Automated Filling and Capping Glass Vials Manual

ENGR 480: Manufacturing

12-14-21

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Introduction

For Fall 2021, ENGR480 students were assigned the automated glass vial project, whose goal was to create a mini-factory plant that uncaps, fills, and recaps a series of glass vials.

To meet these specifications, members of team Bame utilized a programmable logic controller (PLC) in conjunction with a Motoman robot to oversee the overarching logic behind the operation. As an overview, the assembly line begins with a user placing empty, capped glass vials onto the conveyer belt. Once the vials have been singulated and the PLC senses a vial has reached the desired location, the robot arm will pick up the vial and move it to the filling station where it will then uncap the vial, fill it with a desired amount of glycerin, then recap it and deliver it to a specified drop-off point.

While meeting these requirements, it must also meet some other given criteria. These conditions consist of minimizing: spillage, cycle time, variability of fill, and human labor. Some aspects of human labor that should be avoided are the need to clean and intervene in the system as much as possible. This manual provides a list of instructions, diagrams, descriptions, and other important information for the operation and maintenance of the filling and capping assembly line.

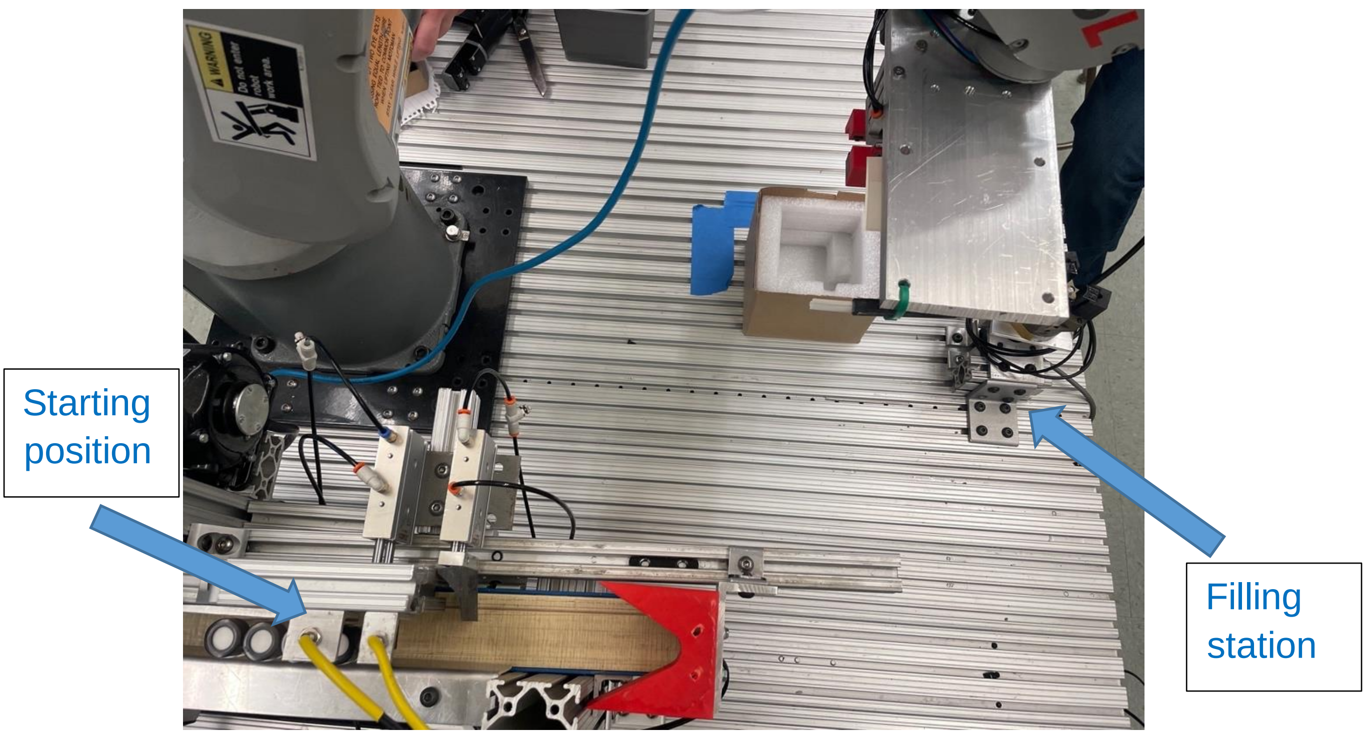


Figure 1 Complete Assembly

Loading the Machine

The assembly line begins with a user placing a glass vial on the conveyer belt. Barriers have been placed along the sides of the assembly line to direct the vials within a shorter section. Multiple vials may be placed on the conveyer belt simultaneously. Further along the belt, there are sensors beside the gates that allow only a single vial to pass.

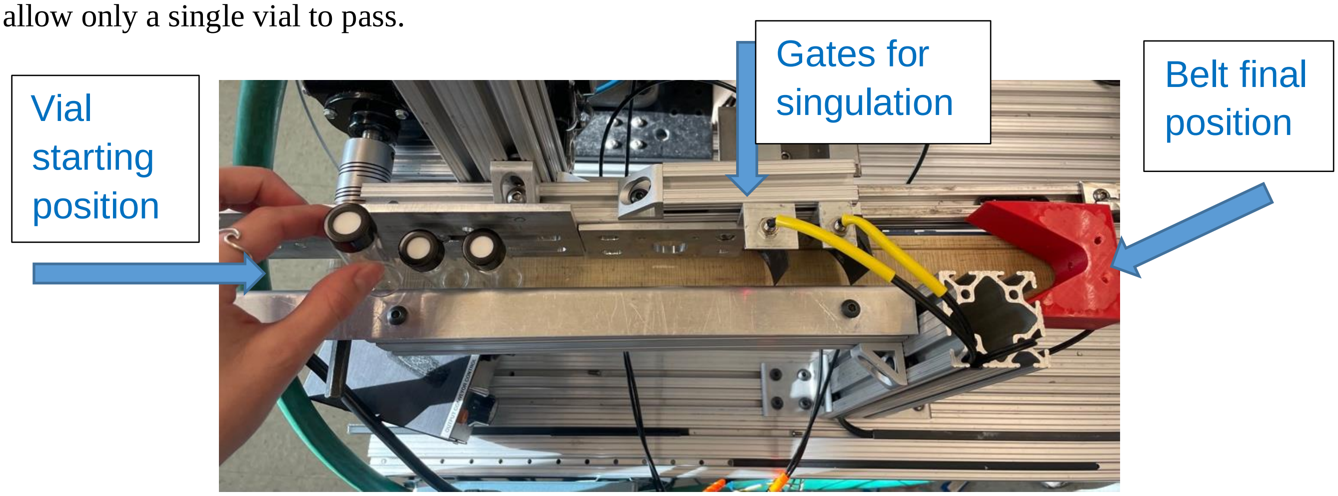


Figure 2 User Loads Vial on Conveyer Belt

Before starting, make sure the glycerin container is filled. If it is not filled before the job is activated, the robot will go through the original placements, however, when the pump starts the put fluid in the vial, only air bubbles will be added.

Starting the Machine

There are a few steps that a user will need to go through to safely start the Filling and Capping Machine. The first step is to ensure that the power strip along the side of the machine is turned to the "on" position. The second step is to turn the 'E-STOP' button clockwise to turn on airflow and power. During this step, make sure that the gray air tube is connected to the apparatus. The third step is to turn the switch on the robot to the "AUTO" position to begin the manufacturing operation.

On the robot controller, select job "2021Master" in the Motoman to begin assembly. Next, press and hold the green button on the table and turn the PLC to 'Run' position. After this, hold the button until fluid has been filled to the tip of the flexible tube on the robot arm. Finally, release the button and turn on the conveyor belt for vials to approach the gates.

Clearing the Machine

A jam that the system may experience is when there are no vials on the conveyor belt approaching the first gate. This issue may cause a vial to not pass the second gate. All operations will stop except for the motion of the conveyor itself. To correct this situation, simply place more vials before the first gate. Normal operations should then resume

Another potential jam is when the fluid container becomes empty. When this occurs, the robot will go through the normal positions, however no fluid will be present to enter the vial. When this happens, stop the robot, the PLC, and the conveyor belt. Then, fill the bladder with glycerin and restart the operation as detailed in “Starting the Machine” section.

One jam that the team encountered was having the lid seal come apart from the lid itself. Each vial is made up of three parts: the glass vial, the plastic cap, and the seal between the glass and the plastic. This plastic seal is held semi-captively in the lid, but can come free occasionally, as it did after having been used with the same vial multiple times. When the problem occured, the robot arm lowered the tube to pump in the liquid, but the vial opening was obstructed, so it could not fill. The seal must be removed before any mess was made. If it had continued, the biggest issue would have been a mess of glycerin, with the system likely continuing to perform as normal.

If there is a major uncommon problem that harms a person or the machine itself, immediately press the ‘E-STOP’ button. Then verify that no parts, in any station, have been damaged.

If a part of the machine has been damaged, replace it with a new, working part of the same kind. If the damaged part is not able to be bought, contact the company support representative.

Description of Operation

Station 1 – Vial Singulation and Positioning

The purpose of the vial singulation and positioning station is to isolate the vials for filling. The vials are placed by hand onto the moving assembly line. There are two gates near the end of the assembly line for singulation. When a vial triggers the first sensor, the first gate opens and allows a vial to advance. This vial then triggers another sensor so gate 1 closes and gate 2 opens. The vial advances to the end of the assembly line where there is a bracket to hold it while the robot picks it up in its pneumatic jaw to take it to the next stage. There is a sensor in the bracket, which, when activated, closes gate 2 and starts the next stage. Figure 3 below shows the robot about to pick up a vial waiting at the bracket.

Figure 3 End section of belt, where jaws are activated to clamp around vial

Station 2 – The Filling Station

The purpose of the filling station is to uncap a vial, fill it with glycerin, and cap it again. The method for capping begins with opening the jaws attached to the three-jaw pneumatic gripper. The robot can then place the vial within the open jaws. Figure 4 shows the vial approaching the jaws. After this step, the jaws are set to close tightly around the vial. Figure 5 shows the three-jaw pneumatic gripper closing around the vial.

Next, while the clamp is still compressed around the cap of the vial, the pneumatic three-jaw gripper then turns clockwise two revolutions. Upon success, the robot arm positions itself so that glycerin fluid fills the vial. Figure 6 below shows the vial being filled with glycerin. The stepper motor drives the peristaltic pump for a pre-defined number of revolutions. As such, the filling is precise and does not fluctuate unless air bubbles enter the flexible tube that is connected to the fluid to the pump.

After the vial has been filled, the robot repositions itself so that the vial can be recapped. After the cap has been replaced, the final stage begins.

Figure 4 Vial approaching placement

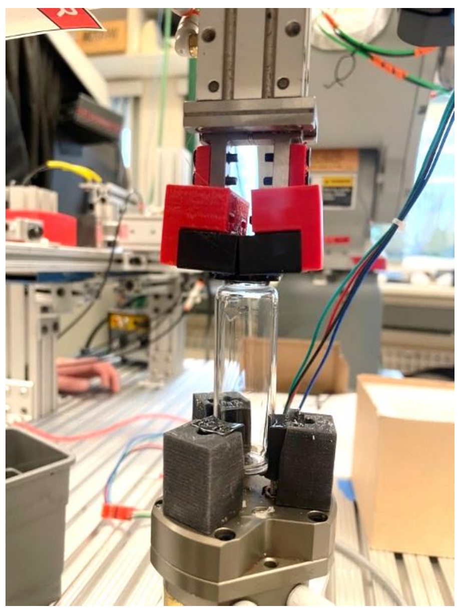


Figure 5 Pneumatic gripper closes around bottom section of vial

Figure 6 Tube begins filling vial

Station 3 - Final Placement Station

The final station places the filled, capped vial into a box for further handling. The robot arm takes the vial to a position right above the box. The pneumatic gripper that has been holding the cap then releases and the vial falls into the box. Figure 7 below shows this last vial position.

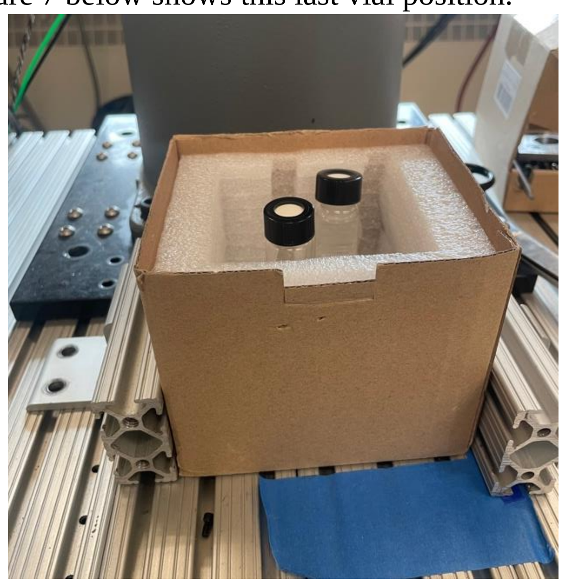


Figure 7 Final placement station

Maintenance

The maintenance of this assembly line begins with a general examination to ensure that each component is working properly. This should be done a minimum of once per week. The 3D printed components of the system can fracture due to excessive loading or fatigue. If this occurs, the SolidWorks files may be referenced to reprint these components. Another error that may occur is leakage from the tubing connected to the bladder containing water. Luckily, this is relatively easy to fix by simply running a new tube to the robot arm. The components on the assembly that have been 3D printed are included at the end of this document under the heading “Drawings of 3D Printed Components.”

Future Improvements/Developments

Some future improvements may be to design the pneumatic gripper attachments with stronger material to avoid breakage. Another beneficial improvement would be to use a different apparatus for the tubing to avoid drippage as this may cause damage to electrical components.

Some stretch goals for this project would be to program the robot so that it could sense the location of the glass vials in the original packaging to eliminate the need for the user to manually load the vials onto the conveyer belt. Another goal is to put the filled vials into the original cardboard carton rather than an arbitrary storage container. Lastly, a final objective would be to apply an adhesive label to the vial at some point during the assembly line process.

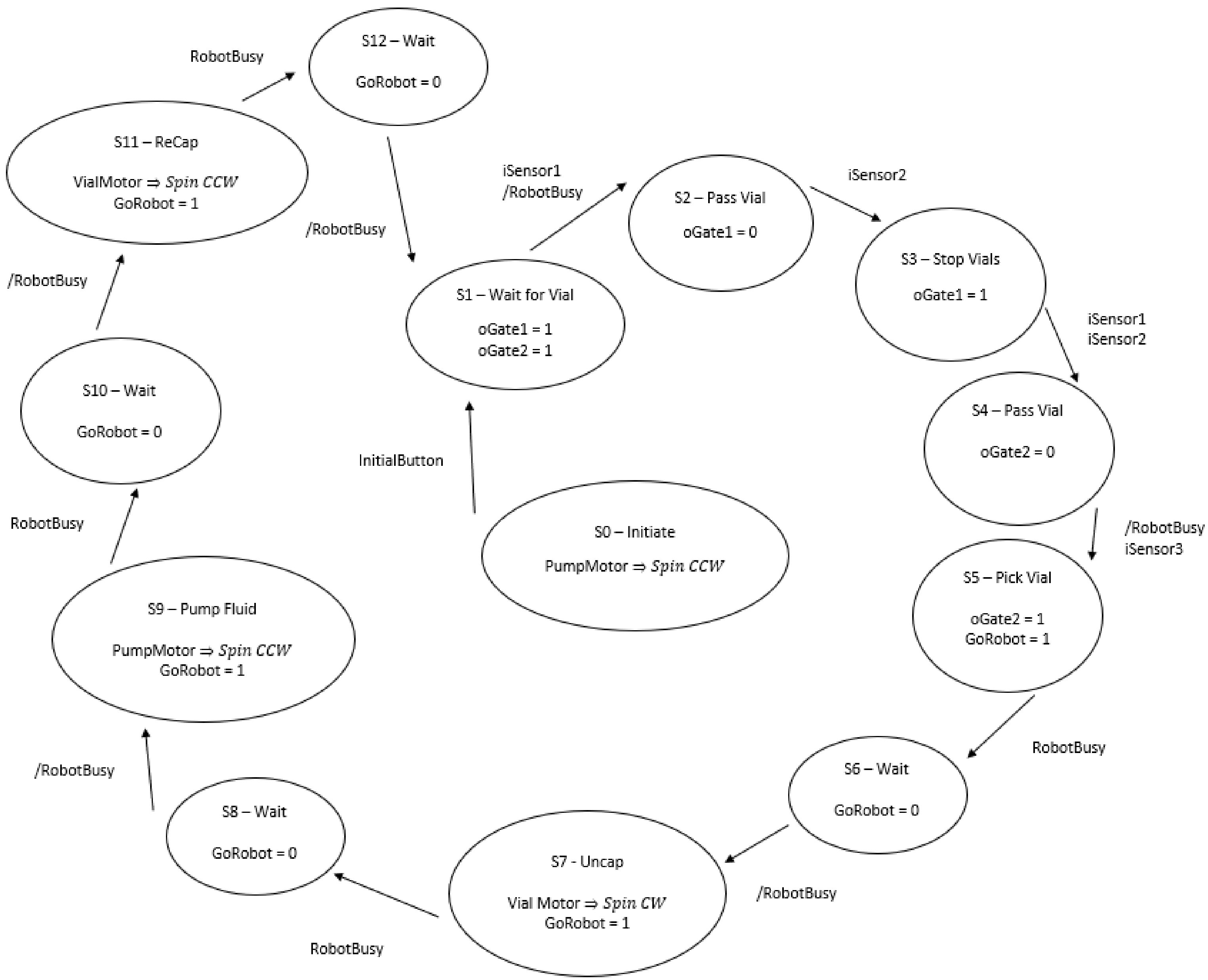
Performance Data

To gather performance data, five (5) vials were weighed, run through the system, then weighed again to determine the average amount filled in each vial, as well as the time each cycle took. The first vial filled was somewhat extraneous, as the following vials were all about 2 grams lighter, but the data point was kept. All vials tested went through the system, were filled, recapped, and were delivered to the end without any issues. Based on the data collected, vials were filling on average with 14.8 g of glycerin. This yields an average difference from the target fill of 15 grams to 0.182 grams. All this was done with each cycle taking about 4 minutes to complete, which equates to 15 vials per hour.

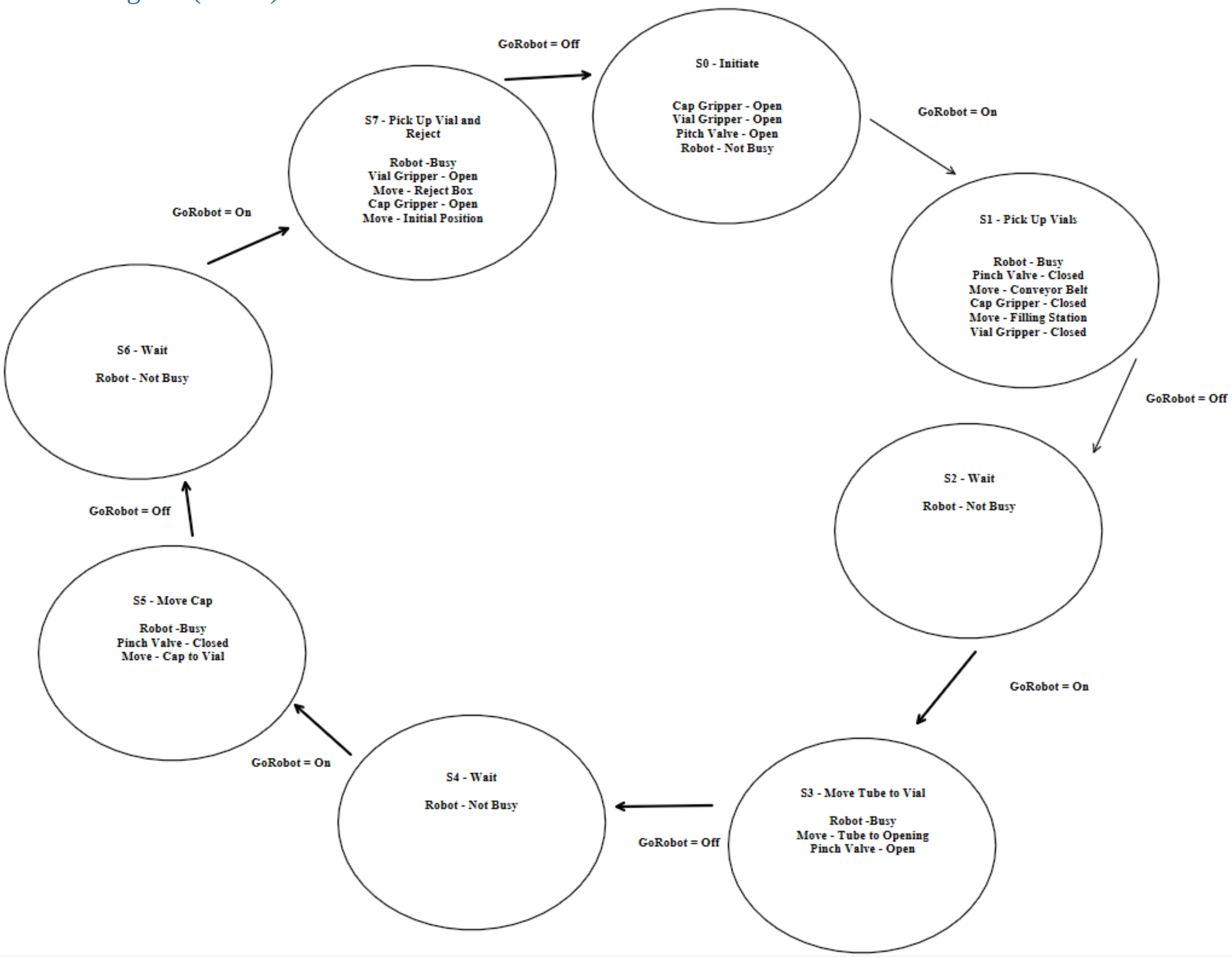
The table below shows the specific performance specifications

							(g)	(g)				
	initial	final	actual	delta from target			target	15				
1	15.18	31.9	16.72	-1.72			min	14.04		diff	2.68	(g)
2	15.25	30.09	14.84	0.16			max	16.72			2.13	(ml)
3	16.48	30.85	14.37	0.63			mean delta	0.182				
4	16.45	30.49	14.04	0.96			average	14.818				
5	16.08	30.2	14.12	0.88								

State Machine Diagram (PLC)



State Machine Diagram (Robot)



Motoman Job Programs

```
/JOB
//NAME 2021MASTER_BACKUP(TUE_WK10)USB
//POS
///NPOS 25,0,0,0,0,0
///TOOL 0
///POSTYPE PULSE
///PULSE
C00000=-3004,-26379,-10768,-11980,10305,-145079
C00001=-57968,4459,-14013,593,-70865,-135547
C00002=-57632,23830,-36902,-1476,-40549,-134936
C00003=-59264,19800,-38535,-1358,-41967,-134348
C00004=-56580,6721,-16595,581,-67641,-136101
C00005=-16078,41732,14500,-68,-69152,-151539
C00006=-766,61119,21972,-328,-62823,-157352
C00007=-1418,63454,19788,-325,-59833,-157093
C00008=-1532,72526,15733,-351,-51411,-157002
C00009=-1532,74111,15339,-355,-50158,-156988
C00010=-1532,73784,15413,-355,-50404,-156984
C00011=-1421,62120,21149,-319,-61626,-157105
C00012=23185,43783,-20992,-22728,38811,-146933
C00013=23184,61095,-22814,-18673,49664,-150758
C00014=23184,55231,-22814,-19648,46346,-149759
C00015=-1421,62121,21149,-319,-61625,-157104
C00016=-1477,72995,14463,-359,-50204,-157017
C00017=-1477,73219,14412,-359,-50038,-157010
C00018=-1477,74553,14147,-364,-49032,-157008
C00019=-1417,63916,19377,-325,-59249,-157081
C00020=6556,37517,-33689,-1056,-36688,-159616
C00021=8620,-7060,-83644,-1425,-27379,-160137
C00022=8620,18415,-85497,-3519,-10658,-158738
C00023=30243,20570,-82316,-4611,-11457,-166377
C00024=1,1,-1,0,-25,-157445
//INST
///DATE 2021/12/07 18:15
///ATTR SC,RW
///GROUP1 RB1
NOP
DOUT OT#(4) OFF
*LABEL
```

```
DOUT OT#(1) OFF
DOUT OT#(2) OFF
WAIT IN#(1)=ON
DOUT OT#(2) ON
DOUT OT#(3) ON
DOUT OT#(4) ON
MOVJ C00000 VJ=5.00
MOVJ C00001 VJ=5.00
'GRAB VIAL
MOVJ C00002 VJ=0.78
DOUT OT#(1) ON
TIMER T=1.00
MOVJ C00003 VJ=0.78
MOVJ C00004 VJ=5.00
'MOVE OVER 3JAW
MOVJ C00005 VJ=5.00
MOVJ C00006 VJ=5.00
MOVJ C00007 VJ=5.00
MOVJ C00008 VJ=0.78
MOVJ C00009 VJ=0.78
'CLOSE ON VIAL
DOUT OT#(3) OFF
TIMER T=1.00
WAIT IN#(1)=OFF
DOUT OT#(2) OFF
TIMER T=2.00
MOVJ C00010 VJ=0.78
WAIT IN#(1)=ON
DOUT OT#(2) ON
MOVJ C00011 VJ=5.00
MOVJ C00012 VJ=5.00
MOVJ C00013 VJ=0.78
DOUT OT#(4) OFF
WAIT IN#(1)=OFF
DOUT OT#(2) OFF
WAIT IN#(1)=ON
DOUT OT#(2) ON
DOUT OT#(4) ON
MOVJ C00014 VJ=0.78
MOVJ C00015 VJ=30.00
```

```
MOVJ C00016 VJ=0.78
MOVJ C00017 VJ=0.78
WAIT IN#(1)=OFF
DOUT OT#(2) OFF
WAIT IN#(1)=ON
DOUT OT#(2) ON
DOUT OT#(3) ON
DOUT OT#(3) OFF
DOUT OT#(1) OFF
TIMER T=2.00
DOUT OT#(3) ON
MOVJ C00018 VJ=0.78
DOUT OT#(3) OFF
DOUT OT#(1) ON
DOUT OT#(3) ON
TIMER T=2.00
MOVJ C00019 VJ=5.00
MOVJ C00020 VJ=5.00
MOVJ C00021 VJ=5.00
MOVJ C00022 VJ=0.78
DOUT OT#(1) OFF
MOVJ C00023 VJ=0.78
TIMER T=1.00
MOVJ C00024 VJ=5.00
JUMP *LABEL
END
```

Stepper Motor Configuration

The PLC and DoMore software were used to operate the stepper motors. The team had one motor, “PumpMotor”, that drives the peristaltic pump and another motor, “VialMotor”, that spins the three-jaw gripper to cap or recap the vial. The configuration of the stepper motor can be found in the ladder logic. Overall, the motors maintain 2000 pulses per revolution and use the “AXPOSTRAP” command to specify the number of rotations.

Wiring Diagram

List all I/O connections between PLC, sensors, pneumatic valves, step motor amplifiers, robot controller, or other devices.

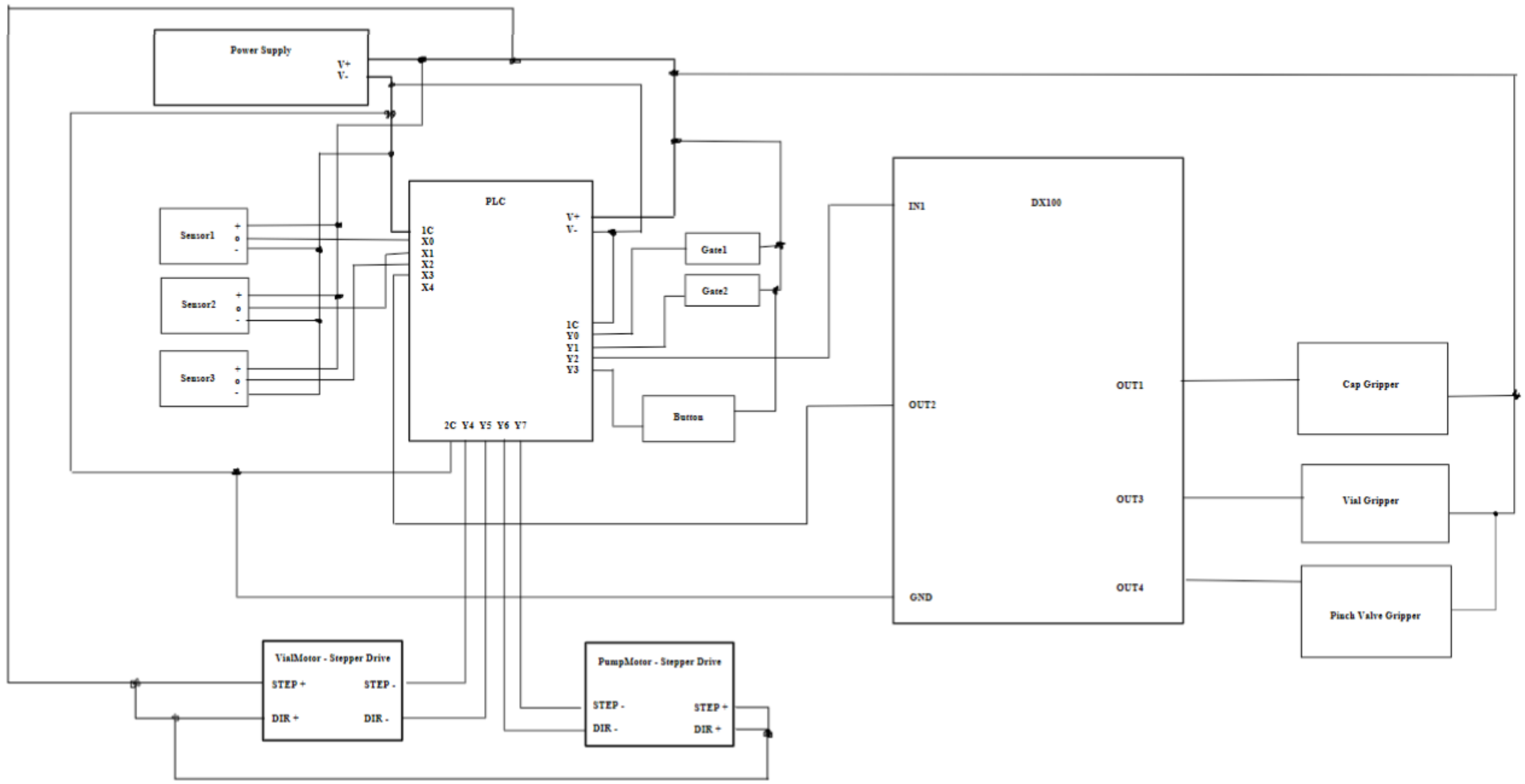


Figure 10. Wiring Diagram with Connections between Stepper Drives and Motor Excluded

Drawings of 3D Printed Components

Below are the STL files of the 3D printed components used in our assembly line.

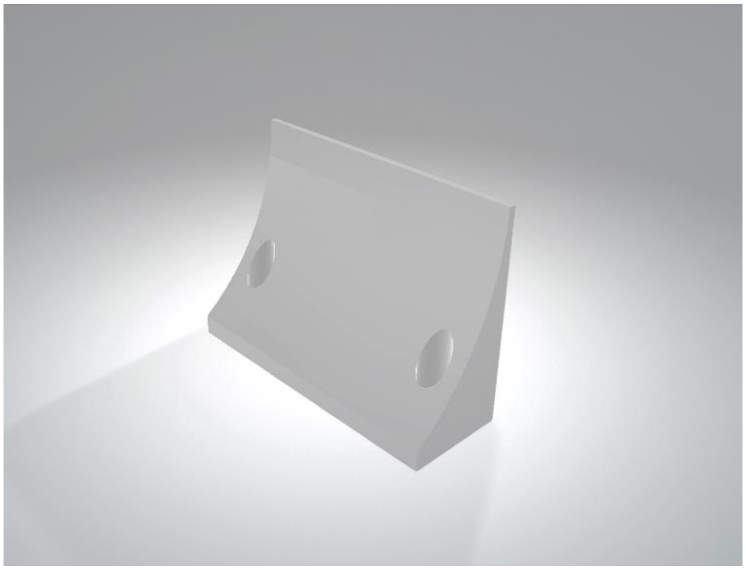


Figure 8: Wedge for Singulation

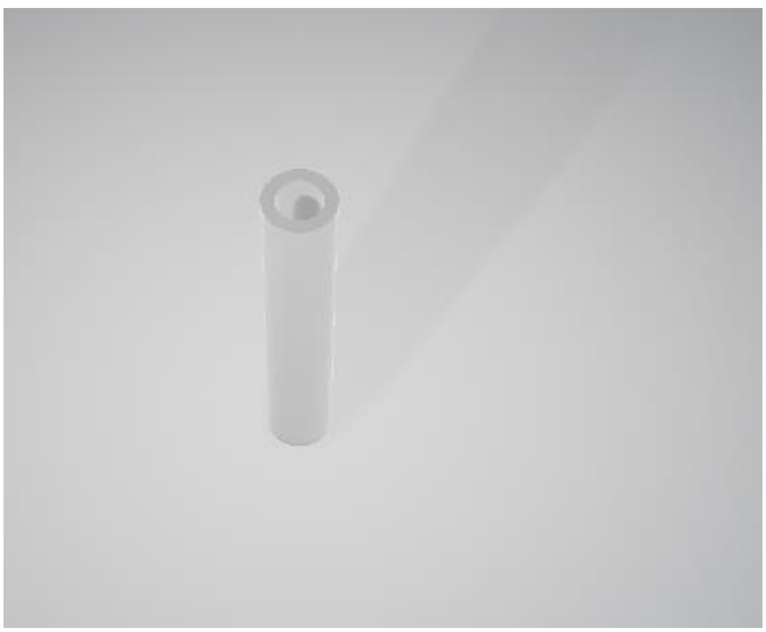


Figure 9. Support for Glycerin Tube

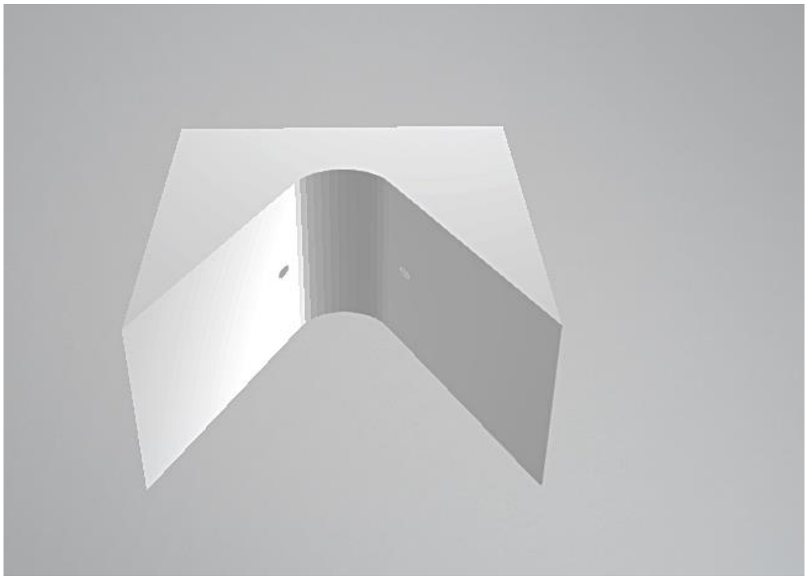


Figure 10. Component to allow for vial end position

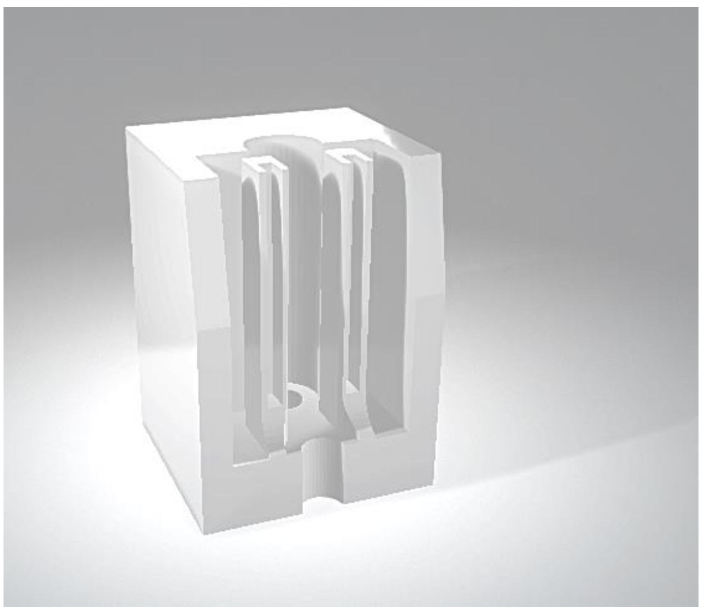


Figure 11. Bottom Pneumatic Gripper Jaw

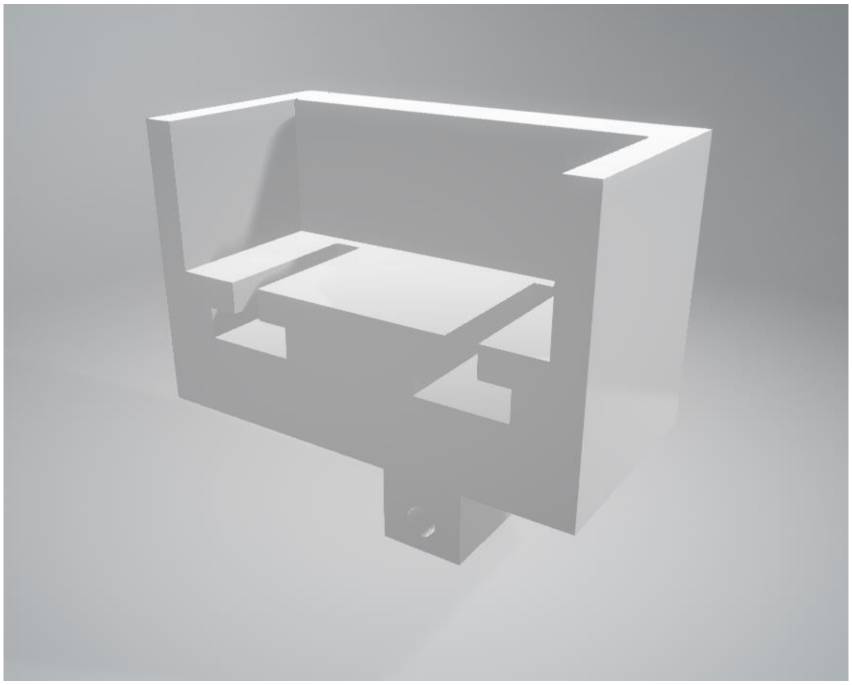


Figure 12. Robot Arm Pneumatic Gripper Jaw

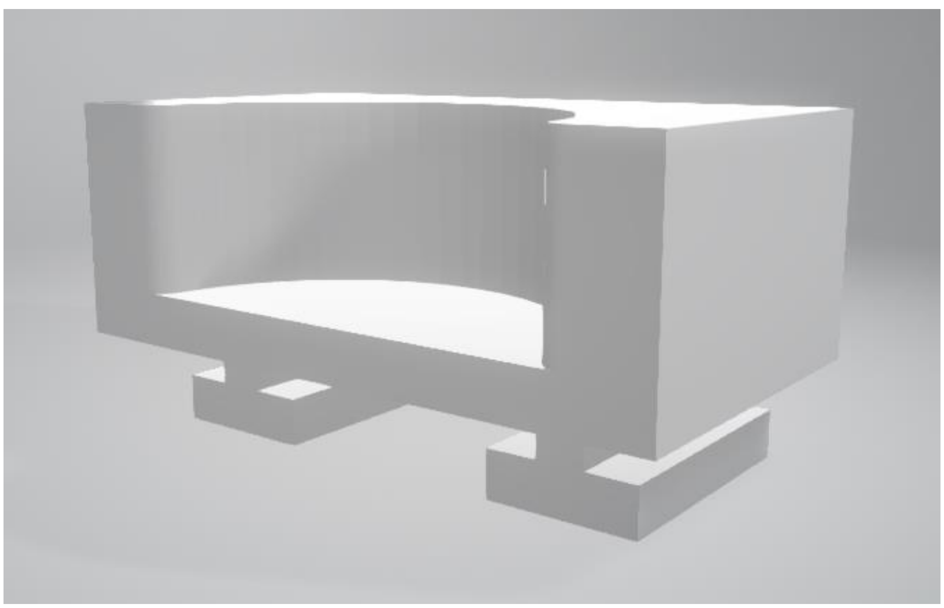


Figure 13. Inner component of pneumatic jaw for top section

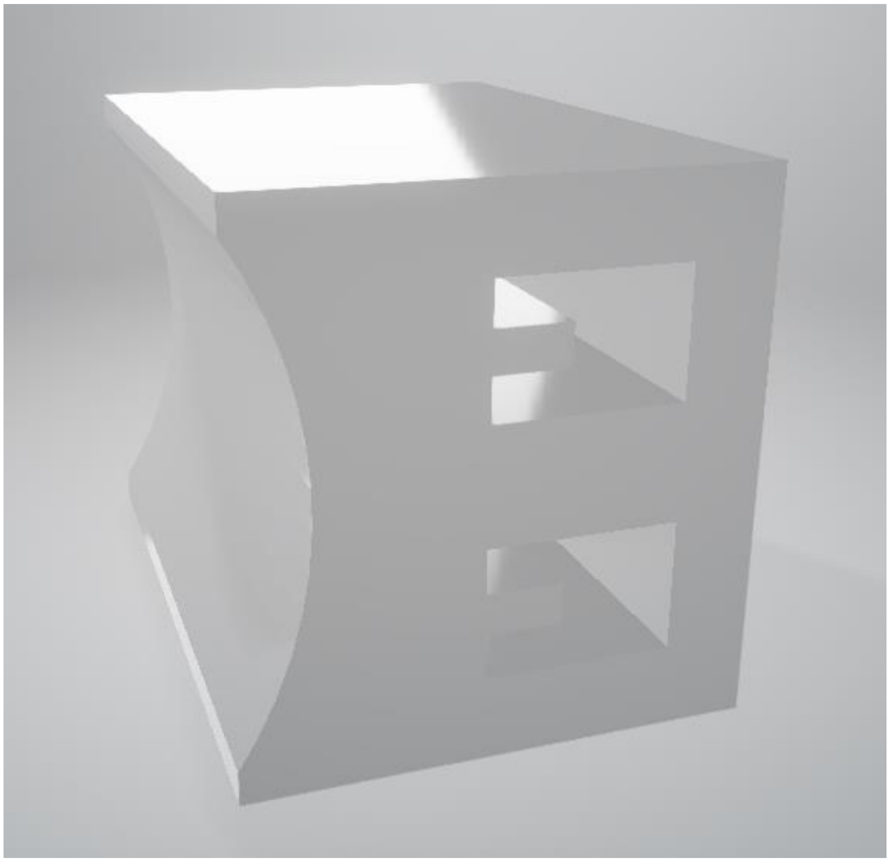
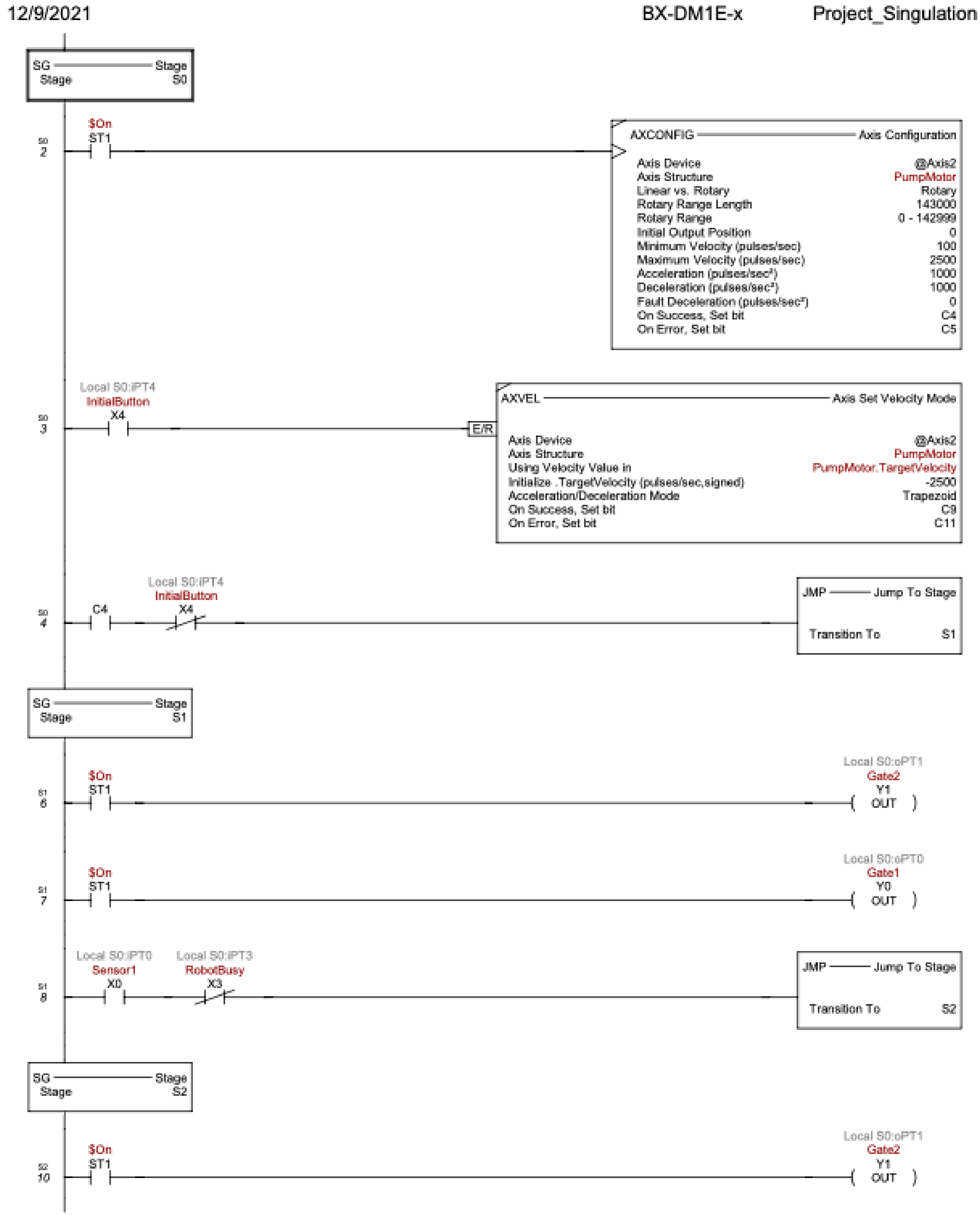
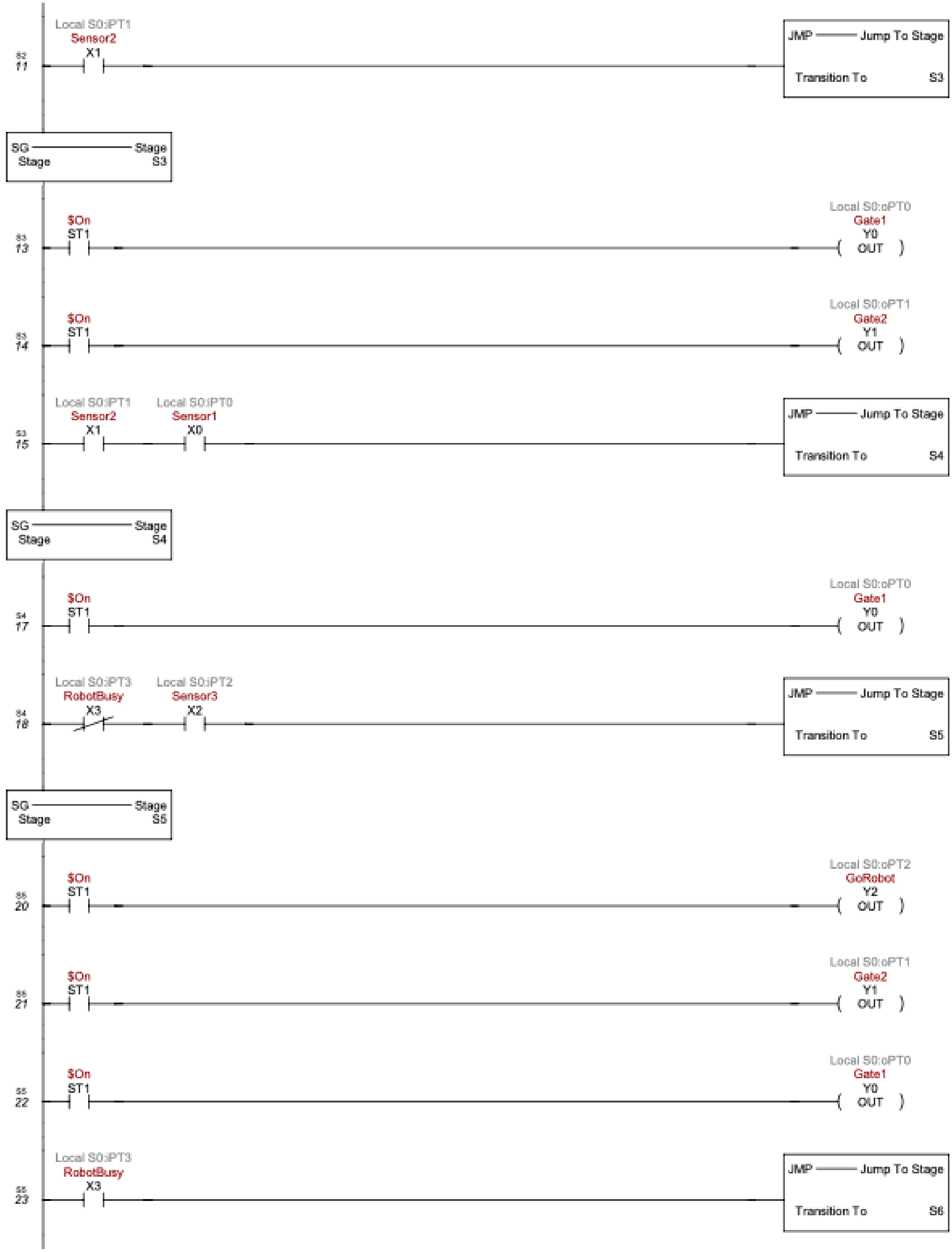


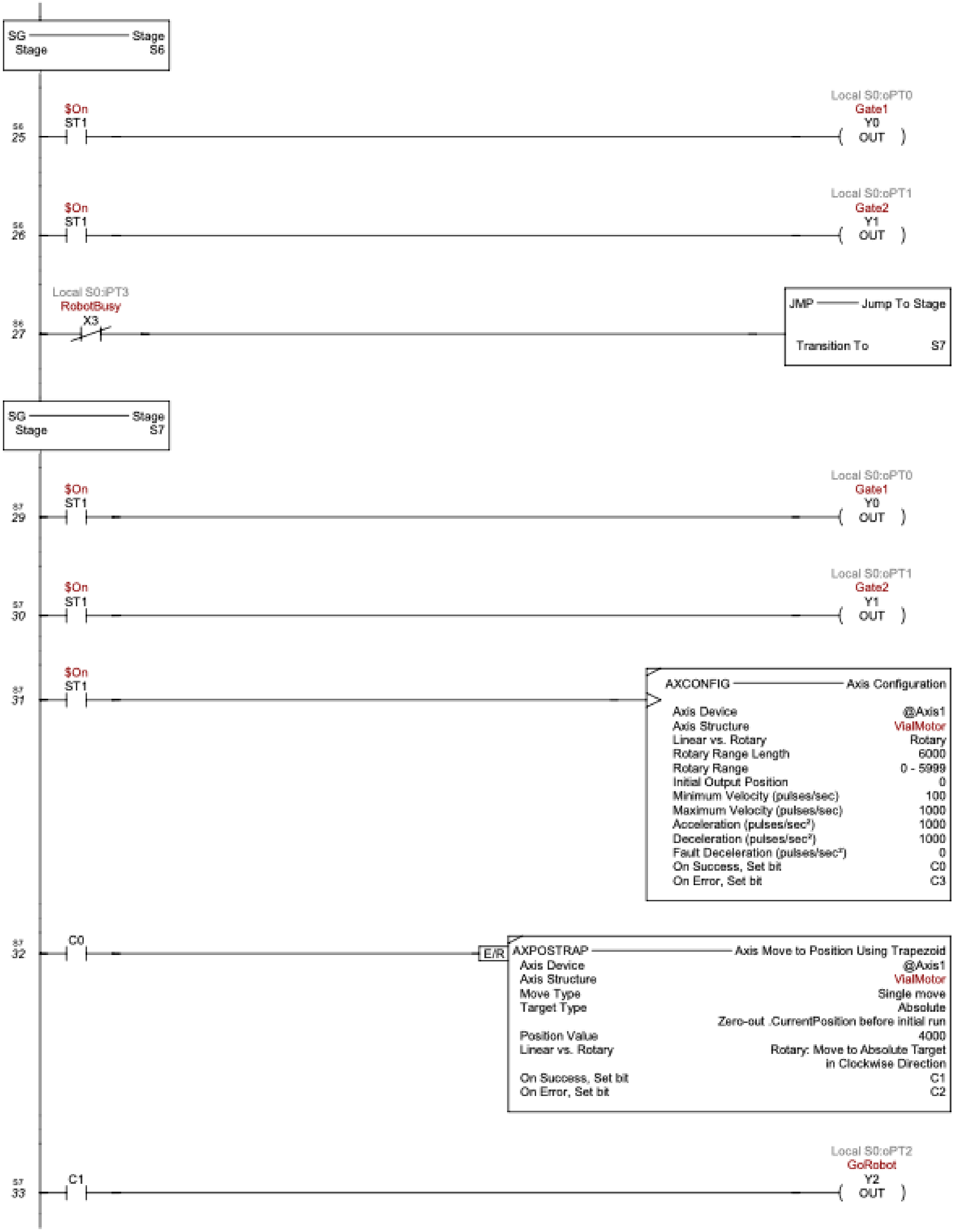
Figure 14. Inner jaw component of bottom pneumatic gripper

PLC Ladder Logic





S2 11
Local S0:iPT1
Sensor2
X1
JMP Jump To Stage
Transition To S3
SG Stage
Stage S3
S3 13
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S3 14
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S3 15
Local S0:iPT1
Sensor2
X1
Local S0:iPT0
Sensor1
X0
JMP Jump To Stage
Transition To S4
SG Stage
Stage S4
S4 17
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S4 18
Local S0:iPT3
RobotBusy
X3
Local S0:iPT2
Sensor3
X2
JMP Jump To Stage
Transition To S5
SG Stage
Stage S5
S5 20
$On
ST1
Local S0:oPT2
GoRobot
Y2
OUT
S5 21
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S5 22
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S5 23
Local S0:iPT3
RobotBusy
X3
JMP Jump To Stage
Transition To S6


SG Stage
Stage S6
S6 25
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S6 26
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S6 27
Local S0:iPT3
RobotBusy
X3
JMP Jump To Stage
Transition To S7
SG Stage
Stage S7
S7 29
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S7 30
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S7 31
$On
ST1
AXCONFIG Axis Configuration
Axis Device @Axis1
Axis Structure VialMotor
Linear vs. Rotary Rotary
Rotary Range Length 6000
Rotary Range 0 - 5999
Initial Output Position 0
Minimum Velocity (pulses/sec) 100
Maximum Velocity (pulses/sec) 1000
Acceleration (pulses/sec²) 1000
Deceleration (pulses/sec²) 1000
Fault Deceleration (pulses/sec²) 0
On Success, Set bit C0
On Error, Set bit C3
S7 32
C0
E/R
AXPOSTRAP Axis Move to Position Using Trapezoid
Axis Device @Axis1
Axis Structure VialMotor
Move Type Single move
Target Type Absolute
Zero-out .CurrentPosition before initial run
Position Value 4000
Linear vs. Rotary Rotary: Move to Absolute Target in Clockwise Direction
On Success, Set bit C1
On Error, Set bit C2
S7 33
C1
Local S0:oPT2
GoRobot
Y2
OUT

S7 34 — Local S0:iPT3 RobotBusy X3 (NO contact) — JMP — Jump To Stage; Transition To S8

SG — Stage; Stage S8

S8 36 — $On ST1 (NO contact) — Local S0:oPT0 Gate1 Y0 (OUT)

S8 37 — $On ST1 (NO contact) — Local S0:oPT1 Gate2 Y1 (OUT)

S8 38 — Local S0:iPT3 RobotBusy X3 (NC contact) — JMP — Jump To Stage; Transition To S9

SG — Stage; Stage S9

S9 40 — $On ST1 (NO contact) — Local S0:oPT0 Gate1 Y0 (OUT)

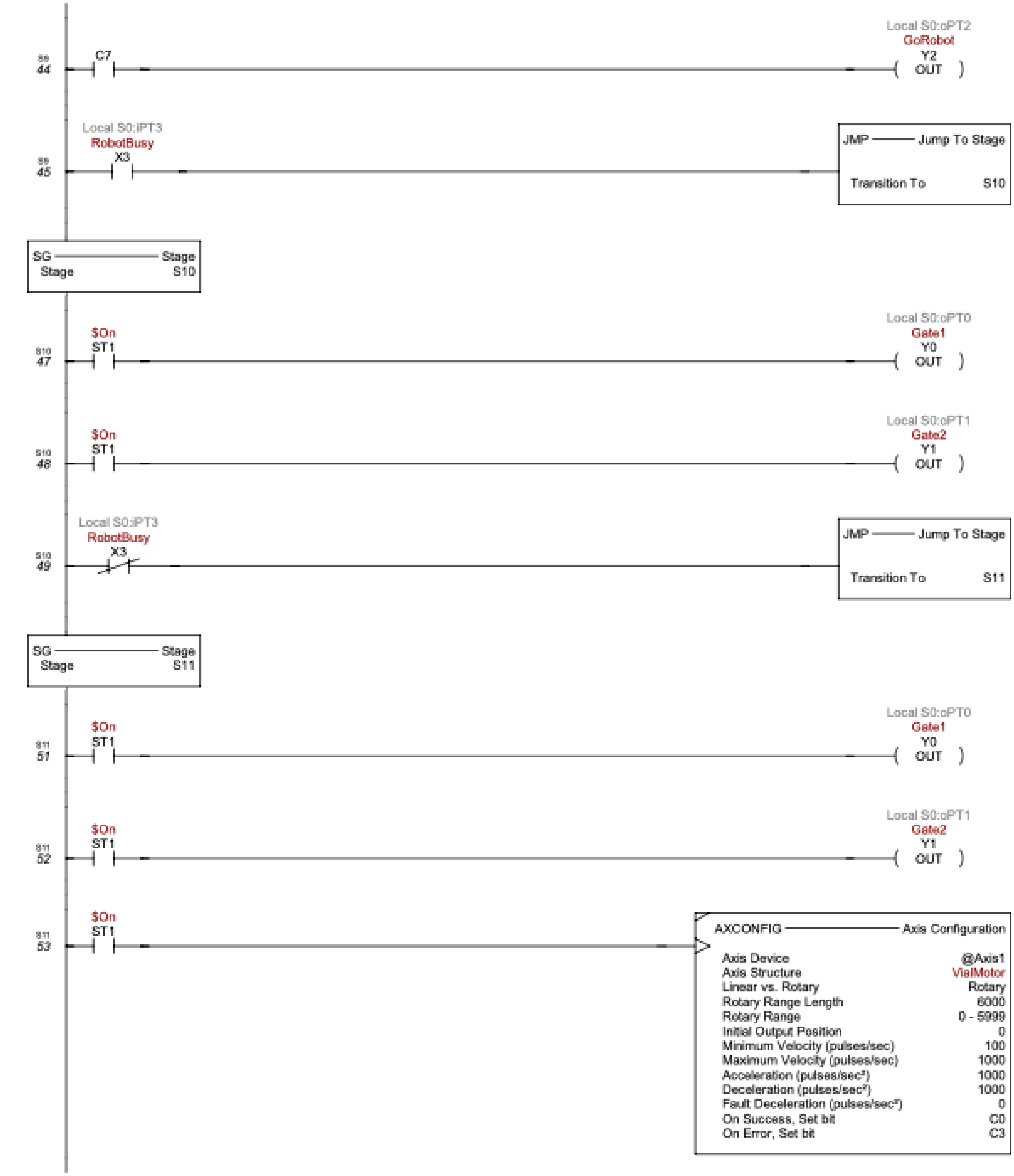
S9 41 — $On ST1 (NO contact) — Local S0:oPT1 Gate2 Y1 (OUT)

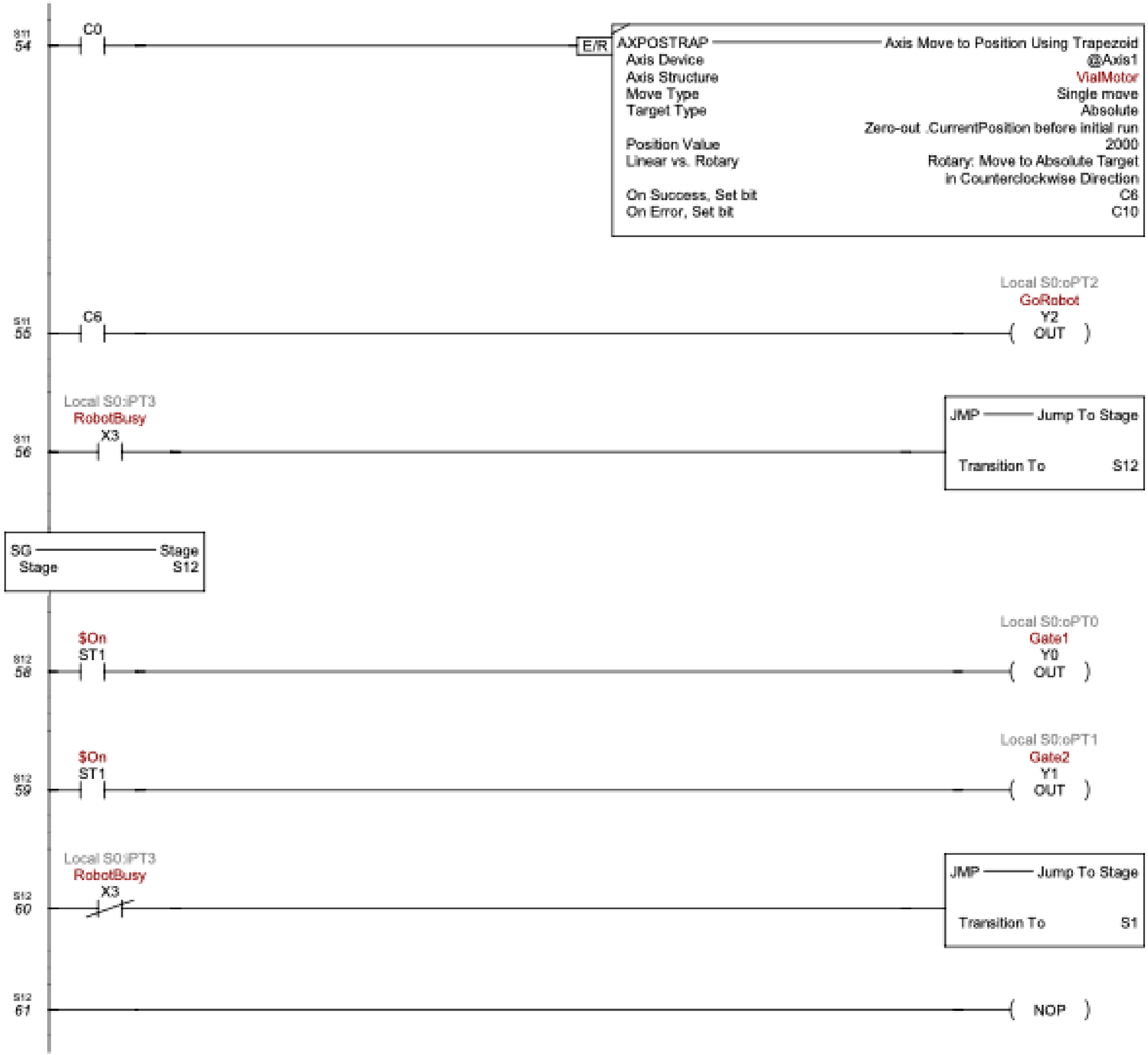
S9 42 — $On ST1 (NO contact) — AXCONFIG — Axis Configuration

Axis Device	@Axis2
Axis Structure	PumpMotor
Linear vs. Rotary	Rotary
Rotary Range Length	325000
Rotary Range	0 - 324999
Initial Output Position	0
Minimum Velocity (pulses/sec)	100
Maximum Velocity (pulses/sec)	2700
Acceleration (pulses/sec²)	1000
Deceleration (pulses/sec²)	1000
Fault Deceleration (pulses/sec²)	0
On Success, Set bit	C4
On Error, Set bit	C5

S9 43 — C4 (NO contact) — E/R AXPOSTRAP — Axis Move to Position Using Trapezoid

Axis Device	@Axis2
Axis Structure	PumpMotor
Move Type	Single move
Target Type	Absolute
	Zero-out .CurrentPosition before initial run
Position Value	1
Linear vs. Rotary	Rotary: Move to Absolute Target in Counterclockwise Direction
On Success, Set bit	C7
On Error, Set bit	C8


S9
44
C7
Local S0:oPT2
GoRobot
Y2
OUT
S9
45
Local S0:iPT3
RobotBusy
X3
JMP Jump To Stage
Transition To S10
SG Stage
Stage S10
S10
47
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S10
48
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S10
49
Local S0:iPT3
RobotBusy
X3
JMP Jump To Stage
Transition To S11
SG Stage
Stage S11
S11
51
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S11
52
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S11
53
$On
ST1
AXCONFIG Axis Configuration
Axis Device @Axis1
Axis Structure VialMotor
Linear vs. Rotary Rotary
Rotary Range Length 6000
Rotary Range 0 - 5999
Initial Output Position 0
Minimum Velocity (pulses/sec) 100
Maximum Velocity (pulses/sec) 1000
Acceleration (pulses/sec²) 1000
Deceleration (pulses/sec²) 1000
Fault Deceleration (pulses/sec²) 0
On Success, Set bit C0
On Error, Set bit C3


S11
54
C0
E/R
AXPOSTRAP Axis Move to Position Using Trapezoid
Axis Device @Axis1
Axis Structure VialMotor
Move Type Single move
Target Type Absolute
Zero-out .CurrentPosition before initial run
Position Value 2000
Linear vs. Rotary Rotary: Move to Absolute Target in Counterclockwise Direction
On Success, Set bit C6
On Error, Set bit C10
S11
55
C6
Local S0:oPT2
GoRobot
Y2
OUT
S11
56
Local S0:iPT3
RobotBusy
X3
JMP Jump To Stage
Transition To S12
SG Stage
Stage S12
S12
58
$On
ST1
Local S0:oPT0
Gate1
Y0
OUT
S12
59
$On
ST1
Local S0:oPT1
Gate2
Y1
OUT
S12
60
Local S0:iPT3
RobotBusy
X3
JMP Jump To Stage
Transition To S1
S12
61
NOP