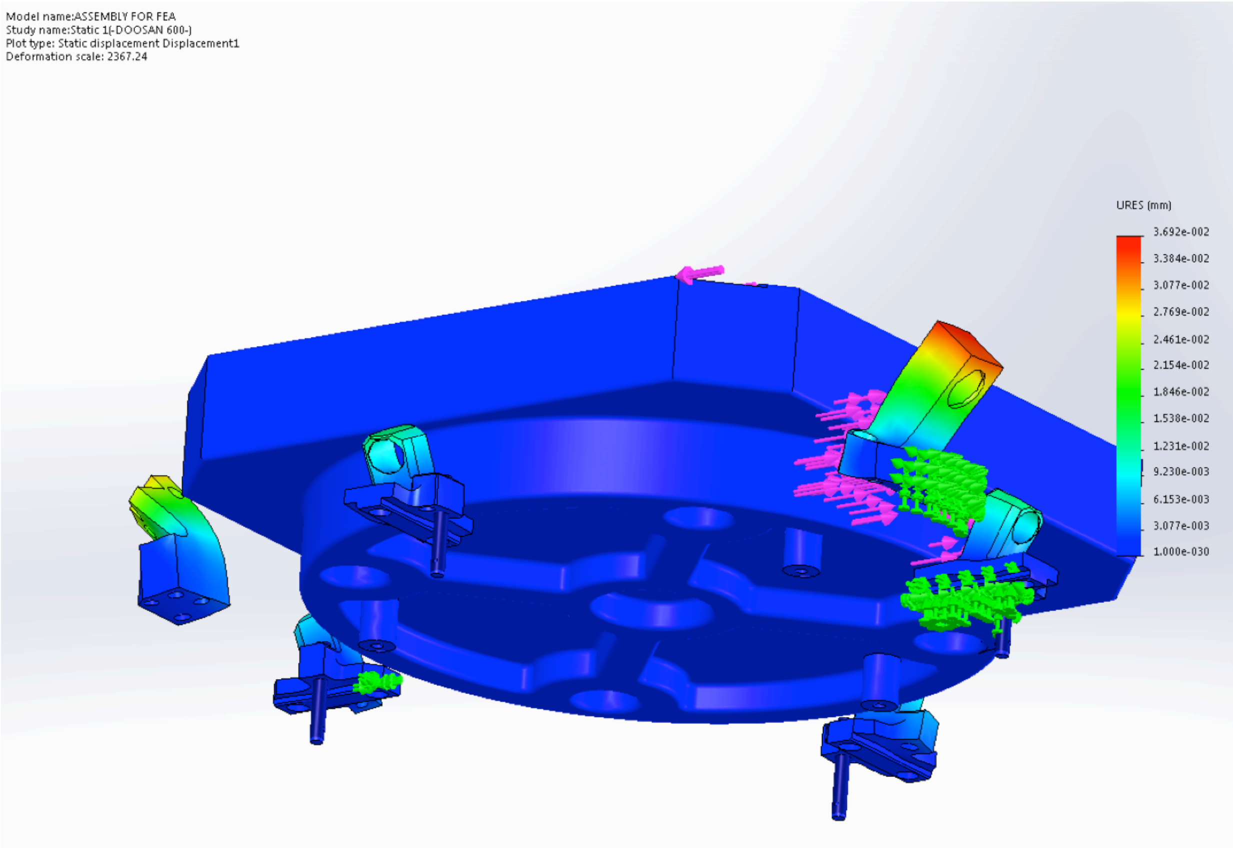

2X PF ⌀ .500 THRU ALL
⌀ .531 THRU ALL
⌴ ⌀ .813 ↧ .500
.438
2.750
2.2500
1.625
2X .5000
0
.500 X 45°
2.000
2X 1.5000
1.125
.500
0
⌀ .531 THRU ALL
⌴ ⌀ .813 ↧ .500
⌀ .422 THRU ALL
1/2-13 UNC THRU ALL
3.500
2.375
1.000
ETCH AS SHOWN
F2562-011
R.250
TYP
4.125
1.875
0
0
INCH
TOLERANCES
UNLESS OTHERWISE
SPECIFIED
.X ±.02
.XX ±.02
.XXX ±.005
.XXXX ±.0002
SCALE: 1:1
SHEET 1 OF 1
SIZE: B
DESIGNED: J FISHER
DETAILED: J FISHER
DATE: 3-28-2016
MATERIAL: CRS
FINISH: BLACK OXIDE
HEAT TREAT: ****
PART NO: F2562-011
DESCRIPTION: TERTIARY DATUM BLOCK
CUSTOMER: PDQ
PDQ
Workholding
PO BOX 371
1100 S WILLIAMS DRIVE
COLUMBIA CITY, IN 46725
(260) 244-2919
WWW.PDQWH.COM
PRINTED DATE: 3/28/2016
FILE PATH: C:\Users\jfisher\Desktop\school project\

Appendix D

ITEM NO.	QTY.	MATERIAL	DESCRIPTION	MANUFACTURER	PART NUMBER
1	1	HRS	BASE PLATE	PDQ	F2562-001
2	2	4140 PH	DATUM SLIDER	PDQ	F2562-002
3	2	4140 PH	CYLINDER SLIDER	PDQ	F2562-003
4	1	CRS	WORK SUPPORT RISER	PDQ	F2562-004
5	1	CRS	WORK SUPPORT RISER 2	PDQ	F2562-005
6	1	CRS	TERTIARY DATUM RISER	PDQ	F2562-006
7	3	A-2	RISER 1	PDQ	F2562-007
8	1	CRS	TERTIARY DATUM RISER 2	PDQ	F2562-008
9	3	PUR/ALT	GRIPPER BOLT	CARR LANE	F2562-009(CL-505-GC8)
10	1	CRS	WORK SUPPORT BLOCK	PDQ	F2562-010
11	1	CRS	TERTIARY DATUM BLOCK	PDQ	F2562-011
12	3	A-2	RISER 2	PDQ	F2562-012
13	3	A-2	RISER 3	PDQ	F2562-013
14	3	A-2	RISER 4	PDQ	F2562-014
15	3	A-2	RISER 5	PDQ	F2562-015
16	3	A-2	RISER 6	PDQ	F2562-016
17	3	A-2	RISER 7	PDQ	F2562-017
18	1	STK	SHIM	PDQ	F2562-(0.355 SHIM)
19	3	STK	SAE 4 90° SWIVEL	PDQ	F2562-(4C50X-S)
20	3	PUR	CYLINDER	VEKTEK	F2562-(20-0110-00)
21	1	PUR	SAE4 PORT PLUG	VEKTEK	F2562-(30-6011-44)
22	1	PUR	MANIFAL DECOUPLER	VEKTEK	F2562-(56-0006-04)
23	1	PUR	SEQUENCE VALVE	VEKTEK	F2562-(70-4400-02)
24	1	PUR	GAUGE	VEKTEK	F2562-(72-1221-55)
25	4	PUR	3/4-10 X 1 3/8 SHCS	MCMASTER	F2562-(91251A520)
26	4	PUR	3/4-10 X 1 3/4 HEX HEAD CAP SCREW	MCMASTER	F2562-(91286A454)
27	74	PUR	1/2X13 SET SCREW	MCMASTER	F2562-(91375A707)
28	38	PUR	3/8 - 16 X 1 1/2 LOW PRO SHCS	MCMASTER	F2562-(92220A255)
29	2	PUR	LINER BUSHING	MPOWER	F2562-(AL-300002)
30	2	PUR	SPEEDLOC BOLT	MPOWER	F2562-(AS-300002)
31	8	PUR	T NUT	CARR LANE	F2562-(CL-7-TN)
32	4	PUR	PULL PIN	CARR LANE	F2562-(CL-8-DEP-2.75)
33	3	PUR	GRIPPER BOLT	CARR LANE	F2562-(CL-810G-C8)
34	1	STK	GAUGE GUARD	PDQ	F2562-(PDG-GG-01)



Appendix E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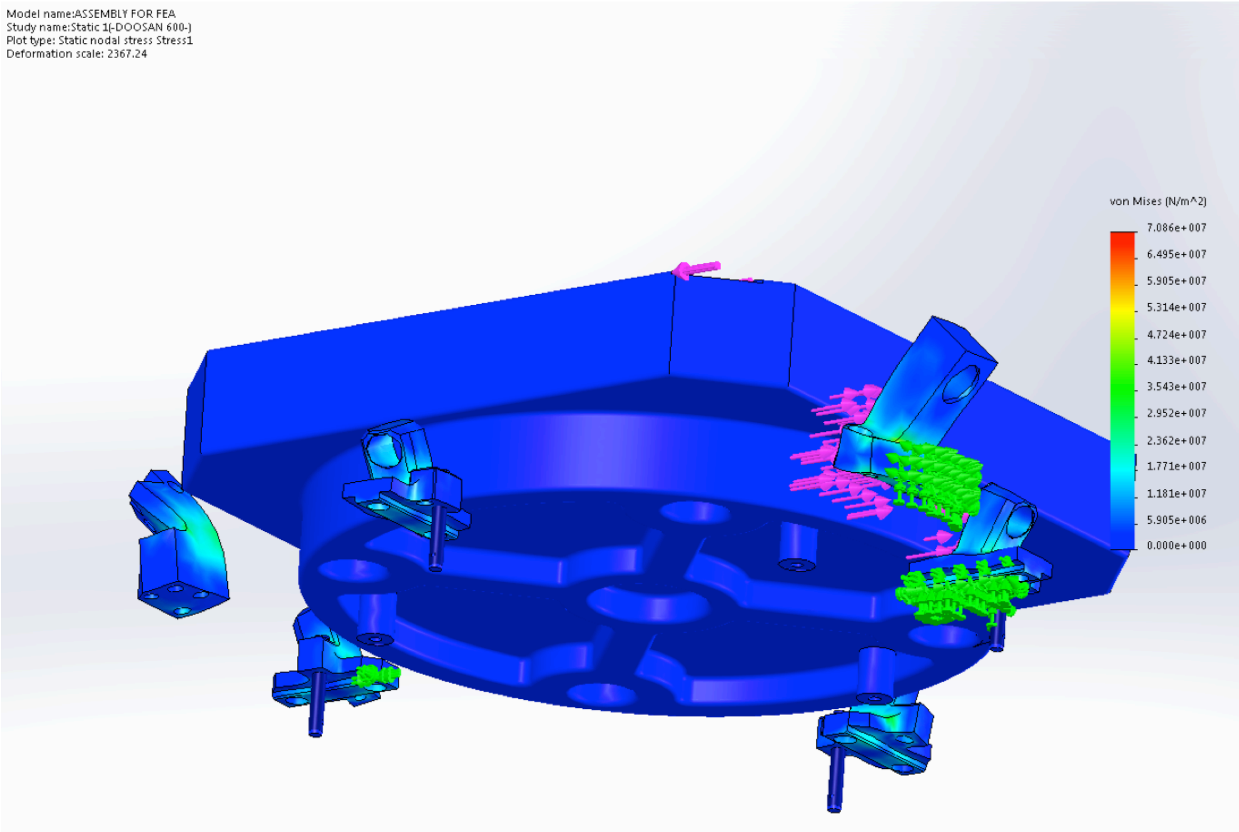
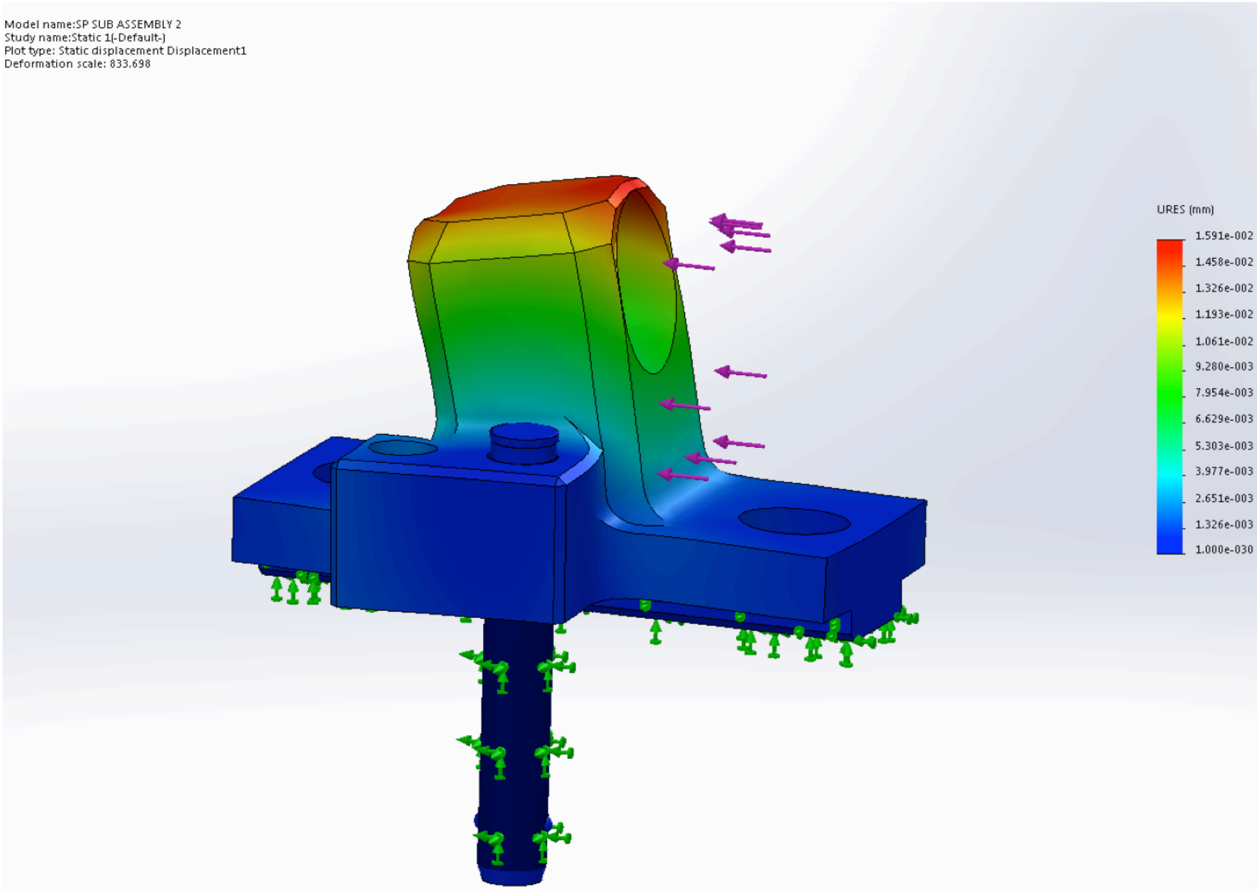
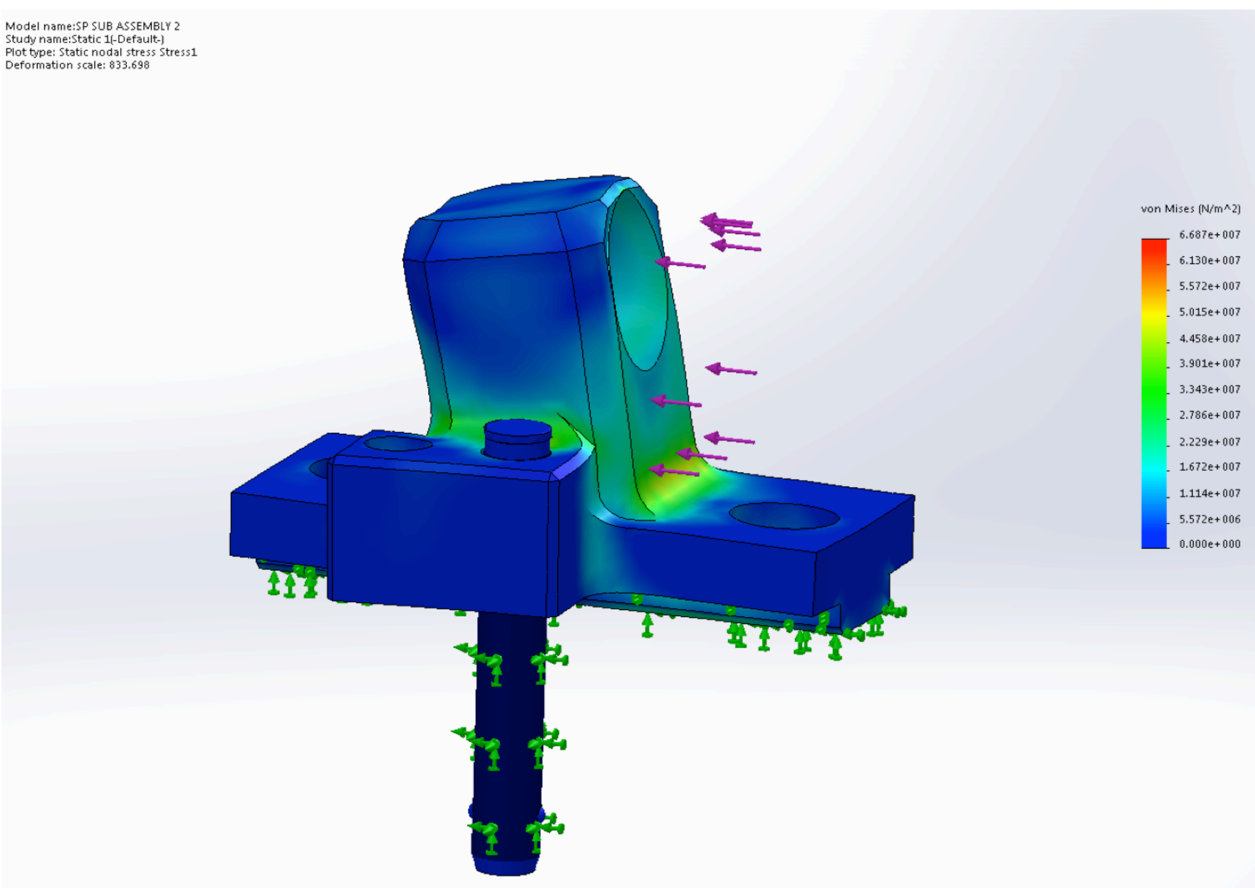
Study name:Static 1(-DOOSAN 600-)
Plot type: Static displacement Displacement1
Deformation scale: 2367.24
URES (mm)
3.692e-002
3.384e-002
3.077e-002
2.769e-002
2.461e-002
2.154e-002
1.846e-002
1.538e-002
1.231e-002
9.230e-003
6.153e-003
3.077e-003
1.000e-030


Model name:ASSEMBLY FOR FEA
Study name:Static 1(-DOOSAN 600-)
Plot type: Static nodal stress Stress1
Deformation scale: 2367.24
von Mises (N/m^2)
7.086e+007
6.495e+007
5.905e+007
5.314e+007
4.724e+007
4.133e+007
3.543e+007
2.952e+007
2.362e+007
1.771e+007
1.181e+007
5.905e+006
0.000e+000


Model name:SP SUB ASSEMBLY 2
Study name:Static 1(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 833.698
URES (mm)
1.591e-002
1.458e-002
1.326e-002
1.193e-002
1.061e-002
9.280e-003
7.954e-003
6.629e-003
5.303e-003
3.977e-003
2.651e-003
1.326e-003
1.000e-030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Study name:Static 1(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 833.698
von Mises (N/m^2)
6.687e+007
6.130e+007
5.572e+007
5.015e+007
4.458e+007
3.901e+007
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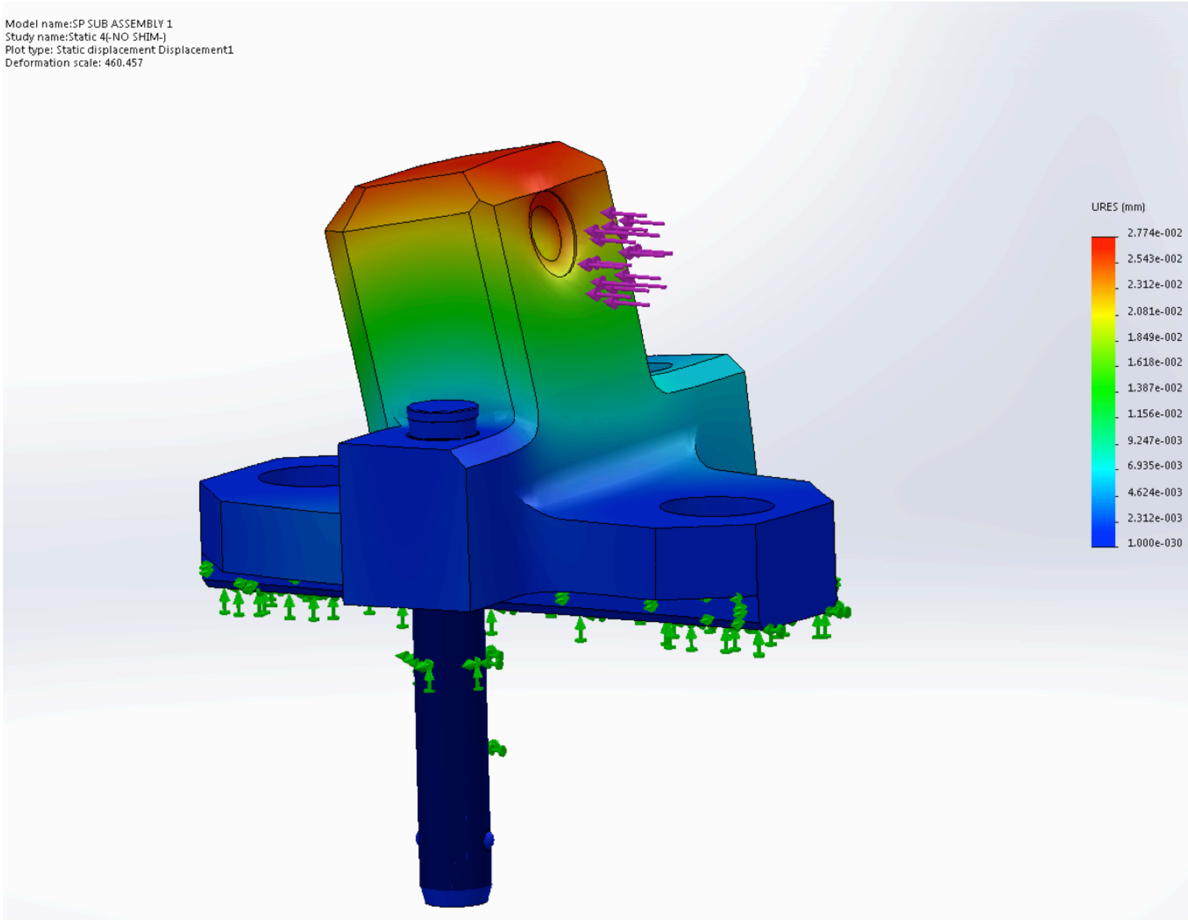
0.000e+000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Study name:Static 4(-NO SHIM-)
Plot type: Static displacement Displacement1
Deformation scale: 460.457
URES (mm)
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2.312e-002
2.081e-002
1.849e-002
1.618e-002
1.387e-002
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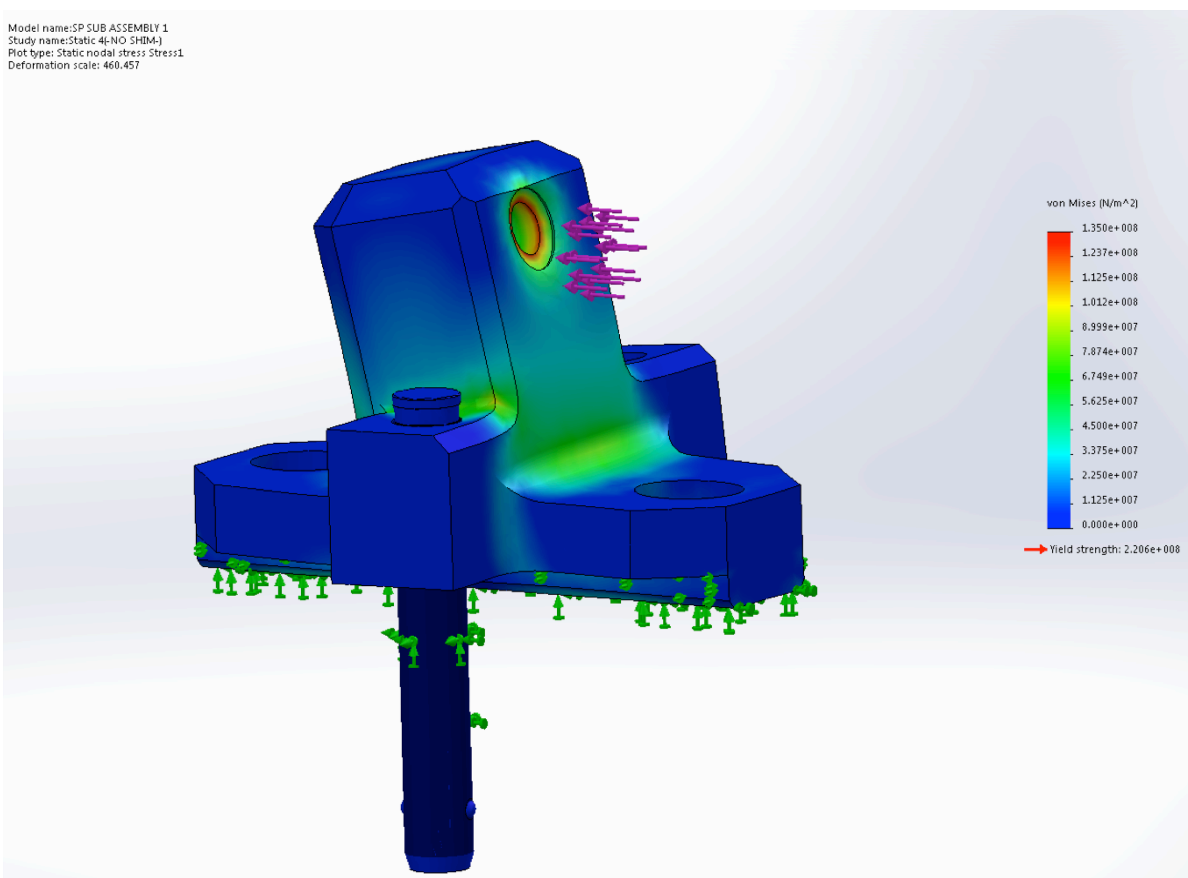
6.935e-003
4.624e-003
2.312e-003
1.000e-030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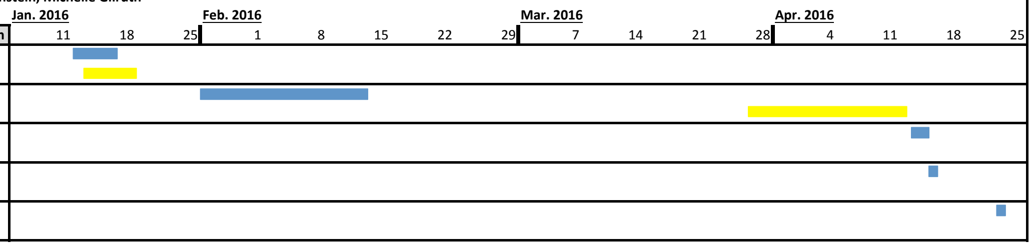
Study name:Static 4(-NO SHIM-)
Plot type: Static nodal stress Stress1
Deformation scale: 460.457
von Mises (N/m^2)
1.350e+008
1.237e+008
1.125e+008
1.012e+008
8.999e+007
7.874e+007
6.749e+007
5.625e+007
4.500e+007
3.375e+007
2.250e+007
1.125e+007
0.000e+000
Yield strength: 2.206e+008

Appendix F

SENIOR DESIGN GANTT CHART - John Fisher, Rachael Klopfenstein, Michelle Gilruth

	Task	Start	Finish	Duration
1	**Design (Planned)**	1/11/16	1/15/16	5 days
2	Design (Actual)	1/13/16	1/18/16	6 days
3	**Ordering of parts (Planned)**	1/25/16	2/12/16	19 days
4	Ordering of parts (Actual)	3/25/16	4/11/16	18 days
5	**Fabrication (Planned)**	4/12/16	4/14/16	2 days
6	Fabrication (Actual)			
7	**Assembly (Planned)**	4/15/16	4/15/16	1 day
8	Assembly (Actual)			
9	**Testing (Planned)**	4/22/16	4/22/16	1 day
10	Testing (Actual)			



PDQ will perform Fabrication and Assembly of the pallet fixture after the writing of this report.

Appendix G

Bibliography

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