MET 494

Final Report

4-27-15

Axle Assembly Poke-Yoke

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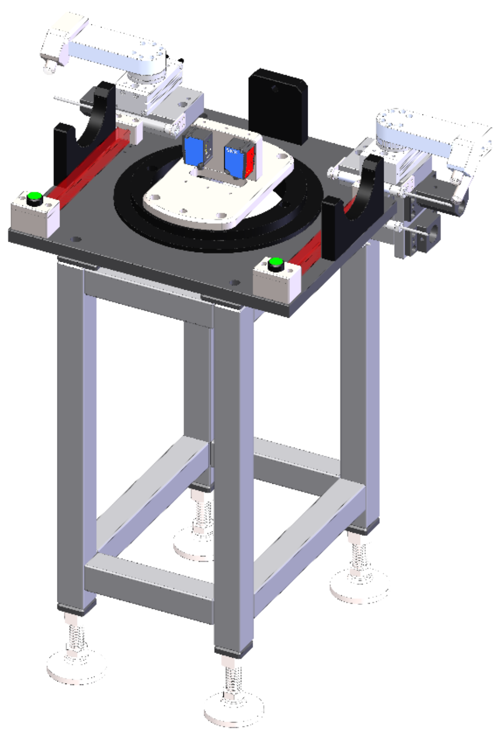


Introduction

Our team was contracted to design and fabricate an automated Poka-Yoke (mistake proofing) system to be retrofitted to an existing axle assembly and tack weld fixture in a local manufacturing facility. The problem was presented to us after this companies management realized how easily these assemblies could be welded incorrectly, and that $20,000.00 worth of scrap could potentially be generated in one day.

The Problem

In the existing process there are 3 different assemblies$_1$ that utilize the current fixture. Each assembly consists of a machined carrier casting $_{1.1}$ with one of three different axle tubes $_{1.2}$ pressed in and welded in place (this is done in a previous operation) and one of six different brackets $_{1.3}$ slip fit over the axle tube and welded in place.

The slip fit diameter on the axle tubes are all the same dimension therefore an operator could potentially weld the wrong bracket onto the assembly. In the current process, two supervisors are required to visually confirm that the correct parts are present before the operator welds the brackets in place. This is a time consuming procedure which could easily be compromised if the operator became impatient while waiting for the supervisor to come around. This process still allows for the possibility of human error if the supervisor misses an incorrect assembly as well.

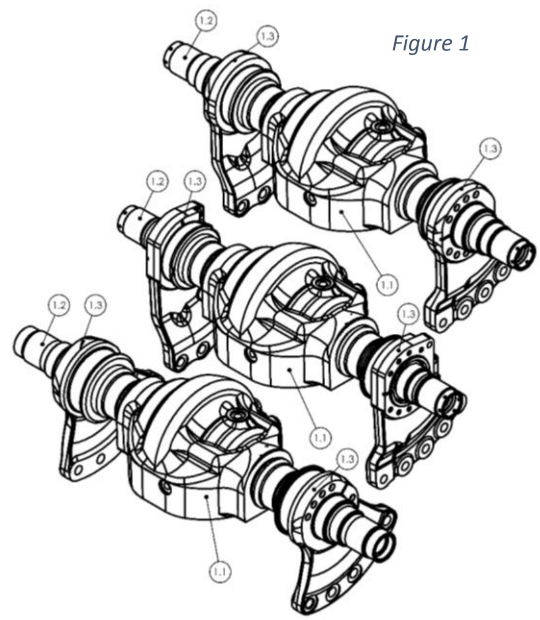


Figure 1

The Solution

In order to eliminate the possibility of an assembly error we designed a solution that addresses the following objectives:

1. Must not add additional time to the existing process.
2. Must be easy to use and train someone to use.
3. Must utilize the current fixture.
4. Must provide clear visual confirmation of test results.
5. Must not exceed a budget of $3000.00.

To accomplish this we used a combination of pneumatic cylinders, laser sensors, and proximity sensors interfaced with a PLC (programmable logic controller) to identify which parts are present.

The Build

In modern custom machine building, there is a close synergy between the designing side and the machining side that goes into a custom machine. These two aspects are important because when used appropriately together they can reduce manufacturing time and cost, prevent potential interferences or problems, and overall improve the quality of machine produced.

Design

For the design aspect of this project, Solid Works was used. This program allowed us to digitize all of the parts used in the axle assemblies, the purchased components and parts we had to build for the testing process.

With these parts digitized and in a 3D environment, we were able to position the work parts onto the fixture. From there we would build and create parts that would allow us to perform the test we would need. Whether it was putting a simple block in to raise a cylinder up an inch or a contoured piece that held a sensor on the swing arm, all were done in this environment first.

We were able to manipulate the pieces, add and remove material were need be, adjust hole spacing, change a design to eliminate a machining process, and swap out parts all at a click of a button. It is this ease of design and corrective measures that help maximize the efficiency of a project.

Once the parts were verified to not interfere and all necessary tests could be performed, 2D drawings (Appendix A) were created for each custom part that would have to be created. However these 2D prints were for reference only. The digital file of the 2D print is what was used to program the CNC machine g-code.

Machining

The 2D print file described above was imported into MasterCam. This program that can take these files and use them to produce g-code programs for CNC machines. This program reduces the input of programming to clicks instead of manually computing g-codes and typing them by hand into the control, once again, another step of efficiency.

In the program you will select geometry on the prints and then assign a tool path to it. This can be a simple point to drill a hole at or a contoured face to run an end mill along. Once assigned, these tool paths can be set to run at certain speeds, feeds, depths, climb milling or conventional milling. Once the tool paths are ready, the program will post the g codes for the selected operations and download them into the CNC machine.

Once downloaded, the machine can be cycled and perform the operations programmed.

Machining (Cont.)

The following list is how the various parts of this test station were created and the finish process they were given.

Part	Manufacturing Process	Finish
Rotary Riser (SD-2005)	Vertical Machine Center	Black Anodizing
Swing Arms (SD-2001)	Vertical Machine Center	Black Anodizing
Web Sensor Holder (SD-2002)	Vertical Machine Center	Black Anodizing
Cylinder Brackets (SD-2013, SD-2006)	Plasma Cut / Bend Press	Black Oxide
Laser Riser Base (SD-2010)	Vertical Machine Center	Black Oxide
Laser Mount (SD-2011)	Vertical Machine Center	Black Oxide
Tube Plug (SD-2009)	Manual Lathe	Black Oxide
Tube End (SD-2016)	Vertical Machine Center	Black Anodizing
Button Mount Riser (SD-2017)	Vertical Machine Center	Black Anodizing
Button Plate (SD-2018)	Vertical Machine Center	Black Anodizing
Light Tube (SD-2015)	Purchased	Glass Bead Blast
Laser Guard (SD-2019)	Plasma Cut / Bend Press	Black Oxide

Finishing

The parts were finished with either black oxide or black anodizing for two reasons. The first is for an extra layer of protection and the second is aesthetics. The steel parts received the black oxide finish. This finish is essential a controlled rust finish. The process converts the outer most surface of the parts to this rust and is black in color. The aluminum parts received the black anodizing. The second reason is for aesthetics. The parts have a cleaner and a more appealing look instead of shiny machined surfaces.

The light tube was clear polycarbonate that has been bead blasted. The blasting was done to put a satin finish on the tube. This roughed surface dulls the intensity of the LED lights. It also captures the light and produces a better indicator light.

Programming

Nearly, if not all automated machines today use an industrial computer, more specifically a PLC. These devices allow for a less complicated, smaller and more efficient control to be built for these machines. The PLC is the heart of the system controlling when to actuate solenoids or contacts, while also reading in inputs and other status.

For this project a Click PLC was used. This is an entry level, cost effective plc that suits the cost and performance aspect of this project. One of the nice things this plc has to offer is the free programming software, as compared to other higher end plc manufactures, were the programming software has to be purchased. The software was easily downloaded and installed from Automation Direct.

The main principle behind the programming was to divide it into easy to understand and corresponding sections. This was done thru the use of a main program and over four sub routines. This structure breaks down what would be a larger single program into smaller easy to troubleshoot sections.

Located in appendix D is the plc ladder diagram. The program will start in the main program then go into the tube length check sub routine. After a tube length has been determined it will jump back into the main program and then jump back into other sub routines until the check either passes or fails. This is shown by figure 2.

What is also nice about PLC's is, if one were to go online with the plc while it is doing a check process, the status of inputs and ladder logic can be monitored. This allows for easy trouble shooting and diagnosis of problems if and when they were to occur.

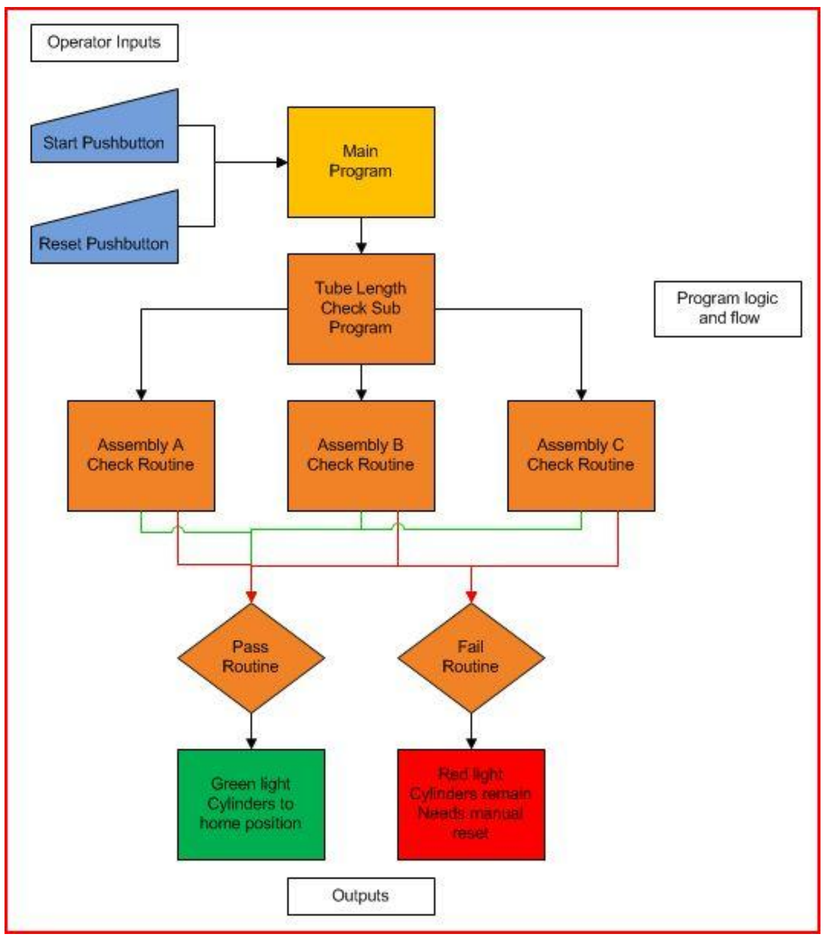


Figure 2: Program Logic Diagram

Electrical

The electrical system of any machine is critical to its operation. It is in this system that the machine is able to provide power to components and communicate with sensors or devices. If it were to be wired wrong a component could not work or worse, become damaged. That is why it is important to correctly wire the machine.

Wiring

Wiring a machine is usually done by following a set of electrical prints (Appendix B). These prints show how the machine is wired between its main power coming in and the electrical components on it. The prints can also help in troubleshooting any possible electrical problem.

We used AutoCAD to produce our electrical prints. Using a generic electrical schematic layout, we created our prints for us to follow after we had specified all of the electrical components that will be used in the control panel and sensors on the test station.

Panel Layout

We used SolidWorks to digitally layout the control panel before we built it. This is an important step to ensure that there will be plenty of space in the panel. Always go with a slightly larger enclosure than what you need, if able to. This not only allows for extras features that may be added later but also space for possible forgotten/unforeseen needed components.

After a layout had been established, construction began. We used DIN mounted hardware which simplifies installation. DIN rail is a generic metal extrusion in which the electrical components can easily snap on to and be held in place. This eliminates the need to drill many mount holes and now can be done with just a few for each piece of rail.

Enclosure

The enclosure is the box where the panel and air solenoids are located. This box come pre assembled with the only required action to do are: mount the box, mount the panel inside, and put holes in it for the cables.

The holes for the cables where made by using a step drill and hydraulic knockout set. The step drill is preferred as it doesn’t catch as a normal drill would when going thru thinner sheet metals. Once the holes had been created we used a hydraulic knockout set to take them to their final size. The hydraulic knock out is essentially a large hole punch.

Once the holes were made, we installed cord grips to run our cables thru. The cord grips serve three purposes: seal the cabinet, protect the wires from strain, and protect the wires from a sharp edge if not used.

The Test Results

The test station preformed very well throughout the testing. Although several program changes had to be made during this time to fix the pass/fail indicator not changing states, the test station preformed 100 percent. It didn't allow a bad part to pass and a good to fail. This is shown in the appendix E.

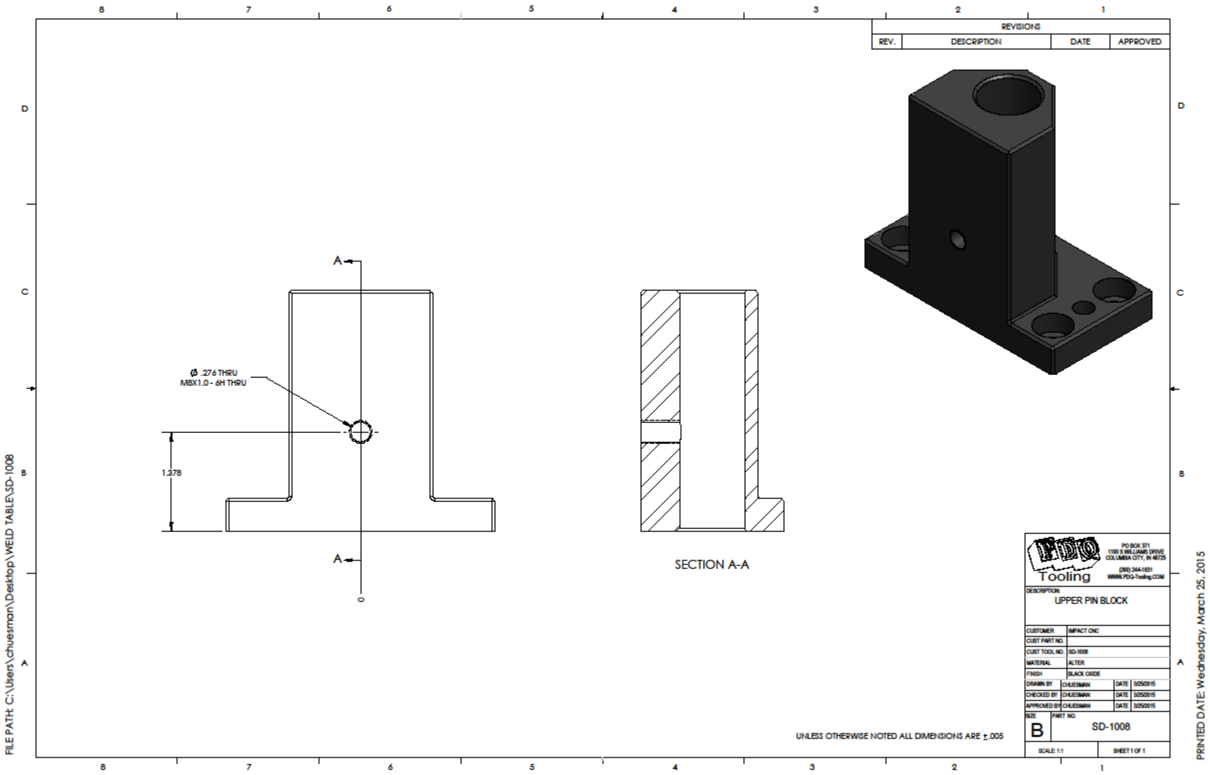
The Conclusion

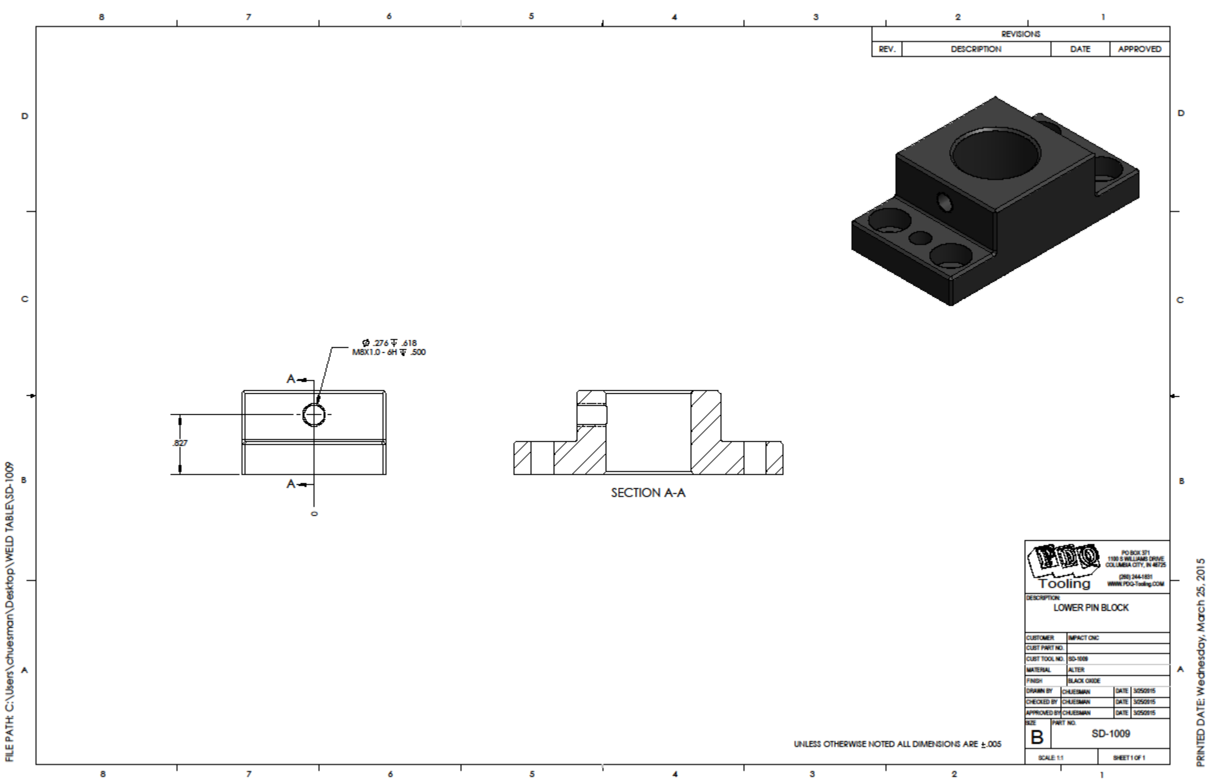
Given the problem, the parameters, and the budget for this project, it was a success. The test station performs ideal and is a vast improvement on the original station. However, no project is complete without a bit of setbacks. These were minimal for us though. For example: a broken sensor, figuring out how to fix the program when a bug appeared, and some time restrictions due to work.

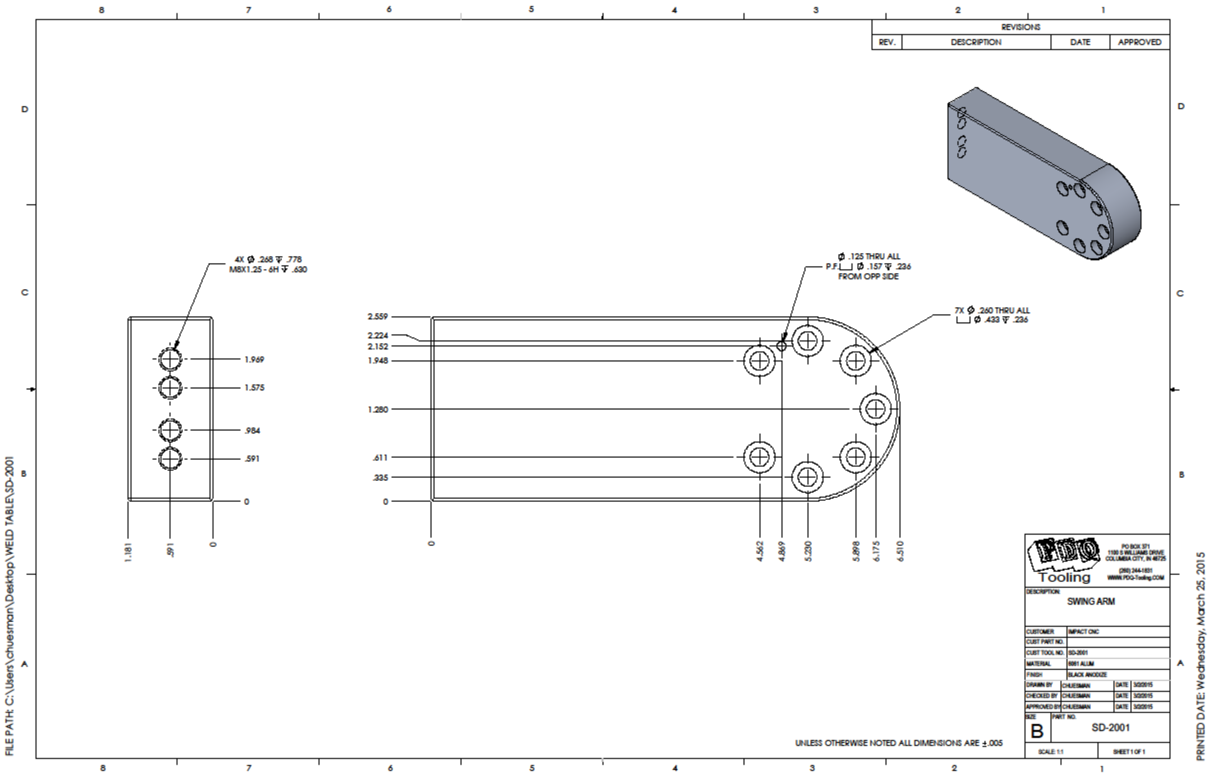
This project also came in under budget. As shown in appendix F, we came roughly 17 percent under budget. Granted if the machining was to be shopped out this would not have been the case.

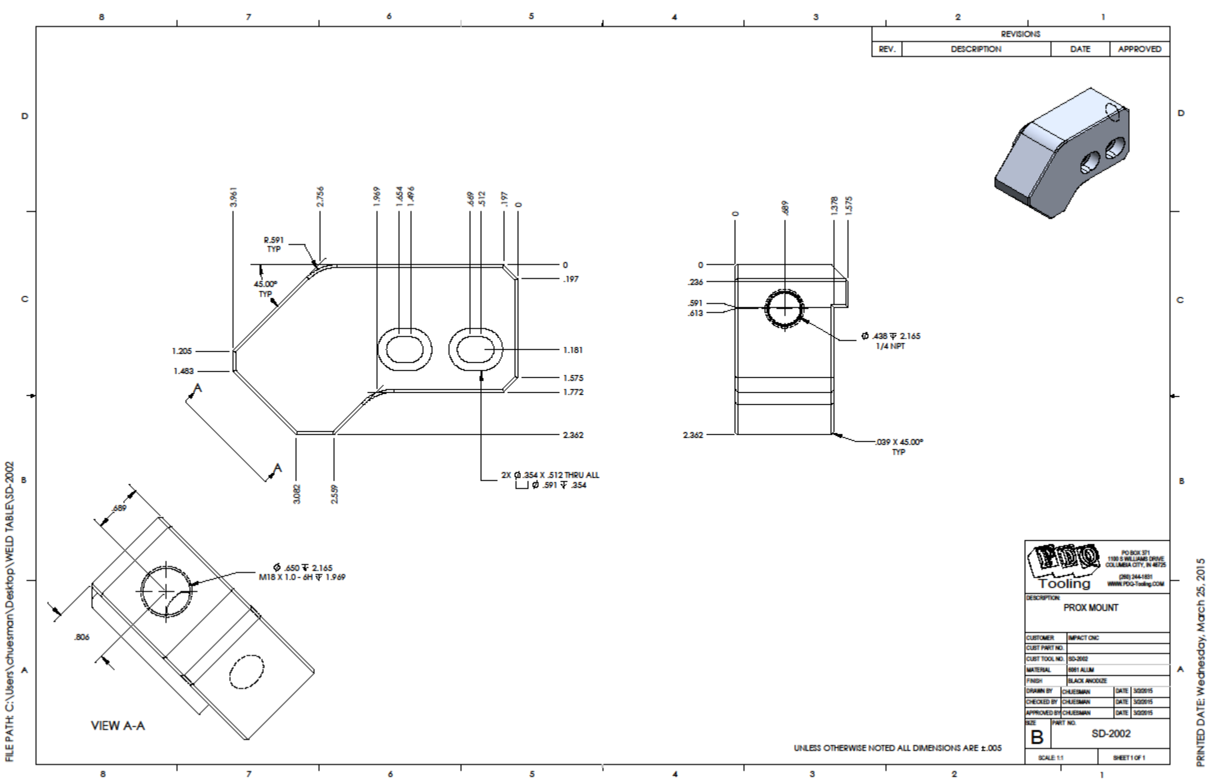
Appendix

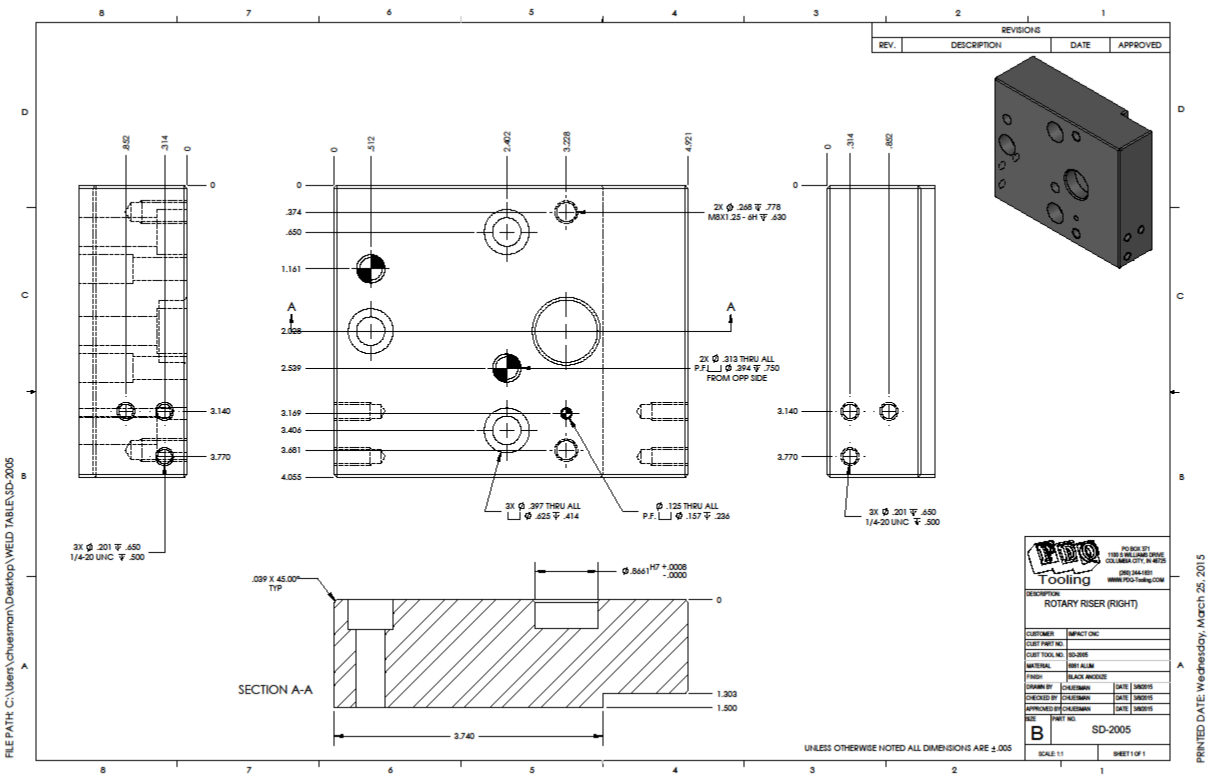
Appendix A: Part Prints

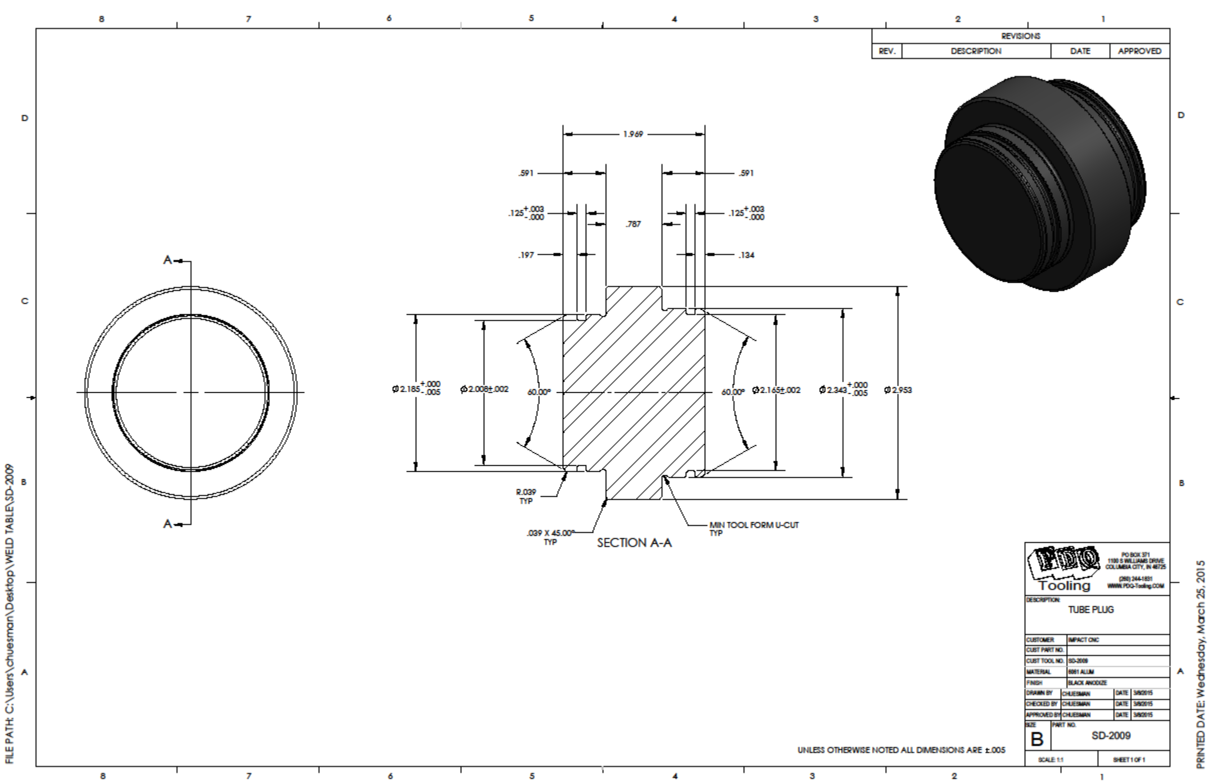


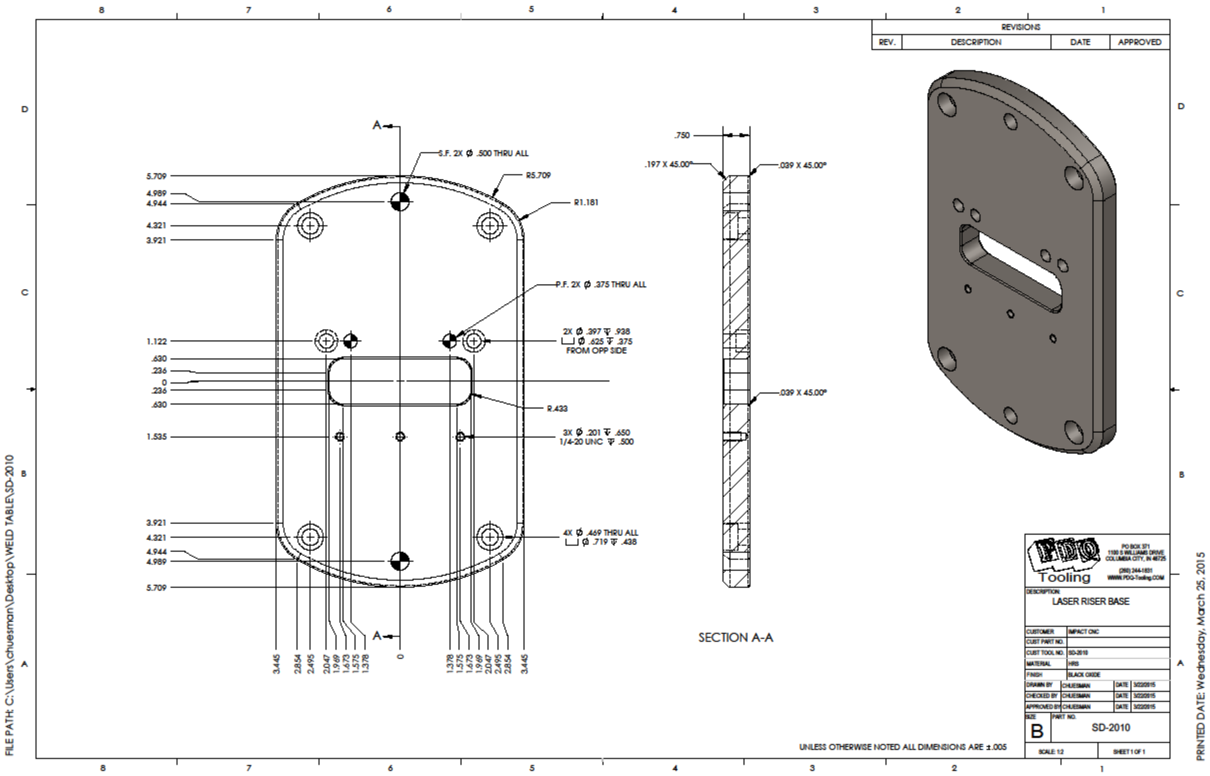


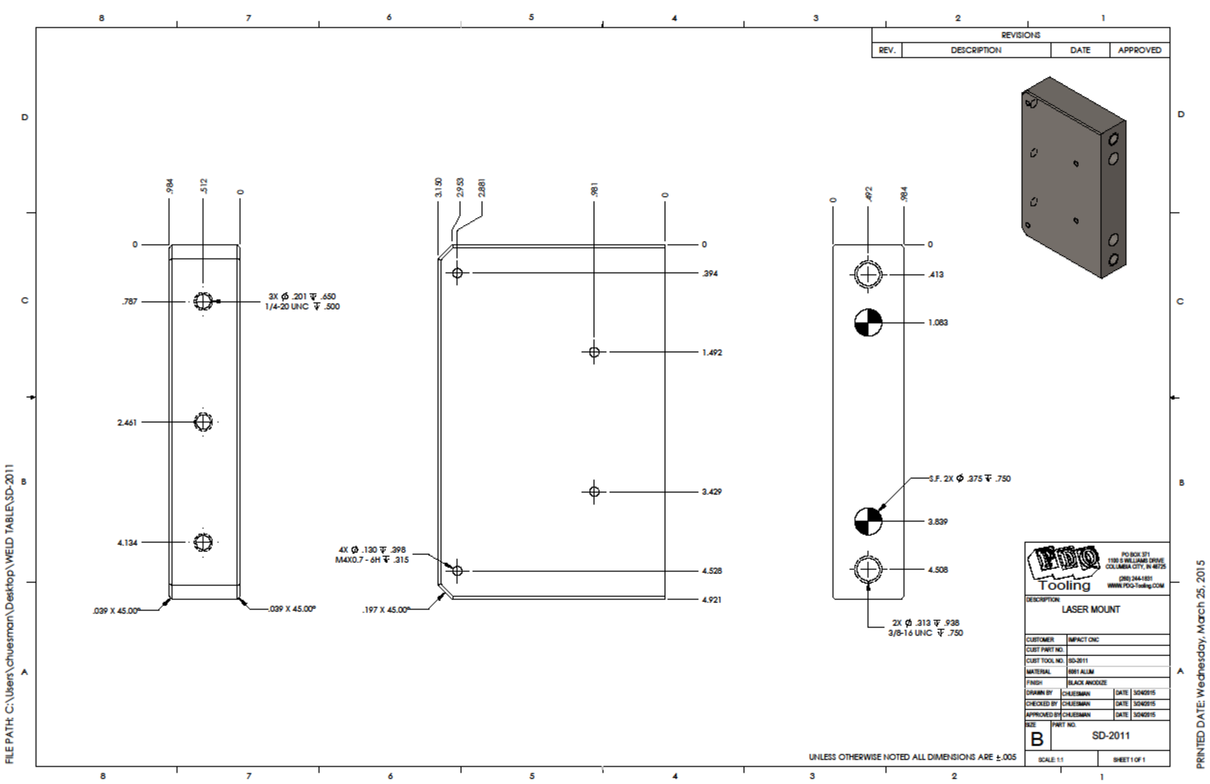

REVISIONS
REV. DESCRIPTION DATE APPROVED
4X ⌀ .268 ↧ .778
M8X1.25 - 6H ↧ .630
⌀ .125 THRU ALL
FROM OPP SIDE
7X ⌀ .260 THRU ALL
⌴ ⌀ .433 ↧ .236
PDQ Tooling
SWING ARM
CUSTOMER IMPACT CNC
CUST TOOL NO. SD-2001
MATERIAL 6061 ALUM
FINISH BLACK ANODIZE
SD-2001
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2001
PRINTED DATE: Wednesday, March 25, 2015

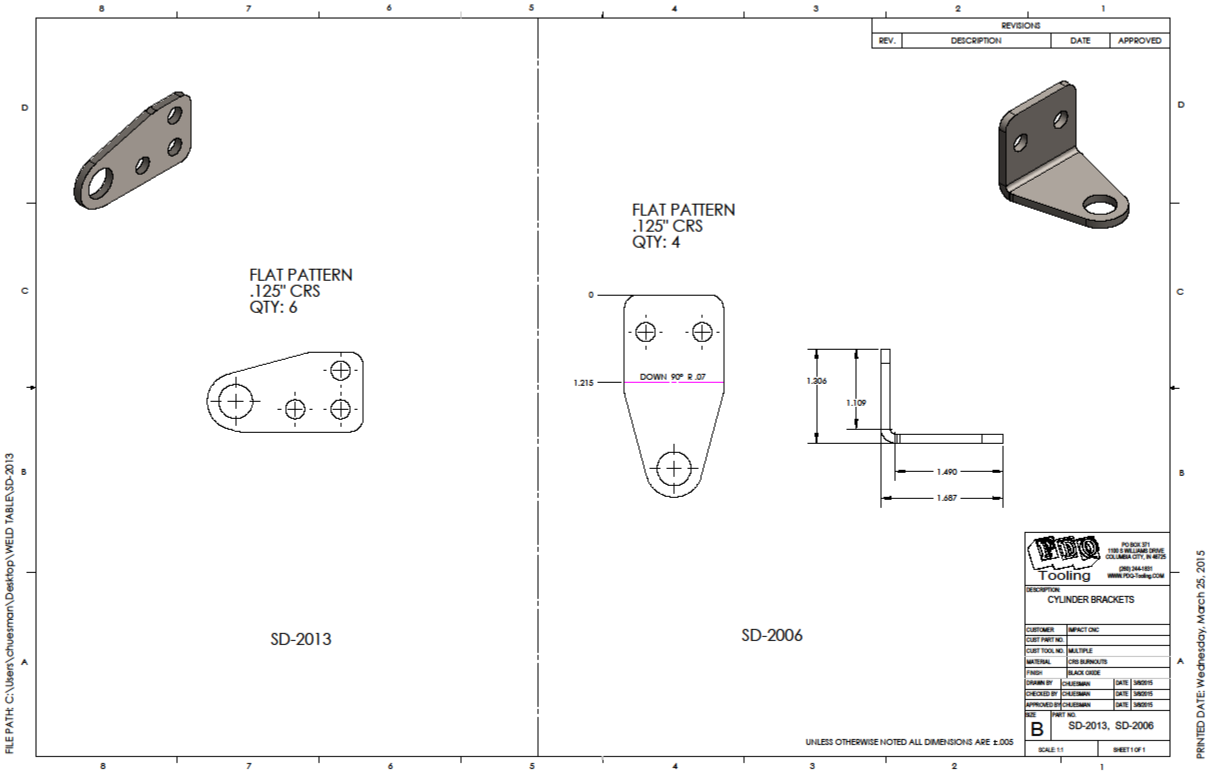

REVISIONS
REV. DESCRIPTION DATE APPROVED
R.591 TYP
45.00° TYP
2X ⌀ .354 X .512 THRU ALL
⌴ ⌀ .591 ↧ .354
⌀ .438 ↧ 2.165
1/4 NPT
.039 X 45.00° TYP
⌀ .650 ↧ 2.165
M18 X 1.0 - 6H ↧ 1.969
VIEW A-A
PDQ Tooling
PROX MOUNT
CUSTOMER IMPACT CNC
CUST TOOL NO. SD-2002
MATERIAL 6061 ALUM
FINISH BLACK ANODIZE
SD-2002
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2002
PRINTED DATE: Wednesday, March 25, 2015

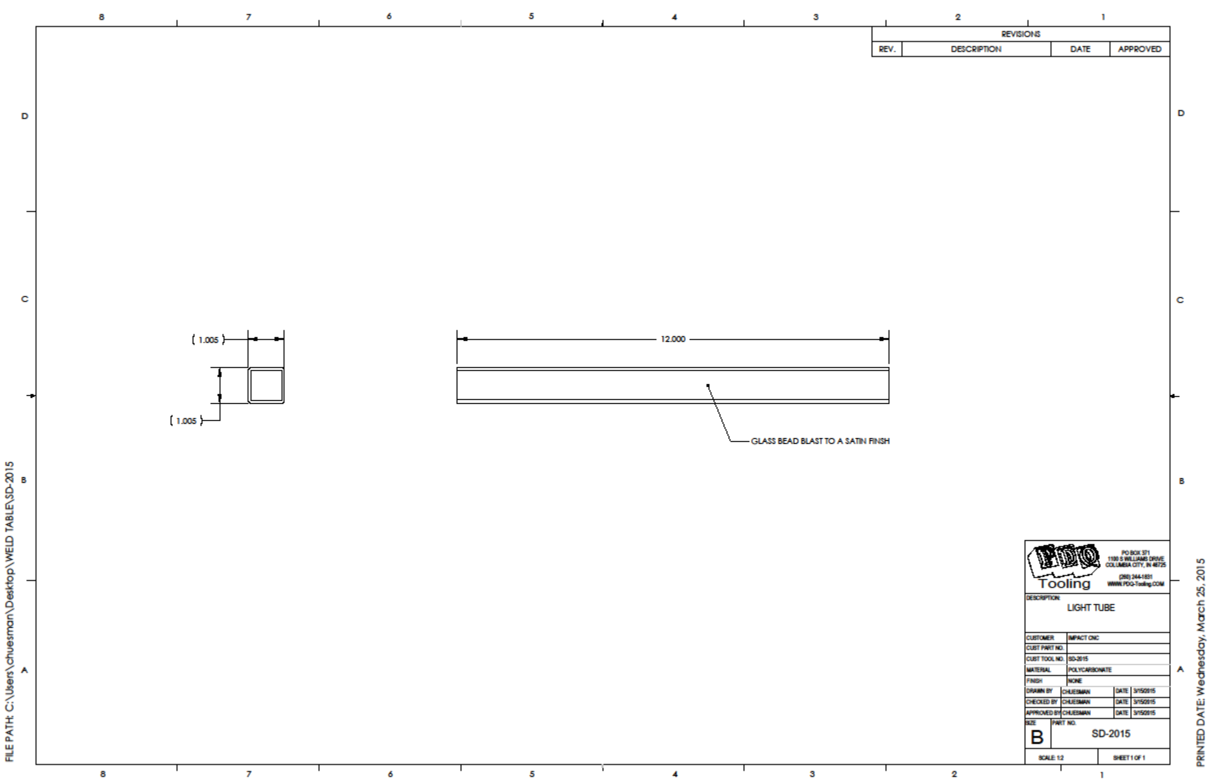

REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
SECTION A-A
PDQ Tooling
ROTARY RISER (RIGHT)
CUSTOMER IMPACT CNC
MATERIAL 6061 ALUM
FINISH BLACK ANODIZE
B
SD-2005
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2005
PRINTED DATE: Wednesday, March 25, 2015

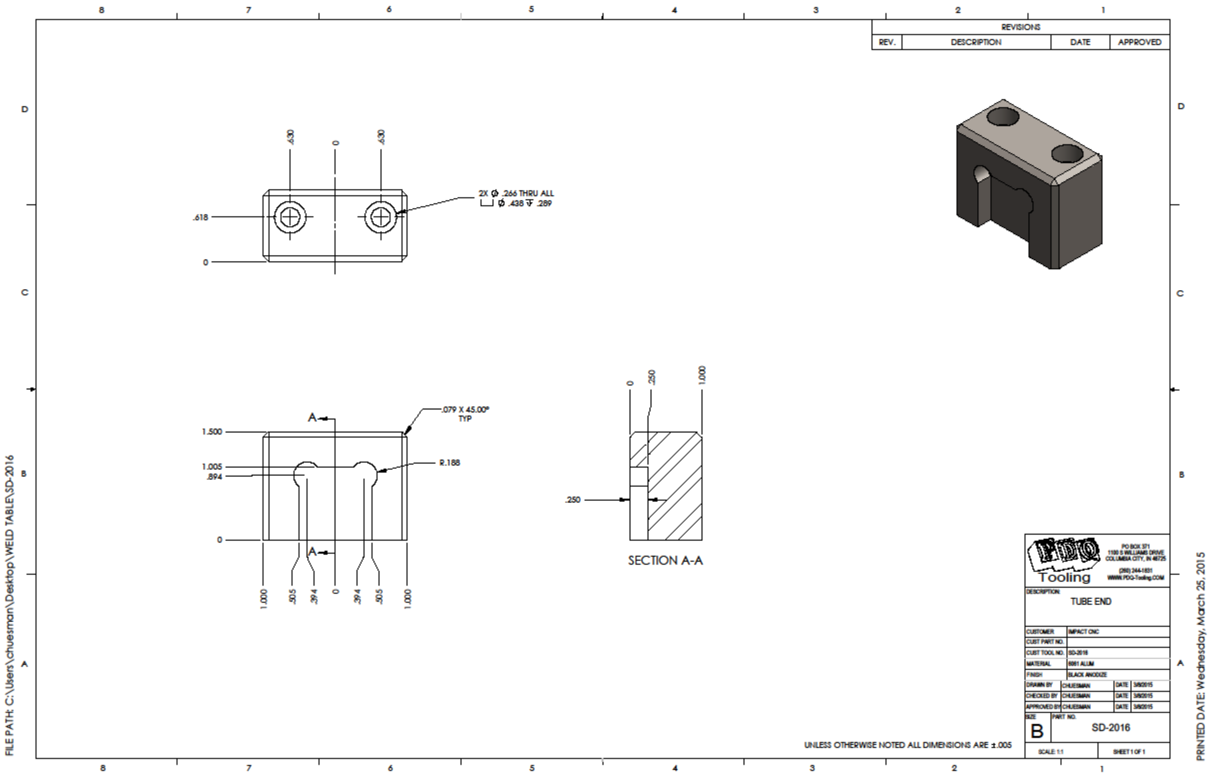

REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
SECTION A-A
MIN TOOL FORM U-CUT TYP
PDQ Tooling
TUBE PLUG
CUSTOMER IMPACT CNC
MATERIAL 6061 ALUM
FINISH BLACK ANODIZE
B
SD-2009
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2009
PRINTED DATE: Wednesday, March 25, 2015

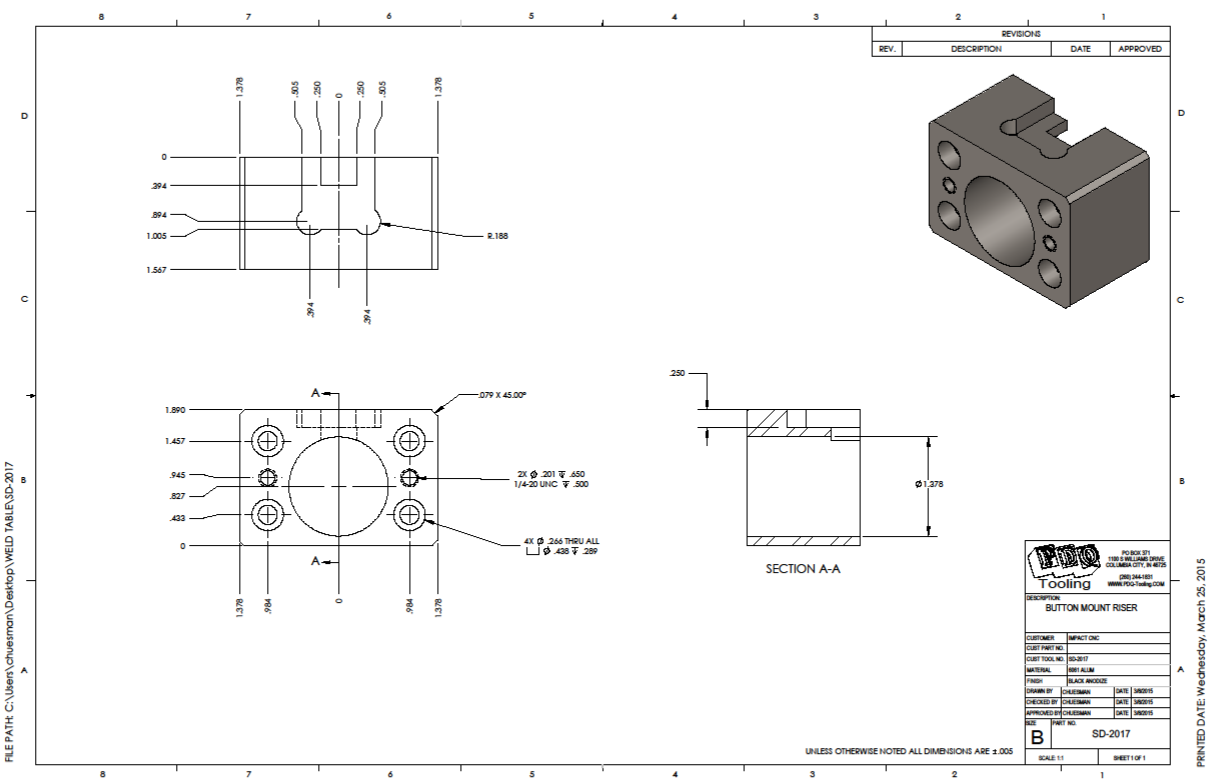

LASER RISER BASE
SECTION A-A
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
SD-2010

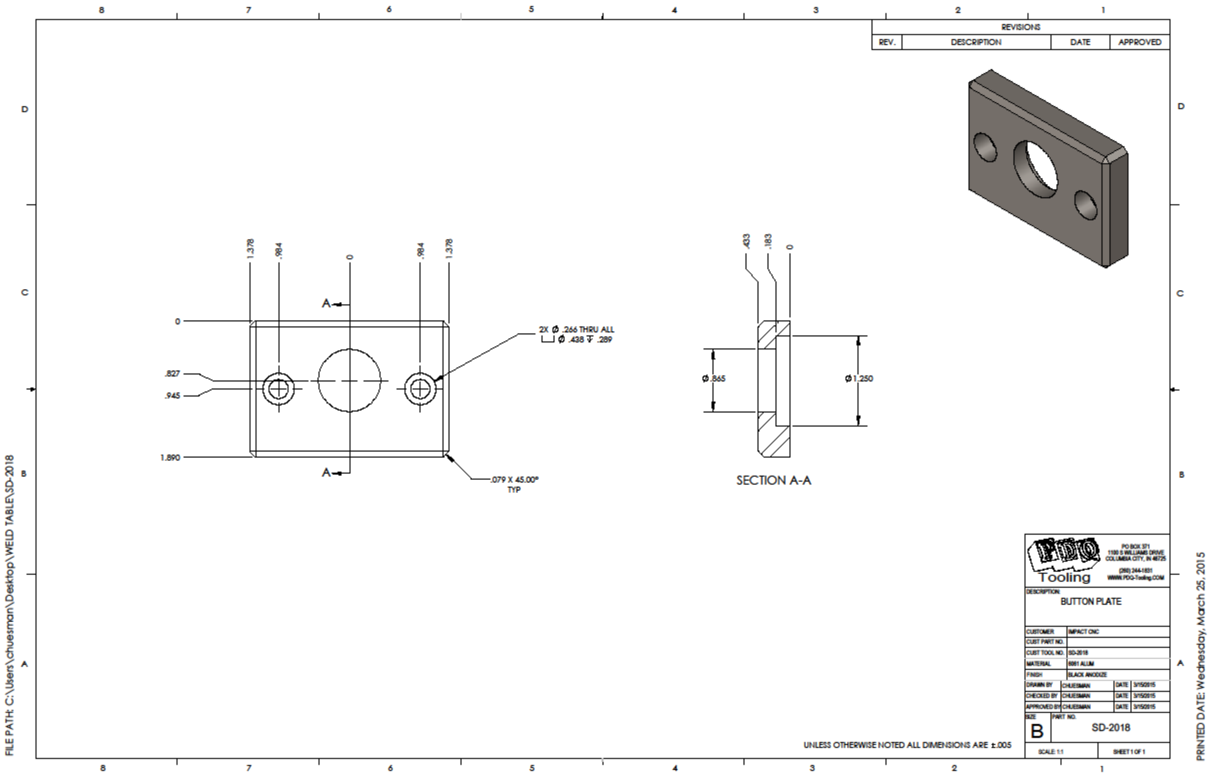

LASER MOUNT
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
SD-2011

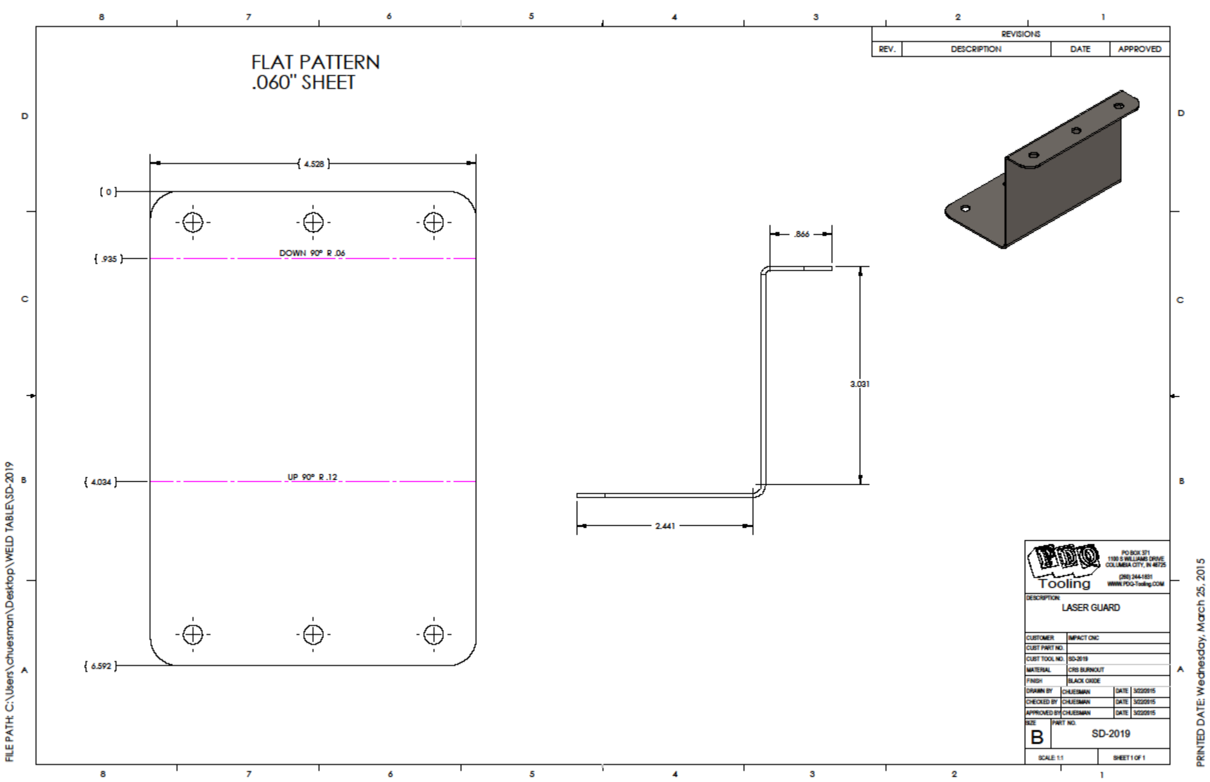

REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
FLAT PATTERN
.125" CRS
QTY: 6
SD-2013
FLAT PATTERN
.125" CRS
QTY: 4
DOWN 90° R .07
1.215
1.306
1.109
1.490
1.687
SD-2006
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
Tooling
CYLINDER BRACKETS
B
SD-2013, SD-2006
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2013
PRINTED DATE: Wednesday, March 25, 2015


REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
(1.005)
(1.005)
12.000
GLASS BEAD BLAST TO A SATIN FINISH
Tooling
LIGHT TUBE
B
SD-2015
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2015
PRINTED DATE: Wednesday, March 25, 2015


REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
2X ϕ .266 THRU ALL
ϕ .438 ↧ .289
.079 X 45.00°
TYP
R.188
SECTION A-A
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
PDQ Tooling
TUBE END
IMPACT CNC
SD-2016
6061 ALUM
BLACK ANODIZE
CHUESMAN
B
SD-2016
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2016
PRINTED DATE: Wednesday, March 25, 2015


REVISIONS
REV.
DESCRIPTION
DATE
APPROVED
R.188
.079 X 45.00°
2X ϕ .201 ↧ .650
1/4-20 UNC ↧ .500
4X ϕ .266 THRU ALL
ϕ .438 ↧ .289
ϕ1.378
SECTION A-A
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
PDQ Tooling
BUTTON MOUNT RISER
IMPACT CNC
SD-2017
6061 ALUM
BLACK ANODIZE
CHUESMAN
B
SD-2017
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2017
PRINTED DATE: Wednesday, March 25, 2015


REVISIONS
REV. DESCRIPTION DATE APPROVED
2X ⌀ .266 THRU ALL
⌀ .438 ↧ .289
.079 X 45.00° TYP
SECTION A-A
⌀ .865
⌀ 1.250
BUTTON PLATE
CUSTOMER IMPACT CNC
CUST TOOL NO. SD-2018
MATERIAL 6061 ALUM
FINISH BLACK ANODIZE
DRAWN BY CHUESMAN DATE 3/15/2015
CHECKED BY CHUESMAN DATE 3/15/2015
APPROVED BY CHUESMAN DATE 3/15/2015
B SD-2018
SCALE 1:1 SHEET 1 OF 1
UNLESS OTHERWISE NOTED ALL DIMENSIONS ARE ±.005
FILE PATH: C:\Users\chuesman\Desktop\WELD TABLE\SD-2018
PRINTED DATE: Wednesday, March 25, 2015


REVISIONS
REV. DESCRIPTION DATE APPROVED
FLAT PATTERN
.060" SHEET
4.528
DOWN 90° R .06
UP 90° R .12
.866
3.031
2.441
LASER GUARD
CUSTOMER IMPACT CNC
CUST TOOL NO. SD-2019
MATERIAL CRS BURNOUT
FINISH BLACK OXIDE
DRAWN BY CHUESMAN DATE 3/22/2015
CHECKED BY CHUESMAN DATE 3/22/2015
APPROVED BY CHUESMAN DATE 3/22/2015
B SD-2019
SCALE 1:1 SHEET 1 OF 1
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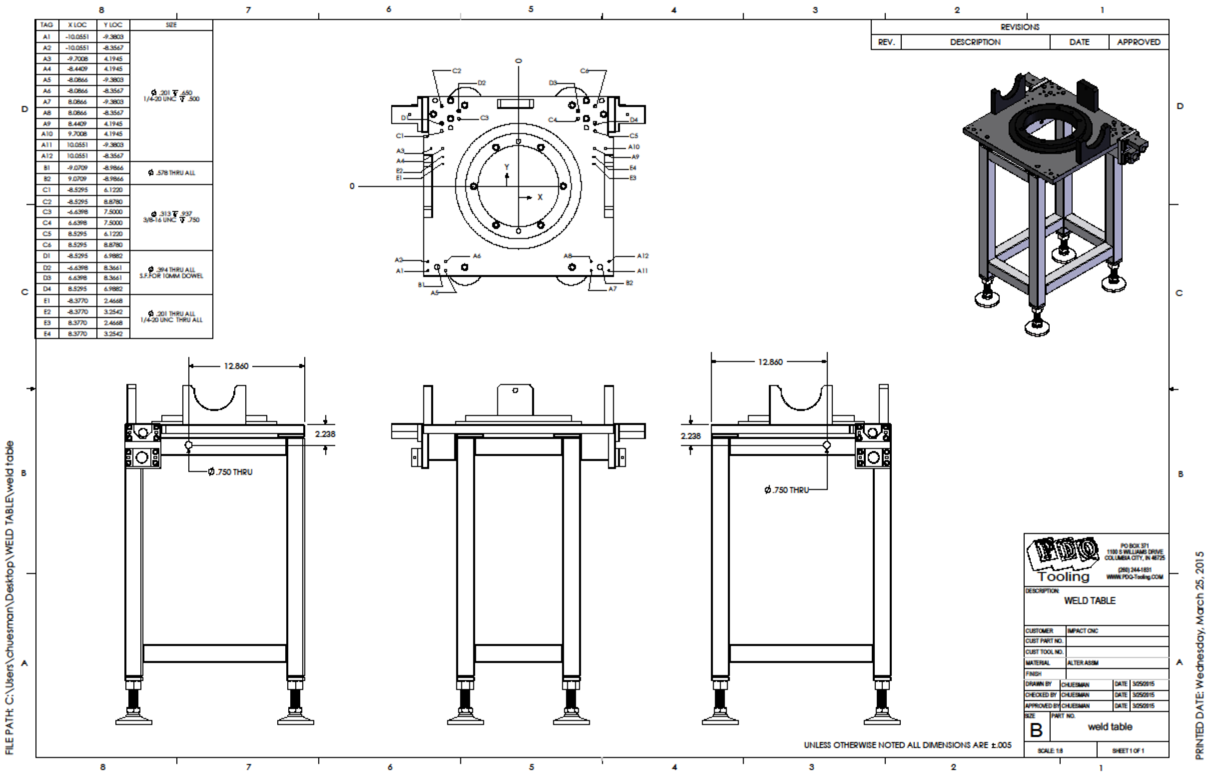
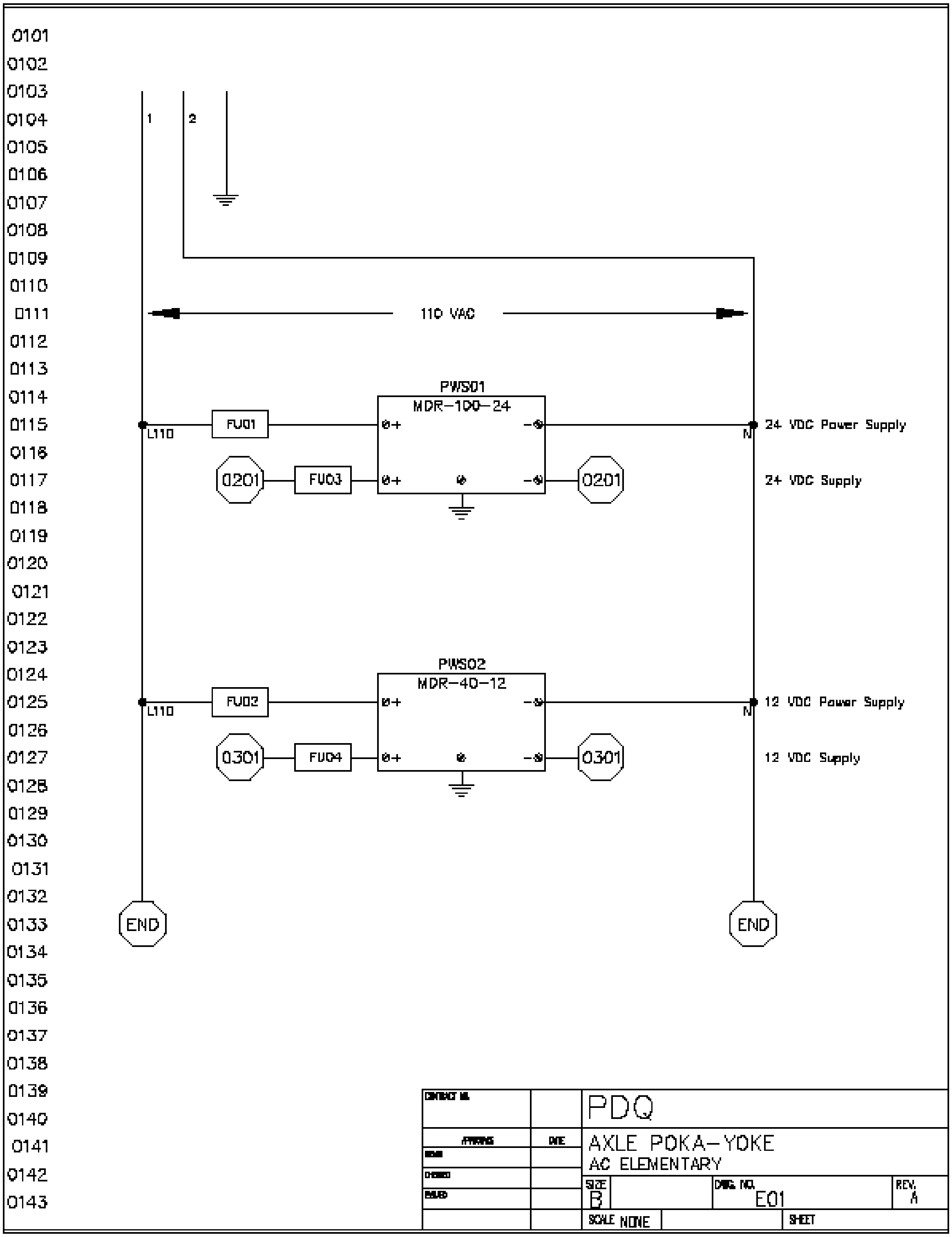
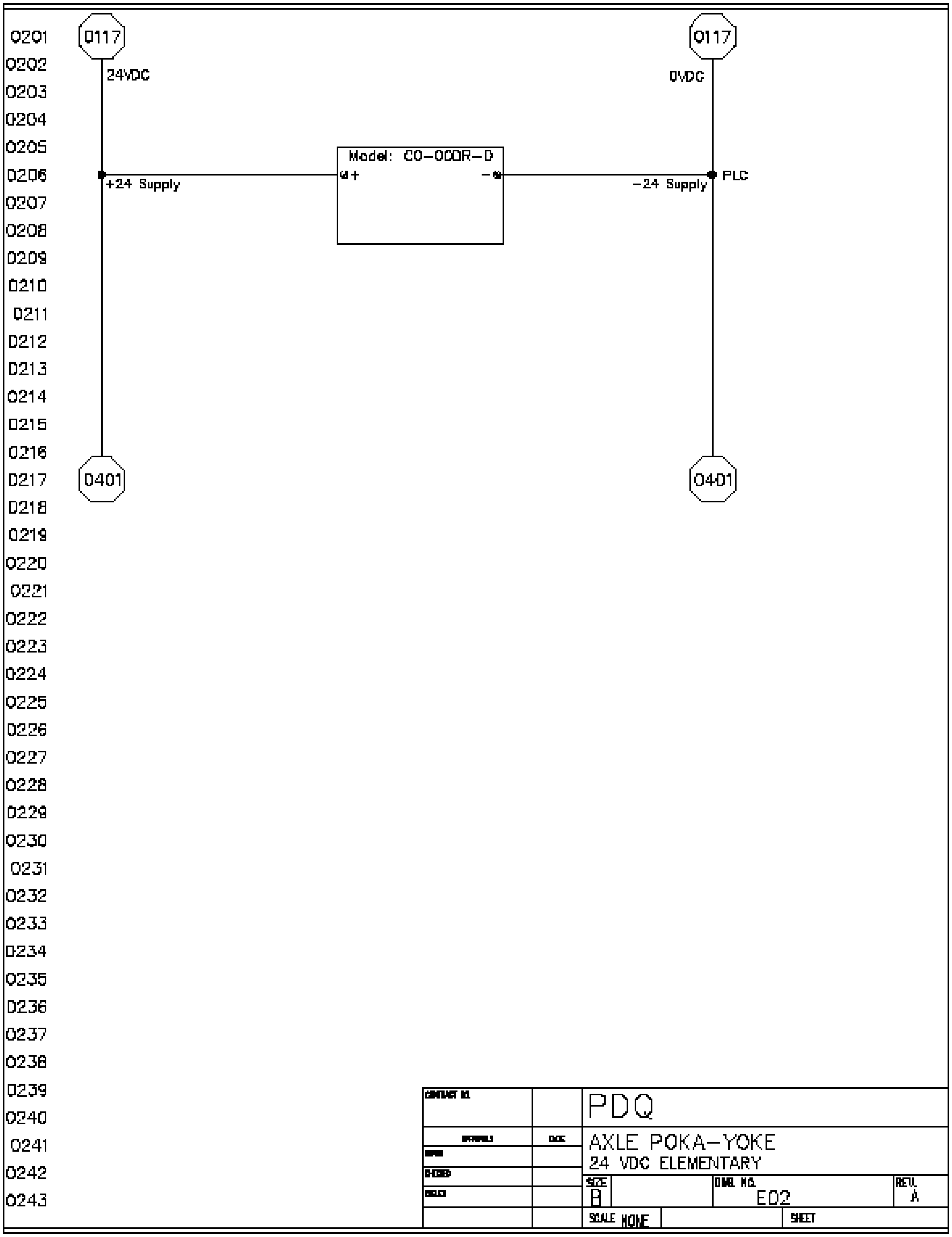


TAG	X LOC	Y LOC	SIZE
A1	-10.0551	-9.3803	⌀ .201 ↧ .650 1/4-20 UNC ↧ .500
A2	-10.0551	-8.3567	
A3	-9.7008	4.1945	
A4	-8.4409	4.1945	
A5	-8.0866	-9.3803	
A6	-8.0866	-8.3567	
A7	8.0866	-9.3803	
A8	8.0866	-8.3567	
A9	8.4409	4.1945	
A10	9.7008	4.1945	
A11	10.0551	-9.3803	
A12	10.0551	-8.3567	
B1	-9.0709	-8.9866	⌀ .578 THRU ALL
B2	9.0709	-8.9866	
C1	-8.5295	6.1220	⌀ .313 ↧ .937 3/8-16 UNC ↧ .750
C2	-8.5295	8.8780	
C3	-6.6398	7.5000	
C4	6.6398	7.5000	
C5	8.5295	6.1220	
C6	8.5295	8.8780	
D1	-8.5295	6.9882	⌀ .394 THRU ALL S.F.FOR 10MM DOWEL
D2	-6.6398	8.3661	
D3	6.6398	8.3661	
D4	8.5295	6.9882	
E1	-8.3770	2.4668	⌀ .201 THRU ALL 1/4-20 UNC THRU ALL
E2	-8.3770	3.2542	
E3	8.3770	2.4668	
E4	8.3770	3.2542	

Appendix B: Electrical Prints




0201
0202
0203
0204
0205
0206
0207
0208
0209
0210
0211
0212
0213
0214
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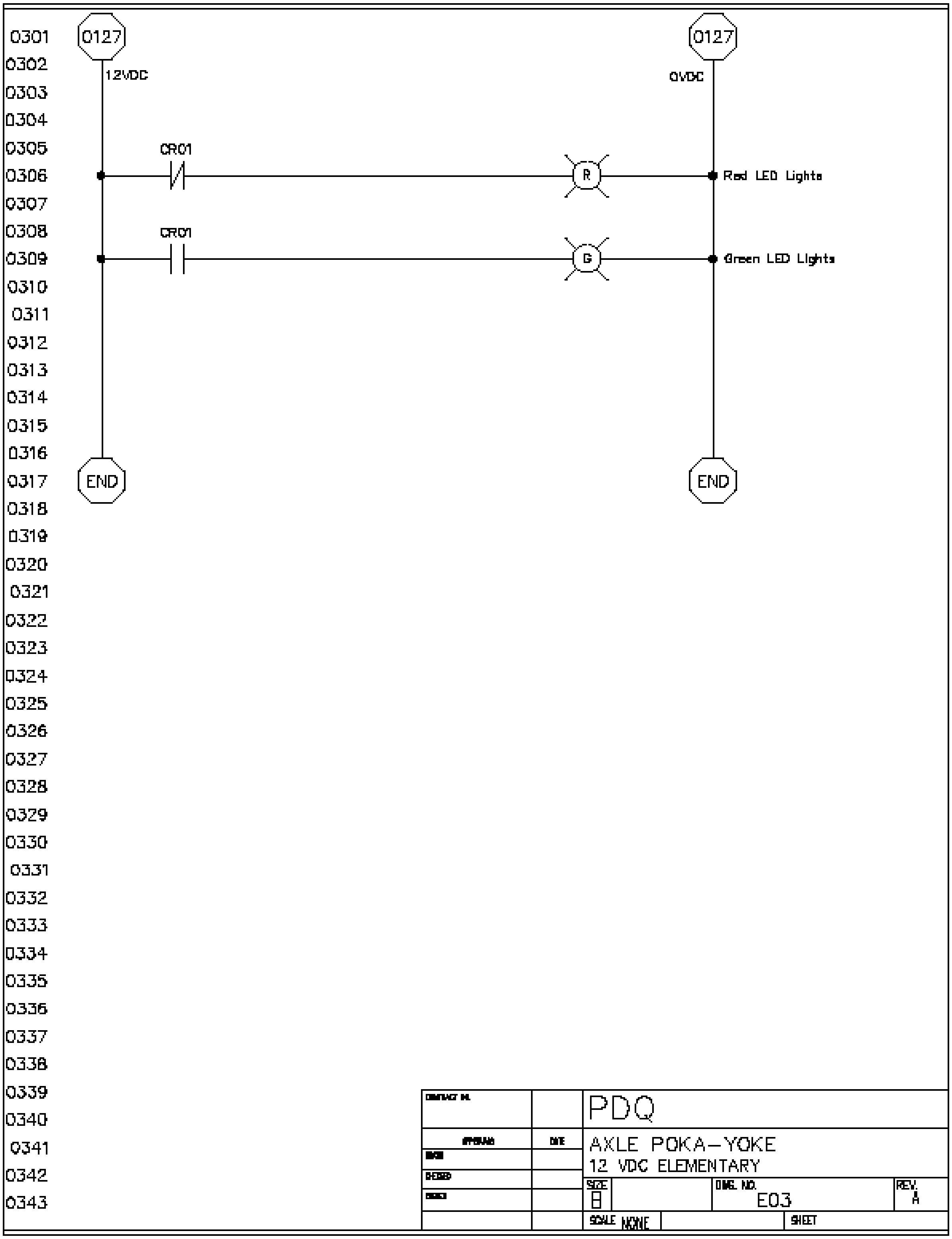
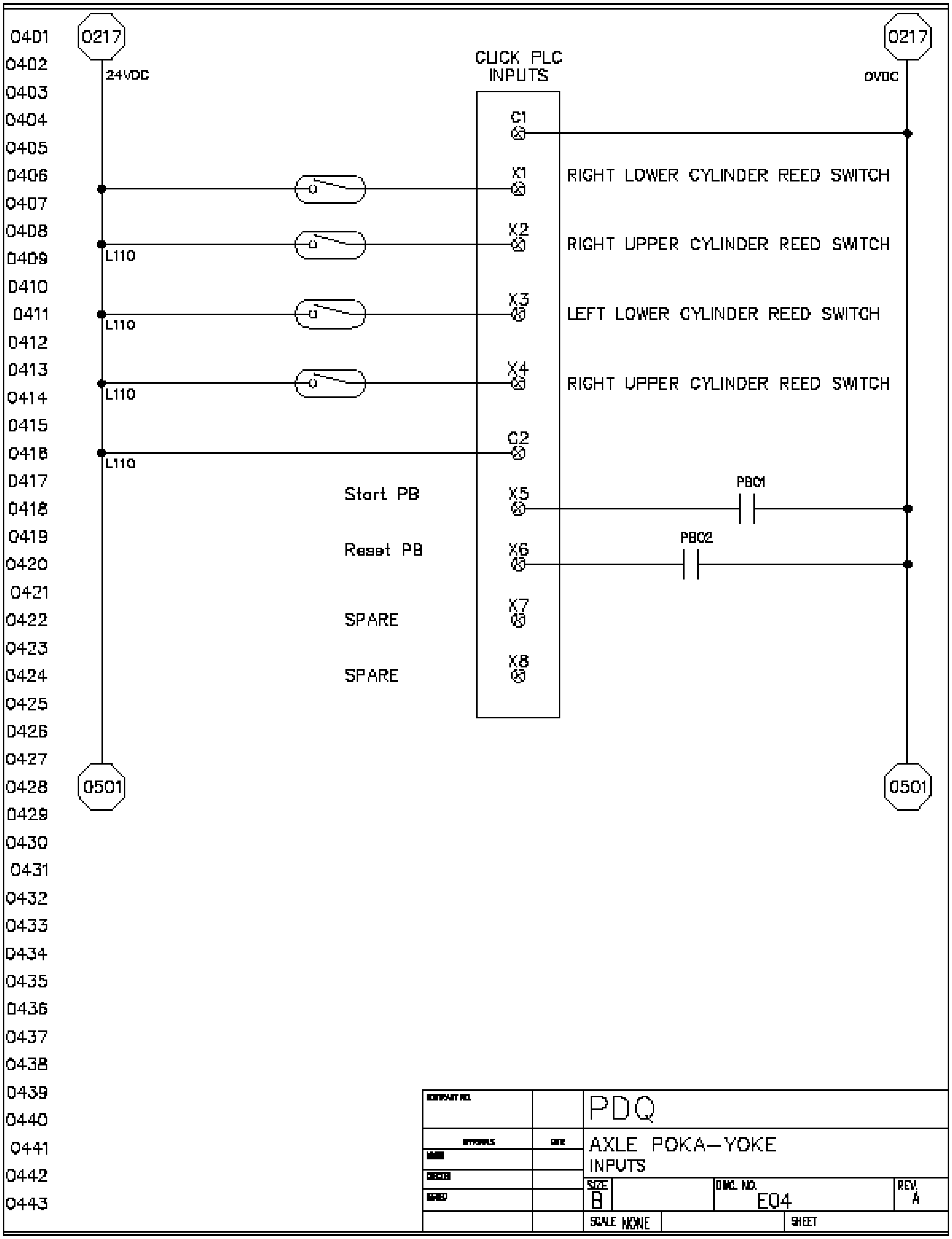
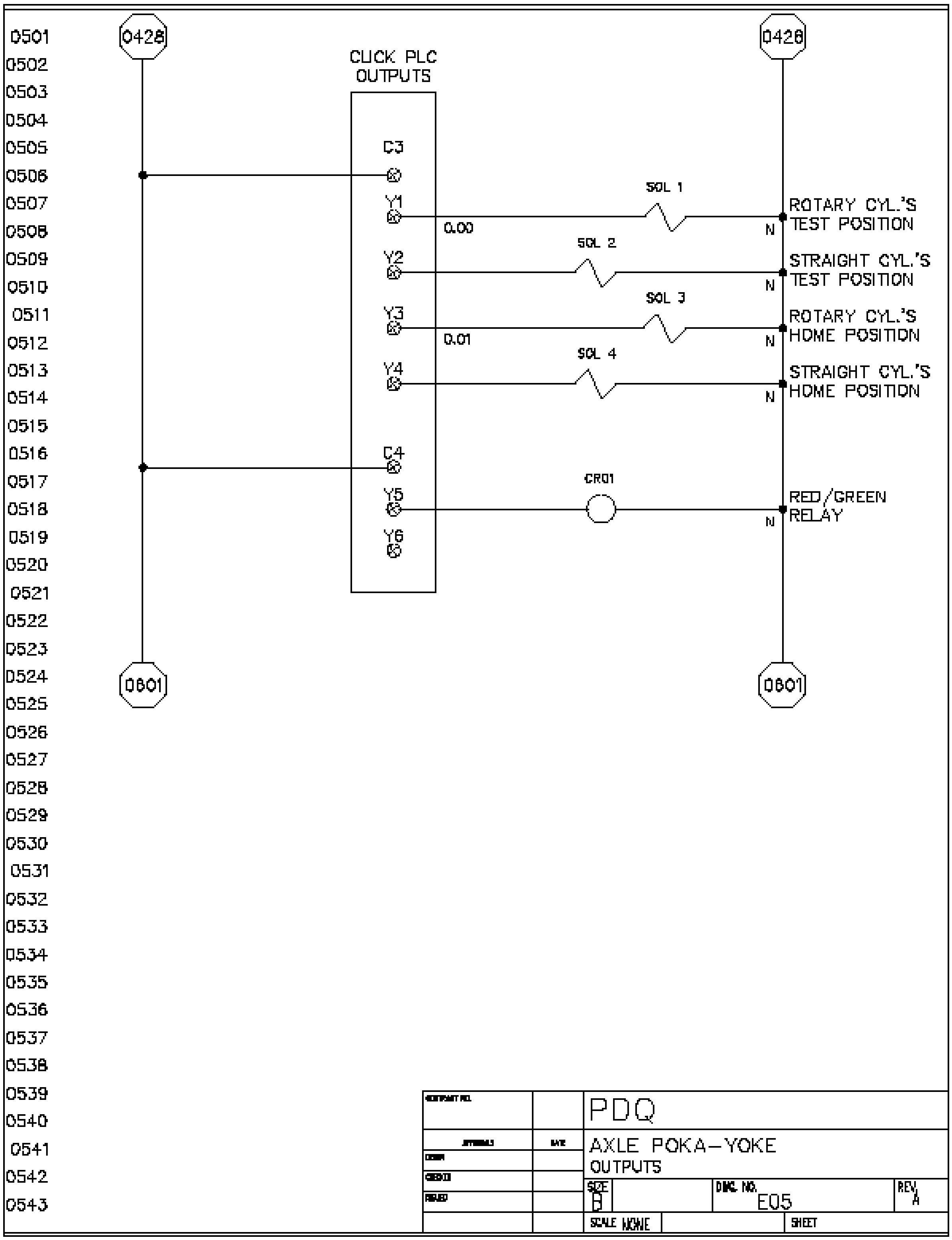
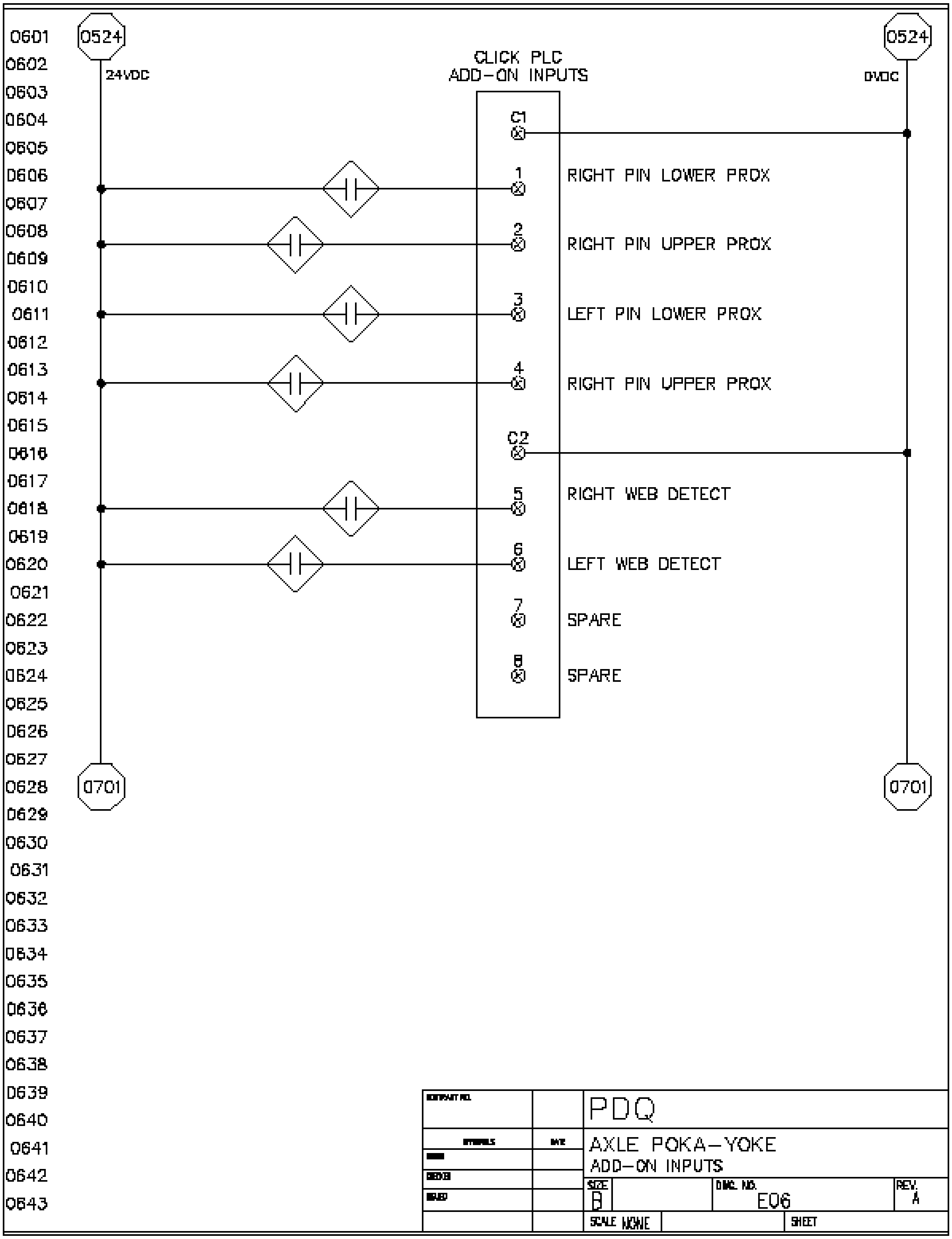
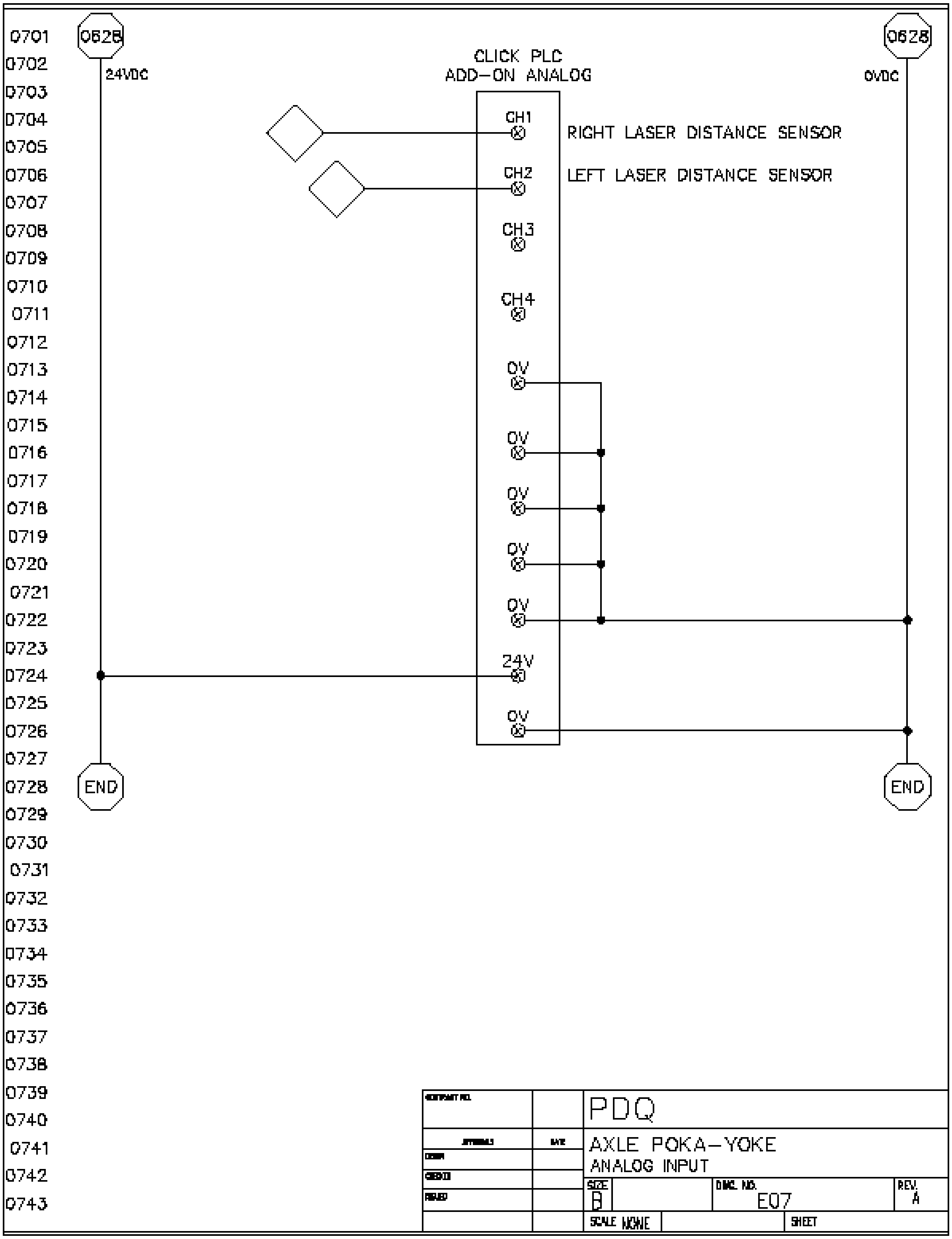
0216
0217
0218
0219
0220
0221
0222
0223
0224
0225
0226
0227
0228
0229
0230
0231
0232
0233
0234
0235
0236
0237
0238
0239
0240
0241
0242
0243
0117
24VDC
+24 Supply
0401
Model: CO-00DR-D
+
-
0117
0VDC
PLC
-24 Supply
0401
PDQ
AXLE POKA-YOKE
24 VDC ELEMENTARY
SIZE
B
DWG NO.
E02
REV.
A
SCALE NONE
SHEET


0127
12VDC
0VDC
CR01
CR01
R
G
Red LED Lights
Green LED Lights
END
END
PDQ
AXLE POKA-YOKE
12 VDC ELEMENTARY
SIZE B
DWG. NO. E03
REV. A
SCALE NONE
SHEET


0217
24VDC
CLICK PLC
INPUTS
0217
0VDC
C1
X1
RIGHT LOWER CYLINDER REED SWITCH
X2
L110
RIGHT UPPER CYLINDER REED SWITCH
X3
L110
LEFT LOWER CYLINDER REED SWITCH
X4
L110
RIGHT UPPER CYLINDER REED SWITCH
C2
L110
Start PB
X5
PB01
Reset PB
X6
PB02
SPARE
X7
SPARE
X8
0501
0501
PDQ
AXLE POKA-YOKE
INPUTS
SIZE
B
DWG. NO.
E04
REV.
A
SCALE NONE
SHEET


0501
0502
0503
0504
0505
0506
0507
0508
0509
0510
0511
0512
0513
0514
0515
0516
0517
0518
0519
0520
0521
0522
0523
0524
0525
0526
0527
0528
0529
0530
0531
0532
0533
0534
0535
0536
0537
0538
0539
0540
0541
0542
0543
0428
0428
CLICK PLC
OUTPUTS
C3
Y1
Y2
Y3
Y4
C4
Y5
Y6
0.00
0.01
SOL 1
SOL 2
SOL 3
SOL 4
CR01
N
N
N
N
N
ROTARY CYL.'S
TEST POSITION
STRAIGHT CYL.'S
TEST POSITION
ROTARY CYL.'S
HOME POSITION
STRAIGHT CYL.'S
HOME POSITION
RED/GREEN
RELAY
0601
0601
PDQ
AXLE POKA-YOKE
OUTPUTS
SIZE
B
DWG. NO.
E05
REV.
A
SCALE NONE
SHEET


0524
24VDC
CLICK PLC
ADD-ON INPUTS
0524
0VDC
C1
1
RIGHT PIN LOWER PROX
2
RIGHT PIN UPPER PROX
3
LEFT PIN LOWER PROX
4
RIGHT PIN UPPER PROX
C2
5
RIGHT WEB DETECT
6
LEFT WEB DETECT
7
SPARE
8
SPARE
0701
0701
PDQ
AXLE POKA-YOKE
ADD-ON INPUTS
SIZE
B
DWG. NO.
E06
REV.
A
SCALE NONE
SHEET


0701
0702
0703
0704
0705
0706
0707
0708
0709
0710
0711
0712
0713
0714
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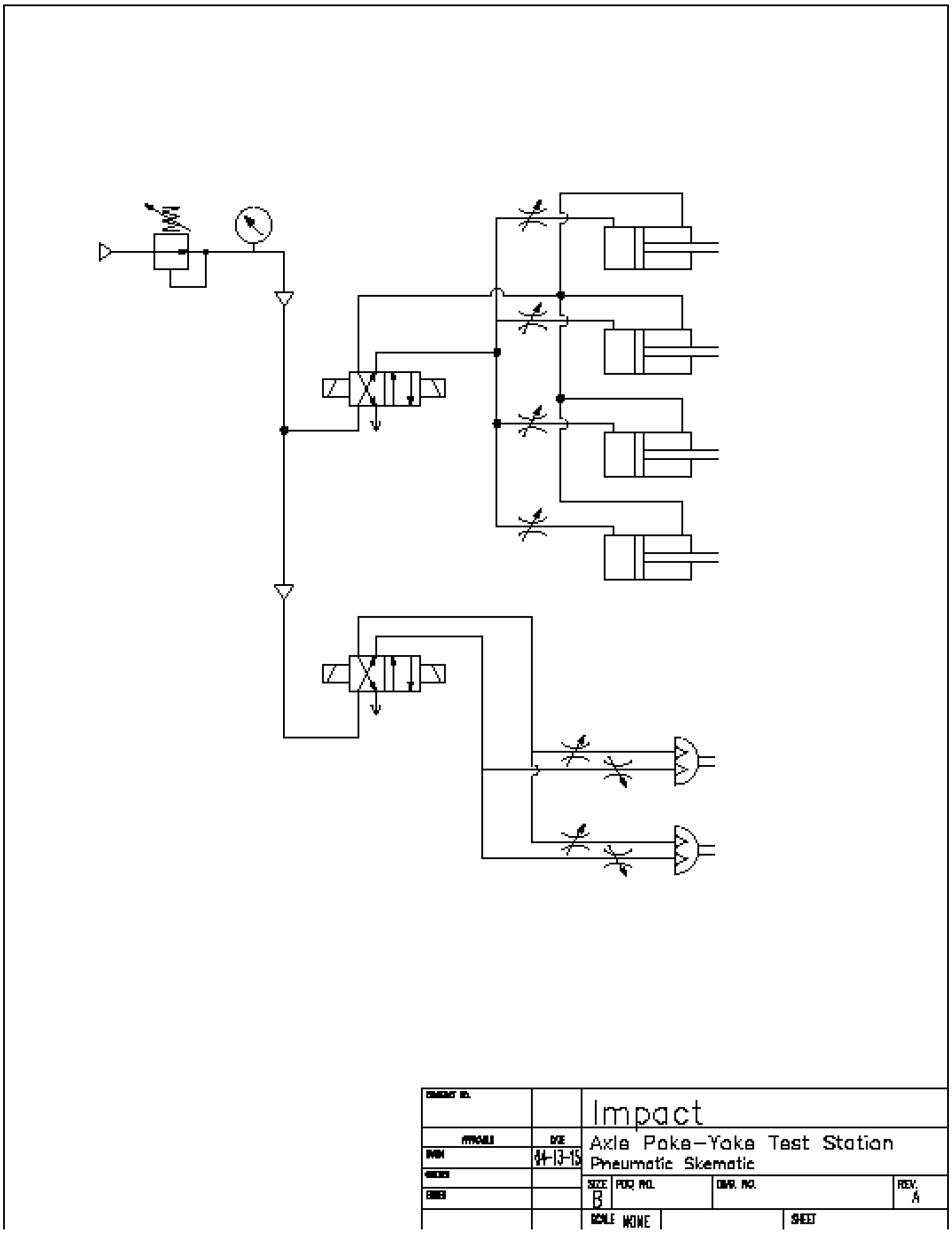
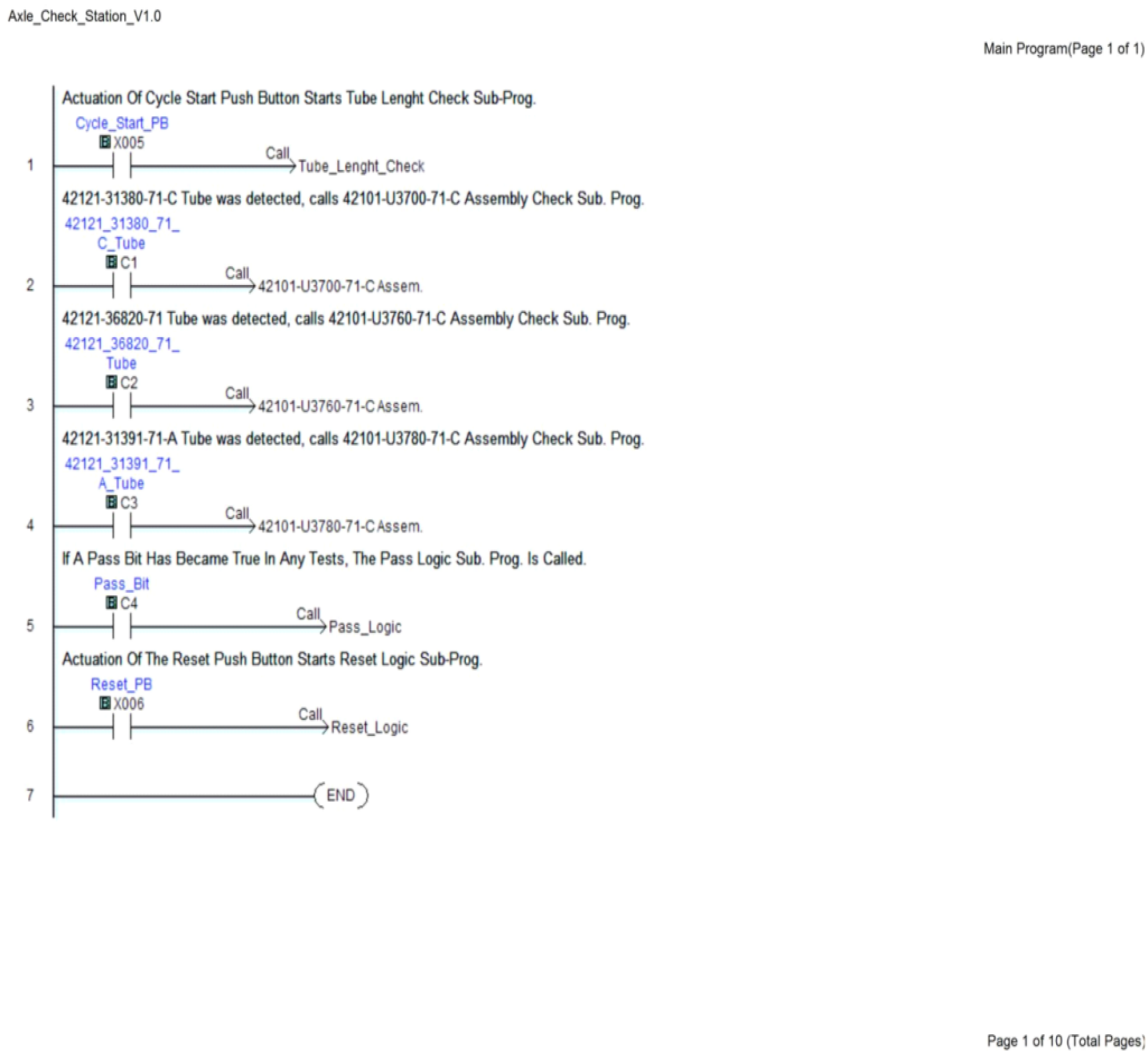
0716
0717
0718
0719
0720
0721
0722
0723
0724
0725
0726
0727
0728
0729
0730
0731
0732
0733
0734
0735
0736
0737
0738
0739
0740
0741
0742
0743
0628
24VDC
0628
0VDC
CLICK PLC
ADD-ON ANALOG
CH1
RIGHT LASER DISTANCE SENSOR
CH2
LEFT LASER DISTANCE SENSOR
CH3
CH4
0V
0V
0V
0V
0V
24V
0V
END
END
PDQ
AXLE POKA-YOKE
ANALOG INPUT
SIZE
B
DWG. NO.
E07
REV.
A
SCALE NONE
SHEET

Appendix C: Pneumatic Print

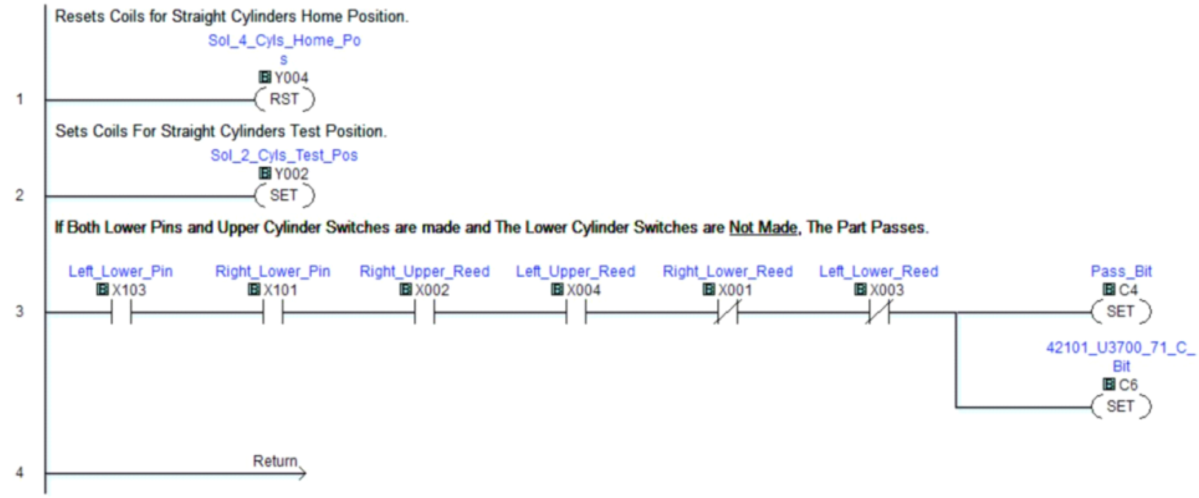


Appendix D: PLC Ladder Logic



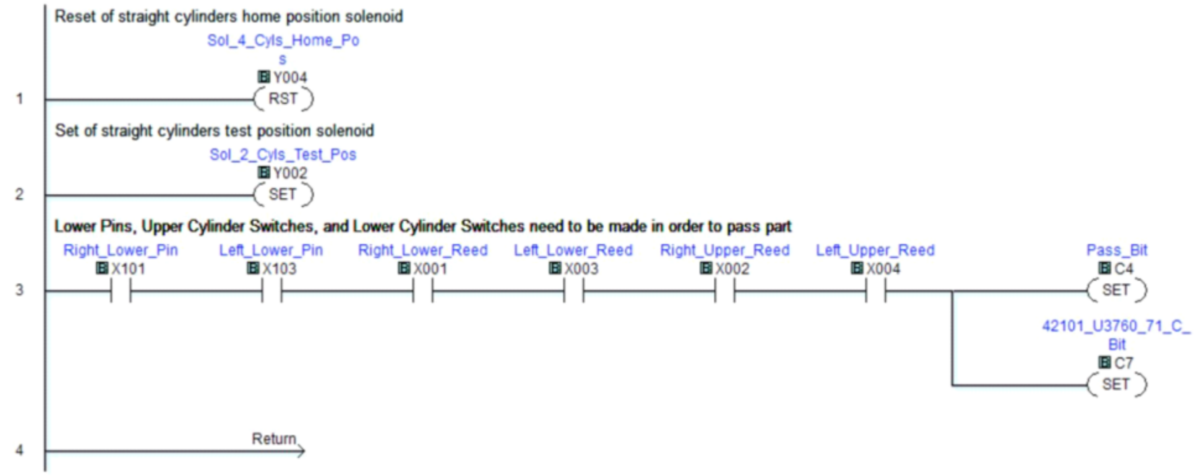
Axle_Check_Station_V1.0

Subroutine Program : 42101-U3700-71-C Assem.(Page 1 of 1)



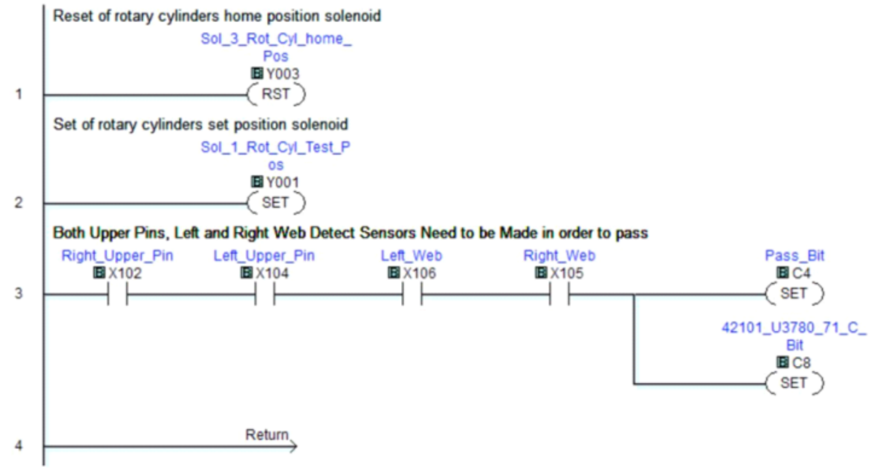
Axle_Check_Station_V1.0

Subroutine Program : 42101-U3760-71-C Assem.(Page 1 of 1)



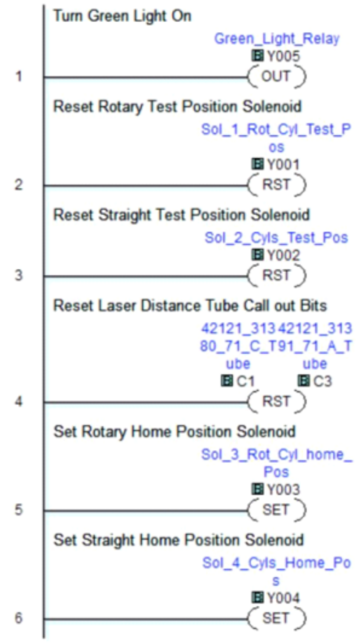
Axle_Check_Station_V1.0

Subroutine Program : 42101-U3780-71-C Assem.(Page 1 of 1)



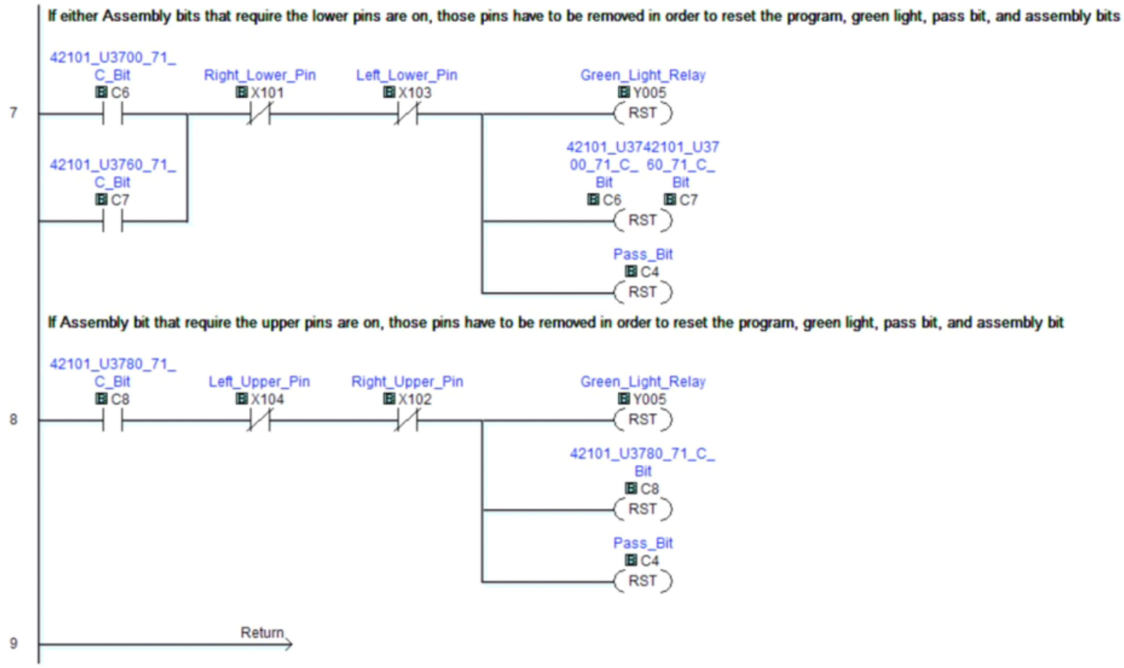
Axle_Check_Station_V1.0

Subroutine Program : Pass_Logic(Page 1 of 2)



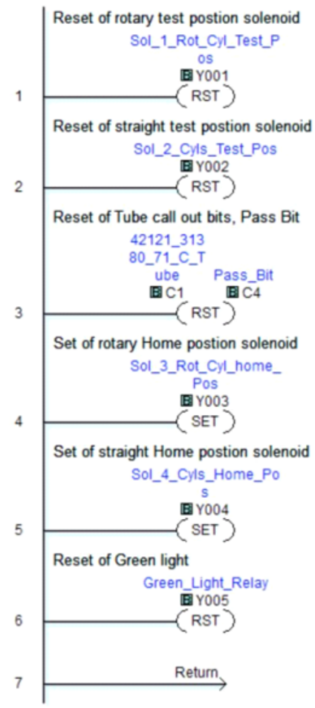
Axle_Check_Station_V1.0

Subroutine Program : Pass_Logic(Page 2 of 2)



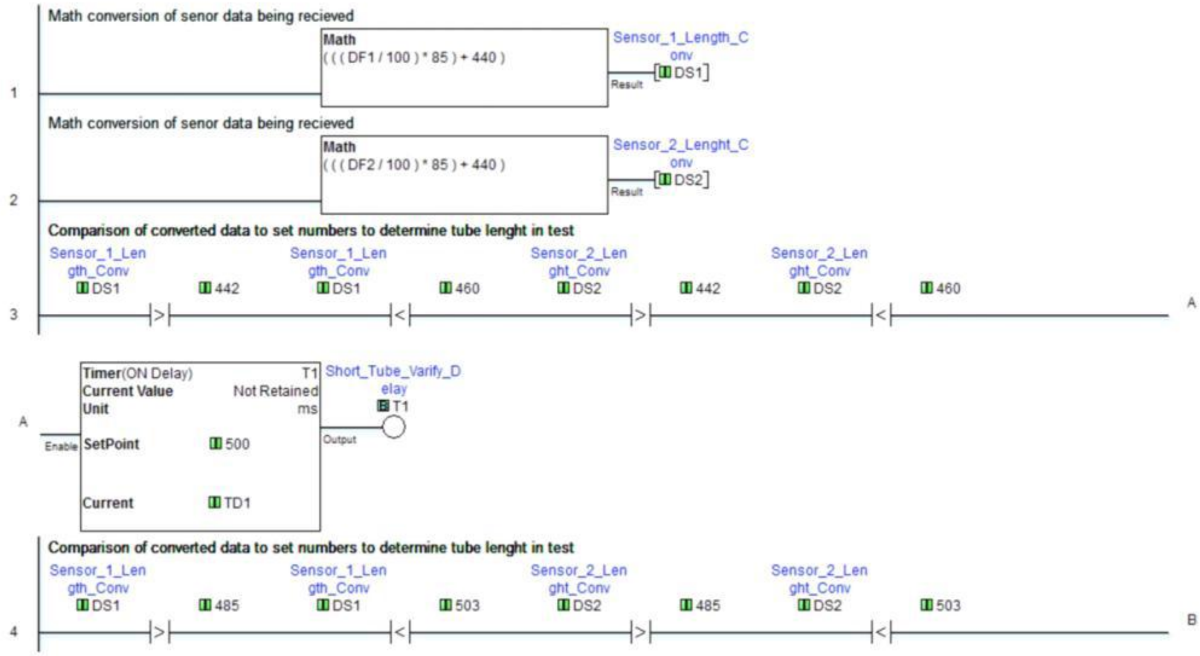
Axle_Check_Station_V1.0

Subroutine Program : Reset_Logic(Page 1 of 1)



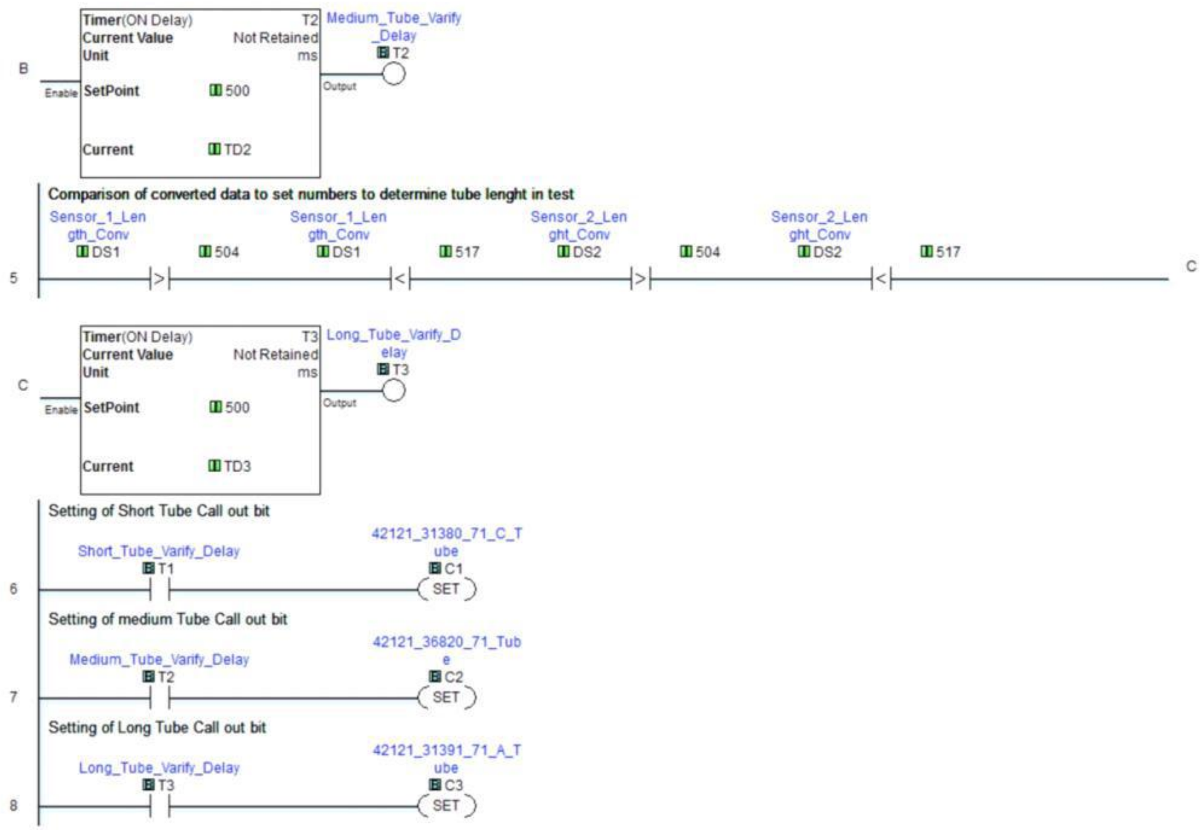
Axle_Check_Station_V1.0

Subroutine Program : Tube_Lenght_Check(Page 1 of 3)



Axle_Check_Station_V1.0

Subroutine Program : Tube_Lenght_Check(Page 2 of 3)



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Appendix E: Test Results

WELD CELL POKE-YOKE FUNCTIONAL TEST									
ASSEMBLY VARIATION				EXPECTED RESULT	TEST ATTEMPT				
CARRIER	TUBE	LEFT BRACKET	RIGHT BRACKET	PASS/FAIL	1	2	3	4	5
42111-U3700-71	42121-31380-71	42212-U3700-71	42211-U3700-71	PASS					
			42212-U3700-71	FAIL					
			42212-U3760-71	FAIL					
			42211-U3760-71	FAIL					
			42212-U3780-71	FAIL					
			42211-U3780-71	FAIL					
			180° 42211-U3700-71	FAIL					
			180° 42212-U3700-71	FAIL					
			180° 42212-U3760-71	FAIL					
			180° 42211-U3760-71	FAIL					
			180° 42212-U3780-71	FAIL					
			180° 42211-U3780-71	FAIL					
		42212-U3700-71	42211-U3700-71	FAIL					
		42212-U3760-71		FAIL					
		42211-U3760-71		FAIL					
		42212-U3780-71		FAIL					
		42211-U3780-71		FAIL					
		180° 42212-U3700-71		FAIL					
		180° 42211-U3700-71		FAIL					
		180° 42212-U3760-71		FAIL					
		180° 42211-U3760-71		FAIL					
		180° 42212-U3780-71		FAIL					
		180° 42211-U3780-71		FAIL					
42111-U3700-71	42121-31370-71	42212-U3780-71	42211-U3780-71	PASS					
			42212-U3780-71	FAIL					
			42211-U3760-71	FAIL					
			42212-U3760-71	FAIL					
			42212-U3700-71	FAIL					
			42211-U3700-71	FAIL					
			180° 42211-U3780-71	FAIL					
			180° 42212-U3780-71	FAIL					
			180° 42211-U3760-71	FAIL					
			180° 42212-U3760-71	FAIL					
			180° 42212-U3700-71	FAIL					
			180° 42211-U3700-71	FAIL					
		42211-U3780-71	42211-U3780-71	FAIL					
		42211-U3760-71		FAIL					
		42212-U3760-71		FAIL					
		42212-U3700-71		FAIL					
		42211-U3700-71		FAIL					
		180° 42211-U3780-71		FAIL					
		180° 42212-U3780-71		FAIL					
		180° 42211-U3760-71		FAIL					
		180° 42212-U3760-71		FAIL					
		180° 42212-U3700-71		FAIL					
		180° 42211-U3700-71		FAIL					
42111-U3700-71	42121-36820-71	42212-U3760-71	42211-U3760-71	PASS					
			42212-U3760-71	FAIL					
			42211-U3780-71	FAIL					
			42212-U3780-71	FAIL					
			42212-U3700-71	FAIL					
			42211-U3700-71	FAIL					
			180° 42211-U3760-71	FAIL					
			180° 42212-U3760-71	FAIL					
			180° 42211-U3780-71	FAIL					
			180° 42212-U3780-71	FAIL					
			180° 42212-U3700-71	FAIL					
			180° 42211-U3700-71	FAIL					
		42211-U3760-71	42211-U3760-71	FAIL					
		42211-U3780-71		FAIL					
		42212-U3780-71		FAIL					
		42212-U3700-71		FAIL					
		42211-U3700-71		FAIL					
		180° 42212-U3760-71		FAIL					
		180° 42211-U3760-71		FAIL					
		180° 42211-U3780-71		FAIL					
		180° 42212-U3780-71		FAIL					
		180° 42212-U3700-71		FAIL					
		180° 42211-U3700-71		FAIL					

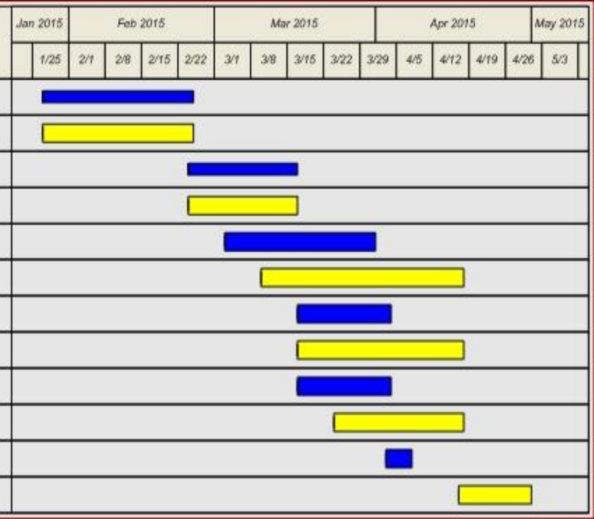
Appendix F: Budget

VENDOR	DESCRIPTION	PART #	PRICE
AUTOMATION DIRECT	ANALOG INPUT MODULE	C0-04AD-1	$ 89.00
	SINK/SOURCE INPUT MODULE	C0-08ND3	$ 33.00
	PRESSURE GAUGE	PGU14	$ 17.75
	PRESSURE REGULATOR	PRU14	$ 20.25
	Y REDUCER 1/4-1/8 (PKG OF 5)	URY-14-18	$ 18.50
	5 PORT 2 POSITION SOLENOID VALVE	AVS-5323-24D	$ 81.00
	2 STATION AIR MANIFOLD	AM-532	$ 9.75
	SOLENOID CABLE	SC9-LS24-3	$ 44.00
	9/16in BORE 3in STROKE AIR CYLINDER	A09030DD-M	$ 118.00
	MAG POSITION SWITCH PNP N.O	CPS-AP-F	$ 80.00
	MAG POS SWITCH CABLE	CD08-0A-020-A1	$ 33.00
	SWITCH BAND	CPSSB-14	$ 11.00
	FLOW CONTROL METER OUT (PKG OF 2)	FVS14-18N	$ 25.00
	FLOW CONTROL METER OUT (PKG OF 2)	FVS18-10N	$ 21.00
	MALE ELBOW FOR CYLINDERS (PKG OF 5)	ME18-10N	$ 11.00
	1/8in TUBING (100FT) BLU	PU18BLU100	$ 13.50
	1/8in TUBING (100FT) BLK	PU18BLK101	$ 13.50
	1/4in TUBING (100FT) BLU	PU14BLU100	$ 19.00
	1/4in TUBING (100FT) BLK	PU14BLK101	$ 19.00
	3/8 MNPT-1/4 TUBE ELBOW (PKG OF 5)	ME14-38N	$ 7.75
	3/8 MNPT-1/4 TUBE STRAIGHT (PKG OF 5)	MS14-38N	$ 6.00
	1/4 FEMALE BULKHEAD (PKG OF 5)	FB14-14N	$ 15.00
	1/4 TUBE BULKHEAD (PKG OF 5)	UB14	$ 13.00
	1/4 T UNION (PKG OF 5)	UT14	$ 8.25
	1/4 ELBOW (PKG OF 5)	UL14	$ 11.50
	1/8 ELBOW (PKG OF 5)	UL18	$ 14.00
	1/4 SILENCER (PKG OF 2)	SBC	$ 3.00
	ENCLOSURE	N1C121606S	$ 84.00
	PROX CABLE	CD08-0A-020-A1	$ 33.00
	10A RELAY	QL2N1-D24	$ 9.75
	RELAY SOCKET	SQL08D	$ 4.00
	24V POWER SUPPLY 3.75A 90W	PSC-24-090	$ 87.00
	12V POWER SUPPLY 2.5A 30w	PSC-12-030	$ 57.00
MCMASTER	POLYCARBONATE TUBE	3161T31	$ 17.88
	PIPE PLUG	4452K543	$ 6.81
	CORD GRIPS	7807K94	$ 8.46
	55MM ORING	9262K407	$ 5.45
	51MM ORING	9262K751	$ 6.32
TEC-HACKETT	TERMINAL JUMPERS	11354412	$ 26.00
	SINGLE LEVEL TERMINAL BLOCKS	11548603	$ 51.76
	SENSOR TERMINAL CONNECTORS	11554212	$ 52.06
	SICK 8MM PROX	1040838	$ 76.80
	SICK DT35 LASER DISTANCE MEASURING	1057652	$ 588.37
	FABCO ROTARY ACUATOR	FRC20X180	$ 525.76
Chris/Mark	machined components at no cost	-	$ -
MAMERICAN ANODIZING	OUTSOURCED ANODIZING	-	$ 95.00
		TOTAL	$ 2,491.17

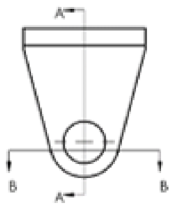
Budget	$ 3,000.00
Cost	$ 2,491.17
Remainder	$ 508.83
% Underbudget	16.96%

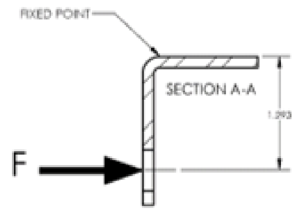
Appendix G: Project Gantt Chart

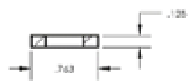
ID	Task Name	Start	Finish	Duration
1	**Design (Planned)**	**1/27/2015**	**2/24/2015**	**4w 1d**
2	Design (Actual)	1/27/2015	2/24/2015	4w 1d
3	**Ordering of parts (Planned)**	**2/24/2015**	**3/16/2015**	**3w**
4	Ordering of parts (Actual)	2/24/2015	3/16/2015	3w
5	**Fabrication (Planned)**	3/3/2015	3/31/2015	4w 1d
6	Fabrication (Actual)	3/10/2015	4/17/2015	5w 4d
7	**Assembly (Planned**	3/17/2015	4/3/2015	2w 4d
8	Assembly (Actual)	3/17/2015	4/17/2015	4w 4d
9	**Programming (Planned)**	3/17/2015	4/3/2015	2w 4d
10	Programming (Actual)	3/24/2015	4/17/2015	3w 4d
11	**Testing (Planned)**	4/3/2015	4/7/2015	3d
12	Testing (Actual)	4/17/2015	4/30/2015	2w



Appendix H: Calculation







SECTION B-B
SIMPLIFIED MINIMUM CROSS SECTION
FOR MOMENT OF INERTIA CALCULATION

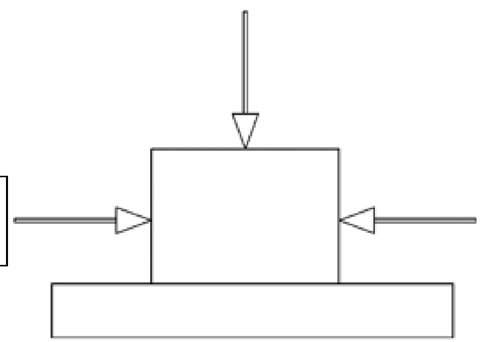
$I = \frac{.763 \times .125^3}{12} = .000124$

$\Delta_{max} = \frac{FL^3}{3EI} \Rightarrow F = \frac{\Delta_{max} 3EI}{L^3}$

$F_{max} = \frac{.010 \times 3(30 \times 10^6).000124}{1.292^3} = 51.746 lbf$

Determined from lightest component

$N = mg \Rightarrow N = 47.61 lbf$



Max cylinder force with 1.5 safety factor

$F_{max} = \frac{F_f}{SF} \Rightarrow F_{max} = \frac{9.522}{1.5} = 6.348 lbf$

$F_f = \mu N$

$\mu = .2$

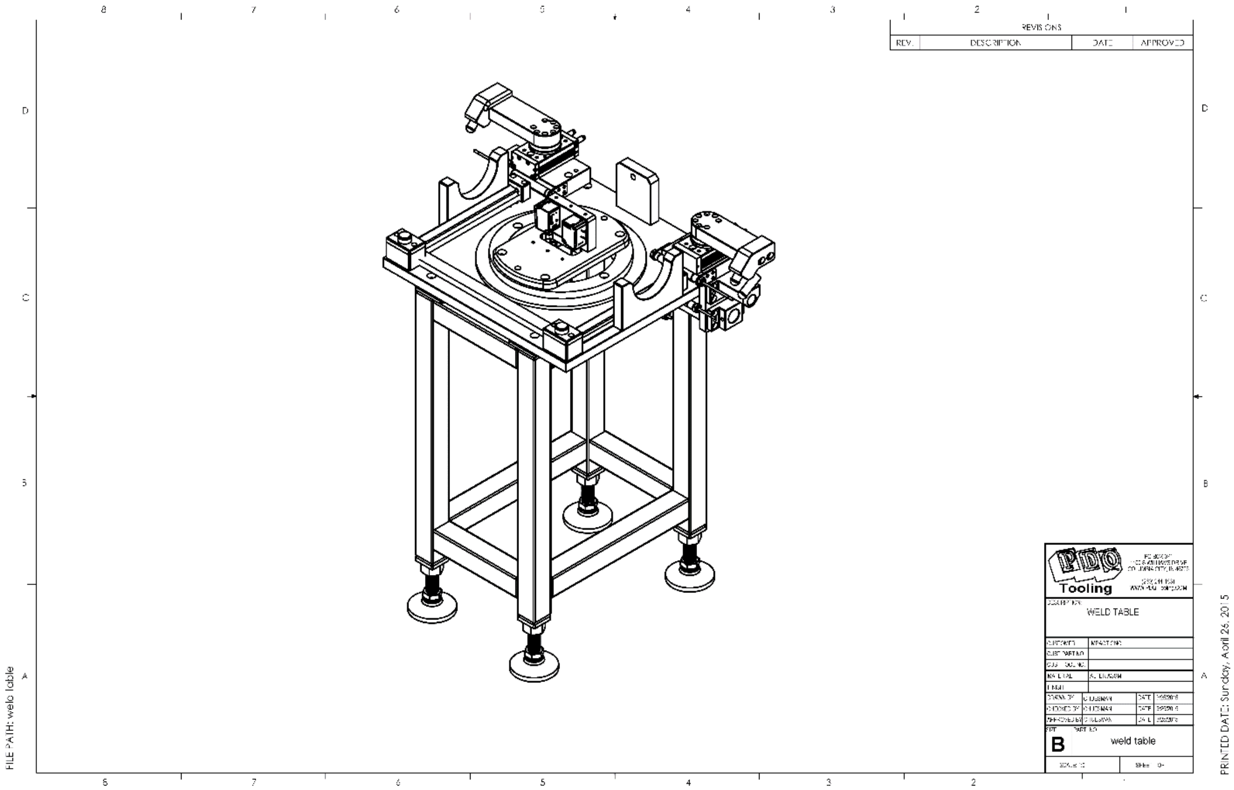
$F_r = .2(47.61) = 9.522 lbf$

Max air pressure determined from lowest max cylinder force.

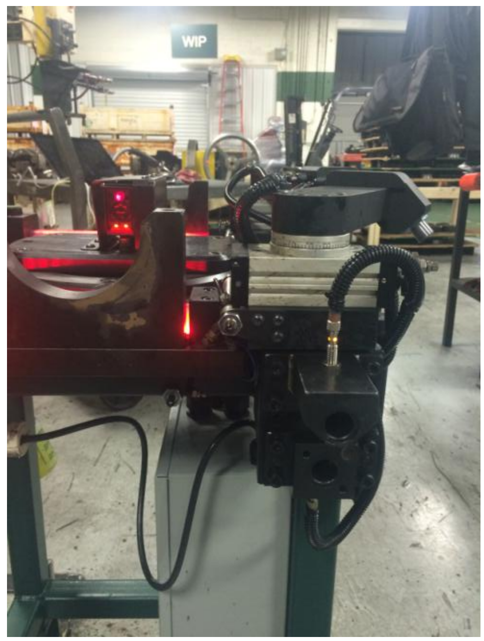
$SA_{cylinder} = \frac{\pi D^2}{4} \Rightarrow SA_{cylinder} = \frac{\pi(\frac{9}{16})^2}{4} = .248505 in^2$

$P_{max} = \frac{F_{max}}{SA_{cylinder}} \Rightarrow P_{max} = \frac{6.348}{.248505} = 25.5448 psi$

Appendix I: Assembly



Appendix J: Finished Photos



Appendix K: Bibliography

Bibliography

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