ELECTRICAL AND PROGRAMMABLE LOGIC CONTROLLER DESIGN, CONSTRUCTION, AND ECONOMIC ANALYSIS OF A REUSABLE PLASTIC CONTAINER DUMPER

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ABSTRACT

This senior project discusses the electrical and programmable logic controller design, the construction, and an economic analysis of a reusable plastic container dumper. The RPC Dumper will be part of the processing of citrus fruits at Bee Sweet Citrus, Inc. This system will be a mobile and partially automated system to dump these reusable plastic containers full of citrus fruit instead of having them manually dumped.

The total bill of materials of the project totaled $11,257.05 and the RPC Dumper was able to dump four RPCs per minute.

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INTRODUCTION

For years the citrus industry has been looking for machinery to perform certain tasks that would normally be performed by manual labor. The goal has always been to develop machinery that will cut down labor costs while meeting or exceeding current production capacities. Some citrus packing houses store the citrus that they have already ran through their processing lines into foldable plastic crates called reusable plastic containers or RPCs. Citrus packing houses use RPCs as shipping containers to send their product to their customers or use RPCs as temporary storage before the product is bagged or packed. Most of the time, these RPCs are dumped by hand to be run through a line to be packed; however, to keep up with production needs, there are usually many men dumping these RPCs by hand.

Bee Sweet Citrus located in Fowler, CA is looking for a machine that will dump the RPCs full of fruit and help reduce their labor costs. A bin dumper with a conveyor that could be able to dump these RPCs onto a sorting belt would be one way to increase productivity and reduce labor costs. The advantages of using such a machine would be: it will cut down on manual labor costs, be physically easier for workers operating the conveyor, and be a low-impact dump on the fruit. These benefits would cut labor costs, help minimize worker injuries, and help reduce fruit bruising and breakdown.

In the industry, there are many types of bin or tote dumpers used by many different packing houses; however, all of these machines are stationary structures that integrated into a particular processing line. Bee Sweet Citrus wants a machine that will be small and mobile so that the machine could be moved from line to line where it was needed. The initial design process produced many different designs, but a bin dumper style machine like many of the four foot by four foot bin dumpers in many packing houses was the most feasible to design and used a concept that was already proven. The problem here is associated with the desires of Bee Sweet Citrus was that this machine needed to be mobile.

The objectives of this senor project was to design the electrical system for the machine, construct and build the electrical and structural components of the machine, test the machine, and perform a cost analysis of the machine while considering the following constraints:

1. The machine must be able to dump at least four RPCs per minute.
2. A team of two workers will operate the machine
3. The machine must dump the RPCs of citrus fruit with the same or less damage compared to the other sections of the processing line
4. The RPC dumper must be able to be moved by forklift from place to place at Bee Sweet Citrus.

LITERATURE REVIEW

Processing Damage to Citrus Fruits

The mechanical processing of citrus in packing houses inevitably causes damage to the product. Reports of post-harvest loses of fresh produce, which includes citrus varieties like Navel oranges, range from 5 to 40% of the total production; injuries due to mechanical forces must be reduced in order to decrease the amount of post-harvest losses. Cellular respiration is a metabolic process where chemical energy is produced to be used by the cell for vital reactions and processes such as synthesis and maintenance. For produce, respiration is measured in mL CO_2 per kg of produce per hour (mL CO_2/kg/h).The respiration rate is directly related to the shelf-life of any fresh produce. This damage caused by mechanical damages, which include impact and compression damages, causes the respiration rate to increase. As shown in Figure 1, the respiration rate increases with the greater compressive force applied to the citrus. These readings for respiration were recorded from one up to six hours after the compressive force was applied to citrus. (Scherrer-Montero et al, 2011)

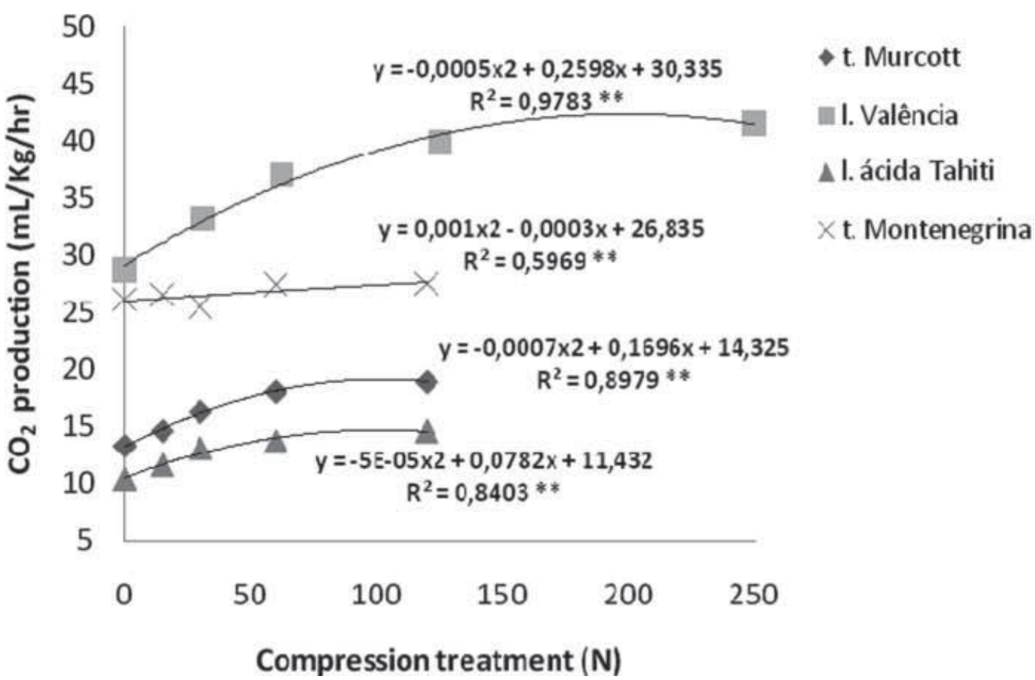

Figure 1. Compression Treatment vs. CO2 Production (Scherrer-Montero et al,

Burkner et al. performed a test, in their paper Padded Collecting Surfaces for Reducing Citrus Fruit Injury, comparing the drop height and collecting surface of a holding container to the rate of respiration of the oranges. The test was performed with a number of different citrus selected at random and dropped from different heights onto different surfaces. The respiration rate of the fruits in the test was measured using a particular apparatus over a 76 hour period to get an average rate. The results of the tests are shown in Figure 2; in Figure 3, the Navel orange drop test numbers are represented on a graph which correlates the drop height to the increased rate of respiration of the Navels. The results found that the increased rate of respiration is directly correlated to the drop height and inversely correlated to the impact surfaces' ability to absorb the impact force of the fruit. (Burkner et al, 1972)

TABLE 1. SUMMARY OF DROP TEST RESULTS

Treatment			Avg. respiration rate for 76 hr period, $\frac{ml\ CO_2}{kg-hr}$		
Drop	Surface	Support	Grape-fruit	Navel orange	Valencia orange
Check			6.34	15.80	6.16
1/2 ft	Plywood	Concrete	6.59	17.33	6.72
1 ft	Plywood	Concrete	6.79	18.39	7.16
2 ft	Plywood	Concrete	7.85	19.19	8.12
4 ft	Plywood	Concrete	9.44	23.12	9.36
6 ft	Plywood	Concrete	10.49	23.75	11.82
4x1/2 ft	Plywood	Concrete	6.94	20.26	7.35
2x1 ft	Plywood	Concrete	7.89	20.44	7.69
4x1 ft	Plywood	Concrete	8.31	23.22	8.50
6x1 ft	Plywood	Concrete	9.57	—	10.29
4x1 - 1/2 ft	Plywood	Concrete	10.07	—	11.23
10 ft	3/4 in. Ensolite	Wire	7.30	16.51	7.06
10 ft	1/2 in. Ensolite	Wire	9.43	17.90	10.15
10 ft	3/4 in. Ensolite	Plywood	9.26	19.26	7.19
10 ft	1/2 in. Ensolite	Plywood	12.31	17.93	12.26
10 ftq	3/4 in. Rubatex tubular sponge	1 in. EMT	8.84	17.88	8.14

Figure 2. Summary of Drop Test Results (Burkner et al, 1972).

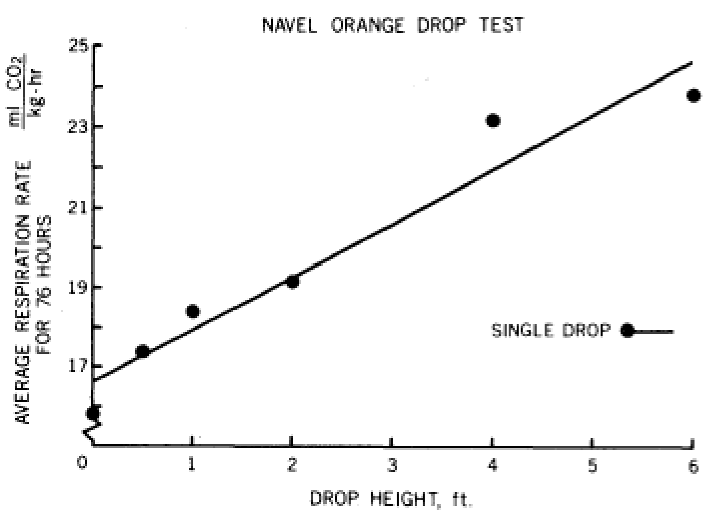

Figure 3. Drop Height vs. Average Respiration Rate (Burkner et al, 1972).

NIOSH Manual Lifting Evaluations

The National Institute for Occupational Health and Safety (NIOSH) developed a guide for manual lifting in the workplace in 1981 and revised it in 1991 describing an equation to evaluate lifting conditions. The equation is,

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \quad (1)$$

The equation's purpose is to give a recommended weight limit (RWL) that all healthy workers can perform over an extended period time without putting an excessive load on the back for a certain lifting condition. LC is the load constant, HM is the horizontal multiplier, VM is the vertical multiplier, DM is distance multiplier, AM is the asymmetric multiplier, FM is the frequency multiplier, and CM is the coupling multiplier. Figure 4 describes the meaning of some of the values of the coupling multiplier, and Figure 5 lists some of the values used to figure out the frequency multiplier. This equation is used to determine if a certain lifting task is putting too much strain on a worker's back which could lead back injuries. Even though OSHA hasn't created any regulations governing manual lifting conditions in the workplace, OSHA does enforce that workers will work in a safe environment that won't affect their health. (OSHA, 1999)

GOOD	FAIR	POOR
CM = 1.00	**V < 30" then CM = 0.95**	**CM = 0.90**
	V > or = to 30" then CM = 1.00	
1. For containers of optimal design, such as some boxes, crates, etc., a "Good" hand-to-object coupling would be defined as handles or hand-hold cut-outs of optimal design.	1. For containers of optimal design, a "Fair" hand-to-object coupling would be defined as handles or hand-hold cut-outs of less than optimal design.	1. Containers of less than optimal design or loose parts or irregular objects that are bulky or hard to handle.
2. For loose parts or irregular objects, which are not usually containerized, such as castings, stock, supply materials, etc., a "Good" hand-to-object coupling would be defined as a comfortable grip in which the hand can be easily wrapped around the object.	2. For containers of optimal design with no handles or hand-hold cut-outs or for loose parts or irregular objects, a "Fair" hand-to-object coupling is defined as a grip in which the hand can be flexed about 90 degrees.	2. Lifting non-rigid bags (i.e., bags that sag in the middle).

Figure 4. Coupling Multiplier (OSHA, 1999).

TABLE VII:1-1. FREQUENCY MULTIPLIER TABLE (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	< 1 Hour		> 1 but < 2 Hours		> 2 but < 8 Hours	
	V < 30 †	V > 30	V < 30	V > 30	V < 30	V > 30
< 0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
> 15	.00	.00	.00	.00	.00	.00

Figure 5. Frequency Multiplier (OSHA, 1999).

NEMA Standards and Ratings

The National Electrical Manufacturers Association (NEMA) has written standards and guidelines for implementing industrial automation equipment in the industrial workplace. These standards have guided engineers and technical personnel in many industries in the selection of electrical components and the design of power and control schematics.

“NEMA Standards Publication ICS 19-2002” deals with standardizing the diagrams and schematic symbols for industrial control systems. This standard helps to ensure that documentation of automated machinery using electrical systems is organized and can be read and understood by other individuals with knowledge in electrical systems. This standard also includes the graphic symbols used in such diagrams; for instance, graphical symbols used for push buttons, grounding connections, and limit switches. The electrical system of the RPC dumper will need wiring diagrams, controller diagrams, and logic diagrams to fully document how the system functions, so other people can read and understand how the machine will work and wire the machine according to the diagrams. (NEMA, 2007)

Another NEMA standard that would apply to this project would be "NEMA Standards Publication ICS 7.1-2006." This document pertains to the safety standards in the construction and a guide for the selection, installation, and the operation of adjustable-speed drives or variable frequency drives (VFDs). In particular, section 4 of the document is a guide for selecting, installing and operating VFDs. Since a VFD application will be involved with the design of the RPC dumper, this document can be used as a guide in selecting the proper VFD. Such factors that must be considered when choosing a VFD include the environment which it will be placed, who will have access to the VFD controls, and the control application to start and stop the VFD. Some control application factors to consider are interlocking the VFD using limit switches and stop functions like an emergency stop button. (NEMA, 2006)

NEMA also sets standards for electrical enclosure ratings, so, enclosures can be tested in a variety of different environments. "NEMA Enclosure Types" is a document listing the definitions from NEMA 250-2003 about the different enclosure rating types. Food safety is paramount in any food processing facility even in a packing house such as Bee Sweet Citrus. There has been a trend in the industry to have machinery fabricated out of material that is better for food safety such as stainless steel; so, wash-down of such equipment must be taken into consideration, and the equipment must be built from material resistant to water corrosion. Looking at the "NEMA Enclosure Types," any enclosure with a Type 4X designation from NEMA would be sufficient to handle the environment the RPC dumper will be in. (NEMA, 2005)

OSHA Electrical Safety Regulations

Since Bee Sweet Citrus is considered an industrial environment, OSHA's electrical safety standards for general industry apply to any equipment inside the facility. Specifically, OSHA regulations 1910.303, 1910.304, 1910.305, and 1910.306 pertain to this equipment and its application.

OSHA regulation 1910.303 refers to general requirements for electrical safety in the industrial setting. Such topics in this regulation that would apply to this project include proper electrical insulation, mechanical execution of work, mounting and cooling, marking of electrical equipment, and terminal block use. This regulation is implemented to ensure that all of the electrical equipment is properly insulated, mounted, and connections are secure to ensure the safety of personnel working around the equipment and the safety of the equipment itself. ($OSHA_1$, 2008)

OSHA regulation 1910.304 deals with proper wiring design and protection in general industry applications. For instance, this regulation requires all equipment to be properly grounded and the grounding wire shall only be used for grounding. Among other parts of this regulation, 1910.304 also states that all electrical systems must have a disconnection means such as a circuit breaker or switch and must have overcurrent protection as well to protect the system from shorts that may cause electrical fires. ($OSHA_2$, 2008)

OSHA regulation 1910.305 explains what the proper wiring methods that can be used and where electrical components and equipment can be placed for general use in industrial places. Mainly, this document explains the proper application of proper wiring methods used in enclosures, raceways, cable trays, fittings, and other parts dealing with the protection and transportation of conductors. For instance, enclosures must be placed in a dry location or must be sealed in wet locations so that the electrical components inside the enclosure stay dry. This regulation also deals with the proper wiring of electrical motors, motor circuits, and controllers; regulations pertaining to motors include having some form of disconnecting device within the vicinity of the motors themselves. ($OSHA_1$, 2007)

The final regulation that particularly pertains to this project is OSHA regulation 1910.306 which deals with the specific purpose of equipment and installations. This regulation specifically deals with describing disconnection devices for electrical equipment that will properly and safely disconnect an electrical circuit. The identification and warning signs dealing with disconnection devices are also included with this regulation. ($OSHA_2$, 2007)

Bee Sweet Citrus Lemon Pack Line Bin Dumper

An engineering company based in Reedly, CA called Valley Packline Solutions (VPS) designed, fabricated, and installed a bin dumper system for Bee Sweet Citrus's Lemon Pack Line in 2012. This bin dumper is used to dump a larger container, a 48 inch by 48 inch by 28 inch bin, compared to the RPCs, 16 inch by 28 inch by 10 inch. However, the electrical design and control logic of this bin dumper system uses some of the same components and the same concepts compared to other bin dumper systems in the industry. These components and concepts can be applied to this project.

The bin dumper system developed by VPS utilizes a variety of sensors to help the programmable logic controller control the bin dumper. Some of the sensors that are utilized are photoeyes and proximity sensors. The photoeyes are used to detect the presence of bins at a certain location or fruit along a conveyor belt. In a special case, the shaft of the bin dumper is extended out on one side and cams are put onto the shaft. The cams are positioned in a certain way so that the lobes of the cams represent a certain position of the dumper in the dumping cycle. Proximity sensors installed near the cams detect when the dumper is at these certain positions. The PLC along with a touchscreen control the bin dumper system; the touchscreen is used to start and stop the system insead of having physical pushbuttons, and to look at the status of inputs and outputs for diagnostic purposes. All of these applications of electical control equipment and sensors can be applied to a system on a smaller scale, such as the RPC dumper for this project. (Valley Packline Solutions, 2012)

The electrical panel layout that will house all of the electical equipment is another consideration that must be taken into account. Figures 6 and 7 show the panel layout used by VPS in the Lemon Pack Line dumper system. (Valley Packline Solutions, 2012)

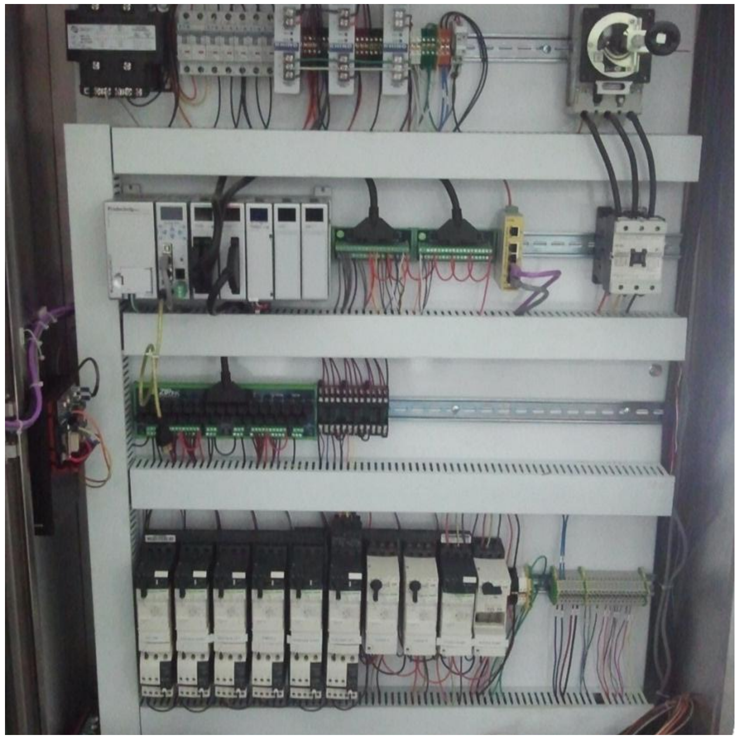

Figure 6. VPS Panel Layout, Inside (Valley Packline Solutions, 2012).

Figure 7. VPS Panel Layout, Outside (Valley Packline Solutions, 2012).

Victor Galindo of Bee Sweet Citrus is the head of the maintenance department, he oversees the maintenance personnel that keep the packing house up and running. He has overseen and coordinated the installation of the electrical systems for various machines at Bee Sweet Citrus. Galindo suggested that when designing the panel layout for the RPC dumper to try and group all of the control equipment together and group all of the power equipment together. For instance, this means that all of the control relays, the power supply for the control wiring, and PLC should be grouped together separate from the contactors and other actuators for the outputs. (Galindo, 2012)

Techmark Impact Recording Device

The Techmark Impact Recording Device (IRD) is a device used to measure impact forces; this device has been used to evaluate the damages that a processing facility has on the produce being packed. The IRD is an internationally patented product developed by Techmark, shown in Figure 8; this device can be, “transferred through machinery and equipment with the flow of fruit or produce, to experience the same bumps and bruises.” (Techmark, 2008). This device has been used worldwide to evaluate many different pieces of machinery and equipment that handle fruit and produce. (Techmark, 2008)

Figure 8. Techmark IRD with Components (Techmark, 2008).

The IRD measures the impacts in both acceleration and velocity measured in G's and meters per second, respectively. The data is recorded internally by the device to be transerted to a computer later. The IRD software can graph the data collected from the test; an example of the graph and what the data represents is shown in Figure 9. (Techmark, 2008)

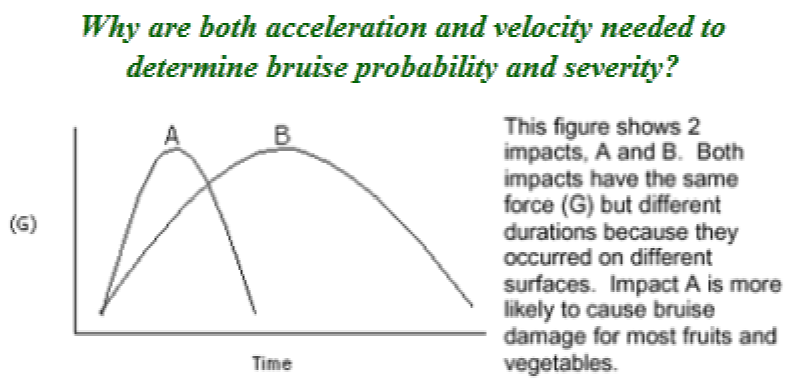

Figure 9. Techmark IRD Data Graph (Techmark, 2008).

This device can be used to evaluate the damages done to citrus fruit for this project. With this device, the processing lines at Bee Sweet Citrus can be analyzed and evaluated to see how much damages are done during these processes. The device can also be used to compare the impact damages done to the citrus fruit when the RPCs are manually dumped by hand or when they are dumped using the RPC dumper to see which process causes more damage to the fruit.

PROCEDURE

Preliminary Testing with the IRD

Before any major design work was done, preliminary testing with the Techmark IRD was performed at Bee Sweet Citrus. The IRD was obtained from Dr. Andrew Holtz of the BioResource and Agricultural Engineering Department at Cal Poly San Luis Obispo. The tests at Bee Sweet Citrus were carried out on November 9-10, 2012 at Bee Sweet Citrus's packing facility in Fowler, California.

The IRD was first used to measure the impact forces and the duration of these forces on the Navel Line at Bee Sweet Citrus. The IRD was run through the whole processing line a few times and each time the data was recorded and downloaded onto a computer. A graph was then generated using the Techmark IRD software. The data depicted where the most damage and the duration of each event occurred. During the test, a video camera was used to record the IRD as it went through the entire packing line. With the use of the data gathered from the IRD and the video taken during the test, the spots where the most damage occurred can exactly be pin pointed and analyzed as to why so much impact occurred.

The next set of tests with the IRD occurred on the Navel Bag Line; the same process for the tests taken on the Navel Line was taken on the Navel Bag Line. Figure 10 shows an example of the graph generated from the Techmark software with the data.

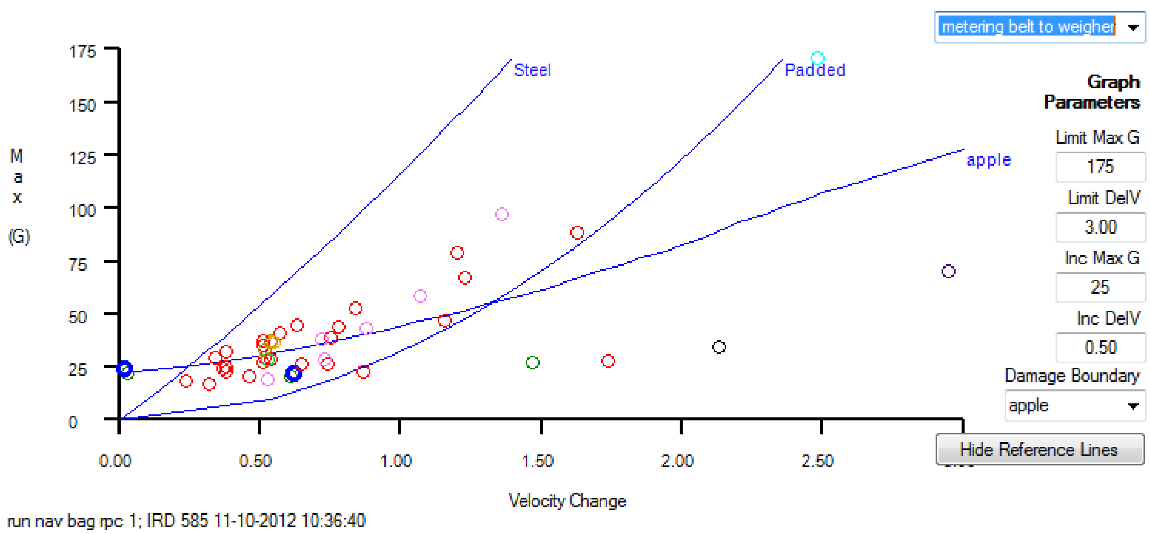

Figure 10. Example of Navel Bag Line Test.

Two tests were taken with the IRD through the entire Navel Bag Line, but a number of other tests were performed at this location. A series of tests were taken by putting the IRD into a RPC of navels and manually dumping the navels with the IRD by hand onto a conveyor belt shown here in Figure 11.

Figure 11. RPC Dump Test by Hand.

In the RPC dump test by hand, the IRD was placed in a specific location each time, for example the IRD was placed in the bottom right corner or in the middle of the box on the top of the fruit. The reason for this is to determine how the position of the fruit in the box when it is dumped could affect the amount of damage taken by the fruit. All of the IRD testing results can be found in Appendix D.

Preliminary Electrical Design

The preliminary design phase consisted of coming up with a control narrative on how the dumper's PLC will cycle through and dump the RPCs. Each step of the process had to be taken into consideration, like how the RPCs would enter the dumper cradle and how will the PLC know when the RPCs are empty when they are being dumped. With a preliminary mechanical and structural design, the step by step process can be visualized and analyzed further to ensure there weren't any steps missing.

The next step is to determine which type of sensors to use so that the PLC knows the location of the RPCs on the conveyor, where the dumper cradle is on the rotation, and when the RPCs are ready to be dumped. The choice of sensors is critical because if the wrong sensor is placed in the wrong location then the RPC dumper wouldn't work right.

It was determined that the electrical system would have two different circuits: an AC circuit to power the electric motors used in the dumper, and a DC circuit for all of the control wiring, power for the sensors, and power for the PLC.

Choosing Parts

Due to Bee Sweet Citrus's relationship with All-Phase Medallion and Electric Motor Shop in Fresno, the parts were chosen and bought from these businesses. Design calculations were made by looking at the required amperage, or ampacity, of both the DC circuit and AC circuits of the electrical design. The main point about looking in the manufacturers' catalogs was to pick parts that were rated for job that they would be performing in the electrical system. For instance, the contactors and overloads needed to be rated for the amps that the AC three phase motors would be pulling, fuses needed to be selected to properly protect the power supply and variable frequency drive (VFD), and the power supply needed to supply enough DC amperage to power sensors, the PLC, and the control wiring. The ampacity calculations for the AC and DC circuits are located in Appendix B.

Since All-Phase Medallion is a Schneider Electric and Square D dealer, parts such as the contactors, overloads, PLC, touchscreen, terminals, and the VFD were chosen from the catalogs of these electrical equipment manufacturers. Electric Motor Shop is a dealer for Banner Electric, Saginaw Control and Engineering (SCE), Ferraz-Bussmann, Emerson Electrical Group, so components such as photo eyes, fuses, and a power supply were chosen from these manufacturers.

From the AC and DC ampacity calculations in Appendix B, it was determined that type SJOOW 12 AWG 4 wire cable would be used to supply the current and voltage for the electrical system since 12 AWG cable can handle 20 amps. For the control wiring it is common practice to choose 16 AWG wire, and for AC three phase motors pulling less than 15 amps, it is common to use 14 AWG wire. (Galindo, 2012)

Panel Layout

With all of the parts selected for the electrical system, the panel layout was created based on the dimensions of the electrical parts' specification sheets. In the panel layout, all of the AC electrical components, such as the VFD and contactors, were grouped together and kept separate from the DC electrical components, such as the power supply, PLC, and control relays. For some components such as the PLC and Power supply, space was left between these components for ventilation purposes, so these components would not over heat. Space was also left between the electrical components and the Panduit to ensure there was space for the wires to hook up to the terminals of the electrical components. A series of panels from SCE were selected to see if these panels could hold all of the electrical components required for the project, ultimately a 24 inch by 24 inch by 8 inch stainless steel electrical panel with a 21 inch by 21 inch subpanel was chosen for the project. The drawing of the panel layout is in Appendix C.

PLC and Touchscreen Programming

The PLC ladder logic will be written using Schneider Electric's TwidoSuite software. In writing the control logic, all considerations and scenarios possible were taken into account. For instance, if the operator hit the emergency stop button in the middle of a dump, the machine will stop in a safe manner to help ensure that no one could get hurt. All of the inputs and outputs were addressed and named before the actual programming, and all other internal memory bits and timers were addressed and named as the program was being written. The ladder logic was separated into different sections and each section controlled a specific operation. For instance, one section of logic controlled the conveyors, another controlled the dumper while the cradle was lifting, another section controlled the dumper on its way down, and another section controlled the manual operation of the dumper. The PLC ladder logic program is included in Appendix F.

The Magelis touchscreen was programmed using Schneider Electric's Vijeo Designer Limited Edition Software. For the touchscreen, four different screens were programmed each having a specific purpose. The main home screen would tell the PLC to start, stop, and be in auto and manual mode. Some other operations include a bypass option to override the dumper to dump the boxes, and a setting to control the speed of the dumper in RPC's per minute. The second screen indicated the status of all of the inputs. The third screen was used to control all of the outputs when the machine is in manual mode. Finally the fourth screen was used to be able to change the presets of all of the timers in the PLC program without having to hook up a computer to the PLC. In the programming of the touchscreen, all variables were addressed according to the corresponding variable they were monitoring or controlling in the PLC ladder logic. A view of each of the touchscreen's screens is located in Appendix F.

The PLC and the touchscreen will be communicating using Modbus TCP/IP protocol, so as a result; both the PLC and the touchscreen would have their own IP address. An Ethernet switch was using in the panel to connect the two devices and be able to hook up a computer to the network easily to make changes to the devices.

Building Panel

By looking at the design drawings for the panel layout as a guide, the Panduit and din rail were cut to the lengths required and placed on the SCE subpanel, along with all of the electrical components, to ensure that there was enough space for the components. The Panduit mounting holes were then marked on the subpanel, as shown in Figure 12, and drilled. With the holes drilled in the subpanel, the Panduit was mounted using self-tapping crews as shown in Figure 13.

Figure 12. Subpanel with Panduit mounting locations marked.

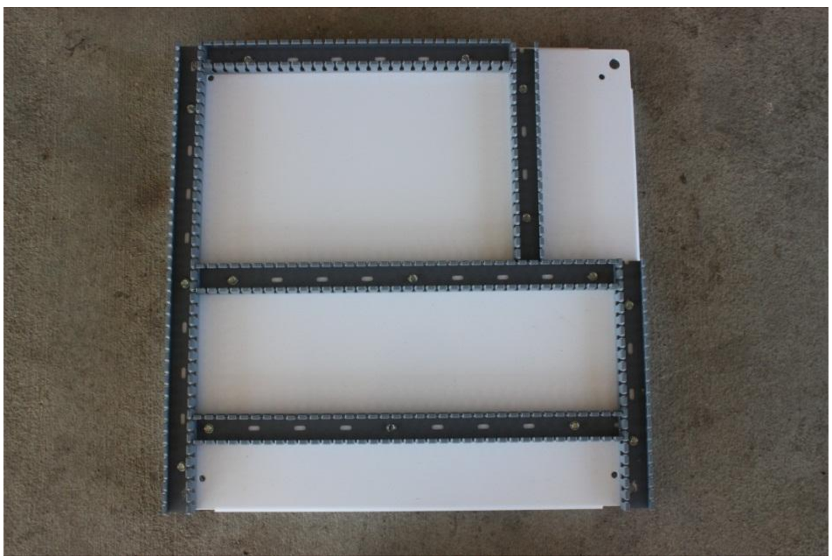

Figure 13. Subpanel with Panduit mounted.

With all of the mounting holes drilled, all of the DIN rail, Panduit, and the other electrical components that mount onto the DIN rail were mounted onto the panel; figures 14 and 15 show these components mounted

Figure 14. Subpanel with DIN rail, VFD, and distribution block mounted.

Figure 15. Subpanel with all electrical components mounted.

The next step is to wire up the components in the panel according to the wiring diagrams listed in Appendix C. There are three separate circuits that need to be wired up: the 208-230 VAC power distribution, the input circuit for the PLC, the output circuit for the PLC, and the 24 VDC power distributions. During this process, all wires should be tagged according to the wiring diagrams in Appendix C. Figure 16 shows how the panel looks when all of the components are hooked up accordingly.

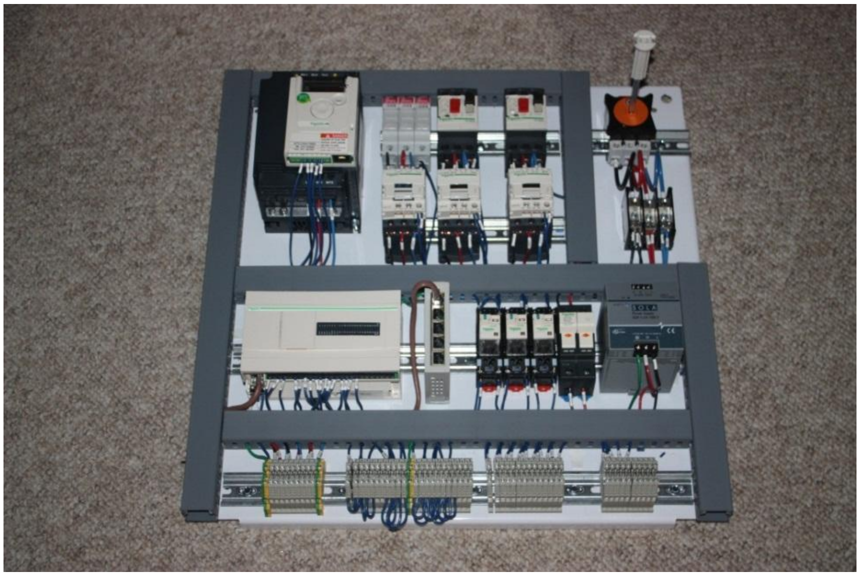

Figure 16. Subpanel with all electrical components wired up.

On the front of the panel, some holes need to be drilled in order to mount the emergency stop button, the touchscreen, and the electrical disconnect switch. These holes need to be drilled according to the manufacturer’s specifications for mounting, and the components need to be mounted on the door of the panel according to the construction drawings in Appendix C. Figure 17 depicts how the front of the panel looks with these components mounted.

Figure 17. Panel with touchscreen, emergency stop button, and disconnect switch mounted.

With the emergency stop button and touchscreen mounted, these components should be wired up according to the wiring diagrams in Appendix C. To run the wires from the terminal blocks to the components, zip ties and zip tie mounting pads should be used as seen in figure 18.

Figure 18. Panel with touchscreen and emergency stop wired up.

The subpanel should then be put inside the electrical enclosure and all components from the door of the enclosure should be wired up to ensure that everything looks correct and there are no wires being pinched, bent too much, or rubbing on sharp edges. Figure 19 shows the electrical panel with all components mounted.

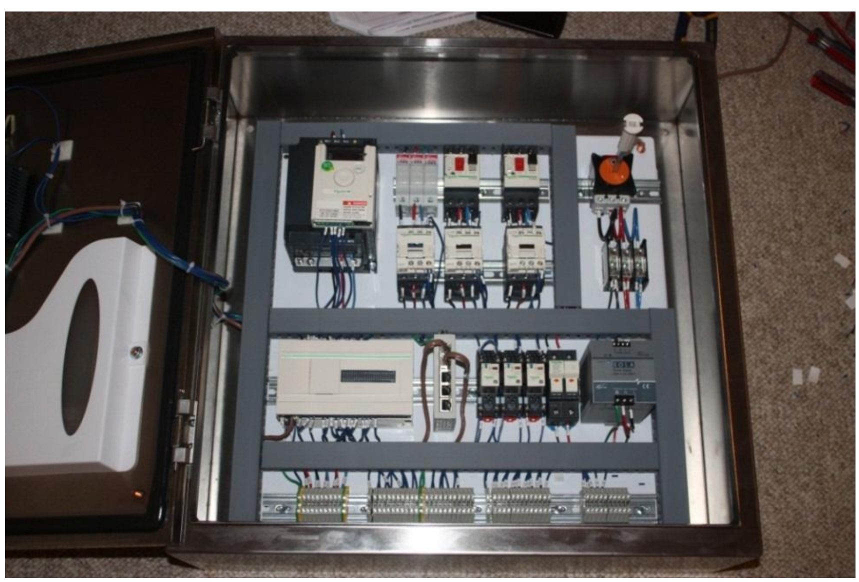

Figure 19. Subpanel mounted with electrical components in panel.

With every electrical component inside the electrical panel wired up and verified that everything is according to the design, the subpanel should be removed and the holes to mount the grommets for the sensors and conduit should be made. Once the knockouts are made to the correct size, then all of the grommets should be installed.

Dumper Frame Fabrication

During the setup of the electrical components, the frame for the dumper can be fabricated according to the design drawings and SolidWorks model being provided. The major steps of the fabrication should be done as follows

- Acquire material and conveyor frame
  - The conveyor frame for this project was cut and formed by Exeter Engineering.
- Cut all tubing and plate out using the band saws or a CNC plasma cutter
- Fabricate the legs and lower conveyor support structure according to the design drawings
- Fabricate the dumper cradle according to the drawings
- Fabricate the conveyor frame and all included components, such as the RPC stop and the inner chain guide supports
- Mount all mechanical components such as the AC motors and air cylinders
  - Certain components require special mounting areas and should be fabricated at this time
  - The take-ups for the chains systems should be installed and welded that this time as well.
- Assemble all large subcomponents together

Final Electrical Wiring

With the dumper frame fabricated, the next step is to mount all of the photo-eyes and limit switches onto the dumper frame and all Reed switches on the air cylinders. When these sensors are mounted, they need to be mounted in such a way to make sure that they sense the position of an object in the correct spot. For instance, the photo-eyes that will see the RPCs in the dumper cradle must be mounted so that they will see the RPCs clearly and not too early or too late.

At this time, the electro-valves for the air cylinders and the AC motors themselves should be wired up as well. Flexible conduit will be used to take the wires to the outputs and protect the wires from the elements. The electro-valves will have their own enclosure that will be sealed to ensure that moisture won’t get to the electrical components of the valves.

Once all of the sensors and actuators are mounted, all of the wires could be routed to the electrical box and wired up into their respective terminals according to the electrical schematics.

Testing

The initial testing of the entire system will be done at Cal Poly State University; RPCs full of citrus fruit will be used and run through the machine. The fruit will be dumped into a larger bin and reused until the initial testing is done. In the initial testing, all of the system components were looked at and the PLC control system were tested to make sure there are no bugs in the program. Many different scenarios were done during the testing to ensure the dumper system worked effectively.

For the initial testing, all of the input sensors were powered up and using the touchscreen the state of each input could be seen. All of the photo-eyes were adjusted using the sensitivity adjustment screw on the sensor to ensure that the sensor wouldn't see any background surfaces. The next step was to place an RPC in front of each photo-eye to see if the sensor would detect the presence of the box (see Figure 20); if the sensor did detect something it would show up on the touchscreen. The limit switches were manually engaged as well and the state of each limit switch was looked at on the touchscreen. Once the inputs were adjusted and checked out, each output was manually actuated using the touchscreen to see if the outputs would work correctly. During this point, the cams on the dumper shaft, as seen in Figure 21, were adjusted so that the limit switches would engage at the right spots in the dumper cycle.

Figure 20. Banner Electric Photo-eye.

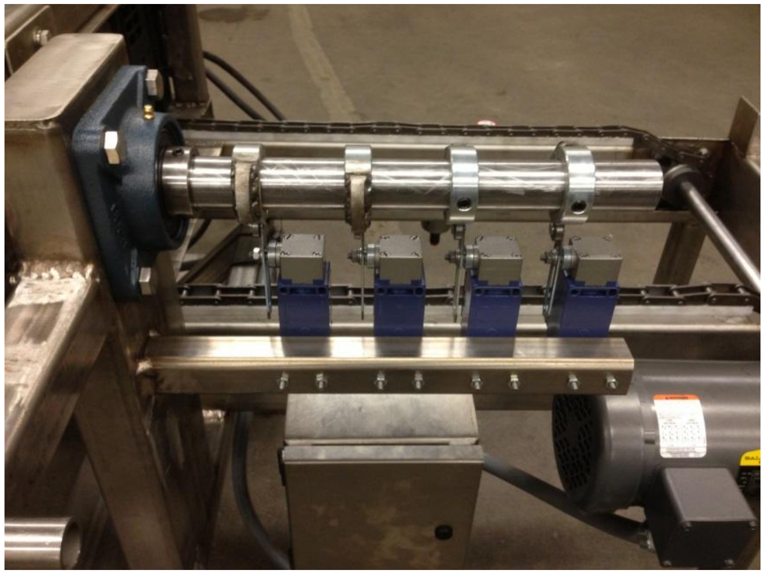

Figure 21. Adjusting Cams on Dumper Shaft for Limit Switches.

Once all of the inputs and outputs were checked, the dumper was run in auto mode to see how the machine would cycle. Any bugs in the programming were fixed at this point, and the machine was cycled again. The RPC Dumper was ready to be loaded up and transported to Bee Sweet Citrus once the machine cycled without any problems.

The actual performance and efficiency testing of the machine was done at Bee Sweet Citrus; the dumper was put into one of Bee Sweet Citrus's production lines and tested extensively, see Figure 22 and 23. The average number and maximum number of RPCs dumped per minute were measured here. Also, the machine's accessibility and mobility in the facility was looked at as well. The IRD was used during the testing here as well, so that the data acquired from this testing could be compared to the initial tests done in November with the IRD and hand dumping. The IRD testing results are in Appendix D.

Figure 22. Dumper Setup at Test Location.

Figure 23. RPC Dumper Test Run.

RESULTS

The total cost of material for the electrical system and the control system of the RPC dumper was about $3,650 with all discounts included. The total cost of materials for the entire project was $11,257.05, which is over the budget of $10,000 provided by Bee Sweet Citrus.

During the testing at Bee Sweet Citrus, the RPC Dumper was able to dump four boxes a minute very easily. The dumper was very easy to move around using a forklift, and setting the machine up to the right height and horizontal distance in respect to the conveyor was simple.

The PLC program and the touchscreen program worked fine without too many bugs in the programming. Any bugs or programming errors were done at the BRAE Department labs or at Bee Sweet Citrus during the testing. The electrical design and layout of the machine's controls worked great with only minor issues with the arrangement of some of the sensors, and with the frequency of the power applied to the brake of the brake motor.

The IRD was used during the testing at Bee Sweet Citrus. From the testing results, the velocity change of the impacts was decreased by about 80% compared to the testing results done in November. The impact duration was decreased by 38% compared to the testing results of hand dumping done in November.

DISCUSSION

The project overall was a huge undertaking but a good project; many valuable things were learned from this project from the PLC control to the fabrication process. The fabrication process was particularly difficult in some cases. Working with stainless steel can be very challenging, especially the welding of stainless steel. In order to keep everything straight or perpendicular, numerous clamps had to be used to keep the parts from distorting. In some cases, a scrap piece of tubing was placed between two members and tacked into place in order for distortion control. Some mistakes were made during the fabrication process and some welds weren't sufficient enough, so some parts needed to be redone. For example, the legs weren't exactly perpendicular to the 10 gage sheets acting as feet at first; the tacks had to be broken down redone.

The mechanical design had some strong points to it, but there were some mistakes in the design that needed to be corrected. The space clearances between certain parts of the machine had to be adjusted because they were too tight; as a result, more time had to be used to fix these problems. Time was a crucial factor from the beginning, and these errors in the mechanical design kept putting the project back. Another mistake that had to be changed was the larger 36 tooth 80 pitch sprocket used on the dumper shaft found to be hitting the RPCs before they got into the dumper cradle. Luckily, there was a large safety factor involved with the chain and motor system for the dumper cradle, and a smaller sprocket was able to be used. Another problem with this chain system was that the RPC stopper was interfering with the path of the chain, so an idler sprocket had to be bought and installed.

During the design and fabrication process, communication between the other members of the group was difficult as well. One aspect of the project was being able to work efficiently with another person on the same project; however, communication and coming to an agreement on certain aspects of the design was difficult. Despite the difficult communication at times, there were some times that the communication was good and problems were able to be solved quickly when they arose.

Testing and Program Debugging

In the testing phase of this project, small errors in the electrical design and bugs in the program were found, but these factors didn't affect the overall end result of the project. For the most part the electrical design and layout was sound and worked very well. The placement of some of the photo-eyes had to be adjusted because these sensors couldn't detect the presence of the RPCs very well. For instance, the photo-eyes underneath the cradle couldn't detect the RPCs no matter how much the sensitivity of the sensors was adjusted. The problem was determined to be that the photo-eyes were mounted at too much of an angle compared to the RPCs; this meant that the infrared light produced by the sensor couldn't reflect back to the sensor. The solution to the problem was to decrease that angle so that the sensors were very close to being perpendicular to the bottom of the RPC surface.

Another issue that was found during the debugging phase of the programming was that the variable frequency drive (VFD) couldn't be programmed like was initially thought. The VFD could still do the job that it was intended to do, but the programming and the PLC outputs going to the VFD had to be changed slightly in order to get the VFD to work properly. During the actual testing of the machine, the timer presets in the programming had to be adjusted in order to time the machine correctly; in some cases, the base unit of the timer had to be adjusted in order for the dumper to react so certain conditions faster. For instance, the delay to stop the set on conveyor of the dumper had to be changed from a base 10ms timer to a base 1ms timer because the set on conveyor couldn't be stopped quickly enough once the photo-eye positioned there detected an RPC.

One of the issues with the electrical design had to deal with the two horsepower brake motor and the VFD; at low frequency, the brake of the brake motor couldn't fully disengage. The problem what was determined during an examination was that the brake is rated for 60 Hz, and since the power applied to the brake was spliced off of the motor conductors after the VFD, the frequency was below 60 Hz. Once the frequency dropped below 15 Hz on the VFD, you could hear some noise coming from the brake; however, this didn't prevent the motor from running correctly. At any frequency above 15 Hz, the brake disengaged fine.

Besides all of the minor issues with the program and the design, the RPC Dumper operated as expected and very smoothly. The machine was able to dump four RPCs per minute without any trouble at all. The machine could definitely operate at a greater speed, because there were some parts during the cycle where there were long delays. However, this was due to the fact that fruit was still on the delivery and interfering with the photo-eye located at the delivery. The reason why fruit was being backed up on the belt was due to the fact that the location used for the test had a conveyor that was very narrow and very slow. This conveyor was limiting the speed of the machine during the testing; however, there are other locations inside the facility where the conveyors are running faster and are wider. At these locations is where the full potential of the RPC Dumper can be realized.

Cost Analysis

The cost of material for the entire machine totaled $11,257.05; this cost, however, doesn't include the cost of using the BRAE department's facilities or the cost of labor for the project. The amount of hours spent on this project between the both people working on the project was about 1000 hours which was way over the estimated amount of hours set at the beginning of the project of 500 hours. These 1000 hours represents the time developing and fabricating this machine for the first time.

By going through and improving and simplifying the design so it would be easier to fabricate, the labor spent on each machine could drop drastically. It can be assumed that if this machine were to be fabricated again with an improved design and improved fabricating process, then the labor spent building the machine again could easily drop to

300 hours. At a labor cost of $50 per hour, the labor cost during manufacturing would be $15,000. With an improved design, the cost of material could easily drop as well below $10,000. With these factors considered, the machine could easily be sold for $30,000. A cost analysis was performed by looking at the proposed sale value for the RPC Dumper and the benefits the machine will produce for the company. The cost analysis calculations are listed in Appendix G.

With the RPC Dumper, one of the workers that would normally be hand dumping this fruit could be put to another job. With all benefits, wages, and other taxes included, the cost of that one worker to Bee Sweet Citrus is $15 an hour. If the employee works 50 hours a week, and this is a very generous assumption, at four weeks in a month and 12 months in a year, the cost of this employee is $36,000 dollars. This assumption of the cost of the employee doesn't even include overtime, so potentially this cost could easily be higher. The results of the cost analysis concluded that this machine could very easily pay itself off within one year. After it has paid itself off, the benefit of that one employee doing something other than dumping RPCs will continue year after year, so the return on investment of this machine is 120%.

Another factor to consider is that this machine is a more efficient way to dump the RPCs that will reduce the strain and physical requirements of the workers and be less damaging to the fruit. The reduced amount of physical work required by the workers can potentially reduce workplace injuries and worker's compensation claims. This in itself could save the company thousands of dollars in workers compensation claims that would have been caused by worker injuries from manually dumping RPCs. The reduced damage to the fruit can also help to reduce decay seen in transport and at the stores, and as a result, will reduce the amount of rejections at the store and save thousands of dollars in unnecessary transportation costs back to the packing facility. With these other factors considered, the RPC Dumper can easily pay itself off with in a year and could potentially save Bee Sweet Citrus thousands of dollars in the long run.

RECOMMENDATIONS

The RPC Dumper can be improved by making the design simpler to fabricate. One way the fabrication process could be made easier and more efficient is to make stronger fixtures and jigs to help prevent distortion and square parts. Another way to simplify the fabrication process is to make an instruction sheet on how to properly and most efficiently fabricate the RPC dumper. Some parts of the fabrication for this project were trial and error; this method at times caused more work and took up too much time. Having an instruction booklet or list of procedures on how to fabricate this particular machine would definitely make this part of the project much more efficient. This way, many of these machines can be built faster and using less materials.

The cost of the entire project was more than was initially thought, but this is primarily because this machine is the first type of RPC dumper to be made. Therefore, there are going to be changes to the design. If this machine were to be built again, the time and material used to build the dumper would be less, because of the knowledge and skill acquired during the construction of this project.

In order to correct some of the issues in the electrical and PLC design, some changes could be made that won’t greatly affect the layout of the machine. To solve the issue with the brake on the brake motor, a separate circuit can be made before the VFD using another available output on the PLC and another ice cube relay. This ice cube relay can be energized only when the VFD sends current to the motor. With this separate circuit controlling the brake, there will always be a 60 Hz AC voltage at the brake no matter what frequency the VFD is outputting.

In some locations at Bee Sweet Citrus, the conveyor belt might limit the capacity of the RPC Dumper, like in the location used for the testing. To solve the problem of fruit piling up on top of each other on the conveyor belt, some adjustments to the Reed switches on the air cylinder controlling the gate on the lid can be made. One way to decrease the fruit piling up is to decrease the opening in which the fruit rolls out of; the Reed switch on the air cylinder telling the PLC that the lid is open can be moved closer to the center of the air cylinder. This way the cylinder will only open up part way and the fruit can be throttled back. When the machine is transferred to a different location where the full potential of the machine can be realized, the Reed switch that was previously moved can be moved back to the end of the air cylinder very easily so that the gate opens up completely.

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APPENDIX A

HOW PROJECT MEETS REQUIREMENTS FOR THE ASM MAJOR

HOW PROJECT MEETS REQURIMENTS FOR THE ASM MAJOR

ASM Project Requirements

The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving.

Application of Agricultural Technology. The project involves the application of mechanical systems, electrical systems, programmable logic controllers, and fabrication technologies.

Application of Business and/or management skills. The project involves business/management skills in the areas of economic and productivity analyses, and labor considerations.

Quantitative, Analytical Problem Solving. Quantitative problem solving will include the cost analysis, the design of the electrical subsystem, and performance tests.

Capstone Project Experience

The ASM project must incorporate knowledge and skills acquired in earlier coursework (Major, Support, and/or GE courses).

- BRAE 129 Lab Skills/Safety
- BRAE 133 Engineering Graphics
- BRAE 151 AutoCAD
- BRAE 142 Machinery Management
- BRAE 301 Hydraulic/Mechanical Power Systems
- BRAE 302 Servo Hydraulics
- BRAE 321 Ag Safety
- BRAE 324 Agricultural Electrification
- BRAE 342 Ag Materials
- BRAE 418/419 Ag Systems Management
- ENGL 149 Technical Writing
- AGB 310 Ag Finance
- AGB 401 Managing Cultural Diversity in Labor

ASM Approach

Agricultural Systems Management involves the development of solutions to technological, business, or management problems associated with agricultural or related industries. A systems approach, interdisciplinary experience, and agricultural training in specialized areas of common features of this type of problem solving.

Systems Approach. The project involves the integration of multiple functions, which include mechanical power transmissions, electrical system design and wiring, PLC applications, and the integration of citrus processing systems to provide Bee Sweet Citrus, Inc. with a mechanical means of dumping RPCs.

Interdisciplinary Features. The project touches on aspects of mechanical systems, electrical systems, programmable logic controllers, agricultural safety, and labor management.

Specialized Agricultural Knowledge. The project applies specialized knowledge in the areas of mechanical systems, fabrication systems, electrical systems, programmable logic controllers, and citrus processing.

APPENDIX B

DESIGN CALCULATIONS

Table 1. AC Ampacity

Quantity	Name	Model Number	Max Amps (A)*	Total Amps (A)	Total Power (VA)
			Source Voltage (VAC) =	208	
2	Baldor 1/2 Hp AC 3-Phase Motor	VM3538	2.500	5.00	1040.00
1	Schneider Electric 2 HP VFD	ATV12HU15M3	11.100	11.10	2308.80
1	SOLA HD Power Supply 4A	SDP-4-24-100LT	1.000	1.00	208.00
			Total	17.10	3556.80
			Safety Factor	15%	15%
			Total REQ'D	19.67	4090.32

Table 2. DC Ampacity

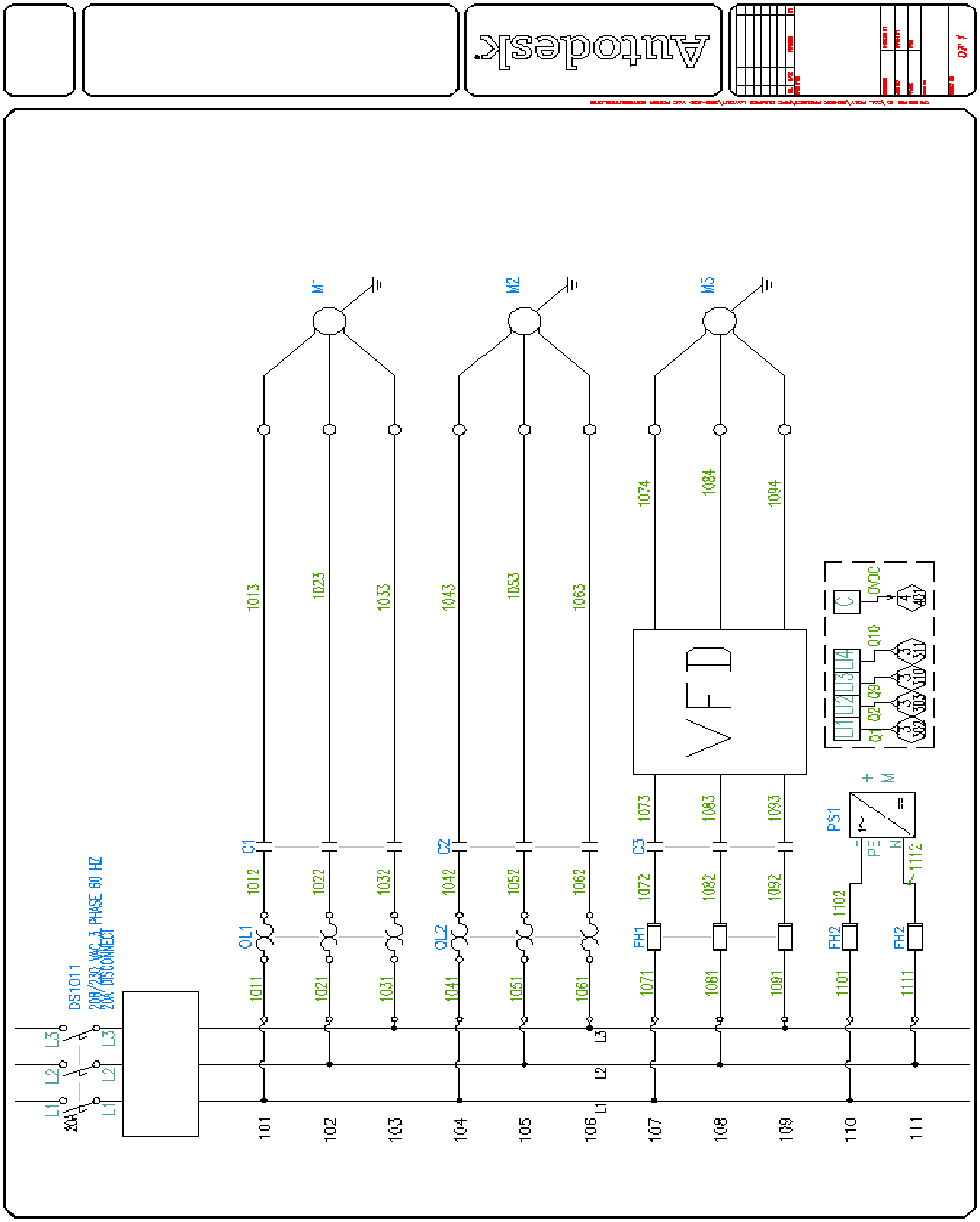
Quantity	Name	Model Number	Max Amps (A)*	Total Amps (A)	Total Wattage (W)
			Source Voltage (VDC) =	24	
4	Banner Mini-Beam Sensor Power	SM312QD	0.025	0.10	20.80
1	Banner Mini-Beam Sensor Power	SM312LVQD	0.025	0.03	5.20
1	SMC Auto Switch Sensor Power	D-C73Z	0.040	0.04	8.32
3	SMC Auto Switch Sensor Power	D-A93Z	0.040	0.12	24.96
1	Schneider Electric PLC Power	TWDLCDE40DRF	0.717	0.72	149.14
1	Schneider PLC Input Current	TWDLCDE40DRF	0.177	0.18	36.82
1	Schneider Electric Touchscreen	HMISTU655	0.271	0.27	56.37
3	Schneider Electric Contactor	LC1D09BD	0.225	0.68	140.40
3	Schneider Electric Relay	RXM2AB2BD	0.038	0.11	23.71
1	Schneider Electric Ethernet Swtich		0.092	0.09	19.14
4	Schneider Electric VFD Logic Inputs		0.010	0.04	8.32
2	5 port electrovalve SMC		0.017	0.03	6.95
1	3 port electrovalve SMC		0.017	0.02	3.47
			Total	2.42	503.59
			Safety Factor	15%	15%
			Total REQ'D	2.78	579.13

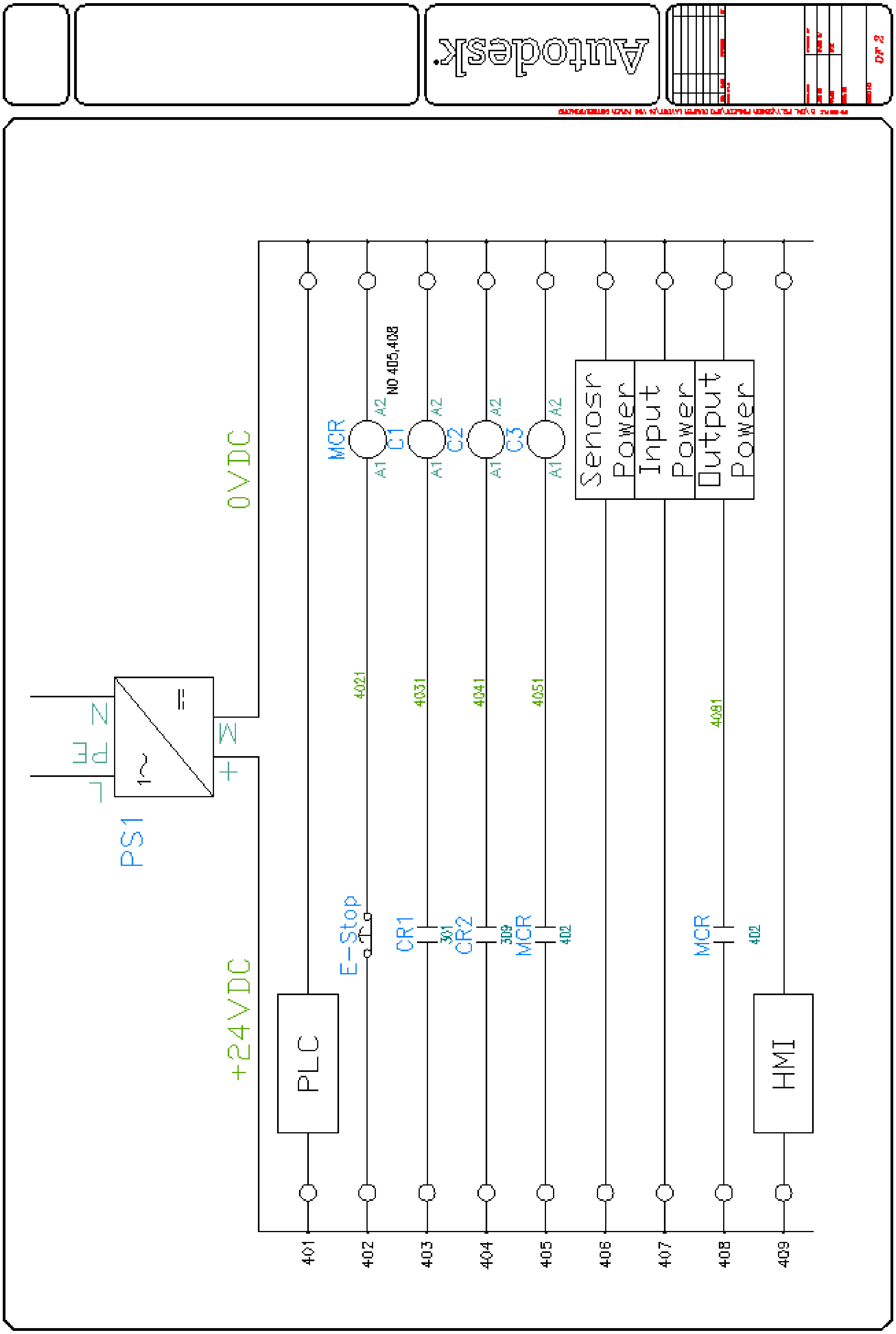
*The max amperage values for each component were gathered from the components specification sheets in the manufacturers' catalogs.

Total Power = Total Amps * Source Voltage = 5.00 A * 208 VAC = 1040 VA

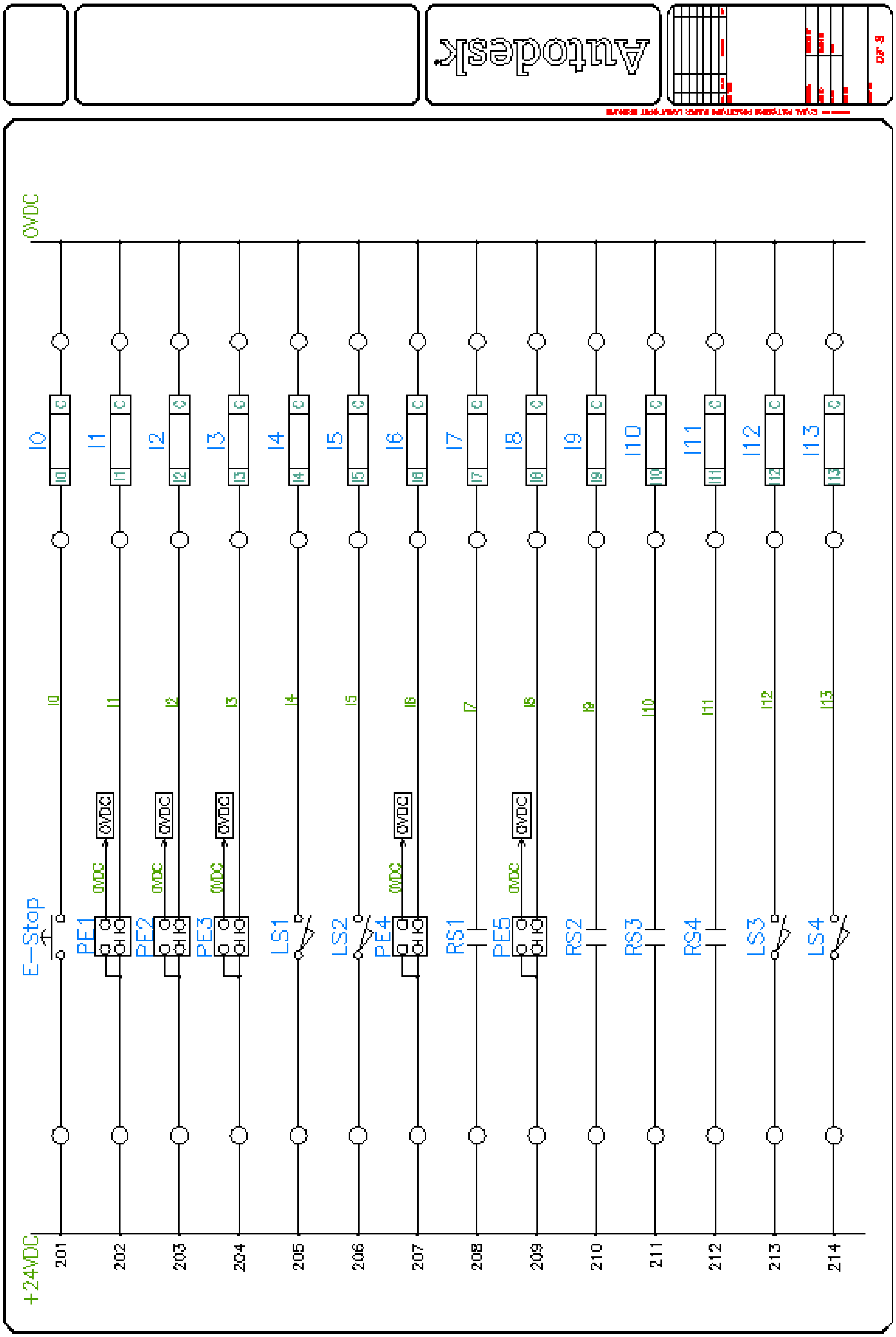
APPENDIX C

CONSTRUCTION DRAWINGS


Autodesk
DS1011
208/230 VAC 3 PHASE 60 HZ
20A DISCONNECT
L1
L2
L3
OL1
OL2
C1
C2
C3
FH1
FH2
PS1
VFD
M1
M2
M3
101
102
103
104
105
106
107
108
109
110
111



Autodesk
PS1
L
PE
N
M
+
0VDC
+24VDC
PLC
E-Stop
CR1
301
CR2
309
MCR
402
MCR
C1
C2
C3
A1
A2
NO 405,408
4021
4031
4041
4051
4091
Senosr Power
Input Power
Output Power
HMI
401
402
403
404
405
406
407
408
409


Autodesk
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+24VDC
E-Stop
PE1
PE2
PE3
PE4
PE5
LS1
LS2
LS3
LS4
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RS2
RS3
RS4
I0
I1
I2
I3
I4
I5
I6
I7
I8
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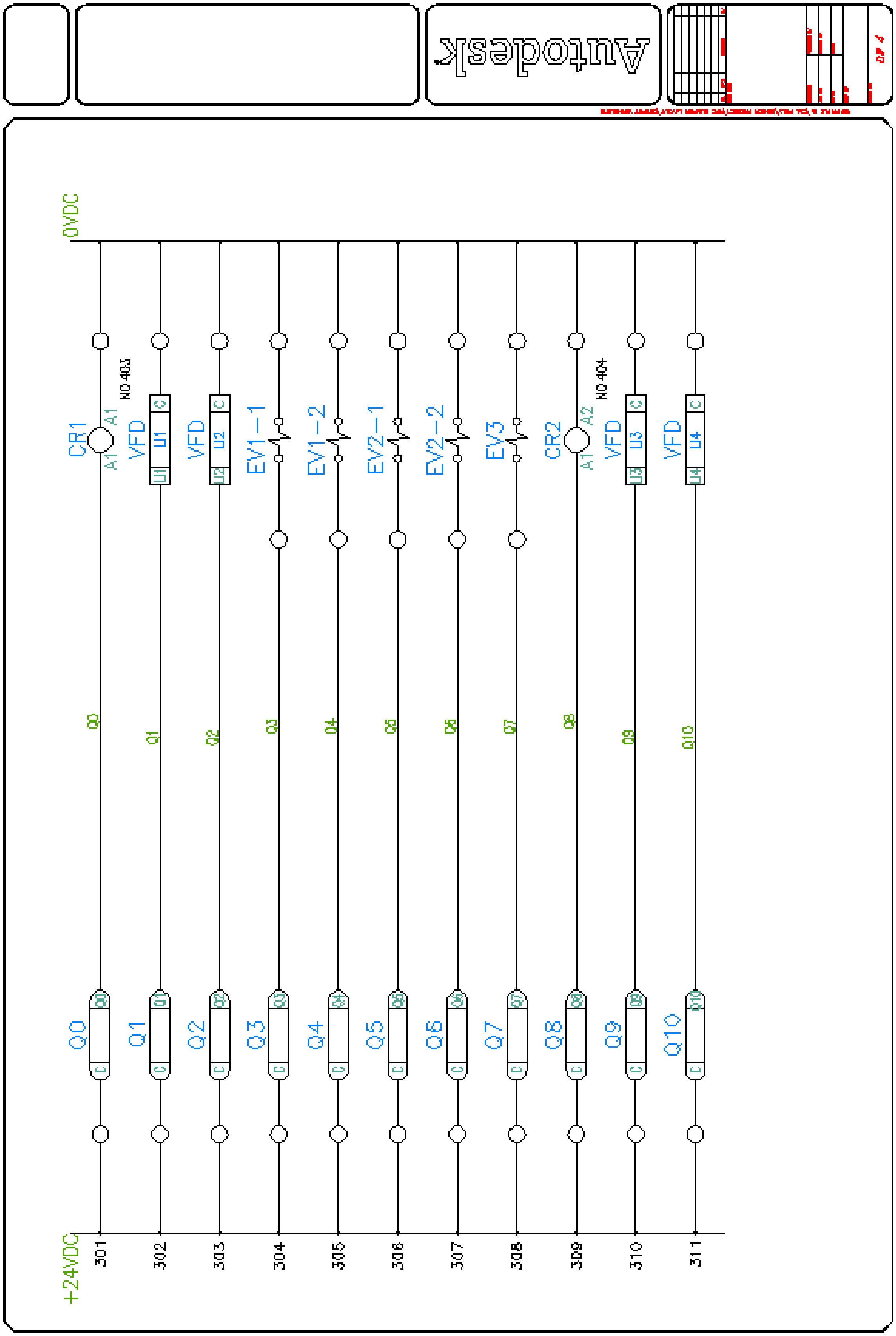
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+24VDC
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A1
A2
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U1
VFD
U2
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EV1-2
EV2-1
EV2-2
EV3
CR2
NO 404
VFD
U3
VFD
U4
Q0
Q1
Q2
Q3
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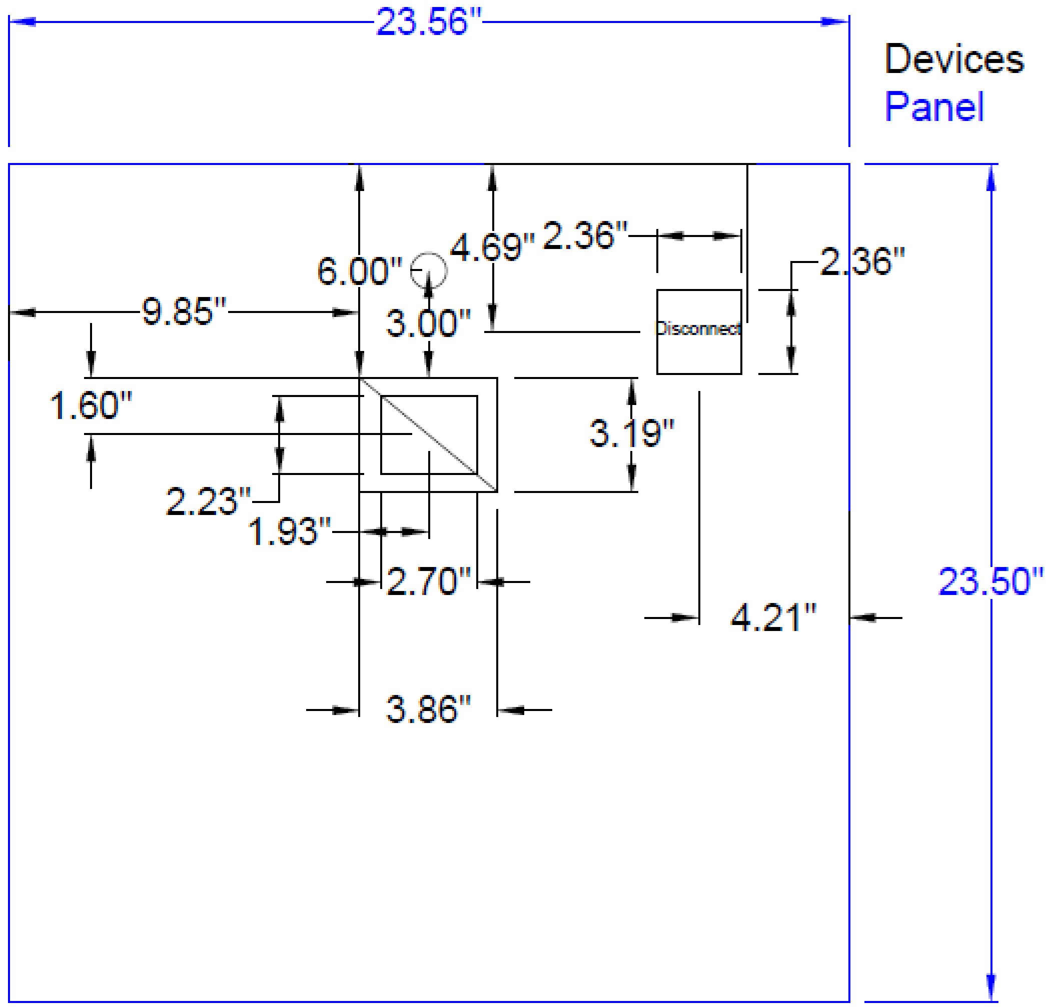
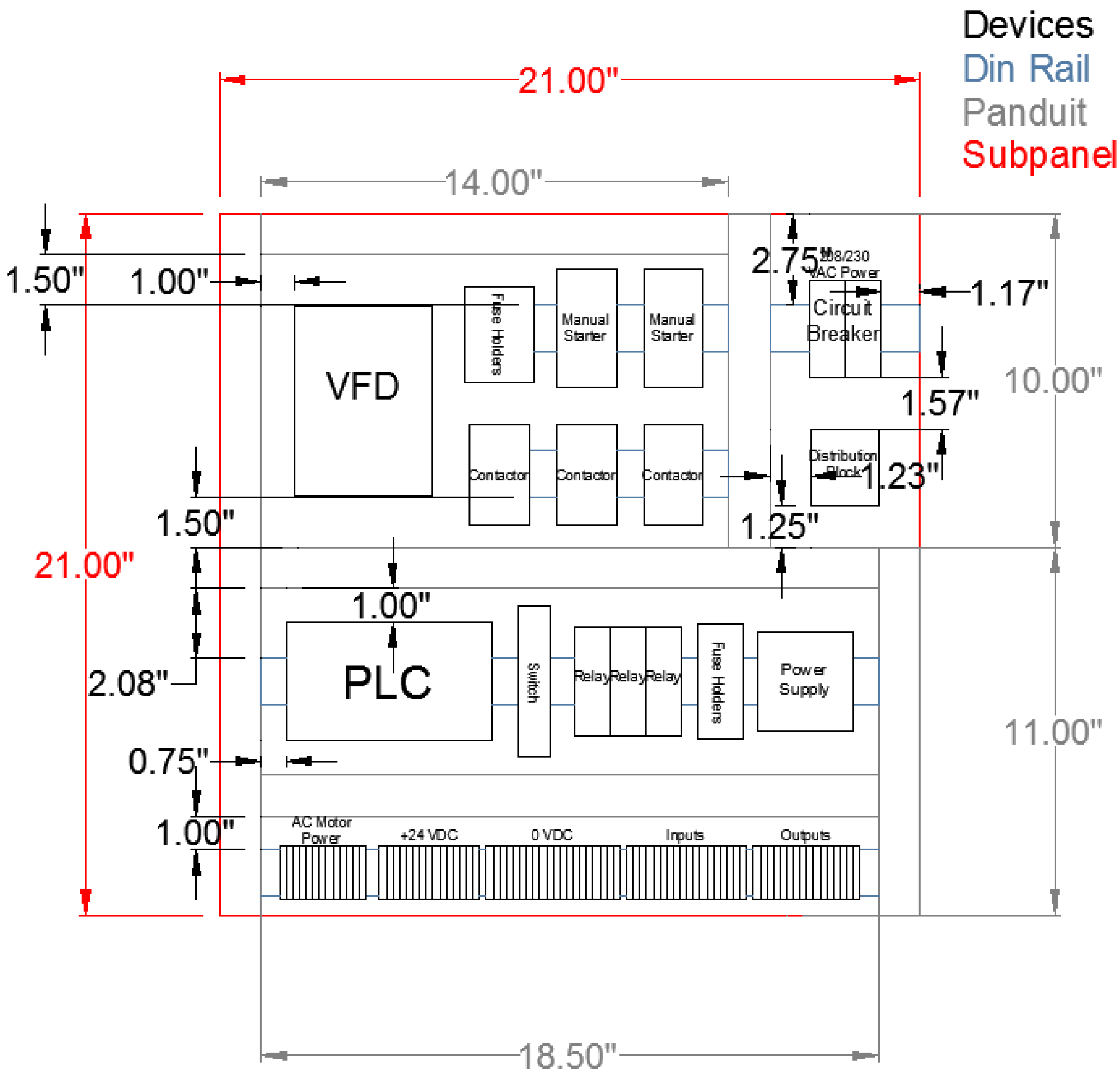

23.56"
Devices
Panel
6.00"
4.69"
2.36"
2.36"
9.85"
3.00"
Disconnect
1.60"
3.19"
2.23"
1.93"
2.70"
23.50"
4.21"
3.86"

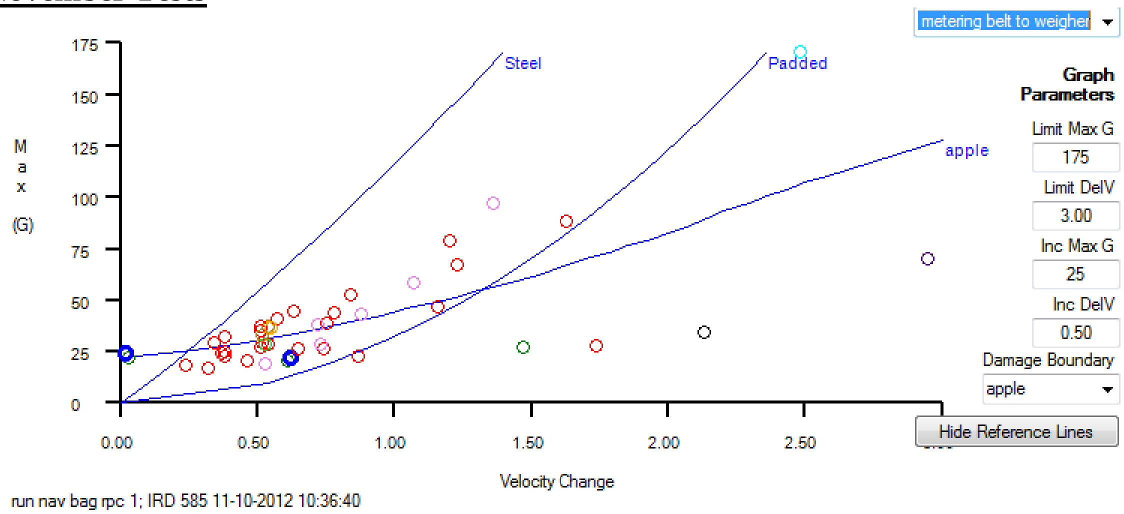


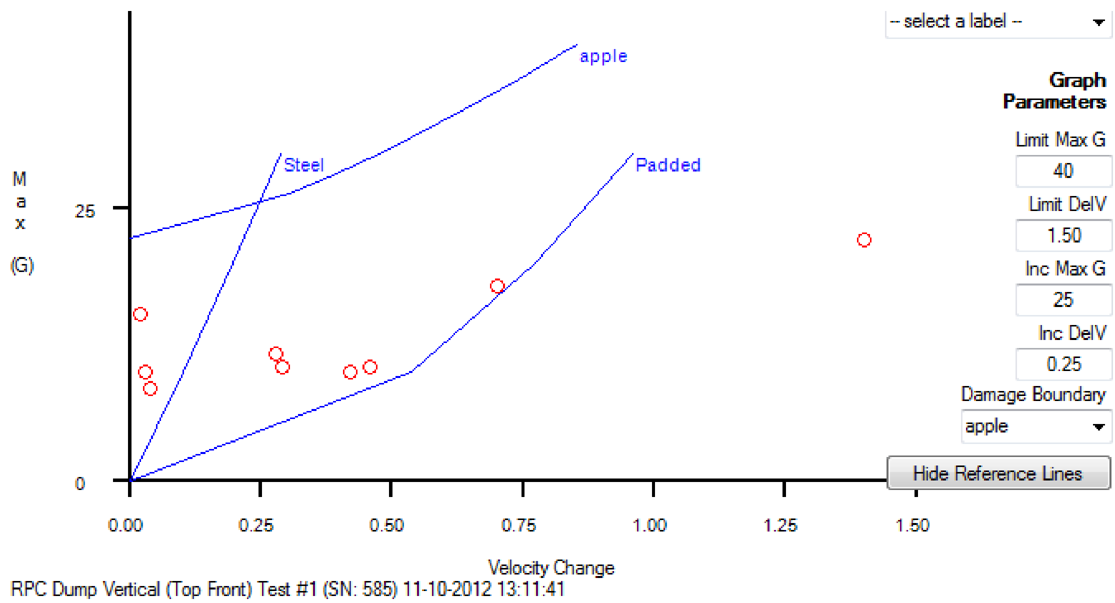
Devices
Din Rail
Panduit
Subpanel
21.00"
14.00"
1.50"
1.00"
VFD
Fuse Holders
Manual Starter
Manual Starter
Contactor
Contactor
Contactor
2.75"
208/230 VAC Power
Circuit Breaker
1.17"
1.57"
Distribution Block
1.23"
10.00"
1.25"
1.50"
21.00"
1.00"
PLC
Switch
Relay
Relay
Relay
Fuse Holders
Power Supply
2.08"
0.75"
1.00"
11.00"
AC Motor Power
+24 VDC
0 VDC
Inputs
Outputs
18.50"

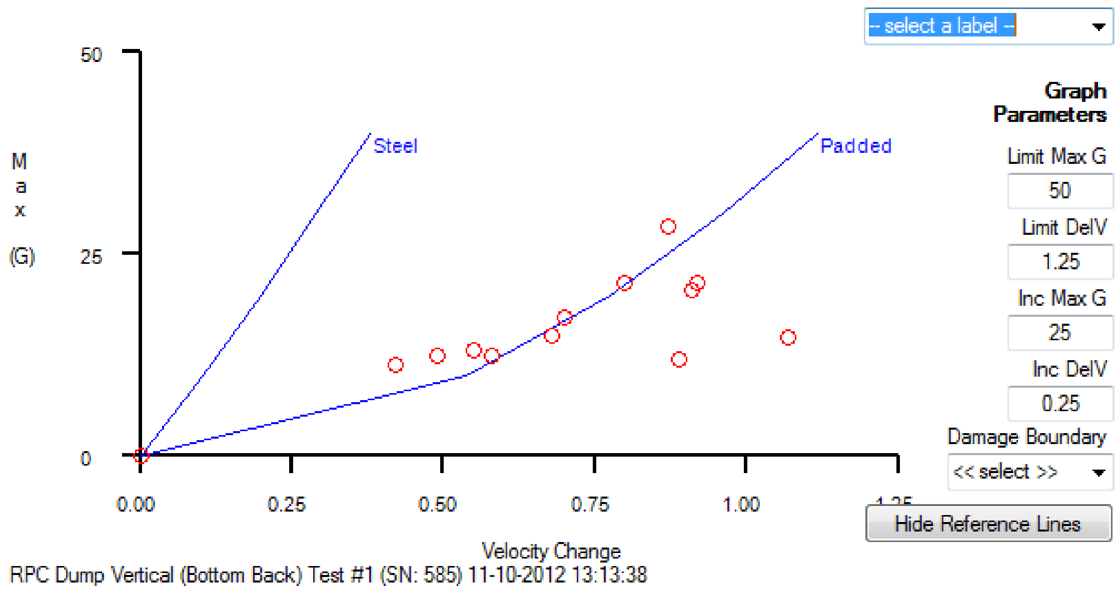
APPENDIX D

TECHMARK IRD TESTING RESULTS

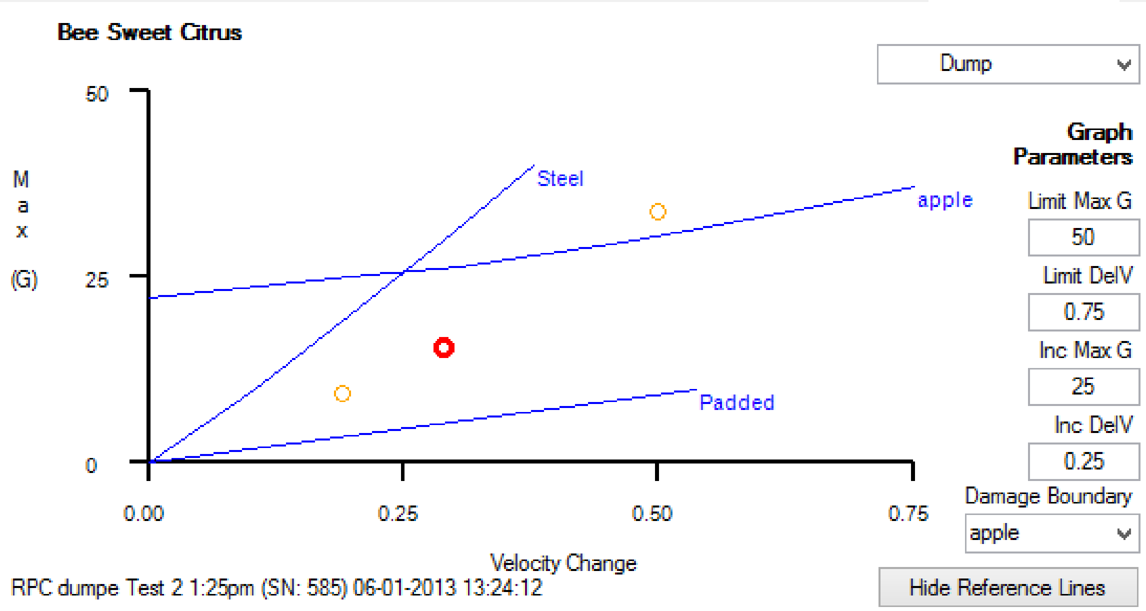
November Tests

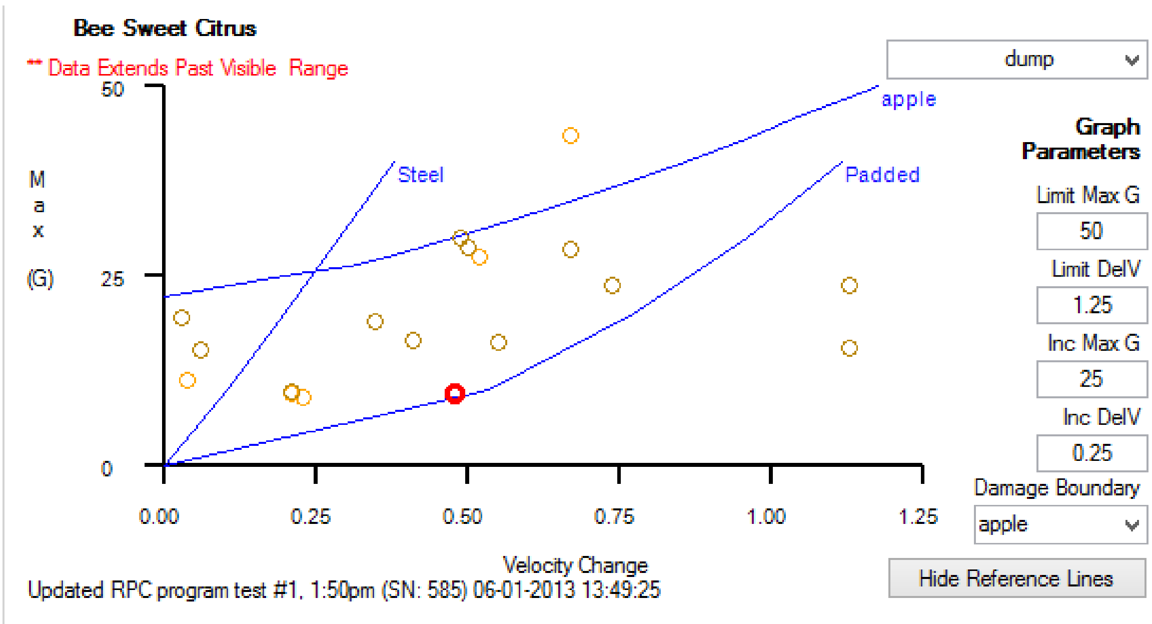


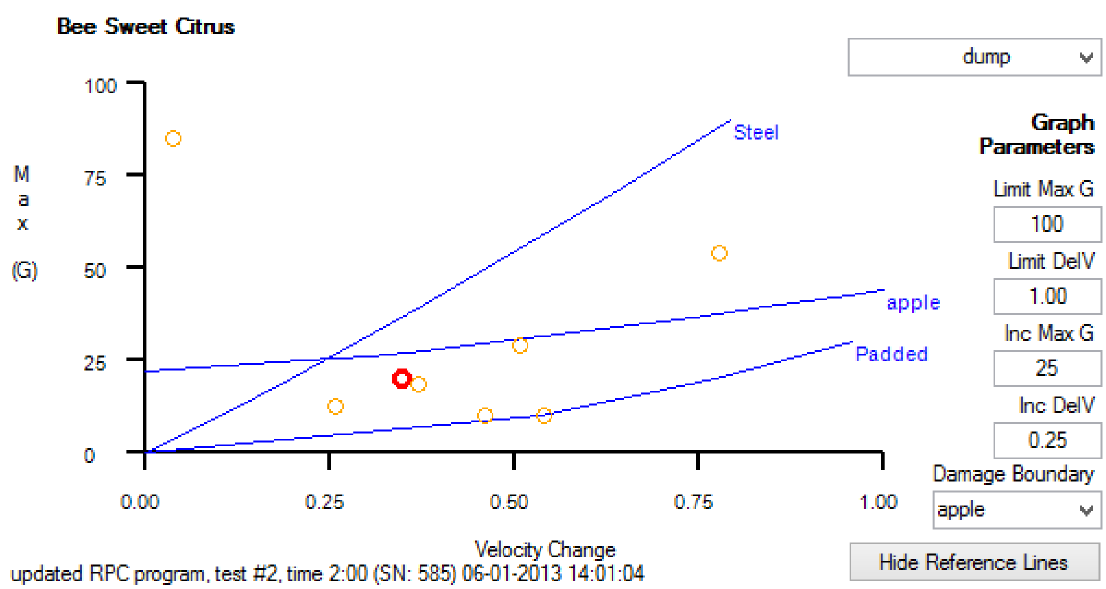


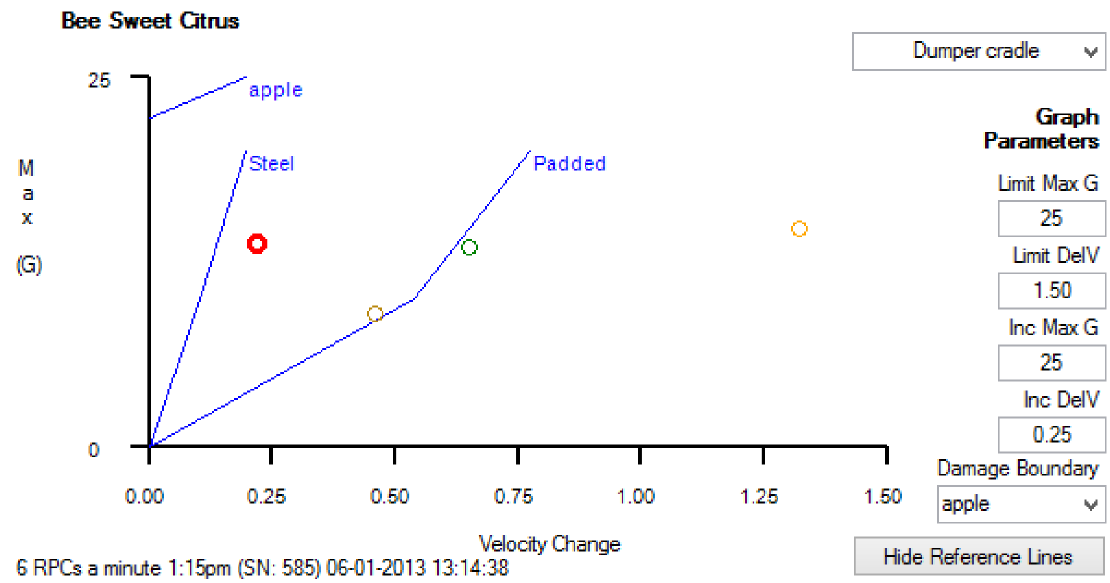


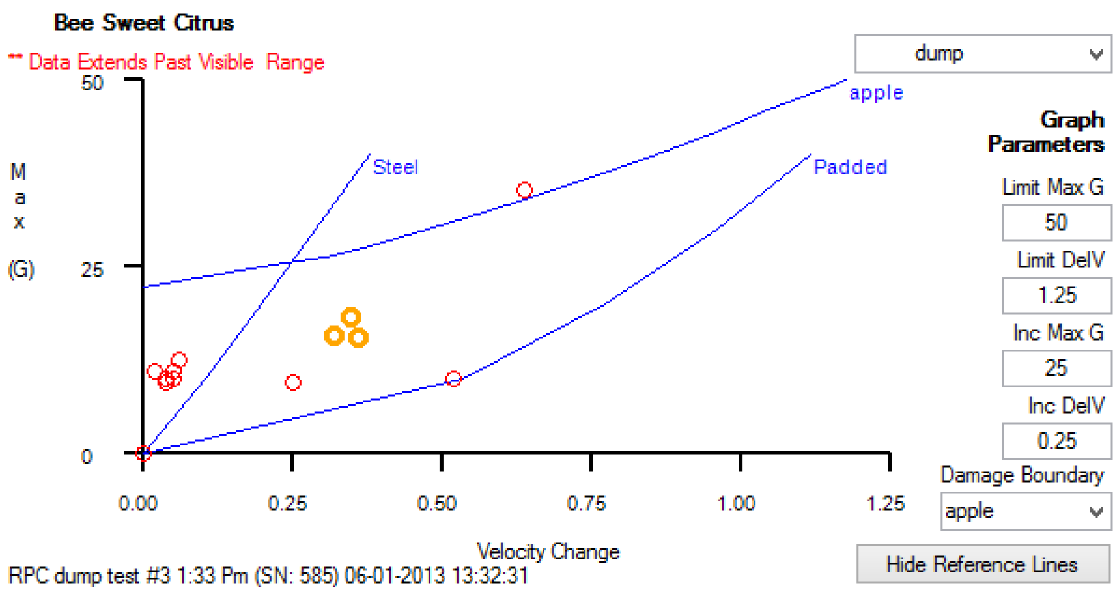
RPC Dumper Tests

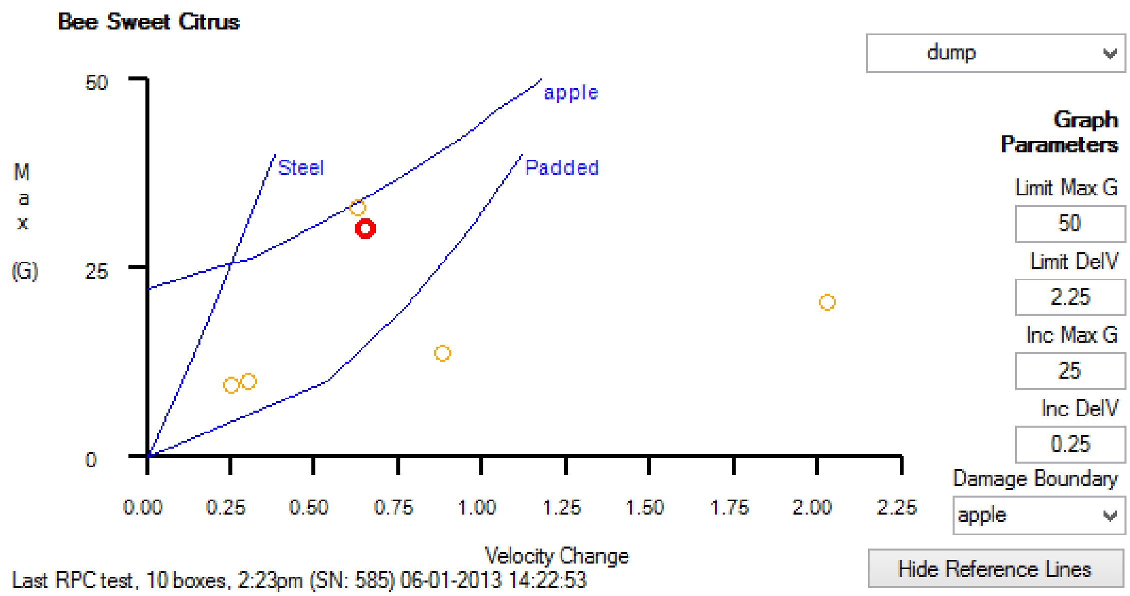



Bee Sweet Citrus
** Data Extends Past Visible Range
dump
apple
Steel
Padded
Graph Parameters
Limit Max G
50
Limit DelV
1.25
Inc Max G
25
Inc DelV
0.25
Damage Boundary
apple
Hide Reference Lines
Max (G)
50
25
0
0.00
0.25
0.50
0.75
1.00
1.25
Velocity Change
Updated RPC program test #1, 1:50pm (SN: 585) 06-01-2013 13:49:25


Bee Sweet Citrus
dump
Steel
apple
Padded
Graph Parameters
Limit Max G
100
Limit DelV
1.00
Inc Max G
25
Inc DelV
0.25
Damage Boundary
apple
Hide Reference Lines
Max (G)
100
75
50
25
0
0.00
0.25
0.50
0.75
1.00
Velocity Change
updated RPC program, test #2, time 2:00 (SN: 585) 06-01-2013 14:01:04


Bee Sweet Citrus
Dumper cradle
25
apple
Steel
Padded
Max
(G)
0
0.00
0.25
0.50
0.75
1.00
1.25
1.50
Velocity Change
6 RPCs a minute 1:15pm (SN: 585) 06-01-2013 13:14:38
Graph Parameters
Limit Max G
25
Limit DelV
1.50
Inc Max G
25
Inc DelV
0.25
Damage Boundary
apple
Hide Reference Lines


Bee Sweet Citrus
** Data Extends Past Visible Range
dump
50
apple
Steel
Padded
Max
(G)
25
0
0.00
0.25
0.50
0.75
1.00
1.25
Velocity Change
RPC dump test #3 1:33 Pm (SN: 585) 06-01-2013 13:32:31
Graph Parameters
Limit Max G
50
Limit DelV
1.25
Inc Max G
25
Inc DelV
0.25
Damage Boundary
apple
Hide Reference Lines


Bee Sweet Citrus
dump
Graph Parameters
Limit Max G
50
Limit DelV
2.25
Inc Max G
25
Inc DelV
0.25
Damage Boundary
apple
Hide Reference Lines
M a x (G)
50
25
0
apple
Steel
Padded
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
Velocity Change
Last RPC test, 10 boxes, 2:23pm (SN: 585) 06-01-2013 14:22:53

APPENDIX E

BILL OF MATERIALS

Bill of Materials			
Item	Price/Unit	Quantity	Price
SM312DQD Banner Diffuse Mini		4	
QS30LPQ Retro NPN World Beam		1	
MQDC-415 Banner QD Cable, 4-C		4	
MQDC1-515RA 5 Pin Euro Right Ang		1	
SDP424100LT Power Supply 100W 24		1	
F1X1LG6 DUCT P/FT		12 ft	
C1LG6		12 ft	
SCE-24EL2408SSLP 24x24x8 NEMA 4X 304SS		1	
SCE-24P24 24x24 Back Panel		1	
AJT12 600V Class J TD Fuse		3	
ATDR2A 600V 2A CC TD FU		2	
Electric Motor Shop Bill			$ 1,157.72
Schneider Electric LC1D09BD 600V 9A Contactor		2	
Schneider Electric GV2ME08 2.5-4A 600V Man Starter		2	
Schneider Electric TWDLCDE40DRF DC24 Base Unit		1	
Schneider Electric HMISTU655 3.5" 22mm Touchscreen		1	
Schneider Electric TCSESU053FN0 ETH SW		1	
Schneider Electric RXM2AB2BD Plug-In Relay 250V		3	
Schneider Electric RXZE2S108M Relay Socket 300V		3	
Schneider Electric ZB4BZ102 MTG Base N/C Contact		1	
Schneider Electric ZB4BT4 Red Mushroom PB		1	
Schneider Electric 9080MH379 Termianl Block Rail		1	
Schneider Electric VCCF1 Switch Kit		1	
Schneider Electric AB1VV235U Terminal Block 600V		1	
Schneider Electric 9080LBA361104 PWR Dist. Block		1	
Schneider Electric ATV12HU15M3 Altivar VFD		1	
Schneider Electric DFCC2V Fuseholder 600V 30 Amp		1	
All-Phase Medallion Bill			$ 2,425.00
Valley Iron Bill			$ 2,118.83
Motion Industries Bill			$ 1,104.28
Steve Perry (Power Transmission) Bill			$ 3,012.80
McMaster Carr Bill			$ 1,038.42
Miscellaneous Items (wire, welding gas, bolts, nuts, etc.)			$ 400.00
	Total Price		$ 11,257.05

APPENDIX F

PLC LADDER LOGIC AND TOUCHSCREEN CONTROLS

PLC Ladder Logic

Memory objects configuration

Timer configuration (%TM)

Used	%TM	Symbol	Type	Adjustable	Time Base	Preset
Yes	%TM0	STOP_SET_ON_CONV_DELAY	TON	Yes	1 ms	100
Yes	%TM1	CLEARING_RPCS	TON	Yes	10 ms	500
Yes	%TM2	LOWER_LID_DELAY	TON	Yes	10 ms	100
Yes	%TM3	RAISE_DUMPER_DELAY	TON	Yes	10 ms	200
Yes	%TM4	RAISE_DUMPER_SLOW_DELAY	TON	Yes	10 ms	25
Yes	%TM5	GATE_OPEN_DELAY	TON	Yes	10 ms	100
Yes	%TM6	DELIVERY_CLEAR_DELAY	TON	Yes	1 s	12
Yes	%TM7	LOWER_DUMPER_SLOW_DELAY	TON	Yes	10 ms	15
Yes	%TM8	STOPPER_UP_DELAY	TON	Yes	10 ms	300
Yes	%TM9	DELIVERY_CLEARING	TON	Yes	10 ms	75

Counter configuration (%C)

Register configuration (%R)

Drum configuration (%DR)

Scheduler block configuration (%SCH)

Fast counters configuration (%FC)

Very fast counters configuration (%VFC)

Memory words (%MD)

Memory words (%MW)

Used	%MW	Symbol	Allocated
Yes	%MW0		Yes
Yes	%MW2		Yes
Yes	%MW4		Yes
Yes	%MW6		Yes
Yes	%MW8		Yes
Yes	%MW10		Yes
Yes	%MW12		Yes
Yes	%MW14		Yes
Yes	%MW16		Yes
Yes	%MW18		Yes
Yes	%MW20		Yes

Memory words (%MF)

Memory bits (%M)

Used	%M	Symbol	Allocated
Yes	%M0	START	Yes
Yes	%M1	STOP	Yes
Yes	%M2	RUN	Yes
Yes	%M3	RPCS_LOADED	Yes
Yes	%M4	DUMPER_EMPTYING	Yes
Yes	%M5	DUMPER_CYCLE	Yes
Yes	%M6	LID_LOWER	Yes
Yes	%M7	DUMPER_RAISE	Yes

Used	%M	Symbol	Allocated
Yes	%M8	DUMPER_RAISE_SLOW	Yes
Yes	%M9	GATE_WANT_OPEN	Yes
Yes	%M10	FRUIT_EMPTYING	Yes
Yes	%M11	DELIVERY_WANT_CLOSE	Yes
Yes	%M12	DUMPER_LOWER	Yes
Yes	%M13	DUMPER_LOWER_SLOW	Yes
Yes	%M14	LID_RAISE	Yes
Yes	%M15	RPCS_CLEARING	Yes
Yes	%M16	MANUAL	Yes
Yes	%M17	MANUAL_OP	Yes
Yes	%M18	BYPASS	Yes
Yes	%M19	SET_ON_CONV_ON	Yes
Yes	%M20	EXIT_CONV_ON	Yes
Yes	%M21	RAISE_DUMPER_ON	Yes
Yes	%M22	RAISE_DUMPER_SLOW_ON	Yes
Yes	%M23	LOWER_DUMPER_ON	Yes
Yes	%M24	LOWER_DUMPER_SLOW_ON	Yes
Yes	%M25	STOPPER_ON	Yes
Yes	%M26	LOWER_LID_ON	Yes
Yes	%M27	RAISE_LID_ON	Yes
Yes	%M28	OPEN_GATE_ON	Yes
Yes	%M29	CLOSE_GATE_ON	Yes
Yes	%M30	SET_ON_CONV_RUN	Yes
Yes	%M31	EXIT_CONV_RUN	Yes
Yes	%M32	RAISE_DUMPER_RUN	Yes
Yes	%M33	RAISE_DUMPER_SLOW_RUN	Yes
Yes	%M34	LOWER_DUMPER_SLOW_RUN	Yes
Yes	%M35	LOWER_DUMPER_RUN	Yes
Yes	%M36	STOPPER_RUN	Yes
Yes	%M37	LOWER_LID_RUN	Yes
Yes	%M38	RAISE_LID_RUN	Yes
Yes	%M39	OPEN_GATE_RUN	Yes
Yes	%M40	CLOSE_GATE_RUN	Yes
Yes	%M41	RESET_DUMPER_CYCLE	Yes
Yes	%M42	DUMPER_CYCLE_RESET_RUN	Yes
Yes	%M43	DELIVERY_CLEARED	Yes

PID configuration (PID)

Constant configuration (%KD)

Constant configuration (%KW)

Used	%KW	Symbol	Decimal	Hexadecimal	Bin-value	Ascii
Yes	%KW0		120	16#0078	0000000001111000	x
Yes	%KW2		12	16#000C	0000000000001100	

Constant configuration (%KF)

PLS/PWM configuration (%PLS/%PWM)

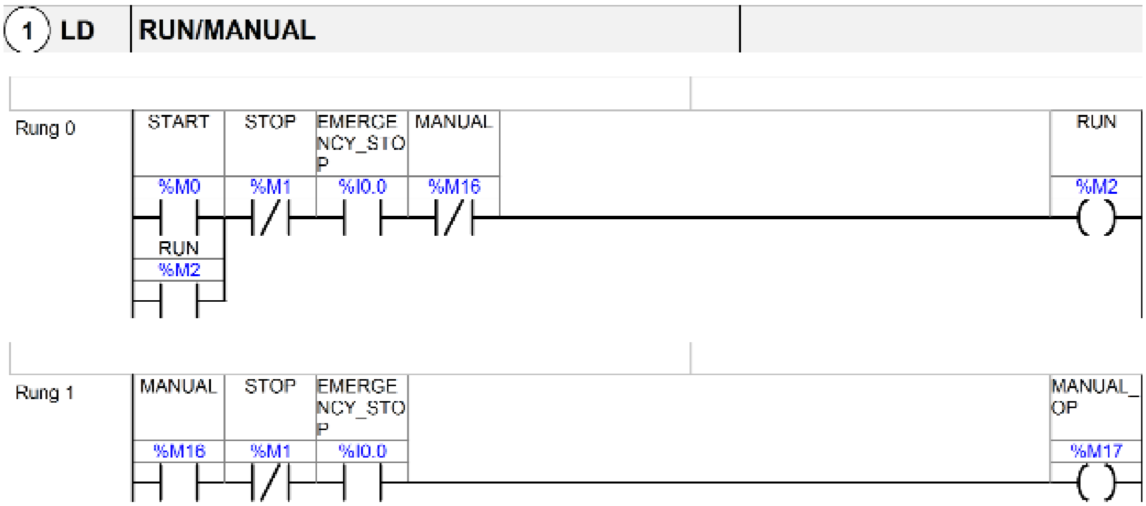
Configuration of external objects Comm

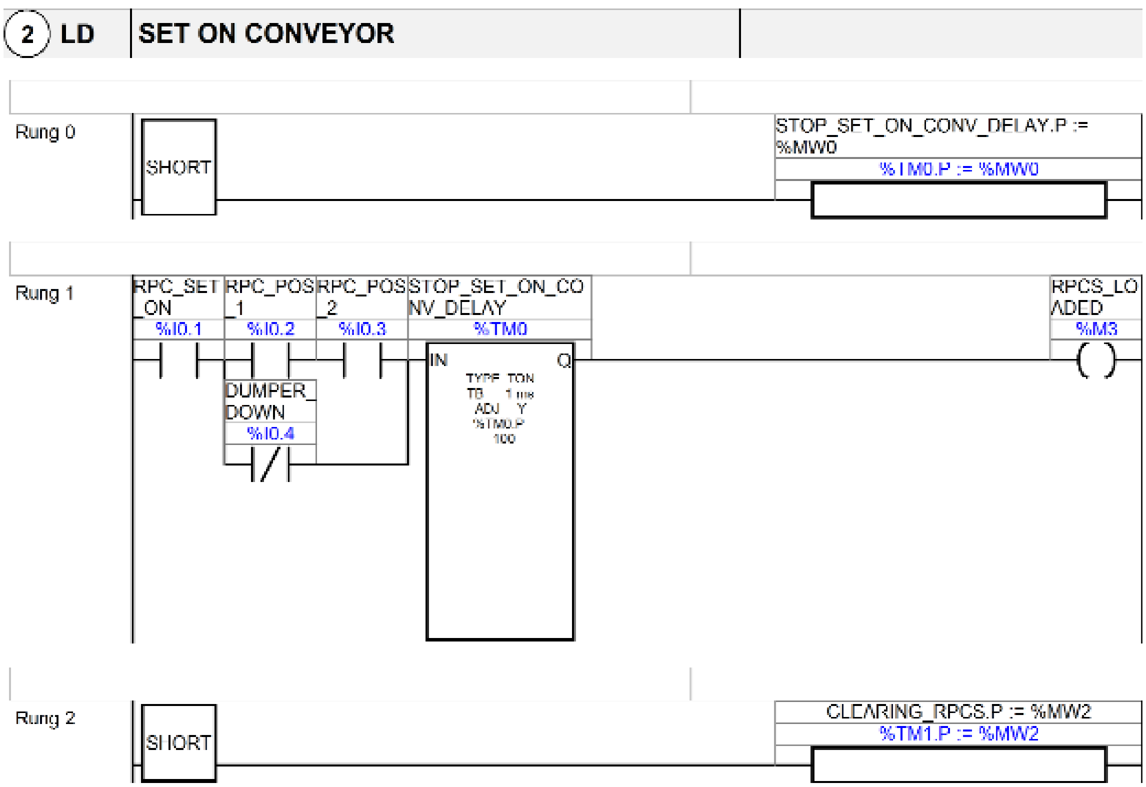
Configuration of external objects Drive

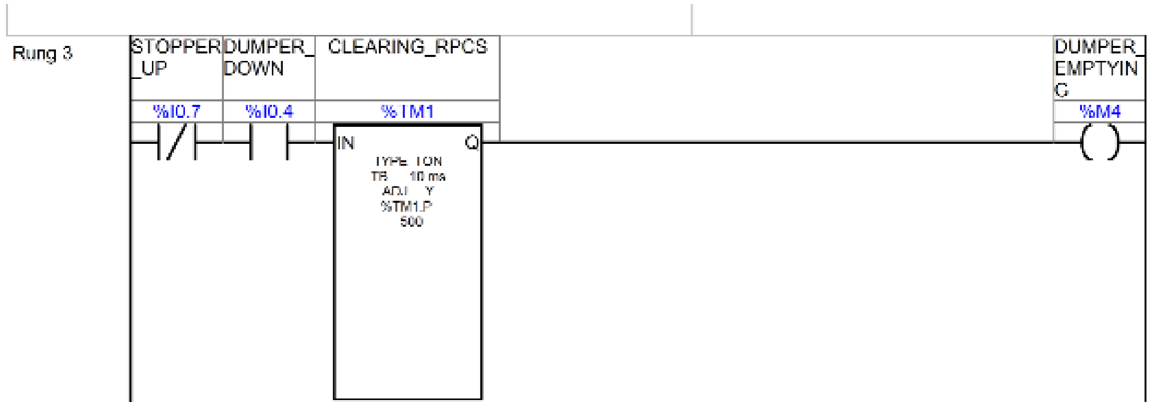
Configuration of external objects Tesys

Configuration of external objects Advantys OTB

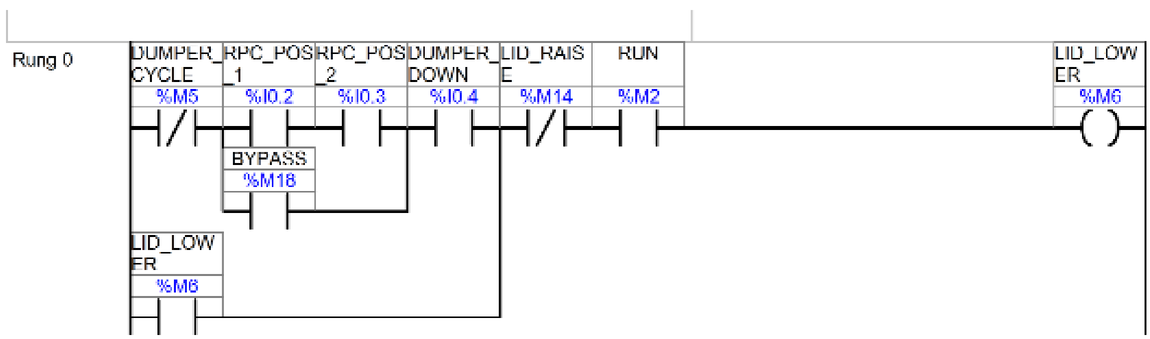
Program lists and diagrams

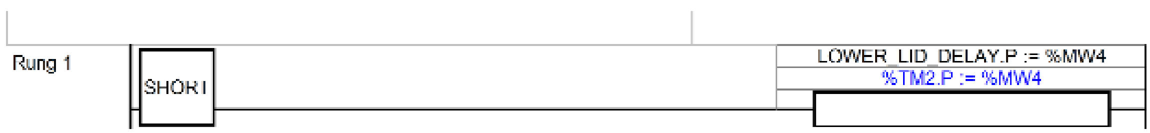


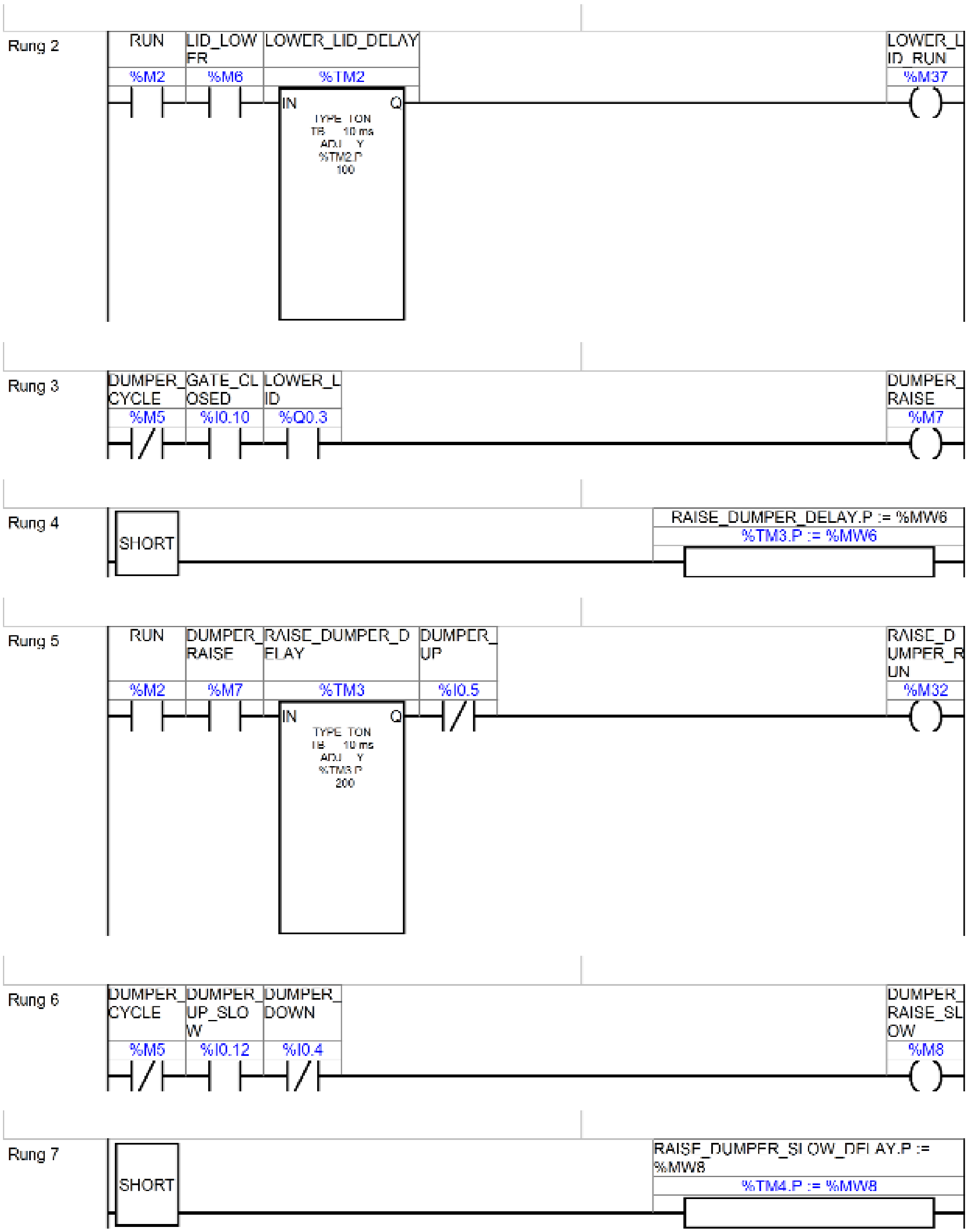


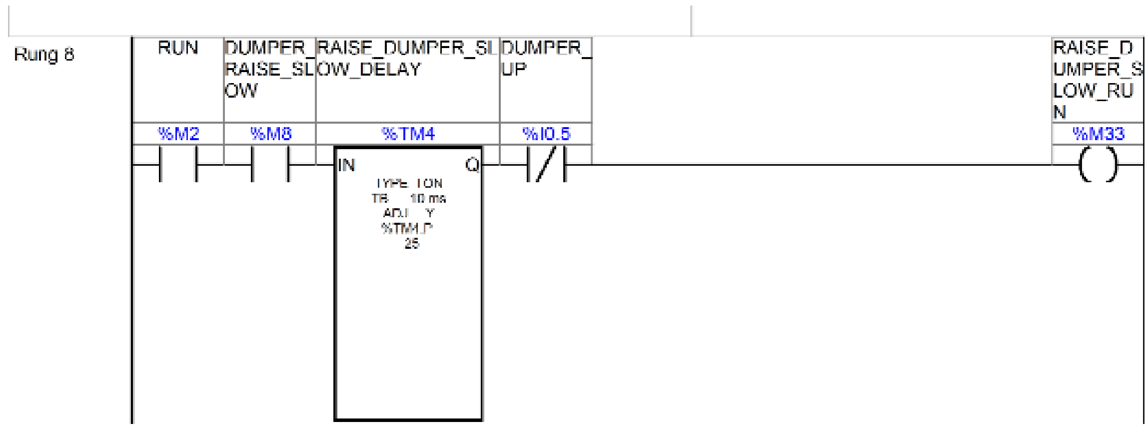


3 LD RAISE DUMPER/LOWER LID

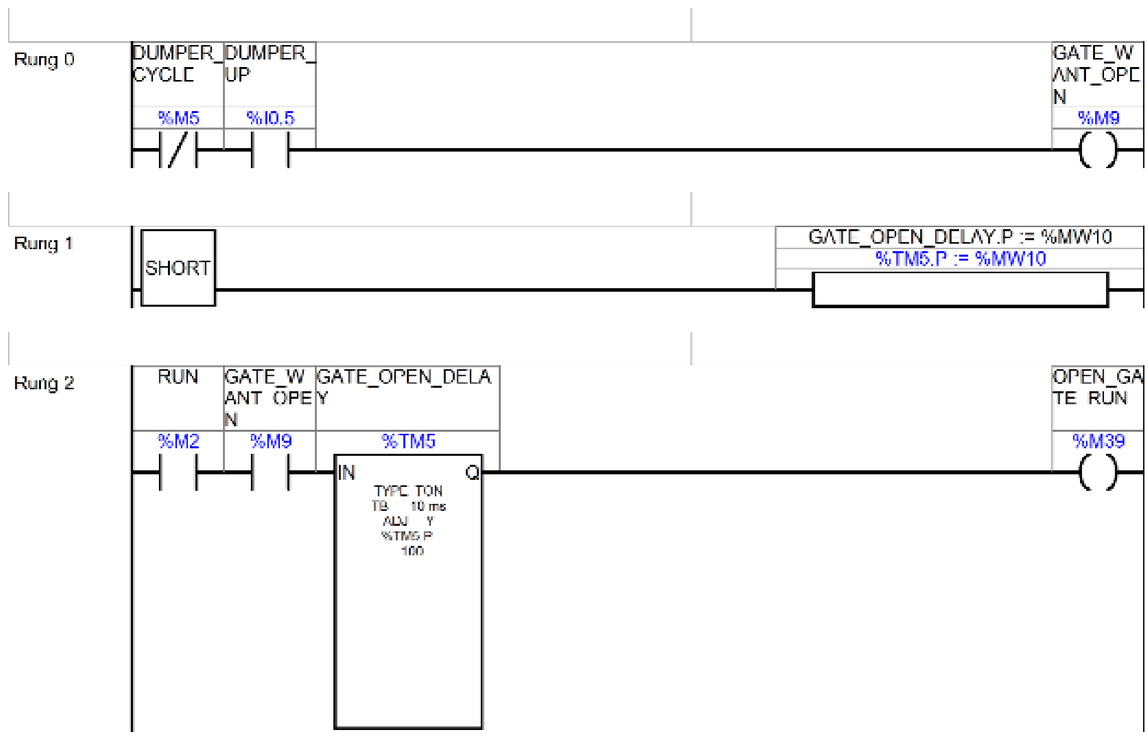


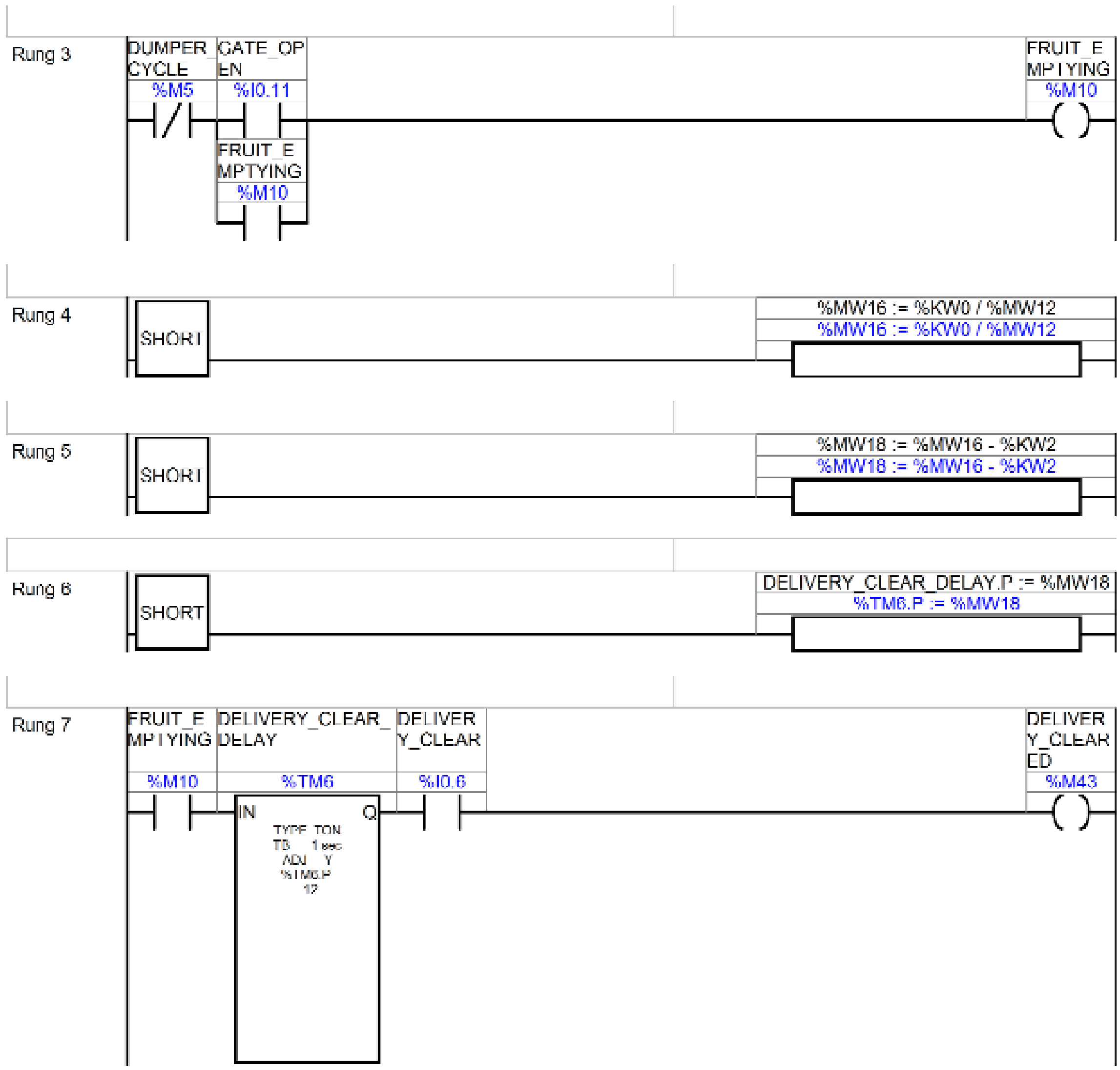


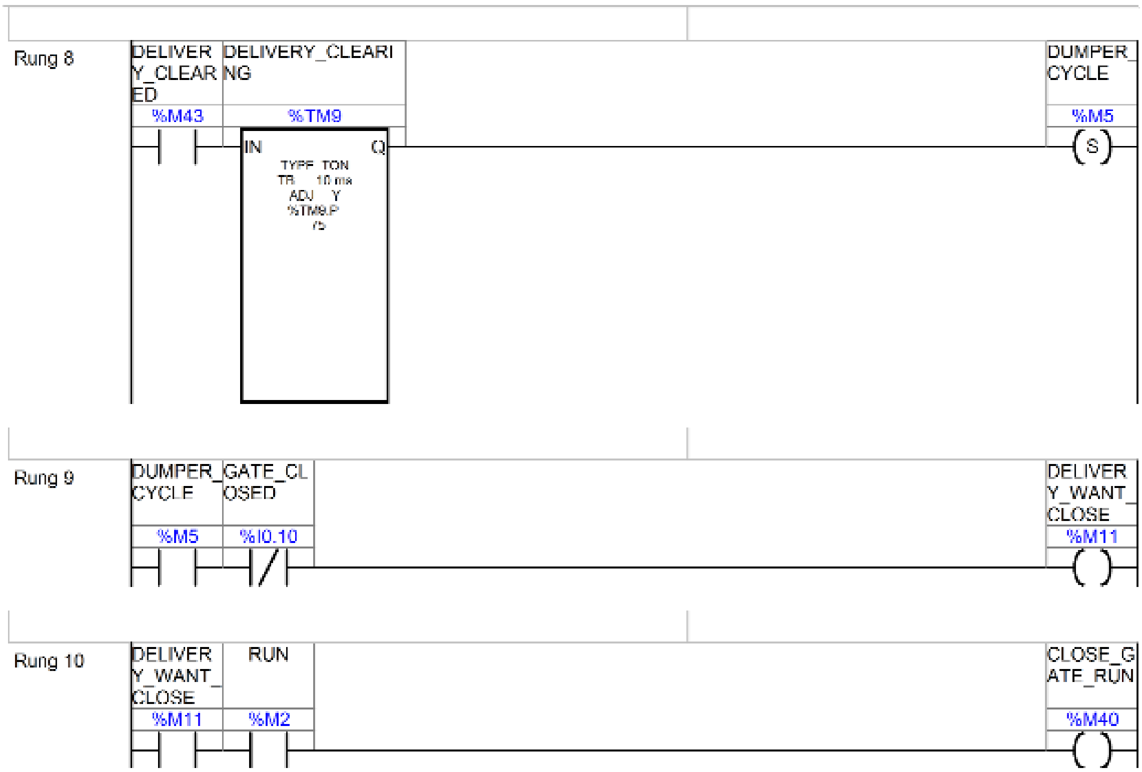

Rung 2
RUN
%M2
LID_LOWER
%M6
LOWER_LID_DELAY
%TM2
IN
Q
TYPE TON
TB 10 ms
ADJ Y
%TM2.P
100
LOWER_LID_RUN
%M37
Rung 3
DUMPER_CYCLE
%M5
GATE_CLOSED
%I0.10
LOWER_LID
%Q0.3
DUMPER_RAISE
%M7
Rung 4
SHORT
RAISE_DUMPER_DELAY.P := %MW6
%TM3.P := %MW6
Rung 5
RUN
%M2
DUMPER_RAISE
%M7
RAISE_DUMPER_DELAY
%TM3
IN
Q
TYPE TON
TB 10 ms
ADJ Y
%TM3.P
200
DUMPER_UP
%I0.5
RAISE_DUMPER_RUN
%M32
Rung 6
DUMPER_CYCLE
%M5
DUMPER_UP_SLOW
%I0.12
DUMPER_DOWN
%I0.4
DUMPER_RAISE_SLOW
%M8
Rung 7
SHORT
RAISE_DUMPER_SLOW_DELAY.P := %MW8
%TM4.P := %MW8



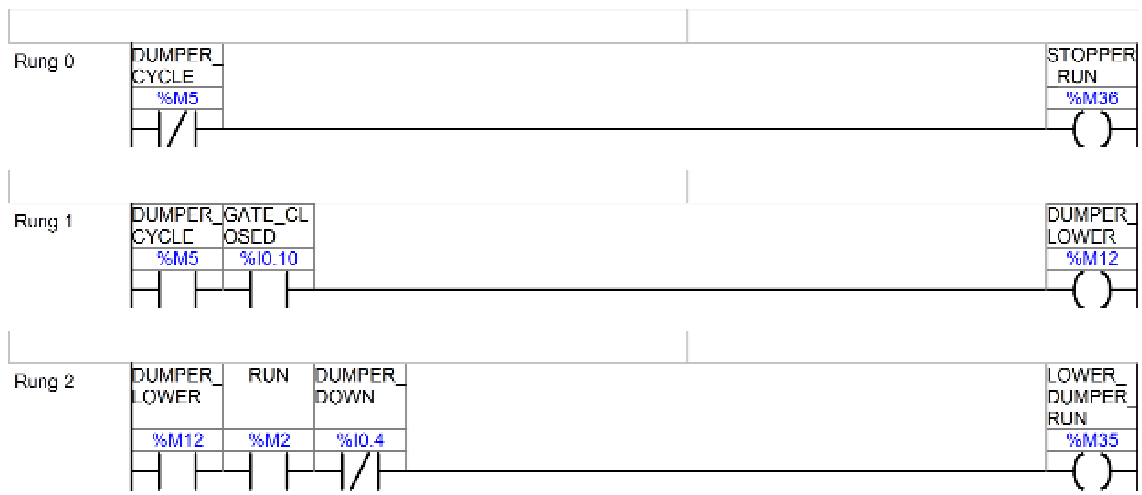
4 LD SPEED CONTROL/GATE OPERATION

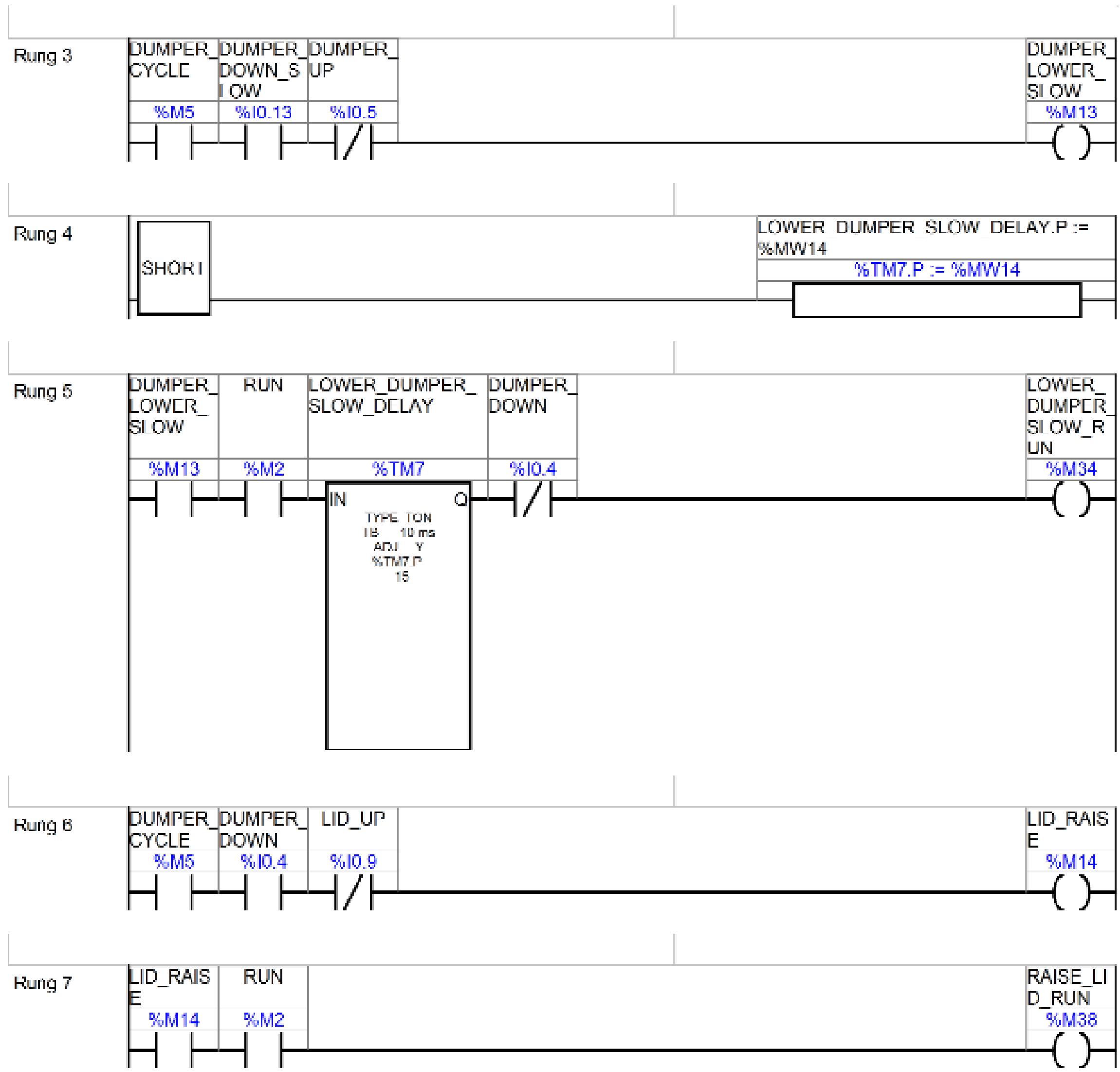



Rung 3
DUMPER CYCLE
%M5
GATE_OPEN
%I0.11
FRUIT_EMPTYING
%M10
FRUIT_EMPTYING
%M10
Rung 4
SHORT
%MW16 := %KW0 / %MW12
%MW16 := %KW0 / %MW12
Rung 5
SHORT
%MW18 := %MW16 - %KW2
%MW18 := %MW16 - %KW2
Rung 6
SHORT
DELIVERY_CLEAR_DELAY.P := %MW18
%TM6.P := %MW18
Rung 7
FRUIT_EMPTYING
%M10
DELIVERY_CLEAR_DELAY
%TM6
IN
Q
TYPE TON
DELIVERY_CLEAR
%I0.6
DELIVERY_CLEARED
%M43

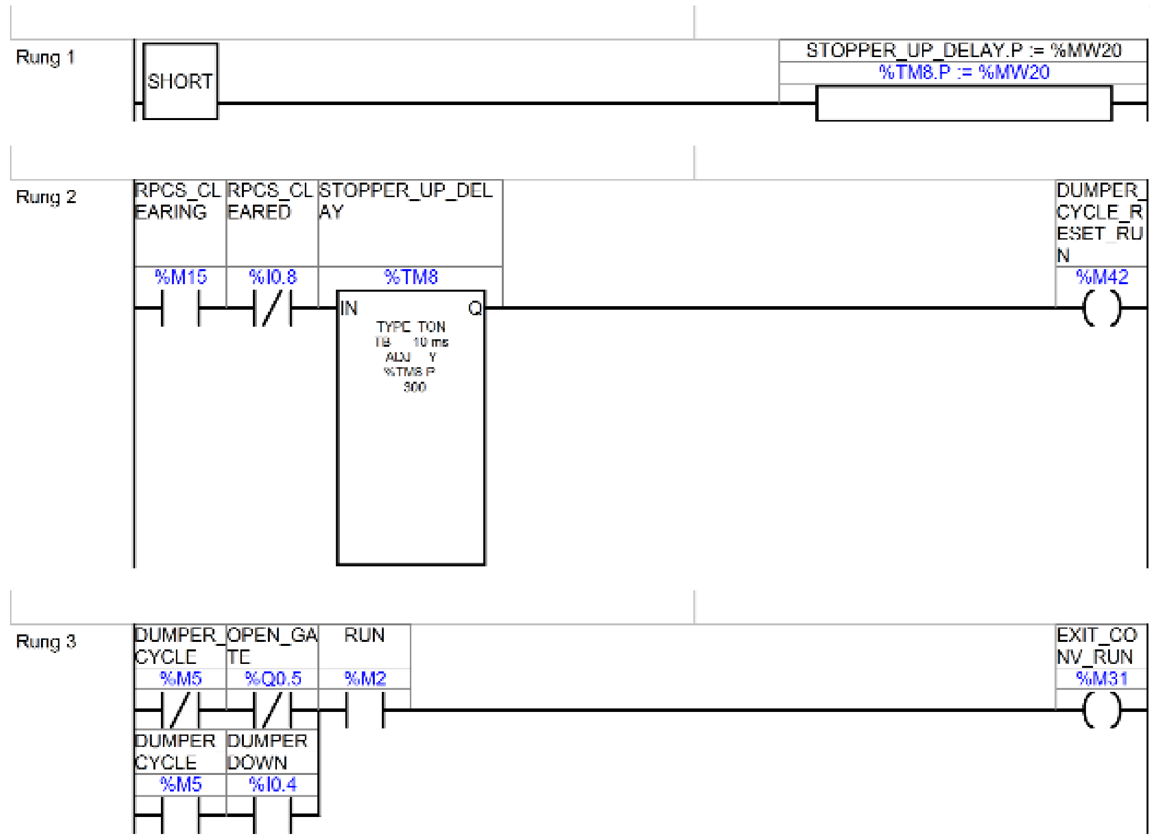


5 LD LOWER DUMPER/RAISE LID/STOPPER

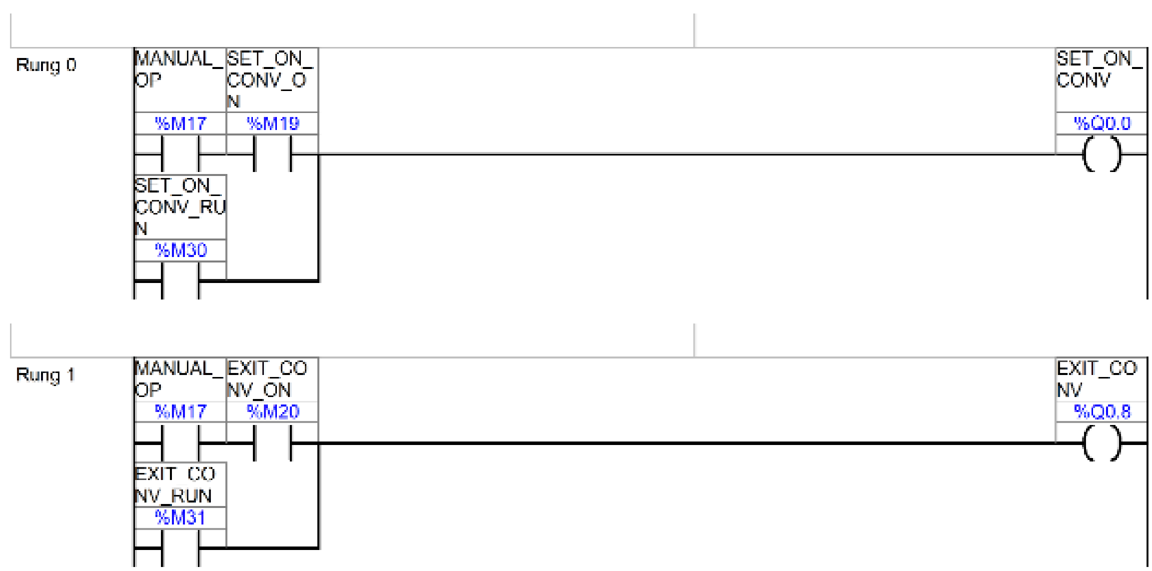


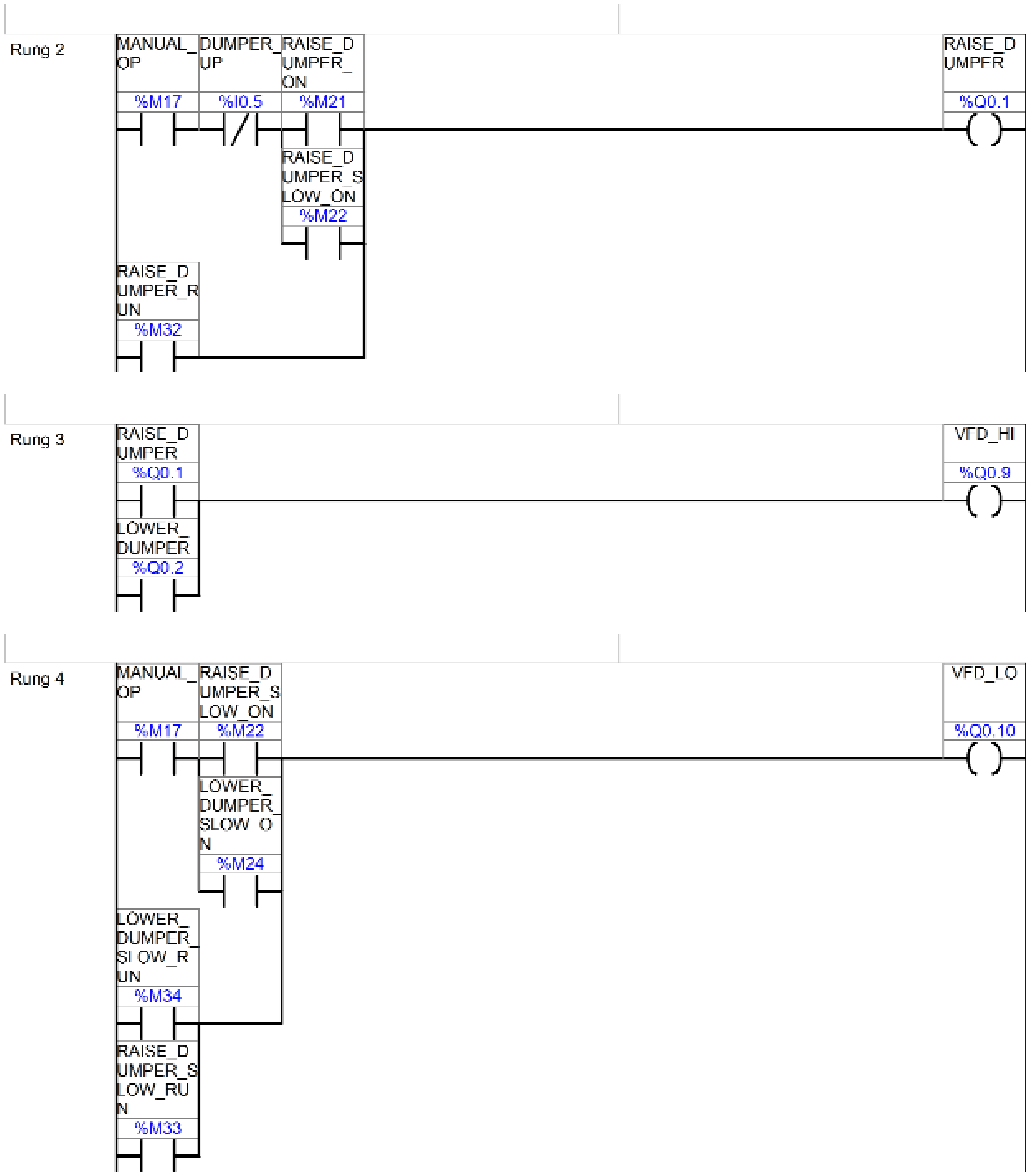


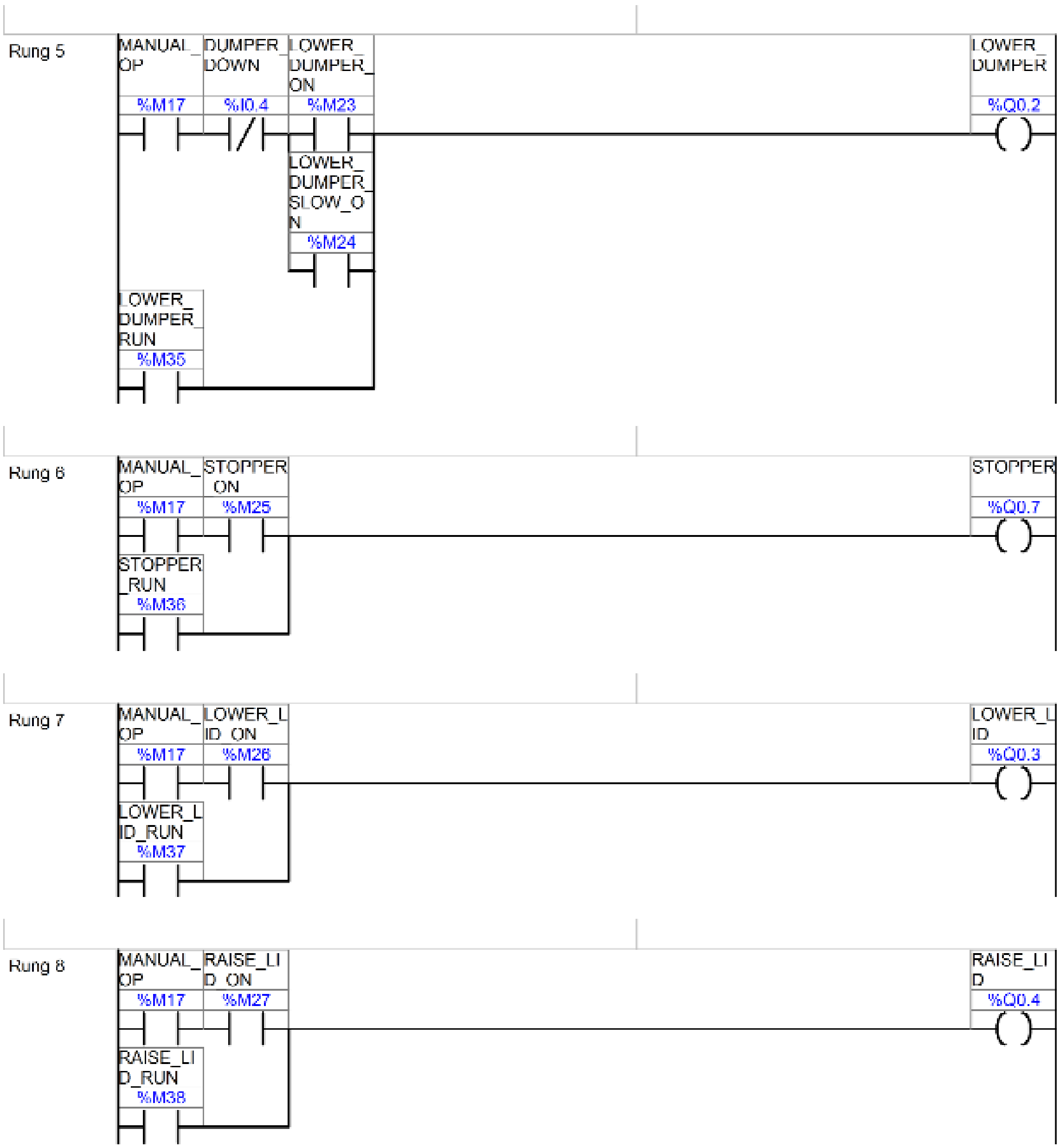
6 LD EXIT CONVEYOR/STOPPER UP

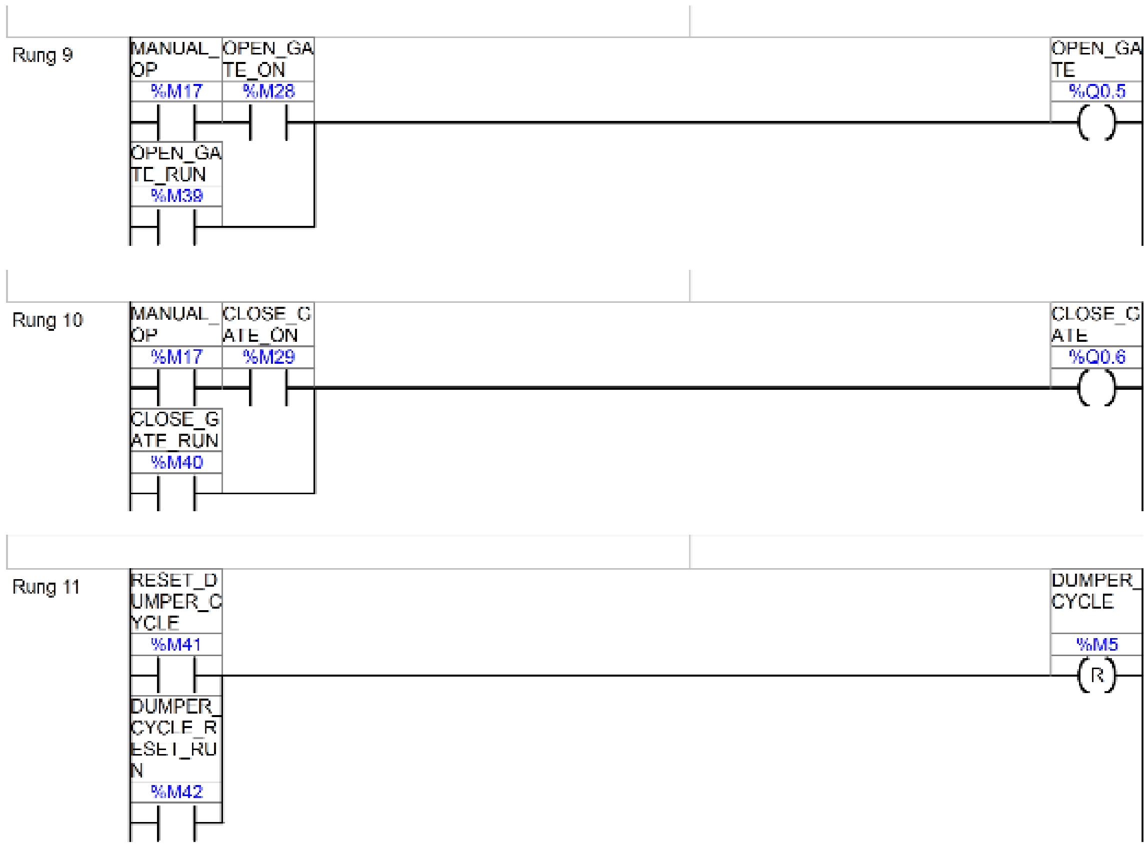


7 LD MANUAL OPERATION




Rung 2
MANUAL_OP
%M17
DUMPER_UP
%I0.5
RAISE_DUMPER_ON
%M21
RAISE_DUMPER_SLOW_ON
%M22
RAISE_DUMPER_RUN
%M32
RAISE_DUMPER
%Q0.1
Rung 3
RAISE_DUMPER
%Q0.1
LOWER_DUMPER
%Q0.2
VFD_HI
%Q0.9
Rung 4
MANUAL_OP
%M17
RAISE_DUMPER_SLOW_ON
%M22
LOWER_DUMPER_SLOW_ON
%M24
LOWER_DUMPER_SLOW_RUN
%M34
RAISE_DUMPER_SLOW_RUN
%M33
VFD_LO
%Q0.10


Rung 5
MANUAL_OP %M17
DUMPER_DOWN %I0.4
LOWER_DUMPER_ON %M23
LOWER_DUMPER_SLOW_ON %M24
LOWER_DUMPER_RUN %M35
LOWER_DUMPER %Q0.2
Rung 6
MANUAL_OP %M17
STOPPER_ON %M25
STOPPER_RUN %M36
STOPPER %Q0.7
Rung 7
MANUAL_OP %M17
LOWER_LID_ON %M26
LOWER_LID_RUN %M37
LOWER_LID %Q0.3
Rung 8
MANUAL_OP %M17
RAISE_LID_ON %M27
RAISE_LID_RUN %M38
RAISE_LID %Q0.4


Rung 9
MANUAL_OP
%M17
OPEN_GATE_ON
%M28
OPEN_GATE
%Q0.5
OPEN_GATE_RUN
%M39
Rung 10
MANUAL_OP
%M17
CLOSE_GATE_ON
%M29
CLOSE_GATE
%Q0.6
CLOSE_GATE_RUN
%M40
Rung 11
RESET_DUMPER_CYCLE
%M41
DUMPER_CYCLE
%M5
R
DUMPER_CYCLE_RESET_RUN
%M42

Symbols

Used	Address	Symbol	Comment
Yes	%M18	BYPASS	
Yes	%TM1	CLEARING_RPCS	
Yes	%Q0.6	CLOSE_GATE	
Yes	%M29	CLOSE_GATE_ON	
Yes	%M40	CLOSE_GATE_RUN	
Yes	%I0.6	DELIVERY_CLEAR	
Yes	%M43	DELIVERY_CLEARED	
Yes	%TM9	DELIVERY_CLEARING	
Yes	%TM6	DELIVERY_CLEAR_DELAY	
Yes	%M11	DELIVERY_WANT_CLOSE	
Yes	%M5	DUMPER_CYCLE	
Yes	%M42	DUMPER_CYCLE_RESET_RUN	
Yes	%I0.4	DUMPER_DOWN	
Yes	%I0.13	DUMPER_DOWN_SLOW	
Yes	%M4	DUMPER_EMPTYING	
Yes	%M12	DUMPER_LOWER	
Yes	%M13	DUMPER_LOWER_SLOW	
Yes	%M7	DUMPER_RAISE	
Yes	%M8	DUMPER_RAISE_SLOW	
Yes	%I0.5	DUMPER_UP	
Yes	%I0.12	DUMPER_UP_SLOW	
Yes	%I0.0	EMERGENCY_STOP	
Yes	%Q0.8	EXIT_CONV	
Yes	%M20	EXIT_CONV_ON	
Yes	%M31	EXIT_CONV_RUN	
Yes	%M10	FRUIT_EMPTYING	
Yes	%I0.10	GATE_CLOSED	
Yes	%I0.11	GATE_OPEN	
Yes	%TM5	GATE_OPEN_DELAY	
Yes	%M9	GATE_WANT_OPEN	
Yes	%M6	LID_LOWER	
Yes	%M14	LID_RAISE	
Yes	%I0.9	LID_UP	
Yes	%Q0.2	LOWER_DUMPER	
Yes	%M23	LOWER_DUMPER_ON	
Yes	%M35	LOWER_DUMPER_RUN	
Yes	%TM7	LOWER_DUMPER_SLOW_DELAY	
Yes	%M24	LOWER_DUMPER_SLOW_ON	
Yes	%M34	LOWER_DUMPER_SLOW_RUN	
Yes	%Q0.3	LOWER_LID	
Yes	%TM2	LOWER_LID_DELAY	
Yes	%M26	LOWER_LID_ON	
Yes	%M37	LOWER_LID_RUN	
Yes	%M16	MANUAL	
Yes	%M17	MANUAL_OP	
Yes	%Q0.5	OPEN_GATE	
Yes	%M28	OPEN_GATE_ON	
Yes	%M39	OPEN_GATE_RUN	
Yes	%Q0.1	RAISE_DUMPER	
Yes	%TM3	RAISE_DUMPER_DELAY	
Yes	%M21	RAISE_DUMPER_ON	
Yes	%M32	RAISE_DUMPER_RUN	
Yes	%TM4	RAISE_DUMPER_SLOW_DELAY	
Yes	%M22	RAISE_DUMPER_SLOW_ON	
Yes	%M33	RAISE_DUMPER_SLOW_RUN	
Yes	%Q0.4	RAISE_LID	
Yes	%M27	RAISE_LID_ON	

Used	Address	Symbol	Comment
Yes	%M38	RAISE_LID_RUN	
Yes	%M41	RESET_DUMPER_CYCLE	
Yes	%I0.8	RPCS_CLEARED	
Yes	%M15	RPCS_CLEARING	
Yes	%M3	RPCS_LOADED	
Yes	%I0.2	RPC_POS_1	
Yes	%I0.3	RPC_POS_2	
Yes	%I0.1	RPC_SET_ON	
Yes	%M2	RUN	
Yes	%Q0.0	SET_ON_CONV	
Yes	%M19	SET_ON_CONV_ON	
Yes	%M30	SET_ON_CONV_RUN	
Yes	%M0	START	
Yes	%M1	STOP	
Yes	%Q0.7	STOPPER	
Yes	%M25	STOPPER_ON	
Yes	%M36	STOPPER_RUN	
Yes	%I0.7	STOPPER_UP	
Yes	%TM8	STOPPER_UP_DELAY	
Yes	%TM0	STOP_SET_ON_CONV_DELAY	
Yes	%Q0.9	VFD_HI	
Yes	%Q0.10	VFD_LO	

Cross references

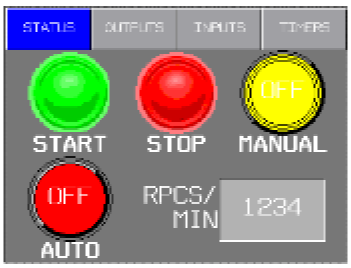
Address	Symbol	Section	Lines/Networks	Operator
%I0.0.0	EMERGENCY_STOP	1	1	AND
%M1	STOP	1	1	ANDN
%M16	MANUAL	1	1	LD
%M17	MANUAL_OP	1	1	ST

__Touchscreen Program__

RPCDUMPER

Panels & Panel Actions

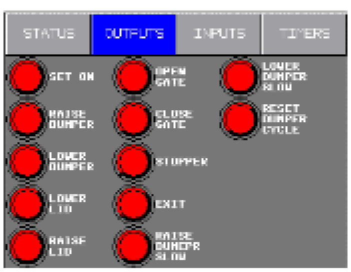
Base Panels\STATUS



STATUS: Panel Actions

No Actions

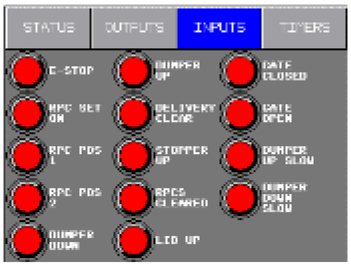
Base Panels\OUTPUTS



OUTPUTS: Panel Actions

No Actions

Base Panels\INPUTS



INPUTS: Panel Actions

No Actions

Base Panels\TIMERS

TIMERS: Panel Actions

No Actions

All variables by name

Name	Type	Source	Initial Value/Address	Description
_BackLight.Control	DINT	Internal		Controls the Backlight sleep time
_BackLight.Status	DINT	Internal		Indicates the status of the Backlight
_Brightness	DINT	Internal		Indicates the brightness
_Contrast	DINT	Internal		Indicates the contrast
_CurPanelID	DINT	Internal		Indicates the currently opened Panel ID. Assign a Panel ID to open the panel
_Day	DINT	Internal		Indicates Day in BIN format (1 - 31)
_DayoftheWeek	DINT	Internal		Indicates day of the week as 1=Sunday, ... 7=Saturday
_DIOPort.DOut0	BOOL	Internal		Indicates a DIO output port
_FileTransferStatus	DINT	Internal		Indicates the Status of the File Transfer
_Hour	DINT	Internal		Indicates Hour in BIN format (0 - 23)
_InputStatus	DINT	Internal		Indicates the Input Status
_LastErrorString	STRING	Internal		Stores the description of the last error in the user application
_Maintenance	DINT	Internal		Indicates the current state of the maintenance mode
_Minutes	DINT	Internal		Indicates Minutes in BIN format (0 - 59)
_Month	DINT	Internal		Indicates Month in BIN format (1 - 12)
_Seconds	DINT	Internal		Indicates Second in BIN format (0 - 59)
_SystemLanguage	DINT	Internal		Indicates the System Language
_TimeZoneOffset	DINT	Internal		Indicates TimeZoneOffset in BIN format (-720 to +780)
_TouchField	DINT	Internal		Indicates the Field ID
_UserApplicationLanguage	DINT	Internal		Indicates the User Application Language
_UserLevel	DINT	Internal		Indicates the current Security Level of the user currently logged in.
_UserName	STRING	Internal		Indicates the name of the user that is currently logged in.
_Year2	DINT	Internal		Indicates 2 digits of Year in BIN format
_Year4	DINT	Internal		Indicates 4 digits of Year in BIN format
AUTO	BOOL	External	%M2	
CLEARING_RPCS	INT	External	%MW2	
DELIVERY_CLEAR_DELAY	INT	External	%MW12	
GATE_OPEN_DELAY	INT	External	%MW10	
IN0	BOOL	External	%I0.0.0	
IN1	BOOL	External	%I0.0.1	
IN10	BOOL	External	%I0.0.10	
IN11	BOOL	External	%I0.0.11	

IN12	BOOL	External	%I0.0.12	
IN13	BOOL	External	%I0.0.13	
IN2	BOOL	External	%I0.0.2	
IN3	BOOL	External	%I0.0.3	
IN4	BOOL	External	%I0.0.4	
IN5	BOOL	External	%I0.0.5	
IN6	BOOL	External	%I0.0.6	
IN7	BOOL	External	%I0.0.7	
IN8	BOOL	External	%I0.0.8	
IN9	BOOL	External	%I0.0.9	
LOWER_DUMPER_SLOW_DELAY	INT	External	%MW14	
LOWER_LID_DELAY	INT	External	%MW4	
MANUAL	BOOL	External	%M16	MANUAL
OUT0	BOOL	External	%M19	
OUT1	BOOL	External	%M21	
OUT10	BOOL	External	%M24	
OUT2	BOOL	External	%M23	
OUT3	BOOL	External	%M26	
OUT4	BOOL	External	%M27	
OUT5	BOOL	External	%M28	
OUT6	BOOL	External	%M29	
OUT7	BOOL	External	%M25	
OUT8	BOOL	External	%M20	
OUT9	BOOL	External	%M22	
RAISE_DUMPER_DELAY	INT	External	%MW6	
RAISE_DUMPER_SLOW_DELAY	INT	External	%MW8	
RESET_DUMPER_CYCLE	BOOL	External	%M41	
START	BOOL	External	%M0	START
STOP	BOOL	External	%M1	STOP
STOP_SET_ON_CONV_DELAY	INT	External	%MW0	
STOPPER_UP_DELAY	INT	External	%MW20	

APPENDIX G

COST ANALYSIS CALCULATIONS

$$\boldsymbol{Total\ Material\ Cost} = \$\mathbf{11,257.05}$$

$$\boldsymbol{Estimated\ Material\ Cost\ During\ Manufacturing} = \$\mathbf{10,000}$$

$$\boldsymbol{Estimated\ Manufacturing\ Labor\ Cost} = \$50/hr * 300\ hrs = \$\mathbf{15,000}$$

$$\boldsymbol{Total\ Estimated\ Manufacuring\ Cost} = Estimated\ Material\ Cost + Estimated\ Manufacturing\ Labor\ Cost = \$10{,}000 + \$15{,}000 = \$\mathbf{25,000}$$

$$\boldsymbol{Proposed\ Sale\ Value} = \$\mathbf{30,000}\ \boldsymbol{per\ machine}$$

<u>Machine Benefits</u>

Company benefits from removing one worker from dumping RPCs

$$1\ Worker = \frac{\$15}{hr} * \frac{50\ hrs}{week} * \frac{4\ weeks}{month} * \frac{12\ months}{year} = \$\mathbf{36,000}/\boldsymbol{yr}$$

$$Payback\ Period = \frac{Sale\ Value}{Annual\ Savings} = \frac{\$30{,}000}{\$36{,}000/yr} = \mathbf{0.833}\ \boldsymbol{years}$$

$$Return\ on\ Investment = \frac{1}{Payback\ Period} = \frac{1}{0.833\ years} = \mathbf{120}\%/\boldsymbol{yr}$$