Cardboard Box Crusher

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Bachelor of Science

in Mechanical Engineering Technology

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This is a Senior Design report on a Cardboard Box Crusher. This is a miniature model of an industrial carboard baler machine. The Cardboard Box Crusher was manufactured to handle smaller loads and quantities of boxes at a box by box basis. This machine is fully automated and only requires human interaction when problems may arise or for maintenance purposes. The report also includes initial concept designs as well as manufacturing processes that went into the productions of the machine. Finally, this report is adjusted based on the stay home order issued by the Governor of Ohio due to the COVID-19 outbreak.

PROBLEM DEFINITION AND RESEARCH

Problem Statement

The time it takes to fill the cardboard baler at the assembly lines at the Mitsubishi Electric plant is short and it takes too long to empty because the pressing process needs to meet the environmental standards of the plant. This takes time from line workers thus reducing the assembly line efficiency.

Background

During my first week of working at Mitsubishi Electric, my supervisor explained to me the problems with the baler at the assembly lines and the solutions that that have been implemented over the years. Since the plant increased their volumes in 2015 by adding a second building to the main building, operators on the Starter Assembly line have had to empty cardboard box balers over a mile distance due to the upgrade. In a shift, these balers are emptied at least twice, which is about thirty minutes to complete a roundtrip, taking labor power from the assembly line.

One solution was increasing the number and size of the balers to accommodate ~~for~~ more boxes. However, space for these balers are diminishing due to recently installed machines and robots made to improve the workflow of the assembly line. After several meetings with plant planning and other engineers, I was tasked to build a solution to this problem with the available resources.

The box being crushed is a corrugated box sized at 20.00” x 11.00” x 10.00”. These boxes are the maximum sized boxes used at the Starter Assembly branch of the plant. A corrugated box comprises of paperboard with uniform air columns [1]. The air columns in the box act as shock absorber or cushions for products that are placed in the box. These air columns in the walls are directly proportional to the strength of the box [1]. About 95% of U.S products are transported using these types of boxes [1]. These boxes are also used due to how easy it is to recycle. Products like paper towels, cereal boxes and paper are made from recycled cardboard.

The strength of cardboard boxes can be measured using the Burst Strength Test, a test that depends on largely on the tensile strength of a material used as to determine its resistance to rupture and the Edge Crush Test, which is done to measure the cross-section resistance to crushing of any corrugated box [1]. The burst strength for a single wall corrugated box sized 40 inches in dimension can withstand up to 125 lbs. before bursting; a 50-inch box can withstand up to 150 lbs. before bursting; and a 60-inch can withstand 175 lbs. [1]. The Edge Crush test on the other hand is a related to stacking strength of a carton. The minimum edge crush test 23 lbs. per width for a maximum outside dimension of 40 inches [1].

RESEARCH

Current State of the Art

Marathon Heavy-Duty Vertical Balers

This baler manufactured by Marathon is their flagship model with their most innovative technology in order to crush boxes of different shapes and sizes. Due their standard controls and panel box, the user experiences an ease of use that can be associated with that of smaller baler. This baler exerts a maximum pressure of 2500 psi and a max force of 70,690 lbs. [2]. They also boast features such as fixed retainer teeth on the door and back of the baler to reduce material spring back as well as a programmable smart relay to fit the operation style of the customer [2]. Marathon Heavy-Duty Vertical Balers also have optional upgrades to bring a variety of options to the user such as bale auto-eject and wire guides for tying up the bales after the compacting process [2].

The initial investment for a Marathon Heavy-Duty Vertical Baler is very high and requires a dedicated space for installation. Due to its size and immobility, it will not be a suitable solution for the problem at hand.

Figure 1: Marathon Heavy-Duty Vertical Baler

The Extract Pack Aluminum Recycling Machine

This is the very first baler that both bales and extracts the liquid from waste beverage containers. Harmony Enterprise Inc., the company that manufacturers the Extract Pack, claims that their baler performs 7 times better than manually draining the container [3]. Due to the liquid draining process, this baler guarantees complete closure of the doors during the process in order to avoid messy flows around the baler. The baler also has "shark teeth", which are sharp prongs that are lined on the chamber floor and ram face to better extract the liquid [3].

The cost of the Extract Pack Aluminum Recycling Machine is very high. The liquid draining properties are nice to have but are not a necessity for the problem at hand.

Figure 2: Extract Pack Recycling Machine (Model No. BCB2003)

Mil-tek 2102 Cardboard and Plastic Baler

The Mil-tek 2102 is a small compact baler that is suitable for small businesses with a regular flow of carboard usage. It has the ability to bale not only carboard but plastics and other materials. Due to its size, it has a low energy rating and also less noise during the baling operation [4]. It has a maximum pressure of 116 psi and a maximum force of 4960 lbs. [4].

The Mil-tek 2102 Cardboard and Plastic baler is the closest ready-to-buy solution available on the market. The cost for a single unit is fairly affordable for the short-term solution but due to Mitsubishi Electric's long-term goal of incorporating the solution to different parts of the plant, a total cost of purchasing multiple units to be placed at vantage points will be about the available budget set for the solution.

Figure 3: Mil-tek 2102 Cardboard and Plastic Baler

End User

The primary user for the cardboard box crusher is the assembly line operator. The operator at Mitsubishi Electric Automotive America is tasked with packing parts in and out of their packaging as well as man manual add stations on the assembly line for parts that cannot be assembled by a robot or machine. The operator will have the task of supplying the cardboard box crusher with an empty cardboard box.

The secondary user for the cardboard box crusher is the line technician or engineer. In case of improvements and adjustments that need to be made to the cardboard box crusher, the line technician or engineer will have to bypass security and safety locks that protect the box crusher in order to make said changes.

Summary of Research

In conclusion, the ideal solution to the problem does not exist for purchasing purposes and using this research as a basis, a close to ideal solution can be built and in later years can be modified and improved upon to fit different problematic scenarios. An ideal solution will need to be able to bolt temporarily to the conveyor being used. It also needs to be stable enough to withstand repeated pressing force without significant deformity to the machine or conveyor.

QUALITY FUNCTION DEVELOPMENT

Customer Features

- Safety
- Power Consumption
- Ease of Use
- Smart (Responsive to GOT inputs)
- Noise Factor
- Design/Form Factor
- Initial Investment Cost

Engineering Characteristics

- Base Material Selection
- Joining/Fasteners
- Pneumatic Cylinder Selection
- Load Distribution per Design
- Crushing Force and Pressure
- Graphical User Interface Selection

House of Quality

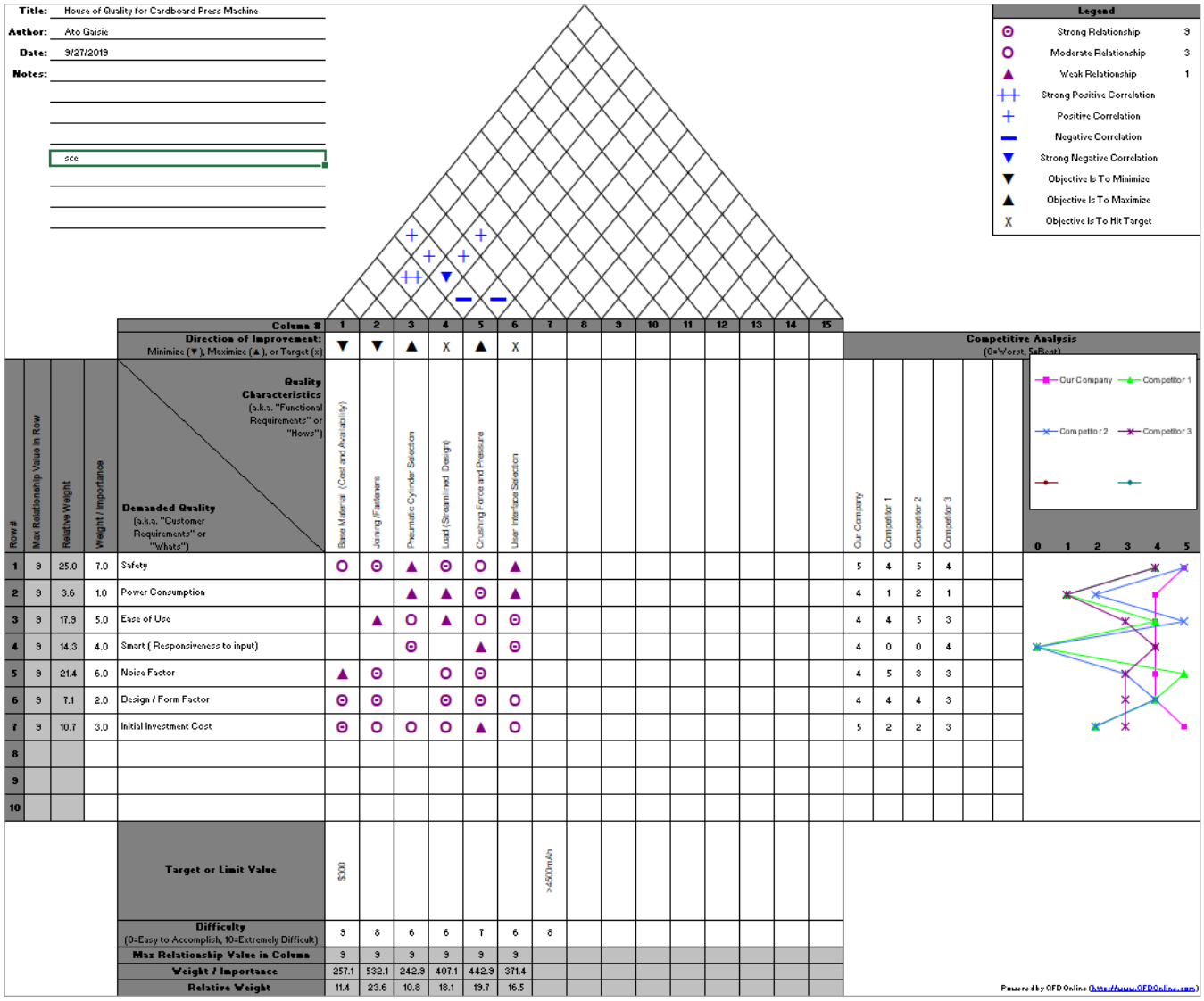

Figure 4: House of Quality for Cardboard Box Crusher

Product Objectives

Safety (25%)

To ensure safety of employees that work closely to the machine, light curtains will be installed at all entry and exit points of the machine. This may include an interlock system for the door to access the machine.

Power Consumption (3.6%)

This feature has to do with selecting the right motor for the belt conveyor to be used.

Ease of Use (17.9%)

The machine should be constructed with material and components that are familiar to the technicians and engineers in any case that I am not able to solve issue that may arise in the future.

Smart (Responsive to GOT inputs) (14.3%)

The outline of the GOT (Graphical user interface manufactured by Mitsubishi) should be well laid out and should function as designed or labeled.

Noise Factor (21.4%)

A muffler will be installed on the air pressure amplifier to reduce noise when the machine is operational.

Design/Form Factor (7.1%)

It should be able to take up the limited amount of space on offer to engineering by the Mitsubishi plant planning team.

Initial Investment Cost (10.7%)

Most components such as plexi-glass and aluminum extrusions will be repurposed from machines that are no longer on use or discarded.

DESIGN

Concepts Drawings

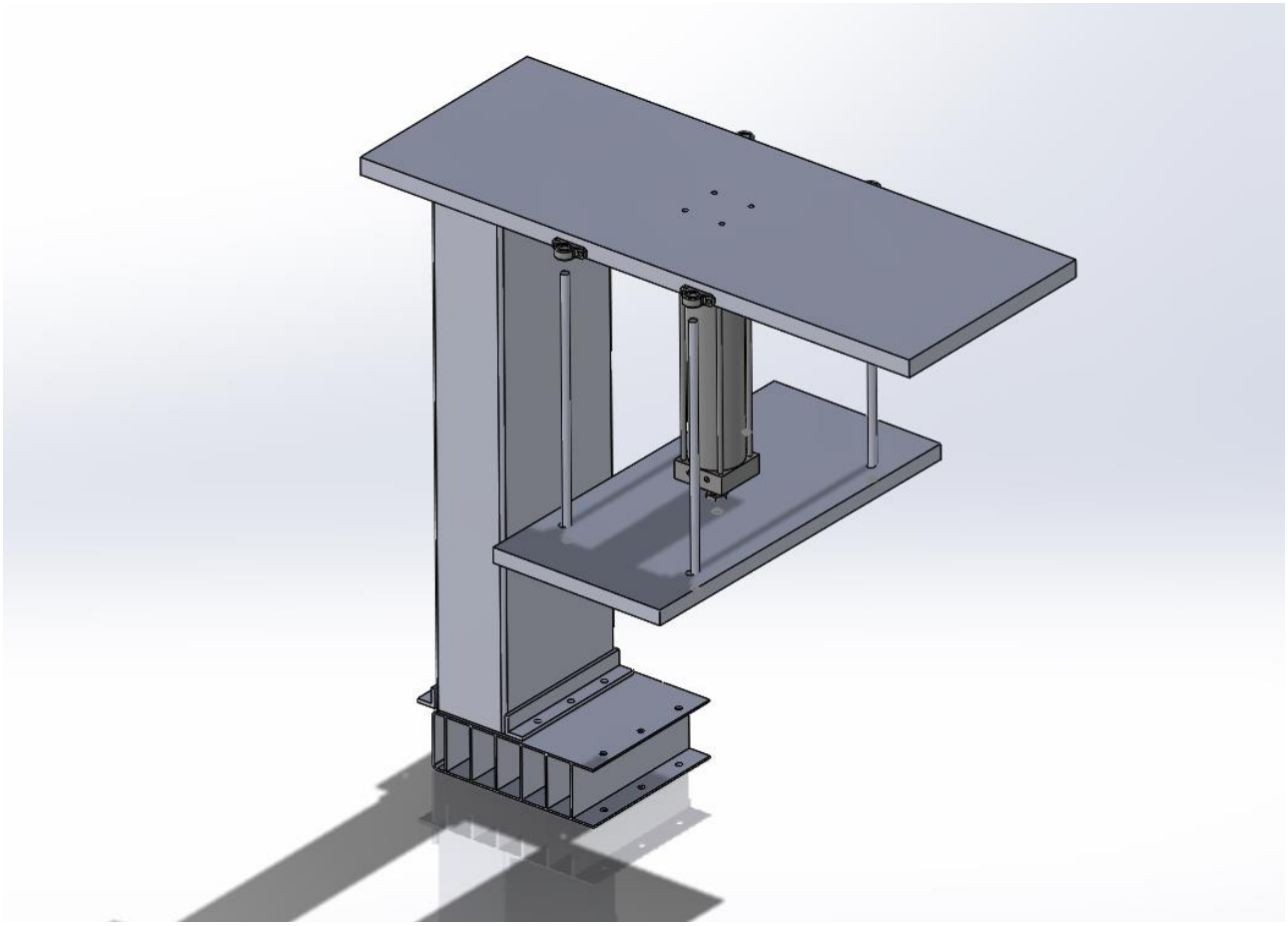

Figure 5: Solidworks depiction of Concept 1

Concept 1

In this concept, an attachment base will be manufactured with fins to serve as structural support. This base will be mounted on one side of the conveyor to be used. A metallic tube will be used as the main load point holding all the other features upright. The pneumatic cylinder will be face mounted beneath the top plate as will as oil bearings that are attached to the sides. The bearing will serve as a holding place that allows the guide rods to move up and down. The cylinder and guide rods will be threaded on the ends that attach to the press plate.

This concept is inexpensive and simple to manufacture. The drawbacks to this design is the imbalance of the press plate that may cause deformity of increased tension in the fasteners of the tube.

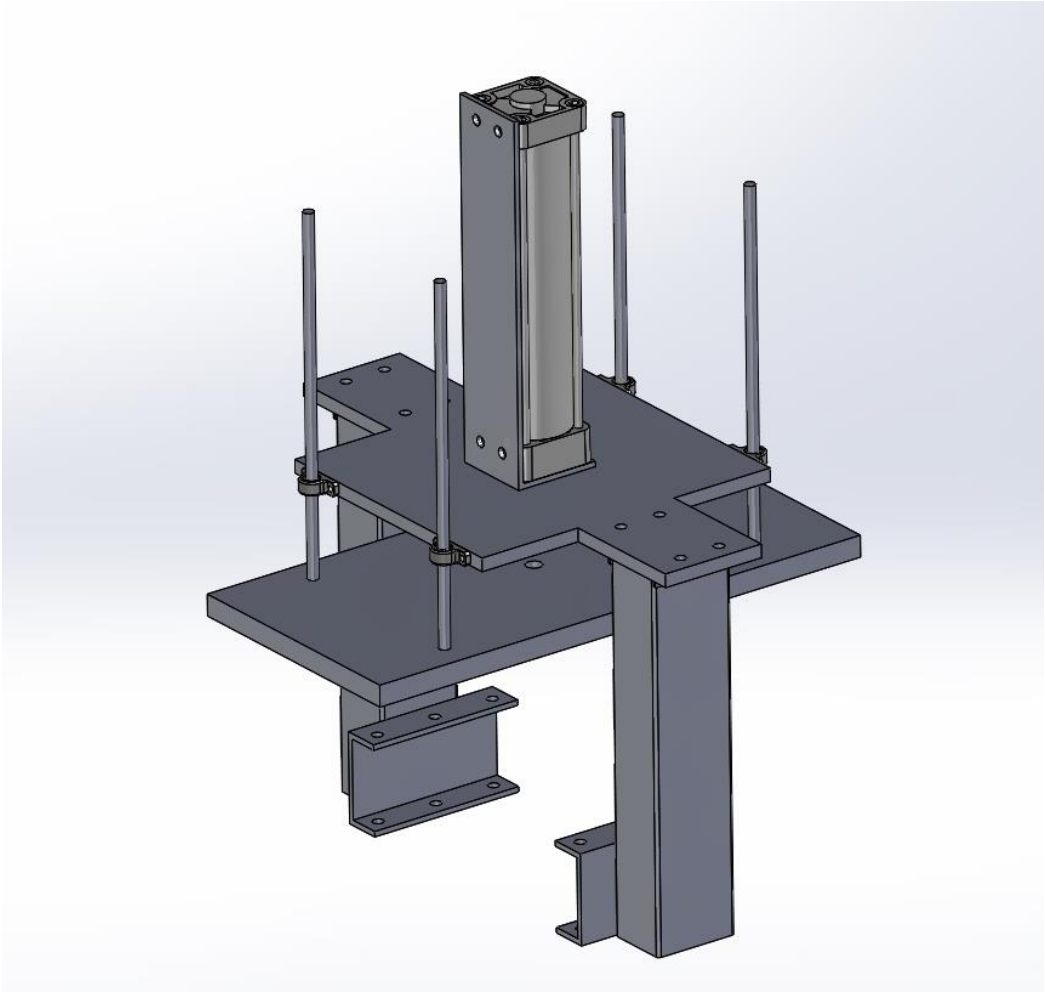

Figure 6: Solidworks depiction of Concept 2

Concept 2 (Final Design)

This concept utilizes two channel extrusions that are cut to size and bolted to each side of the conveyor. Each side will also have a welded to the channel a metallic tube, smaller than that of concept 1. To reduce material cost the top plate will have a t-cutout and the cylinder will be mounted on the piston side to the top plate. The guide rods and bearings from concept 1 will also be used.

This concept is a little more expensive than that of the previous one but due to the double tower system, the stress on fasteners and tubes will be lessened.

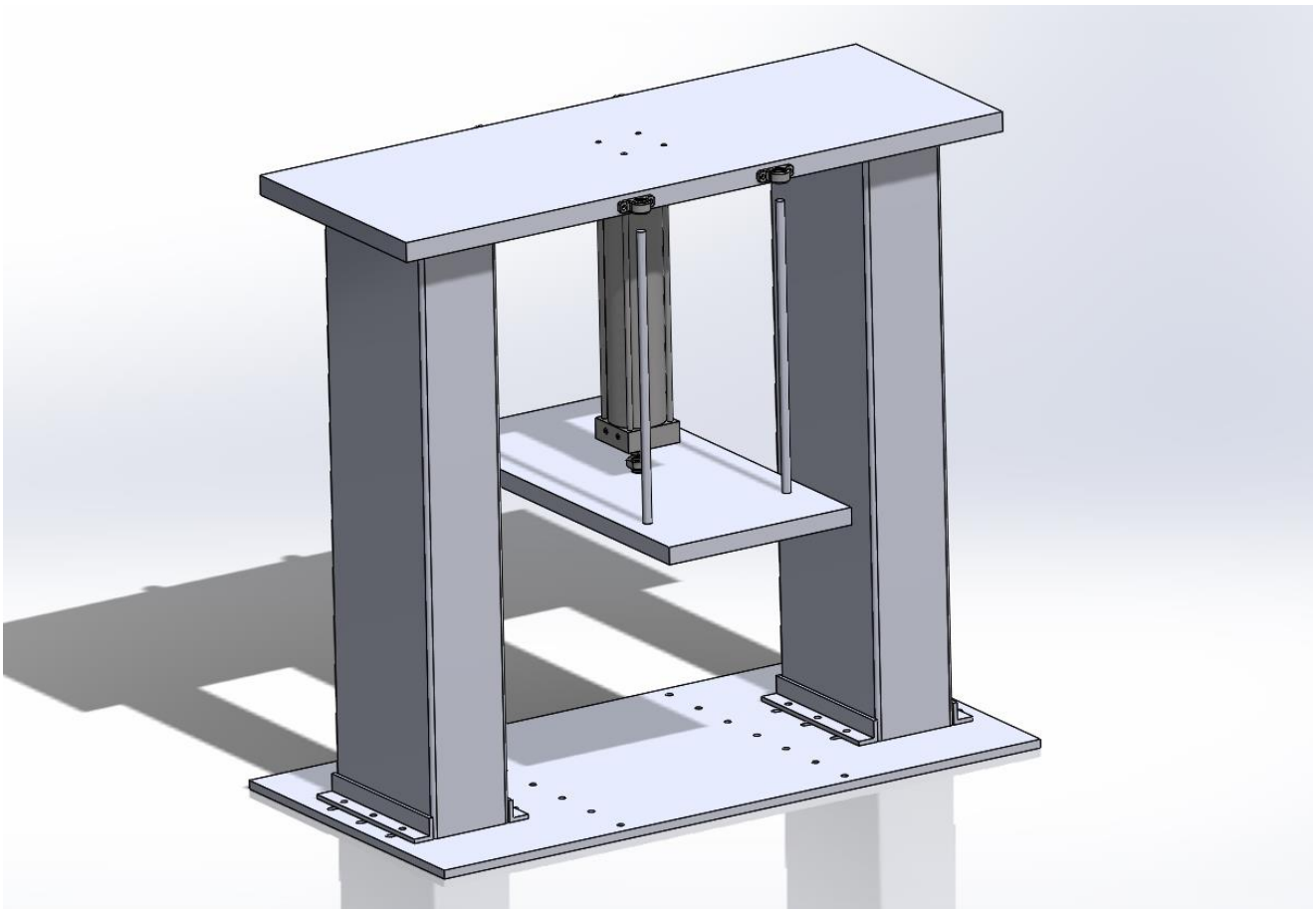

Figure 7: Solidworks depiction of Concept 3

Concept 3

In this concept, the double tower designed is used. The bottom plate will be mounted on top of the conveyor and underneath that moving belt. The tubes will be then mounted on each side of the plate overhung. The cylinder is mounted beneath the top plate like in concept 1 and the guide rods and bearings will also follow the same principle as concept 1.

The bottom plate will be used to reinforce the bed of the conveyor where the crushing will occur. This design implementation is very expensive due to the amount and type of material being used. The bottom plate might also experience a significant amount of stress from the tower ends.

MATERIAL AND COMPONENT SELECTION

Per Mitsubishi requirements, the materials and component brands to be used for the machine were as follows;

- A36 Plates/Bar Stock/Round Bar
- A500 GRB Tubing
- SMC Air Solutions
- Keyence Sensors and Light Curtains
- Mitsubishi PLC Products (CPU, Input/output cards, Graphical User Interfaces)
- Lexan Sheets for Machine Protection
- Aluminum Extrusions (80/20) for Machine Protection

Finite Element Analysis

Solidworks was used to determine pressure points as well as stress factors that needed to be watched for based on the final chosen design. All non-moving parts are constrained, and the guide rods and plate are allowed only the reasonable degrees and directions of freedom. It was then run through a simulation of repeated motion for a given period of time of 360 hours (Estimated time for crushing over a three-year duration).

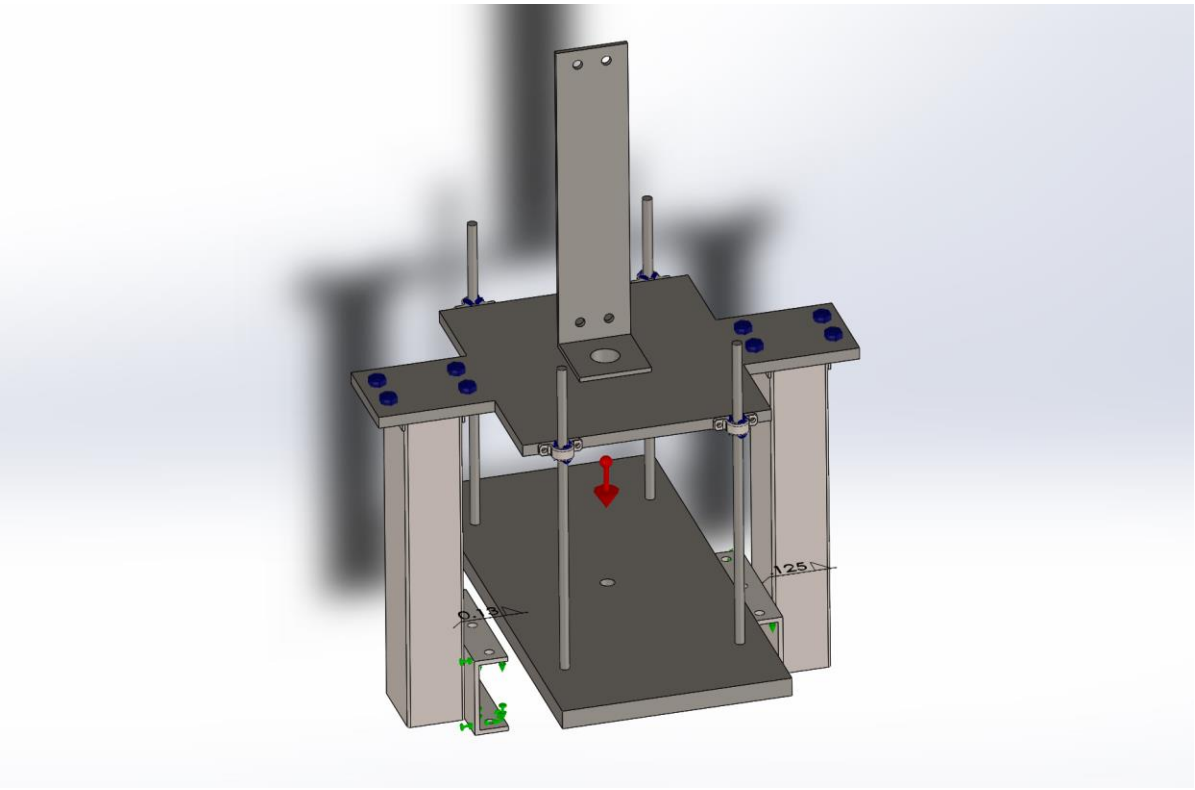

Figure 8: Simulation showing stationary constraints

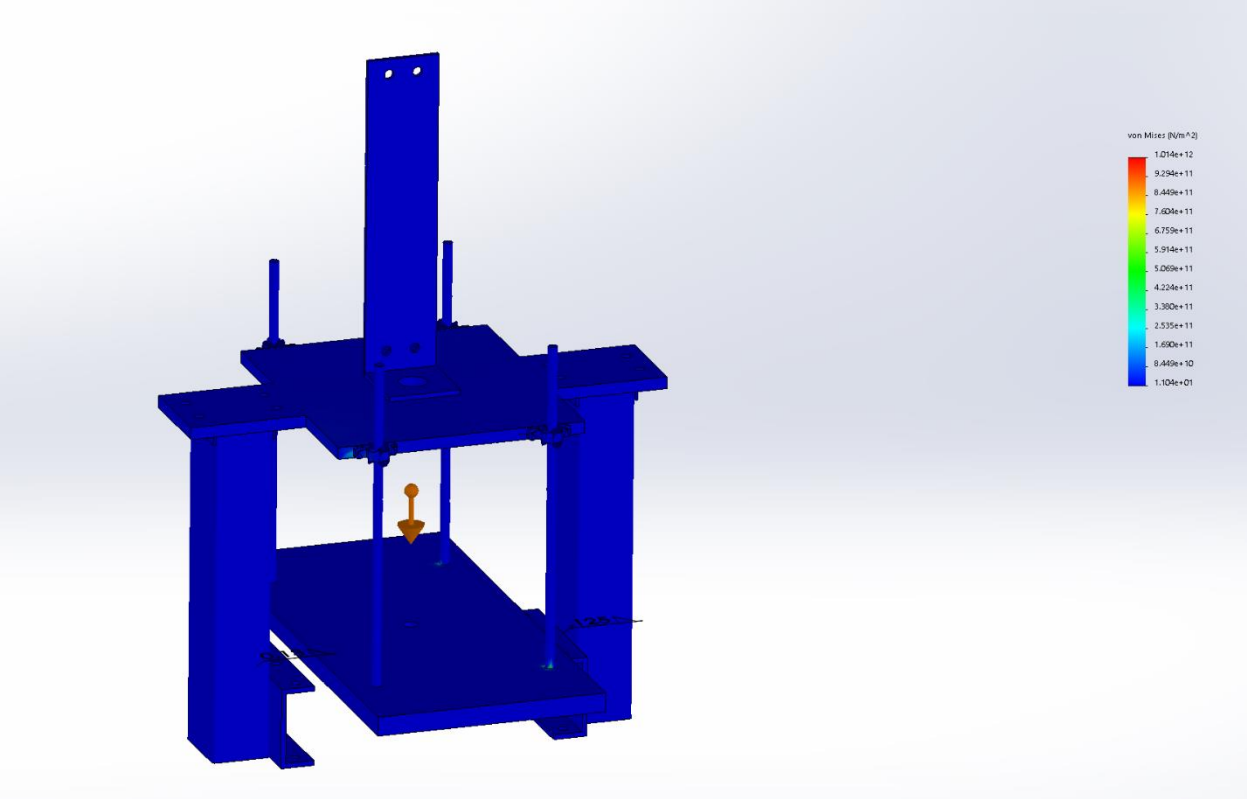

Figure 9: Simulation depicting the plate and guide rod degrees of motion

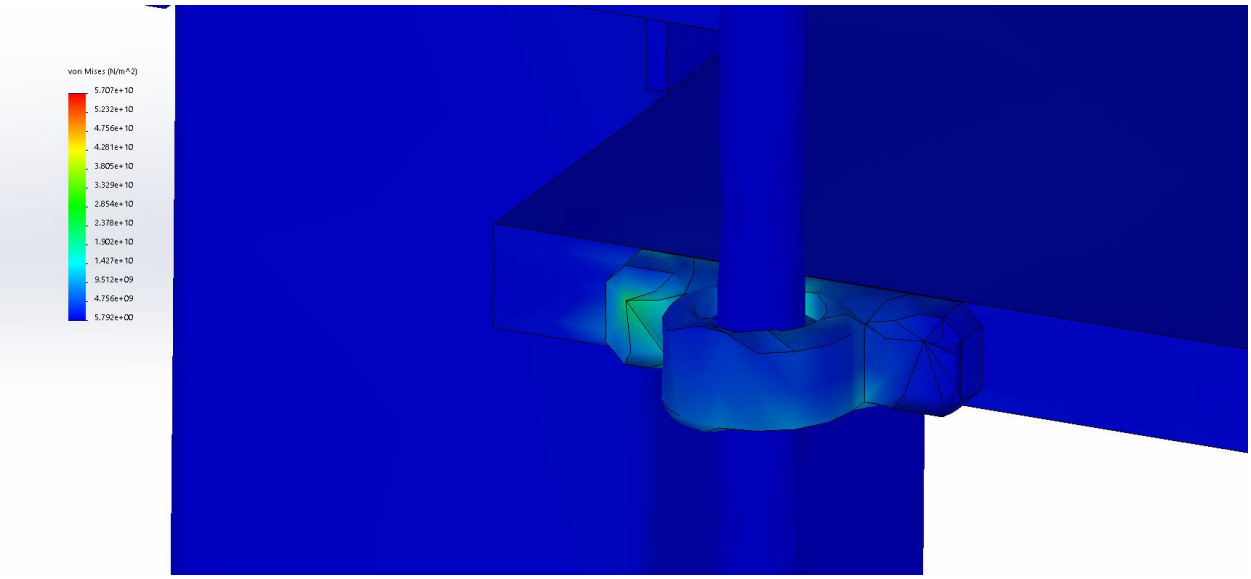

Figure 10: Results of simulation showing guide rod bearing stress factor

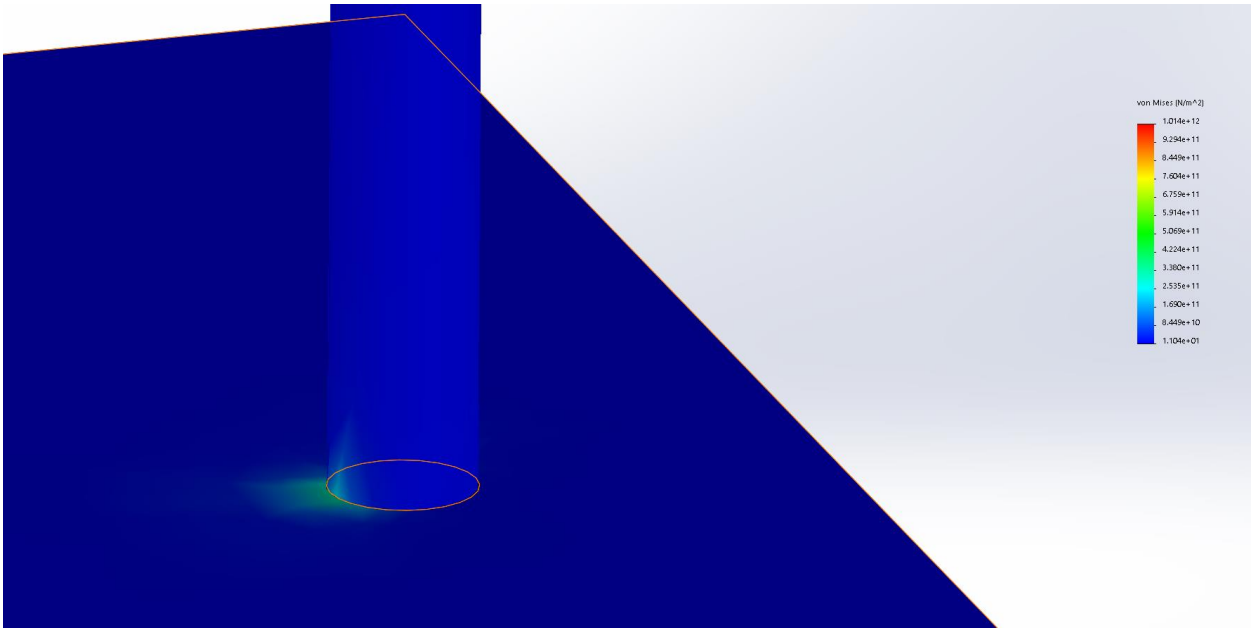

Figure 11: Results of simulation showing guide rod and press plate connection stress

After the simulation was run, there were two major points to consider before manufacturing. The first point of concern was the guide rod bearings as seen in Figure 10. The bearings were changed to better hold the guide rods for a longer time period. The second concern was the stress point between the guide rods and plate. To ease this stress the thread pitch was increases to increase the holding strength of the guide rods.

Pneumatic Cylinder Selection (Design/Safety Factor)

The pneumatic cylinder is the major force generating component of the machine and thus the design and safety factor was built around it. The values and equations used are based on the manufacturer's published work.

Minimum Force Needed to Crush Box

$$BCT = 5.87\ x\ ECT\ x\ \sqrt{h(z)}$$

where h is the box thickness

z is the perimeter of the box

$$BCT = 5.87\ x\ 32\ x\ \sqrt{\frac{3}{16}\left(2(10 + 28.5)\right)}$$

$$BCT = 614.08\ lbs\ x\ 1.3\ (design\ factor)$$

$$Required\ force = 798.3\ lbs$$

BCT = Box Compression Test
ECT = Edge Crush Test

Pneumatic Cylinder Selection

$$Factory\ Air = 100psi + 45psi(max.\ Air\ Pressure\ Boster) = 145psi$$

$$Bore\ Area\ = \frac{F}{P}$$

$$where\ F\ is\ Required\ Force$$

$$P\ is\ the\ Factory\ Air\ Pressure$$

$$Bore\ Area\ = 5.5\ in^2$$

Checking Final Safety factor after Cylinder Section

$$Bore\ Size = 3.25\ in$$

$$Bore\ Area = 8.296\ in^2$$

$$Actual\ Force\ = Operating\ Pressure\ x\ Piston\ Area\ x\ Effeciency$$

$$Actual\ Force\ = 145psi\ x\ 8.296\ \ in^2\ x\ 0.7$$

$$Actual\ Force\ = 842.04\ lbs$$

$$Safety\ Factor\ = \frac{842.04}{614.08} = 1.37$$

Standards and Specifications

- American Society of Testing and Materials (ASTM) for all materials.
- All welding will be done according to the American Welding Society (AWS) and the American Society of Mechanical Engineers (ASME) specifications.
- Every metallic structure must be deburred and painted Mits-blue before being installed on the plant floor.

FABRICATION AND ASSEMBLY

The following are general points or steps used in order to manufacture and assemble the Cardboard Box Crusher from raw material to finished product;

Box Crusher and Aluminum Extrusions

- Top plate and press plate were machined to size from bar stock.
- Side tubing was cut to length and welded to a plate that gets attached to the conveyor.
- Guide rods was threaded at each end and screwed to the press plate.
- Each machine piece was spray painted with Mits-Blue paint as per specification of the plant.
- A third set of Conveyor legs were machined to better support the load from the box crusher main unit.
- Pneumatic Cylinder was face bolted onto the top plate.
- A variation of bolts and nuts were used to assemble the plexiglass protection around the machine.
- Accessories used for joining the extrusions and putting up the plexiglass are from recycled sections of the plant.

Figure 12: Painted Box Crusher Components

Figure 13: Press plate and piston rod fixture

Figure 14: Painted guide rods/tubing

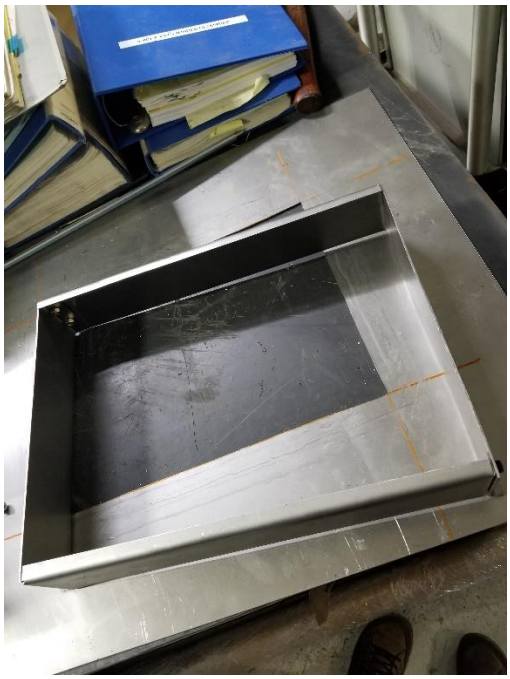

Figure 15: GoT Enclosure

Figure 16: Pneumatic cylinder face bolted

Figure 17: Mounted Aluminum Extrusions

Figure 18: Cardboard Box Crusher Assembled

Figure 19: Plexi-Glass(Lexan) covering

Air Pipes and Electric Wiring

- Based on the manuals for each automation equipment, the machine wiring was completed.
- The factory uses an NPN connection throughout the plant and thus was used to connect most of the light curtain components.
- All wires are run from the machine to the inverter and then finally into the electric junction box.
- CC-Link cables are used to connect all the PLC components to increase response speed.
- The sensors run directly to the PLC in the junction box.
- An air pressure booster was also wired to the cylinder air input to improve the crushing pressure.

Figure 20: Air Pressure Booster

Figure 21: Keyence Light Sensor

Figure 22: Wiring Config. for Conveyor Motor

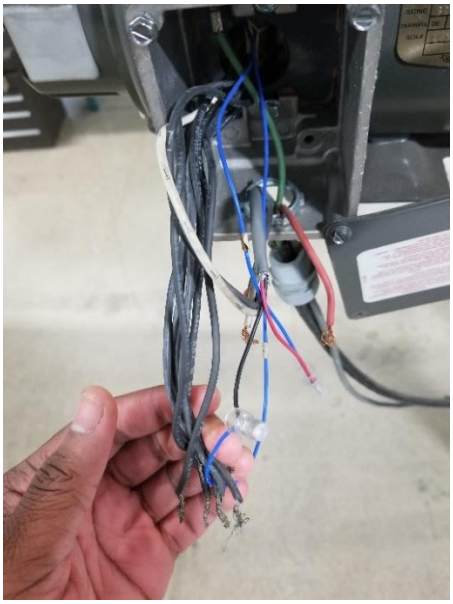

Figure 23: Conveyor motor junction box

TESTING AND PROOF OF DESIGN

At each milestone point within the project, a trial was run with empty cardboard boxes to access progress and correct mistakes. A force/pressure gauge was used to test that the pneumatic cylinder is performing correctly and that the press plate is actual delivering the required amount of force to crush the boxes. A set of 10 boxes were tested for the first wiring configuration so far. Subsequent testing was not done due to the Governor's lockdown order. Due to this situation, there are no comparative values to determine best measure to take for automation going forward.

Figure 24: Process before crushing

Figure 25: Crushed box from a side orientation

CURRENT STATE OF PROJECT

The following figures depict the state with which the project was left in after the stay home order by the Governor of Ohio was put into effect.

Figure 26: Side Profile of the Cardboard Box Crusher

Figure 27: Front Profile of the Cardboard Box Crusher

CONTINUOUS IMPROVEMENT

Based on the fact that the Cardboard Box Crusher, if effective, will be replicated throughout other assembly lines in the plant, future improvements are necessary . From the results of current tests, the box crushes about 85% of the time which is a good running percentage but to increase the efficiency and reduce machinist interactions. I have researched implementing smaller pneumatic cylinders to the sides of the conveyor that presses the box (Indenting it) and guaranteeing a better crushing rate. These implementations are inexpensive and will yield efficiencies closer to 95% approximately.

Figure 28: Parker K1 Air Cylinder

Figure 29: SMC CDQ2B32 Air Cylinder

Figure 30: SMC CDM2QF20 Air Cylinder

PROJECT MANAGEMENT

Project Budget Limit

After a meeting with my supervisor and plant manager, a budget of $4000, excluding parts that can be found at the plant, was set in order to build the Cardboard Box Crusher.

Key Milestones (Initial Estimates)

Fortunately, majority of the project was scheduled before the stay home order was put into effect and therefore, the machine is currently sitting in the '*Program PLC and GOT for Box Crusher/ Implementation of sensors'* stage.

Dates	Milestones Completed
10/29/2019	Re-Design conveyor rails
11/26/2019	Testing crushed boxes flow process
12/17/2019	Re-Construct Plexi glass protection around box crusher
1/28/2020	Install and Configure Safety Features i.e. Light Curtains
2/25/2020	Program PLC and GOT for box crusher/ Implimention of Sensors
3/31/2020	Create all documentation for operators and general public
4/9/2020	Tech Expo Day

Table 1: Initial Estimated Schedule

Full Budget (So Far)

Components	Price
Material and Machining (Main Unit)	$1,900.00
Material and Machining (Legs)	$300.00
Light Curtains	$600.00
Pneumatic Cylinder	$241.00
Extra Hardware	$85.00
Extrusions and Hardware	$200.00
Lexan Sheets (Plexi-glass)	$260.00
PLC CC-Link Card	$160.00
PLC Remote input/output Card	$80.00
Wires	$60.00
Guide Rod Bearings	$22.00
Total	$3,908.00

Table 2: Budget for Cardboard Box Crusher

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APPENDIX A

Based on a survey conducted on the 17th of September 27, 2019 at Mitsubishi Electric, by line workers on the Starter Assembly line, concerns such as ease of use, safety and Noise were raised and based on thirty completed surveys of which as sample has been attached below, clear product objectives were devised.

Survey Sample

Cardboard Press Machine

Hi, my name is Ato Gaisie, a co-op student on the starter side of the plant working under Dennis Dickerson. I have been tasked to build a machine on the empty conveyor by the performance testers that will crush cardboard boxes after they have been emptied. Please answer the following survey questions to help guide this project to completion.

Answer 1 to 5 in order of importance; 1 meaning least important and 5 meaning highest importance

How is important is each feature to you?

Safety (5)
Power Consumption (4)
Ease of Use (5)
Smart (Responsive to GOT inputs) (3)
Noise Factor (5)
Design (4)
Initial Investment Cost (4)

Answer 1 to 5 in order of satisfaction; 1 meaning least satisfied and 5 meaning highest satisfaction

How satisfied are you with the current baler system?

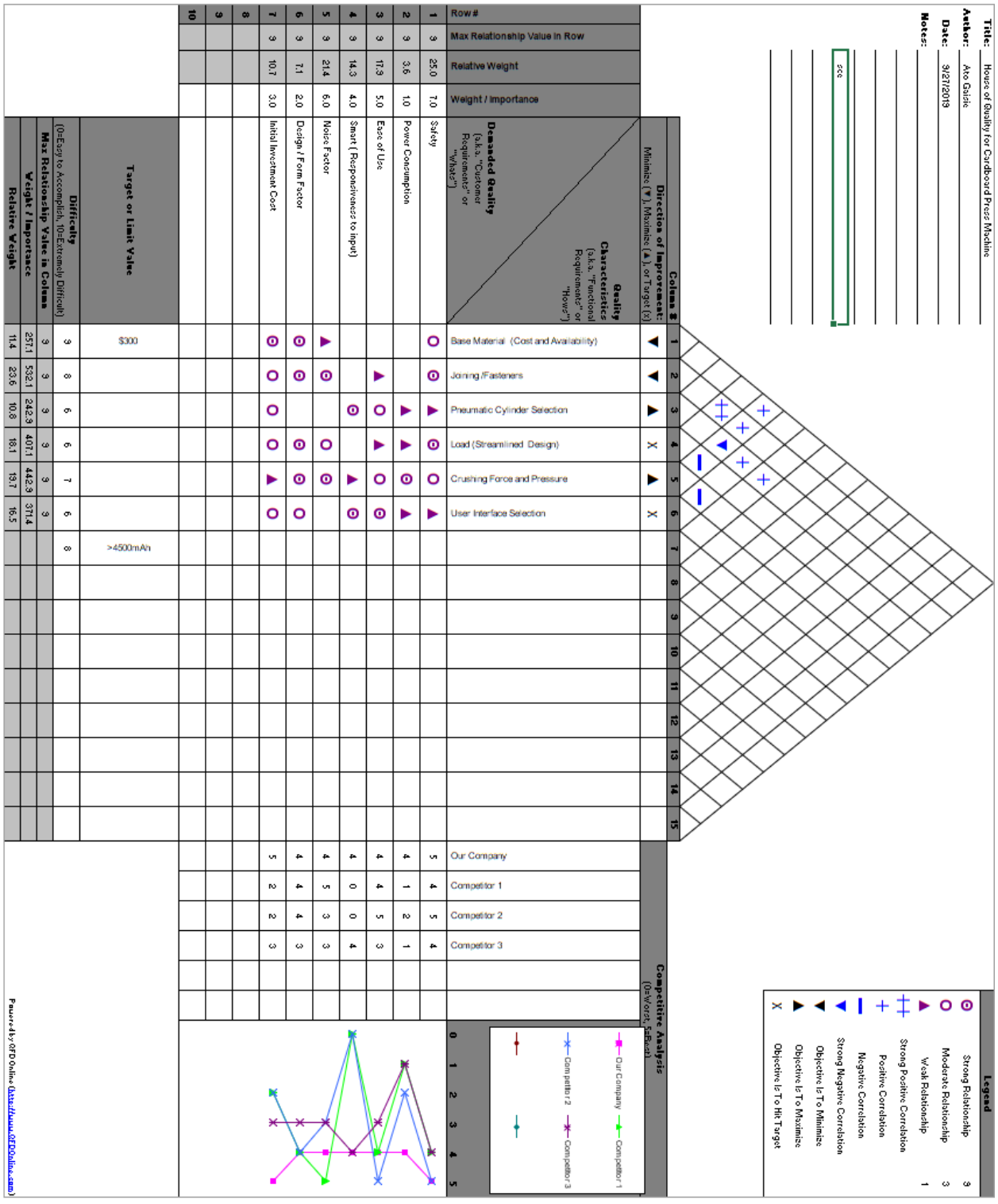
Safety (4)
Power Consumption (1)
Ease of Use (3)
Smart (Responsive to GOT inputs) (2)
Noise Factor (4)
Design (5)
Initial Investment Cost (4)

How much will you be willing to pay for my custom build?

$1000, $2000, $3000+ ($1000)

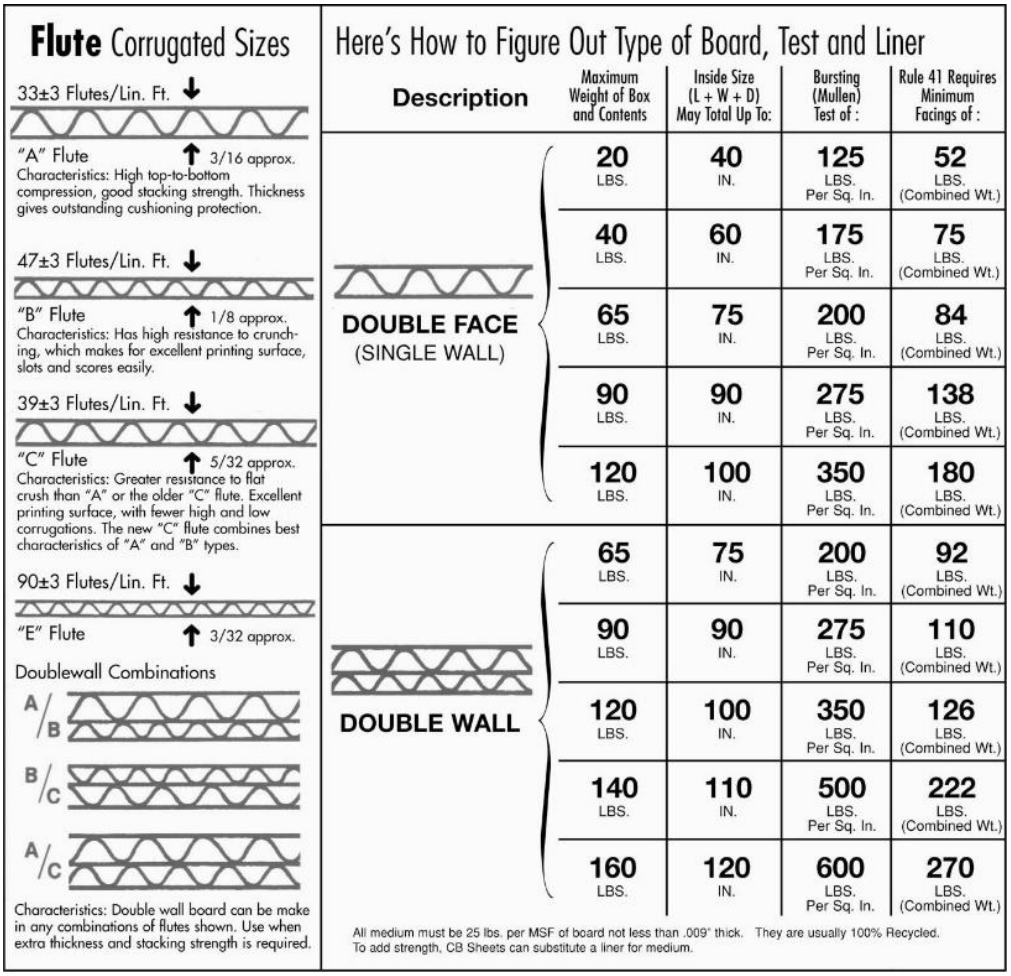
APPENDIX B

House of Quality



APPENDIX C

Corrugated Box values



Flute Corrugated Sizes

33±3 Flutes/Lin. Ft.

"A" Flute — 3/16 approx.
Characteristics: High top-to-bottom compression, good stacking strength. Thickness gives outstanding cushioning protection.

47±3 Flutes/Lin. Ft.

"B" Flute — 1/8 approx.
Characteristics: Has high resistance to crunching, which makes for excellent printing surface, slots and scores easily.

39±3 Flutes/Lin. Ft.

"C" Flute — 5/32 approx.
Characteristics: Greater resistance to flat crush than "A" or the older "C" flute. Excellent printing surface, with fewer high and low corrugations. The new "C" flute combines best characteristics of "A" and "B" types.

90±3 Flutes/Lin. Ft.

"E" Flute — 3/32 approx.

Doublewall Combinations

A/B

B/C

A/C

Characteristics: Double wall board can be make in any combinations of flutes shown. Use when extra thickness and stacking strength is required.

Here's How to Figure Out Type of Board, Test and Liner

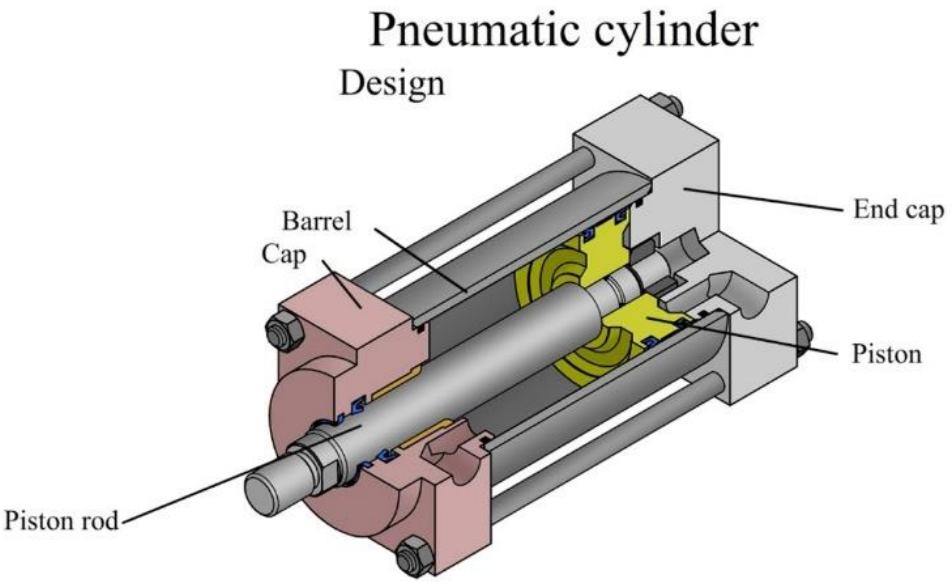
Description	Maximum Weight of Box and Contents	Inside Size (L + W + D) May Total Up To:	Bursting (Mullen) Test of :	Rule 41 Requires Minimum Facings of :
DOUBLE FACE (SINGLE WALL)	20 LBS.	40 IN.	125 LBS. Per Sq. In.	52 LBS. (Combined Wt.)
	40 LBS.	60 IN.	175 LBS. Per Sq. In.	75 LBS. (Combined Wt.)
	65 LBS.	75 IN.	200 LBS. Per Sq. In.	84 LBS. (Combined Wt.)
	90 LBS.	90 IN.	275 LBS. Per Sq. In.	138 LBS. (Combined Wt.)
	120 LBS.	100 IN.	350 LBS. Per Sq. In.	180 LBS. (Combined Wt.)
DOUBLE WALL	65 LBS.	75 IN.	200 LBS. Per Sq. In.	92 LBS. (Combined Wt.)
	90 LBS.	90 IN.	275 LBS. Per Sq. In.	110 LBS. (Combined Wt.)
	120 LBS.	100 IN.	350 LBS. Per Sq. In.	126 LBS. (Combined Wt.)
	140 LBS.	110 IN.	500 LBS. Per Sq. In.	222 LBS. (Combined Wt.)
	160 LBS.	120 IN.	600 LBS. Per Sq. In.	270 LBS. (Combined Wt.)

All medium must be 25 lbs. per MSF of board not less than .009" thick. They are usually 100% Recycled.
To add strength, CB Sheets can substitute a liner for medium.

Burst (Mullen) Test	ECT (Edge Crush Test)
200#	32 ECT
275#	48 ECT
350#	51 ECT
400#	61 ECT
500#	71 ECT
600#	82 ECT
Chainalytics.com	

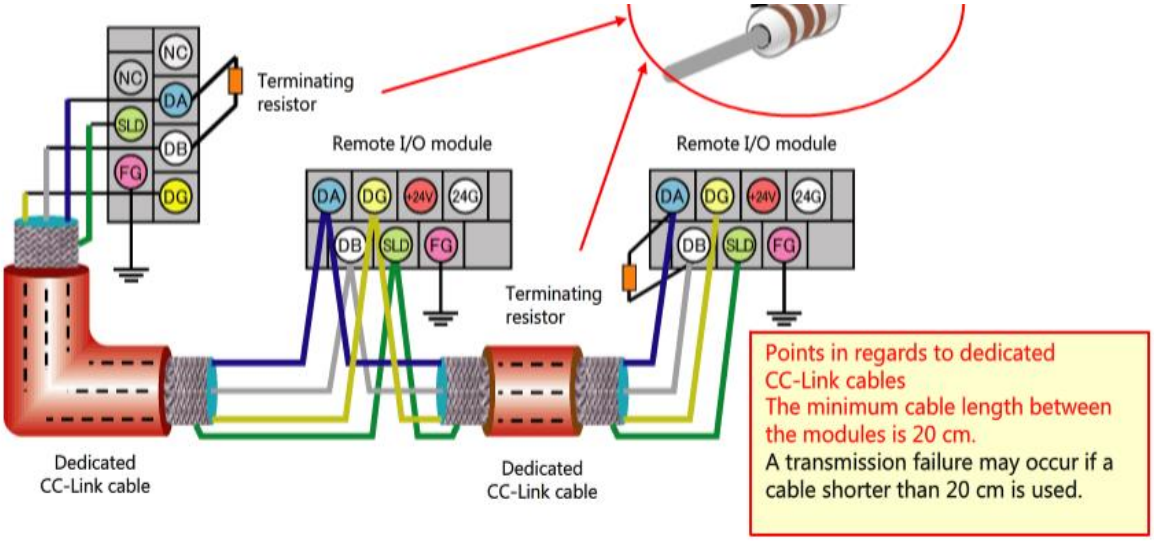
ECT vs Burst Comparative Compression Value Chart

APPENDIX D



APPENDIX E

CC-Link cable connection diagram



APPENDIX F

Conveyor inverter connection diagram

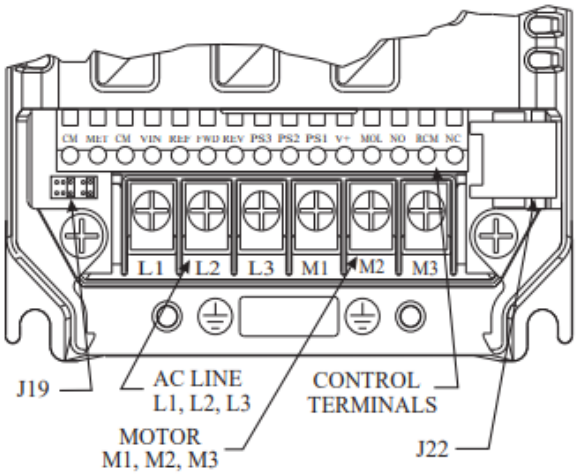


FIGURE 2.8

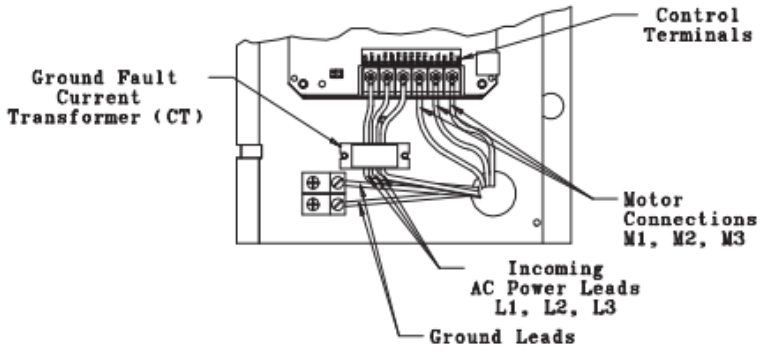
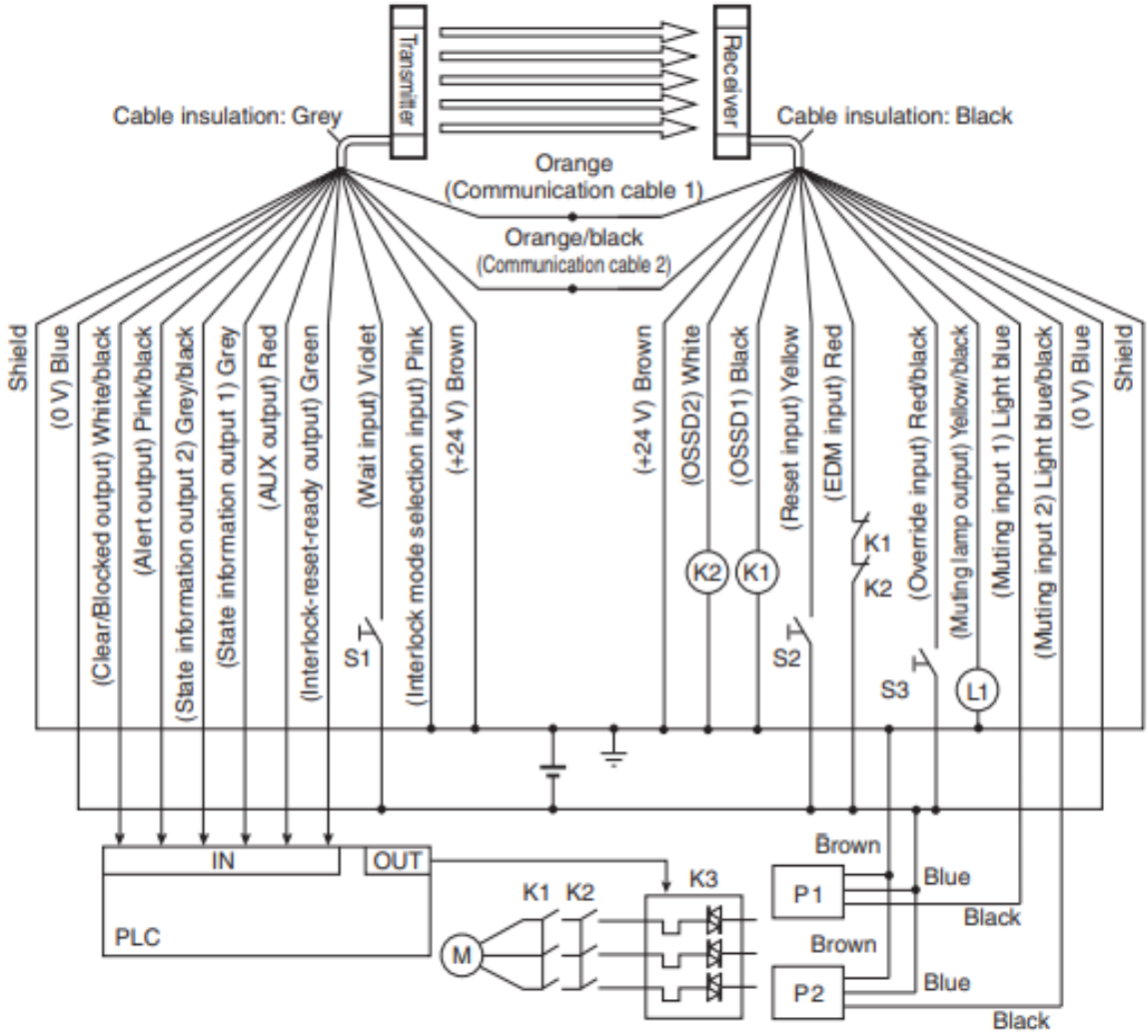


FIGURE 2.9

APPENDIX G

Light Curtain wiring configuration

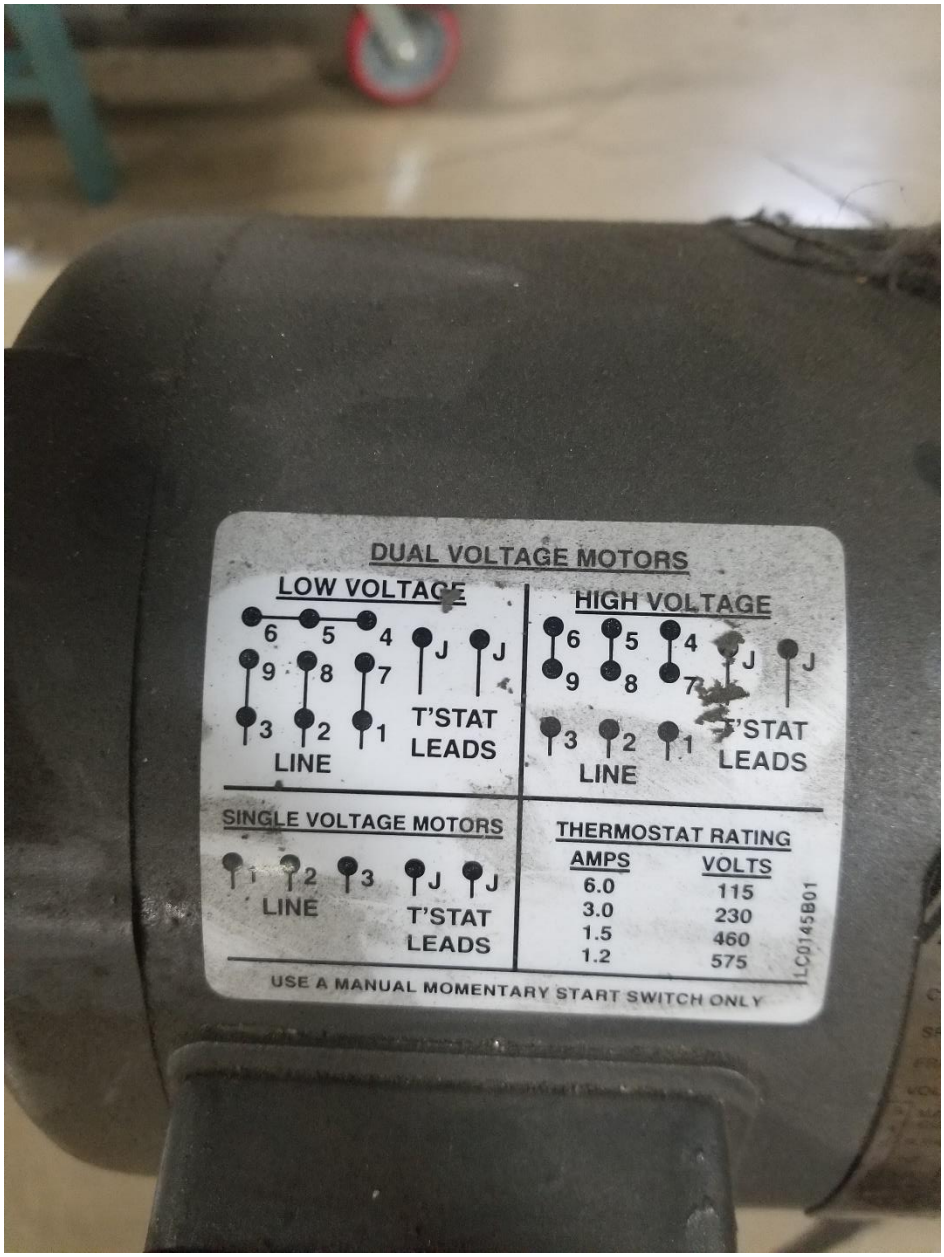
NPN output type cable



Use NPN output type for P1 and P2.

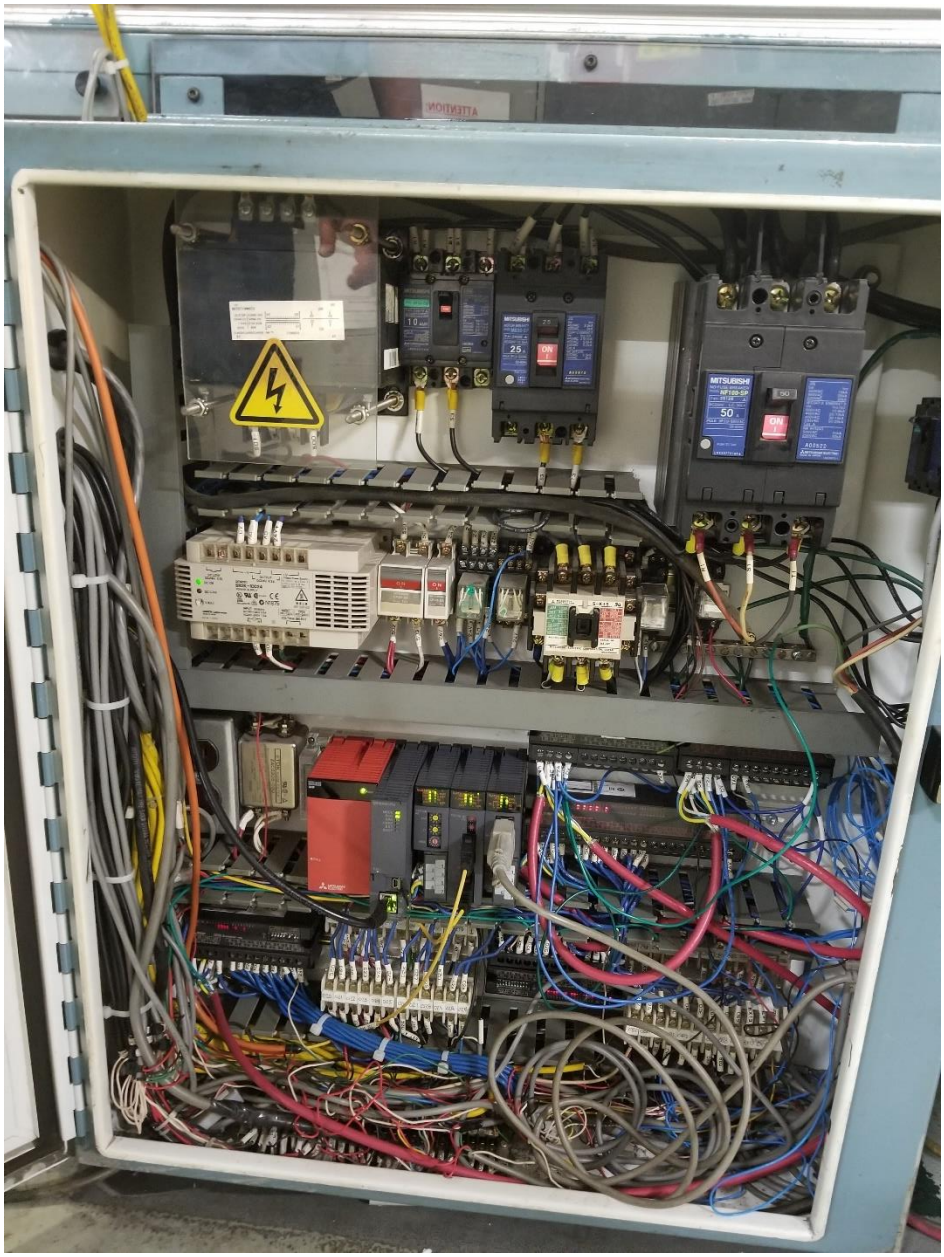
APPENDIX H

Conveyor motor wiring configuration



APPENDIX I

PLC Junction Box used for Cardboard Box Crusher



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