Robotic Flashlight Assembler Instruction Manual

ENGR 480 Manufacturing
Spring 2012

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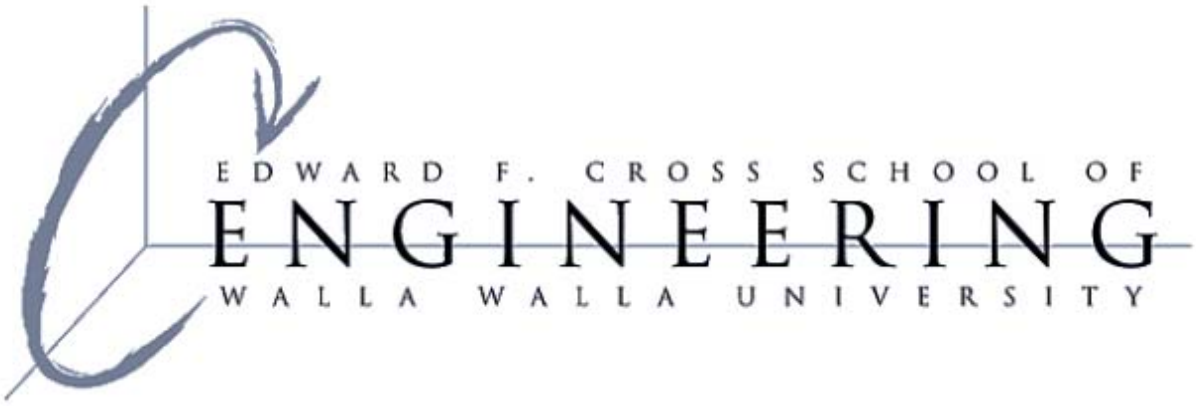

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Operation Instructions

This section includes instructions for starting, loading, clearing jams, and shutting down the flashlight assembly machine. This includes the robotic arm, part feeding stations, PLC controller, and air system.

Starting

1. Ensure parts are loaded in all eight part stations
    1.1. Part stations include: Flashlight noses, body o-rings, nose o-rings, heat sinks, snap rings, flashlight bodies, and batteries, and magnet rings. (See loading description below)
2. Ensure nose o-ring guide is in place at the central assembly station
3. Power on the robotic arm and controller
    3.1. Turn the large knob style switch on the side of the robot controller to 'ON'
    3.2. Wait for the boot cycle in the robot control pendant to complete
        3.2.1. When complete the control pendant will display 'Please select a Main Menu'
    3.3. Ensure the key at the top left of the control pendant is switched to 'PLAY'
    3.4. Ensure the E-stop at the top right of the control pendant is off
4. Power on the PLC
    4.1. Plug the orange extension cord into a standard wall power outlet
    4.2. Ensure the 3-way switch at the bottom right of the PLC is switched to 'RUN'
5. Turn on system air
    5.1. Switch the air valve mounted next to the PLC to 'C-2'
        5.1.1. You should hear a small release of air when switching from the off position (labeled 'N') to the on position (labeled 'C-2') or vice versa
6. Select and start the job 'TEAM_MENSINK' in the robot control pendant
    6.1. Using the touch screen on the control pendant select 'JOB' -> 'SELECT JOB'
    6.2. Using the arrow buttons scroll to 'TEAM_MENSINK' and push the 'SELECT' button
    6.3. Push the 'SERVO ON READY' button and then the green 'START' button
7. Start the machine by pushing the green button mounted next to the PLC

Loading

Eight stations will be loaded with flashlight parts.

1. Flashlight nose – Located on the bottom left (-y direction). The noses will slide down the track stopping at the white pegs at the end.
2. Big o-rings – Located at the top next to the small o-ring guide. These roll on end in a narrow track.
3. Small O-rings – Located at the top next to the big o-ring guide. These also roll on end in a narrow track.
4. Magnet rings – Located on the bottom left (-y direction). These slide down and stack up behind an air cylinder that singles them out.
5. Heat sinks – Located at the top of the right tower (+y). These slide spring side up down extruded track. Insert heat sinks slowly to avoid excessive speed as they slide down the track.
6. Snap rings – Located between the left and right towers these are stacked (like a roll of quarters) in a clear plastic tube.
7. Flashlight bodies – Located at the bottom of the right tower (+y). These roll on their side with the closed end facing away from the tower.
8. Batteries – Located in the middle the right tower (+y). These roll on their side with the negative end facing away from the tower.

Clearing Part Jams

Flashlight part loading station jams – Jams occurring in the loading stations for the flashlight nose, big o-rings, small o-rings, heat sinks, flashlight bodies, magnet rings, or batteries can be cleared by tapping the tower where the jam occurred to cause a small vibration in the tower.

O-ring jams – O-ring jams are the most common and are cleared with a small vibration in the tower.

Flashlight nose and heat sink jams – These are less common and sometimes require a slightly larger vibration to clear than o-ring jams.

Flashlight body and battery jams – These are uncommon, but can still be cleared with a, relatively speaking, large vibration in the tower.

Other jams – For any other jams occurring with the robotic arm, in the central assembly station, in the final assembly threading station, in the snap ring loading station, or in the on/off ring loading station do the following:

1. Push the E-stop on the robot control pendant and turn the switch at the bottom right of the PLC to 'STOP'
2. Clear any jams manually if possible. If the jam involves the robotic arm see "Clearing Jams Involving the Robotic Arm" below
3. After a jam occurs the robotic arm will need to be reset. See "Resetting the Robotic Arm after a Jam"

Clearing Jams Involving the Robotic Arm

1. Decide which direction or directions will be safest to move the robotic arm out of the position in which it is jammed
2. Move the robotic arm to a cleared position away from the jam
   2.1. Turn the key at the top left of the control pendant to 'TEACH'
   2.2. Release the E-stop on the control pendant
   2.3. The robotic arm controller will probably be aware it was involved in a jam and will be displaying an error message. Push 'RESET' on the touch screen to exit the error message
   2.4. Using the 'COORD' button select a coordinate system in which to move
   2.5. Push the 'SERVO ON READY' button on the control pendant
   2.6. Squeeze the black trigger on the back of the control pendant under your left hand to its half way position
   2.7. While holding the trigger in its half way position use the movement buttons on the control pendant to move the robotic arm in the direction decided upon in step 1 to a clear position away from the jam
3. Reset the robotic arm by following the steps below in "Resetting the Robotic Arm after a Jam"

Resetting the Robotic Arm after a Jam

1. Turn the key at the top left of the control pendant to 'TEACH'
2. Release the E-stop on the control pendant
3. If any error messages are displayed on the control pendant clear them by pushing 'RESET' on the touch screen
4. Move the robotic arm near its home position
   4.1. Using the 'COORD' button select a coordinate system in which to move
   4.2. Push the 'SERVO ON READY' button on the control pendant
   4.3. Squeeze the black trigger on the back of the control pendant under your left hand to its half way position
   4.4. While holding the trigger in its half way position use the movement buttons on the control pendant to move each joint of the robotic arm to its zero position except for the first joint at the base of the robotic arm. The first joint should be rotated about ninety degrees counter clockwise so the robotic arm is pointing toward the final assembly threading station.
5. Go to the "Starting" section above. Note that many steps in this section will already be complete

Shutting Down

1. Wait until a finished flashlight has been ejected from the final assembly threading station
2. Press the E-stop on the robot control pendant
3. Put the switch at the bottom right of the PLC to the 'STOP' position
4. Power down the robotic arm and controller
   4.1. Turn the large knob style switch on the side of the robot controller to 'OFF'
5. Power down the PLC
   5.1. Unplug the orange extension cord powering the PLC
6. Turn off system air
   6.1. Switch the air valve mounted next to the PLC to 'N'

Diagrams

State Diagram

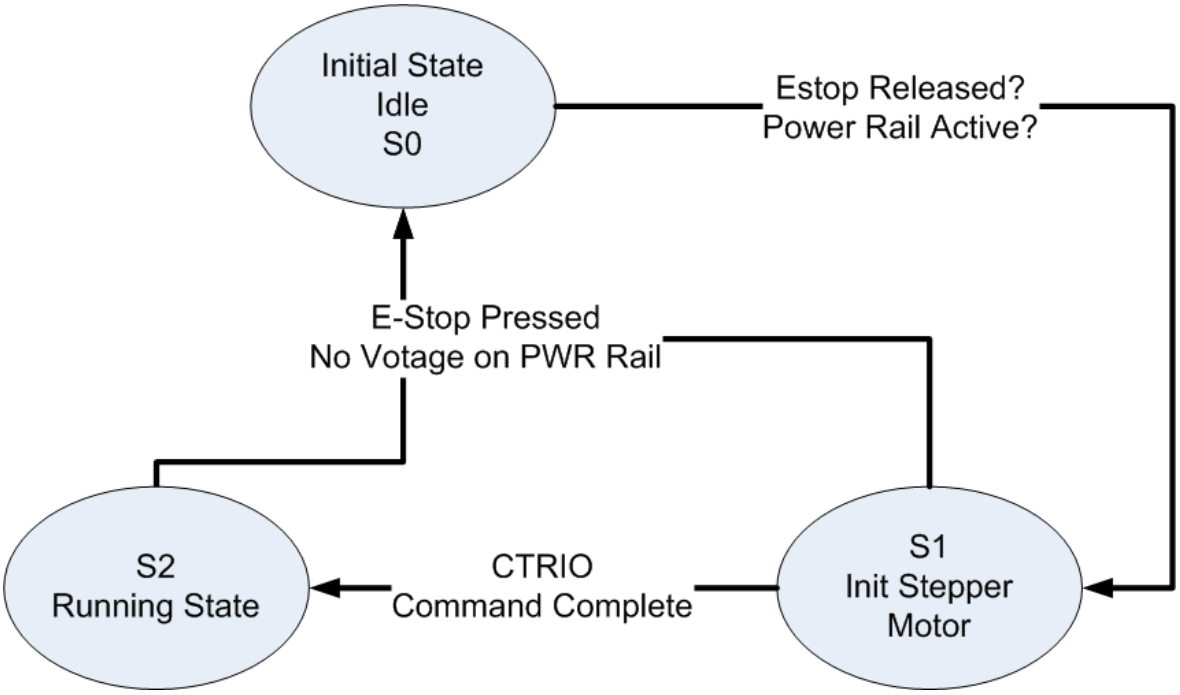


Figure 1 State Diagram

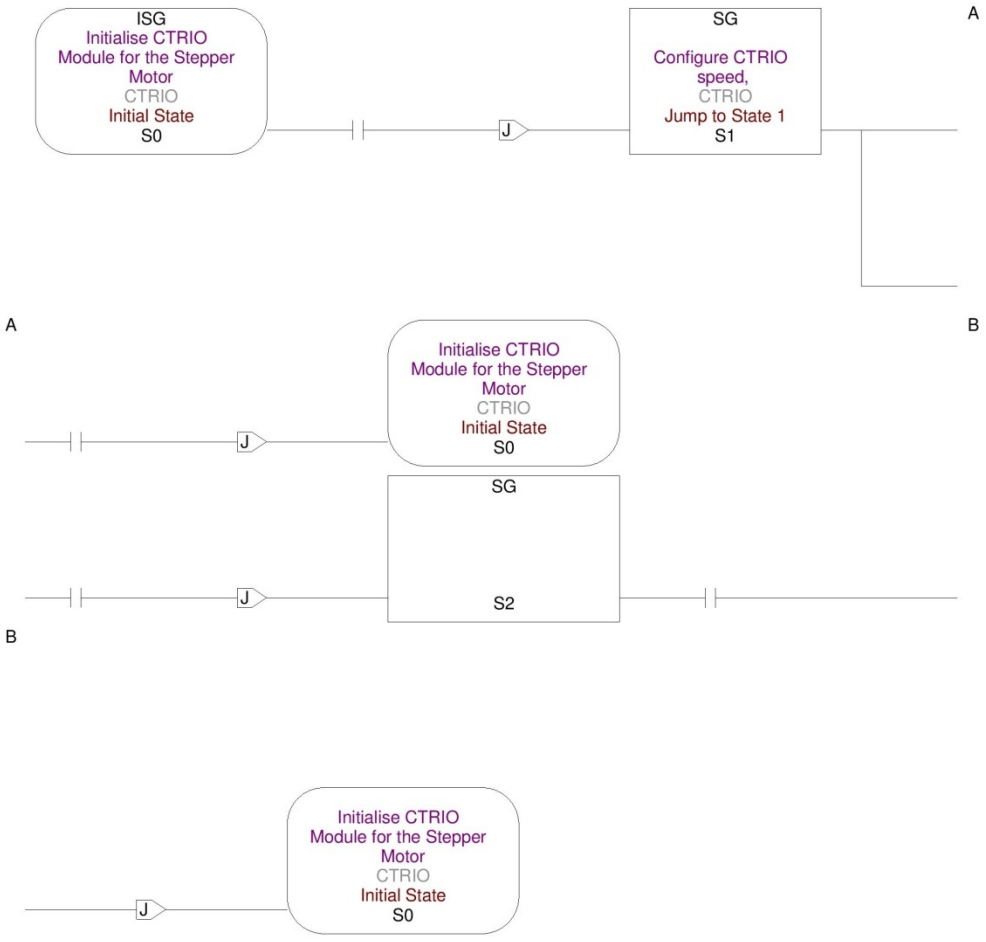


Figure 2 State Diagram from PLC

Stepper Motor Configuration

The stepper motor was configured using the standard velocity profile with the CTRIO Module.

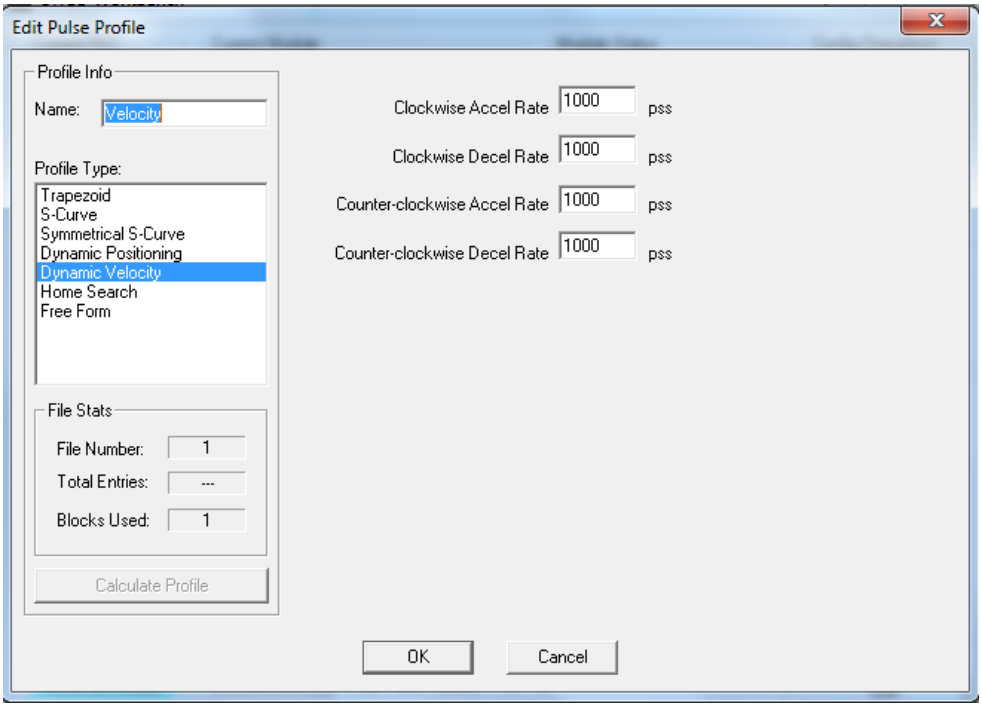


Figure 3 CTRIO Config

Figure 4 Resistor Bank

The Stepper Motor Drive logic was run through 2200Ω resisters to drop from 24V logic levels to 5v logic that the stepper drive was configured for.

Stepper Motor Drive (Below Right)
CTRIO Module (Below Left)

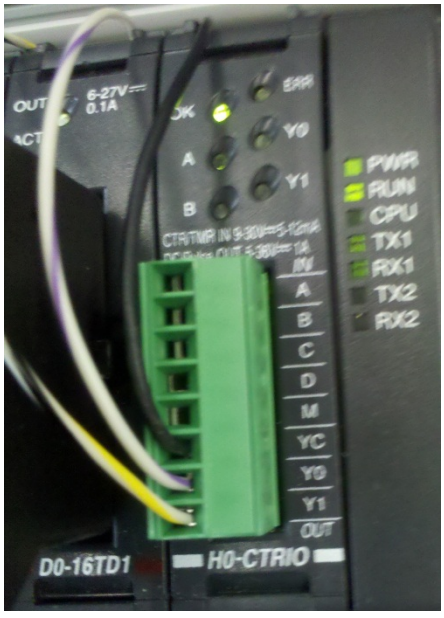


Figure 5 CTRIO Module

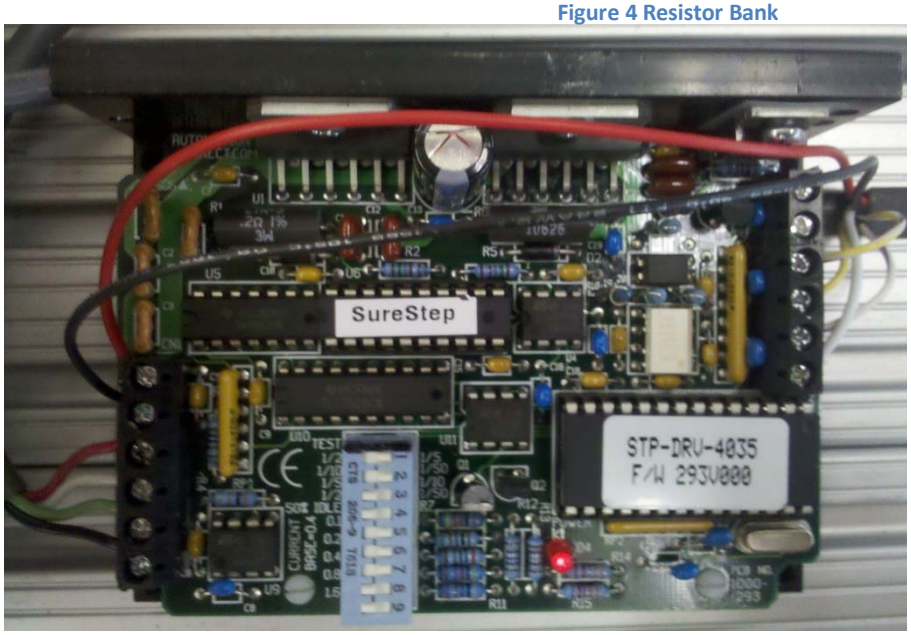


Figure 6 Stepper Driver

Wiring Diagram

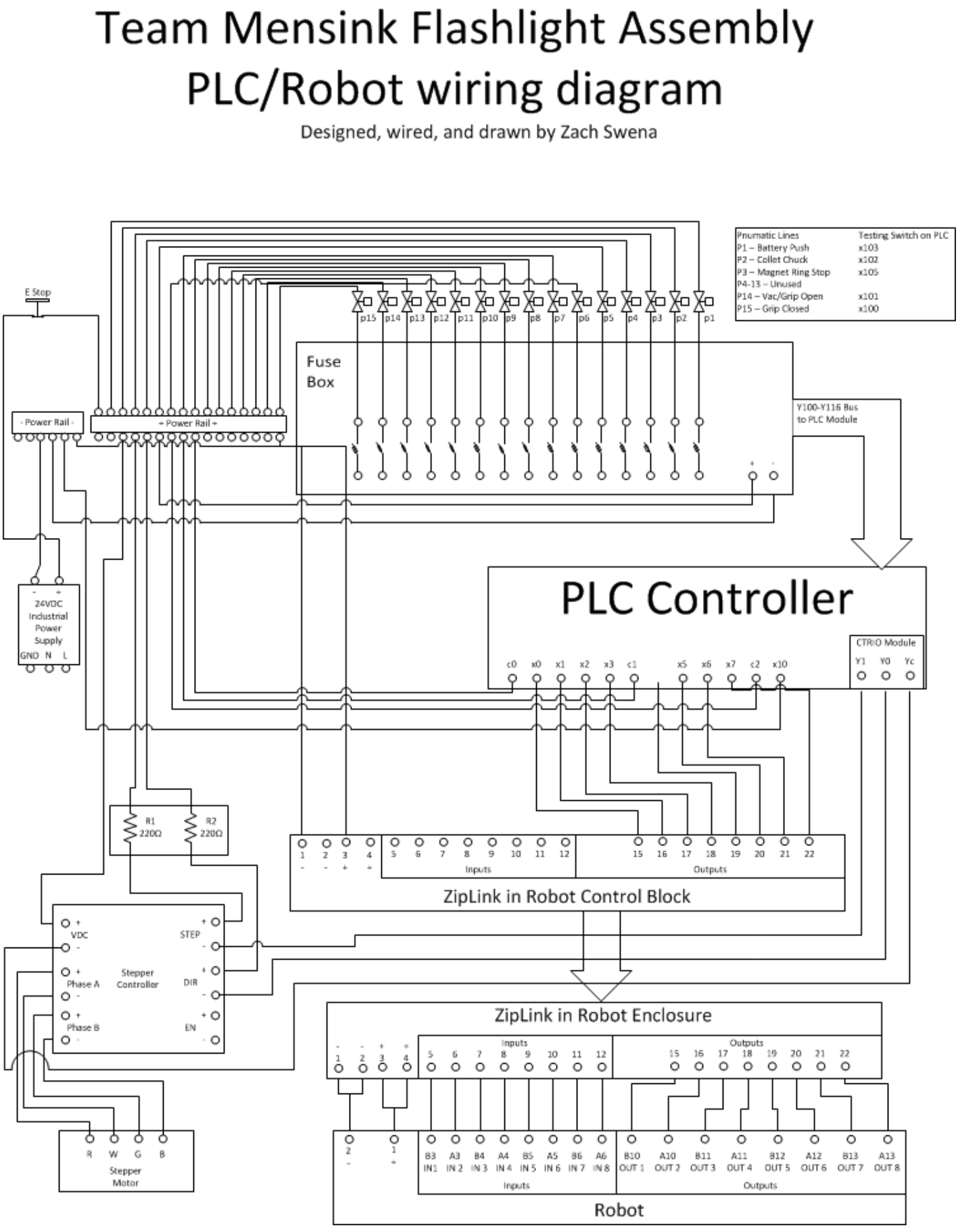


Figure 7 Wiring Diagram

System Parts & Functions

System Outline

We are assembling flashlights with the Motoman MH5L robot. The benefits of this method are flexibility and repeatability. This method is sequential, meaning that the robot can perform one task at a time where as the turret station method allows many things to happen at one time to maximize efficiency. The positions for each part supply station were carefully spaced so at to be accessible to the robot tools and at a relatively uniform distance from the center collet assembly station. One tower station is comprised of the body station, battery station and heat sink station. Another tower is comprised of the groove ring station, nose ring station, magnet ring station, and nose station as seen below. The fiberglass washer station and magnet ring station are on their own smaller towers. The stations are all along the edge of the table across from the robot with the assembly station closest to the robot to minimize pathway interference. Please see Appendix D and E for Motoman points and job program.

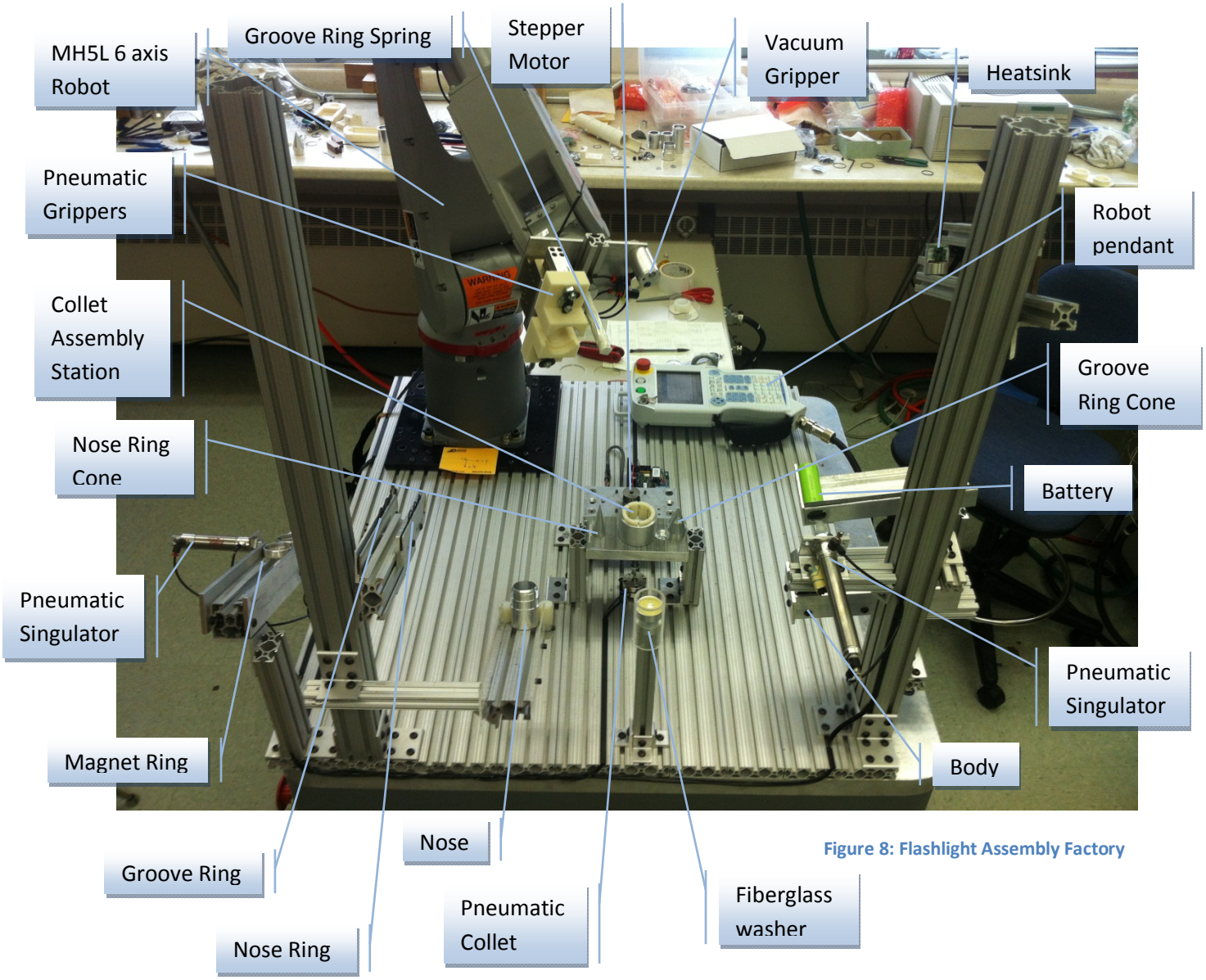


Figure 8: Flashlight Assembly Factory

1. The nose is brought over and set down on the nose ring cone.
2. The nose ring is picked up and set into the nose, guided by the nose ring cone.
3. The nose is picked up and set into the collet with the nose ring in place.
4. The groove ring cone is picked up and set on top of the nose in the collet.
5. The groove ring is brought over and set on the groove ring cone.
6. The groove ring spring comes down and pushes the groove ring into the groove on the nose by rotating around the groove ring nose while pushing the groove ring down.
7. The groove ring cone is taken off the nose and put back in its spot.
8. The magnet ring is picked up and placed over the nose.
9. The heatsink is picked up and placed in the nose.
10. The fiberglass washer is picked up and placed in the nose.
11. The body is picked up and re-clamped against the table to be flush with the magnet on the gripping tool.
12. The battery is inserted into the re-clamped body and together they are brought over the nose in the collet.
13. The stepper motor turns the collet and threads the nose and body together.
14. The completed flashlight is released from the collet and set on the table.

Collet Assembly Station

This station is where parts for the nose cone assembly are brought and assembled. The centralized location of this station makes it an ideal spot for bringing parts that are relatively equidistant from it while still allowing the robot arm to move between points without running into anything. This station consists of three major areas. The first is the area where the nose ring cone has the nose lowered down over it and then the nose ring dropped over the tip of the cone to fall into place in the nose. The second is the collet itself, which holds the nose securely. The third area holds the groove ring cone, which is placed on top of the nose once the nose is in the collet. This platform has a milled spot for the nose ring cone as well as a milled spot for the groove ring cone. The collet housing was made with both the CNC lathe and the manual lathe and is press fit into a bearing which is set into the horizontal plate.

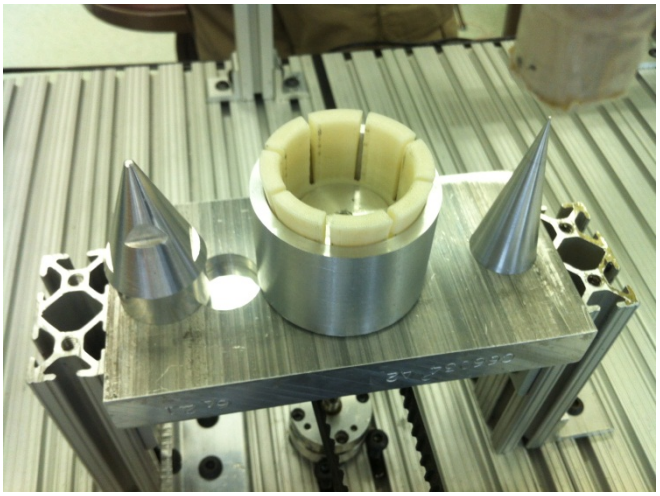


Figure 9: Collet Assembly Station (L to R: groove ring cone, pneumatic rotating collet, nose ring cone)

Nose Station

The parts are gravity fed into position at this station. This is the first part to be placed in the assembly order. It is constructed from cut plastic rods, plastic wall guides and 80/20 structures.

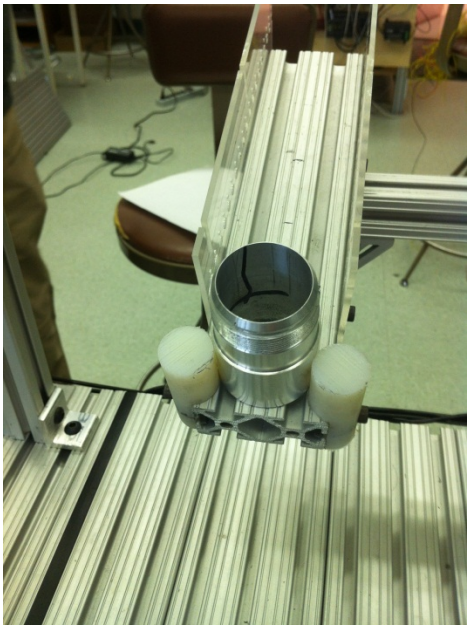


Figure 10: Nose Station

O-ring Stations

This station is gravity fed and allows the o-rings to gently roll down a slot and stop at the end where it waits to be picked up by the Motoman robot. It is made of milled aluminum plates and mounted to the 80/20. This station would be easily supplied with a vibrating singulator bowl.

Figure 11: Large O-ring Station

Magnet Ring Station

This is gravity fed and allows the singulated on-off rings to slide down a tray until they are held in the proper position by two a stopper with the same radius. The pneumatic singulator moves the magnet ring not being gripped out of the way of the gripper. It is made of a double 80/20 beam and 2 aluminum plates that guide the magnet rings down.

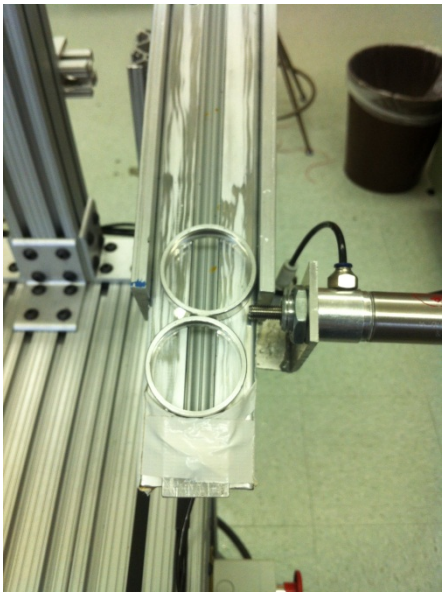


Figure 12: On/Off Ring Station

Heat Sink Station

The heat sink station is gravity fed and uses the top 80/20 piece's groove to guide the spring of the heatsink down to a stop with the same radius.

Figure 13: Heat Sink Station

Fiberglass Washer Station

This is the station where the fiberglass washers are singulated and brought into the assembly. The snap rings are stacked and placed into a vertical hopper that is spring loaded. The fiberglass washer vacuum gripper lowers into the hopper and the vacuum is turned on. This operation picks one fiberglass washer up and then drops it into the nose. This station is built with 1 ½ inch acrylic tubing with 2 aluminum caps with a spring between them. The spring lowers to give snap ring end effecter room to make the proper suction to pick up a snap ring. This way the same suction can be implemented no matter how many fiberglass washers are loaded.

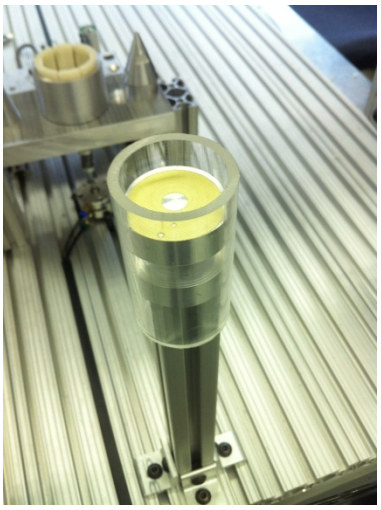


Figure 14: Snap Ring Station

Body Station

The body station is gravity fed and allows the parts to roll into their grabbing position. The body is grabbed with the smaller radius grippers. This station is built with an 80/20 base with aluminum plates to stop bodies from rolling out and has plastic and 80/20 lengths to guide the smaller outer diameter down.

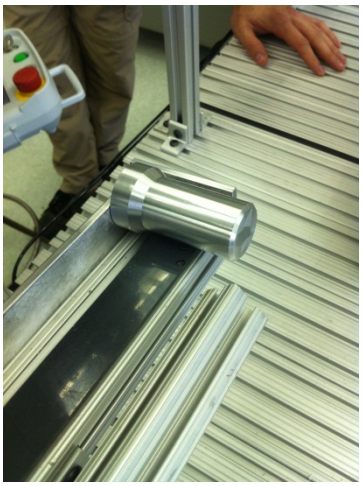


Figure 15: Body Station

Battery Station

This gravity fed station allows for the batteries to roll down to the ready position. They only need to be loaded in the correct orientation, negative out away from the pneumatic pushrod. This would ensure that the magnet in the gripper tool can properly hold both the body and battery for final threading where the body is held with its opening down. This station is built with an aluminum base and a plastic backing plate that keeps them in alignment. A hole is milled out of the side to allow an air cylinder to eject the battery into the body when a body is present.

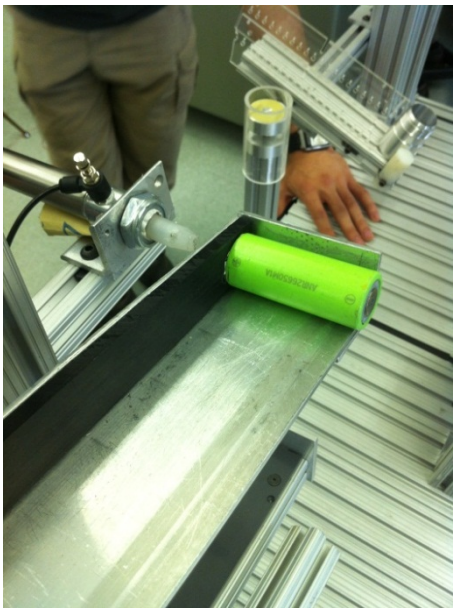


Figure 16: Battery Station

Stepper Motor

This station was built with 80/20 stands and L brackets and t-slot washers. A NEMA 23 stepper motor, which has standardized size and mounting dimensions, was mounted to a CNC milled plate. The motor shaft had a belt drive connected via set screw to turn the collet. The stepper motor driver just sits loose nearby to connect to the motor wires close by and is safe since the robot arm never needed to move to this area for assembly.

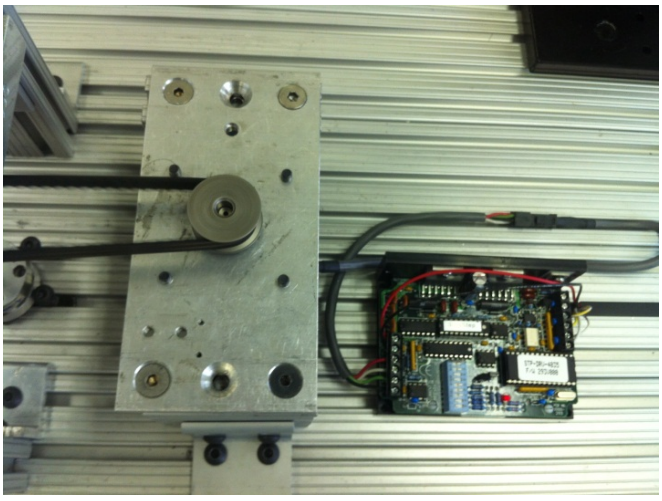


Figure 17 - Stepper Motor and Controller

Robot Arm Tooling

One of the challenging things about using a robotic arm to do the part manipulation is that you need to have all your tooling attached and have enough room around them so that they operate properly. Our tools are strategically placed on the tooling plate. The most used are the grippers. This tool picks and places most of the parts. It has two different radiuses allowing it to grab different size parts as well faces that meet to grab O-rings. It also has a magnet at the base of the grippers to hold the battery in. The groove ring spring is specifically to push the groove ring down the groove ring cone and into the groove, rotating to make sure the groove ring is in place all the way around. It is just a spring covered with frictional tape, allowing it to bend against the shape of the groove ring cone. It was mounted a little offset from the "T" axis of the robot arm so we could just rotate that axis and have the spring move around the groove ring cone as needed. The fiberglass washer tool is a cylindrical suction device that grabs each snap ring via vacuum lines going through the robot arm to the PLC.

Figure 18: End Effecters

Suggestions for future improvements

- Ensure the fiberglass washer OD matches the nose ID
- Machine a new fiberglass washer station with tighter tolerances such that the ID of the station matches the OD of the snap rings
- Make sure the O-rings are flat and able to roll down in their stations.
- Optimize robotic arm paths during assembly with fewer points and appropriate speeds.
- Install sensors at each part station to check if a part is available and update PLC logic
- Improve the rigidity of part stations and add feeders to them

Appendices

Appendix A – Ladder Diagram

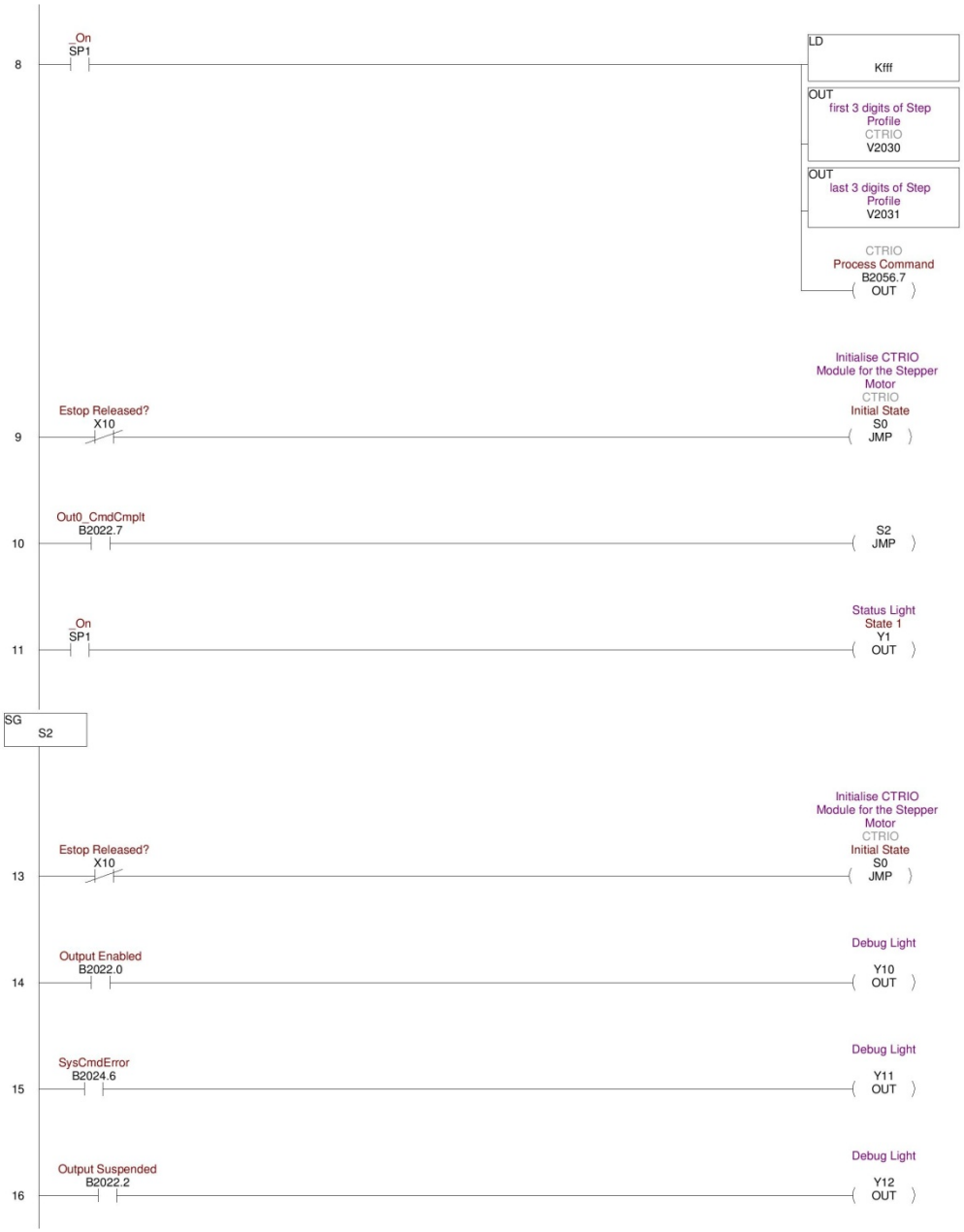


Figure 19 Ladder 1

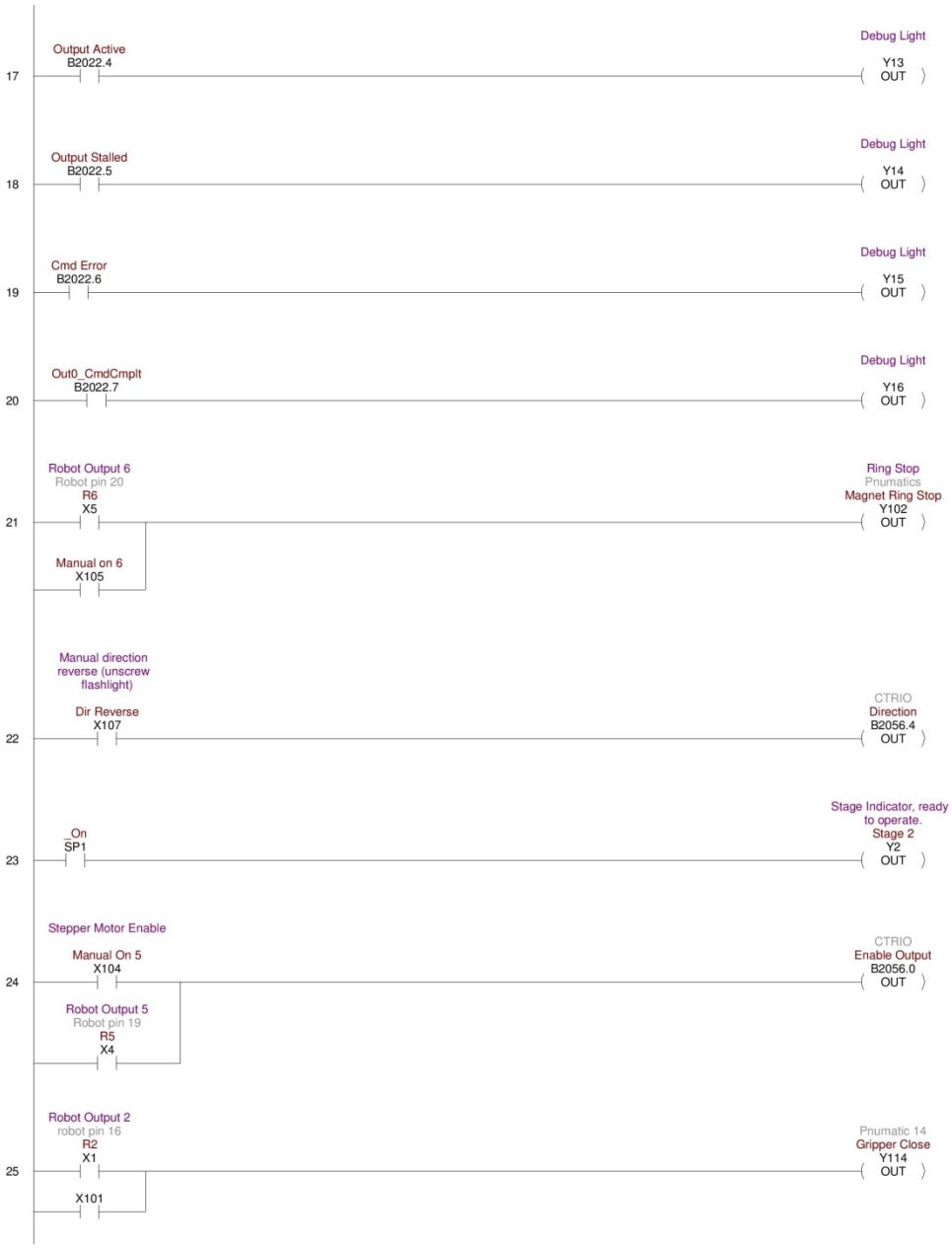


Figure 20 Ladder 2

Appendix B – PLC Variable Assignments

Unassigned
end

Unassigned
y109

X0
R1
Robot pin 15
Robot Output 1

X1
R2
robot pin 16
Robot Output 2

X2
R3
Robot pin 17
Robot Output 3

X3
R4
Robot pin 17
Robot output 4

X4
R5
Robot pin 19
Robot Output 5

X5
R6
Robot pin 20
Robot Output 6

X10
Estop Released?

X104
Manual On 5
Stepper Motor Enable

X105
Manual on 6

X107
Dir Reverse
Manual direction reverse (unscrew flashlight)

Y0
State 0
Status Light

Y1
State 1
Status Light

Y2
Stage 2
Stage Indicator, ready to operate.

Y10
Debug Light

Y11
Debug Light

Y12
Debug Light

Y13
Debug Light

Y14
Debug Light

Y15
Debug Light

Y16
Debug Light

Y100
Battery Push
Pnumatic
1 extend /0 retract

Y101
Collet Release
Pnumatic 2
Normally Closed Toggle. Enable to open collet.

Y102
Magnet Ring Stop
Pnumatics
Ring Stop

Y107
Unused4
Pnumatic

Y110
Unused3
Pnumatic

Y111
Unused2
Pnumatic

Y112
Unused

Y114
Gripper Close
Pnumatic 14

Y115
Gripper Open/Vac
Pnumatics 15

S0
Initial State
CTRIO
Initialise CTRIO Module for the Stepper Motor

S1
Jump to State 1
CTRIO
Configure CTRIO speed,

V2030
CTRIO
first 3 digits of Step Profile

V2031
last 3 digits of Step Profile

V2040
Out0_CmdCode
K20 - Velocity Profile

V2041
Command Code
CTRIO
k1000 - Frequency (Hz)

V2042
CTRIO
K0 - Duty Cycle 0

B2022.0
Output Enabled

Figure 21 Variable Asgn 1

B2022.1
Position Loaded

B2056.7
Process Command
CTRIO

B2022.2
Output Suspended

B2022.4
Output Active

B2022.5
Output Stalled

B2022.6
Cmd Error

B2022.7
Out0_CmdCmplt

B2024.6
SysCmdError

B2056.0
Enable Output
CTRIO

B2056.2
Suspend Output

B2056.4
Direction
CTRIO

Figure 22 Variable Asgn 2

Element	Rung	Addr.	Instr.
X0 R1 Robot pin 15 Robot Output 1	26	74	STR
X1 R2 robot pin 16 Robot Output 2	25	71	STR
X2 R3 Robot pin 17 Robot Output 3	27	77	STR
X3 R4 Robot pin 17 Robot output 4	28	80	STR
	29	88	STR
X4 R5 Robot pin 19 Robot Output 5	24	68	OR
X5 R6 Robot pin 20 Robot Output 6	21	59	STR
X10 Estop Released?	4	7	STR
	9	27	STRN
	13	36	STRN
X100	26	75	OR
X101	25	72	OR
X102	27	78	OR
X103	28	84	OR
	29	92	OR
X104 Manual On 5 Stepper Motor Enable	24	67	STR
X105 Manual on 6	21	60	OR
X107 Dir Reverse Manual direction reverse (unscrew flashlight)	22	62	STR
Y0 State 0 Status Light	3	6	OUT
Y1 State 1 Status Light	11	33	OUT
Y2 Stage 2 Stage Indicator, ready to operate.	23	66	OUT
Y10 Debug Light	14	40	OUT
Y11 Debug Light	15	43	OUT
Y12 Debug Light	16	46	OUT

Element	Rung	Addr.	Instr.
Y13 Debug Light	17	49	OUT
Y14 Debug Light	18	52	OUT
Y15 Debug Light	19	55	OUT
Y16 Debug Light	20	58	OUT
Y100 Battery Push Pnumatic 1 extend /0 retract	28	82	AND
	29	89	STR
	29	93	OUT
Y101 Collet Release Pnumatic 2 Normally Closed Toggle. Enable to open collet.	27	79	OUT
Y102 Magnet Ring Stop Pnumatics Ring Stop	21	61	OUT
Y114 Gripper Close Pnumatic 14	25	73	OUT
Y115 Gripper Open/Vac Pnumatics 15	26	76	OUT

Figure 23 Variable Asgn 3

Appendix C – CNC Code

Flashlight Body

```
%
O0417; (FLASHLIGHT BARREL 4/17/12 BY ANDREW ROTH)
(MOD. 2012-05-31 BY RLS)
; (VARIABLES)
#500=38.1    (STOCK DIAM)
#501=70.5    (STOCK LEN)
#502=150.0   (SURFACE M/MIN)
#503=0.2     (ROUGH FEED M/REV)
#504=0.01    (FINISH FEED M/REV)
#505=34.5                    (MAJOR DIAMETER)
#506=11.65       (LENGTH OF THREAD)
#507=1.0                              (PITCH - MM)
#508=#507 * 0.5/TAN[30.0]   (H)
#509=#508 * 5.0 / 8.0     (THREAD DEPTH - INT)
#511=3.0      (NUMBER OF STARTS)
#512=0        (START NUMBER)
#510=37.5    (FINISH OD)
;
; (STOCK- ALUM 1.5IN X 19MM + 10MM)
; (TOOLS USED)
; (T0101 - 80DEG DIAMOND CNMG)
; (T0202)
; (T0303)
; (T0404)
; (T0505 - CENTER DRILL)
; (T0606)
; (T0707 - 19MM END MILL)
; (T0808 - INT THREADING TOOL)
; (T0909 - 14.4MM MIN DIAM BORING BAR)
; (T1010 - CUTOFF)
; (T1111)
; (T1212 - 0.5IN DRILL)
;
G54
G21
;
; (FACE WITH CNMG)
;
G00 T0101            (SELECT TOOL 1)
G50 S1000            (MAX SPEED 1000RPM)
```

```
G96 S#502            (SET CONST SURFACE SPEED)
G99                 (FEED PER REV)
M03                 (TURN ON SPINDLE)
G00 Z#501           (MOVE TO PLANE OF FACE)
G00 X[#500+1.0]      (MOVE CLOSE TO STOCK OD)
M08                 (TURN ON COOLANT)
G01 X-0.1 F#503      (FACE DOWN TO CENTER)
G01 Z[#501+1.0] F1.0   (BACK OFF)
M09                 (TURN OFF COOLANT)
M05                 (TURN OFF SPINDLE)
G28 U0 W0           (GO HOME)
M01                 (WAIT FOR START BUTTON)
;
; (ID BORE)
G00 T0505        (CENTER DRILL, TOOL 5)
G97 S1000        (1000RPM)
G99
G00 X0 Z[#501 + 2.0]
M03
M08
G01 X0 Z[#501 - 2.0] F0.5
G01 X0 Z[#501 + 2.0] F2.0
M09
M05
G28 U0 W0
M01
;
G00 T1212                (0.5IN DRILL, TOOL 12)
G97 S1000
G99
G00 X0 Z[#501 + 2.0]
M03
M08
G83 Z[#501 - 67.0] F0.1 Q5000 R5.0                    (Peck drill cycle which goes to the depth Z at the feed rate F and retracts to the position R every time it has drilled the distance Q)
G01 X0 Z[#501 + 2.0] F2.0
M09
M05
G28 U0 W0
M01
;

(ROUGH BORE)

G00 T0707 (END MILL)
```

```
G97 S1000
G96 S#502
G99

G00 X18.0 Z[#501 + 2.0]
M03
M08
G71 U2.0 R0.5
G71 P20 Q25 U-0.7 W0.1 F#503
;
N20 G00 X39.0 Z[#501 + 2.0]
   G01 X[#505 - 2*#509 + 0.35] Z[#501 - 2.0] F#504
   G01 Z[#501 - 13.0] F#504
   G01 X27.0 Z[#501 - 16.0] F#504
   G01 Z[#501 - 68.0] F#504
N25 G00 U-0.4
;
M09
M05
G28 U0 W0
M01
;
; (FINISH BORE)
;
G00 T0707
G50 S1200
G96 S#502
G99
G00 X18.0 Z[#501 + 2.0]
M03
M08
G70 P20 Q25
G00 Z[#501 + 2.0]
M09
M05
G28 U0 W0
M01
;
; (ID THREAD)
;
G00 T0808        (INT THREADING TOOL)
G00 X18.6 Z[#501 + 3 * #507 * #511]  (START 3x LEAD AWAY)
G97 S700         (FIXED 800RPM SPEED)
G99              (FEED PER REV)
M03
```

```
M08
WHILE [#512 LT #511] DO 1
  G00 X[#505 - #508 * 2] Z[#501 + #507 * #512 + 3 * #507 * #511]
  G76 P040060 Q005 R0.1
  G76 X[#505 + #509] Z[#501-#506] P[FIX[#509*1000]] Q0200 F[#507 * #511]
  #512 = #512 + 1
END 1
G00 Z[#501+2.0]
M09
M05
G28 U0 W0
M01
;
; (OD WORK)
;
G00 T0202 (FINE OD TOOL)
G50 S1000
G96 S#502
G99
G00 X37.75 Z[#501 + 2.0]
M03
M08
G01 Z-3.2 F#503
G01 X40.0 Z[#501 + 2.0] F2.0
G00 X37.75
G01 Z[#501 - 12.0] F#503
G01 X35.0 Z[#501 - 12.0 - 6.5] F#503
G01 Z-3.2 F#503
G01 X37.75 Z[#501 - 12.0] F2.0
G01 X33.0 Z[#501 - 12.0 - 6.5] F#503
G01 Z-3.2 F#503
G01 X37.75 Z[#501 - 12.0] F2.0
G01 X31.0 Z[#501 - 12.0 - 6.5] F#503
G01 Z-3.2 F#503
G01 X40.0 F2.0
G00 Z[#501 +2.0]
G01 X37.5 F2.0
G01 Z[#501 - 12.0] F#504
G01 X30.7973 Z[#501 - 12.0 - 6.5] F#504
G01 Z-3.2 F#504
G01 X40.0 F2.0
G00 Z[#501 + 2.0]
M09
M05
G28 U0 W0
```

```
M00
;
; (CUTOFF)
;
G00 T1010
G50 S1000
G96 S#502
G00 Z-3.175
G00 X[#500 + 2.0]
M03
M08
G01 X25.0 F0.05
G01 X[#500+2.0] F4.0
G01 Z-1.175 F#503
G01 X30.7973 F#503
G01 X26.7973 Z-3.175 F#504
G01 X[#500+2.0] F4.0
G00 Z-3.175
G01 X-0.4 F0.05
G01 X[#500+2.0] F4.0
M09
M05
G28 U0 W0
M30
%
```

Flashlight Nose Cone

```
%
O0508;
;(TEAM MENSINK CONE PIECE)
;(KENDRICK MENSINK)
;(STOCK: ALUM 38.1MM DIAMETER X #501 + 10MM)
;(18:00 APRIL 10, 2011)
;
; (TOOLS USED)
; (T0101 - 80DEG DIAMOND CNMG)
; (T0202 - 30DEG DIAMOND)
; (T0303)
; (T0404)
; (T0505 - CENTER DRILL)
; (T0606)
; (T0707 - 19MM END MILL)
; (T0808)
; (T0909 - 14.4MM MIN DIAM BORING BAR)
```

```
; (T1010 - CUTOFF)
; (T1111)
; (T1212 - 0.5IN DRILL)
;
;(VARIABLES)
;
#500=38.1               (STOCK DIAMETER)
#501=63.5               (STOCK LENGTH)
#502=150.0              (ROUGHING SURFACE SPEED M/MIN)
#503=0.2                (ROUGHING FEED: MM/REV)
#504=0.05               (FINISHING FEED MM/REV)
#505=150.0              (FINISHING SURFACE SPEED M/MIN)
;
;(INTIAL PARAMETERS)
G54                     (WORK OFFSET)
G21                     (METRIC UNITS)
G50 S2000       (LIMIT SPEED)
G96 S#502       (CONSTANT SURFACE SPEED)
G99                     (FEED PER REVOLUTION)
;
;(FACING)
N1
G28 U0 W0
G00 T0101                               (80 DEGREE DIAMOND TOOL)
M03                                             (SPINDLE ON, NORMAL)
G00 X[#500+1.0] Z#501
M08                                             (COOLANT ON)
G01 X-0.2 Z#501 F#503  (FACE FROM OUTSIDE DOWN TO -0.5)
G01 Z[#501+1.0] F1.0    (MOVE OFF FROM FACE)
M09                                     (COOLANT OFF)
M05                                     (SPINDLE OFF)
G28 U0 W0                               (GO HOME)
M01                                     (OPTIONAL STOP)
;
;
;(ROUGH OD TO +1.0MM)
;
N2
G00 T0101 (80DEG DIAMOND TOOL, TOOL 1)
G50 S2000 (CLAMP SPEED AT 2000)
G96 S#502 (CONST SURF SPEED)
G99 (FEED PER REV) (RETURN TO R LEVEL IN A FIXED CYCLE)
M03 (SPINDLE ON)
M08 (COOLANT ON)
G00 X35.0 Z[#501+1.0] (INITIAL POINT FOR ROUGHING)
```

```
;
G01 X35.0 Z-2.0 F#503 (FIRST PASS)
G01 X[#500+0.5] F#503 (RETRACT X)
G00 Z[#501+2.0] (RETRACT Z)
;
G01 X30.0 (CLOSE IN 5 MM IN X)
G01 Z-2.0 F#503 (SECOND PASS)
G01 X[#500+0.5] F#503 (RETRACT X)
G00 Z[#501+2.0] (RETRACT Z)
;
G01 X24.0 (CLOSE IN 5 MM IN X)
G01 Z-2.0 F#503 (THIRD PASS)
G01 X[#500+0.5] F#503 (RETRACT X)
G00 Z[#501+0.5] (RETRACT Z)
;
G01 X20.0 (START FIRST ANGLED PASS)
G01 X25.0 Z[#501-57.15] (CUT CONE)
G00 Z[#501+0.5] (RETRACT Z)
G01 X10.0 (START SECOND ANGLED PASS)
G01 X25.0 Z[#501-57.15] (CUT CONE)
G00 Z[#501+0.5] (RETRACT Z)
G01 X0.5 (START THIRD ANGLED PASS)
G01 X25.0 Z[#501-57.15] (CUT CONE)
;
M09 (COOLANT OFF)
M05 (SPINDLE OFF)
G28 U0 W0 (GO HOME)
M01 (OPTIONAL STOP)
;
;
;(FINISH OD TO +0.0MM)
N3
;
G00 T0202 (30DEG DIAMOND TOOL, TOOL 2)
G50 S2000 (CLAMP SPEED AT 2000)
G96 S#505 (CONST SURF SPEED)
G99 (FEED PER REV)
M03 (SPINDLE ON)
M08 (COOLANT ON)
;
G00 X0.0 Z[#501+0.5] (CUT FINISH PASS)
G01 X23.0 Z[#501-57.15] F#504
G01 X23.0 Z-2.0 F#504
G01 X39.0 Z[#501+0.5] F#503 (RETRACT X AND Z)
;
```

```
M09
M05
G28 U0 W0
M01  (OPTIONAL STOP)
;
;(CUTOFF)
N4
G00 T1010
M03
M08
G50 S1000
G96 S#502
G00 X[#500+2.0]
G00 Z-2.5
G01 X-0.5 F#504
M09
M05
G28 U0 W0
M30
%
```

Flashlight Magnet Ring

CNC Code not available. I think Brandon Vazquez still has it on his usb stick. We shared our flashlight design with his team: Team Stirn.

Central Assembly Platform

```
%
O19001; (BORING CYCLE MACRO DEFINITION)

(#24=1.500        CENTER X - ARG X)
(#25=1.500        CENTER Y - ARG Y)
(#7=0.906         FINAL DIAM - ARG D)
(#26=0.250        DEPTH - ARG Z)
(#20=0.250        EM DIAM - ARG T)
(#6=0.100         DELTA Z - ARG K)

#510=0.0;         (CIRCLE START POS VARIABLE)
#511=#20/2.0;     (EM RADIUS)
#512=0;           (INNER BREAK FLAG)
#513=0;           (OUTER BREAK FLAG)
#514=0;           (Z VARIABLE)
#515=#511;        (DELTA X)

G0 X#24 Y#25 Z0.2;
```

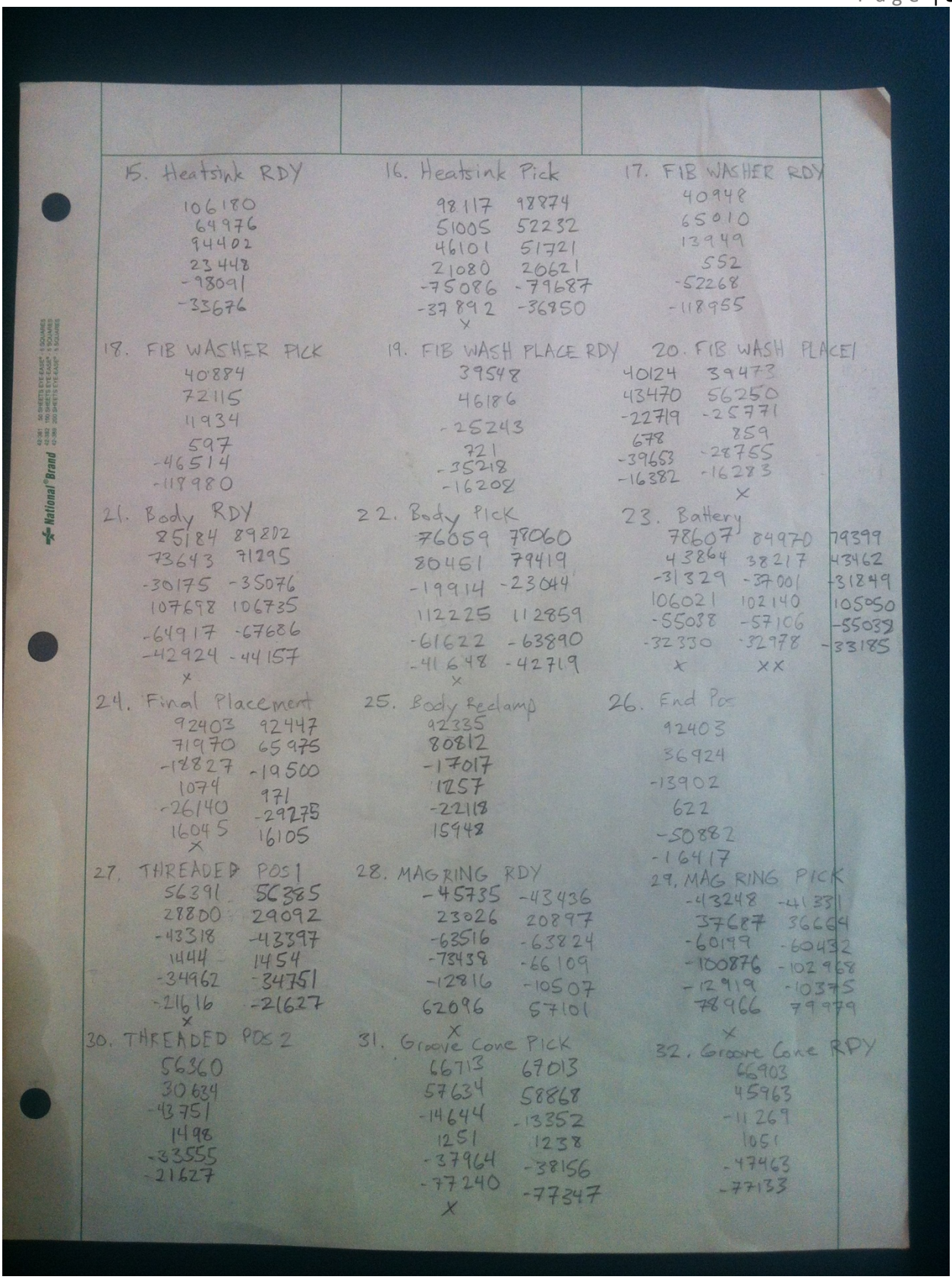
```
G1 Z0.2 F20.0;    (RETRACT)

(OUTER LOOP)
N10
    #514 = #514 - #6;          (DROP Z)
    IF [#514 LT #26] GOTO11;
      #514 = #26;            (ELSE DO LAST PASS)
      #513 = 1;
    G1 Z#514 F4.0;  (PLUNGE AT CENTER)
N11
    #512=0;     (CLEAR INNER BREAK FLAG)
    G01 X#24 F8.0;
    G01 Z#514 F4.0;
N12
    (INNER LOOP)
        #515 = #515 + #511;          (STEPOVER BY EM RAD)
        IF [#515 LT #7 - #511] GOTO13; (CHECK FOR LAST PASS)
            #515 = #7 - #511;      (ELSE DO LAST INNER PASS)
            #512 = 1;           (SET INNER BREAK FLAG)
N13
        G01 X[#24 + #515] F8.0;
        G02 X[#24 + #515] Y#25 I-#515 J0 F8.0;
        IF [#513 NE 0] GOTO14;      (DONE)
        IF [#512 NE 0] GOTO10;      (NEXT Z LEVEL)
        GOTO12;                 (NEXT X DIAM)
N14
G1 Z0.2 F20.0;    (RETRACT)
M99

M30
%
```

Appendix D – Motoman Tool Paths/Points

These are taken by hand and saved as position variables in the robot pendant. A file with a dat extension from the robot pendant was saved to external USB memory. The actual joint coordinate points are in Appendix E and on the attached paper.



15. Heatsink RDY
106180
64976
94402
23448
-78091
-33676

16. Heatsink Pick
98117 98874
51005 52232
46101 51721
21080 20621
-75086 -79687
-37892 -36850
X

17. FIB WASHER RDY
40948
65010
13949
552
-52268
-118955

18. FIB WASHER PICK
40884
72115
11934
597
-46514
-118980

19. FIB WASH PLACE RDY
39548
46186
-25243
721
-35218
-16208

20. FIB WASH PLACE!
40124 39473
43470 56250
-22719 -25771
678 859
-39653 -28755
-16382 -16283
X

21. Body RDY
85184 89202
73643 71295
-30175 -35076
107698 106735
-64917 -67686
-42924 -44157
X

22. Body Pick
76059 78060
80451 79419
-19914 -23044
112225 112859
-61622 -63890
-41648 -42719
X

23. Battery
78607 84970 79399
43864 38217 43462
-31329 -37001 -31849
106021 102140 105050
-55088 -57106 -55039
-32330 -32978 -33185
X XX

24. Final Placement
92403 92447
71970 65975
-18827 -19500
1074 971
-26140 -29275
16045 16105
X

25. Body Reclamp
92335
80812
-17017
1257
-22118
15948

26. End Pos
92403
36924
-13902
622
-50882
-16417

27. THREADED POS1
56391 56385
28800 29092
-43318 -43397
1444 1454
-34962 -34751
-21616 -21627
X

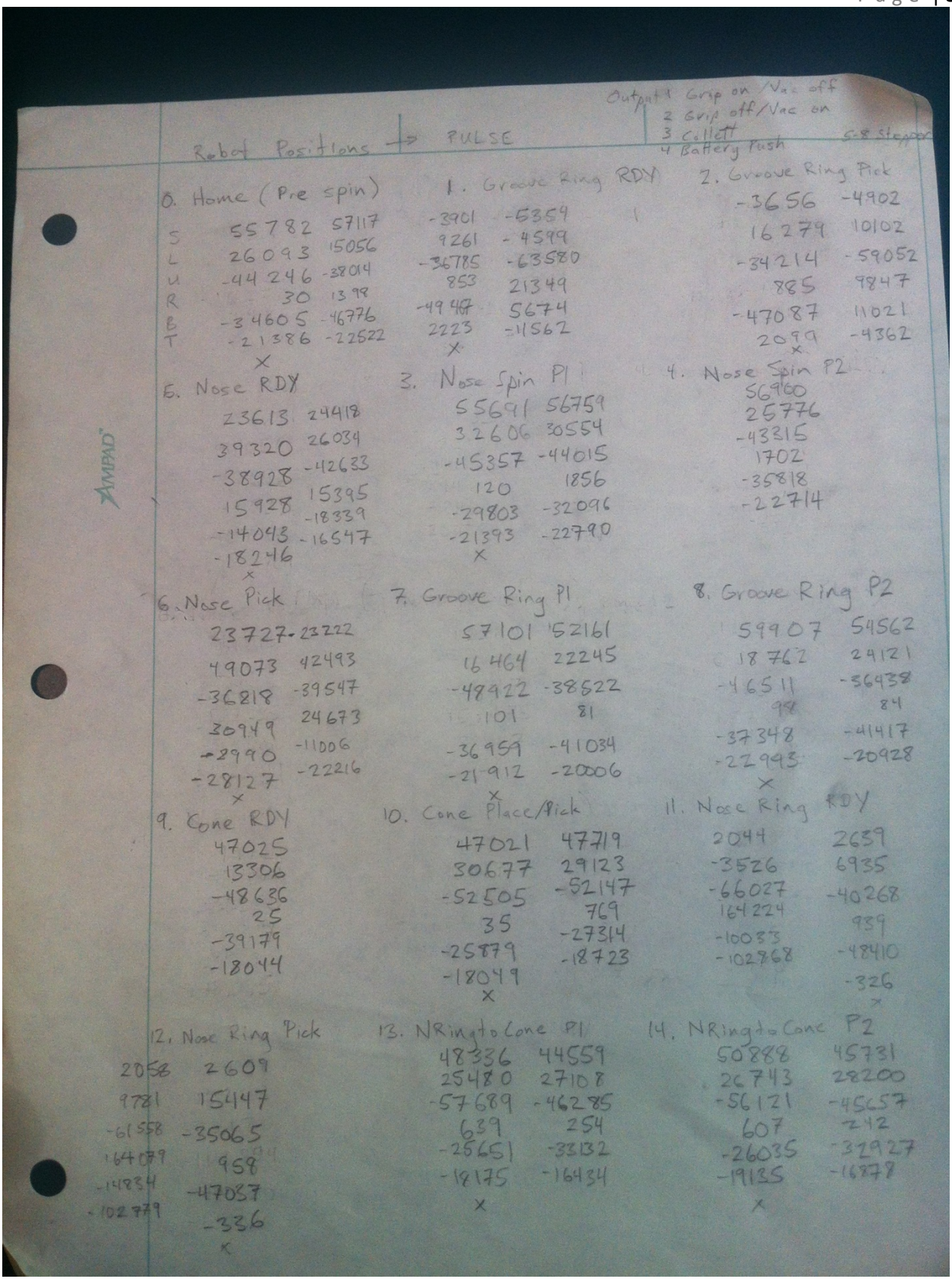
28. MAG RING RDY
-45735 -43436
23026 20897
-63516 -63824
-78438 -66109
-12816 -10507
62096 57101
X

29. MAG RING PICK
-43248 -41331
37687 36669
-60199 -60432
-100876 -102968
-12919 -10375
78966 79979
X

30. THREADED POS 2
56360
30634
-43751
1498
-33555
-21627

31. Groove Cone PICK
66713 67013
57634 58868
-14644 -13352
1251 1238
-37964 -38156
-77240 -77347
X

32. Groove Cone RDY
66903
45963
-11269
1051
-47463
-77133



Appendix E – Motoman Robot Job

The jbi suffix is associated with JobEditor32 by Motoman Inc. These files are used in the MOTOMAN XRC robot controller. The XRC robot controller uses ASCII coded jobs (*.JBI) as opposed to (*.JBB) binary files.

TEAM_MENSINK.JBI

```
/JOB
//NAME TEAM_MENSINK
//POS
///NPOS 0,0,0,41,0,0
///TOOL 0
///POSTYPE PULSE
///PULSE
P00000=57117,15056,-38014,1398,-46776,-22522
P00001=-5354,-4599,-63580,21349,5674,-11562
P00002=-4902,10102,-59052,9847,11021,-4362
P00003=56759,30554,-44105,1856,-32096,-22790
P00004=56900,25776,-43315,1702,-35818,-22714
P00005=24418,26034,-42633,15395,-18339,-16547
P00006=23222,42493,-39547,24673,-11006,-22216
P00007=52161,22245,-38522,81,-41034,-20006
P00008=54562,24121,-36438,84,-41417,-20927
P00009=47025,13306,-48636,25,-39179,-18044
P00010=47719,29123,-52147,769,-27314,-18723
P00011=2044,-3526,-66027,164224,-10033,-102868
P00012=2058,9781,-61558,164079,-14834,-102779
P00013=44559,27108,-46285,254,-33132,-16434
P00014=45731,28200,-45657,242,-32927,-16878
P00015=106180,64976,94402,23448,-98091,-33676
P00016=98874,52232,51721,20621,-79687,-36850
P00017=40948,65010,13949,552,-52268,-118955
P00018=40884,72115,11934,597,-46514,-118980
P00019=39548,46186,-25243,721,-35218,-16208
P00020=40124,43470,-22719,678,-39653,-16382
P00021=89802,71295,-35076,106735,-67686,-44157
P00022=78060,79419,-23044,112859,-63890,-42719
P00023=79399,43462,-31849,105050,-55038,-33185
P00024=92447,65975,-19500,971,-29275,16105
P00025=92335,80812,-17017,1257,-22118,15948
P00026=92403,36924,-13902,622,-50882,-16417
P00027=56385,29092,-43397,1454,-34751,-21627
P00028=-43436,20897,-63824,-66109,-10507,57101
P00029=-41331,36664,-60432,-102968,-10375,79979
P00031=67013,58868,-13352,1238,-38156,-77347
P00032=66903,45963,-11269,1051,-47463,-77133
P00033=59289,17262,-46722,1693,-37238,-23568
P00034=51515,20183,-23211,1496,-54034,-20754
P00035=50986,37944,-32592,2008,-36478,-21035
P00036=59204,21211,-47843,1824,-34032,-23643
P00037=56597,25569,-43651,1702,-35735,-22600
P00038=56715,20056,-41805,1540,-40403,-22510
P00039=40010,57465,-24316,858,-30030,-16481
P00040=50986,37945,-32593,2007,-36479,75000
P00041=50987,37945,-32596,2008,-36481,-150000
//INST
///DATE 2012/06/05 13:46
///COMM 2012FLASHLIGHT_ASSEMBLY
///ATTR SC,RW
///GROUP1 RB1
NOP
```

```
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P000 V=50.0 PL=0
TIMER T=1.00
MOVL P005 V=50.0 PL=0
MOVL P006 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P005 V=50.0 PL=0
MOVL P009 V=50.0 PL=0
MOVL P010 V=50.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P009 V=50.0 PL=0
MOVL P011 V=50.0 PL=0
MOVL P012 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P011 V=50.0 PL=0
MOVL P013 V=50.0 PL=0
MOVL P014 V=50.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P009 V=50.0 PL=0
MOVL P010 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P009 V=50.0 PL=0
MOVL P000 V=50.0 PL=0
DOUT OT#(3) ON
MOVL P004 V=20.0 PL=0
MOVL P003 V=20.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
DOUT OT#(3) OFF
MOVL P000 V=50.0 PL=0
MOVL P032 V=50.0 PL=0
MOVL P031 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P032 V=50.0 PL=0
MOVL P000 V=50.0 PL=0
TIMER T=0.50
MOVL P033 V=20.0 PL=0
MOVL P036 V=20.0 PL=0
TIMER T=0.50
DOUT OT#(1) OFF
```

```
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P000 V=50.0 PL=0
TIMER T=0.50
MOVL P001 V=50.0 PL=0
MOVL P002 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P001 V=50.0 PL=0
MOVL P007 V=50.0 PL=0
MOVL P008 V=50.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P000 V=50.0 PL=0
MOVL P034 V=50.0 PL=0
TIMER T=0.50
MOVL P035 V=20.0 PL=0
TIMER T=0.50
MOVJ P041 VJ=2.00 PL=0
MOVJ P040 VJ=2.00 PL=0
MOVJ P035 VJ=2.00 PL=0
MOVL P034 V=20.0 PL=0
MOVL P000 V=50.0 PL=0
TIMER T=0.50
MOVL P034 V=50.0 PL=0
MOVL P033 V=50.0 PL=0
TIMER T=0.50
MOVL P036 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P000 V=50.0 PL=0
MOVL P032 V=50.0 PL=0
MOVL P031 V=50.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P032 V=50.0 PL=0
MOVL P000 V=50.0 PL=0
MOVL P015 V=50.0 PL=0
MOVL P016 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P015 V=50.0 PL=0
MOVL P000 V=50.0 PL=0
MOVL P038 V=50.0 PL=0
TIMER T=0.50
MOVL P037 V=20.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
```

```
MOVL P038 V=50.0 PL=0
MOVL P017 V=50.0 PL=0
MOVL P018 V=50.0 PL=0
DOUT OT#(2) ON
MOVL P017 V=50.0 PL=0
MOVL P000 V=50.0 PL=0
MOVL P019 V=50.0 PL=0
MOVL P020 V=50.0 PL=0
MOVL P039 V=50.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P020 V=50.0 PL=0
MOVL P000 V=50.0 PL=0
DOUT OT#(6) ON
TIMER T=0.50
MOVL P028 V=50.0 PL=0
MOVL P029 V=20.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P028 V=20.0 PL=0
DOUT OT#(6) OFF
MOVL P000 V=50.0 PL=0
MOVL P038 V=20.0 PL=0
MOVL P037 V=20.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P038 V=20.0 PL=0
MOVL P000 V=50.0 PL=0
MOVL P032 V=50.0 PL=0
MOVL P021 V=50.0 PL=0
TIMER T=0.50
MOVL P022 V=50.0 PL=0
DOUT OT#(1) ON
TIMER T=0.50
MOVL P021 V=50.0 PL=0
TIMER T=0.50
MOVL P024 V=50.0 PL=0
TIMER T=0.50
DOUT OT#(1) OFF
MOVL P025 V=50.0 PL=0
DOUT OT#(1) ON
MOVL P024 V=50.0 PL=0
MOVL P023 V=50.0 PL=0
DOUT OT#(4) ON
TIMER T=0.50
DOUT OT#(4) OFF
TIMER T=2.00
MOVL P000 V=50.0 PL=0
MOVL P027 V=20.0 PL=0
DOUT OT#(5) ON
TIMER T=2.00
```

```
DOUT OT#(5) OFF
TIMER T=1.00
DOUT OT#(3) ON
MOVL P000 V=50.0 PL=0
DOUT OT#(3) OFF
MOVL P032 V=50.0 PL=0
MOVL P024 V=50.0 PL=0
DOUT OT#(1) OFF
DOUT OT#(2) ON
TIMER T=0.50
DOUT OT#(2) OFF
MOVL P026 V=23.0 PL=0
END
```