DESIGN OF GREEN TIRE PAINTING MACHINE

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degree of Master of Science

by

SAMINDA ASELA BANDARA

Supervised by Dr. Nalin Wickramarachchi

Department of Electrical Engineering

University of Moratuwa, Sri Lanka

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DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

Saminda Asela Bandara

I endorse the declaration by the candidate.

UOM Verified Signature

Supervisor: Dr. Nalin Wickramarachchi

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Abstract

The tire manufacturing process is a long process that includes lots of hazard operations. Manual green tire painting method is also considered in to this category. Green tire is the tire which builds according to the tire construction and which is ready for the curing process. Before the curing process, it has to apply lubricant inside the green tire and flow property improving agent on the out side. This application is called green tire painting. The main objective of this project is to design a new machine for green tire painting and protect operators from harsh environment, and improve the productivity.

This project is focused more on actual requirements and takes a practical approach. When selecting components, it is restricted to select popular brands, which is recommended by the company. All the selected components are available in the market with reasonable price. As this is an actual machine design, I focused more on durability, productivity, safety and budget.

The green tire painting machine is automated by the control unit which is a commercially available programmable logic controller (PLC). The requirement of the sensor units for the PLC and the control program is also implemented as part of this design.

Acknowledgement

Thanks are due first to my supervisor, Dr. Nalin Wickramarachchi, for his great insights, perspectives, guidance and sense of humor. His guidance directed me to the success of this project. My sincere thanks go to the officers in Post Graduate Office, Faculty of Engineering, University of Moratuwa, Sri Lanka for helping in various ways to clarify the things related to my academic works in time with excellent cooperation and guidance. Sincere gratitude is also extended to the people who serve in the Department of Electrical Engineering office.

I sincerely gratitude to Mr. Jonas Lundgren, General Manager, Light Industrial Tire division, for his approval and guide to perform this project. I must thank Mr. Dian Gunathilake, HR Director, who made financial support for the second year of my masters studies. Their support directed me to the success of this project.

Lastly, I should thank many individuals, friends and colleagues who have not been mentioned here personally in making this educational process a success. May be I could not have made it without your supports.

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Chapter 1

Introduction

1.1 Background

At present, the increase in the number of vehicles manufactured per year has created a higher demand for tires in the world market. Basically, tires can be divided in to two main categories. They are Solid tires and Pneumatic tires. From the total pneumatic tire production in the world, 95% of tires are used for transportation. Other 5% is used for agricultural and farming purposes [1]. Tire manufacturing process is a long process which includes a number of hazardous operations. It involves lots of chemicals that are toxic to the human body. Compared to the solid tire manufacturing processes, pneumatic tire manufacturing involves more difficult processes. Pneumatic tire manufacturing process includes lots of human interacting hazardous operations like Tire building, Green tie painting and curing etc.

Basic steps in pneumatic tire manufacturing process are chemical mixing, Calendaring, Extruding, making beads, tire building and curing process [2}. "Green tire" is the industrial term used for a half-built tire before the curing process. Green tire is the output of the building machine. It is an uncured cylinder shaped tire with two beads at the end. Before the curing process, some amount of paint need to be applied inside and outside of the green tire. Inside paint is used to reduce friction between green tire and curing press bladder [3], and outside paint is used to increase the flow properties of the green tire to form lugs accurately as in the mould [4]. These liquids are highly toxic to inhale. Therefore operators have to wear heavy safety equipments to prevent from inhaling the toxic paint [5}. However it is very difficult to wear such equipments in a hot environment and also the productivity is adversely affected. Also it is difficult to get a uniform paint application all over the tire, as it depends on the operator's skill and ability. Thus, all above mentioned reasons urges to find a solution to increase the productivity, quality and to protect operators from the hazardous environment.

Green tire painting operation is the most hazardous operation among all the operations which involve with tire building and curing process [5]. It uses hazardous chemicals. Statistically, major reason for serious health damages related to the tire manufacturing process is inhaling of toxic chemicals by green tire painting operation [6]. Therefore prevention of this hazardous environment in the tire manufacturing process is highly important.

1.2 Tire manufacturing process

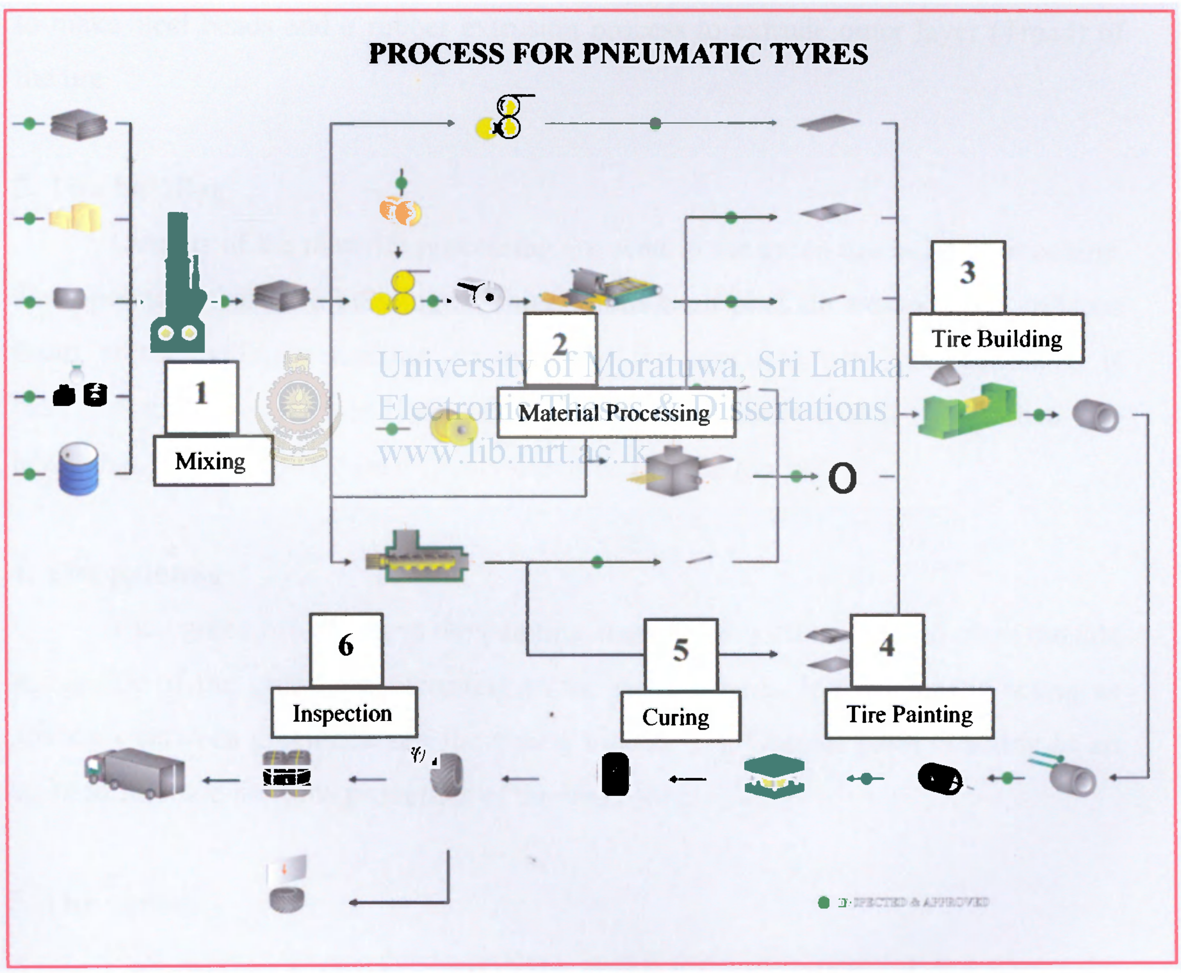


Figure 1.1 Pneumatic tire manufacturing process [2]

Pneumatic tire manufacturing process is shown in figure 1.1.

1. Mixing

As in the first step of tire manufacturing, it has to mix raw materials according to the recipe of each respective tire. The recipe is depending on the requirement of the customer and the performance of the tire. Main raw materials used for tire manufacturing are Natural rubber, Synthetic rubber, Carbon filler, Chemicals and Oil [7].

2. Material Processing

Output compound of the mixture has to undergo several processing operations to make it suitable for tire building. Inner liner calendaring is used to make inner layer of tubeless tires. Also fabric calendaring process is used to cote rubber layers both side of the fabric which is used to build a tire. It uses Nylon or Polyester depending on the performance and price requirements. Separate steel wire coating operation is used to make steel beads and a rubber extrusion process to extrude outer layer (Tread) of the tire.

3. Tire building

Outputs of the material processing are send to the green tire building machine. The operator of the tire building machine winds each plies on expanded or collapse drum of the building machine according to the specified tire construction. It is basically started with inner liner, several plies from rubber coated fabric, then two bead rings at the two edges and finally the thread on the top [8].

4. Tire painting

Then green tire comes to the painting stage. At this stage it has to paint outside and inside of the green tire according to the requirements. Inside paint is acting as lubricant between green tire and the curing bladder [3]. Outside paint is acting as an agent to increase the flow properties of the tread [4].

5. Tire curing

Next stage is the tire curing process. In this stage, the green tire is put over the bladder which is attached in the middle of the tire mould. Mould is fixed to the curing press heated platen. Steam is used to heat up the curing press platen. Firstly apply pre shaping steam pressure in to the bladder and then close the mould and apply high pressure steam in to the bladder. Then the curing bladder pushes the green tire in to the mould. Due to heated mould and bladder inside steam heat, the green tire stats to vulcanize. Normally it takes 30 to 60 minutes to cure the tire depending on the tire dimension and the compound [9]. In the cuing process green tire takes the shape of the mould and the lug pattern.

6. Quality inspection

Then it will move to the quality inspection section. If the quality does not meet the required level, those tires will be sent to the scrap yard. All the tires which have acceptable quality level are sending to packing and warehouse. Those tires will be shipped to various destinations according to the customer requirements.

The basic steps involved with the tire manufacturing process has mentioned as above. In this project it is mainly focused on the tire painting process to introduce new machine to overcome difficulties faced in the current tire painting manual system.

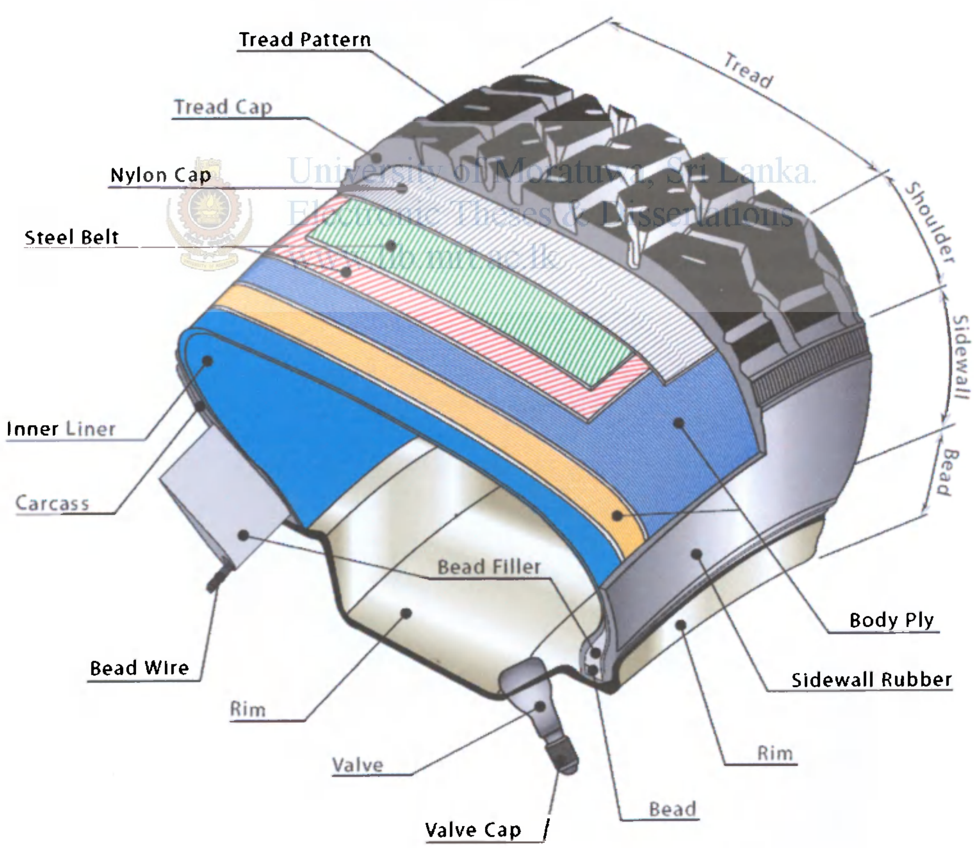


Figure 1.2 Cross section of a tire [10]

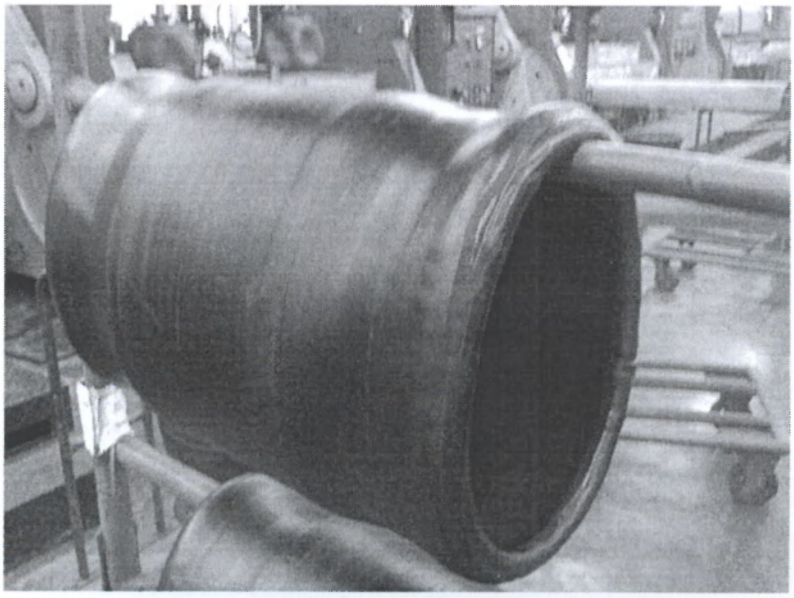


Figure 1.3 Green tire

Figure 1.2 shows a completed green tire which is ready for curing. Figure 1.3 shows the green tire with wrapped protective cover over the beads. This is used to prevent contamination of the paint on the beads. The paint should not be touched with the beads as it will affect badly on the correct bead formation. This protective cover is mostly used for big tires. These covers are normally removed before the curing process.

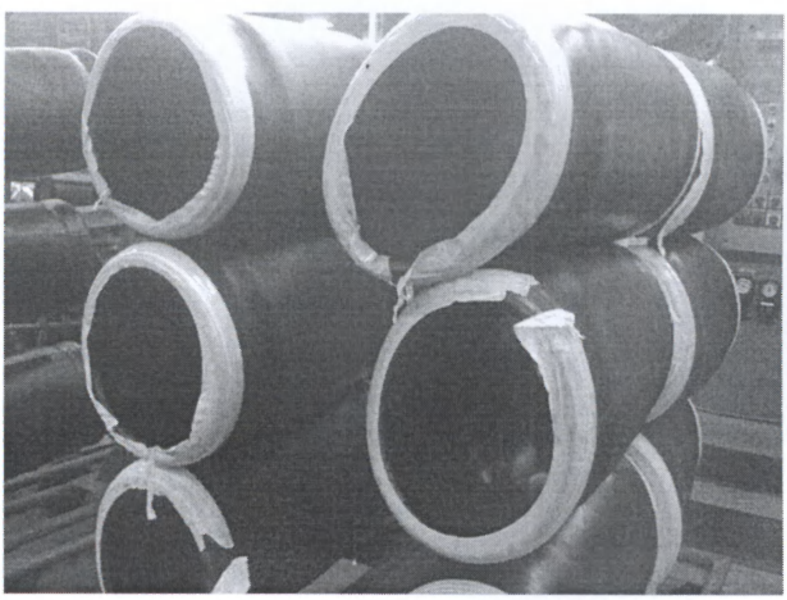


Figure 1.4 Green tire with polyethylene wrap around the bead

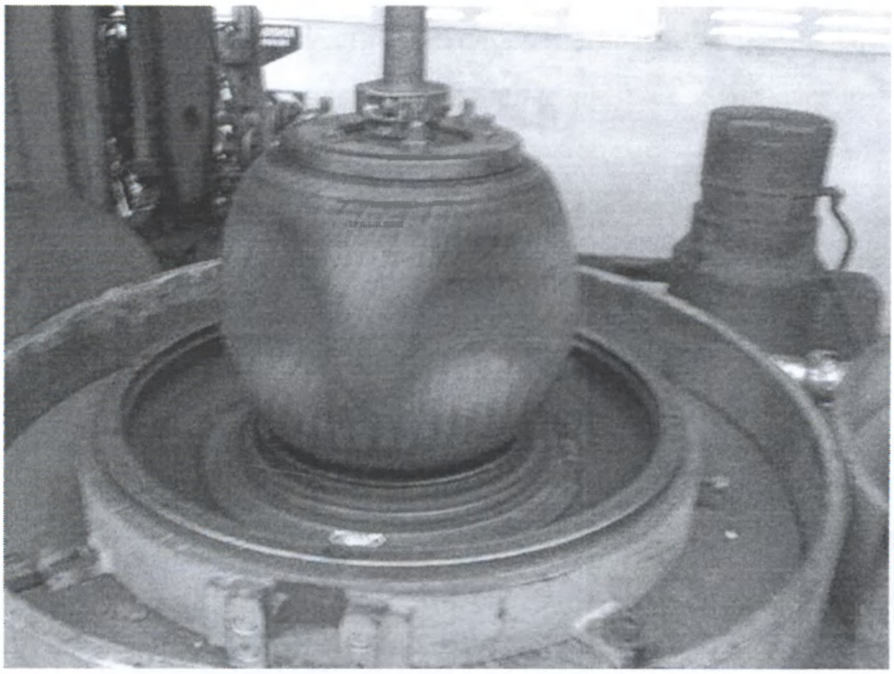


Figure 1.5 Tire mould in the press with curing bladder

Normally the bladder life time is around 150 tires. There is a separate bladder calculation which is used to select suitable bladder for a particular tire.

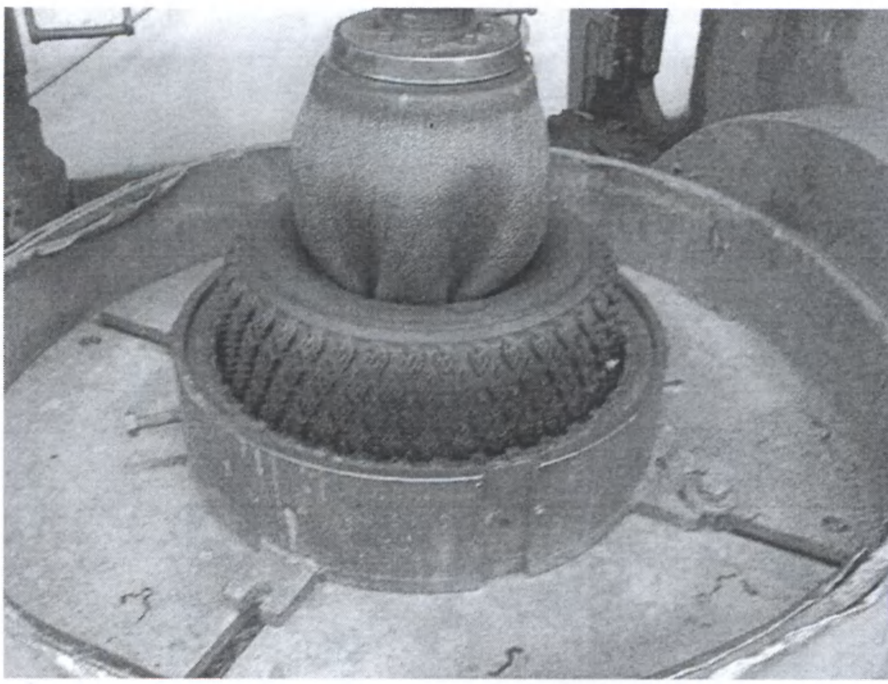


Figure 1.6 Cured tire

1.3 Present method of the green tire painting

To manufacture a good quality final tire, the attention given to the green tire is utterly important. Green tire quality directly determines the quality of the final result. This fact clearly shows that the green tire painting plays a significant role in tire manufacturing process. A number of inside and outside paint types are available in the market. But in this project it is focused on following paint types only.

	Manufacturer	Specific gravity	
Inside paint ->	Darmex	1.25	[3]
Outside Paint ->	Darmex	1.07	[4]

Paint quality is an important factor affecting the final tire quality [2]. The application method and the amount of usage is also affecting to the final outcome. The norm is to apply the inside paint as thin layer. It is water based mixture and has to be dry-off completely before curing. Otherwise the moisture inside the paint will expand in the curing process and will make inside air bubbles in the cured tire.

The existing method of inside painting is done using a manual operation. Operators apply paint according to the specifications as well as their experiences. Therefore it is very difficult to get a uniform output from existing method. It highly depends on the operators' skill. Also the operator has to rotate the tire manually to apply the paint all over the tire, except the beads.

Figure 1.7 Manual green tire inside painting method

In this manual method, lots of paint particles are inhaled by the operators. It is very hazardous for health. Also this is not ergonomically suitable for long hour's continuous working [11]. Figure 1.6 is showing the manual operation of present green tire inside painting method.

The existing method of outside painting system is also a manual operation. Operators use conventional painting brush to apply outside paint. The brush marks give a bad appearance on the final tire. The operator has to rotate the tire to apply paint all over the tire. Also the amount of paint and the quality of the painting process is highly depending on the operator's skill. Figure 1.7 is showing the manual operation of the present green tire outside painting method.

Figure 1.8 Manual green tire outside painting method

Those two above mentioned operations create bottle necks, which need to overcome in order to get high production output. Even, the painting operators cannot work long hours as they get sick due to the harsh environment. Sophisticated safety equipments need to be used to prevent inhaling the paint. It is very difficult to work with wearing heavy safety equipments. This is the utmost requirement behind this project, which is to make a machine with capability to paint inside and outside at the same time with high production output in a safety environment.

1.4 Objective of the project

With the present system, the output is around 650 tires per 8 hour shift when the operators are working at their full capacity. In the 8 hour shift routine, they take ½ hour meal break. Therefore the painting output is 1.5 tires per minute. Company target for the year 2011 is 1500 tires per shift. This equals to 3.3 tires per minute. The possibility with the present method to meet that target is to increase the number of painting operators. But this will not overcome the safety problems and also not a solution for uniform quality output requirement and uniform paint consumption. Therefore the main objective of this project is to give permanent solution to fulfill all production capacity requirements, quality requirements and to create a safe environment to work with.

Main requirements of the new methodology are,

1. Efficiency (Maximum 6 to 8 tires per minute)
2. Easy loading and unloading
3. Protect operators from toxic paint
4. Simplify operation and use of standard components
5. Safety of the operation

Chapter 2

Design Approaches

2.1 Initial attempts and problems

Basically, three different designs are analyzed as follows. First design is to keep the green tire horizontally on horizontal rollers. These rollers are driven by a motor and inside and outside paints are applied while the green tire is rotating.

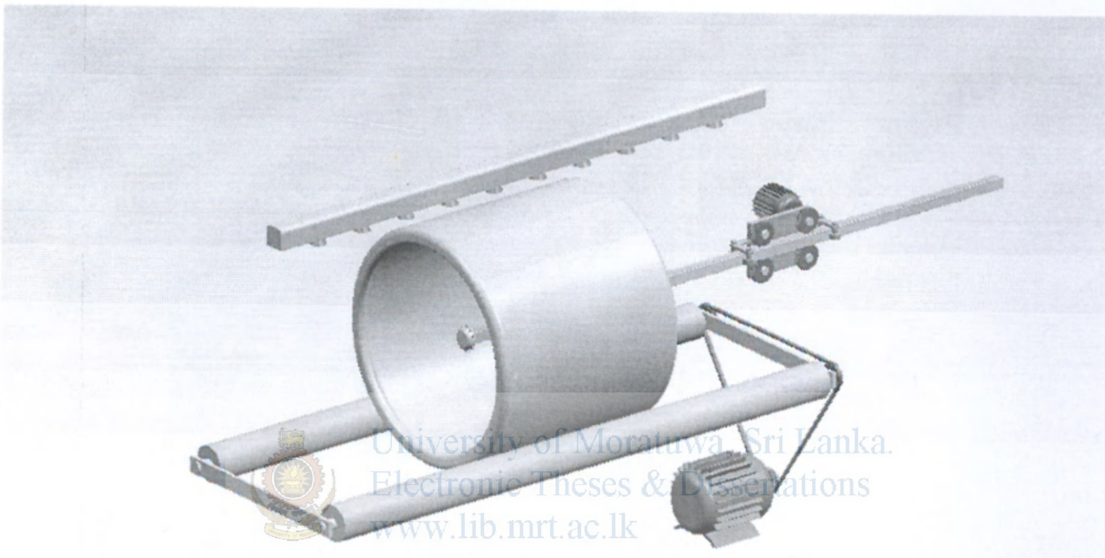


Figure 2.1 Basic design of fist attempt

With the basic experiments it has found that the green tire strength is not enough for this method. This means that the green tire gets an oval shape when it kept horizontally. The green tire is not a cured tire. Therefore it is more flexible. When it gets an oval shape, it is very difficult to rotate the tire with two drive rollers. Also the distance from inner painting nozzle to the inner wall is not a constant. Then some parts get more paint applied, compared to other parts. All green tires have a joint as it is made by winding a fabric and a tread around the drum. It is called as the 'Splicing' joint [12]. In this method, the splicing joint is also blocks the free rotation of the green tire. Even we overcome these difficulties; tire starts to move left and right when it starts to rotate. Then it is difficult to get an even paint distribution all over the tire. When these observations from the experiments are taken in to consideration, this first attempt was rejected because it does not fulfill the requirements.

observations from the experiments are taken in to consideration, this first attempt was rejected because it does not fulfill the requirements.

The second attempt is to keep the tire vertically. Green tire is kept vertically on the loading conveyor and the grabbing disk is placed to grab the tire vertically. After the painting process, the tire is placed on the unloading conveyor.

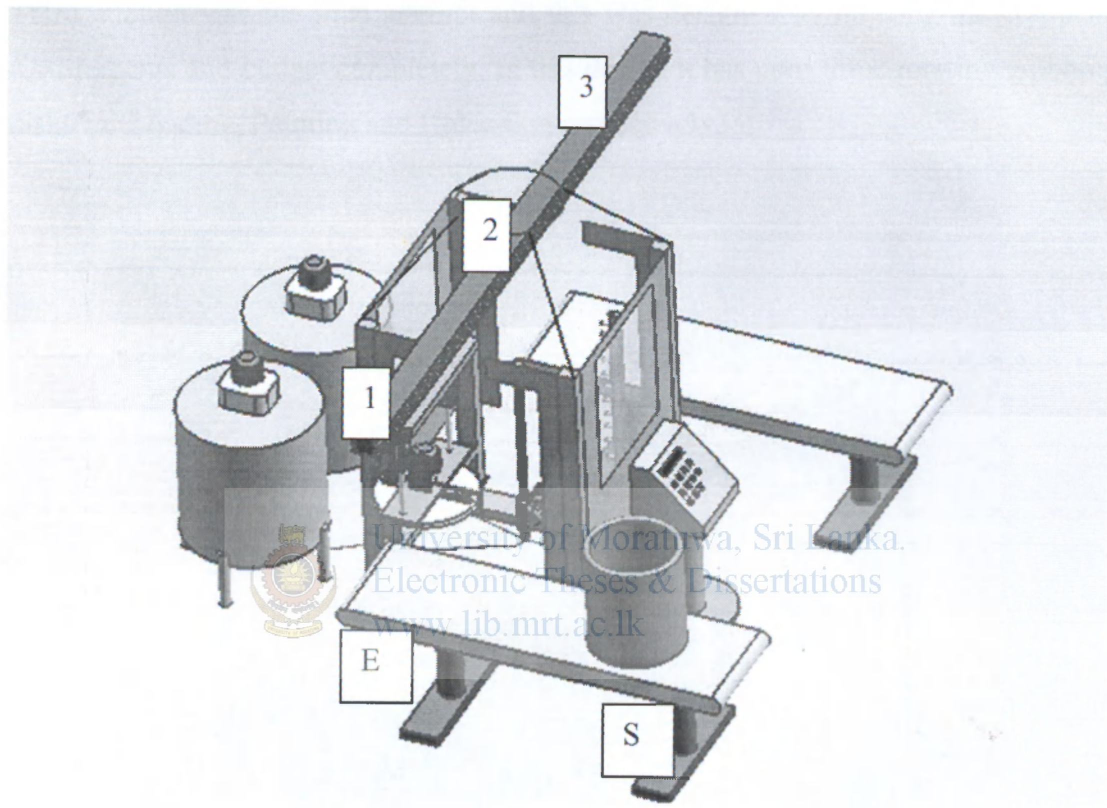


Figure 2.2 Basic design of second attempt

With a basic analysis, it has found that this needs a complicated control system. Grabbing disk is moving to positions 1-Loading, 2-Painting and 3-Unloading. This linier motion has to stop at each position accurately. Green tire is moving from S to E. At the point E, green tire and the grabbing disk has to be aligned accurately to grab the green tire correctly. Position 2 is also very important as the inside painting nozzle is moving within the middle of the green tire. This needs a servo controller to get all this positions accurately, and it is very expensive. Also the basic analysis shows that the maximum output this can execute is limited to 4 tires per minute. This is because there is only one grabbing disk is there to move in all three positions. Though it matches with our near future requirement, it will not be suitable with a long term view. Though this is a workable model, it is not feasible due to usage of expensive equipments and wear and tear caused by extensive movements. Considering these facts, this design was rejected and moved to another design which enables a simple logical control with high productivity.

2.2 Final approach

Third attempt was the final attempt and this was designed by meeting the company requirements and budget completely. In this design it has used three rotating grabbing disks for Loading, Painting and Unloading respectively.

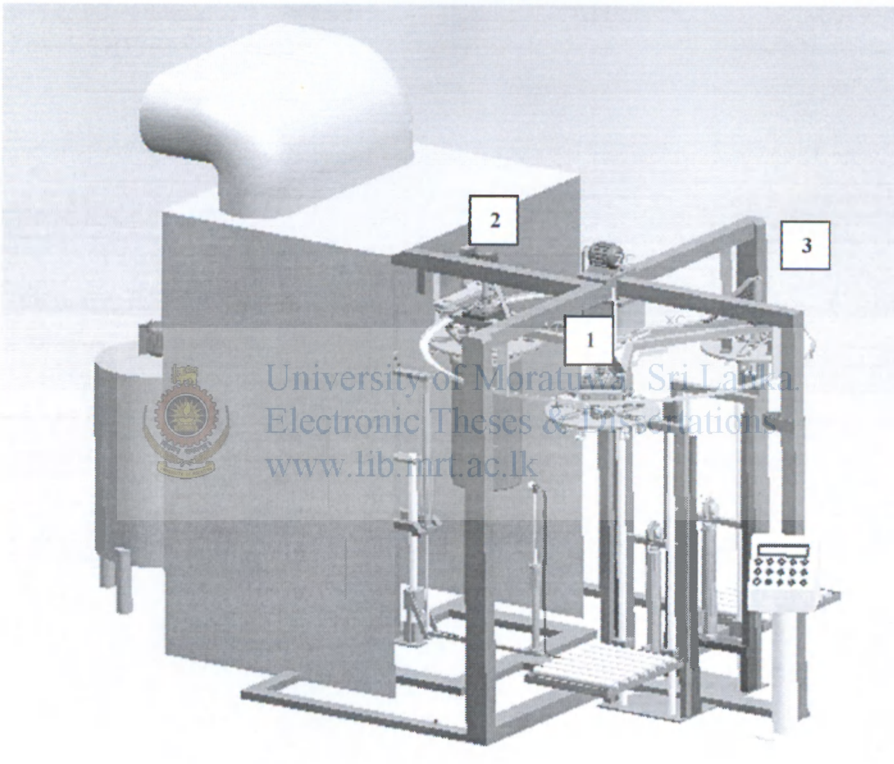


Figure 2.3 Final design

In this design, Position 1 is for loading, Position 2 is for painting and the Position 3 is for unloading. Basic operation of this machine is as follows.

At one instance the grabbing disk 1 comes to the 1st position and grabs the green tire. The loading tray of the 1st position lifts the green tire to the grabbing disk. Then it rotates by 120^{o} which is up to the painting position. Then the painting nozzles paint the green tire and rotate another 120^{o} to the unloading position. At the unloading position also the unloading tray will lift up to get the green tire. After unloading the green tire the same grabbing disk rotates another 120^o to the 1^{st} position to grab the next green tire. These three operations perform simultaneously. Also 120^o indexing gear box gives an accurate positioning without any servo control.

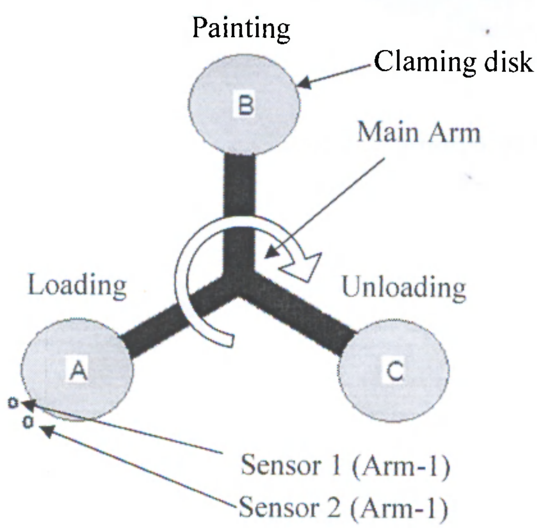
Chapter 3

Detailed design

3.1 Overview of the design

This machine has designed based on the company requirements. That is to increase productivity, make hazards free environment for the operators, reduce paint consumption and unique paint application all over the green tire. Basic design is a simplified logical approach with available components in the market. Other main restriction is the company regulations. This is because some of the components have to be sourced from the company approved standard suppliers. (Eg: ABB motors, Festo pneumatic items, SKF bearings etc.) However these are well established standard suppliers with a vast product range. Therefore selecting a suitable component from those suppliers is quite an easy task.

Basically this machine has three positions. Those are, Loading position, Painting position and Unloading position. The main rotation arm consists with three clamping disks which mounted with 120^0 angle between each other. These disks named as A, B, C and all three rotate with the main arm. For the each operation at each respective position, the position has to identify the disk which has aligned with the position. Therefore the machine controller needs to identify 9 positions. To get this positions, two mechanical sensors are used (named as 'Arm-1' & 'Arm-2') which are mounted align to the main arm disk A. These sensors are operating by cams which located at three positions i.e. Loading, Painting and Unloading and send signals to the PLC.



Arm-1 -> ON

Arm-2 -> ON

A-Loading Station

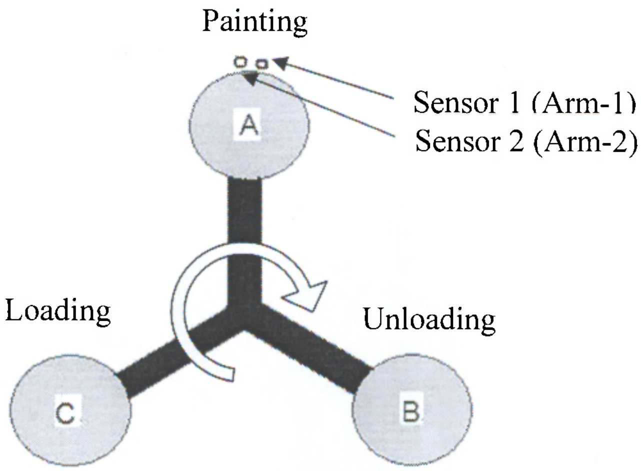
B-Painting Station

C-Unloading Station

In the flowchart this position

Indicated as "**PS1**"

Ladder input = 10.0

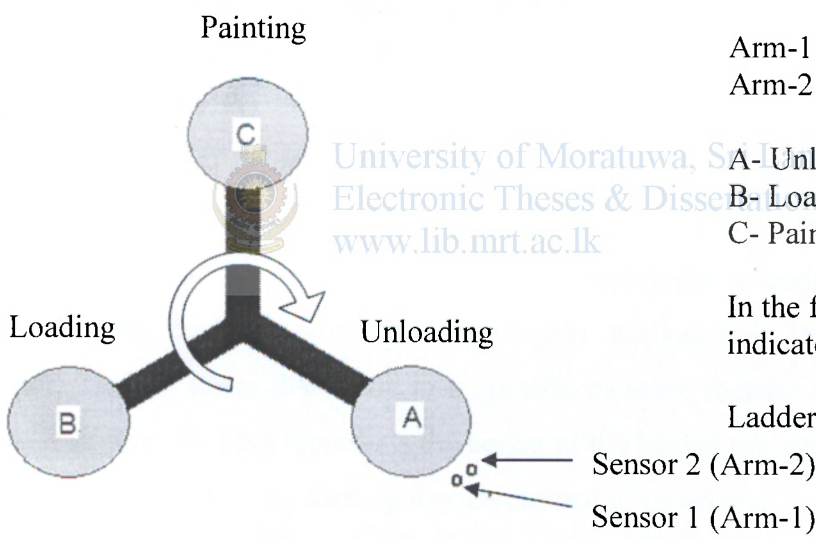


Arm-1 ->ON
Arm-2 -> OFF

A-Painting Station
B-Unloading Station
C-Loading Station

In the flowchart this position indicated as "**PS2**"

Ladder input = I0.1



Arm-1 ->OFF
Arm-2 -> ON

A- Unloading Station
B- Loading Station
C- Painting Station

In the flowchart this position indicated as "**PS3**"

Ladder input = I0.2

Figure 3:1: Main arm rotation and positions

	Loading	Painting	Unloading
A	11	10	01
B	01	11	10
C	10	01	11

Table 3.1 Digital position indication by Arm-1 & Arm-2 sensors

3.2 Loading station

Loading a green tire on to the loading tray is the first operation in the cycle. Operator loads a green tire on to the loading tray manually. When he pushes the loading button, loading tray goes up (SW1).

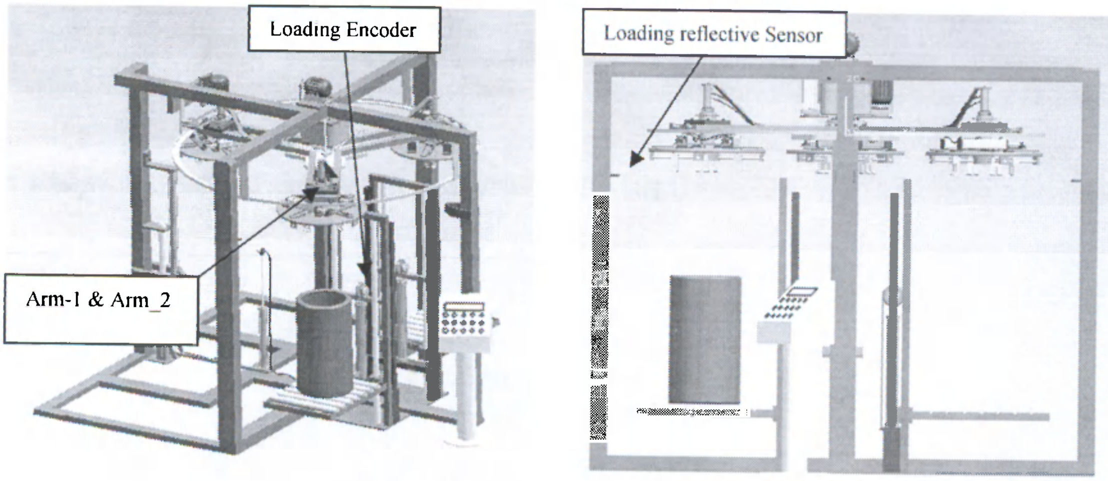


Figure 3:2: Green tire loading-1

When the green tire came to the clamping position, it will block the loading reflective sensor beam (Sen_1). When reflective sensor detects the green tire it will send a signal to the PLC. Then PLC stops the loading tray's upward movement and start clamping action. Green tire height will depend on the tire size. It is vary from 300 mm to 1400 mm. PLC counts the pulses of the Loading incremental encoder (R1) which starts from operator pushes the button till the signal receives from the Loading reflective sensor. Then it stores that value in a specific memory register in the PLC (Reg_A, Reg_B or Reg_3). That represents the height of the loaded tire which is needed for the next operations. Then the loading tray is returned to its original position.

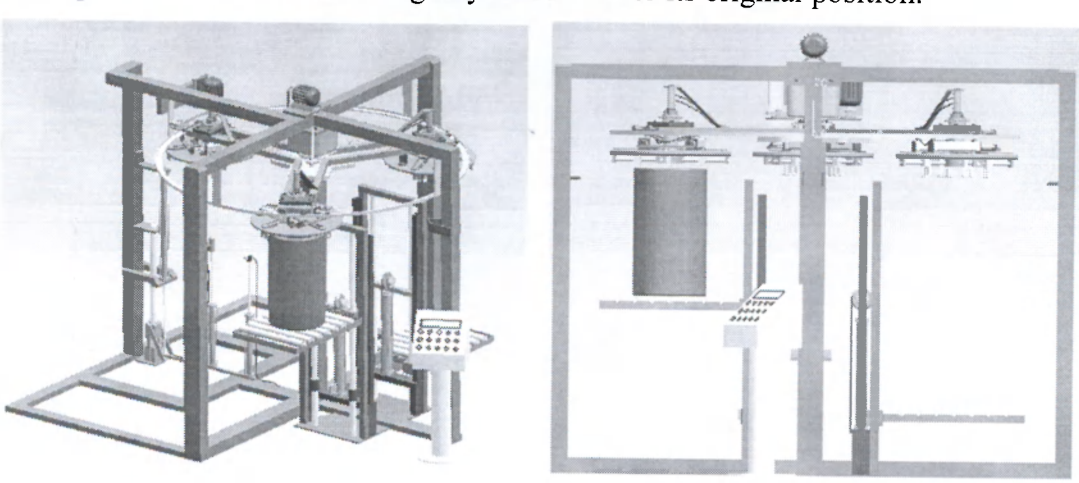


Figure 3:3: Green tire loading-2

3.2.1 Loading station operational flowchart

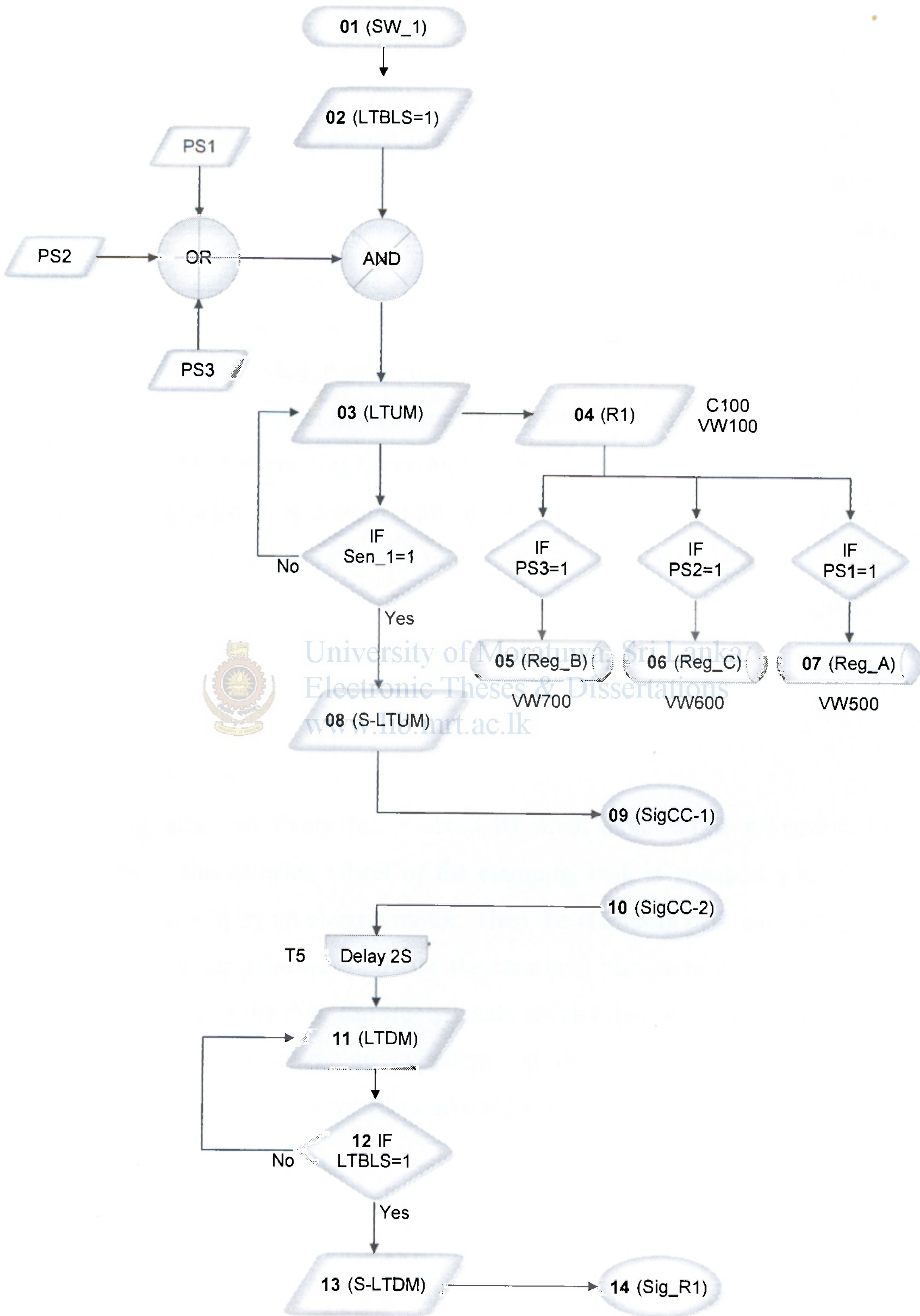


Figure 3:4: Loading station operational flowchart

Description:

Index	Description	FC Symbol	Ladder
(01)	Loading tray lift switch	(SW_1)	10.3
(02)	Loading tray bottom limit switch	(LTBLS)	10.4
(03)	Start Loading tray upward movement	(LTUM)	Q0.1
(04)	Read loading encoder pulses	(R1)	10.6
(05)	Store R1 in memory register B	(Reg_B)	VW700
(06)	Store R1 in memory register C	(Reg_C)	VW600
(07)	Store R1 in memory register A	(Reg_A)	VW500
(08)	Stop loading tray upward movement	(S-LTUM)	
(09)	Send a signal to clamping circuit	(SigCC-1)	Q0.2
(10)	Receive signal from clamping circuit	(SigCC-2)	Q0.3
(11)	Start loading tray down movement	(LTDM)	Q0.4
(12)	Loading tray bottom limit switch	(LTBLS)	10.4
(13)	Stop loading tray down movement	(S-LTDM)	
(14)	Send signal to Main arm circuit	(Sig_R1)	Q0.5

3.3 Painting Station

The clamping disk can freely rotate about its pivot axis. When it reaches to the painting station, the sprocket wheel of the clamping disk is engaged with the drive chain which is driven by an electric motor. Then the clamping disk and the green tire stars to rotate. The air pressure applied to the clamping disk jacks is supplied though a rotary air union. Then the disk can freely rotate around its pivot axis while supplying the air pressure to the clamping cylinders. At this point, painting position tire detecting sensor (Sen_2) is activated to give the signal to the PLC to activate painting position activities.

This electric motor is a 4 pole three phase motor. Its output rpm is 1500. This motor is equipped with a reduction gear box. Selected type is with 25:1 gear reduction ratio. Then the output speed of the gear box is 60 rpm. The same number of teeth sprocket wheel is attached to the clamping wheel. Then the green tire rotational speed is also 60 rpm.

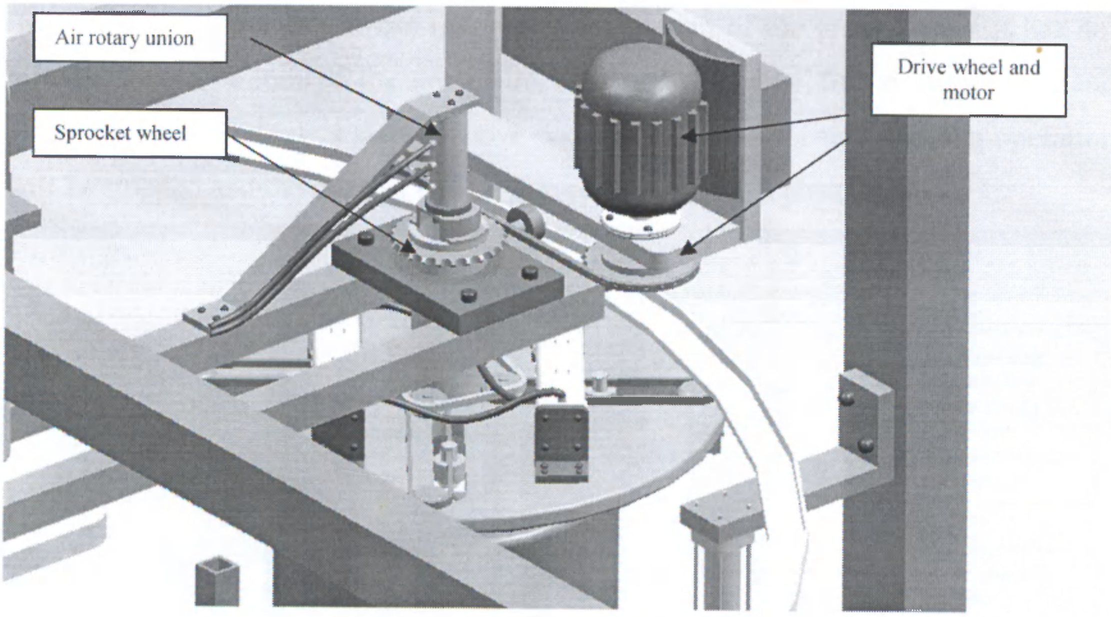


Figure 3.5 Clamping disk at painting position

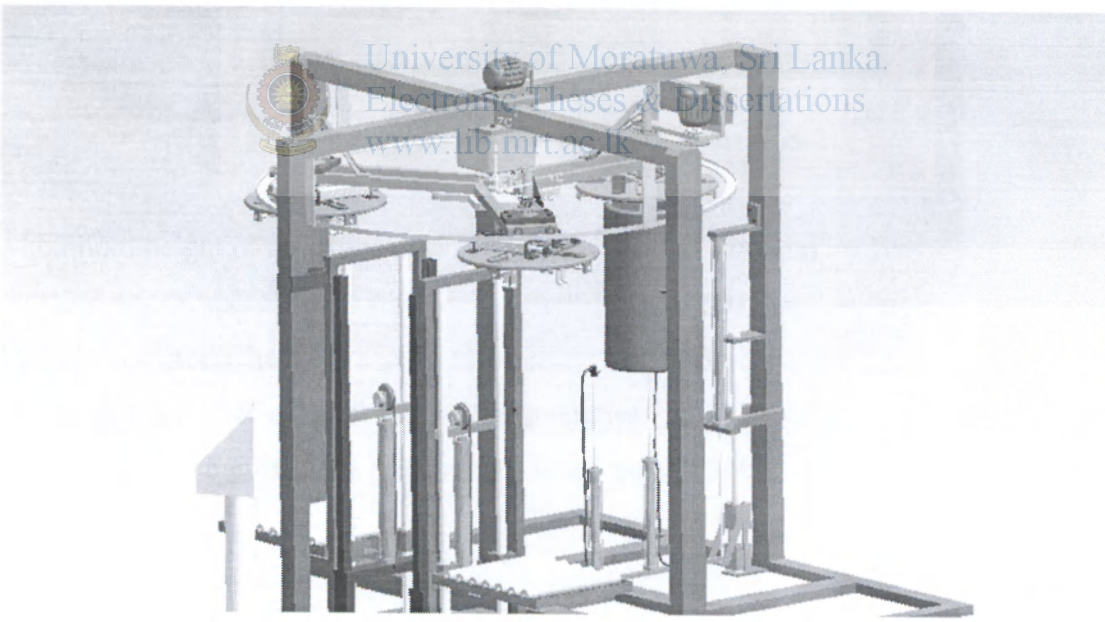


Figure 3.6 Green tire at painting position-1

While the green tire is rotating, paint application process also starts to operate. First it will move the inside and outside paint nozzles to the top of the green tire. (Activating MPCF, IPCF and OPCF). Then it starts to spray inside and outside paint. Inside paint nozzle is 360^{o} spraying nozzle. Outside paint nozzle covers 100 mm length paint strip at a time. Then the main paint jack starts to move backward (MPCD).

The loading position encoder (R1) has recorded a value at the beginning of the cycle. It represents the height of the green tire. PLC counts the main paint encoder pulses (R2) and checks whether it has reached to the bottom of the green tire. If it has not reached to the bottom of the green tire with main cylinder full stroke, inside and outside separate cylinders start to move backward. When R1=R2 painting operation will be stopped and the nozzles will be moved to its original position.

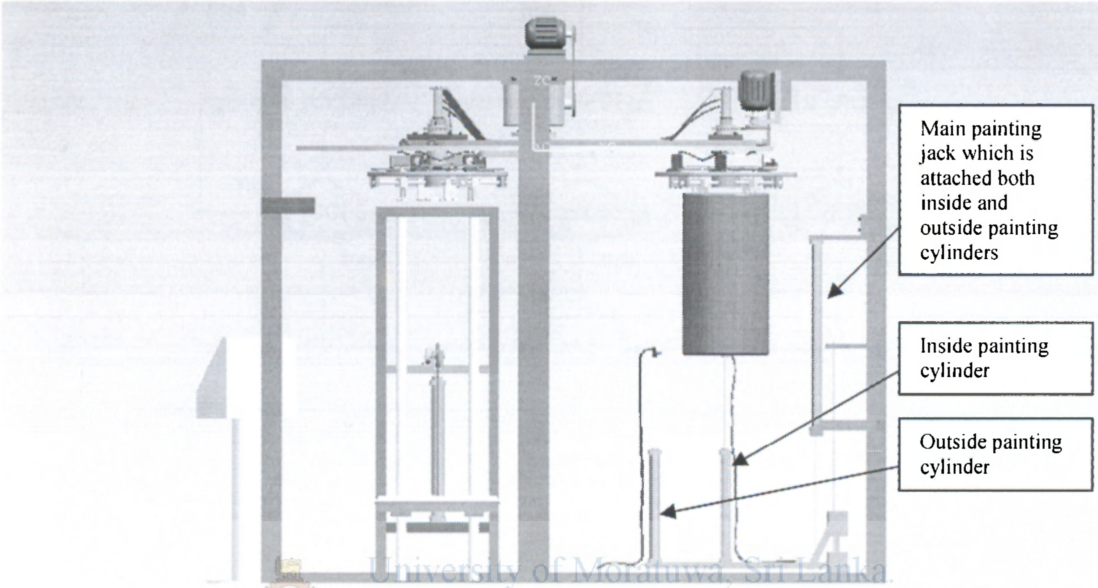


Figure 3.7 Green tire at painting position-2

Maximum height of the green tire = 1400 mm

Outside nozzle spray area = 100 mm

RPM of the green tire = 60

Rotations need to cover total area of the green tire

with 50% covering from the previously painted area = (1400/100)*1.5

= 21

Max: time need to paint total area of the biggest tire = 21/60

= 0.35 minutes (21 S)

Painting process takes much time in the total cycle. Then the rate of painting a biggest tire is around 3 tires per minute. This will meet the required output. Normally the biggest tire percentage is around 3% from the total production.

After the painting process, the main arm rotates 120^0 to the unloading position.

3.3.1 Painting station operational flowchart

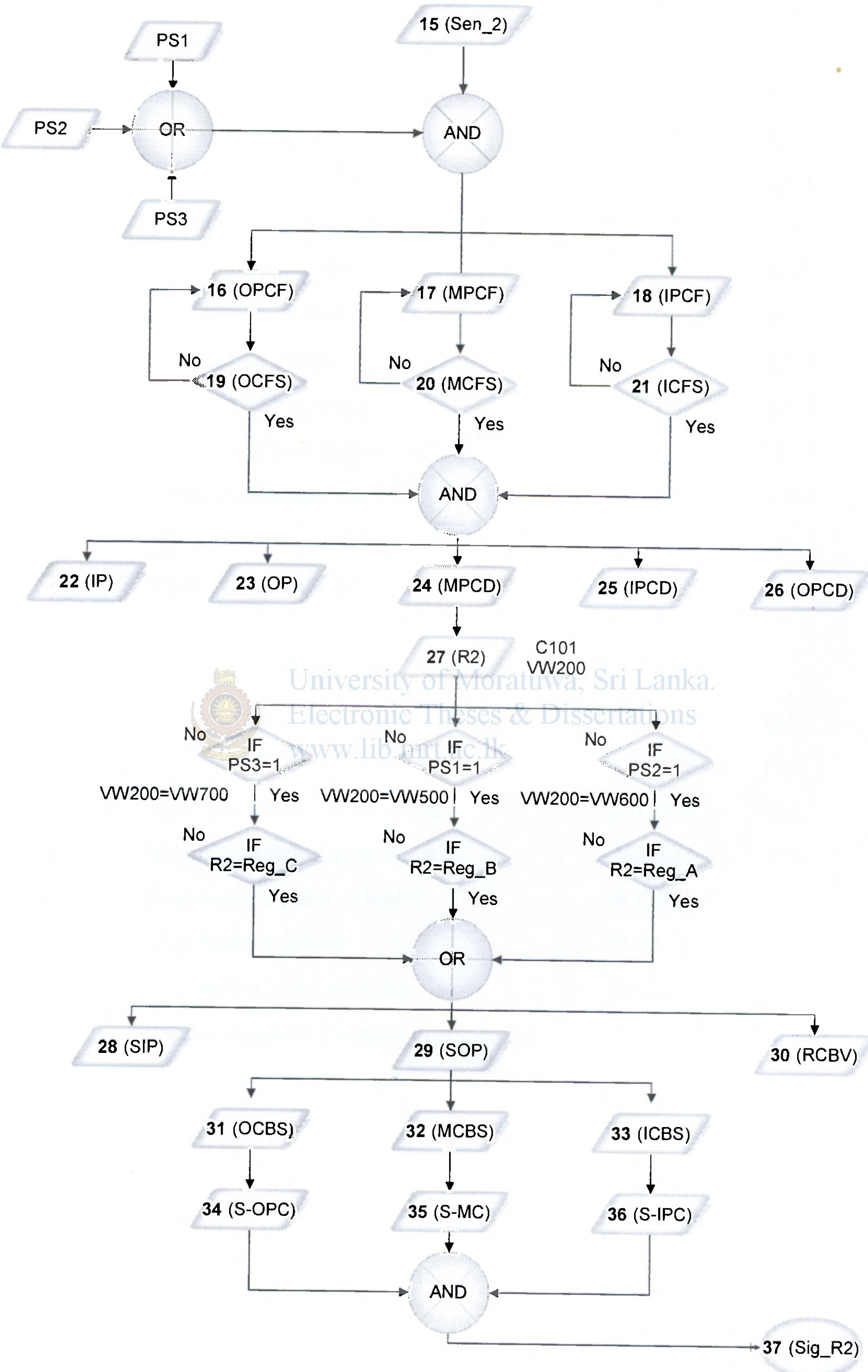


Figure 3:8: Painting station operational flowchart

Description:

Index	Description	FC Symbol	Ladder
(15)	Painting station tire detect sensor	(Sen_2)	I0.7
(16)	Outside painting cylinder forward	(OPCF)	Q0.6
(17)	Main painting cylinder forward	(MPCF)	Q0.7
(18)	Inside painting cylinder forward	(IPCF)	Q1.0
(19)	Outside painting cylinder front sensor	(OCFS)	I1.0
(20)	Main painting cylinder front sensor	(MCFS)	I1.1
(21)	Inside paint cylinder front sensor	(ICFS)	11.2
(22)	Start Inside painting	(IP)	Q1.1
(23)	Start outside painting	(OP)	Q1.2
(24)	Move main painting cylinder down	(MPCD)	Q1.3
(25)	Move inside painting cylinder down	(IPCD)	Q1.4
(26)	Move outside painting cylinder don	(OPCD)	Q1.5
(27)	Read painting encoder pulses	(R2)	I1.3
(28)	Stop Inside painting	(SIP)	
(29)	Stop Outside painting	(SOP)	
(30)	Release cylinder block valve	(RCBV)	Q1.6
(31)	Outside cylinder bottom sensor	(OCBS)	11.4
(32)	Main cylinder bottom sensor	(MCBS)	I1.5
(33)	Inside cylinder bottom sensor	(ICBS)	I1.6
(34)	Stop outside paint cylinder	(S-OPC)	
(35)	Stop Main cylinder	(S-MC)	
(36)	Stop Inside paint cylinder	(S-IPC)	
(37)	Send a signal to the main arm circuit	(Sig_R2)	Q1.7

3.4 Unloading Station

At the unloading position, the PLC detects the disk using unloading tire detect sensor (Sen_3). Then unloading tray moves upward (ULTU). The PLC counts the pulses from unloading encoder (R3) till it matches with the loading encoder value (i.e. R3=R1). At this point the unloading tray stops its movement after reaching the green tire. Then the clamping jacks move backward and release the green tire on to the unloading tray.

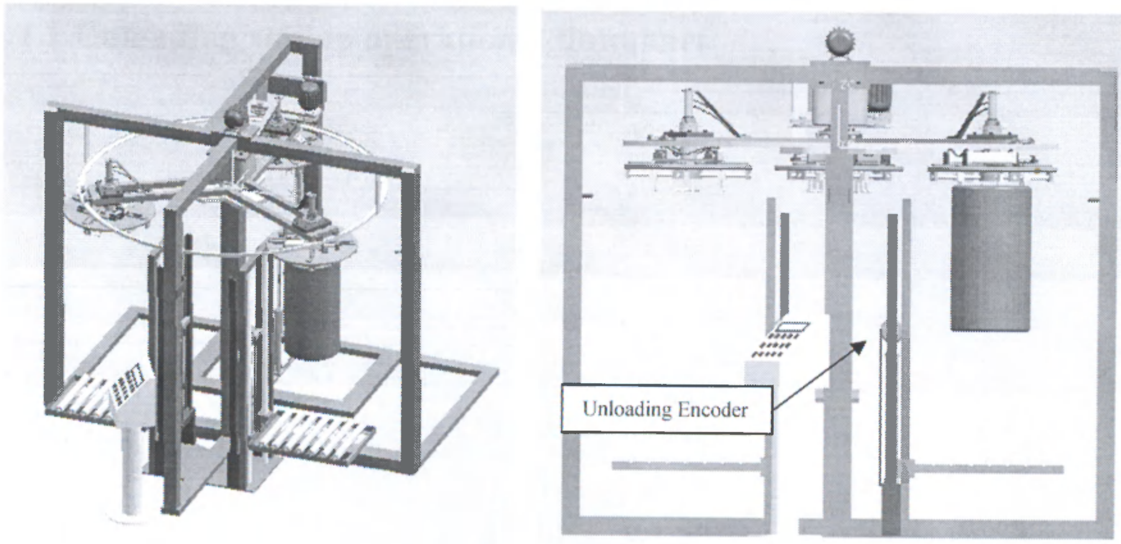


Figure 3.9 Unloading position -1

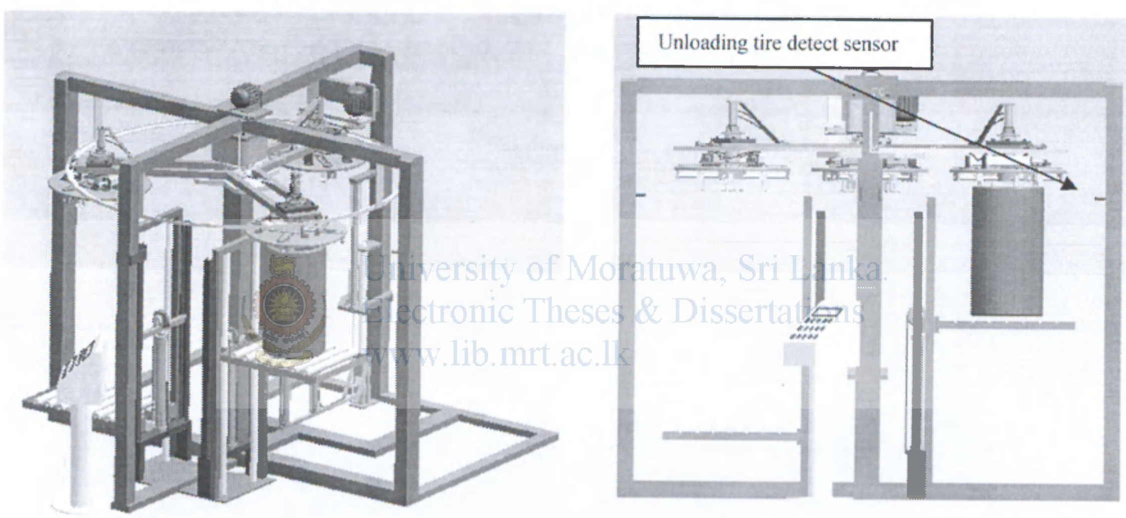


Figure 3.10 Unloading position -2

After finishing the unloading operation, the unloading tire detect sensor (Sen_3) checks whether the tire is perfectly removed from the clamping disk or not. If the reflective sensor is clear, then the arm starts to rotate by another 120° to the starting position. Unloading tray moves downward till the activation of the bottom limit switch (ULTBS). Then it completes one cycle of green tire painting. Within these three steps (Loading, Painting and Unloading) it has to communicate with two other main circuits. Those are the Clamping circuit and Main arm rotation circuit. This is because; these circuits are mainly related to the green tire position.

3.4.1 Unloading station operational flowchart

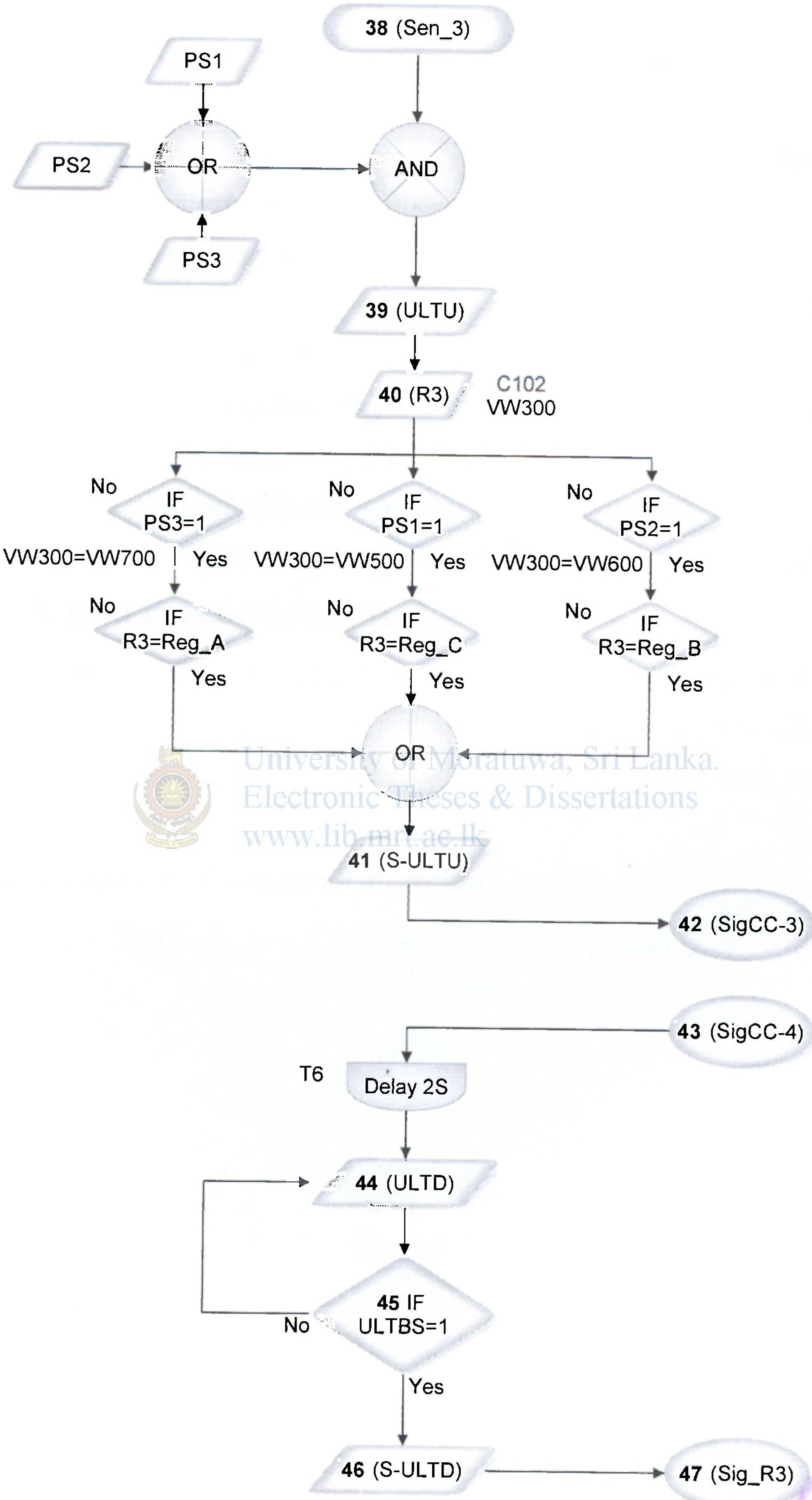


Figure 3:11: Unloading station operational flowchart

Description:

Index	Description	FC Symbol	Ladder
(38)	Unloading station tire detect sensor	(Sen_3)	I1.7
(39)	Start unloading tray upward	(ULTU)	Q2.0
(40)	Read pulses unloading encoder	(R3)	I2.0
(41)	Stop unloading tray upward	(S-ULTU)	
(42)	Send a signal to clamping circuit	(SigCC-3)	Q2.1
(43)	Receive signal from clamping circuit	(SigCC-4)	Q2.2
(44)	Unloading tray down movement	(ULTD)	Q2.3
(45)	Unloading tray bottom sensor	(ULTBS)	I2.1
(46)	Stop unloading tray down movement	(S-ULTD)	
(47)	Send a signal to the main arm circuit	(Sig_R3)	Q2.4

3.5 Main arm rotation circuit

Main arm rotation is directly depends on the each station's operations. It will not activate till each position is confirmed and a signal is sent to the main arm rotation circuit. After it gets the Sig_R1, Sig_R2 or Sig_R3 signals from each position, it rotates the main arm by 120° to next position.

3.5.1 Main arm rotation circuit flowchart

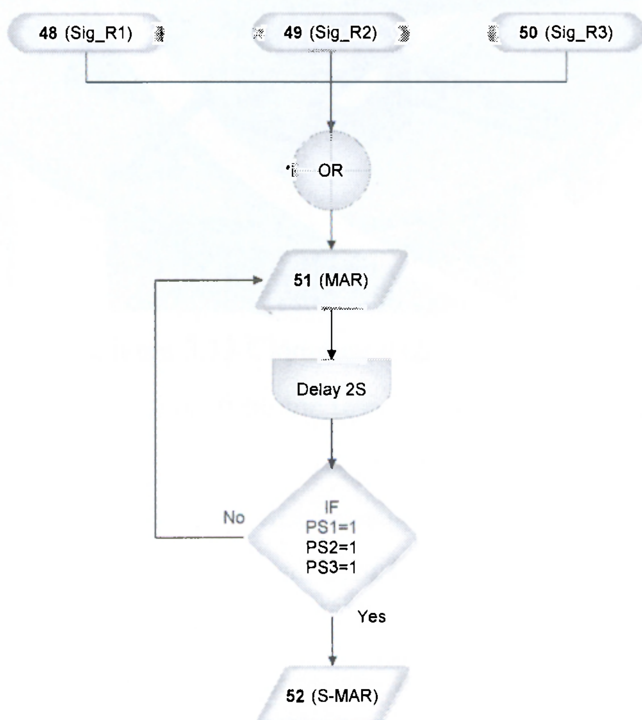


Figure 3:12: Main arm rotation flowchart

Description:

Index	Description	FC Symbol	Ladder
(48)	Signal from loading station	(Sig_R1)	Q0.5
(49)	Signal from painting station	(Sig_R2)	Q1.7
(50)	Signal from unloading station	(Sig_R3)	Q2.4
(51)	Start main arm rotation	(MAR)	Q2.5
(52)	Stop main arm rotation	(S-MAR)	

3.6 Clamping disk circuit

When the PLC receives the signal from loading circuit and PS1, PS2 or PS3 signal, respective clamping disk pistons start to move forward (A,B or C CDJO). Ends of these piston rods are attached to one clamping jaw. That jaw is mechanically connected with other three jaws and expands simultaneously.

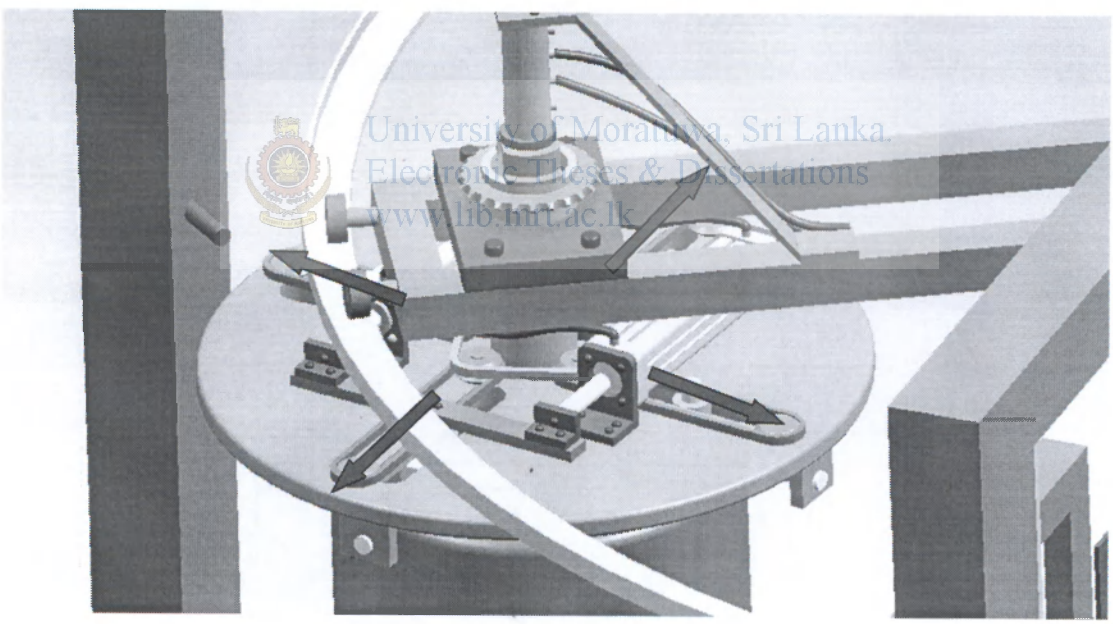


Figure 3.13 Clamping disk operation

Diameters of the green tires depend on the tire size. Required diameters which can be handled by this machine are 8" to 22". Therefore the jaws have to stop when they touch with the green tire. Three pressure sensors are used (PSA, PSB and PSC) for three clamping disks to detect the contact between the green tire and the jaws. These are digital adjustable pressure switches. When jaws touch the green tire, the pressure inside the clamping pistons starts to increase. It will be detected by the respective pressure sensors and a signal will be sent to the PLC. Then the PLC stops the forward movement of the clamping pistons and holds it by using a center closed 5/3 way valve.

3.6.1 Clamping disk operational flowchart

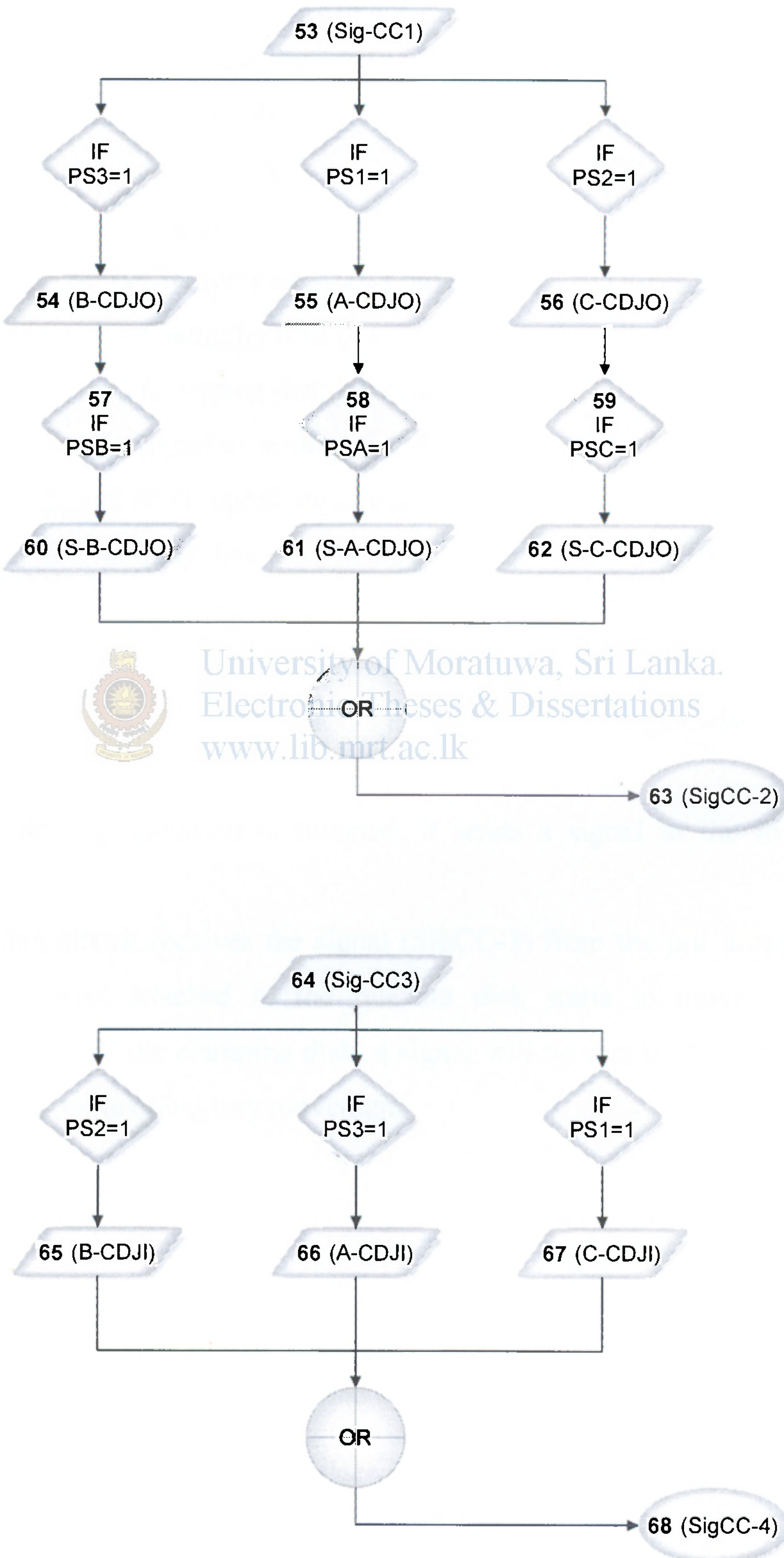


Figure 3.14 Clamping disk operational circuit

Description:

Index	Description	FC Symbol	Ladder
(53)	Signal from loading circuit	(Sig-CC1)	Q0.2
(54)	B-Clamping disk jaws out	(B-CDJO)	Q3.0
(55)	A-Clamping disk jaws out	(A-CDJO)	Q2.6
(56)	C-Clamping disk jaws out	(C-CDJO)	Q2.7
(57)	Pressure Sensor-B	(PSB)	I2.4
(58)	Pressure Sensor-A	(PSA)	I2.2
(59)	Pressure Sensor-C	(PSC)	I2.3
(60)	Stop B-Clamping disk jaws out	(S-B-CDJO)	
(61)	Stop A-Clamping disk jaws out	(S-A-CDJO)	
(62)	Stop C-Clamping disk jaws out	(S-C-CDJO)	
(63)	Send a signal to loading circuit	(SigCC-2)	Q0.3
(64)	Signal from unloading circuit	(SigCC3)	Q2.1
(65)	B-Clamping disk jaws Inward	(B-CDJI)	Q3.2
(66)	A-Clamping disk jaws Inward	(A-CDJI)	Q3.3
(67)	C-Clamping disk jaws Inward	(C-CDJI)	Q3.1
(68)	Send a signal to unloading circuit	(SigCC-4)	Q2.2

When the clamping operation is finished, it sends a signal to the loading circuit (SigCC-2).

When clamping circuit receives the signal (SigCC-3) from the unloading station, the clamping disk jaws attached to the relevant disk starts to move inward. After retracting the jaws of the clamping disk, a signal will be sent to the unloading circuit (SigCC-4) to start unloading tray movement.

Chapter 4

Components Selection

4.1 Pneumatic Cylinders Selection

4.1.1 Loading/ unloading Cylinders

These cylinders are connected with the tire loading and unloading mechanisms. The purposes of these cylinders are to lift the loading tray with a tire at the loading station and gradual unloading at the unloading station. It has used a pulley mechanism as the basis. The sprocket wheel which is connected with the cylinder shaft acts as a pulley. Then the lifting tray moves twice for one cylinder shaft movement. This mechanical advantage is used to get twice the distance of tray travel relative to the cylinder shaft movement. But this will require a doubled force for lifting.

Maximum weight of the green tire	= 80 Kg
Total weight with the lifting tray and friction	= 90 Kg
Required piston force	= 90x2 = 180 Kg = 1800 N
Required piston stroke	= 600 mm (tray travel 1200 mm)

Selected piston is a custom made, Dia: 63, 600mm Double acting cylinder. The standard force at 6 bars is 1870 N. Double acting cylinder is used to get more control when unloading. The down movement of the tray is controlled by regulating the cylinder output air flow.

4.1.2 Clamping Cylinder

Clamping cylinder is only used to move and grab the green tire. Considerable amount of force will be required to overcome the friction between chain and sprocket mechanism and also to grab and lift the green tire. Maximum green tire weight which will be used for this machine is 80 kg.

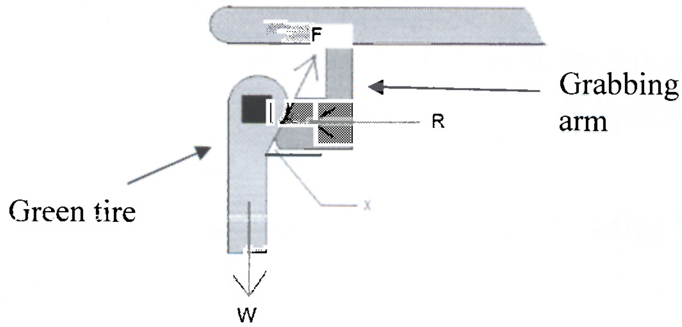


Figure 4.1 Force distributions between green tire and grabbing arm.

Maximum tire weight [13] = 80 kg = 800 N

X= 45°C

Friction between tire and grabbing arm (F) = W Sin x

= 566 N

Required arm force (R) = F Cos x

= 400 N

Required piston force (Used two cylinders) = 400 / 2

= 200 N

Required piston stroke = 200 mm

(For the range of 8" to 23")

Used Festo, [14] DSW-32-200-PPV-A-B, Dia: 32, 200mm Double acting cylinder. The maximum standard forward force is 483 N at 6 bar pressure.

4.1.3 Main painting cylinder

Main painting cylinder is used to lift the two inside and outside painting cylinders and nozzle assembly. Weight of this piston and nozzle assembly is approximately 10 kg.

Weight of the piston nozzle assembly = 10 Kg

Required stroke = 650 mm

(650 mm of total 1100 mm will travel by this piston)

Selected piston is custom made Dia: 32, 650mm Double acting cylinder. Standard force at 6 bars is 483 N.

4.1.4 Inside / Outside painting cylinders

These two pistons only use to lift the paint nozzles. Therefore it is not required to have a great force for this movement. But in order to get a high speed operation, 25 mm diameter piston has been selected.

Selected piston is custom made Dia: 25, 450mm Double acting cylinder. Standard force at 6 bars is 295 N.

4.2 Pressure Switch selection

Green tire diameter depends on the tire dimension. This machine is designed for tires which are having a diameter range from 8" to 23". Clamping jaw arm's movement has to stop after it touches the green tire and should apply a considerable force to grab and lift the tire. Supply air pressure to the clamping cylinder can be used as a parameter to identify this position. This pressure will be measured by a pressure sensor and it will pass a signal to the PLC when it reached to the set value.

Selected pressure switch is SMC, ISE30-01-25-M-L-D, [15] which is an adjustable digital pressure sensor.

Figure 4.2 Pressure switch

4.3 Motor selection

Mainly two motors are required for this machine. One is to drive the main arm which is connected with the three clamping disks is called as the 'Main drive motor. The second one is used to rotate the green tire disk assembly. It is called the 'rotary drive motor'. Also the motor selection has been restricted to select only ABB motors. ABB is the standard motors which permitted to use in this factory.

4.3.1 Main drive motor:

The arm which is connected with the three clamping disk is called 'Main arm'. We can consider the main arm with a lifted green tire, as one assembly unit for this calculation.

Total maximum mass of the main arm with 3 tires = 85+80x3 kg

= 325 kg

Distance of the arm from axis to the mass end = 920 mm

As this mass is kept parallel to the rotary mechanism axis, the motor needs to overcome only the inertia of the mechanism and friction. Center bearing is a friction less thrust bearing. Then in practice, the axis friction will have a very low value and can be neglected for calculations. As these three masses are equal and placed around the axis with a 120° distance, we can assume this mechanism as a uniform disk with 325 kg weight. Then,

The inertia of the assembly (I) = ½*m*r^2 [16]

= ½*325*0.92^2

= 137.54 kg-m^2

Where, m=Mass of the assembly, r=distance from the main arm pivot point to the clamping disk mounting position

Expected total time to rotate 120° (one position to next position) is 6 seconds.

2S – Acceleration – 30°

3S – Constant velocity – 70°

1S – Deceleration (Braking) – 20°

Therefore velocity at 30° = 70/3

= 23.3 Degree/S = 0.41 rad/S

Therefore required angular acceleration = 0.41/2 rad/S^2

= 0.205 rad/S^2

The Newton's second law of motion when applied to rotating bodies state, the torque is directly proportional to the rate of change of angular moment. [16]

Then,

Required torque to accelerate main arm = Iα

= 137.54 x 0.205 x 10

= 281.96 Nm

Where, I = Inertia of the assembly, α = Angular acceleration of the assembly.

(Assumed acceleration of gravity as 10 m/s^2)

Selected Indexing gearbox reduction = 150:1

Motor torque required = 281.96/150

= 1.88 Nm

By considering neglected friction of the main bearing and the gear box,

Selected Motor is -> [17] ABB, M2QA 80 M4A, 0.55kW ,4-poles = 1500 r/min 400 V 50 Hz, Torque -> 3.37 Nm, Starting torque-> 2.4 x T_N Nm

4.3.2 Rotary Drive:

Main purpose of the rotary drive is to rotate clamping disk with a grabbed green tire. Same as previous calculation, we can consider this as one solid cylinder assembly with a mass of 95kg. (Clamping disk + Maximum green tire weight = 15+80 kg)

Distance to the mass can be taken as the radius of biggest green tire which can be handled by this machine.

Radius to the effective mass = 11" = 279.4 mm

The inertia of the assembly (I) = ½*m*r^2 [16]

= ½*95*0.28^2

= 3.724 kg-m^2

Expected rotational speed of the green tire for painting is 10 rpm.

Therefore angular velocity of the green tire = 360 x 10/60

= 60 Degree/S

= 1.05 rad/S

Time for one revolution = 60/10

= 6 S

Expected angular velocity in one revelation,

Therefore required angular acceleration = 1.05/6

= 0.175 ras/S^2

The Newton's second law of motion when applied to rotating bodies state, the torque is directly proportional to the rate of change of angular moment. [16]

Then,

Required torque to accelerate the green tire = Iα

= 3.724 x 0.175 x 10

= 6.517 Nm

Where, I = Inertia of the disk green tire assembly, α = Angular acceleration of the assembly.

(Assumed acceleration of gravity as 10 m/s^2)

This clamping disk and green tire assembly will get connected with the rotary drive motor at the painting position, though the chain and sprocket wheel assembly. The selected sprocket ratio of the green tire assembly and the rotary drive is 25:1.

Then,

Effected gear reduction = 25:1

Motor torque required = 6.517/25

= 0.26 Nm

By considering neglected friction of the bearings and getting a safety factor,

Selected Motor -> [17] ABB, M2QA 71 M4A, 0.37kW ,4-poles = 1500 r/min 400 V 50 Hz

Torque -> 1.71 Nm, Starting torque-> 2.1 x T_N Nm

4.4 Indexing gearbox

Main arm needs to stop at three positions, which are loading, painting and Unloading positions. That means it stops for every 120° position of one rotating circle. Also the main arm and the drive motor have to be connected though a reduction gear box to get the required speed and torque. In this case, the 'Indexing gearbox' is the perfect solution. Those are available in the market with predefined gear ratios and indexing positions. For the purpose of this machine it has defined the required main arm rotation speed as 10 rpm.

Drive motor speed = 1500 rpm

Required gear box out speed = 10 rpm

Selected gear ratio = 150:1

Selected indexing gear box is Boneng, H4DHA150 with internal electrically activated brake. This electrically activated brake is an added advantage which can be used to get a perfect stop at required positions.

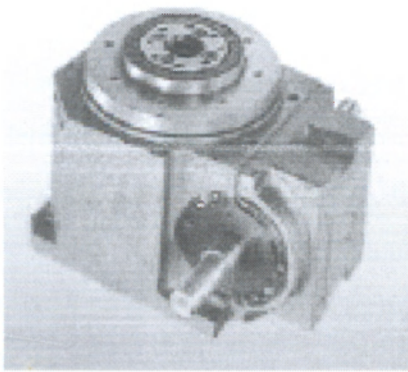


Figure 4.3 Indexing gearbox

4.5 PLC selection

Basically this machine's main controller is a PLC (Programmable logic controller). Different kinds of PLCs are available in the market. Basically all the PLCs are programmed by a ladder diagram programming method. Different kinds of PLC manufacturers are using their own software for their PLC programming. In the PLC selection, the first one is to determine the required number of input and output terminals.

Required digital Inputs = 26 + extra 10

= 36

Required digital Outputs = 20 + extra 10

= 30

Other requirements,

3 high frequency inputs for encoders (25 Hz), 24 V DC outputs, Easy programming, Flexibility to trouble shooting, memory capacity, after sales services and should be a company recommended product.

According to the above requirements the selected PLC is 'S7-200 PV 224 Xpsi CPU' (I/P-14 digital, 2-analog O/P-10 digital, 1-analog) with 'EM223 24V' (I/P-32 digital, O/P-32 digital) expansion module [18]. Total digital input is 46 and 42 outputs. Two analog inputs and one analog output are kept aside for future requirements.

Program memory	12288 bytes
Data memory	10240 bytes
Memory backup	100 hours
High speed counters	4 at 30 kHz
Real time clock	Built-in

Table 4.1 PLC specification

4.6 Proximity sensors / Reflective sensors

Here reflective sensors are used to detect the green tire, to stop the loading tray's upward movement, and to detect the green tire at unloading position. When the sensor beam which reflected by the reflector is cut by the tire, the sensor passes a signal to the controller. The reflective sensor which is used is 'Baumer' NPN FPAM 18N 3151 due to its high reliability in harsh environment and low impedance. Maximum sensing distance of the sensor is 4m.

connection diagram

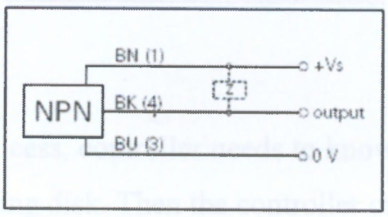


Figure 4.4 Retro reflective sensor

4.7 Nozzles

To get a perfect uniform paint application it needs to use a perfect atomization nozzle. The specific gravity of the inside paint is 1.25 and outside paint is 1.07. World famous brand for this kind of applications is Binks nozzles. Selected nozzle is a USA made 'Binks' B-125-LS nozzle as the inside painting nozzle. It is 360^0 atomization nozzle. This is the nozzle which is used for manual operations also. But this nozzle has 25" diameter 360^0 covering area. Then this nozzle can be used for automated process also.

For the outside painting propose, the selected nozzle is 'Binks' A54-72R 8/06, MAG HVLP automatic spray nozzle.

Figure 4.5 Paint nozzle

This nozzle can be pneumatically activated and can apply 100 mm wide paint strip on the painting surface with a 150 mm distance. Working air pressure is 6 bars and required fluid pressure is 8 bars. Actuating pressure is 3.4 bars. Specific gravity is up to 1.25. These are the available inputs in the factory.

4.8 Encoders

For the paint application process, controller needs to know the green tire height which can be hanged on the clamping disk. Then the controller can limit the paint application distance along the green tire without any losses. Encoder reads the upward movement of the loading tray and the controller gets the green tire height by substituting this value from the total height which is from the bottom to the clamping disk. At the unloading position also, controller counts the unloading tray encoder signals and stops it, when it reaches to the desired value as given in the loading tray encoder.

Selected encoder is HS25 Incremental Optical Encoder. As the operations of this machine do not need high precision, we do not need to use expensive absolute encoders. Therefore an incremental encoder is selected. Also these encoders have to rotate several times for each tray movement. Then it can use low resolution encoder as those are very cost effective. Selected encoder has 100 pulses per revolution.

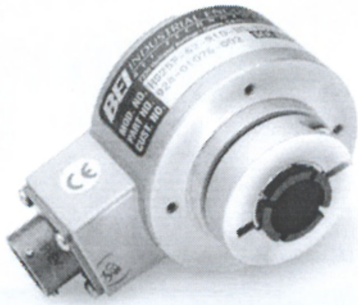


Figure 4.6 Incremental encoder

Lifting jack stroke	= 600 mm
Diameter of the sprocket wheel	= 130 mm
Average lifting jack speed	= 100 mm/S
Max rpm of the sprocket wheel	= 600/(22/7*130)/6
	= 14.67 rpm
	= 0.244 rpS
Max: output frequency of the encoder	= 0.244 x 100
	= 24.4 Hz

This frequency can read by the PLC easily.

4.9 Rotary air union

The main arm with three disks is rotating around the center point. Also three clamping disks are rotating around its pivot axis. It has to supply compressed air though these rotary joints. The equipment used for this purpose is a rotary air union. For the main arm pivot joint 6 port rotary union is used and for each disk 4 port rotary unions are used.

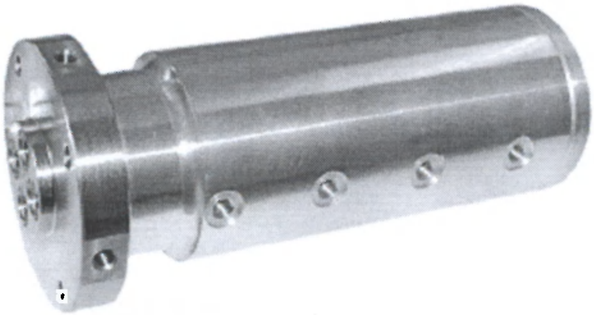


Figure 4.7 Rotary air union

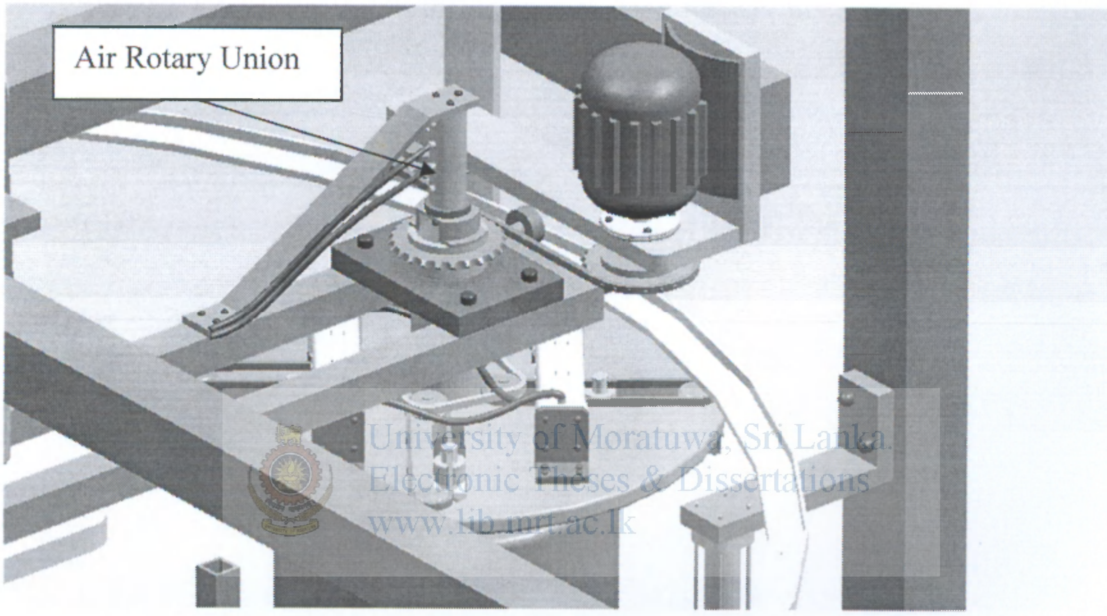


Figure 4.8 Rotary air union assembly

4.10 Display

For easy operation and user friendliness, the electronic display is acting a major role. It does not need to input any parameters though display device in this machine. Also the selected display needs to be perfectly compatible with the PLC. By considering these factors, selected display is Siemens TD 200C display. It is compatible with the selected PLC. It has two lines of text output display with 20 characters per line, for about total of 40 characters.

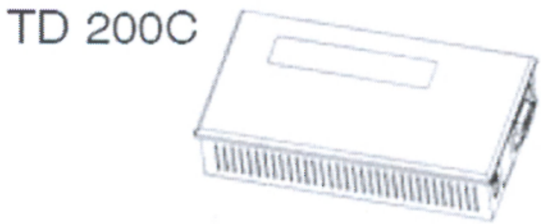


Figure 4.9 TD 200C display

Chapter 5

Discussion

5.1 Discussion

The main objective of industrial automation is to increase productivity, quality, efficiency and also to improve the working conditions in a particular industry. Thus, industrial automation can facilitate number of activities currently in use in the tire industry for further improvements. In this project my main focus was on the Green tire painting system. Machine operators are directly benefited from this machine. This machine will facilitate a safer working environment with minimized hazardous operations. Also it is very easy to load and unload the tire and operators do not need to pay attention on the size of the tire.

In the company point of view they can increase the productivity without any head count increment. Evenly panted tires will reduce the scrap percentage. Also improve the appearance of the tire will be improved ultimately resulting a good quality output. That will give a competitive advantage for the company when competes in the international markets.

Component	Manufacturer	Code	Description	Qty	Unit Price	Price (Rs:)
Loading Cyl:	Custom made		Dia:63, 600mm Double acting	2	19,000.00	38,000.00
Clamping cylinder	Festo	DSW-32-200-PPV-A-B	Dia:32, 200mm Double acting	4	11,000.00	44,000.00
Paint Main Cyl:	Custom made		Dia:32, 650mm Double acting	1	17,500.00	17,500.00
IP Cyl:	Custom made		Dia:32, 450mm Double acting	1	15,500.00	15,500.00
OP Cyl:	Custom made		Dia:32, 450mm Double acting	1	15,500.00	15,500.00
Pressure sensor	SMC	ISE30-01-25-M-L-D	Adjustable digital pressure sensor	3	11,000.00	33,000.00
Main drive	ABB	M2QA 80 M4B	0.75kW ,4-poles = 1500 r/min 400 V 50 Hz	1	45,000.00	45,000.00
Rotary Drive	ABB	M2QA 80 M4A	0.35kW ,4-poles = 1500 r/min 400 V 50 Hz	1	110,000.00	110,000.00
Indexing Gear box	Boneng	H4DHA150	150:1 GR with internal brake	1	225,000.00	225,000.00
PLC	Siemens	S7-200 PV 224 Xpsi CPU	I/P-14, O/P-10 digital	1	65,000.00	65,000.00
Expansion	Siemens	EM223 24V	I/P-32, O/P-32 digital	1	26,000.00	26,000.00
Contactors	Telemechanique			6	7,500.00	45,000.00
Pneumatic Valves	SMC			8	6,500.00	52,000.00
Display	Siemens	TD200c	2 line text display	1	36,000.00	36,000.00
Rotary air union 1	Rotation	Rotation 994514	4 Port rotatable air connector	3	28,000.00	84,000.00
Rotary air union 2	Rotation	Rotation 112569	2 Port rotatable air connector	1	19,000.00	19,000.00
IP nozzle	Binks	B-I25-LS	360 degree atomization nozzle	1	58,000.00	58,000.00
OP nozzle	Binks	77-2797R-5	MAG AA automatic spray gun	7	25,000.00	175,000.00
Inc: encoder	Baumer	HS25 Incremental	Optical Encoder 500 cyl/turn	3	54,000.00	162,000.00
Retro-ref: sensors	Baumer	FPAM 18N 3151	Retro-reflective sensor 4m	2	9,000.00	18,000.00
Bearings	SKF			24	6,000.00	144,000.00
Linear Bearings	SKF	PCM 252850 M		6	12,000.00	72,000.00
Other Pneu: items			Tubes, Connectors, FRL etc			150,000.00
Other Elec: Items			Cables, Connectors, Push Buttons			200,000.00
Mechanical			Clamping Jig, Frame, mountings			800,000.00
Machining						200,000.00
Other expenses						400,000.00
			Total			3,249,500.00

Table 5.1 Costing

Basically this machine is designed with the components which are available in the market. Therefore manufacturing of this machine is not a tricky operation. Also the design is free with any complicated customized components. Therefore it can be easily replaced with available matching components when it is broken or worn out.

There are various types of machines which are available in the market for green tire painting process. But most of the machines are made only for inside painting. Also the maximum diameter range that they can handle is limited to maximum of 6". In other words, even a Chinese machine will cost around 8 million rupees. Apart from that the payback period of this machine is considerably less when compared with other available machines in the market. Also this machine has advanced capabilities.

5.2 Payback calculation

Total cost for the machine = Rs: 3,249,500/=

Current production tonnage per day = 16 Tones

Planned production tonnage per day in 2009 = 18 Tones

More operators need to meet this production = 1 per shift (4 for 4 shifts)

Extra cost need = 20,000 x 4 x 12

= Rs: 960,000/=

Cost for extra accessories and paint booth = Rs: 628,000/=

Average value of the scrap tires per year due to operator painting defects = Rs: 600,000/=

Average customer clams value per year due to Painting defects = Rs: 540,000/=

Rough payback period of the machine =

(3,249,500-628,000)/ (960,000+(600,000+540,000)*3/4)

= 1.5 years

- Assumptions:

Assume 75% of customer clams which are related to the painting defects and painting operator defects can be solved by this machine.

5.3 Future Developments

As this machine is designed in-house, we have more flexibility for further developments and modifications depending on the company requirements. One of the future developments will be to design outside paint nozzle to move forward and backward. Then we can reduce the paint wastage when painting small tires. In this case the PLC has to read the tire diameter. To read the diameter of the tire it can use the clamping jaw movement. By measuring the clamping jaw movement, PLC can identify the diameter of the tire. Then outside nozzle can be moved accordingly.

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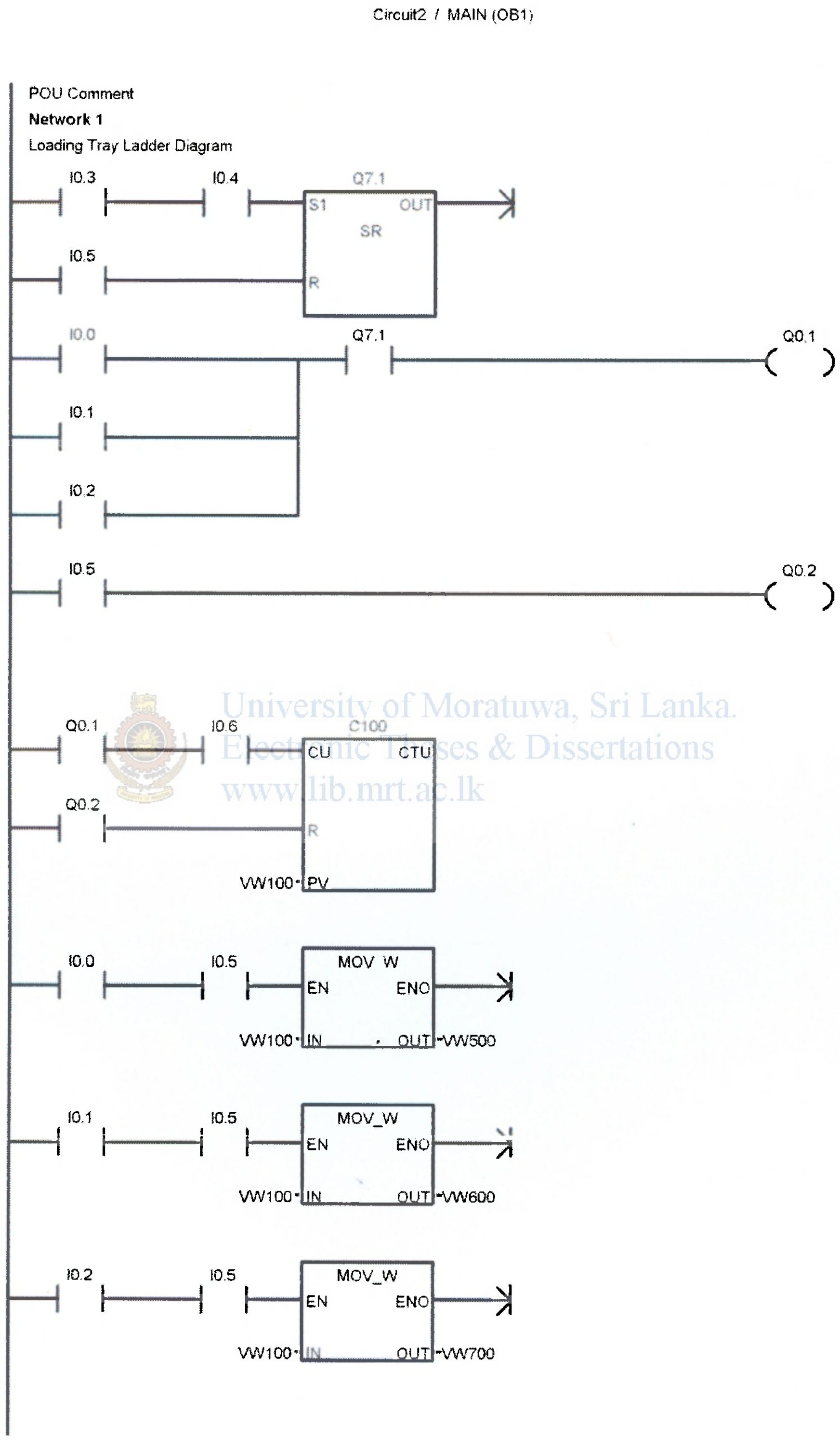
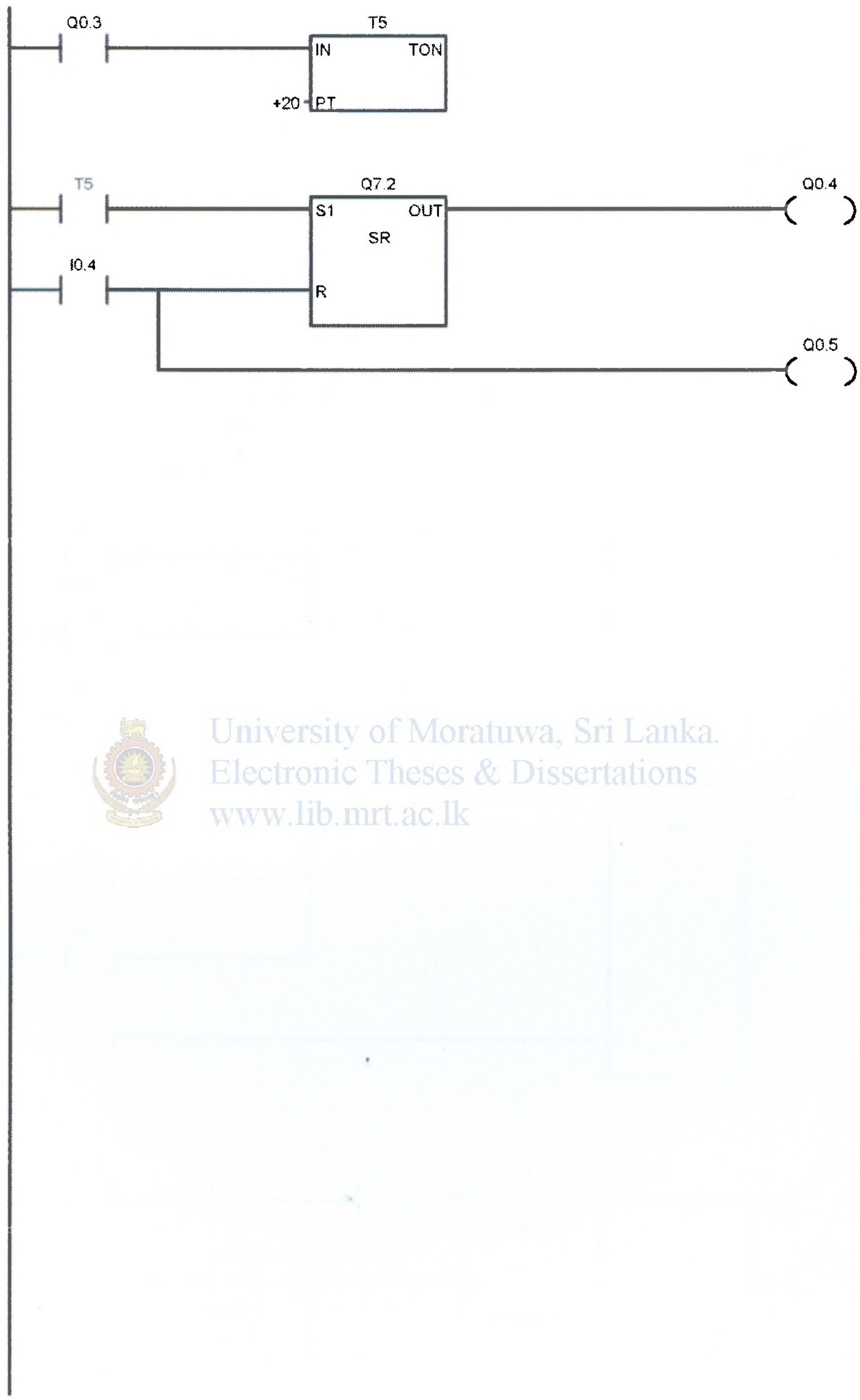
APPENDIX-A: PLC ladder diagram

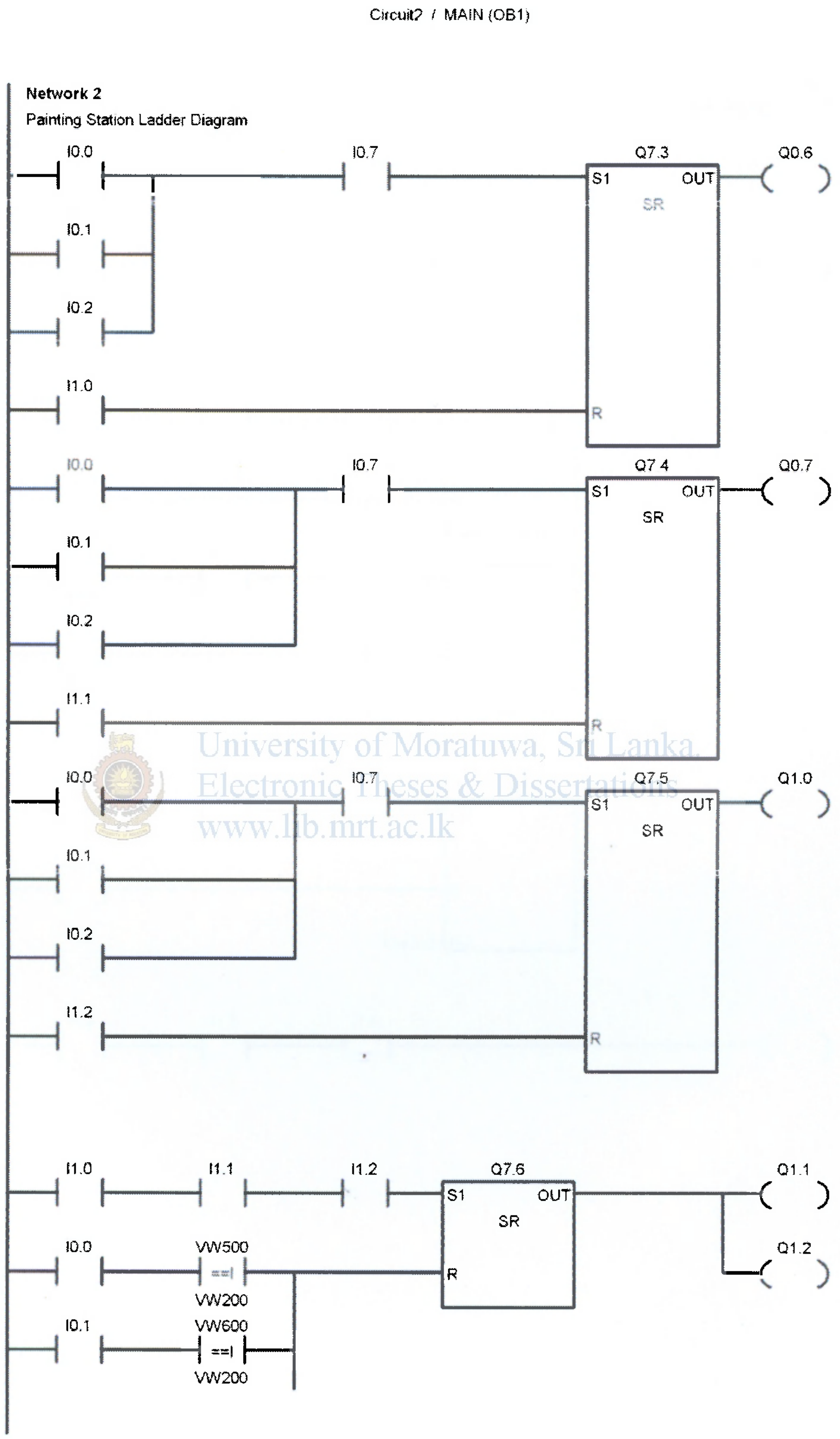
A.1 Loading tray ladder diagram



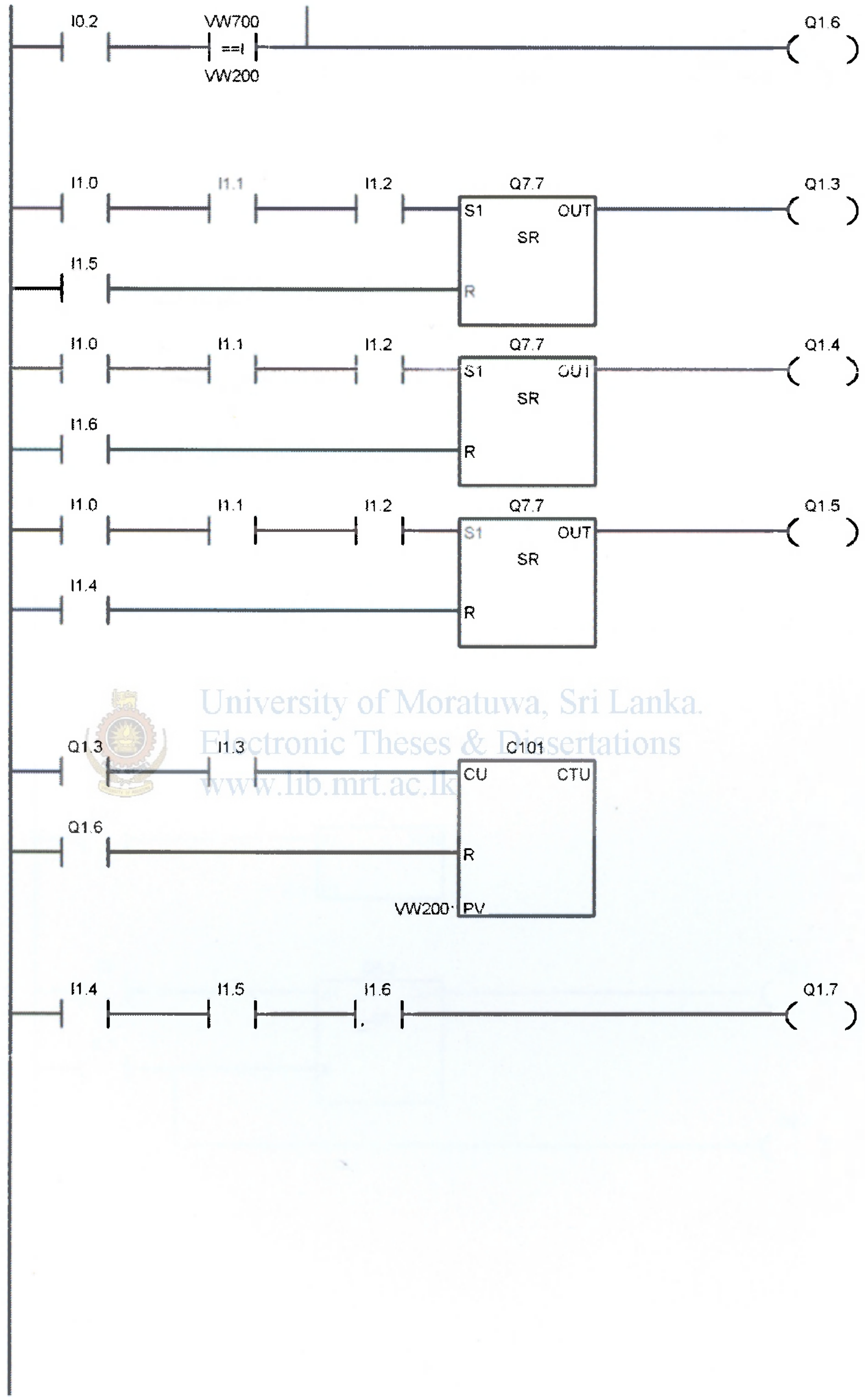
Circuit2 / MAIN (OB1)



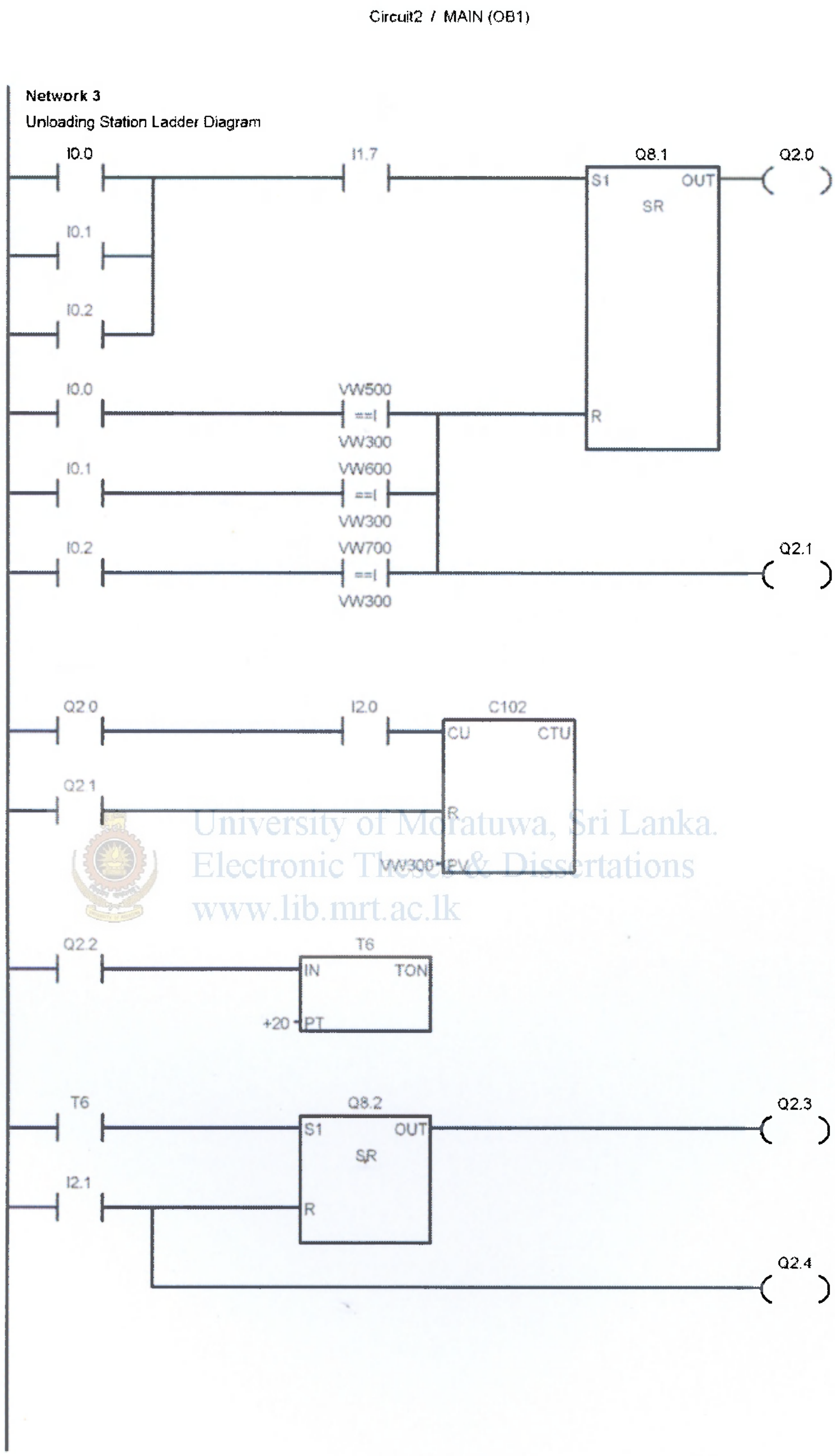
A.2 Painting station ladder diagram



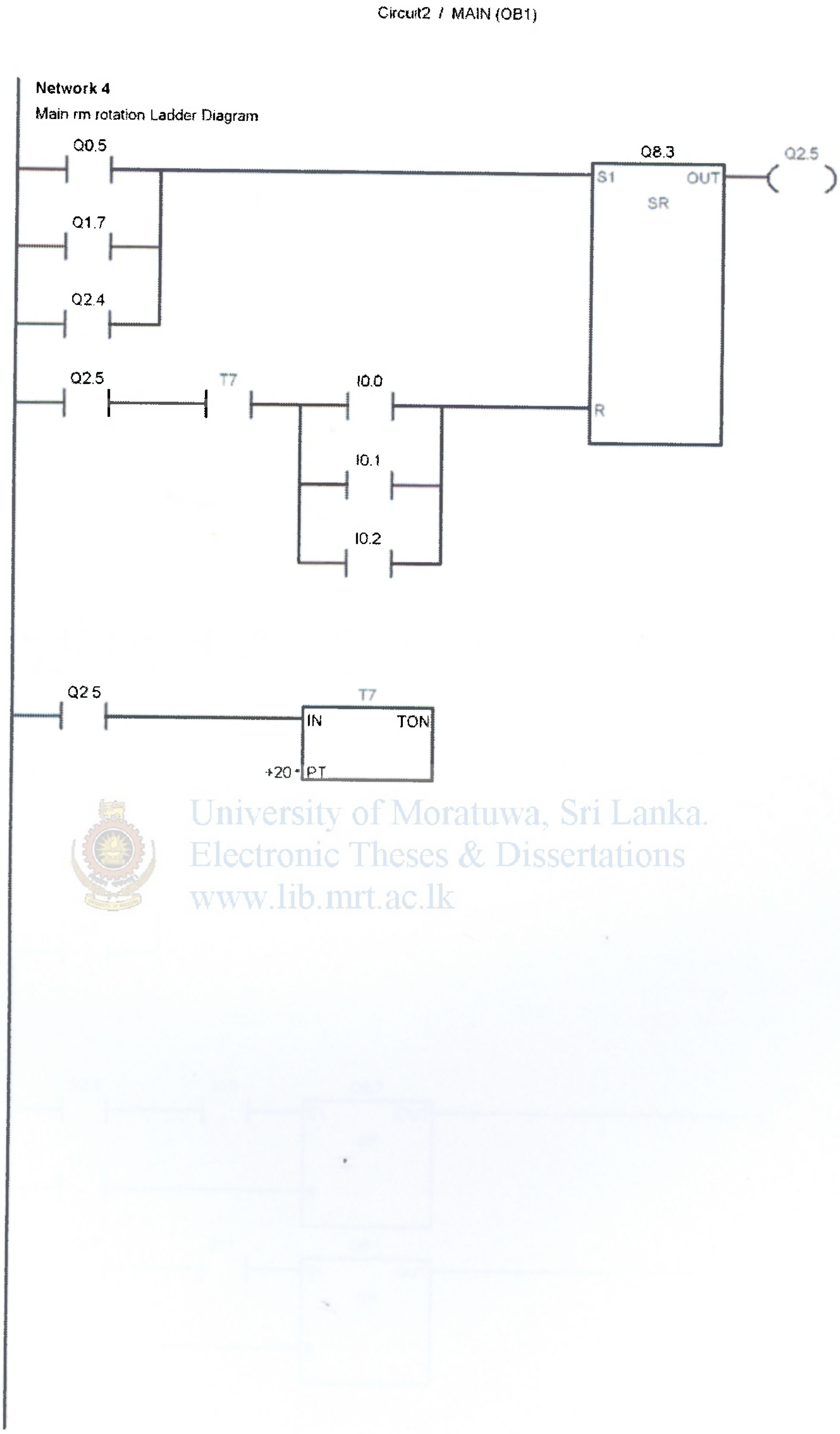
Circuit2 / MAIN (OB1)



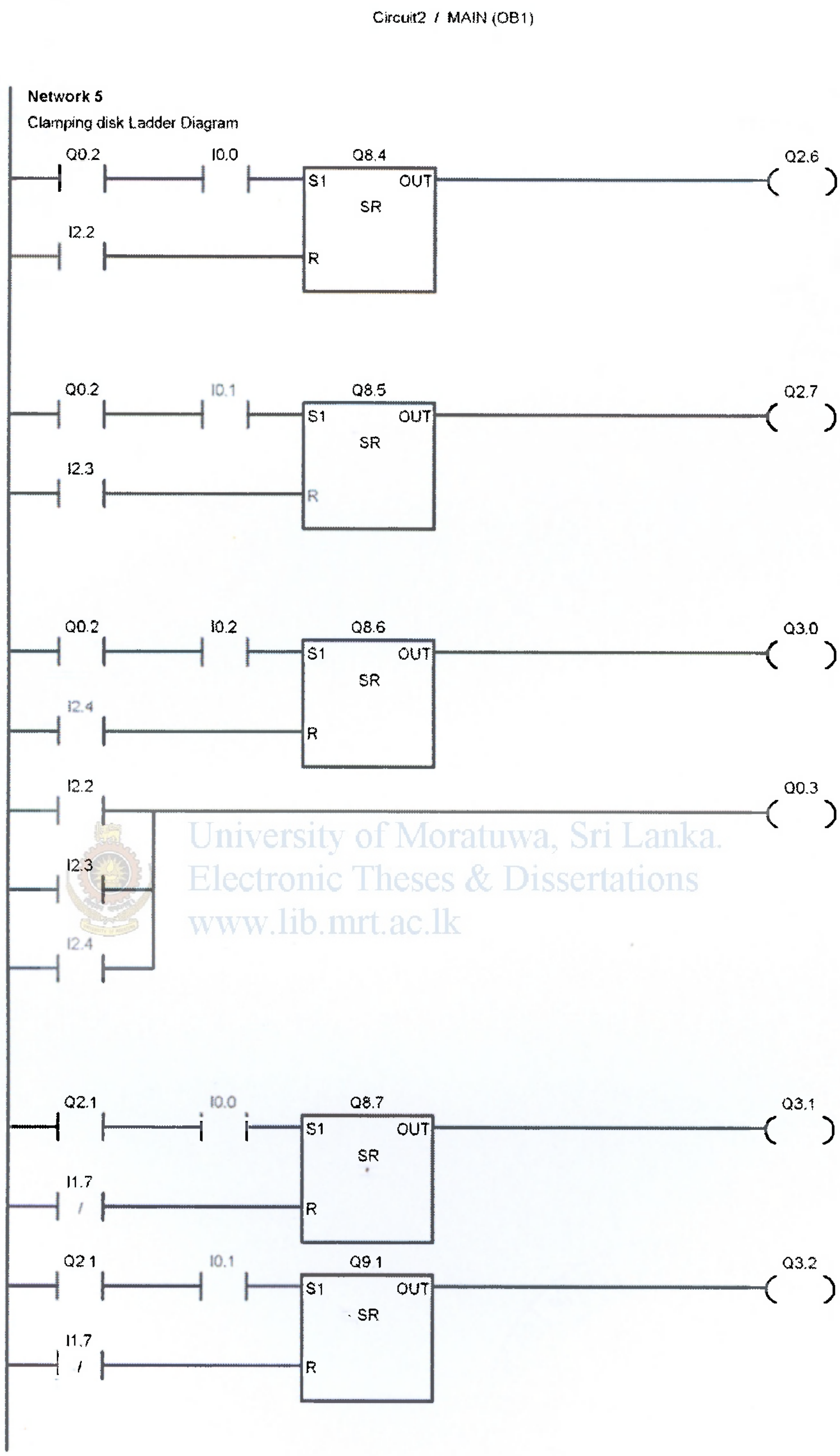
A.3 Unloading station ladder diagram



A.4 Main arm rotation ladder diagram



A.5 Clamping disk ladder diagram



Circuit2 / MAIN (OB1)