

Palestine Polytechnic University
College of Engineering



Sugar Cubes Making Machine

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جامعة بوليتكنك فلسطين
كلية الهندسة
دائرة الهندسة الكهربائية

اسم المشروع
Sugar Cubes Makine Machine

فريق العمل

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بناء على توجيهات المشرف على المشروع وبموافقة جميع اعضاء اللجنة الممتحنة،
تم تقديم هذا المشروع الى دائرة الهندسة الكهربائية للوفاء بمتطلبات الدائرة لدرجة
البكالوريوس.

توقيع المشرف

توقيع اللجنة الممتحنة

توقيع رئيس الدائرة

اهداء

إلى من بلغ الرسالة وأدى الأمانة، ونصح الأمة، إلى نبي الرحمة ونور العالمين
سيدنا محمد صلى الله عليه وسلم

إلى من رسموا بدمائهم خارطة الوطن وطريق المستقبل
شهداء الوطن الحبيب

إلى الذين عشقوا الحرية التي تفوح منها رائحة الياسمين، وتواروا خلف القضبان ليفسحوا لنا
النور
اسرانا البواسل

إلى من كلله الله بالهيبة والوقار، إلى من علمني العطاء بدون انتظار، إلى من أحمل اسمه بكل
افتخار، أرجو من الله أن يمد في عمرك لتري ثماراً قد حان قطافها بعد طول انتظار وستبقى كلماتك
نجوم أهندي بها اليوم وفي الغد وإلى الأبد
والذي العزيز

إلى ملاكي في الحياة، إلى معنى الحب وإلى معنى الحنان والتفاني، إلى بسمة الحياة وسر الوجود،
إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي إلى أعلى الحبايب
أمي الحبيبة

إلى مشرفنا القدير، الذي كان لنا أبا ومعلما
الدكتور عبد القادر الزرو

إلى الكادر الأكاديمي والإداري في دائرة الهندسة الكهربائية

إلى من ضاقت السطور لذكرهم فوسعتهم قلوبنا، اصدقاءنا الأعزاء

المخلص

المشروع عبارة عن آلة لصناعة مكعبات السكر عن طريق ضغط السكر في قالب ذو شكل مكعبي ثم تعريض المكعبات لحرارة معينة ليتم تبخير أجزاء المياه التي يتم خلطها مع السكر بنسبة معينة قبل البدء بعملية الضغط. حيث سيتم التحكم بالآلة من خلال الـ PLC ودوائر التحكم الكهرونيوماتيكي بدلا من الزيت لسهولة توصيله واستعماله في الآلة.

وقد جاءت هذه الفكرة من عدم توافر المنتج في الأسواق المحلية، بالإضافة الى التكلفة العالية للآلة في الأسواق العالمية مقارنة بتصميمها في السوق الفلسطيني، حيث تقدر تكلفتها بما يقارب ٢٠٠٠ دولار امريكي، حيث انه من المتوقع انتاج مكعبات سكر ذات جودة عالية ومناسبة وذات تكلفة إنتاجية منخفضة.

Abstract

Sugar is mainly used in our daily life, so sugar cubes machines were developed by engineers around the world. Sugar cubes can be formed by compressing Sugar in a cubic mold then blow hot air to the cubes to evaporate the water. This machine is to be controlled by a PLC device and electro-pneumatic system.

The Idea came up from the local market needs, in addition, the Machine's price is high in the global market compared to making it in Palestine. Cost is estimated to be around 2000 US Dollars, the Quality of the product is expected to be good and appropriate with low production cost.

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Chapter 1 Introduction

- 1.1. Overview
- 1.2. Background
- 1.3. Machine description
- 1.4. Objectives
- 1.5. Overall cost
- 1.6. Time table

1.1 Overview

1.1.1 Sugar cubes industry.

Sugar industry is one of the ancient and still the largest among food processing industries of the world.

Sugar, in its crude form, is being used as sweetening agent from time immemorial. So, improving it was and still developers' interests.

Machines are developed to satisfy the market, from this idea, producing sugar with different shapes was a need. They started to produce it as powder then it came the Idea to produce sugar as shapes, such as:

1. Cubic shape.
2. Star shape.
3. Heart shape.
4. Christmas tree shape.

1.1.2 Sugar Cubes forming.

Sugar Cubes are cubes of sugar meant for table use. They allow a user of them to sweeten his or beverage as desired. Generally, the beverages are hot, typically coffee or tea, as the cubes dissolve away very quickly into a liquid when the liquid is hot. They can be used to sweeten a cold drink, such as Iced Tea, but you will have to stir a great deal to encourage the cube to dissolve faster.

The cubes are made by pressing granulated sugar, mixed with a bit of sugar liquid to help glue them all together, into cube shapes, Machines form them into cubes, air-dry them, then package them, see figure 1.1.

Most sugar cubes are made from refined white sugar, but you can also get them made from Brown Sugar, Demerara Sugar, etc.

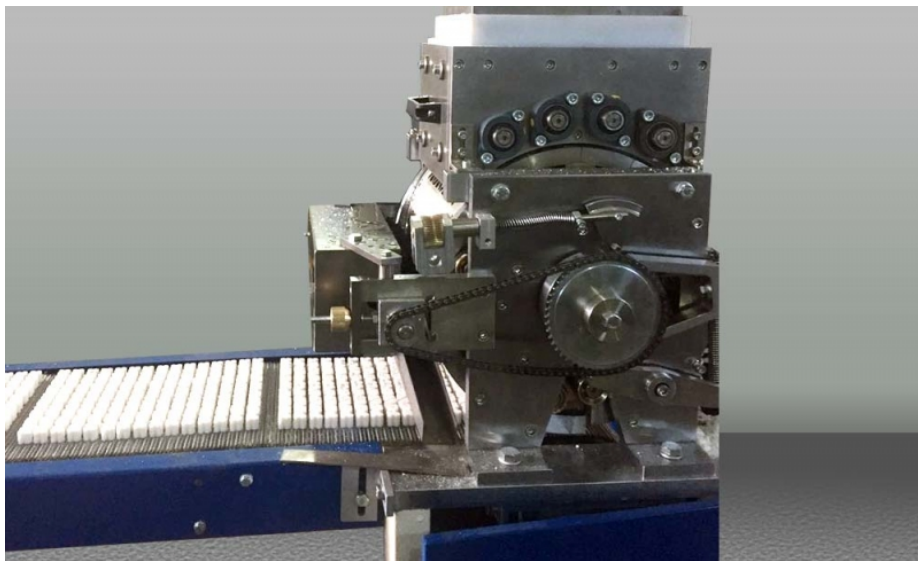


Figure 1. 1 Sugar cubes Machine

1.2 Background

1.2.1 Introduction

Sugar is mainly used in our life for everything, especially in hot drinks like tea, coffee and others. Sugar can be made in multiple shapes, mainly as cubes so it will be easier to use it and maintain it as well, so we decided to create a machine to produce these cubes.

1.2.2 History

In the 1700s, Europeans bought their sugar in brown loafs that had to be hacked, pounded and smashed into smaller pieces. “People just accepted that in order to use sugar, you had to go through all this physical trouble,” says Elizabeth Abbott, the author of “Sugar: A Bittersweet History.” “The big surprise is that there wasn’t a sugar cube invented much earlier.” By the 1800s, stores sold sugar already broken up into random-size pieces. But these chunks could be inconvenient at teatime. They often had to be dunked doughnut-style, because they wouldn’t fit in the cup. When the tea was finished, you were left with a sticky clump to dry out for future use.

In the 1840s, progress was made when Juliana Rad, who was married to the head of a sugar refinery in Moravia, cut a finger while chopping sugar. She complained to her husband, perhaps while waving her bandaged hand: why not make units of sugar that would come perfectly sized for one cup of tea? Jakub Krystof Rad’s innovation was to use a press to make the cubes, and he soon presented a box of them to his wife. He patented this specialized press in 1843.

The Rads might well be the Pierre and Marie Curie of beverage-sweetening, but it took decades before the sugar cube became widespread in Europe. A German named Eugen Langen reinvented the cube for the factory of the 1870s — the molten sugar was spun in a centrifuge and then sawed into small pieces. In the late 1800s, “processed food and refined food all became in vogue,” Abbott says.

Victorians, Abbott notes, loved how clean and neat — how manufactured — the sugar cube was. “It’s only today that we’re trying to make everything look homemade, natural,” she adds. “The pendulum is swinging back again”.

1.2.3 Stages of sugar cubes forming.

1. The first stage of sugar cubes forming is the mixing process, where sugar is mixed with 1 % water, a motor with shaft mixes the sugar and water together and making the mixture ready to go down to the tank.
2. After the sugar reaches the tank, 2 pistons move the tank along the x-axis several times till a mold with cubes is filled with the mixture.
3. When the mold is filled with the mixture, it will experience a pressure process to give the sugar mixture its cubic shape.
4. The tank pushes the cubes to a conveyer, then they will be heated to evaporate the water and give the cubes its hard shape.

1.3 Machine description.

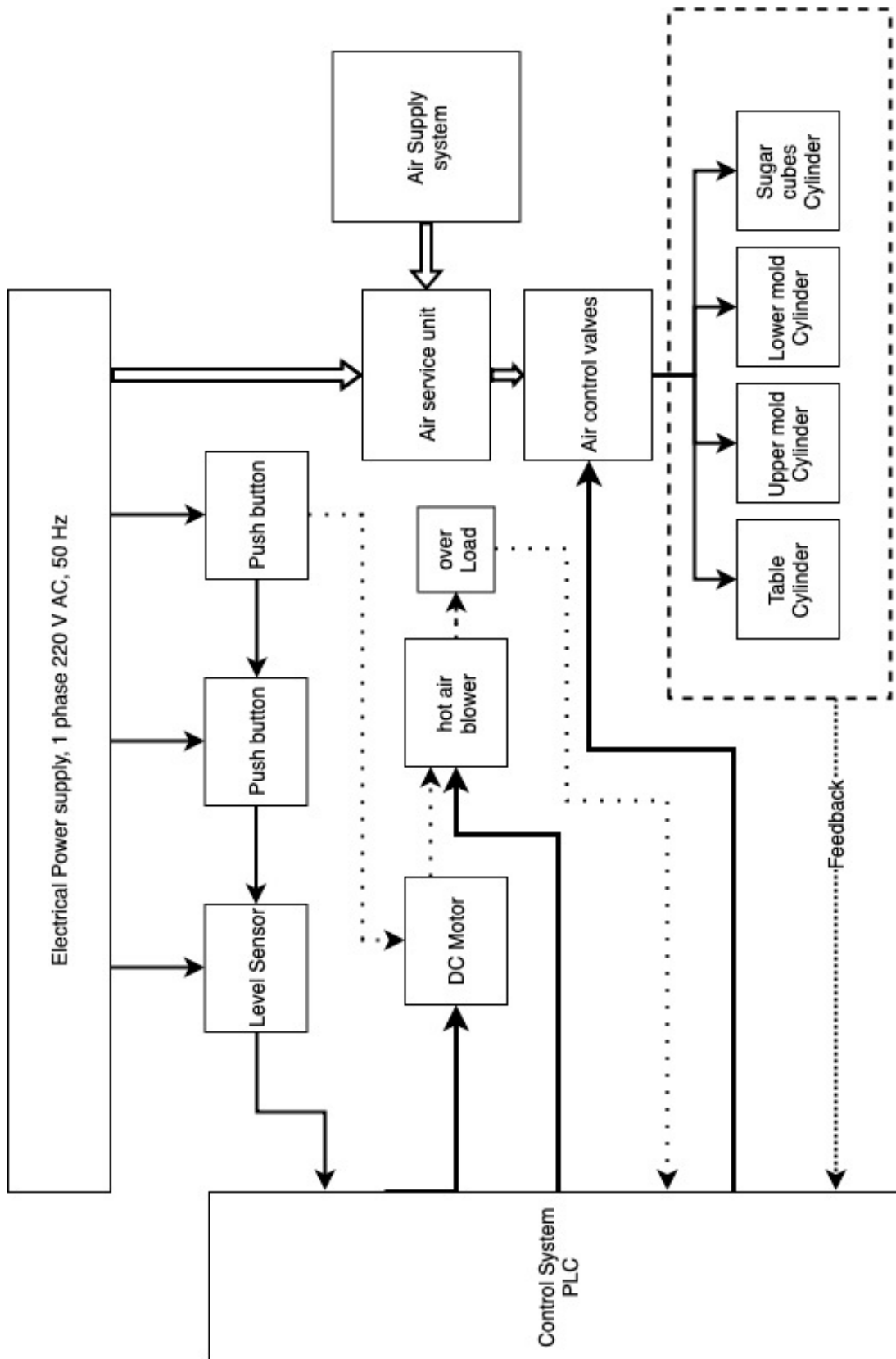


Figure 1. 2 Machine's block diagram

1.4 Objectives

1. Produce sugar cubes in with high quality.
2. Create a machine that satisfies the local market needs.
3. Create a low-cost machine compared to the global market.
4. Develop the cubes machine to be full automated.

1.5 Overall Cost

See Table 1.1

Item name	Cost/part ₪	#of Parts	Total price
PLC	1100	1	1100
1 phase Motor	200	1	200
Double acting cylinder	220	4	880
Solenoid Valve	60	4	240
Contactora	70	2	140
Heater	150	1	150
Limit Switch	60	8	480
Emergency switch	50	1	50
Cables, pipes and others	--	--	400
Body	--	--	1100
	Total Cost		₪4740.00

Table 1. 1 Project total cost(roughly)

1.6 Time table

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Activities																
Data collection	■	■	■	■												
Data analysis					■	■	■	■	■	■						
System design											■	■	■	■		
Documentation					■	■	■	■	■	■	■	■	■	■		
Presentation preparing															■	■

Table 1. 2 Time Table

2

Chapter 2 Theory

- 2.1 Component table
- 2.2 PLC
- 2.3 One-phase DC Motors
- 2.4 Contactors
- 2.5 Limit Switch
- 2.6 Pneumatic System

2.1 System Components

1. Sugar: The input of the process.
2. PLC (Delta).
3. Electro pneumatic system.
4. Switches.
5. Indicators (light bulbs).

2.2 PLC controller

Programmable Logic Controllers (PLC) is essential controller equipment in modern industrial control system. Though it is totally practical equipment it can be changed by the program of its operation that's why it is call Programmable Logic Controllers, and the figure (3.1) below is show a one of types of PLC

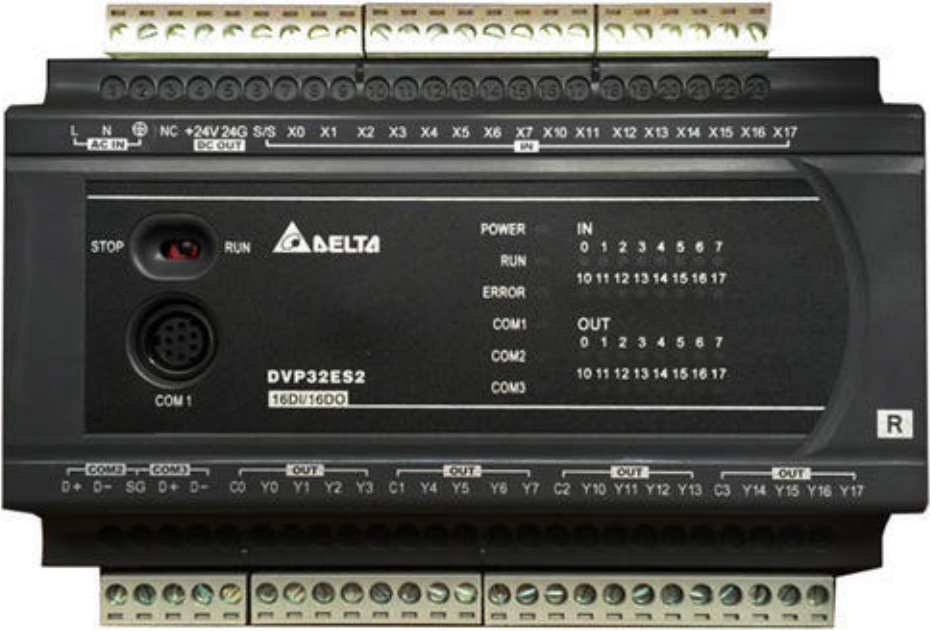


Figure 2. 1 Delta PLC 16 input 16 output type

Using of relay-based switches to implement basic logical expressions and some examples of logic-based industrial system control. This type of control system detects the status of inputs like switches and other on-off logical devices (e.g. position directors, liquid level detectors, etc.) and then uses relays, timers and counters to implement logic and drive outputs by energizing the output coil of some sort of valve or other actuator.

Introduction to PLC

Control engineering has evolved over time. In the past humans was the main method for controlling system. More recently electricity has been used for control and early electrical control was based on relays, these relays allow power to be switched on and off without a mechanical switch. It is common to use relays to make simple logical control decisions. The development of low-cost computer has brought the most recent revolution. The Programmable Logic Controller (PLC). The advent of the PLC began in the 1970s, and has become the most common choice for manufacturing controls. PLCs have been gaining popularity on the factory floor and will probably remain predominant for some time to come Most of this is because of the advantages they offer:

1. Cost effective for controlling complex systems.
2. Flexible and can be reapplied to control other systems quickly and easily.
3. Computational abilities allow more sophisticated control.
4. Trouble shooting aids make programming easier and reduce downtime.
5. Reliable components make these likely to operate for years before failure.

Characteristic of PLC

1. Its Changeable operation.
2. Processing element is used hear.
3. Input & output signal Isolated as if PLC could not damage with electrical fault. - Its reliability is high.

Functional Description of PLC

PLC is actually an industrial microcontroller system where you have hardware and software specially adapted to industrial environment Special attention needs to be given to input and output. because in these blocks you find protection needed in isolating a CPU blocks from damaging influence that industrial environment can be bring to a CPU via input lines. Program unit is usually a computer used for writing a program (often in ladder diagram).

The control program can be entered into the PLC by using a simple from of high level language like ladder diagram, instruction code etc. The input device such as switch, push buttons, sensors and output device such as motors, relays, valves, lamps, etc. are connected to PLC the operator then enters a sequence of instructions (programs) into the memory of the PLC, the controller then monitors the inputs and outputs according to these programs and carries it out of the program.

2.3 One-Phase DC Motors

DC Motor theory

The DC motor has two basic parts: the rotating part that is called the armature and the stationary part that includes coils of wire called the field coils. The stationary part is also called the stator.

The armature is made of coils of wire wrapped around the core, and the core has an extended shaft that rotates on bearings. You should also notice that the ends of each coil of wire on the armature are terminated at one end of the armature. The termination points are called the commutator, and this is where the brushes make electrical contact to bring electrical current from the stationary part to the rotating part of the machine.

The coils that are mounted inside the stator are called field coils and they may be connected in series or parallel with each other to create changes of torque in the motor. You will find the size of wire in these coils and the number of turns of wire in the coil will depend on the effect that is trying to be achieved.

DC Motor Overview

The armature and field in a DC motor can be wired three different ways to provide varying amounts of torque or different types of speed control. The armature and field windings are designed slightly differently for different types of DC motors. The three basic types of DC motors are the series motor, the shunt motor, and the compound motor.

The series motor is designed to move large loads with high starting torque in applications such as a crane motor or lift hoist. The shunt motor is designed slightly differently, since it is made for applications such as pumping fluids, where constant-speed characteristics are important. The compound motor is designed with some of the series motor's characteristics and some of the shunt motor's characteristics.

This allows the compound motor to be used in applications where high starting torque and controlled operating speed are both required.

It is important that you understand the function and operation of the basic components of the DC motor, since motor controls will take advantage of these design characteristics to provide speed, torque, and direction of rotation control. The basic components of a DC motor include the armature assembly, which includes all rotating parts; the frame assembly, which houses the stationary field coils; and the end plates, which provide bearings for the motor shaft and a mounting point for the brush rigging. Each of these assemblies is explained in depth so that you will understand the design concepts used for motor control.

2.4 Contactors

A contactor is an electrically controlled switch (relay) used for switching an electrical power circuit, also it is typically controlled by a circuit which has a much lower power level than the switched circuit, such as a 24-volt coil electromagnet controlling a 230-volt motor switch.

When a relay is used to switch a large amount of electrical power through its contacts, it is designated by a special name " **contactor**".

Contactors typically have multiple contacts, and those contacts are usually (but not always) normally-open, so that power to the load is shut off when the coil is de-energized, perhaps the most common industrial use for contactors is the control of electric motors. And the figure (3.7) is show how it work, the top three contacts switch the respective phases of the incoming 3-phase AC power, the lowest contact is an "auxiliary" contact which has a current rating much lower than that of the large motor power contacts but is actuated by the same armature as the power contacts.

The auxiliary contact is often used in a relay logic circuit, or for some other part of the motor control scheme, typically switching 120 Volt AC power instead of the motor voltage, also we have contactor may have several auxiliary contacts, either normally-open or normally-closed if required.

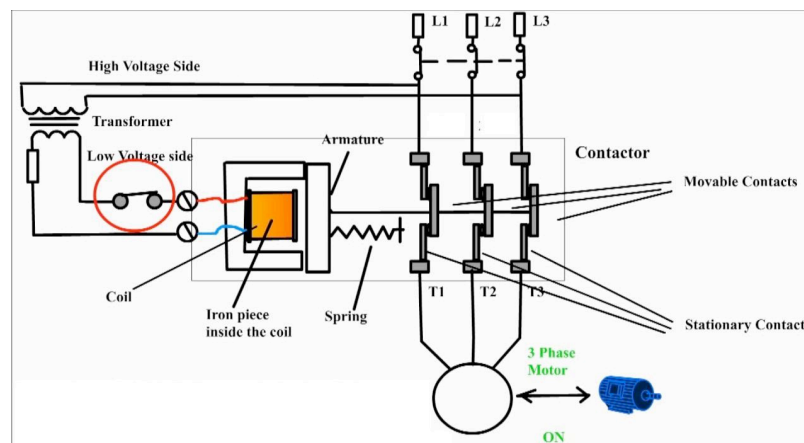


Figure 2. 2 Contactor's structure

3.5 Limit switch

In electrical engineering a limit switch is a switch operated by the motion of a machine part or presence of an object. They are used for controlling machinery as part of a control system, as a safety interlocks, or to count objects passing a point.



Figure 2. 3 Limit Switch

A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. They were first used to define the limit of travel of an object; hence the name "Limit Switch".

Standardized limit switches are industrial control components manufactured with a variety of operator types, including lever, roller plunger, and whisker type. Limit switches may be directly mechanically operated by the motion of the operating lever. A reed switch may be used to indicate proximity of a magnet mounted on some moving part. Proximity switches operate by the disturbance of an electromagnetic field, by capacitance, or by sensing a magnetic field.

Rarely, a final operating device such as a lamp or solenoid valve will be directly controlled by the contacts of an industrial limit switch, but more typically the limit switch will be wired through a control relay, a motor contactor control circuit, or as an input to a programmable logic controller.

Miniature snap-action switch may be used for example as components of such devices as Photocopiers, computer printers, convertible tops or microwave ovens to ensure internal components are in the correct position for operation and to prevent operation when access doors are opened. A set of adjustable limit switches are installed on a garage door opener to shut off the motor when the door has reached the fully raised or fully lowered position. A numerical control machine such as a lathe will have limit switches to identify maximum limits for machine.

2.6 Pneumatic System

Pneumatics has long since played an important role as a technology in the performance of mechanical work. It is also being used in the development of automation solutions. Pneumatic systems are similar to hydraulic systems but in these systems compressed air is used in place of hydraulic fluid.

A pneumatic system is a system that uses compressed air to transmit and control energy. Pneumatic systems are used extensively in various industries. Most pneumatic systems rely on a constant supply of compressed air to make them work. This is provided by an air compressor. The compressor sucks in air from the atmosphere and stores it in a high pressure tank called a receiver. This compressed air is then supplied to the system through a series of pipes and valves.

Advantages of pneumatic systems

Pneumatic systems are widely used in different industries for the driving of automatic machines. Pneumatic systems have a lot of advantages.

1. High effectiveness – There is an unlimited supply of air in the atmosphere to produce compressed air. Also, there is the possibility of easy storage in large volumes. The use of compressed air is not restricted by distance, as it can easily be transported through pipes. After use, compressed air can be released directly into the atmosphere without the need of processing.
2. High durability and reliability – Pneumatic system components are extremely durable and cannot be damaged easily. Compared to electromotive components, pneumatic components are more durable and reliable.
3. Simple design – The designs of pneumatic system components are relatively simple. They are thus more suitable for use in simple automatic control systems. There is choice of movement such as linear movement or angular rotational movement with simple and continuously variable operational speeds.
4. High adaptability to harsh environment – Compared to the elements of other systems, compressed air is less affected by high temperature, dust, and corrosive environment, etc. Hence, they are more suitable for harsh environment.
5. Safety aspects – Pneumatic systems are safer than electromotive systems because they can work in inflammable environment without causing fire or explosion. Apart from that, overloading in pneumatic system only leads to sliding or cessation of operation. Unlike

components of electromotive system, pneumatic system components do not burn or get overheated when overloaded.

6. Easy selection of speed and pressure – The speeds of rectilinear and oscillating movement of pneumatic systems are easy to adjust and subject to few limitations. The pressure and the volume of the compressed air can easily be adjusted by a pressure regulator.
7. Environmentally friendly – The operation of pneumatic systems do not produce pollutants. Pneumatic systems are environmentally clean and with proper exhaust air treatment can be installed to clean room standards. Therefore, pneumatic systems can work in environments that demand high level of cleanliness. One example is the production lines of integrated circuits.
8. Economical – As the pneumatic system components are not expensive, the costs of pneumatic systems are quite low. Moreover, as pneumatic systems are very durable, the cost of maintenance is significantly lower than that of other systems.

Limitations of pneumatic systems

Although pneumatic systems possess a lot of advantages, they are also subject to several limitations. These limitations are given below.

1. Relatively low accuracy – As pneumatic systems are powered by the force provided by compressed air; their operation is subject to the volume of the compressed air. As the volume of air may change when compressed or heated, the supply of air to the system may not be accurate, causing a decrease in the overall accuracy of the system.
2. Low loading – As the cylinders used in pneumatic systems are not very large, a pneumatic system cannot drive loads that are too heavy.
3. Processing required before use – Compressed air must be processed before use to ensure the absence of water vapor or dust. Otherwise, the moving parts of the pneumatic components may wear out quickly due to friction.
4. Uneven moving speed – As air can easily be compressed, the moving speeds of the pistons are relatively uneven.
5. Noise – Noise is usually produced when the compressed air is released from the pneumatic components.

Basic Components of the system

Pneumatic system carries power by employing compressed gas generally air as a fluid for transmitting the energy from an energy-generating source to an energy – use point to accomplish useful work. Figure 2.9 shows the simple circuit of a pneumatic system with basic components.

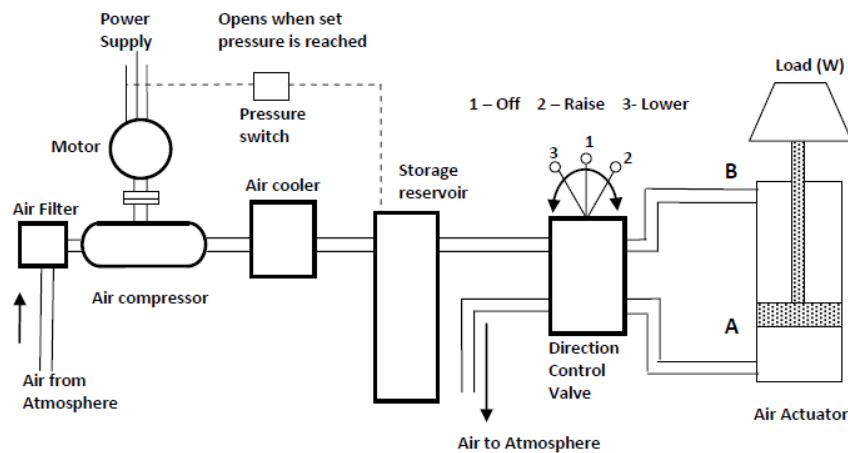


Figure 2. 4 An example for a Pneumatic system

Functions of components

1. Pneumatic actuator converts the fluid power into mechanical power to do useful work
2. Compressor is used to compress the fresh air drawn from the atmosphere.
3. Storage reservoir is used to store a given volume of compressed air.
4. Valves are used to control the direction, flow rate and pressure of compressed air.
5. External power supply (Motor) is used to drive the compressor.
6. Piping system carries the pressurized air from one location to another.

3

Chapter 3 Mechanical design

- 3.1 Introduction
- 3.2 Sugar mold
- 3.3 Mixer
- 3.4 Trolley
- 3.5 Machine body

3.1 Introduction

This chapter will include the 3D Design for the Machine parts using Catia software. Starting from mixing tank till the sugar reaches the mold, as well as other needed parts during the process.

3.2 Mixer tank

It used to mix the sugar with a certain percent of water (1%), water is added so the sugar cube can be strong until it is heated, the Mixer is made out of stainless steel as shown in figure 3.1, and it is connected with a motor to mix the sugar.

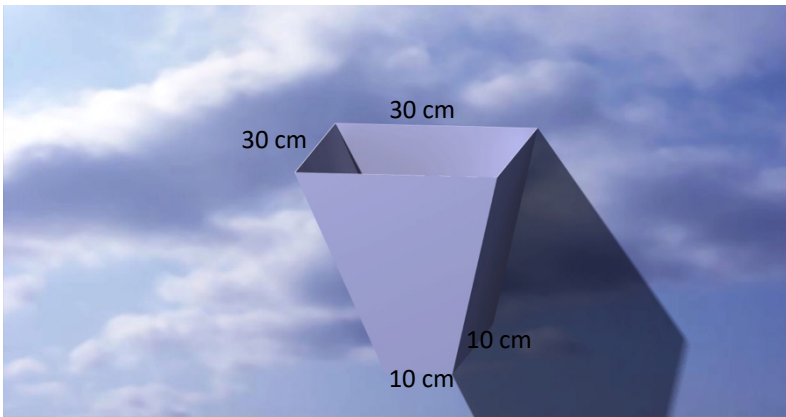


Figure 3. 1 Mixer tank 3D design

3.3 Trolley

It is connected with two pistons to fill sugar in the mold and to push it to move the compressed sugar after being compressed.
Dimension: 20*20*10 cm.

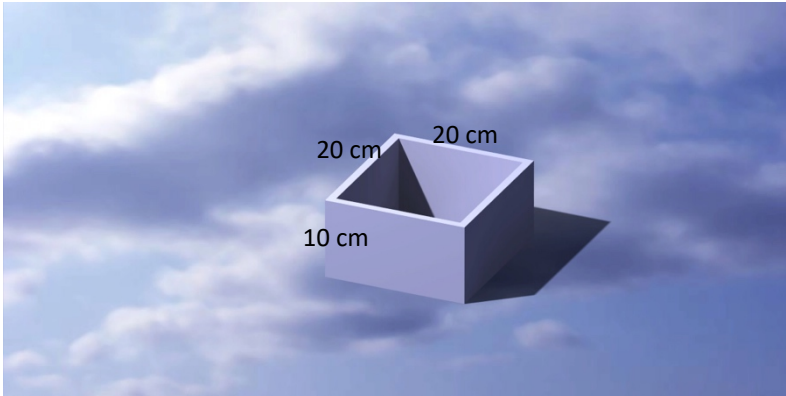


Figure 3. 2 Trolley 3D design

3.4 Sugar molds

The mold is made out of stainless steel, and it has a capacity of 30 cube to be filled with sugar and then compressed in order to create the sugar cubes.

The Mold has six rows and five columns. The dimensions of each cube are 2.5 cm x 2.5 cm x 2.5 cm.

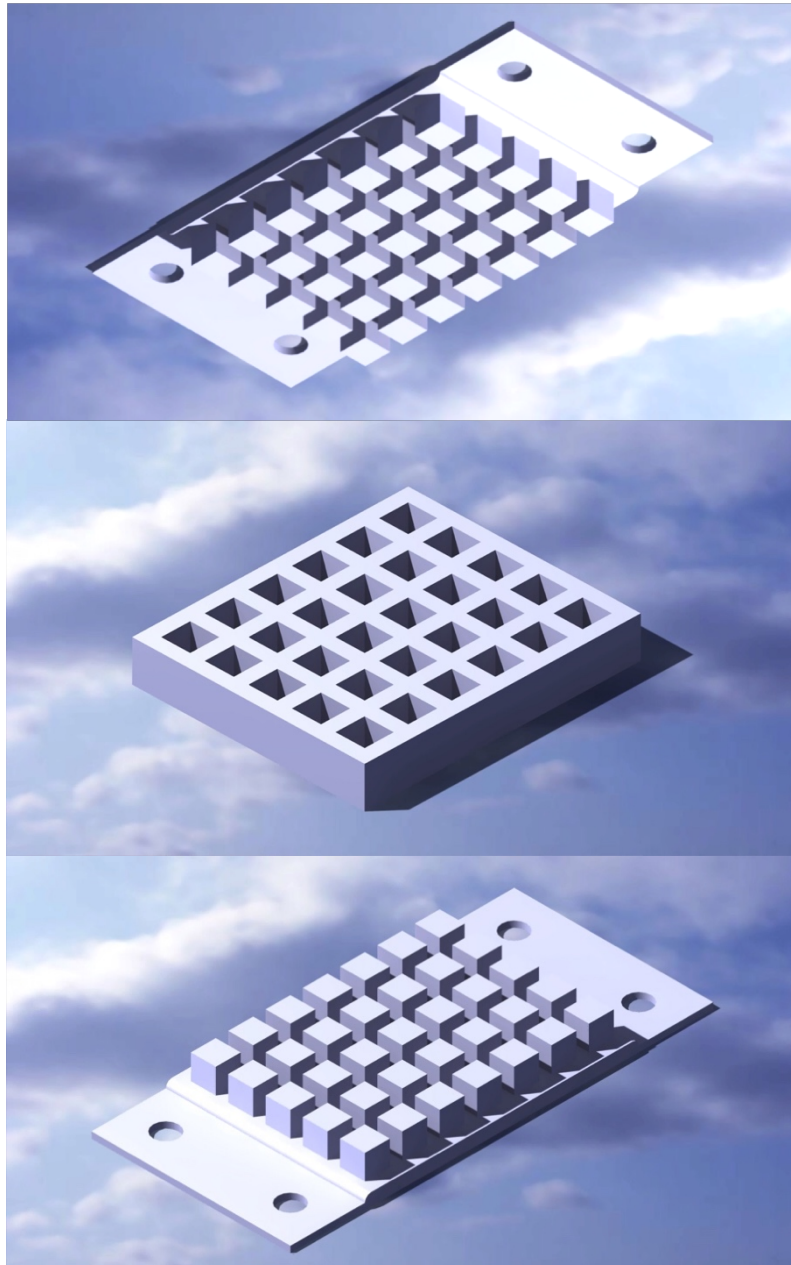


Figure 3. 3 Sugar upper, middle and lower molds

3.5 Machine body

The table that hold all the Machine part is made of stainless steel and metal.
Dimension: 120*60*80 cm

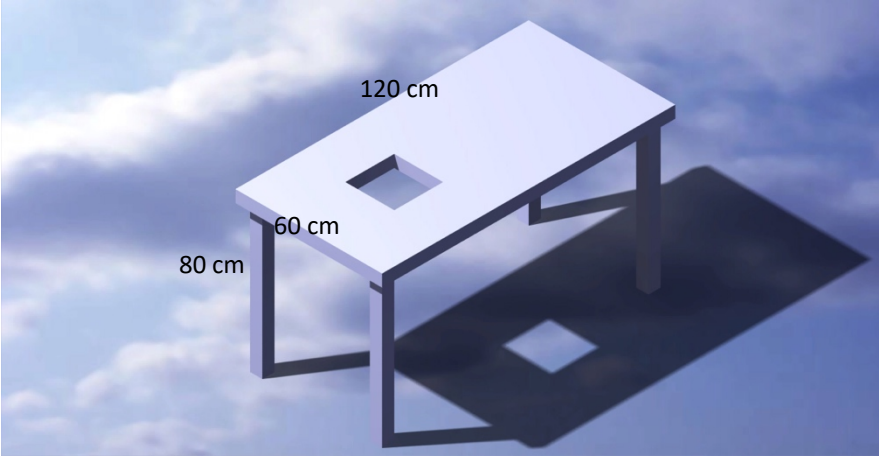


Figure 3. 4 Machine main body (table)

- Electrical Panel: This Panel contains electrical parts like contactors, MCB's, RCD, etc.

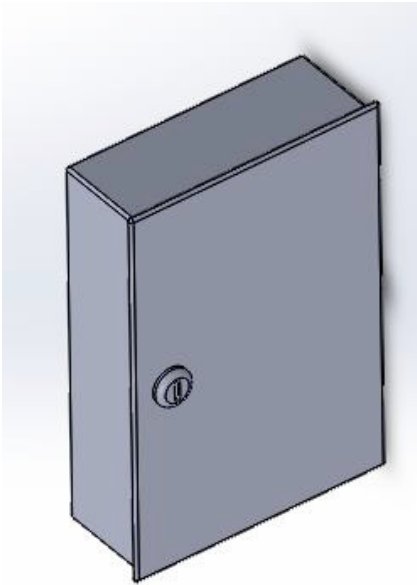


Figure 3. 5 Electrical parts Panel

4

Chapter 4 Electrical Design

- 4.1 Introduction.
- 4.2 Cylinders calculation.
- 4.3 PLC Control Circuit.
- 4.4 PLC Input-Output table.
- 4.5 Motor and Heater Power Circuit.
- 4.6 Pneumatic Circuit.

4.1 Introduction

In this chapter, PLC, Motor and pistons connections will be explained. Also, The Calculations for the pistons will be explained.

4.2 Cylinders calculation.

For the upper and lower molds pistons

$$F = A \times P$$

$$F = (\mu_F \times W) + W$$

Where,

$$\begin{aligned} W &= m \times g \\ W &= 12 \text{ kg} \times 9.81 \text{ m/s}^2 \\ W &= 120 \text{ N} \end{aligned}$$

Thus,

$$\begin{aligned} F &= (0.2 \times 120) + 120 \\ F &= 140 \text{ N} \end{aligned}$$

And

$$A = \frac{\pi}{4} d^2 = \frac{F}{P}$$

That means

$$\begin{aligned} d &= \sqrt{\frac{4F}{\pi P}} \\ d &= 5.00 \text{ mm} \end{aligned}$$

For the trolley piston, first, the trolley can hold up to 6.348 Kg.

$$\begin{aligned} \text{Trolley volume} &= 20\text{cm} \times 20\text{cm} \times 10\text{cm} = 4000 \text{ cm}^3 \\ \text{Density} &= \frac{\text{mass}}{\text{volume}} \end{aligned}$$

Thus,

$$\text{mass} = 1.587 \times 4000\text{cm}^3 = 6348 \text{ grams}$$

$$F = A \times P$$

$$F = (\mu_F \times W) + W = 82.5 \text{ N}$$

Where,

$$\begin{aligned} W &= m \times g \\ W &= 6.348 \text{ kg} \times 9.81 \text{ m/s}^2 \\ W &= 62.27 \text{ N} \end{aligned}$$

Thus,

$$A = \frac{\pi}{4} d^2 = \frac{F}{P}$$

That means

$$d = \sqrt[2]{\frac{4F}{\pi P}}$$
$$d = 4.10 \text{ mm}$$

F: Force

W: Weight

m: mass

A: Rod Area

d: rod diameter

μ_F : Friction factor

4.3 PLC control circuit.

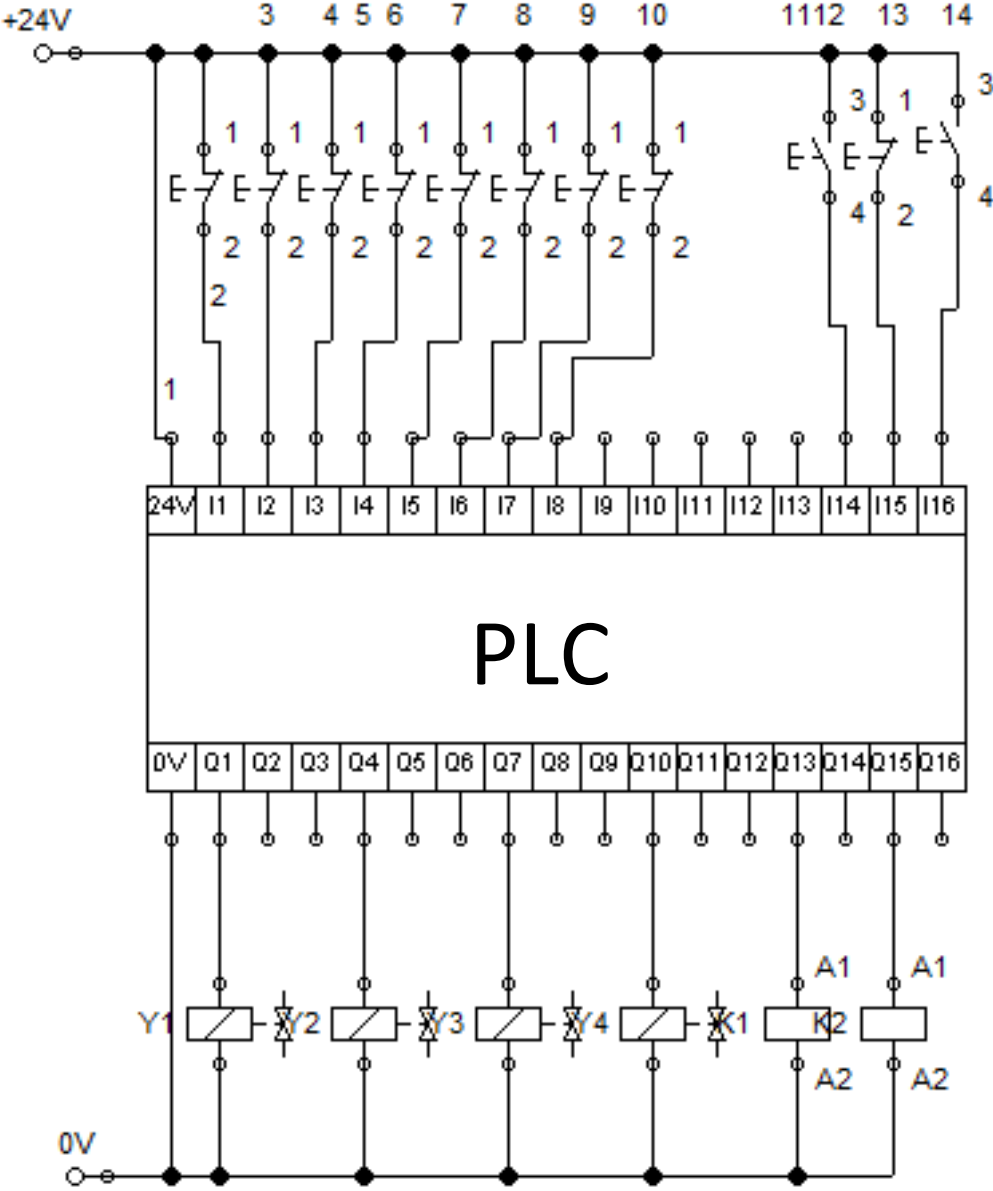


Figure 4. 1 PLC Control circuit

4.4 PLC input output table.

Shown in Table 4.1 the PLC inputs and outputs with the description for each as well as the address in the PLC.

Symbol	Description	Address
INPUTS		
Soff	OFF pushbutton	X0
Son	ON Pushbutton	X1
LS1	Limit switch-cyl1	X2
LS2	Limit switch-cyl1	X3
LS3	Limit switch-cyl2	X4
LS4	Limit switch-cyl2	X5
LS5	Limit switch-cyl3	X6
LS6	Limit switch-cyl3	X7
LS7	Limit switch-cyl4	X8
LS8	Limit switch-cyl4	X9
LvlS	Level Sensor	X10
OUTPUTS		
Y1	Valve Relay-Cyl1	Y0
Y2	Valve Relay-Cyl2	Y1
Y3	Valve Relay-Cyl3	Y2
Y4	Valve Relay-Cyl4	Y3
K1	Motor contactor	Y4
K2	Heater Contactor	Y5
LEDred	Indicator	Y6
LEDorange	Indicator	Y7
LEDgreen	Indicator	Y8

Table 4. 1 PLC Input/Output allocation table

4.5 Motor and Heater power circuit.

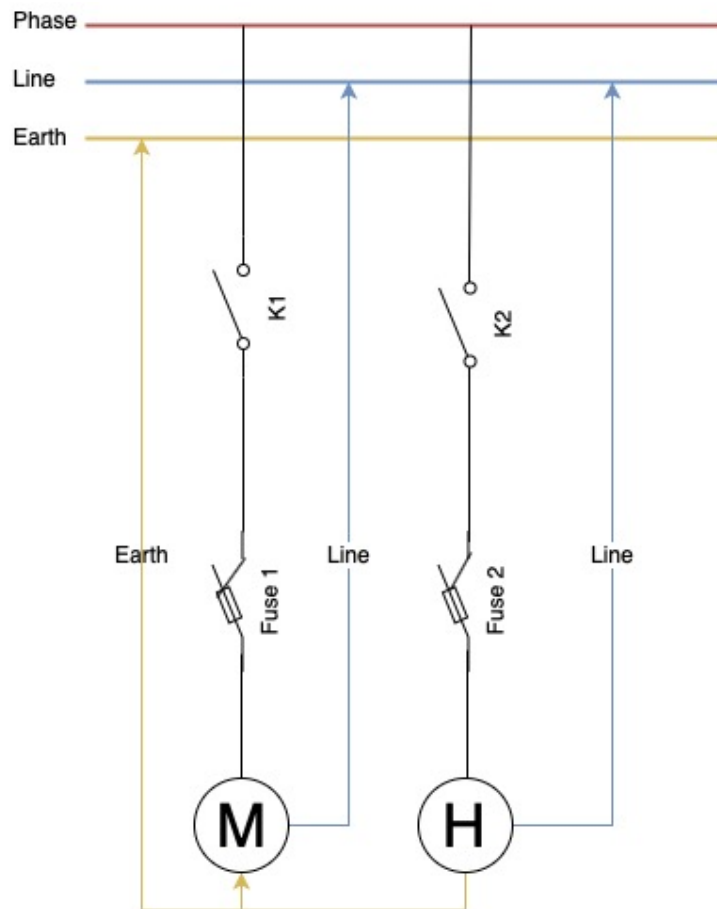


Figure 4. 2 Motor and Heater Power circuit

As shown in figure 4.2, both, The Motor and The Heater are connected to the supply voltage with 2 contactors that to be controlled by the PLC. The 2 OL switches are connected in series to protect the electrical devices from being overloaded.

4.6 Pneumatic circuit.

We used FESTO software to design the Pneumatic circuit as it is needed in the Machine. The circuit shown in **Appendix B** is a translation to the processes sequence by the PLC.

*See **Appendix B**

5

Chapter 5 Results and Conclusion

5.1 Results

5.2 Conclusions

5.3 Recommendation

5.4 References

5.5 Photos of The Machine

5.1 Results

- The Machine is controlled by PLC unlike other machines.
- Heating the sugar cubes with hot air is good, but using a microwave to evaporate the water will be a lot better.
See Appendix A for microwave process.
- Stainless steel is the best metal for food industry, but it is more expensive than others

5.2 Conclusion

- Pneumatic system is a good choice for Sugar industry because unlike Oil, Air will not pollute the Sugar.
- PLC is the best choice to control the machine since it is hard to build a Machine with normal control methods.
- Building a Machine from A-Z is not an easy thing, so an upgrade to this machine will be a good choice.

5.3 Recommendation

- Convert the machine to a production line.
- Upgrade it to have automated packing system to reduce workers.
- Add a HMI to the Machine.

5.4 References

- [1] Book of Festo Company "Standards based cylinders DSBC to ISO 15552"
- [2] Zoher Wazwaz, Pneumatic System, PPU, Hebron-Palestine, 2017.
- [3] T. Jefferson, Switches, Arezona: Tots-n-Tech, 2009.
- [3] Taysan Makina Company, <http://www.taysanmakina.com/>
- [4] Novel process for the drying of sugar cubes applying microwave technology, March 2001 (Appendix A)
- [5] Who made sugar cubes?, Newyork Times, <https://www.nytimes.com/2012/11/18/magazine/who-made-that-sugar-cube.html>.
- [6] Nptel Company, https://nptel.ac.in/courses/112106175/?fbclid=IwAR2SMALyfkUr_toxDRHwzkejti9M9Z8KggYiTkvyij-29E9wdCNatDa8RvA

5.5 Photos of the Machine

See Appendix C

Appendix A

Novel process for the drying of sugar cubes applying microwave technology

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ABSTRACT

Drying of sugarcubes is traditionally performed with long-wave ceramic infrared heating elements. These drying units including a cooling section have a length of about 50 m, a drying/cooling time of 12 minutes with a throughput of 1600 kg/h. Required final moisture content is 0.4% (wet basis) and water evaporation required is 10 – 15 kg/h. The infrared drying unit has a low rate of heating up (max. 6 °C/min) and a low thermal efficiency (38%). A feasibility study has been carried out applying microwave heating at a frequency of 2450 MHz and radio-frequency heating at a frequency of 27.15 MHz. These techniques together with infrared drying are evaluated with respect to drying performance and quality characteristics. The newly developed microwave drying process has been patented and several units are implemented on an industrial scale. In the paper the

entire sequence from feasibility study to commercialisation is described.

INTRODUCTION

Aquarius Machine Factory, Weert, The Netherlands constructs among other things integrated systems for the production of sugar cubes. A production line consists of a unit for compression of sugar-water mixture to cubes, a drying section and a packing system, see *figure 1*.

In general sugar cubes are dried applying infrared heating. The energy density of the infrared radiation is high, so an effective surface evaporation can be obtained. However, the penetration depth is rather small and most heating up occurs via conduction from surface to centre of the cube. This strong dependence on conduction results in significant temperature gradients with the consequence that diffusion from the inner-part of the cube to the surface is limited.

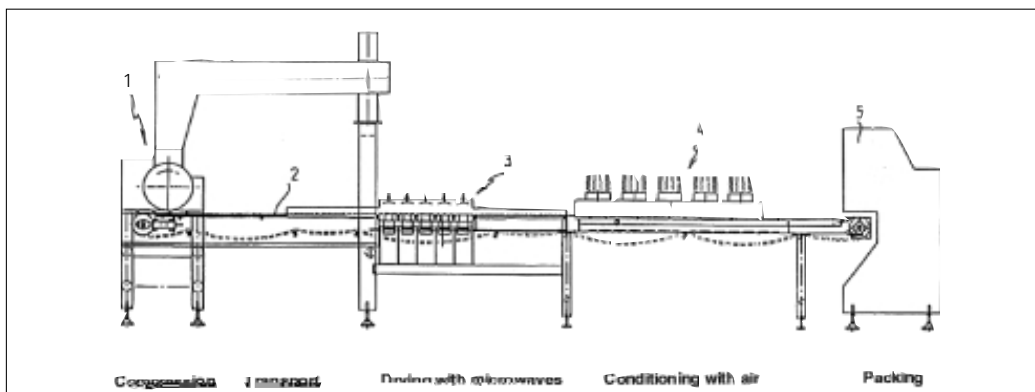


Figure 1: Schematic drawing of sugar cube production unit.

The market for sugar cube production units is especially attractive with respect to the replacement market. Many units operate with outdated technology and could be replaced or updated. If the production figures for sugar cubes are studied (see *table 1*), the outcome is that the yearly sugar cube consumption of the inhabitants of the mentioned countries is considerable.

Table 1: Consumption figures of sugar cubes of several European countries in 1995.

Country	daily production (10 ³ kg)	annual production (10 ³ kg)	annual production per inhabitant (kg/person)
Netherlands	250	62.500	4.1
Belgium	250	62.500	6.2
France	1200	300.000	5.2
Germany	600	150.000	1.9
United Kingdom	100	25.000	0.4

If it is assumed that all produced sugar is consumed in the country of production, the figures indicate that several kg of sugar cubes are consumed by an inhabitant per year, for instance a Dutch person consumes more than 3 sugar cubes per day per person. From the assumption that a unit produces about 25 tons sugarcubes per day, it can be concluded that approximately 100 units are operational in the mentioned countries.

The motivation for innovating the infrared drying process is:

- low volume averaged heating rate
- low drying rate
- high energyconsumption/low thermal efficiency
- large dimensions of the infrared dryer

APPROACH

The objective of the feasibility study is to assess the technical and economical feasibility of microwave and/or radio-frequency drying. The approach of the project is:

- comparison of different drying techniques with respect to temperature profiles, drying curves and energy consumption: microwave, radio-frequency and infrared drying
- quality assessment of dried product with respect to colour, hardness, corner strength and solubility
- assessment of temperature sensitivity of the product, determination of maximum acceptable product temperatures

- economical evaluation of estimated investment costs and necessary installed power

The drying experiments are carried out at pilot plant scale with the following characteristics:

- microwave continuous conveyor belt dryer, operating frequency 2450 MHz, power 6 kW
- radio-frequency batch unit, operating frequency 27.15 MHz, power 7 kW
- infrared conveyor belt dryer, short and medium wave emitters, power 10 kW

During drying the weight loss was measured from taking out sugarcubes and determining moisture content with a polarimeter. Temperature inside the cube with fluoroptic thermocouples, incident and reflected power with an HP-Spinner couple and absorbed electric power with a standard measuring device.

Quality evaluation was performed using:

- Minolta Hunter L,a,b meter for colour, L value is a measurement for the whiteness of the cube
- Q-tester for cornerstrength measurement, rotating the cubes for a specific time at specific rotation velocity in a box and measure the weight of the bigger parts
- a beaker with water and a metal mesh sugar cube holder to determine the solubility time for the sugar cube to dissolve in water of 35 °C with a magnetic stirrer at 200 RPM
- Instron universal compression unit to determine hardness and breaking strength from compression with a flat element at 50 mm/min

RESULTS

Drying curves

The drying curves are shown in *figure 2* for microwave, radio-frequency and infrared drying. The power density for the different drying techniques is based on the electromagnetic power put into the drying process. The initial moisture content of the sugarcube after the pressing procedure is in between 1 and 1.5% moisture. The minimum drying time for microwave heating is 4 minutes, for radio-frequency treatment 5 minutes and for infrared heating a minimum drying time of 8 minutes, which is exactly the drying time of an industrial system. Based on the drying curves, the drying time can be decreased maximally with 50%.

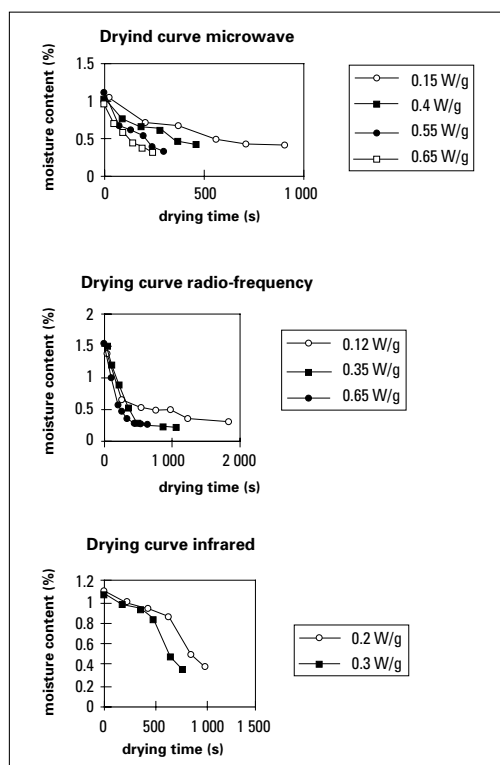


Figure 2: Drying curves of the different drying techniques.

Temperature profiles

In figure 3 the temperature profiles are shown for microwave, radio-frequency and infrared drying.

All temperatures are measured in the centre of the cube during processing. The heating up with microwaves or radio-frequency energy gives a much higher heating rate compared to infrared heating. The maximum heating rate with microwave and radio-frequency drying is 25°C/min. and for infrared drying 6°C/min. The penetration depth of infrared energy is much smaller than the thickness of the cube, while the penetration depths of microwave and radio-frequency heating are larger than the dimensions of the sugar cube. If the absorbed power is studied as a function of maximum reached temperatures and related to drying time, it can be concluded that using a power higher than 0.5 W/g gives significant higher product temperatures, but only slightly shorter drying times. Further experimenting showed that heating till a temperature

of approximately 75°C is sufficient for evaporation of the remaining moisture within the product. The latent heat in the volumetric heated cube is sufficient for the evaporation till final moisture content.

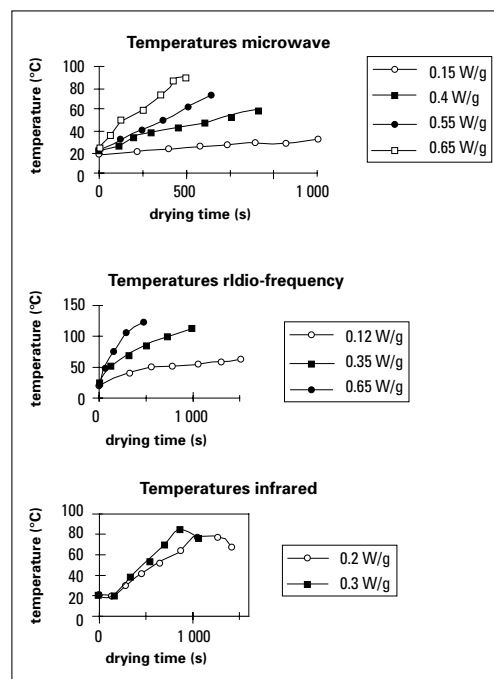


Figure 3: Temperature profiles of sugar cubes for the different drying techniques.

Colour

The colour is measured with a tri-stimulus Minolta spectro-colorimeter. Measurements are done in L,a,b mode. The L parameter represents a photometric value giving the total amount of reflected light. This value can be used to quantify the whiteness of a sugar cube. In table 2 the whiteness of the sugar cubes after microwave, radio-frequency and infrared drying is shown. No differences in colour were observed.

Corner strength

The corner strength of the cubes for the different drying techniques are measured with a Q-tester. The cubes are weighed, put into a metal box and rotated for 2 minutes. Next the sugar cubes are sieved and the parts remaining on the sieve are weighed. The ratio of the part remaining after rotating and the initial weight is the plost num-

Table 2: Colour values, pfast number and compression properties of sugar cubes dried with different drying techniques.

Microwave Drying				
power density	L parameter (-) (colour)	Pfast number (%) (corner strength)	Force at fracture (N) (breaking strength)	Slope on compression curve (N) (hardness)
0.15	41.68	75	150	20
0.4	42.66	76	170	30
0.55	43.52	80	180	35
0.65	43.45	78	190	35
reference cubes	42.62	79	350	50
Radio Frequency Drying				
power density				
0.12	86.7	89	200	30
0.35	86.5	87	175	25
0.65	85.8	85	200	30
reference cubes	86.9	79	350	50
Infrared Drying				
power density				
0.3	90.69	89	400	60
0.2	90.86	85	300	50
reference cubes	90.86	79	350	50

ber and a high number represents relative strong corners of the sugar cubes. In table 2 the results are shown, the corner strength seems to be slightly higher for higher intensity drying with microwaves, but within the reproducibility of the measuring method this increase is not significant. The solid bridges within the sugar cubes are not weaker applying volumetric heating (microwave or radio-frequency) compared to surface heating (infrared), while from common experience it is known that slow dried sugar cubes become harder and stronger.

Mechanical Properties

The mechanical properties are determined with an Instron material compression system. The cube is compressed with a flat plate element with a velocity of 50 mm/min. The force as a function of replacement is recorded and shown in figure 4.

The force quickly increases with the element touching the cube and after the breaking of the cube, the force rapidly decreases. The maximum force represents the breaking strength of the cube and the slope the hardness of the cube. These kinds of tests need a lot of repetition, because the weight of the sugar cubes at the same moisture content is slightly different, which means that more material is available in the same size. The standard deviation is 15 N for the maximum breaking force and 10 N/mm for the hardness. In table 2 the microwave and infrared dried cubes seem to break

at higher force and are a bit harder, when dried with higher intensity. The radio-frequency dried cubes, which are more equally dried, are not becoming significantly harder with more intensive drying. Volumetric dried cubes are a bit less hard than infrared dried cubes. The conditioning part after drying increases the strength of the cube and production can be controlled to produce a cube sufficiently strong according to the needs of the customer.

Solubility

The solubility of the sugar cubes is measured with a new developed method. A beaker of 1000 ml is filled with 800 ml water. A metal gauge with a square perforation of 4 mm is put under the water level at the 600 ml tick. The

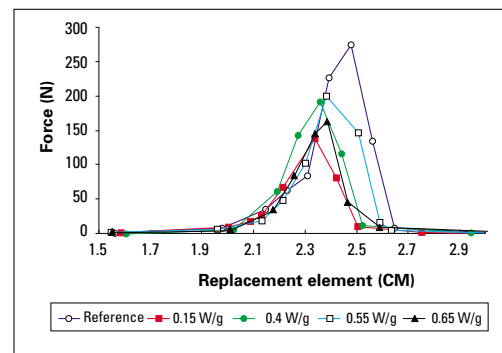


Figure 4: Compression curve for sugar cubes for microwave drying at different intensities.

water is stirred with a magnetic element at 200 RPM. An amount of 6 sugarcubes is put on the gauge and time is measured when all sugar cubes are dissolved. In *table 3* the solubility rate of the sugar cubes is shown. The standard deviation is 0.02 g/s. Radio-frequency dried sugar cubes have a higher solubility rate. This is probably due to the more homogeneous drying compared to microwave and infrared drying resulting in a more homogeneous structure.

Table 3: Solubility of sugar cubes with different drying techniques.

Drying technique	Solubility rate (g/s)
reference, infrared	0.35
microwave	0.35
radio-frequency	0.58

Dimensioning of the drying unit

The approximate dimensions can be calculated from the experimental results. From the experiments the absorbed electromagnetic power is measured. With the conversion efficiency, the supplied electrical power can be calculated. The drying time and the required throughput will give the load in the oven. The dimensions of the oven follow from either product dimensions or dimension of the multiple generators. In this case, the product size is limiting. The installed power is calculated from the load in the oven and the necessary power absorption of the product. Finally the specific energy consumption is assessed. The microwave unit has the smallest dimensions and has the lowest energy consumption.

CONCLUSIONS

The research project has led to a successful technical-economical feasibility of the drying of

sugar cubes with microwave or radio-frequency energy. From a constructional and economical point of view an implementation has been proposed applying a multimode, multiple generator input. Motivation for this choice:

- small microwave generators have become cheaper the last 4 years and are attractive in continuous conveyor belt applications
- high electrical field strength necessary for radio-frequency heating, because of the unfavourable dielectric properties of the sugar cube
- the conveyor belt length requires more radio-frequency generators, which is costly

The study shows that the following advantages can be obtained:

- 35 – 50% reduction drying time
- 20 – 40% energy saving depending on the final mechanical properties required of the sugar cube, a harder cube requires more energy input
- 40 - 60% space saving by higher compactness of the unit
- 20% lower product temperatures and more homogeneous heating up
- higher flexibility in production, drying process independent of cube size
- lower electricity peak at start-up
- adjustable hardness, other quality demands can be fulfilled with respect to colour, solubility and corner strength
- improved process control, supply of heat can be terminated instantaneously by shutting off microwave power, terminating infrared energy supply causes some after-heating of the cubes

At present Aquarius is producing sugar cube production units applying microwave heating at industrial scale. The first units are utilised in 1998.

Table 4: Dimensioning of the unit.

	microwave unit	infrared unit (Aquarius)	radio-frequency unit
electromagnetic absorbed power (W/kg)	ca. 550	ca. 265	ca. 475
conversion efficiency	0.7	0.5	0.7
electrically supplied power (W/kg)	785	660	680
drying time (min)	3.5	8	5
load in the oven at throughput 1600 kg/h (kg)	95	215	135
amount rows of cubes with 50 cubes in a row and cube weight 3.3 g (-)	575	1300	820
physical length drying unit as a result of the load (m)	10.5	23.5	15.0
required power determined from absorbed power in experimenting (kW)	75	145	95
specific energie consumption unit (Wh/kg)	45	90	55

Acknowledgement

The financial support of the Dutch department for energy and environment with reference to Novem-Mint project 338.320/1080 is greatly acknowledged.

LITERATURE

Derckx, H.A.J.M. and Torringa, H.M. (1997), Unit for the drying of sugarcubes (in dutch), Dutch patent 1006216.

Appendix B

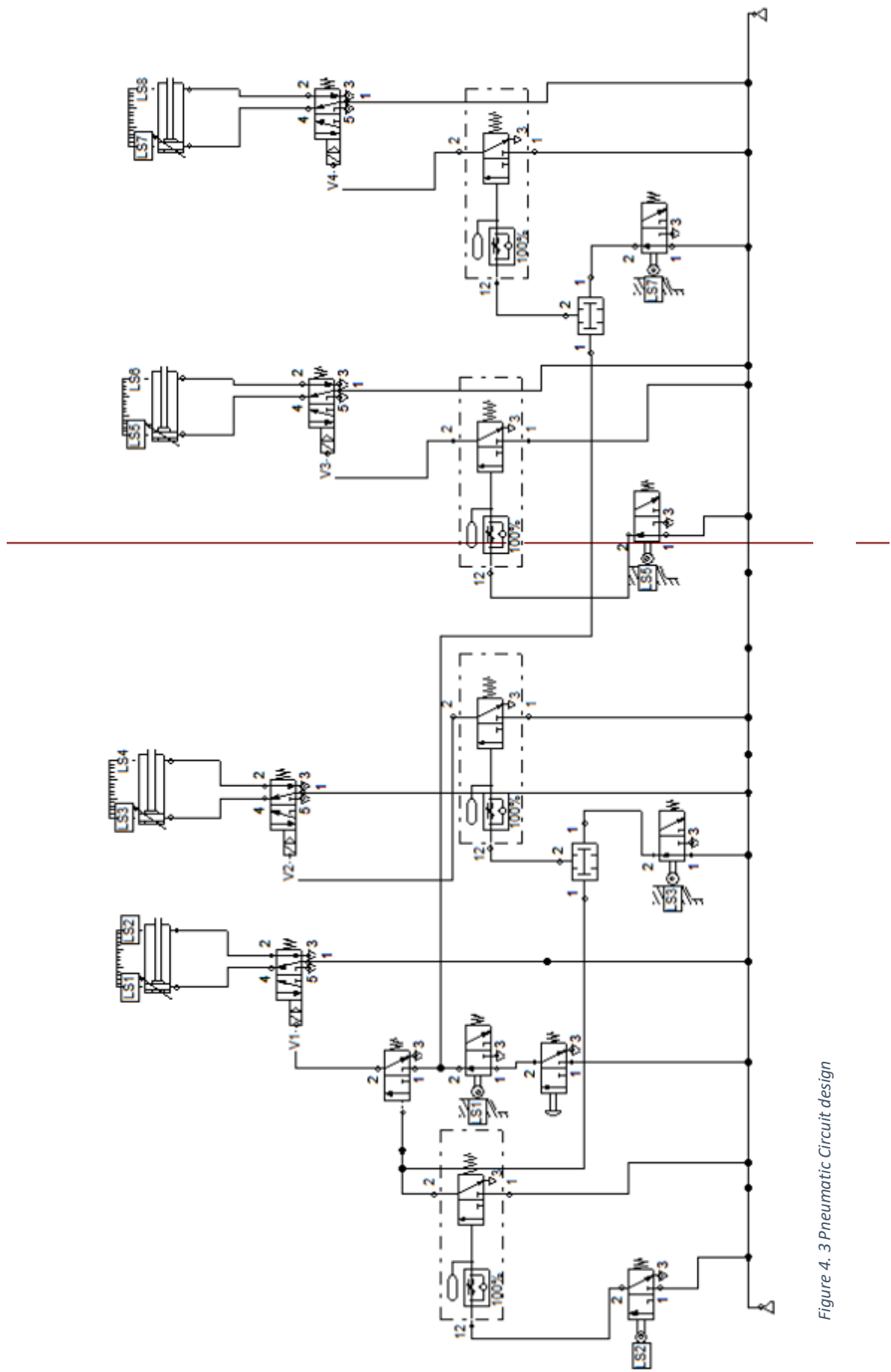


Figure 4. 3 Pneumatic Circuit design

Appendix C





