# Design and Implementation of an Automatic Sorting Machine

By


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Supervisor: Eng. Zoheir Wazwaz


Submitted to College of Engineering
in partial fulfillment of the requirements for the
Bachelor degree in Mechatronics Engineering


Palestine Polytechnic University


May, 2018

Palestine Polytechnic University

College of Engineering

Department of Mechanical Engineering

Hebron – Palestine

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Supervisor Signature

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Testing Committee Signature

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Chair of the Department Signature

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# إهداء

**إلى معلمنا و قائدنا وحبيبنا وشفيعنا و قدوتنا محمد صلى الله عليه وسلم.**

**إلى من رسموا بدمائهم طريق المستقبل وهندسوا بأجسادهم معاقل العزة والكرامة وإلى من هم أكرم منا جميعا شهداء الامة الاسلامية.**

**إلى الذين عشقوا الحرية التي تفوح منها رائحة الياسمين وتواروا خلف القضبان ليفسحوا لنا النور أسرانا البواسل.**

**إلى أبي الذي لم يبخل علي يوماً بشيء، وأمي التي زودتني بالحنان والمحبة أقول لهم:**
**أنتم وهبتموني الحياة والأمل والنشأة على شغف الإطلاع والمعرفة.**

**إلى إخوتي و أسرتي جميعا.**

**إلى كل من علمني حرفاً أصبح سنا برقه يضيء الطريق أمامي.**

**إلى من ضاقت السطور لذكرهم فوسعتهم قلوبنا أصدقاءنا الأعزاء.**

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**نتقدم بالشكر إلى القلب الحنون من كانت بجانبنا بكل المراحل التي مضت من تلذذت بالمعاناه وكانت شمعه تحترق لتنير دربنا إلى أمهاتنا الحبيبات**

**وإلى من علمنا أن نقف وكيف نبدأ الألف ميل بخطوة إلى يدنا اليمنى إلى من علمنا الصعود وعيناه تراقبنا ....والدنا لمن أمسك بيدينا وعلمنا حرفا ..حرفا ..سنهدي له نجاحنا اليوم إلى من كانوا سندا لنا**

**إلى من لهم الفضل بإرشادنا إلى طريق العلم والمعرفه إلى أساتذتنا الأفاضل كم نحن فخورون بكم**

**إلى أصدقائنا وأحبتنا ومن سهروا معنا في مسيرتنا العلميه إلى من مدوا أياديهم البيضاء في ظلام الليل وكانوا عونا لنا**

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# Abstract


## Design and Implementation of Automatic Sorting Machine

Sorting and recycling require fast and accurate processing. Millions of tons of scrap are processed each year moreover sorting scrap adds value at all stages of the material recycling process and then achieve a maximum price of the scrap.

The main idea of our project is to design and implement a machine that sorts, and classifies three different types of materials which are iron, aluminum, and plastic. Then guide materials to different carts to prepare for the material recycling process.

Materials are gravity-fed from the hopper to the conveyor. Then the entered materials are scanned by sensors (inductive and magnetic) that are connected to a programmable logic controller (PLC) which gives the order to air pistons that are located at the edges of the conveyor to move each type of materials to specific cart.


Keywords: Sorting, Piston, Sensor.

## الملخص

## تصميم وتنفيذ آلة الفرز الآلي

تتطلب عملية فرز وإعادة تدوير المواد معالجة سريعة ودقيقة. تتم معالجة ملايين الأطنان من الخردة سنويا، ويضيف فرز الخردة القيمة لها في جميع مراحل عملية إعادة التدوير ومن ثم تحقيق السعر الأقصى من هذه الخردة.

والفكرة الرئيسية لمشروعنا هي تصميم وتنفيذ آلة، تقوم بفرز ثلاثة أنواع مختلفة من المواد و هي الحديد والألومنيوم والبلاستيك، ثم توجيهها إلى حاويات مختلفة لإعدادها لعملية إعادة التدوير.

بحيث يتم ادخال المواد عن طريق استغلال قوة الجاذبية لدفع المواد من الحاوية، ثم يتم فحص المواد المدخلة بواسطة أجهزة الاستشعار(الحثية و المغناطيسية) المتصلة بوحدة التحكم المنطقي القابلة للبرمجة التي تقوم باعطاء الاوامر لضواغط الهواء الموجودة على حواف السير الناقل لتقوم بتوجيه المواد الى حاويات محددة.



الكلمات المفتاحية : تصنيف, ضواغط , مجسات.

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# 1

# Chapter 1

# Introduction

## 1.1 Introduction

Around the world, waste generation rates are rising. So many companies are involved in designing systems that can be able to sort and classify solid waste and scrap into different types to facilitate the process of recycling and then achieve the maximum price of each material from the scrap.

Sorting is the first step of a waste management process. It should be sorted according to the type of material.so the main idea of our project is to design and implement a machine that sorts, and classifies three different types of materials which are iron, aluminum, and plastic. Then guide materials to different carts to prepare for the material recycling process.

## 1.2 Recognition of the need

In this section, we will define the need for the automatic sorting machine.

Solid waste is a stand-alone environmental problem because it leads to pollution of the environment if it is not recycled, and is used instead of being thrown randomly as we currently do. Garbage is thrown on the sides and edges of the main and subsidiary roads as well as in the agricultural land or transferred to a general landfill to be collected and then buried without treatment some countries use modern techniques to take advantage of solid waste by sorting and classifying them in different ways.

The problem of solid waste is one of the major environmental problems that governments currently start paying attention not only to their harmful effects on public health and the environment but also to their social and economic impacts. Each of these effects has a high cost on governments that will bury or burn it. They can avoid this by sort and classify it into many types to prepare it for the recycling process. Global waste management market reported that the amount of waste generated worldwide produced is 2.02 billion tons. Wastes are not always waste if it is processed as it was. Therefore, we must work to separate, transport and recycle waste, to reduce risks to public life and the sustainable environment [1].

Waste sorting is the process of separating waste into different types. The global trend is to work on the separation of solid waste and recycling, so this process must be done as soon as possible, and there emerged the need to complete the process of separation [2].

## 1.3 History

Material sorting has evolved over the ages to meet human needs at every stage. This process is evolved with the development and progress of human life, for example, in the ancient, the human had to use his hand to separate things like impurities from the food grains and this takes a lot of times. After this, he invented a new tool to facilitate the sortation process and enable him to invest his time in a better way this tool is a sieve. The invention of the sieve formed an important transitional stage in his life that made him accomplish his tasks in a better way.

With the increasing number of people and the development of the industrial application, the tasks become hard and the needs arose again. So the scientists work on developing new technology that can help in solving this problem which are sensors. The sensors start to play a key role in all areas of life and contribute to making it easier by using it in every field in our life.

So instead of using our senses to classify and sort material, we can now use sensors to determine the presence, color, type and other things about this material without any importance of human observation. Furthermore, in most of the cases, the response of sensors can be faster than humans.

## 1.4 Literature Review

In this section, we represent the most important papers that published in IEEE Explore and ScienceDirect.

### 1.4.1 Design of an Automated Pepper Sorting Machine.

The study aims to present a unique design and development of Automated Pepper Sorting Machine (APSM) for industrial application. The design consists of several mechanical and electrical components such as motors, a microcontroller, hopper mechanism, suction tube, belt, and pulley. A gantry crane is used to move the suction pipe across the conveyor belt to the exact position of the defective pepper. A camera is attached to the machine to identify defective pepper based on the color of the defective pepper. The main purpose of this design is to automate the sorting procedure for the pepper industry and to optimize its work efficiency.

Actuators and sensors that are used in this work: Gantry crane, conveyor, DC motor, hopper mechanism, camera, suction mechanism.

Control that is used in this work: National Instruments PCI -7344 Motion Controller, ST Microelectronics L297 Stepper Driver, ST Microelectronics L298N Dual Full Bridge Driver [3].

### 1.4.2 Design and Development of a High-Speed Sorting System Based on Machine Vision Guiding.

It is desired to make a vision-based control strategy to perform a high-speed pick and place tasks between two synchronous conveyors using Delta robot. The whole control system in this project composed of vision module and motion control module, the vision module is consisting of a computer, image acquisition card, and camera, and the motion control module is composed of a computer, motion control card, and motor. The communication between these modules is realized by a computer.

Actuators, sensors, and software that are used in this work: servo motor, conveyer, camera, machine vision software and VC++.

Control that is used in this work: Computer [4].

### 1.4.3 Belt-type Corona-Electrostatic Separator for the Recovery of Conductive and Non-conductive Products from Micronized Wastes.

This article works on the optimum design of an industrial belt-type corona-electrostatic separator for the recycling of metals and plastics from waste electric and electronic equipment.

This study aims to validate that a belt-type corona-electrostatic separator could be an appropriate solution for the selective sorting of conductive and non-conductive products contained in micronized wastes, using two different physical mechanisms for particle charging: corona discharge of positive or negative polarity and electrostatic induction.

The uncharged non-conductive particles are not affected by the electric field and they are collected in a special box.

The actuators that are used in this work: metal belt conveyor, three-phase electric motor [5].

### 1.4.4 Automatic Conveyor Belt Driving and Sorting Using SIEMENS Step 7-200 Programmable Logic Controller.

An example application based on a programmable logic controller module used for the operation and the control of an industrial unmanned system is presented, namely, two conveyors and a pneumatic crane. In the first belt Sensor checks the presence of the piece and then the robot moves the piece to the second belt, and in the second belt, there are two sensors. If the first sensor is given a signal, the piece is transferred to the first box. If the second sensor gives a signal, the piece is transferred to the second box.

Actuators and sensors that are used in this work: inductive sensors, capacitive sensors, conveyor, single-phase AC motor, pneumatic actuators, "Pick and Place" unit.

Control that is used in this work: Programmable Logic Controller (PLC) [6].

### 1.4.5 Automation of Plastic, Metal and Glass Waste Materials Segregation using Arduino in Scrap Industry.

This study aims to properly manage the waste that it has to be handled, segregated, transported and disposed of, to reduce the risks to the public. They propose an automation of waste material segregation in the scrap industry that is designed to sort the trash into metallic waste, plastic waste and glass waste, to be processed separately for the next process of operation.

Actuators and sensors that are used in this work: inductive sensors, capacitive sensors, conveyor, IR sensors, DC motor, pivot motor.

Control that is used in this work: Arduino UNO [1].

### 1.4.6 Scrap Metal Sorting with Color Vision and Inductive Sensor Array

This study presents an automatic scrap metal sorting system, by seeing a color vision based optical sensing system and an inductive sensor. This system can only run correctly when reddish (brass, copper) and bright metals (stainless steel).

Actuators and sensors that are used in this work: Sony XC003P CCD matrix camera, individual sensor elements for the three-color components.

Control that is used in this work: Computer [7].

### 1.4.7 Intelligent Solid Waste Processing Using Optical Sensor Based Sorting Technology

This study presents an indirect sorting process by using optical sensor and mechanical separating system was developed an indirect sorting process by using optical sensor and mechanical separating system was developed. Sorting by particle sizes and positions, colors and shapes.

The mechanical sorting device consists of a compressed air nozzle which is controlled by a computer.

Actuators and sensors that are used in this work: Optical sensors, laser beam, 3D visual sensors, camera, compressed air nozzle.

Control that is used in this work: Computer [8].

### 1.4.8 Automated Waste Segregator

This study presents an Automated Waste Segregator (AWS) which is a cheap, easy to use solution for a segregation system for household use. And sorting by dry, wet and metallic wastes at the household level.

Actuators and sensors that are used in this work: IR proximity sensor, capacitive sensing module.

Control that is used in this work: Microcontroller [9].

### 1.4.9 Extended Spectral Un-mixing for the Classification of Fluorescently Labeled Plastic Waste

This study presents the results of a hyperspectral imaging prototype system developed for the Real-time identification and sorting of a mixture of small plastic flakes delivered on a conveyor belt.

Sorting by different plastics at the ppm level according to a binary coding scheme serve as unique optical fingerprints for classification purposes [10].

## 1.5 Project Objective

Our project objective is to design, build and control an automated material sorting machine that sort and classify three different types of materials which are iron, aluminum, and plastic.

## 1.6 Specification and Requirement

The materials and scraps are in different shapes and sizes. Therefore, the sizes to be sorted should be determined, so the maximum allowed size is (5cm×5cm×5cm), and the minimum size is (2cm×2cm×2cm). Our machine will operate at three different speeds. The first speed will sort three pieces per minute, the second speed will sort seven pieces per minute, and the third speed will sort nine pieces per minute.

### 1.7 Project Outline

Depending on mechatronics project design by Shetty [11], we separate the project into three levels, modeling /simulation, prototyping and deployment, The first one is separated to recognition of the need, conceptual design, function speciation ,sensors and actuator, mathematical, control system design and optimizing design, The second level separate to hardware in the loop simulation and optimizing designs. The third level contains, deployment of embedded software and lifecycle optimization, and all of these blocks will be complete or part of the chapter as follows. See Figure 1.1

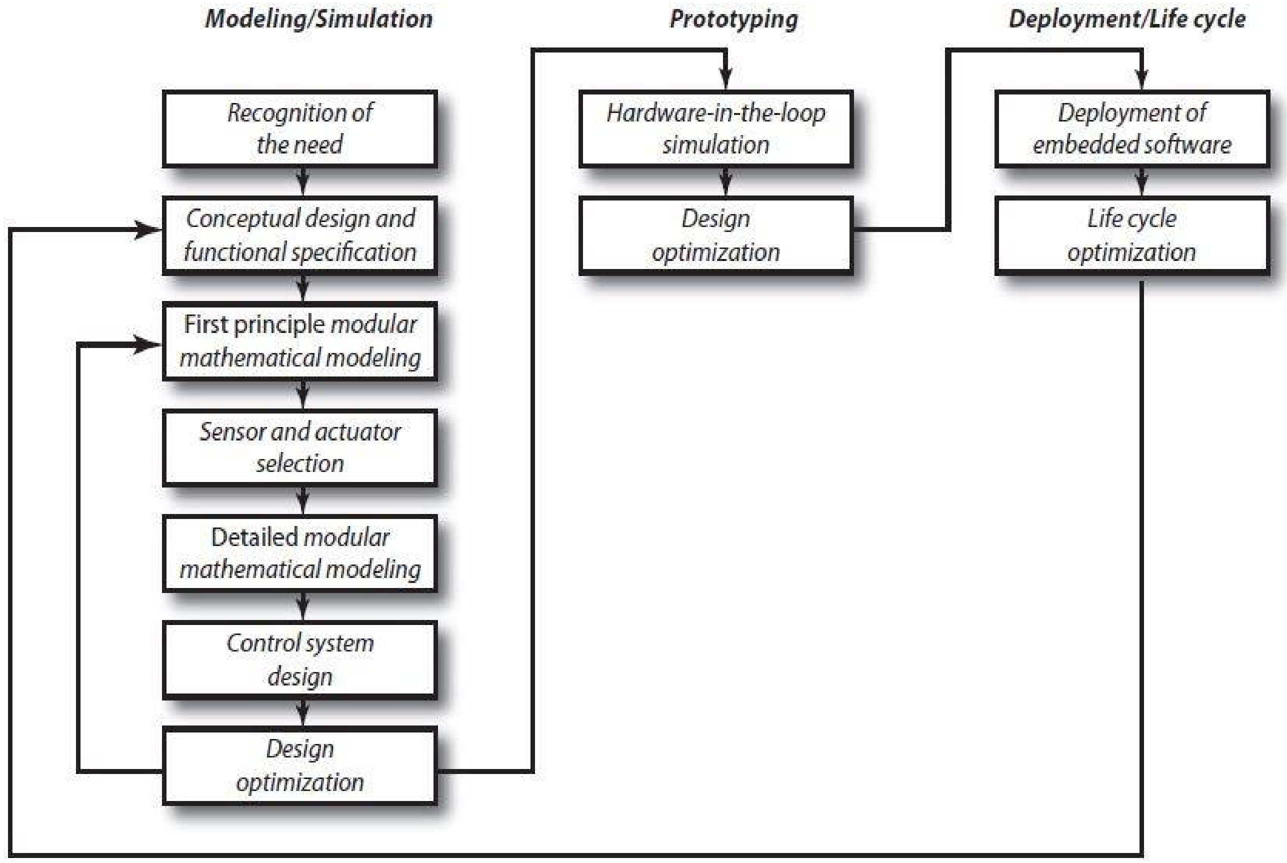



**Figure 1.1:** Mechatronics project design by Shetty

## 1.8 Cost Table

Table 1.1 shows the cost of the machine.

**Table 1.1:** Cost Table

| Item Name | Items No. | Total Cost (NIS) |
|---|---|---|
| **Inductive sensor** | **1** | **300** |
| **Emergency switch** | **1** | **30** |
| **Magnetic sensor** | **1** | **350** |
| **Pneumatic actuators** | **3** | **600** |
| **Conveyor belt** | **1** | **200** |
| **Induction motor** | **2** | **450** |
| **Switches** | **4** | **100** |
| **Overload** | **1** | **100** |
| **Relay** | **1** | **50** |
| **PLC** | **1** | **650** |
| **Overall machine body** | **1** | **2000** |
| **Electric panel** | **1** | **500** |
| **Total Cost** | | **5330 NIS** |

## 1.9 Time Table

Table 1.2 and Table 1.3 show the project work for the first and the second semester.

**Table 1.2:** First semester time plan

| Tasks \ Weeks | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification of Project Idea | ■ | ■ | ■ | | | | | | | | | | | | |
| Drafting a Preliminary Project Proposal | | | ■ | ■ | | | | | | | | | | | |
| Introduction Chapter (1) | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| Conceptual Design and Functional Specifications (2) | | | | | | | ■ | ■ | ■ | | | | | | |
| Mechanical Design Chapter (3) | | | | | | | | | ■ | ■ | ■ | ■ | | | |
| Electrical Design Chapter (4) | | | | | | | | | | | | ■ | ■ | | |
| Control Design Chapter (5) | | | | | | | | | | | | | ■ | ■ | ■ |

**Table 1.3:** Second semester time plan

| Tasks \ Weeks | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Purchase of project parts | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| Assembly and installation | | | | | | ■ | ■ | ■ | ■ | ■ | | | | | |
| Testing and calibration | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Implementation and validation | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Writing graduation final report | | | | | | | | | | | | | ■ | ■ | ■ |
| Preparing the final presentation | | | | | | | | | | | | | | | ■ |

# Chapter 2

# Conceptual Design and Functional Specifications

## 2.1 Introduction

In this chapter, we identify the conceptual design, flowchart and the main component that will be used in the project. The Automatic Sorting Machine consists of some sensors, actuators, and controller. That works together with functionality interference to achieve the main purpose that we need.

## 2.2 Flow Chart

Figure 2.1 shows the sequence steps and decisions that are needed to perform the sorting process. This allows anyone to logically follow the process from beginning to the end.

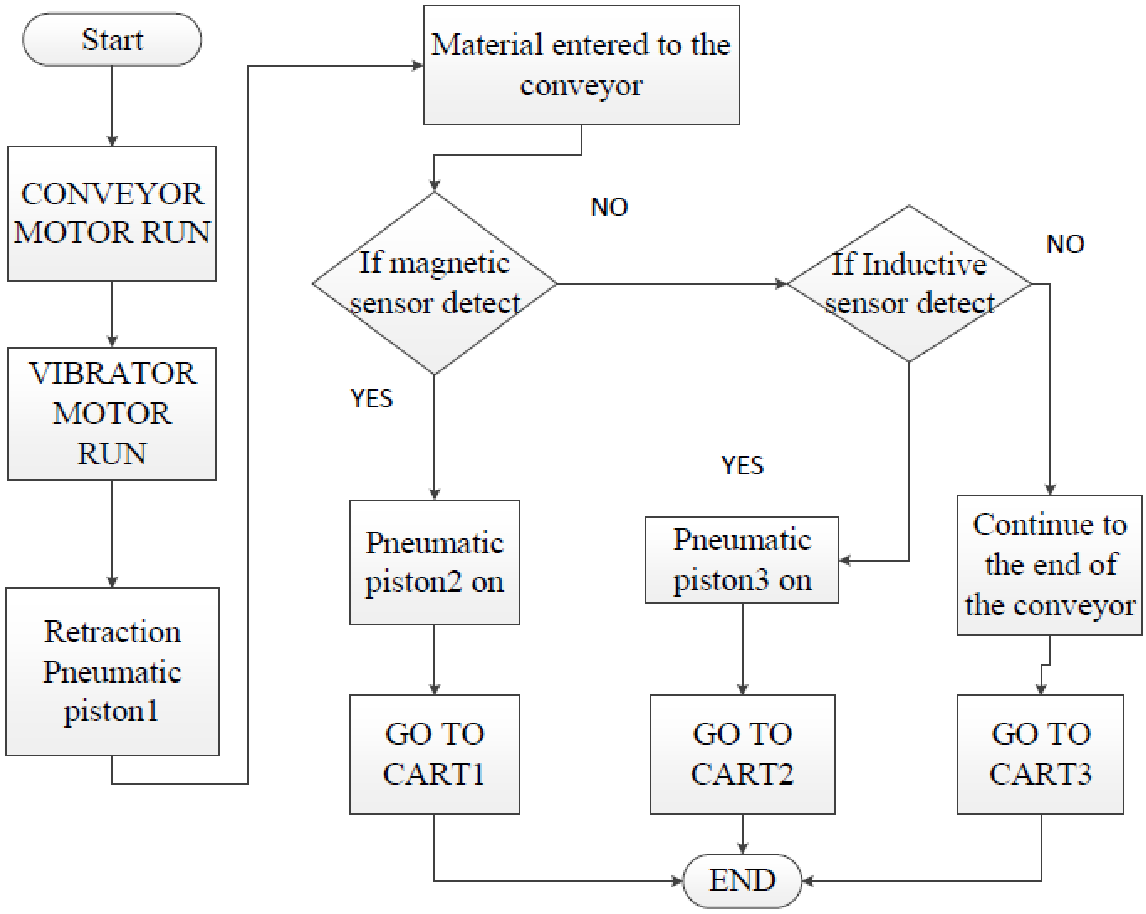



**Figure 2.1:** Machine flow chart

## 2.3 Block Diagram

Figure 2.2 shows the block diagram that represents the principal part of our machine and the relationship between them.

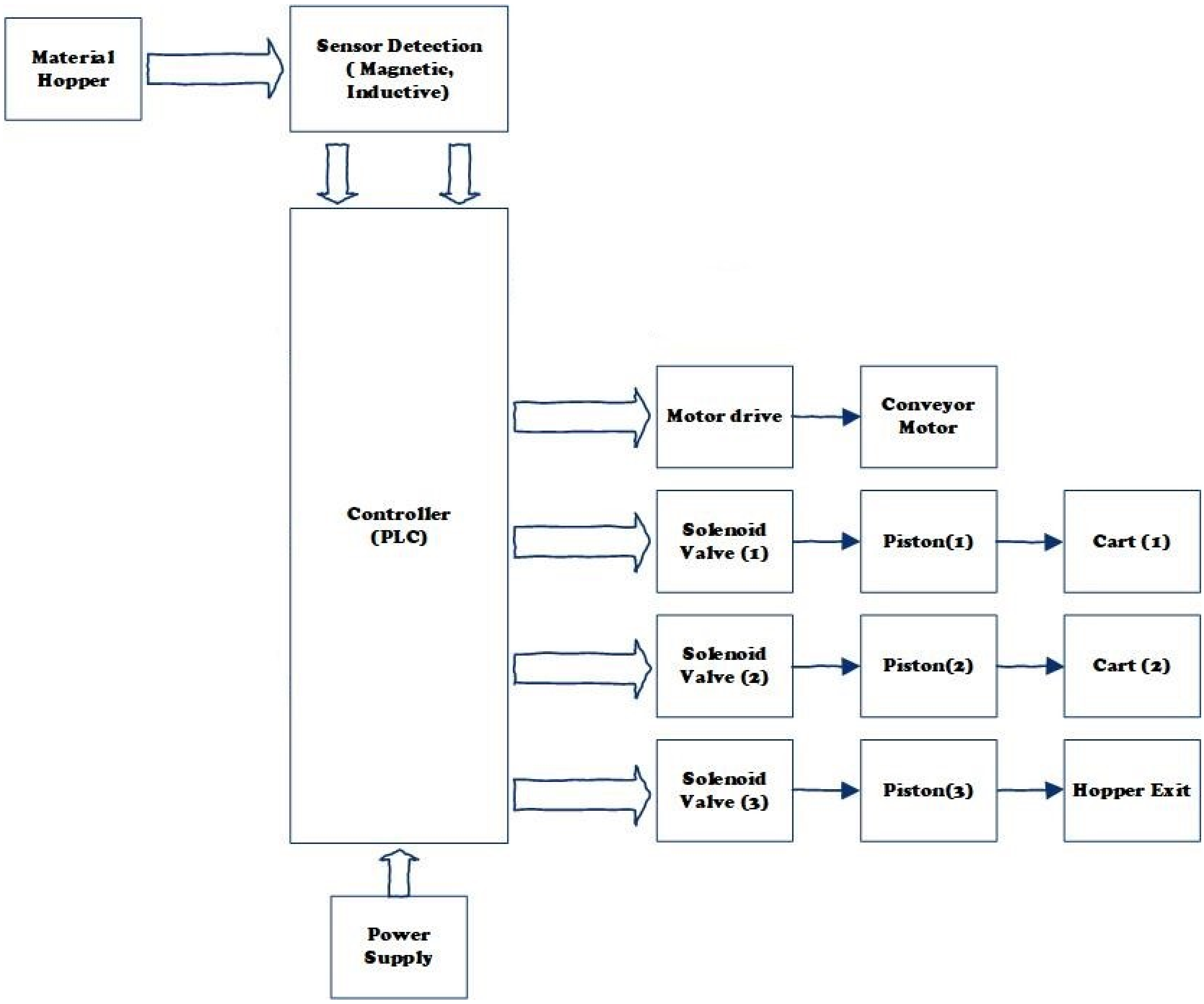



**Figure 2.2:** Machine block diagram

**Working principle of Automatic Sorting Machine**

1) The pieces are entered by hand in the hopper.

2) In the hopper, the pieces move on an inclined surface, using vibrator motor.

3) The pieces are inserted into the conveyor belt, by a first pneumatic piston which connected to the inclined surface, In the retraction mode, the piece is allowed to enter to the conveyor, In the extension mode, pieces are blocked to entering to the conveyor belt.

4) After entering the object into the conveyor belt, the piece is checked through sensors in a sequential manner.

5) If the magnetic sensor activated, that means this piece is iron, the second pneumatic piston will push the piece into the iron box, otherwise, the pieces complete their path on the conveyor belt.

6) If the inductive sensor activated, that means this piece is aluminum, the third pneumatic piston will push the piece into the aluminum box. Otherwise, the pieces complete their path on the conveyor.

7) If the magnetic sensor and the inductive sensor deactivate, that means this piece is plastic, then continue to plastic box at the end of the conveyor.

## 2.4 Sorting System Components

### 2.5.1 Conveyor System

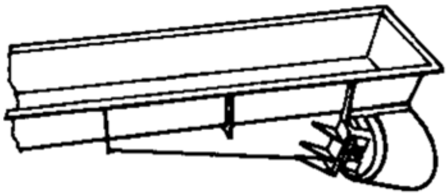
Conveyors system is a piece of material handling equipment that carries material from one location to another. Conveyors are especially useful in an application involving the transportation of heavy materials. As shown in Figure 2.3

**Figure 2.3:** Conveyor system

**The most famous types of conveyors systems are:**

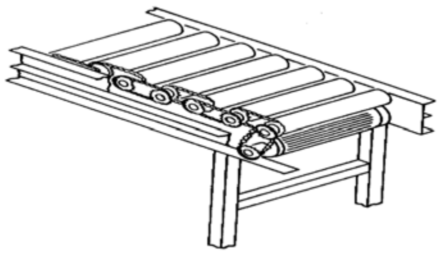
1. Vibrating Conveyor Systems.
2. Roller Conveyor Systems.
3. Vertical Conveyor Systems.
4. Belt Conveyor Systems.

Figure 2.4 shows the types of conveyors:



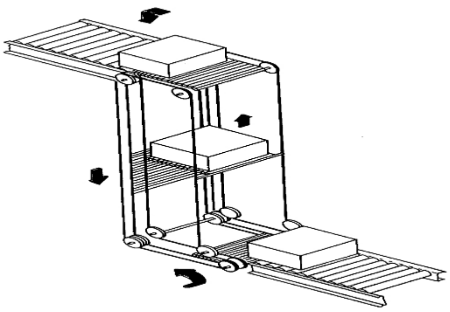
Vibrating conveyor

(a)



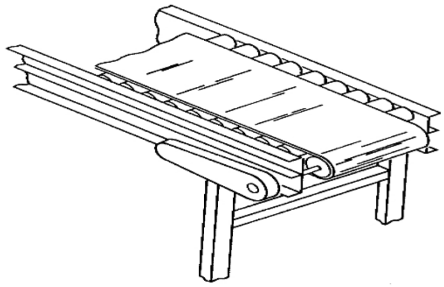
Roller conveyor

(b)



Vertical conveyor

(c)



Belt conveyor

(d)

**Figure 2.4:** Conveyor system types

### 2.5.2 Sensors

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.

#### 2.5.2.1 Magnetic Sensors

Magnetic proximity sensors are operated by the closeness of a permanent magnet. Their working principle is based on the use of reed contacts, whose thin plates are hermetically sealed in a glass bulb with an inert gas. The closeness of a magnetic field make the thin plates flex and touch each other causing an electrical contact. The plate's surface has been treated with a special material particularly suitable for low current or high inductive circuits [12]. See Figure 2.5

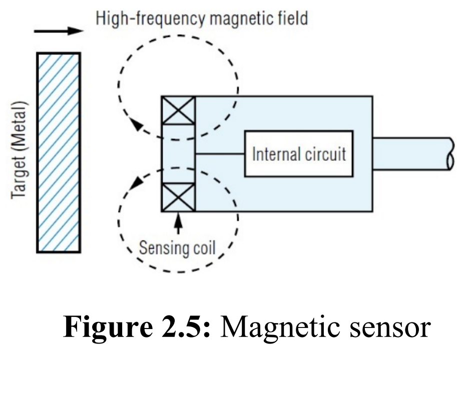



**Figure 2.5:** Magnetic sensor

#### 2.5.2.3 Inductive Sensors

Inductive proximity sensors are used for non-contact detection of metallic objects. Their operating principle is based on a magnetic field is generated. When the metal intersects the field, current eddy currents are generated, resulting in loss of energy in the orbit of the oscilloscope. The amplitude of the magnetic field decreases. The detector detects the change in field capacity and generates a signal that changes the contact points. [12]. See Figure 2.6

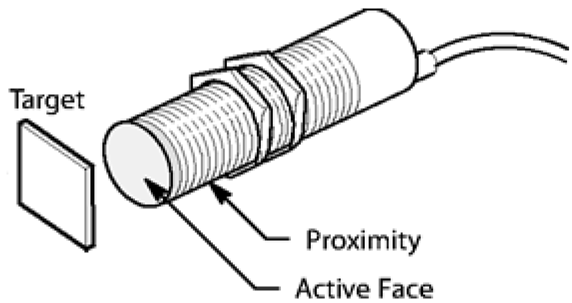



**Figure 2.6:** Inductive sensor

### 2.5.3 PLC (Programmable Logic Control)

A central control system from which one can operate and program functions of several independent or dependent systems. The PLC consists of a user interface, central processor, links to subsidiary system controls, and an electrical control interface. See Figure 2.7

The PLC-type that will be used is DELTA-DVP16ES2 that has 8 inputs and 8 outputs. We chose Delta PLC because of its good quality, it is easy to be programmed, has accepted the price and meet the required purpose.

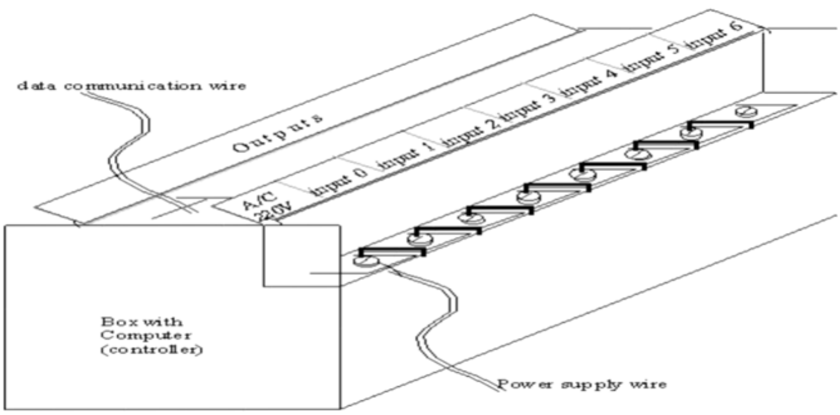



**Figure 2.7:** PLC

### 2.5.4 Protection System

#### 2.5.4.1 Circuit Breaker (CB)

The main circuit breaker function is to protect the electrical and human devices from the risk of electric current. By cutting the circuit in the case of an unusual current in the circuit (overloading, short circuit or leakage current). To detect the change in electricity, which represents a danger to the surrounding, the electric circuit breaker uses three different techniques. [13]. See Figure 2.8

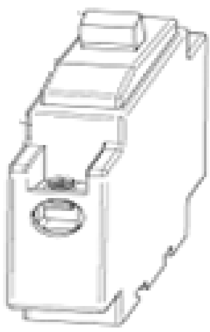


**Figure 2.8:** Circuit breaker

#### 2.5.4.2 Overload

Overload relays are intended to protect motors, controllers and branch-circuit conductors against excessive heating due to long motor overcurrent and including locked rotor currents. Protection of the motor and other branch-circuit components from higher currents, due to short circuits or grounds, is a function of branch-circuit fuses, circuit breakers or motor short circuits protectors [14]. See the Figure 2.9

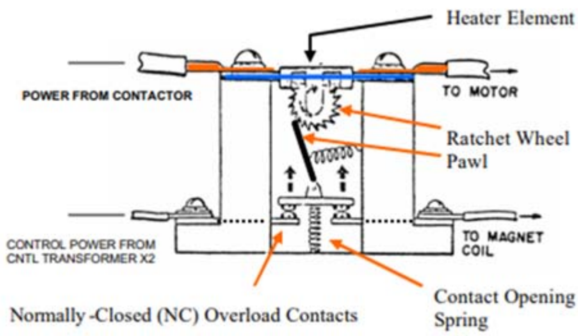



**Figure 2.9:** Overload

#### 2.5.4.3 Emergency Stop Button

Emergency Stop Button is shown in a Figure 2.10 provides safety for humans and the machine; it offers a wide range of safety components for the protection of humans, machine and production goods in emergency situations.

The purpose of the emergency-stop device is to deflect or minimize the risk as quickly as possible and optimally in the event of an emergency arising.

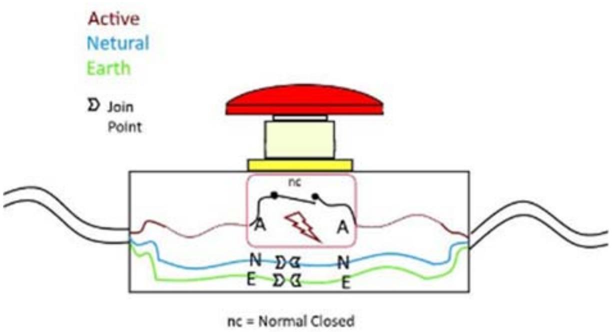
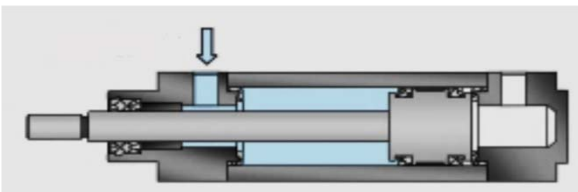



**Figure 2.10:** Emergency stop button

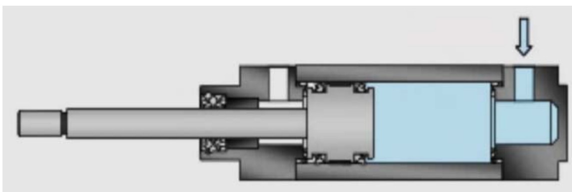
### 2.5.5 Pneumatic System

#### 2.5.5.1 Double Acting Cylinder

The double-acting cylinder requires compressed air for every direction of movement. On this type of cylinder, the extension and retraction are built up using compressed air. The simplest way of actuating a double-acting cylinder is by using a 5/2-way valve [15]. See the Figure 2.11



Double acting cylinder retracted



Double acting cylinder advanced

**Figure 2.11:** Double Acting Cylinder

### 2.5.5.2 Solenoid Valve

The solenoid valve is an electromechanical device used for controlling liquid or gas flow. The solenoid valve is controlled by electrical current, which is run through a coil. When the coil is energized, a magnetic field is created, causing a plunger inside the coil to move. Depending on the design of the valve, the plunger will either open or close the valve. When electrical current is removed from the coil, the valve will return to its de-energized state [16]. See the Figure 2.12

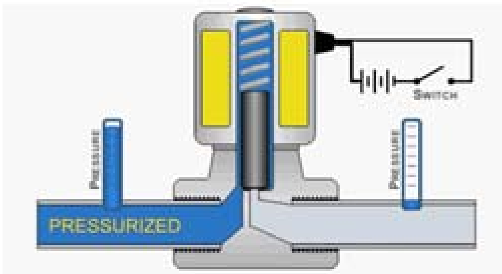



**Figure 2.12:** Solenoid valve

### 2.5.5.4 Compressor

An air compressor is a device that converts power (using an electric motor, diesel or gasoline engine, etc.) into potential energy stored in pressurized air (i.e., compressed air). By one of the several methods, an air compressor forces more and more air into a storage tank, increasing the pressure. When tank pressure reaches its upper limit the air compressor shuts off. See Figure 2.13

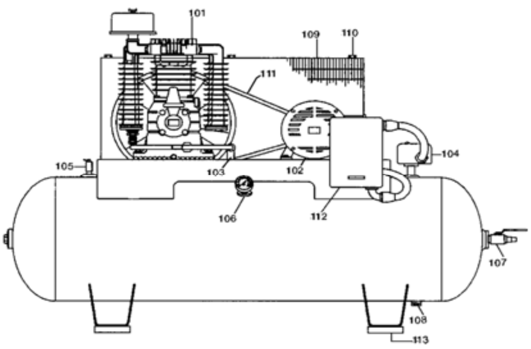



**Figure 2.13**: Compressor

### 2.5.6 Material Hopper

In the sorting process, the samples materials are supplied. The material hopper holds and supplied these materials. The materials then are gravity fed from the hopper to the conveyor. Figure 2.14 clarify the first prototype of the material hopper.

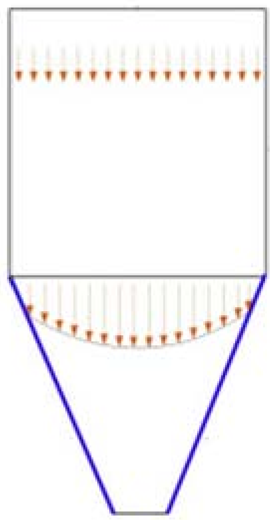
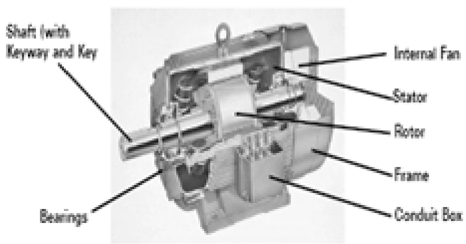


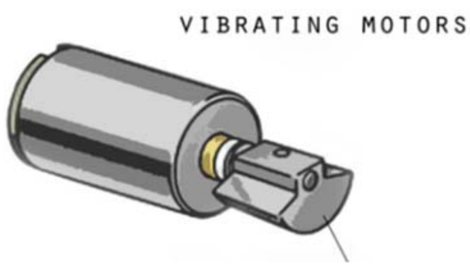
**Figure 2.14:** Hopper

### 2.5.7 Motors

The machine needs two motors, the first is three-phase induction motor with gearbox for conveyor, the second is AC vibrator motor for the hopper. See Figure 2.15




(a) 3 phase IM




(b) Vibrator motor

**Figure 2.15:** System motors

### 2.5.8 Variable frequency drive (VFD)

It is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor by varying motor input frequency and voltage. See Figure 2.16

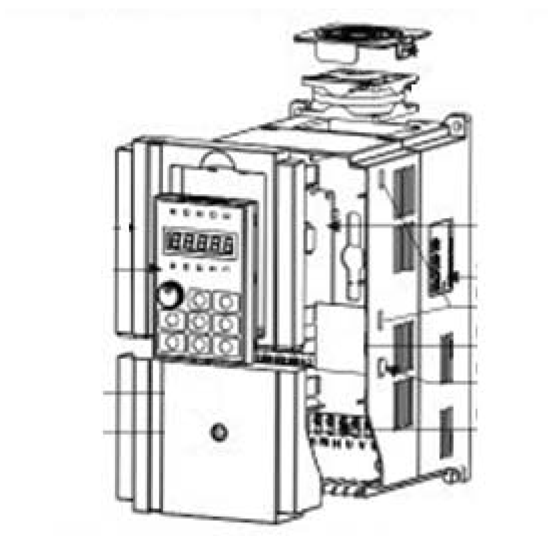


**Figure 2.16:** VFD

# 3

# Chapter 3

# Mathematical model

## 3.1 Mathematical model equations

The mathematical model is used to describe the system to be designed. According to Newton's second law, the dynamic state of the system is described.

The mathematical model is used to facilitate control of each part of the system. Then the system is controlled as a whole. Knowing that each piece of the system is connected to another piece, for example, part of the conveyor is wrapped around the two pulleys, the first pulley is connected to the motor shaft. When the motor spins, this pulley rotates, then conveyor moves and the second pulley rotates, producing controlling of the system as a whole. See Figure 3.1

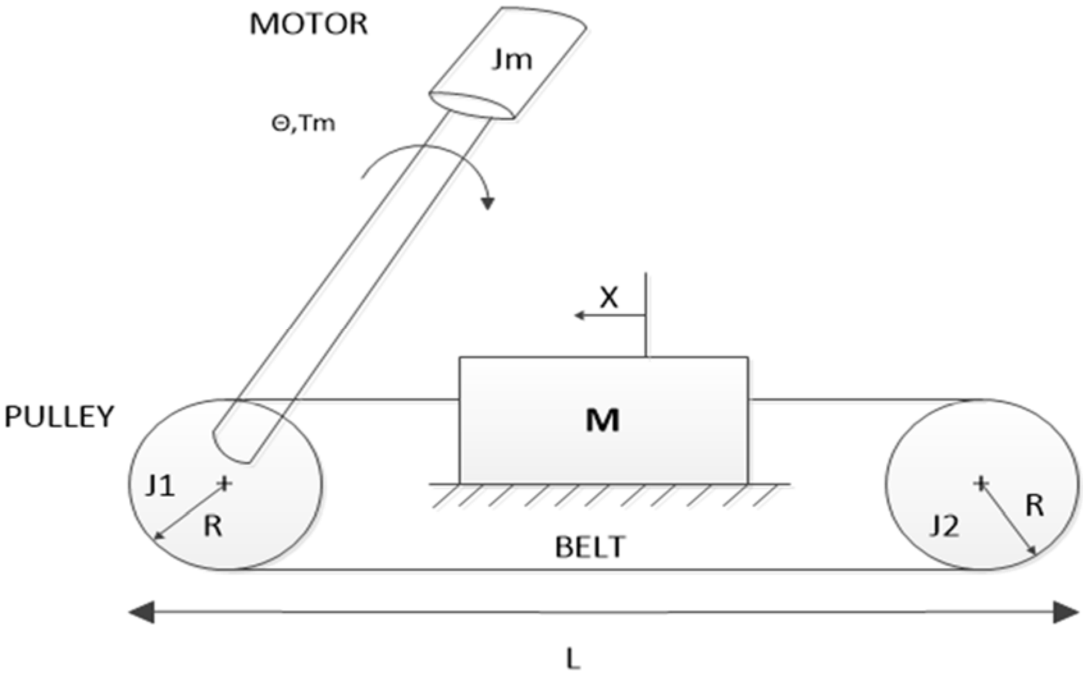



**Figure 3.1**: Description of the selected system

**The assumption to analysis system:**

1-There is no relative motion between objects and conveyor belt.

2- The motor produces torque in a short time

3- Motor shaft for rotation only.

4-The rotation angle of the motor is equal to the rotation angle of the pulley there is no gears.

**The hypotheses that were considered in the mathematical model**

1- The conveyor belt is assumed to be spring

2- The mass is distributed along the conveyor belt is considered to be in the middle.

3- Since the mass is taken in the middle, for this $k_1=k_2$.See Figure 3.2

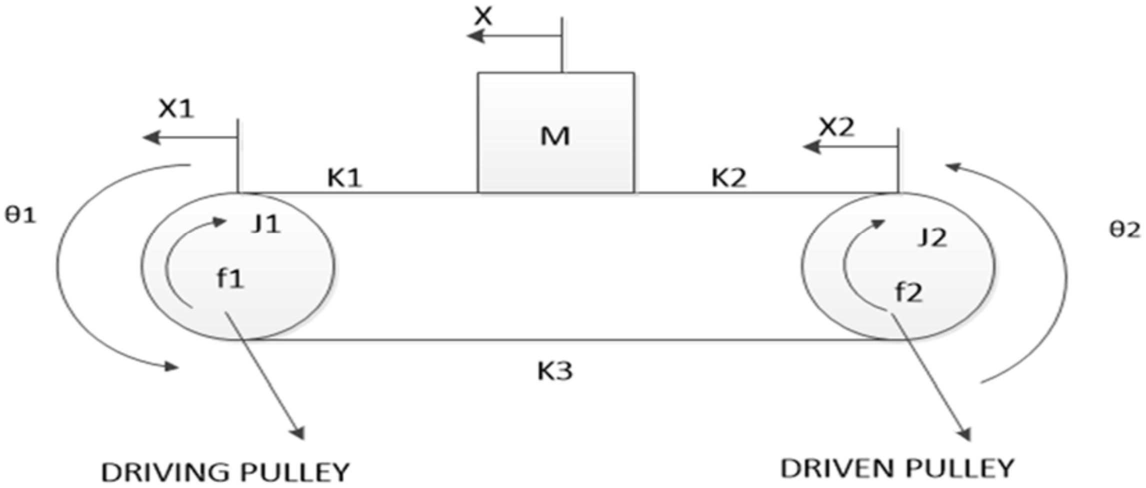



**Figure 3.2:** System diagram

**Table 3.1:** Definition Symbols

| Variables | Definition |
|---|---|
| $J_1$, $J_2$ | The inertia moments of driving and driven pulleys |
| $J_m$ | The inertia moments of the motor |
| M | The mass of material |
| R | The radius of pulleys |
| $k_1$, $k_2$, $k_3$ | The elasticity coefficients of the belt which change with respect to object position |
| X | The direction of motion |
| $T_m$ | The torque developed by the motor |
| $\Theta_1$, θ2, $\theta_3$ | The angular position of driving pulley, driven pulley, and motor, respectively |
| $f_1$, $f_2$ | The friction moments in the driving pulley and driven pulley, respectively |
| $F_m$ | Friction force which acts to the material. |

**Mathematical model equations:**

1) Mass of objects

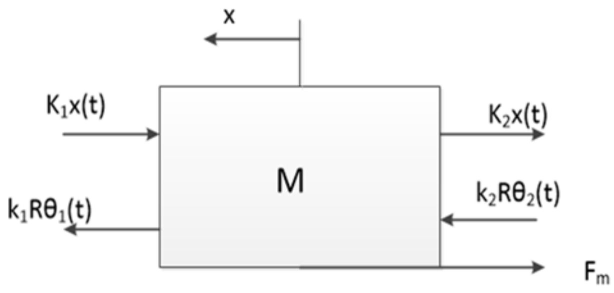



**Figure 3.3:** Forces on object

According to Newton's Second Law:

$$\sum F = m\ddot{x} \tag{3.1}$$

Where:

F: Resultant force on object

m: Mass of object

$\ddot{x}$ : Acceleration of object

Note that the forces that affect the mass are the spring force of both sides, and the value of the first and second spring varies depending on where the mass is located, That is, when the mass is at the beginning of the conveyor, the value of $k_2$ is almost zero, and the value of $k_1$ is the highest value, either when the mass moves in the direction shown in the Figure above(3.3), the value of $k_2$ starts increasing and the value of $k_1$ starts decreasing until it reaches zero, and then the value of $k_2$ is the highest value, and that when the mass reaches the end of the conveyor.

As for the direction of the force of the two spring, when the mass moves in the direction shown in the Figure (3.3), the spring $k_1$ will be in compression mode, leading to a reaction to reverse the direction of movement, the spring $k_2$ will be in tension mode, leading to a reaction to reverse the direction of movement, Therefore, the force of the two spring will be in the reverse direction of movement.

The other forces are the forces of the two pulleys on the mass, as the pulleys affect the tension force in the reverse direction of movement of the mass, the reaction of these two tension forces is in the direction of mass movement, as shown in the Figure (3.3), and when apply Newton's Second Law will be as follows:

$$m\ddot{x}(t) = -k_1x(t) + k_1R\theta_1(t) - k_2x(t) + k_2R\theta_2(t) - F_m \tag{3.2}$$

$$m\ddot{x}(t) = -k_1\big(x(t) - R\theta_1(t)\big) - k_2\big(x(t) - R\theta_2(t)\big) - F_m \quad (3.3)$$

$$\theta_1 = \frac{x_1}{R} \quad (3.4)$$

$$\theta_2 = \frac{X_2}{R} \quad (3.5)$$

$$m\ddot{x}(t) + F_m = -k_1\big(x(t) - x_1(t)\big) - k_2(x(t) - x_2(t)) \quad (3.6)$$

2) Driving pulley

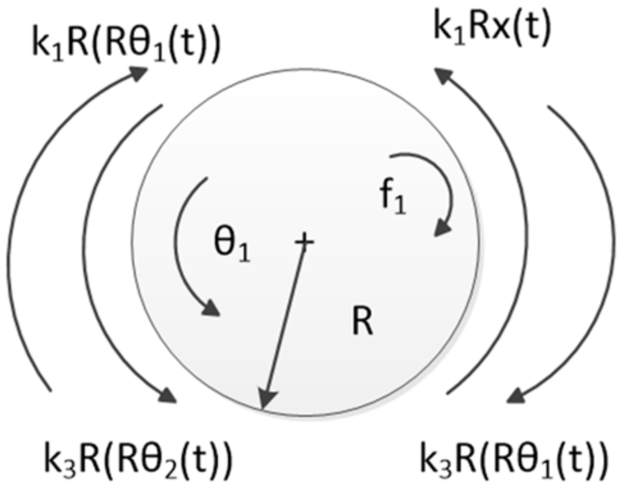



**Figure 3.4:** Moments on the driving pulley

According to Newton's Second Law:

$$\sum M = J\ddot{\theta} \quad (3.7)$$

Where:

M: Moment on pulley

J: Moment of inertia of pulley

$\ddot{\theta}$: Angular acceleration of pulley

As for the driving pulley, we note that the forces affecting it is the forces of the springs, $k_1$ and $k_3$ and the forces of the reaction resulting from the tension of materials on the conveyor and the effect of the driven pulley on it.

When the pulley moves in the direction shown in Figure (3.4), which is counterclockwise, the spring $k_3$ in a compression mode, leading to a reaction to reverse the direction of the pulley as shown in Figure (3.4).

For spring $k_1$ is in tension mode, which means the reaction force will be in reverse direction of the pulley as shown in Figure (3.4).

The other force is the tension force of objects on a conveyor, which mean the conveyor tightening the driving pulley, leading to a reaction to forward direction of the pulley.

For effect of the driven pulley on the driving pulley, it too tension force, leading to a reaction to forward direction of the pulley.

When applying Newton's Second Law will be as follows:

$$(J_1 + J_m)\ddot{\theta_1}(t) = -k_1R\big(R\theta_1(t)\big) + k_1Rx(t) - k_3R\big(R\theta_1(t)\big) + k_3R\big(R\theta_2(t)\big) - f_1 + T_m \quad (3.8)$$

$$(J_1 + J_m)\ddot{\theta_1}(t) = -k_1R(R\theta_1(t) - x(t)) - k_3R(R\theta_1(t) - R\theta_2(t)) - f_1 + T_m \quad (3.9)$$

$$(J_1 + J_m)\ddot{\theta_1}(t) + f_1 = -k_1R(R\theta_1(t) - x(t)) - k_3R(R\theta_1(t) - R\theta_2(t)) + T_m \quad (3.10)$$

$$\frac{(J_1+J_m)}{R}\ddot{x_1}(t) + f_1 = -k_1R(x_1(t) - x(t)) - k_3R(x_1(t) - x_2(t)) + T_m \quad (3.11)$$

3) Driven pulley

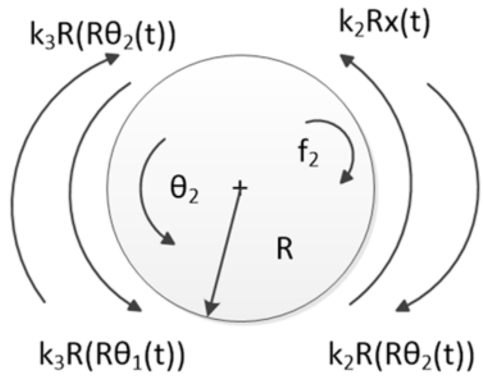



**Figure 3.5:** Moments on the driven pulley

The spring $k_3$ in a tension mode, and the spring $k_2$ in a compression mode, leading to a reaction to reverse the direction of the driven pulley.

The other forces are the tension force of objects on conveyor and effect of the driving pulley on driven pulley, leading to a reaction to forward direction of the driven pulley as shown in Figure (3.5).

When applying Newton's Second Law will be as follows:

$$J_2\ddot{\theta_2}(t) = -k_2R\big(R\theta_2(t)\big) + k_2Rx(t) - k_3R\big(R\theta_2(t)\big) + k_3R\big(R\theta_1(t)\big) - f_2 \quad (3.12)$$

$$J_2\ddot{\theta_2}(t) = -k_2R(R\theta_2(t) - x(t)) - k_3R(R\theta_2(t) - R\theta_1(t)) - f_2 \quad (3.13)$$

$$J_2\ddot{\theta_2}(t) + f_2 = -k_2R(R\theta_2(t) - x(t)) - k_3R(R\theta_2(t) - R\theta_1(t)) \quad (3.14)$$

$$\frac{(J2)}{R}\ddot{x_2}(t) + f_2 = -k_2R(R\theta_2(t) - x(t)) - k_3R(x_2(t) - x_1(t)) \quad (3.15)$$

## 3.2 State space model:

The state space representation of a system replaces an nth order differential equation with a single first-order matrix differential equation.

The state space representation of a system is given by two equations:

$$\dot{X}(t) = AX + BU(t) + NV(t) \quad (3.16)$$

$$Y(t) = CX(t) + DU(t) \quad (3.17)$$

Where:

$\dot{X}$: Derivative of the state vector with respect to time

X: State vector

U: Input vector

$A$: System matrix

$B$: Input matrix

$C$: Output matrix

$D$: Feedforward matrix

N: Disturbance matrix

V: Disturbance vector

In the mechanical system, the distances are adopted as variables for the state. For the derivative of these distances for time (velocity), they are also variables of state.

$$z = x \quad (3.18)$$

$$z_1 = x_1 \quad (3.19)$$

$$z_2 = x_2 \quad (3.20)$$

Where:

z: state space distance variable for objects

$z_1$: state space distance variable for driving pulley

$z_2$: state space distance variable for driven pulley

$z_3 = \dot{x}$ (3.21)

$z_4 = \dot{x_1}$ (3.22)

$z_5 = \dot{x_2}$ (3.23)

Where:

$z_3$: state space velocity variable for objects

$z_4$: state space velocity variable for driving pulley

$z_5$: state space velocity variable for driven pulley

Based on Equations (3.6), (3.11), (3.15), state space equations will be:

$\dot{z} = \dot{x} = z_3$ (3.24)

$\dot{z_1} = \dot{x_1} = z_4$ (3.25)

$\dot{z_2} = \dot{x_2} = z_5$ (3.26)

Based on Equation (3.6)

$$m\ddot{x}(t) + F_m = -k_1\big(x(t) - x_1(t)\big) - k_2(x(t) - x_2(t))$$

$$\ddot{x}(t) = -\frac{k_1}{m}\big(x(t) - x_1(t)\big) - \frac{k_2}{m}\big(x(t) - x_2(t)\big) - \frac{F_m}{m}$$

(3.27)

$$\dot{z_3} = -\frac{k_1}{m}(z - z_1) - \frac{k_2}{m}(z - z_2) - \frac{F_m}{m} \quad (3.28)$$

Based on Equation (3.11)

$$\frac{(J_1 + J_m)}{R}\ddot{x}_1(t) + f_1 = -k_1R(x_1(t) - x(t)) - k_3R(x_1(t) - x_2(t)) + T_m$$

$$\ddot{x}_1 = \frac{-Rk_1R}{J_1+J_m}(x_1 - x) - \frac{Rk_3R}{J_1+J_m}(x_1 - x_2) + \frac{TmR}{J_1+J_m} - \frac{f_1R}{J_1+J_m} \quad (3.29)$$

$$\dot{z_4} = \frac{-R^2k_1}{J_1+J_m}(z_1 - z) - \frac{R^2}{J_1+J_m}(z_1 - z_2) + \frac{T_mR}{J_1+J_m} - \frac{f_1R}{J_1+J_m} \quad (3.30)$$

Based on Equation (3.15)

$$\frac{(J_2)}{R}\ddot{x}_2(t) + f_2 = -k_2R\big(R\theta_2(t) - x(t)\big) - k_3R\big(x_2(t) - x_1(t)\big)$$

$$\ddot{x}_2 = \frac{-Rk_2R}{J_2}(x_2 - x) - \frac{Rk_3R}{J_2}(x_2 - x_1) - \frac{f_2R}{J_2} \quad (3.31)$$

$$\dot{z}_5 = \frac{-R^2k_2}{J_2}(z_2 - z) - \frac{R^2k_3}{J_2}(z_2 - z_1) - \frac{f_2R}{J_2} \quad (3.32)$$

When we arrange these equations (2.28), (2.30), (2.32), will be as follow:

$$\dot{z}_3 = -\left(\frac{k_1+k_2}{m}\right)z - \frac{k_1}{m}z_1 + \frac{k_2}{m}z_2 - \frac{F_m}{m} \quad (3.33)$$

$$\dot{z}_4 = \frac{R^2k_1}{J_1+J_m}z - \frac{R^2(k_1+k_3)}{J_1+J_m}z_1 + \frac{k_3R^2}{J_1+J_m}z_2 + \frac{TmR}{J_1+J_m} - \frac{f_1R}{J_1+J_m} \quad (3.34)$$

$$\dot{z}_5 = \frac{R^2k_2}{J_2}z + \frac{R^2k_3}{J_2}z_1 - \frac{(k_2+k_3)R^2}{J_2}z_2 - \frac{f_2R}{J_2} \quad (3.35)$$

State space equations:

$$\begin{bmatrix}\dot{z}\\ \dot{z}_1\\ \dot{z}_2\\ \dot{z}_3\\ \dot{z}_4\\ \dot{z}_5\end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & 0 & 1\\ \frac{-(k_1+k_2)}{m} & \frac{k_1}{m} & \frac{k_2}{m} & 0 & 0 & 0\\ \frac{k_1R^2}{J_1+J_m} & \frac{-(k_1+k_3)R^2}{J_1+J_m} & \frac{k_3R^2}{J_1+J_m} & 0 & 0 & 0\\ \frac{k_2R^2}{J_2} & \frac{k_3R^2}{J_2} & \frac{-(k_2+k_3)R^2}{J_2} & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}z\\ z_1\\ z_2\\ z_3\\ z_4\\ z_5\end{bmatrix} + \begin{bmatrix}0\\0\\0\\0\\1\\0\end{bmatrix}T_m + \begin{bmatrix}0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ \frac{-R}{J_1+J_m} & 0\\ 0 & \frac{-R}{J_2}\end{bmatrix}\begin{bmatrix}f_1\\ f_2\end{bmatrix}$$

(3.36)

$$\begin{bmatrix}x\\ x_1\\ x_2\end{bmatrix} = \begin{bmatrix}\frac{-(k_1+k_2)}{m} & \frac{k_1}{m} & \frac{k_2}{m} & 0 & 0 & 0\\ \frac{k_1R^2}{J_1+J_m} & \frac{-(k_1+k_3)R^2}{J_1+J_m} & \frac{k_3R^2}{J_1+J_m} & 0 & 0 & 0\\ \frac{k_2R^2}{J_2} & \frac{k_3R^2}{J_2} & \frac{-(k_2+k_3)R^2}{J_2} & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}z\\ z_1\\ z_2\\ z_3\\ z_4\\ z_5\end{bmatrix} + \begin{bmatrix}0\\1\\0\end{bmatrix}T_m \quad (3.37)$$

Where:

$$\dot{X}=\begin{bmatrix} \dot{z} \\ \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4 \\ \dot{z}_5 \end{bmatrix} \tag{3.38}$$

$$A=\begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ \frac{-(k_1+k_2)}{m} & \frac{k_1}{m} & \frac{k_2}{m} & 0 & 0 & 0 \\ \frac{k_1 R^2}{J_1+J_m} & \frac{-(k_1+k_3)R^2}{J_1+J_m} & \frac{k_3 R^2}{J_1+J_m} & 0 & 0 & 0 \\ \frac{k_2 R^2}{J_2} & \frac{k_3 R^2}{J_2} & \frac{-(k_2+k_3)R^2}{J_2} & 0 & 0 & 0 \end{bmatrix} \tag{3.39}$$

$$X=\begin{bmatrix} z \\ z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{bmatrix} \tag{3.40}$$

$$B=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} \tag{3.41}$$

$$U = Tm \tag{3.42}$$

$$N=\begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{-R}{J_1+J_m} & 0 \\ 0 & \frac{-R}{J_2} \end{bmatrix} \tag{3.43}$$

$$V=\begin{bmatrix} f1 \\ f2 \end{bmatrix} \tag{3.44}$$

$$Y=\begin{bmatrix} x \\ x_1 \\ x_2 \end{bmatrix} \tag{3.45}$$

$$C=\begin{bmatrix} \frac{-(k_1+k_2)}{m} & \frac{k_1}{m} & \frac{k_2}{m} & 0 & 0 & 0 \\ \frac{k_1R^2}{J_1+J_m} & \frac{-(k_1+k_3)R^2}{J_1+J_m} & \frac{k_3R^2}{J_1+J_m} & 0 & 0 & 0 \\ \frac{k_2R^2}{J_2} & \frac{k_3R^2}{J_2} & \frac{-(k_2+k_3)R^2}{J_2} & 0 & 0 & 0 \end{bmatrix} \tag{3.46}$$

$$D=\begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \tag{3.47}$$

# 4

# Chapter 4

## Mechanical Design

## 4.1 Material Hopper:

In the sorting process, the samples materials are supplied. The material hopper holds and supplies these samples. The materials then gravity fed from the hopper to the conveyor.

Before starting to design the hopper, we have to select appropriate material to create the hopper, and since our system depends on gravity force to feed materials to the conveyor, it was necessary to know the coefficient of friction between the hopper material and materials to be fed, because the coefficient of friction of the inclined surfaces depend on the angle by Equation 4.1.

$$\mu = \tan\theta \tag{4.1}$$

Where:

$\mu$: coefficient of friction

$\theta$: angle of inclined surfaces

After checking the friction coefficient between the materials, especially the materials to be separated shown in Table 4.1[17], it was selected that the material of the hopper will make of plastic, and the angle of inclined surfaces will be 20 degrees.

**Table 4.1:** The coefficient of friction between materials

| Material#1 | Material#2 | The coefficient of friction | The angle of the inclined surface |
|---|---|---|---|
| steel | aluminum | 0.47 | 25° |
| steel | plastic | 0.3 | 17° |
| steel | steel | 0.57 | 30° |
| aluminum | aluminum | 1.4 | 55° |
| aluminum | plastic | 0.3 | 17° |
| Plastic | plastic | 0.4 | 22° |

As stated in chapter 1, the maximum size (5cm×5cm×5cm), and the minimum size (2cm×2cm×2cm) was selected. We developed two different design of the material hopper and we will introduce these design in this section.

**First prototype**

Figure 4.1 represents the full hopper system designed using CATIA software.

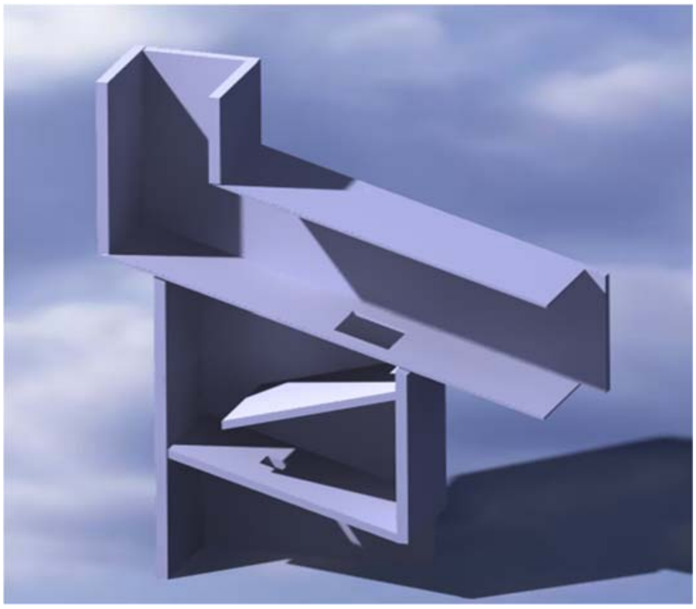


**Figure 4.1:** Full hopper system first prototype design

Figure 4.2 shows the model that we have done, to experiment the process of material transmission across the system.

**Figure 4.2:** Hopper first prototype implementation

**Second prototype**

Figure 4.3 represents full hopper system designed using CATIA software.

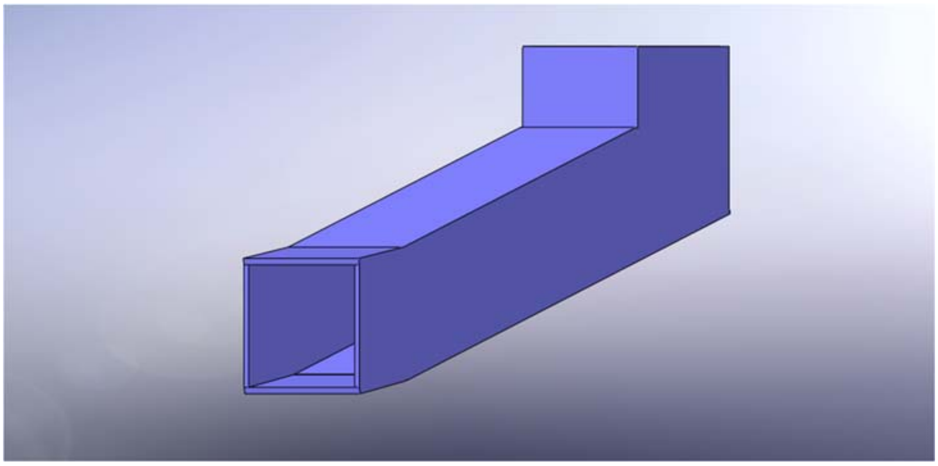


**Figure 4.3:** Second prototype full hopper system design

## 4.2 Calculating the Torque of the Conveyor

Table 4.2 represents the main mechanical properties of the conveyor belt and some mechanical coefficients [17].

**Table 4.2** Mechanical Properties:

| **Properties** | **Value** |
|---|---|
| Steel density | 8000 Kg/$m^3$ |
| Belt density | 1200 Kg/$m^3$ |
| Belt thickness | 0.005 m |
| Belt width | 0.2 m |
| The diameter of the pulley | 0.058 m |
| Friction coefficient μ | 0.35 |

Belts and other similar elastic or flexible machine elements are used in conveying systems and in the transmission of power over comparatively long distances. Because of its inherent advantage that it can absorb a good amount of shock and vibration. It can take care of some degree of misalignment between the driven and the driver machines. Figure 4.4 shows a flat belt geometry

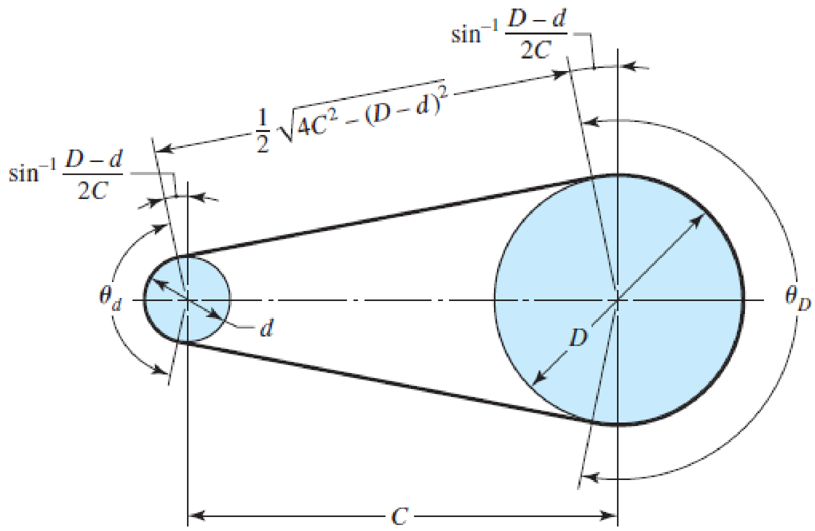



**Figure 4.4**: Flat-belt geometry.

The angle of contact in the driven and driver roller Eq. 4.1 and Eq. 4.2.

$$\theta_d = \pi - 2\sin^{-1}\frac{D-d}{2C} \tag{4.2}$$

$= \pi$

$$\theta_D = \pi - 2\sin^{-1}\frac{D-d}{2C} \tag{4.3}$$

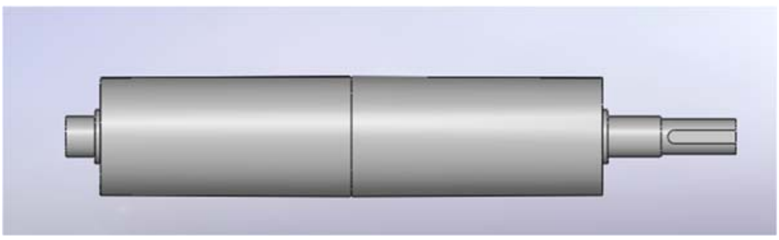
$= \pi$

The length of the belt is found by summing the two arc lengths with twice the distance between the beginning and end of the contact. The result is

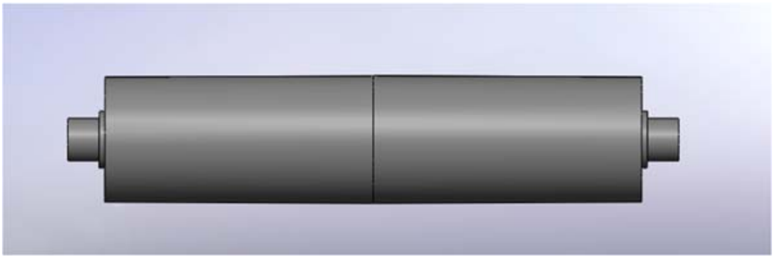
$$L = \sqrt{4C^2 - (D-d)^2} + 0.5(D\theta_D + d\theta_d) \tag{4.4}$$

$= \sqrt{41^2 - (0.058 - 0.58)^2} + 0.5(0.058 * \pi + 0.058 * \pi)$

$= 2.18$ m



(a) Driver pulley



(b) Driven pulley

**Figure 4.5:** Driver and Driven pulleys

Where:

*D*: diameter of the large pulley

*d*: diameter of the small pulley

*C*: center distance

Ɵ: angle of contact

L: total length of the conveyor belt (m)

The area of the belt = L × W (4.5)

= 2.18×0.2

= 0.436 $m^2$

The Volume of the belt = thickness × Area (4.6)

=0.005 × 0.436

= 2.18 × $10^{-3}$ $m^3$

The Mass of the belt = ρ × V (4.7)

= 1200 × 2.18 × $10^{-3}$

=2.616 kg

We suppose that the belt will carry ten pieces of steel with following dimensions (0.05, 0.05, and 0.05) m

Volume of one piece = length × width × height (4.8)

=0.05 × 0.05 × 0.05

=1.25 × $10^{-3}$ $m^3$

Mass of object = 10 × $\rho_{steel}$ × Volume of one piece (4.9)

=10 × 8000 × 1.25 × $10^{-3}$

=10 kg

The total mass (M) = Mass of the belt + Mass object

= 2.616 + 10 =12.616 kg

The force produce from this mass F = M × g (4.10)

= 12.616 × 9.81 = 123.76 N

The friction force $F_f = F \times \mu$ (4.11)

=123.76 × 0.35

=43.32 N

Figure 4.6 shows the free body diagram of the force that the motor is effect by.

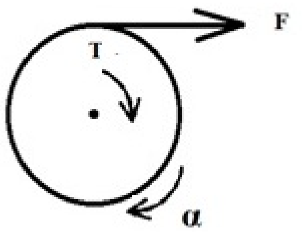



**Figure 4.6:** Free body diagram of the force affect the motor

The belt motor torque found by substitution in Newton's second law:

$\Sigma M_o = J_o \ddot{\theta}$ (4.12)

$T - F_f \times r - C_t \dot{\theta} = J_o \ddot{\theta}$

$T = J_o \ddot{\theta} + C_t \dot{\theta} + F_f . r$

$\alpha = \ddot{\theta}$

Now we have to calculate the mass moment of inertia

$J_o = \frac{1}{2} m_{equivalent} \times r^2$ (4.13)

$T = \frac{1}{2} m_{equivalent} \times r^2 \alpha + C_t \omega + F_f . r$

Maximum speed =0.05 m/s

$\omega = \frac{speed}{r} = \frac{0.05}{0.029} = 1.72\, rad/s$ (4.14)

$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega_2 - \omega_1}{t_2 - t_1}$ (4.15)

$\omega_2 = 1.72$ rad/s

$t_2$ = 0.5 sec

α= 3.44 rad/s$^2$

$m_{equivalent} = m_{belt} + 2m_{pulley} + m_{object}$

$m_{pulley}$ = $\rho_{steel} \times area\ of\ the\ pulley \times length\ of\ the\ pulley$

= 8000 × $0.029^2 \times \pi \times 0.2$

= 4.23 kg

Mass moment of inertia $J_o = m_{equivalent} \times 0.029$

= 0.0177 kg/m$^2$

T= $J_o\ddot{\theta}$+$C_t\dot{\theta}$ + $F_f$.r

The value of the bearing friction ( $C_t$ ) is taken from the Table 4.3 [17].

**Table 4.3**: Bearing coefficient factor ( $C_t$ )

| Bearing type | Friction factor $\mu \times 10^{-3}$ |
|---|---|
| Deep groove ball bearings | 1.0~1.5 |
| Angular contact ball bearings | 1.2~1.8 |
| Self-aligning ball bearings | 0.8~1.2 |
| Cylindrical roller bearings | 1.0~1.5 |
| Needle roller bearings | 2.0~3.0 |
| Tapered roller bearings | 1.7~2.5 |
| Self-aligning roller bearings | 2.0~2.5 |
| Thrust ball bearings | 1.0~1.5 |
| Thrust roller bearings | 2.0~3.0 |

= (0.0177 × 3.44) +4 × (1.5 × $10^{-3}$ × 1.72) + (43.32 × 0.029)

= 1.33 N.m

## 4.3 Calculating the Power of the Motor

After calculating the required torque of the conveyor motor we can now calculate the required power by equation 4.16

$$P_{out} = w.T \tag{4.16}$$

= 2.2876 watts

Where:

V: Volume($m^3$).

A: Area ($m^2$)

M: mass (kg)

ρ: density of stainless steel (Kg/$m^3$)

$C_t$ : Bearing coefficient factor

μ: Friction coefficient

$J_o$: Mass moment of inertia

α: Angular acceleration

$\omega$: Angular velocity

## 4.4 Bearing Design

In this section, we will choose appropriate bearing. Figure 4.7 illustrates the main part of the ball bearing.

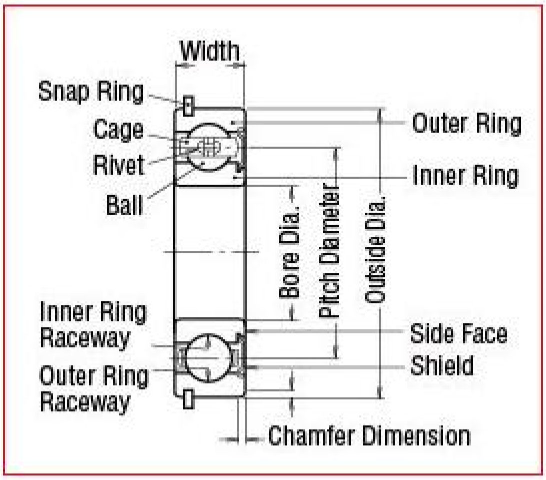



**Figure 4.7:** The main part of the ball bearing

We have to compute the forces by applying these equations

$F_x$= ma (4.17)

$F_y$=0 (4.18)

By applying Eqs. (4.17/18)

$F_x = 10 \times 118.62$

= 1186.2 N

$F_y = Total\ mass \times g$

= 123.76 N

The resultant radial force $F_r = \sqrt{F_x{}^2 + F_y{}^2} = \sqrt{(1186.2)^2 + (123.76)^2}$

= 1192.64 N

Now the desired radial load $F_D = F_r$ = 1192.64 N

We have to calculate catalog load rating (dynamic load rating) $C_{10}$

$$C_{10} = F_D(\frac{L_D}{L_R})^{\frac{1}{a}} = F_D(\frac{L_D n_D * 60}{10^6})^{\frac{1}{a}} \quad (4.19)$$

Where:

$L_D$ : $desired\ life, hours$

$n_D$ : Desired speed, rev/min

a: Load factor

**Table 4.4:** load application factor

| Type of Application | Load Factor |
|---|---|
| Precision gearing | 1.0–1.1 |
| Commercial gearing | 1.1–1.3 |
| Applications with poor bearing seals | 1.2 |
| Machinery with no impact | 1.0–1.2 |
| Machinery with light impact | 1.2–1.5 |
| Machinery with moderate impact | 1.5–3.0 |

**Table 4.5:** Bearing-life recommendations

| Type of Application | Life, kh |
|---|---|
| Instruments and apparatus for infrequent use | Up to 0.5 |
| Aircraft engines | 0.5–2 |
| Machines for short or intermittent operation where service interruption is of minor importance | 4–8 |
| Machines for intermittent service where reliable operation is of great importance | 8–14 |
| Machines for 8-h service that are not always fully utilized | 14–20 |
| Machines for 8-h service that are fully utilized | 20–30 |
| Machines for continuous 24-h service | 50–60 |
| Machines for continuous 24-h service where reliability is of extreme importance | 100–200 |

From Table 4.4 [17], a=0.7

And from Table 4.5 [17], $L_D = 30\ Kh$

$$C_{10} = 1.192\left(\frac{30000 * 16.42 * 60}{10^6}\right)^{0.7} = 12.756\ KN$$

**Table 4.6:** Dimensions for single-row 02-series deep-groove and angular-contact ball bearings

Dimensions and Load Ratings for Single-Row 02-Series Deep-Groove and Angular-Contact Ball Bearings

| Bore, mm | OD, mm | Width, mm | Fillet Radius, mm | Shoulder Diameter, mm | | Load Ratings, kN | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Deep Groove | | Angular Contact | |
| | | | | $d_S$ | $d_H$ | $C_{10}$ | $C_0$ | $C_{10}$ | $C_0$ |
| 10 | 30 | 9 | 0.6 | 12.5 | 27 | 5.07 | 2.24 | 4.94 | 2.12 |
| 12 | 32 | 10 | 0.6 | 14.5 | 28 | 6.89 | 3.10 | 7.02 | 3.05 |
| 15 | 35 | 11 | 0.6 | 17.5 | 31 | 7.80 | 3.55 | 8.06 | 3.65 |
| 17 | 40 | 12 | 0.6 | 19.5 | 34 | 9.56 | 4.50 | 9.95 | 4.75 |
| 20 | 47 | 14 | 1.0 | 25 | 41 | 12.7 | 6.20 | 13.3 | 6.55 |
| 25 | 52 | 15 | 1.0 | 30 | 47 | 14.0 | 6.95 | 14.8 | 7.65 |
| 30 | 62 | 16 | 1.0 | 35 | 55 | 19.5 | 10.0 | 20.3 | 11.0 |
| 35 | 72 | 17 | 1.0 | 41 | 65 | 25.5 | 13.7 | 27.0 | 15.0 |

From Table 4.6 [17], we choose a bearing with the following specification

Bore = 20 mm, OD = 47 mm and width = 14 mm

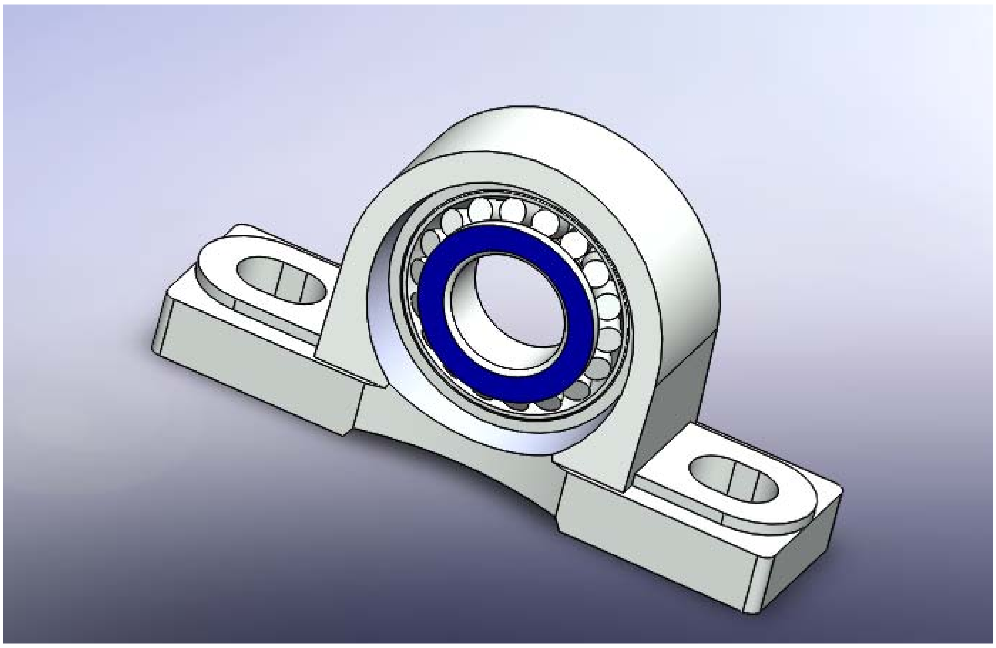


**Figure 4.8:** Block bearings - bearing house

The following Figures show our conveyor Figure 4.9, Top view Figure 4.10 and all dimensions shown are in mm.

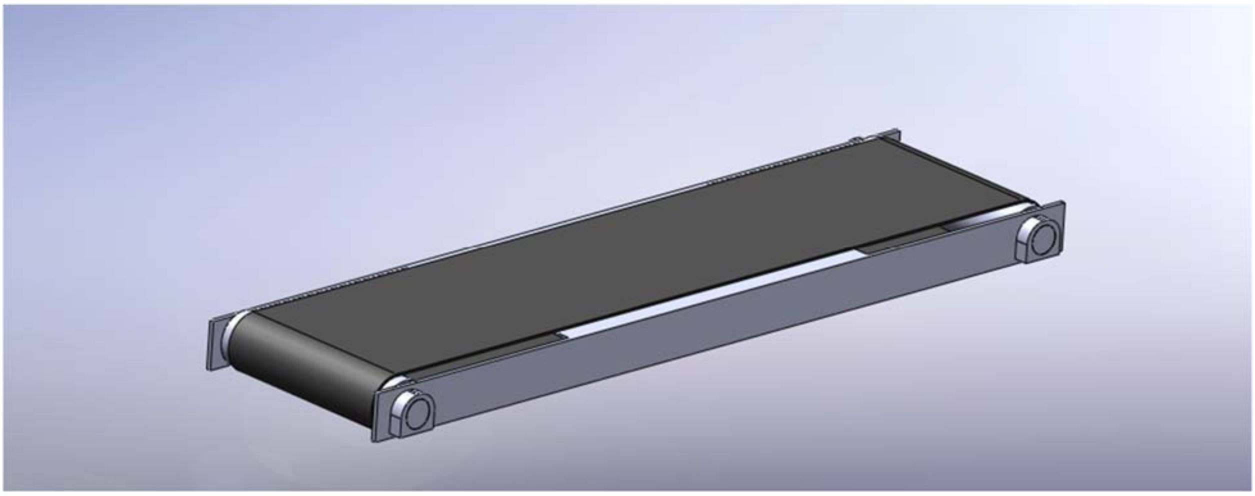


**Figure 4.9:** Conveyor

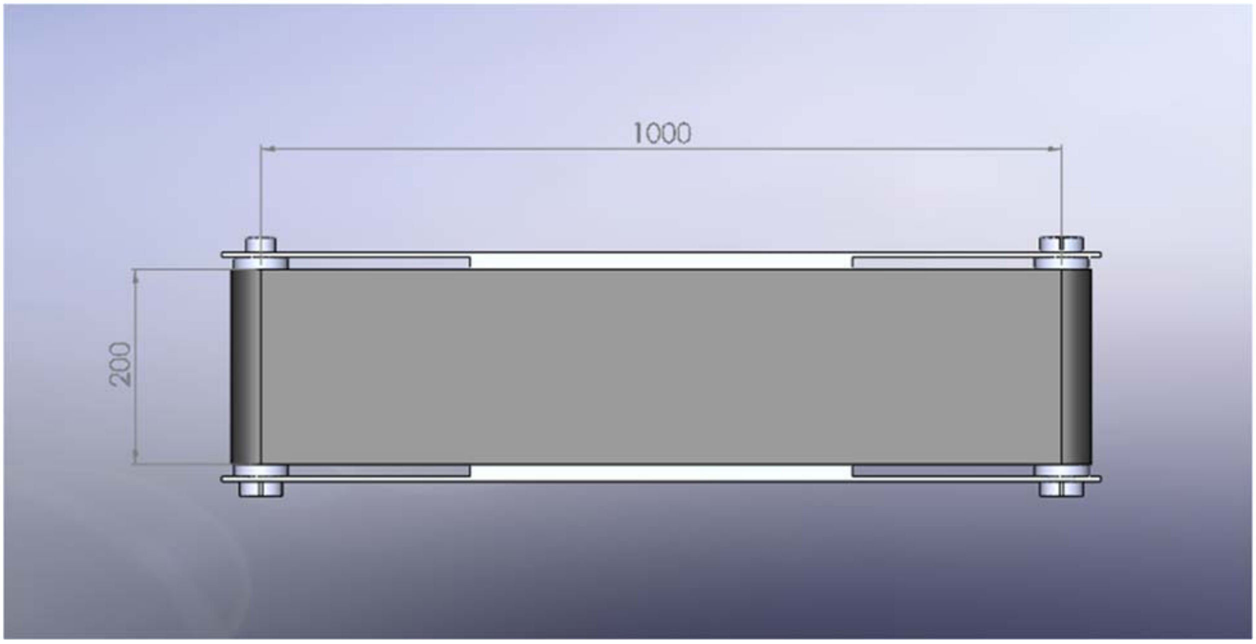



**Figure 4.10:** Top view

# 5

# Chapter 5

# Electrical and Pneumatic Design

## 5.1 Introduction

In this chapter, we will select a motor. Protection circuits will be selected and pneumatic calculations will be done.

## 5.2 Motors Sizing

From chapter 4 the required torque for the conveyor T=1.33 N.m and the power is

P =2.2876 watts, so we choose an AC motor with the following specification

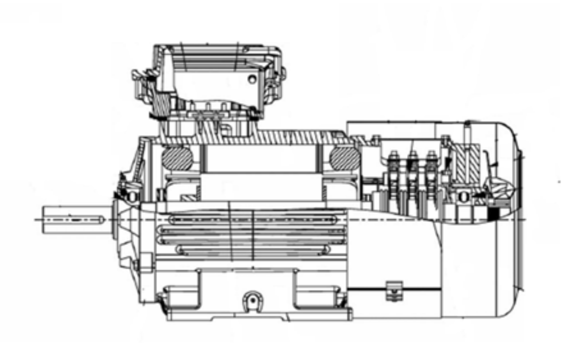


**Figure 5.1:** Induction motor

**Table 5.1**: Motors nameplates

| **Name** | **Torque** | **Power** | **V** | **A** | **Rpm** |
|---|---|---|---|---|---|
| **Conveyor Motor** | 2 N.m | 370 watt | 250V/AC | 1.9 A | 1430 |

## 5.3 Protection Circuit Sizing

**Conveyor motor protection circuit**

- Overload [18].

  OL = In = 1.9 A (5.1)

- MCB (Main Circuit Breaker) [18].

  MCB = 1.25In = 2.375 A (5.2)

Table 5.2 shows the selected components ratings.

**Table 5.2:** Selected protection components ratings

| Name | Overload size | MCB size |
|---|---|---|
| **Conveyor Motor** | 1.9 A | 2.375 A |

**5.4 Pneumatic calculations:**

Since the system contains three air pistons, the dimensions of these pistons had to be calculated. These dimensions are calculated by the following equation:

$$F = P \times A \tag{5.3}$$

Where:

F=Force

P=Pressure=0.5 N/mm$^2$

A= Cross section area of the piston rod

According to Newton's second law, force can be calculated by the following equation:

$$F = m \times a \tag{5.4}$$

Where:

F= Resultant Force

m=Mass of piece=1Kg

a=Acceleration

Since acceleration is unknown, it is calculated using Newton's laws of motion, according to the following equation:

$$d = v_0 \times t + \frac{1}{2} \times a \times t^2 \tag{5.5}$$

Where:

d: Distance

v: Velocity

t: Time =0.5 second

a: Acceleration

$$0.2 = 0 + \frac{1}{2} \times a \times (0.5)^2$$

$$a = 1.6\, m/sec^2$$

The friction force is calculated based on the following equation:

$$F_f = \mu \times N \tag{5.6}$$

Where:

$F_F$: friction force

$\mu$: Friction coefficient = 0.4

N: normal force=10 N

$$F_f = 4\ N$$

Based on equation (5.4):

$$F = (1 \times 1.6) + 4$$

$$F = 5.6\ N$$

Based on equation (5.3):

$$A = \frac{F}{P}$$

$$A = \frac{5.6}{0.5} \cong 12mm^2$$

The piston diameter is calculated by the following equation:

$$A = \frac{\pi}{4} \times d^2 \tag{5.7}$$

$$d = 4mm$$

Since the width of the conveyor is 20 cm, the length of the piston is 20 cm.

# 6

# Chapter 6

# Control Design

## 6.1 Programmable Logic Control (PLC)

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 and then uses relays, timers, and counters to implement logic and drive outputs by energizing the output coil of some sort of valve or another actuator.

## 6.2 PLC Input-Output table

Table 6.1 shows the PLC I/O's.

**Table 6.1:** PLC I/O's

| Identifiers | Function | Address |
|---|---|---|
| | **Inputs** | |
| **Emergency** | **Emergency Switch** | **X2** |
| **Stop_1** | **Stop PB** | **X1** |
| **Start** | **Start PB** | **X4** |
| **Magnetic** | **Magnetic Sensor** | **X5** |
| **Inductive** | **Inductive Sensor** | **X6** |
| **Speed_2** | **Speed 2** | **X3** |
| **Speed_3** | **Speed 3** | **X0** |
| | **Outputs** | |
| **Speed_2_out** | **Speed 2** | **Y1** |
| **Speed_3_out** | **Speed 3** | **Y5** |
| **Piston_1** | **Solenoid Valve (steel cylinder)** | **Y2** |
| **Piston_2** | **Solenoid Valve (aluminium cylinder)** | **Y3** |
| **Piston_3** | **Solenoid Valve (feeding cylinder)** | **Y6** |
| **Conveyor** | **Conveyor Motor** | **Y0** |
| **Vibrator** | **Vibrator Motor** | **Y7** |

## 6.3 PLC Control Circuit

Figure 6.1 shows PLC control circuit for our machine.

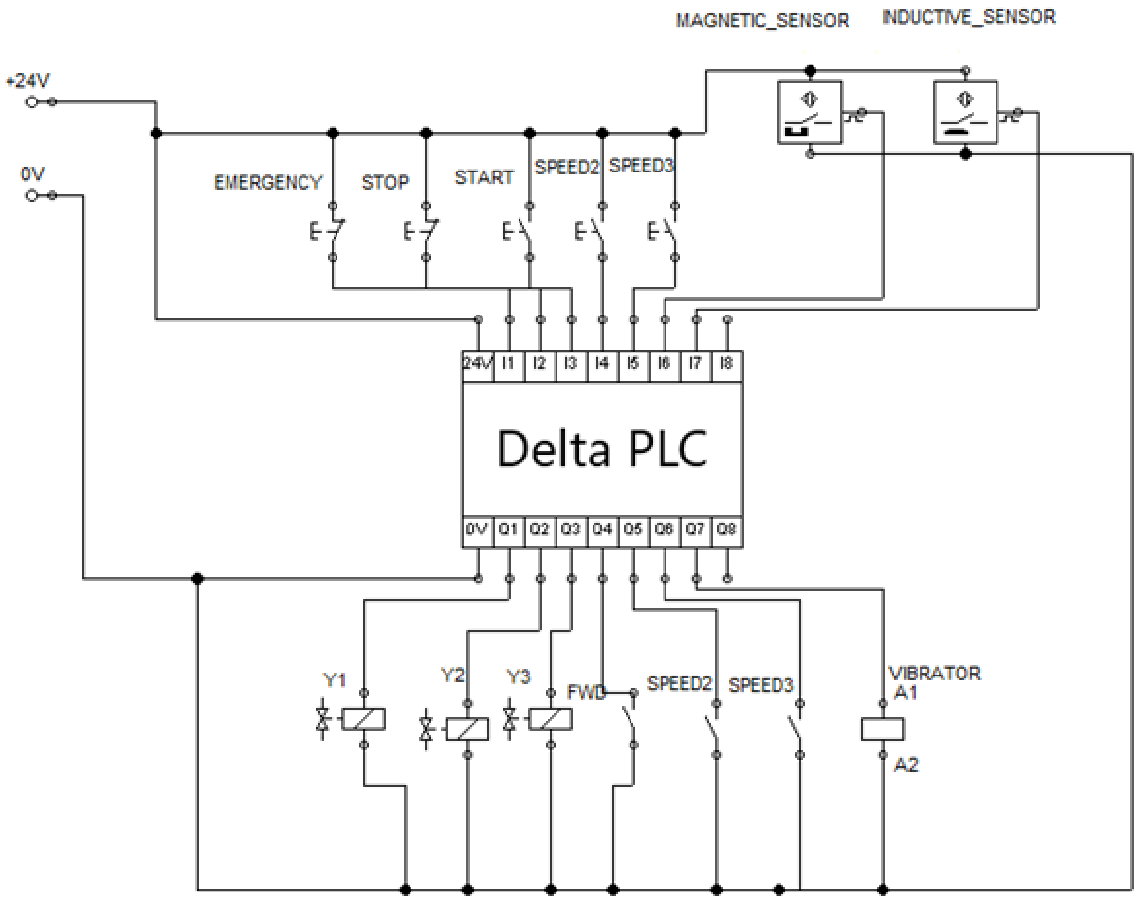



**Figure 6.1:** PLC Control circuit

## 6.4 Pneumatic Power Circuit

Figure 6.2 shows pneumatic power circuit.

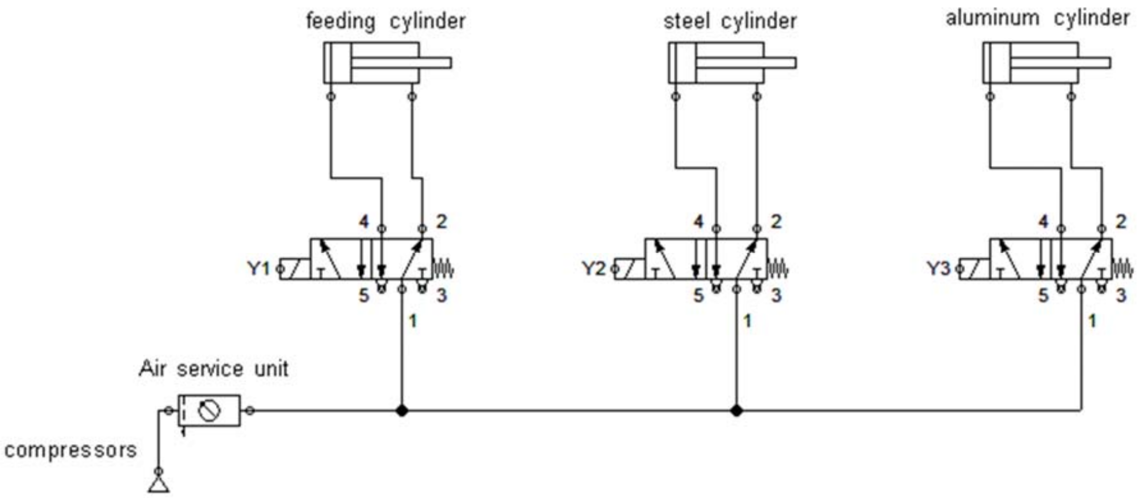



**Figure 6.2:** Pneumatic power circuit

# 7

# Chapter 7

## Implementation and Results

**7.1 Introduction**

**7.2 Implementation**

**7.3 Results**

**7.4 Recommendations**

### 7.1 Introduction

This chapter provides work implementation, experimental result and some recommendations from work we learned. We listed some goals hope to be accomplished or to be considered for the future project.

### 7.2 Implementation

This section provides work implementation, which is divided into four subsystems:

#### 7.2.1 Mechanical System:

The implementation of the mechanical system of our project is divided into:

(A) Conveyor:

According to Chapter 4, after mechanical calculations of the conveyor belt, we purchased used parts for the conveyor belt, due to the high cost in case it is fully manufactured, we also manufactured a number of bases for the conveyor belt, and then we assembled it to be ready for movement. See Figure 7.1

(a)

(b)

(c) (d)

**Figure 7.1:** Conveyor System Parts

(B) Hopper:

According to the mechanical design of the hopper in chapter 4, the hopper was designed using CATIA program, we purchased a plastic board, and cut the required pieces using CNC machine, and then the pieces were assembled and obtained the final form of the hopper. See Figure7.2

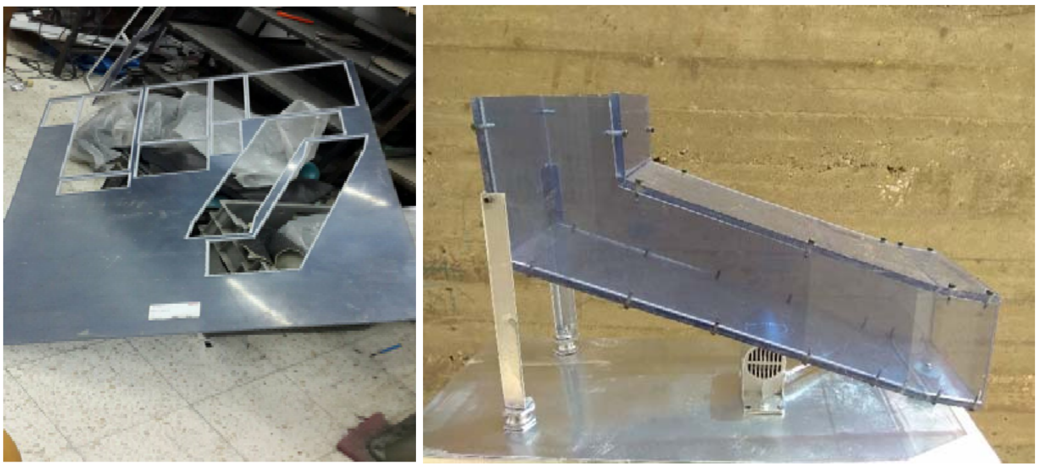


**Figure 7.2:** Hopper System Parts

### 7.2.2 Electrical System:

The implementation of the electrical system of our project is divided into:

(A) Motors:

According to the calculations of motor selecting in Chapter 4, due to the high price of the new motor, we purchased a used motor, which is a 3 phase induction motor with gearbox, with the power of 0.5 hp. We run it and make sure that it works properly. See Figure 7.3

**Figure 7.3:** 3-Phase IM

We also purchased a vibrator motor, which makes it easy to drop material inside the hopper so that the material does not hang inside the hopper. We run it and make sure it works properly. See Figure 7.4

**Figure 7.4:** Vibrator motor

(B) Variable frequency drive(VFD):

According to chapter 1, we will run the system at three different speeds, so we needed a VFD, which works of controlling speed for AC motor, so we purchased a used FUJI VFD, with power 1hp. We run it and make sure it works properly. See Figure 7.5

The Fuji Electric-General-Purpose Inverter FVR-C11S-7EN Series datasheet is attached in Appendix B.


**Figure 7.5:** VFD

(C) PLC

In accordance with Chapter 2, we purchased the system's main controller, Delta PLC, which has 8 inputs and 8 outputs, and we run and check it. See Figure 7.6

The PLC DELTA-DVP16ES2 datasheet is attached in Appendix A.


**Figure 7.6:** Delta PLC

(D) Sensors

Since the sorting process is done only by the presence of sensors, and because they are not available in the country, we bought them from Germany through Jordan, and after the arrival of sensors, we checked them and ensure their work properly. See Figure 7.7

The IFM Sensors datasheet is attached in Appendix B.

**Figure 7.7:** Magnetic and Inductive sensor

(E) Electrical Board

Since the system contains a number of electrical devices had to be an electric board, these devices are placed inside it to preserve and protect, containing the circuit protection system (overload, circuit breaker), See Figure 7.8

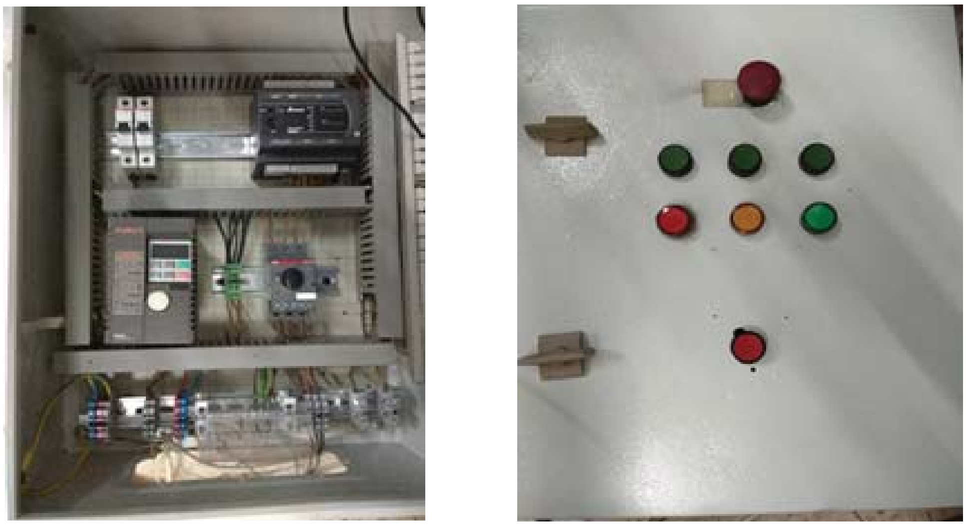


**Figure 7.8:** Electric Board

### 7.2.3 Pneumatic system

The implement works of the pneumatic system of our project are divided into:

(A) Double Acting Cylinder:

Since the system needs 3 pistons, and according to the pneumatic calculations in Chapter 5, we purchased the required pistons. See Figure 7.9

**Figure 7.9:** Double acting cylinder

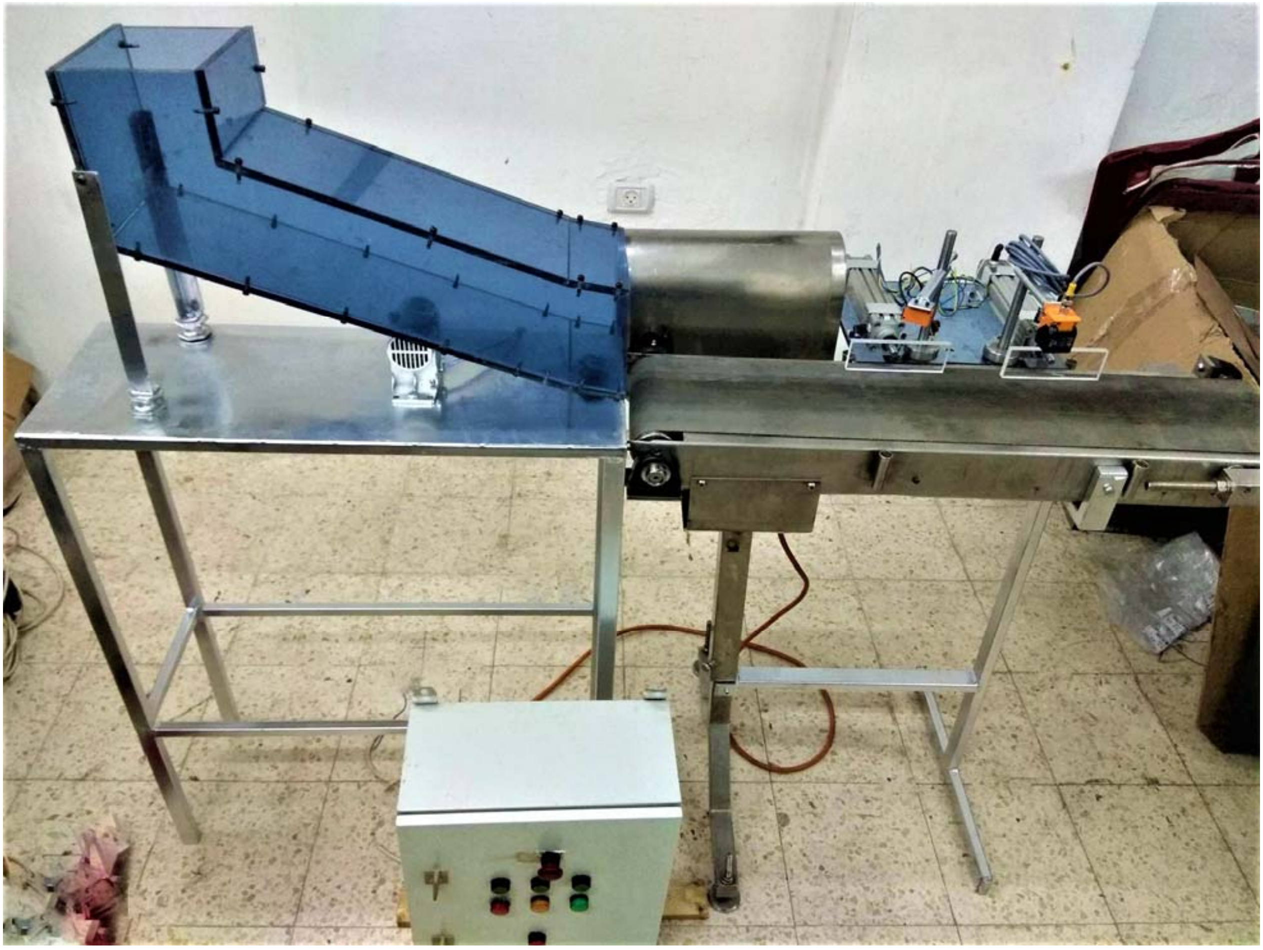
(B) Solenoid Valve:

Since the control of the pistons will be via PLC, so we need to Solenoid Valve. See Figure 7.10

**Figure 7.10:** Solenoid valve

### 7.2.4 Overall System

After we purchased all the parts needed for the project, we began to assemble the project, connect parts with each other, connect the electrical circuits inside the electric board, and the programming of the controller (PLC), began operation and the results. See Figure 7.11



(a)

(b)

**Figure 7.11: Overall system**

## 7.3 Result

The speed of the conveyor was controlled using a variable frequency driver (VFD), the PLC was programmed and the sorting process was run at three speeds. The high speed sorted 18 pieces, the moderate speed sorted 15 pieces, and the process of sorting during low speed did not work properly.

## 7.4 Recommendations:

For the project outlook, it must be considered that adding modification for the same machine it's recommended the following:

1. Adding human machine interface (HMI) to the machine to control and monitor the process.
2. Adding load cell to identify weight for a certain material.
3. Add more sensors to the machine to cover more area and sort larger part.

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# Appendix A

## "Delta PLC User Manual"

2011-04-12
5011685804-E204

DELTA ELECTRONICS, INC.

# DVP-ES2
# INSTRUCTION SHEET
# 安裝說明
# 安装说明

▲ ***Programmable Logic Controller***

▲ 可程式控制器

▲ 可编程控制器

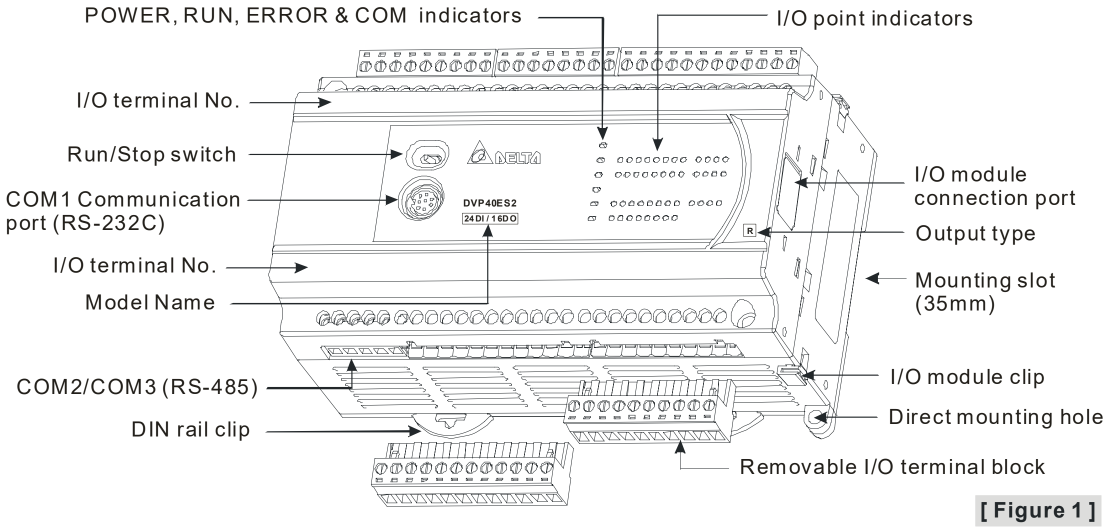
http://www.delta.com.tw/industrialautomation

DVP-1130070-02

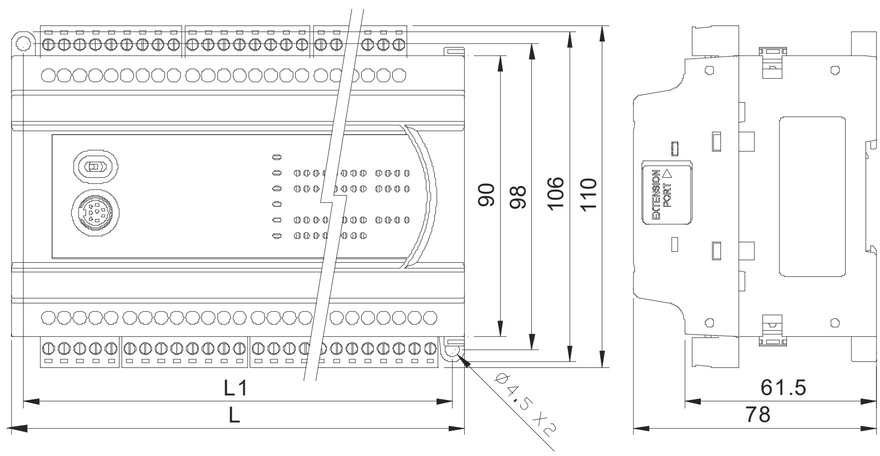
Thank you for choosing Delta's DVP-ES2 series PLC. DVP-ES2 series provides 16~ 60 points MPU and 8 ~ 32 points digital I/O module. The maximum I/O points including those on the MPU are 256 points. DVP-ES2 can be used for various applications with different I/O points, power supply, digital I/O and analog I/O modules.

- This instruction sheet provides only information on the electrical specification, general functions, installation and wiring. For detailed program design and applicable instructions for DVP-ES2, please refer to "DVP-ES2 Operation Manual: Programming". For details on the optional peripheral, please refer to the instruction sheet enclosed in the package.
- DVP-ES2 series PLC is an OPEN TYPE device and therefore should be installed in an enclosure free of airborne dust, humidity, electric shock and vibration. The enclosure should prevent non-maintenance staff from operating the device (e.g. key or specific tools are required for operating the enclosure) in case danger and damage on the device may occur.
- DO NOT connect the input AC power supply to any of the I/O terminals; otherwise serious damage may occur. Check all the wiring again before switching on the power. Make sure the ground terminal ⏚ is correctly grounded in order to prevent electromagnetic interference.

## ■ Product Profile & Dimension




**[ Figure 1 ]**




**[ Figure 2 ]**

Unit: mm

| Model name | 16ES2 00R/T | 24ES2 00R/T | 32ES2 00R/T | 40ES2 00R/T | 60ES2 00R/T | 20EX2 00R/T | 32ES2 11T |
|---|---|---|---|---|---|---|---|
| L | 105 | 125 | 145 | 165 | 225 | 145 | 145 |
| L1 | 97 | 117 | 137 | 157 | 217 | 137 | 137 |

## ■ Electrical Specifications

| Item \ Model | | 16ES2 00□ | 24ES2 00□ | 32ES2 00□ | 40ES2 00□ | 60ES2 00□ | 20EX2 00□ | 32ES2 11T |
|---|---|---|---|---|---|---|---|---|
| Power supply voltage | | 100 ~ 240VAC (-15% ~ 10%), 50/60Hz ±5% | | | | | | 24VDC (-15~+20%) |
| Connector | | European standard removable terminal block (Pin pitch: 5mm) | | | | | | |
| Operation | ES 200 | DVP-ES2 starts to run when the power rises to 95 ~ 100VAC and stops when the power drops to 70VAC. If the power is suddenly cut off, the MPU will continue running for 10ms. | | | | | | |
| | ES 211 | DVP-ES2 starts to run when the power rises to 20.4VDC~28.8VDC and stops when the power drops to 17.5VDC. If the power is suddenly cut off, the MPU will continue running for 10ms. | | | | | | |
| Power supply fuse | | 2A/250VAC | | | | | | 2.5A / 30VDC, Polyswitch |
| Power consumption | | 30VA | 30VA | 30VA | 30VA | 30VA | 30VA | 1.8W |
| DC24V current output | | 500mA | 500mA | 500mA | 500mA | 500mA | 500mA | – |
| Power supply protection | | DC24V output short circuit protection | | | | | | – |
| Voltage withstand | | 1,500VAC (Primary-secondary), 1,500VAC (Primary-PE), 500VAC (Secondary-PE) | | | | | | |
| Insulation resistance | | > 5MΩ at 500VDC (between all I/O points and ground) | | | | | | |
| Noise immunity | | ESD: 8KV Air Discharge<br>EFT: Power Line: 2KV, Digital I/O: 1KV, Analog & Communication I/O: 1KV<br>RS: 26MHz ~ 1GHz, 10V/m | | | | | | |
| Grounding | | The diameter of grounding wire shall not be less than that of L, N terminal of the power supply. (When many PLCs are in use at the same time, please make sure every PLC is properly grounded.) | | | | | | |
| Environment | | Operation: 0°C~55°C (temperature), 50~95% (humidity), pollution degree 2<br>Storage: -25°C~70°C (temperature), 5~95% (humidity) | | | | | | |
| Agency approvals | | UL508<br>European community EMC Directive 89/336/EEC and Low Voltage Directive 73/23/EEC | | | | | | |
| Vibration/shock immunity | | International standards: IEC61131-2, IEC 68-2-6 (TEST Fc)/ IEC61131-2 & IEC 68-2-27 (TEST Ea) | | | | | | |
| Weight | | R: 377g<br>T: 351g | R: 414g<br>T: 387g | R: 489g<br>T: 432g | R: 554g<br>T: 498g | R: 696g<br>T: 614g | R: 462g<br>T: 442g | T: 321g |

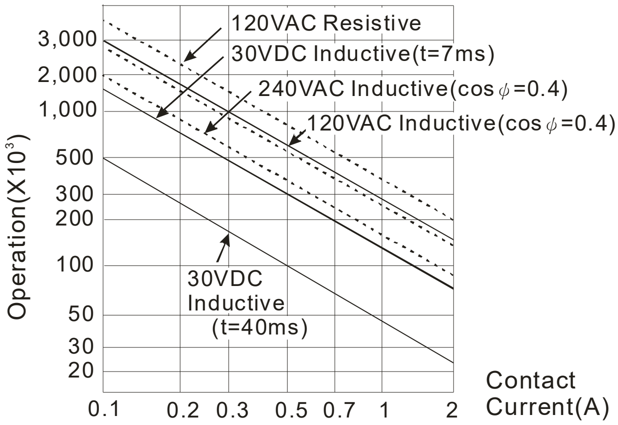
| Input Point | | | | |
|---|---|---|---|---|
| Input No. | ES200, EX200 | X0, X2 | X1, X3 ~ X7 | X10 ~ X17, X20 ~[#1] |
| | ES211 | X0 ~ X3 | X4 ~ X7 | |
| type | | Digital input | | |
| Input type | | DC (SINK or SOURCE) | | |
| Input current | | 24VDC, 5mA | | |
| Input impedance | | 4.7KΩ | | |
| Max. frequency | | 100kHz | 10kHz | 60Hz |
| Action level | Off → On | >15VDC | | |
| | On → Off | < 5VDC | | |
| Response time | Off → On | < 2.5μs | < 20μs | < 10ms |
| | On → Off | < 5μs | < 50μs | < 15ms |
| Filter time | X0 ~ X7 | Adjustable within 0 ~ 20ms in D1020 (Default: 10ms) | | |

| Output Point | | | | | |
|---|---|---|---|---|---|
| Output point type | | Relay-R | Transistor-T | | |
| Output point number | | All | Y0, Y2 | Y1, Y3 | Y4~Y17, Y20~ #1 |
| Voltage specification | | < 250VAC, 30VDC | 5 ~ 30VDC #2 | | |
| Max. frequency | | 1Hz | 100kHz | 10kHz | 1kHz |
| Maximum load | Resistive | 2A/1 point (5A/COM) | 0.5A/1 point (4A/COM) #4 | | |
| | Inductive | #3 | 15W (30VDC) | | |
| | Lamp | 20WDC/100WAC | 2.5W(30VDC) | | |
| Response time | Off → On | Approx .10ms | < 2μs | < 20μs | < 100μs |
| | On → Off | | < 3μs | < 30μs | < 100μs |

#1: Please refer to "I/O Terminal Layout" for the max. X/Y No. on each model.

#2: UP, ZP must work with external auxiliary power supply 24VDC (-15% ~ +20%), rated consumption approx. 1mA/point.

#3: Life curves



**[ Figure 3 ]**

#4: ZP for NPN COM, UP for PNP COM.

## A/D and D/A Specifications (For EX2 Model Only)

| Items | Analog Input (A/D) | | | Analog Output (D/A) | | |
|---|---|---|---|---|---|---|
| | Voltage | Current | | Voltage | Current | |
| Analog I/O range | ±10V | ±20mA | 4 ~ 20mA #1 | ±10V | 0 ~ 20mA | 4 ~ 20mA #1 |
| Digital conversion range | ±2,000 | ±2,000 | 0 ~ +2,000 | ±2,000 | 0 ~ +4,000 | 0 ~ +4,000 |
| Resolution #2 | 12-bit | | | | | |
| Input impedance | > 1MΩ | 250Ω | | - | | |
| Output impedance | - | | | 0.5Ω or lower | | |
| Tolerance carried impedance | - | | | > 5KΩ | < 500Ω | |
| Overall accuracy | Non-linear accuracy: ±1% of full scale within the range of PLC operation temperature<br>Maximum deviation: ±1% of full scale at 20mA and +10V | | | | | |
| Response time | 2ms (set up in D1118) #3 | | | 2ms #4 | | |
| Absolute input range | ±15V | ±32mA | | - | | |
| Digital data format | 2's complement of 16-bit, 12 significant bits | | | | | |
| Average function | Provided (set up in D1062) #5 | | | - | | |
| Isolation method | No Isolation between digital circuit and analog circuit | | | | | |
| Protection | Voltage output has short circuit protection, but a long period of short circuit may cause internal wire damage and open circuit of current output. | | | | | |

#1: V1.2 and above supports this mode. Please refer to the detailed explanation of D1115.

#2: Resolution formula

| Analog Input (A/D) | | Analog Output (D/A) | |
|---|---|---|---|
| Voltage | Current | Voltage | Current |
| $(5mV = \frac{20V}{4000})$ | $(10\mu A = \frac{40mA}{4000})$ | $(5mV = \frac{20V}{4000})$ | $(5\mu A = \frac{20mA}{4000})$ |

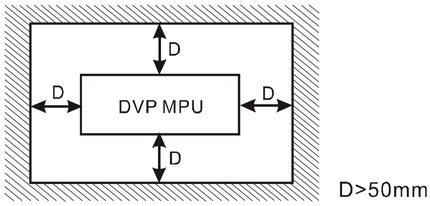
#3: When the scan period is longer than 2ms or the set value, the setting will follow the scan period.

#4: When the scan period is longer than 2ms, the setting will follow the scan period.

#5: When the sampling range is "1", the present value will be read.

## ■ Installation

Please install the PLC in an enclosure with sufficient space around it to allow heat dissipation, as shown in the figure.




- **Direct Mounting:** Please use M4 screw according to the dimension of the product.
- **DIN Rail Mounting:** When mounting the PLC to 35mm DIN rail, be sure to use the retaining clip to stop any side-to-side movement of the PLC and reduce the chance of wires being loose. The retaining clip is at the bottom of the PLC. To secure the PLC to DIN rail, pull down the clip, place it onto the rail and gently push it up. To remove the PLC, pull the retaining clip down with a flat screwdriver and gently remove the PLC from DIN rail.

## ■ Wiring

1. Use the 12-24 AWG single-core bare wire or the multi-core wire for the I/O wiring. The PLC terminal screws should be tightened to 3.80 kg-cm (3.30 in-lbs) and please use 60/75°C copper conductor only.
2. DO NOT wire empty terminal. DO NOT place the input signal wire and output power wire in the same wiring circuit.
3. DO NOT drop tiny metallic conductor into the PLC while screwing and wiring.
   - Please attach the dustproof sticker to the PLC before the installation to prevent conductive objects from dropping in.
   - Tear off the sticker before running the PLC to ensure normal heat dissipation.

### ◆ Power Supply

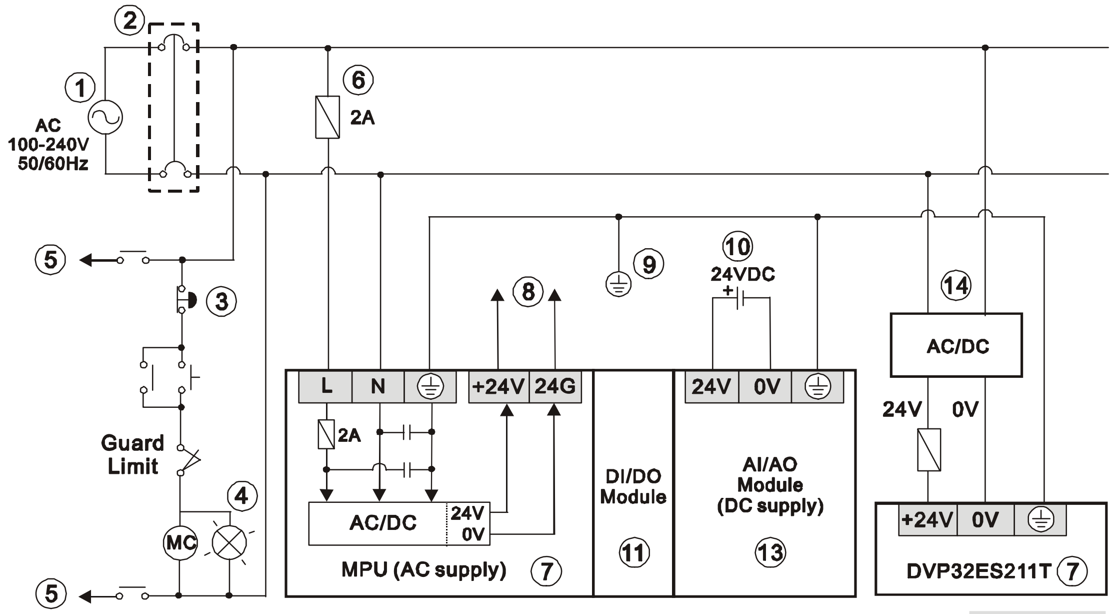
The power input type for DVP-ES2 model is AC input. When operating DVP-ES2, please note the following points:

1. The range of the input voltage should be 100 ~ 240VAC. The power supply should be connected to L and N terminals. Please note that wiring AC110V or AC220V to +24V output terminal or digital input points will result in serious damage on the PLC.
2. The AC power inputs for the MPU and the digital I/O module should be ON or OFF at the same time.
3. Use 1.6mm wire (or longer) for the grounding of the PLC.
4. The power shutdown of less than 10ms will not affect the operation of the PLC. However, power shutdown time that is too long or the drop of power supply voltage will stop the running of the PLC, and all outputs will go "OFF". When the power returns to normal status, the PLC will automatically resume operation. (Care should be taken on the latched auxiliary relays and registers inside the PLC when programming.)
5. The +24V output is rated at 0.5A from MPU. DO NOT connect other external power

supplies to this terminal. Every input terminal requires 5 ~ 7mA to be driven; e.g. the 16-point input will require approximately 100mA. Therefore, +24V terminal cannot give output to the external load that is more than 400mA.

## ◆ Safety Wiring

In PLC control system, many devices are controlled at the same time and actions of any device could influence each other, i.e. breakdown of any device may cause the breakdown of the entire auto-control system and danger. Therefore, we suggest you wire a protection circuit at the power supply input terminal. See the figure below.




[ Figure 4 ]

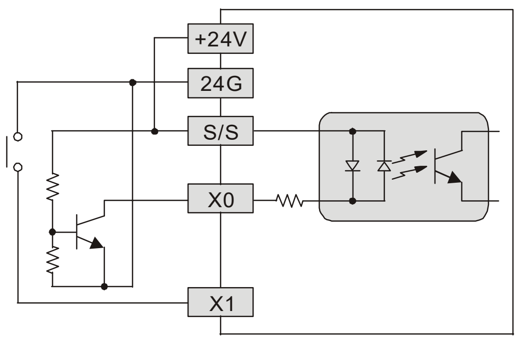
| | |
|---|---|
| ① AC power supply:100 ~ 240VAC, 50/60Hz | ② Breaker |
| ③ Emergency stop: This button cuts off the system power supply when accidental emergency takes place. | |
| ④ Power indicator | ⑤ AC power supply load |
| ⑥ Power supply circuit protection fuse (2A) | ⑦ DVP-PLC (main processing unit) |
| ⑧ DC power supply output: 24VDC, 500mA | ⑨ Grounding resistance: < 100Ω |
| ⑩ DC power supply: 24VDC | ⑪ Digital I/O module (DC supply) |
| ⑫ Digital I/O module (AC supply) | ⑬ Analog I/O module (DC supply) |
| ⑭ DC power supply: 20.4VDC~28.8VDC | |

## ◆ I/O Point Wiring

There are 2 types of DC inputs, SINK and SOURCE. (See the example below. For detailed point configuration, please refer to the specification of each model.)

- DC Signal IN – SINK mode

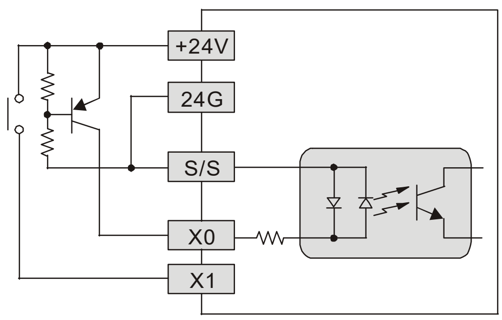
Input point loop equivalent circuit




[ Figure 5 ]

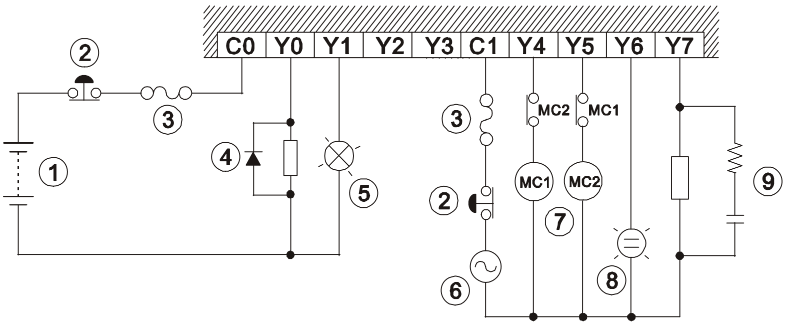
- DC Signal IN – SOURCE mode

Input point loop equivalent circuit

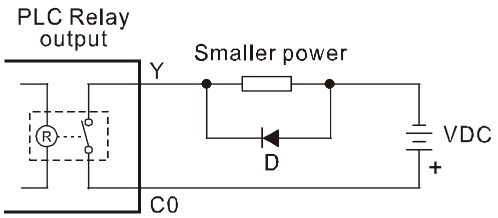



[ Figure 6 ]

• Relay (R) output circuit wiring

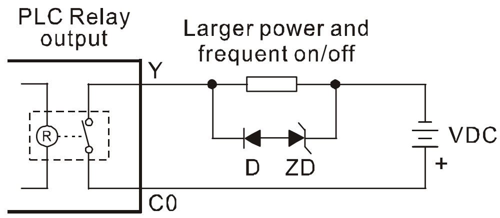



[ Figure 7 ]



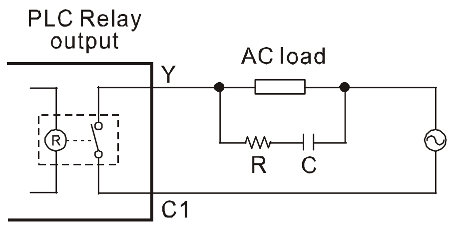

D: 1N4001 diode or equivalent component

[ Figure 8 ]




D: 1N4001 diode or equivalent component
ZD: 9V Zener, 5W

[ Figure 9 ]




R: 100~120Ω
C: 0.1~0.24uF

[ Figure 10 ]

① DC power supply

② Emergency stop: Uses external switch

③ Fuse: Uses 5 ~ 10A fuse at the shared terminal of output contacts to protect the output circuit

④ Transient voltage suppressor: To extend the life span of contact.
1. Diode suppression of DC load: Used when in smaller power (Figure 8)
2. Diode + Zener suppression of DC load: Used when in larger power and frequent On/Off (Figure 9)

⑤ Incandescent light (resistive load)

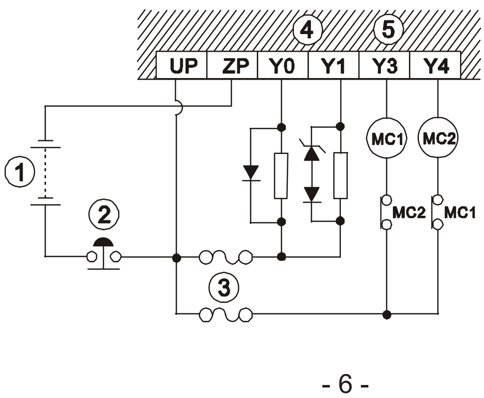
⑥ AC power supply

⑦ Manually exclusive output: For example, Y4 and Y5 control the forward running and reverse running of the motor, forming an interlock for the external circuit, together with the PLC internal program, to ensure safe protection in case of any unexpected errors.

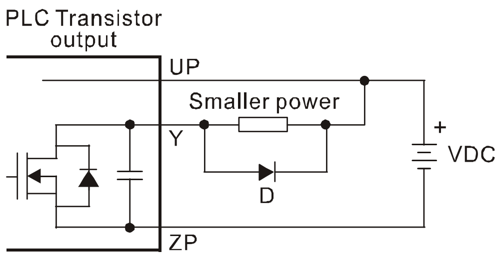
⑧ Neon indicator

⑨ Absorber: To reduce the interference on AC load (Figure 10)

• Transistor (T) output circuit wiring

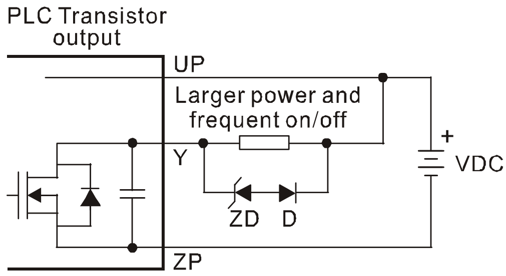



[ Figure 11 ]




D: 1N4001 diode or equivalent component

[ Figure 12 ]



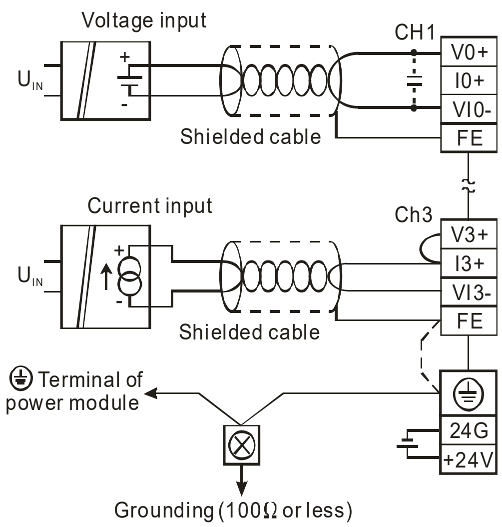

D: 1N4001 diode or equivalent component
ZD: 9V Zener, 5W

[ Figure 13 ]

| | |
|---|---|
| ① DC power supply | ② Emergency stop |
| ③ Circuit protection fuse | |
| ④ The output of the transistor model is "open collector". If Y0/Y1 is set to pulse output, the output current has to be bigger than 0.1A to ensure normal operation of the model.<br>1. Diode suppression: Used when in smaller power (Figure 12)<br>2. Diode + Zener suppression: Used when in larger power and frequent On/Off (Figure 13) | |
| ⑤ Manually exclusive output: For example, Y3 and Y4 control the forward running and reverse running of the motor, forming an interlock for the external circuit, together with the PLC internal program, to ensure safe protection in case of any unexpected errors. | |

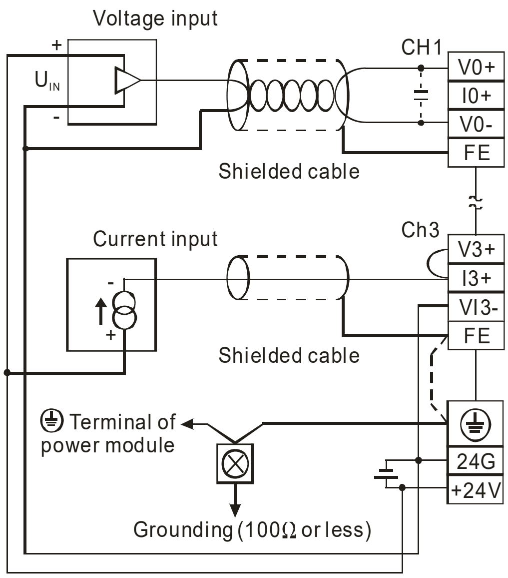
## ◆ A/D and D/A External Wiring (For EX2 Model Only)

- A/D: Active



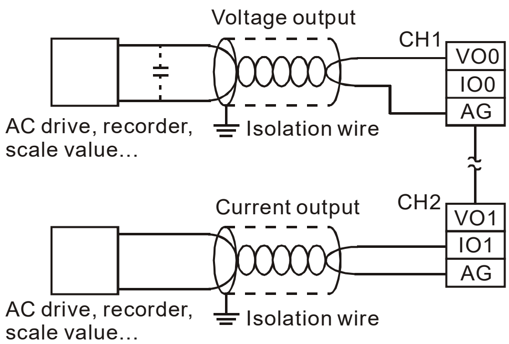

[ Figure 14 ]

- A/D: Passive




[ Figure 15 ]

- D/A




[ Figure 16 ]

Note: When the A/D module is connected to current signals, make sure to short-circuit "V+" and "I+" terminals.

## ◆ RS-485 Wiring

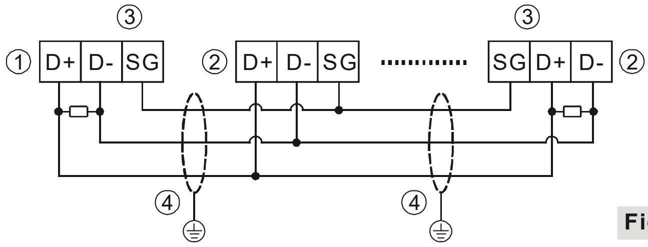



Figure 17

| | |
|---|---|
| ① Master node | ② Slave node |
| ③ Terminal resistor | ④ Shielded cable |

Note: 1. Terminal resistors are suggested to be connected to master and the last slave with resistor value of 120Ω.
2. To ensure communication quality, please apply double shielded twisted pair cable (20AWG) for wiring.
3. When voltage drop occurs between the internal ground references of two systems, connect the systems with Signal Ground point (SG) for achieving equal potential between systems so that a stable communication can be obtained.

# ■ I/O Terminal Layouts

- DVP16ES200R/T

L N ⏚ NC +24V 24G S/S X0 X1 X2 X3 X4 X5 X6 X7

***DVP16ES2-R (8DI/8DO)***

D+ D- SG D+ D- C0 Y0 Y1 Y2 Y3 C1 Y4 Y5 Y6 Y7

L N ⏚ NC +24V 24G S/S X0 X1 X2 X3 X4 X5 X6 X7

***DVP16ES2-T (8DI/8DO)***

D+ D- SG D+ D- UP ZP Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7

- DVP24ES200R/T

L N ⏚ NC S/S X0 X1 X2 X3 X4 X5 X6 X7 X10 X11 X12 X13 X14 X15 X16 X17

***DVP24ES2-R (16DI/8DO)***

D+ D- SG D+ D- +24V 24G C0 Y0 Y1 Y2 Y3 C1 Y4 Y5 Y6 Y7

L N ⏚ NC S/S X0 X1 X2 X3 X4 X5 X6 X7 X10 X11 X12 X13 X14 X15 X16 X17

***DVP24ES2-T (16DI/8DO)***

D+ D- SG D+ D- +24V 24G UP ZP Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7

- DVP32ES200R/T

L N ⏚ NC +24V 24G S/S X0 X1 X2 X3 X4 X5 X6 X7 X10 X11 X12 X13 X14 X15 X16 X17

***DVP32ES2-R (16DI/16DO)***

D+ D- SG D+ D- C0 Y0 Y1 Y2 Y3 C1 Y4 Y5 Y6 Y7 C2 Y10 Y11 Y12 Y13 C3 Y14 Y15 Y16 Y17

L N ⏚ NC +24V 24G S/S X0 X1 X2 X3 X4 X5 X6 X7 X10 X11 X12 X13 X14 X15 X16 X17

***DVP32ES2-T (16DI/16DO)***

D+ D- SG D+ D- UP0 ZP0 Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7 UP1 ZP1 Y10 Y11 Y12 Y13 Y14 Y15 Y16 Y17

- DVP40ES200R/T

L N ⏚ NC S/S X0 X1 X2 X3 X4 X5 X6 X7 X10 X11 X12 X13 X14 X15 X16 X17 X20 ⇨

***DVP40ES2-R (24DI/16DO)***

D+ D- SG D+ D- +24V 24G C0 Y0 Y1 Y2 Y3 C1 Y4 Y5 Y6 Y7 C2 Y10 Y11 Y12 Y13 ⇨

⇨ X21 X22 X23 X24 X25 X26 X27

⇨ C3 Y14 Y15 Y16 Y17

L N ⏚ NC S/S X0 X1 X2 X3 X4 X5 X6 X7 X10 X11 X12 X13 X14 X15 X16 X17 X20 ⇨

***DVP40ES2-T (24DI/16DO)***

D+ D- SG D+ D- +24V 24G UP0 ZP0 Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7 UP1 ZP1 Y10 Y11 Y12 ⇨

⇨ X21 X22 X23 X24 X25 X26 X27

⇨ Y13 Y14 Y15 Y16 Y17

- DVP60ES200R/T

**DVP60ES2-R (36DI/24DO)**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | N | ⏚ | NC | S/S | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | X17 | X20 |
| D+ | D- | SG | D+ | D- | +24V | 24G | C0 | Y0 | Y1 | Y2 | Y3 | C1 | Y4 | Y5 | Y6 | Y7 | C2 | Y10 | Y11 | Y12 | Y13 |

⇨

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X21 | X22 | X23 | X24 | X25 | X26 | X27 | X30 | X31 | X32 | X33 | X34 | X35 | X36 | X37 | X40 | X41 | X42 | X43 |
| C3 | Y14 | Y15 | Y16 | Y17 | C4 | Y20 | Y21 | Y22 | Y23 | C5 | Y24 | Y25 | Y26 | Y27 | | | | |

**DVP60ES2-T (36DI/24DO)**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | N | ⏚ | NC | S/S | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | X17 | X20 |
| D+ | D- | SG | D+ | D- | +24V | 24G | UP0 | ZP0 | Y0 | Y1 | Y2 | Y3 | Y4 | Y5 | Y6 | Y7 | UP1 | ZP1 | Y10 | Y11 | Y12 |

⇨

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X21 | X22 | X23 | X24 | X25 | X26 | X27 | X30 | X31 | X32 | X33 | X34 | X35 | X36 | X37 | X40 | X41 | X42 | X43 |
| Y13 | Y14 | Y15 | Y16 | Y17 | UP2 | ZP2 | Y20 | Y21 | Y22 | Y23 | Y24 | Y25 | Y26 | Y27 | | | | |

- DVP20EX200R/T

**DVP20EX2-R (8DI/6DO/4AI/2AO)**

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | N | ⏚ | NC | S/S | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | FE | V0+ | I0+ | VI0- | V1+ | I1+ | VI1- | V2+ | I2+ | VI2- | | |
| D+ | D- | SG | D+ | D- | +24V | 24G | C0 | Y0 | Y1 | Y2 | Y3 | C1 | Y4 | Y5 | FE | V3+ | I3+ | VI3- | VO0 | IO0 | AG | VO1 | IO1 | AG |

**DVP20EX2-T (8DI/6DO/4AI/2AO)**

| | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | N | ⏚ | NC | S/S | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | FE | V0+ | I0+ | VI0- | V1+ | I1+ | VI1- | V2+ | I2+ | VI2- | | |
| D+ | D- | SG | D+ | D- | +24V | 24G | UP | ZP | Y0 | Y1 | Y2 | Y3 | Y4 | Y5 | FE | V3+ | I3+ | VI3- | VO0 | IO0 | AG | VO1 | IO1 | AG |

- DVP32ES211T

**DVP32ES211T (16DI/16DO)**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SG3 | D+ | D- | SG2 | D+ | D- | S/S | X0 | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | X17 | |
| 24V | 0V | ⏚ | NC | NC | UP0 | ZP0 | Y0 | Y1 | Y2 | Y3 | Y4 | Y5 | Y6 | Y7 | UP1 | ZP1 | Y10 | Y11 | Y12 | Y13 | Y14 | Y15 | Y16 | Y17 |

# Appendix B

## “Fuji Electric-General-Purpose Inverter FVR-C11S-7EN Series”

Solutions for Drives


FVR C11S

# *Instruction manual*


Fuji Electric-General-Purpose Inverter FVR-C11S-7EN Series

Single-phase 230V 0.1 - 2.2kW

# 5 Selecting Function

## 5-1 Function Selection List

### F: Fundamental functions

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| F00 | Data protection | 0: Data change enabled,<br>1: Data protected | - | - | 0 | X | |
| F01 | Frequency command | 0: Key operation (△, ▽ key)<br>1: Voltage input (terminal [12]) (0 to +10VDC)<br>2: Current input (terminal[C1]) (4 to 20mADC)<br>3: Voltage input + current input (terminals[12]+[C1])<br>4: Analog (VR built in inverter) | - | - | 4 | X | |
| F02 | Operation method | 0: Key operation (rotation direction: By terminal block)<br>1: External signal (digital input)<br>2: Key operation (forward rotation)<br>3: Key operation (reverse rotation) | - | - | 2 | X | |
| F03 | Maximum output frequency | 50 to 120Hz | Hz | 1 | 50 | X | |
| F04 | Base frequency | 25 to 120Hz | Hz | 1 | 50 | X | |
| F05 | - | Data cannot be changed. | - | - | 0 | - | |
| F06 | | | | | 0 | | |
| F07 | Acceleration time | 0.0 to 60.0s<br>0.01 second is set when 0.0 is specified. | s | 0.1 | 6.0 | ○ | |
| F08 | Deceleration time | 0.1 to 60.0s | s | 0.1 | 6.0 | ○ | |
| F09 | Torque boost | 0,1 : Variable torque characteristic<br>2 to 31: Constant torque characteristic | - | 1 | 13 | ○ | |

Change during operation: X = impossible, △ = possible (enabled by using FUNC/DATA), ○ = possible (enabled by using △ ▽)

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during opera-tion | User setting |
|---|---|---|---|---|---|---|---|
| F10 | Electronic thermal overload relay for motor (Select) | 0: Inactive<br>1: Active (for 4-pole standard motor)<br>2: Active (for 4-pole FUJI inverter motor) | - | - | 1 | △ | |
| F11 | (Level) | 20 to 135% of inverter rated current | A | 0.01 | Typical value of FUJI 4-pole motor | △ | |
| F12 | (Thermal time constant) | 0.5 to 10.0min | min | 0.1 | 5.0 | △ | |
| F14 | Restart after mo-mentary power failure (Select) | 0: Inactive (Trip and alarm when power fail-ure occurs)<br>1: Inactive (Trip and alarm when power re-covers)<br>2: Active (Momentarily stops and restarts at setting frequency of before power failure)<br>3: Active (Momentarily stops and restarts at starting frequency) | - | - | 0 | X | |
| F15 | Frequency limiter (High) | 0 to 120Hz | Hz | 1 | 70 | ○ | |
| F16 | (Low) | 0 to 120Hz | | | 0 | ○ | |
| F17 | Gain (for frequency setting signal) | 0: For 0 to 10VDC (4 to 20 mA DC)<br>1: For 0 to 5VDC (4 to 12 mA DC) | - | - | 0 | X | |
| F18 | Bias frequency | -120 to 120Hz | Hz | 1 | 0 | ○ | |
| F20 | DC injection brake (Starting freq.) | Fixed to 3Hz | Hz | - | 3.0 | - | |
| F21 | (Level) | 0 to 100% | % | 1 | 50 | ○ | |
| F22 | (Braking time) | 0.0 s (Inactive), 0.1 to 30.0 s | s | 0.1 | 0.0 | ○ | |
| F23 | Starting frequency | 1 to 6Hz | Hz | 1 | 1 | X | |
| F24 | - | Data cannot be changed. | - | - | 0.0 | - | |
| F25 | Stop frequency | 1 to 6Hz | Hz | 1 | 1 | X | |

Change during operation: X = impossible, △ = possible (enabled by using FUNC/DATA), ○ = possible (enabled by using △ ▽)

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| F26 | Motor sound (carrier freq.) | 0 to 15kHz<br>0.75kHz is set when 0 is specified | kHz | 1 | 15 | ○ | |
| F27 | (sound tone ) | 0: Level 0 1: Level 1<br>2: Level 2 3: Level 3 | - | - | 0 | ○ | |
| F30 | FM terminal (Voltage adjust) | 0 to 200% | % | 1 | 100 | ○ | |
| F31 | (Function) | 0: Output frequency<br>1: Output current<br>2: PID feedback amount<br>3: DC link circuit voltage | - | - | 0 | △ | |
| F36 | 30Ry operation mode | 0: Excited when tripped<br>1: Normally excited | - | - | 0 | X | |

5

## E: Extension Terminal Functions

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| E01 | X1 terminal (function selection) | Use the code values listed below to select [X1], [X2] and [X3] terminal functions. | - | - | 0 | X | |
| E02 | X2 terminal (function selection) | | - | - | 2 | X | |
| E03 | X3 terminal (function selection) | | - | - | 3 | X | |
| | | 0: Multistep frequency 1 (SS1)<br>1: Multistep frequency 2 (SS2)<br>2: Coast-to-stop command (BX)<br>3: Alarm reset (RST)<br>4: External alarm (THR)<br>5: Write enable command for keypad (WE-KP)<br>6: PID control cancel (Hz/PID)<br>7: Link operation selection (LE) | | | | | |

Change during operation: X = impossible, △ = possible (enabled by using FUNC DATA), ○ = possible (enabled by using △ ▽)

## C: Control Functions of Frequency

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| C01 | Jump frequency1 | 0 to 120Hz | Hz | 1 | 0 | ○ | |
| C02 | 2 | | | 1 | 0 | ○ | |
| C03 | 3 | | | 1 | 0 | ○ | |
| C04 | (Hysteresis) | 0 to 30Hz | Hz | 1 | 3 | ○ | |
| C05 | Multistep frequency 1 | 0.0 to 120Hz | Hz | 0.1 | 0.0 | ○ | |
| C06 | 2 | | | 0.1 | 0.0 | ○ | |
| C07 | 3 | | | 0.1 | 0.0 | ○ | |

## P: Motor Parameters

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| P00 | Motor characteristics | 0 to 10 | - | - | 2 | ○ | |

## H: High Performance Functions

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| H01 | Operation time | Operation time accumulation | 100 Hr | 1 | 0 | - | |
| H02 | Trip history | The contents of the last four alarms are displayed sequentially. | - | - | --- | - | |
| H03 | Data initialization | 1: Initialized (return to factory setting value) | - | - | 0 | X | |

Change during operation: X = impossible, △ = possible (enabled by using FUNC/DATA), ○ = possible (enabled by using ∧ ∨)

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| H04 | Retry (count) | 0: No retry<br>1: Retry (Count is fixed to 5.) | - | - | 0 | △ | |
| H06 | Cooling fan on/off control | 0: Inactive<br>1: Active | - | - | 0 | △ | |
| H20 | PID control (Mode select) | 0: Inactive<br>1: Active (forward operation)<br>2: Active (reverse operation) | - | - | 0 | X | |
| H21 | (Feedback signal select) | 0: Terminal [12] (0 to +10VDC) Input<br>1: Terminal [C1] (4 to 20mADC)Input<br>2: Terminal [12] (+1 to +5VDC) Input | - | - | 1 | X | |
| H22 | (P-gain) | 0.01 to 10.0 times (1to1000%) | - | 0.01 | 0.01 | ○ | |
| H23 | (I-gain) | 0.0s : Inactive<br>0.1 to 999s | s | 0.1 | 0.0 | ○ | |
| H24 | (D-gain) | 0.00s : Inactive<br>0.01 to 10.0s | s | 0.01 | 0.00 | ○ | |
| H25 | (Feedback filter) | 0.0 to 60.0s | s | 0.1 | 0.5 | ○ | |

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## O: Optional Functions

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| o00 | Option selection (RS485 communication) | 0: Option inactive<br>1: Option active<br>Set 0 when the optional RS485 communication unit is not used. | - | - | 0 | △ | |
| o01 | Station address | 1 to 31 | - | - | 1 | △ | |

Change during operation: X = impossible, △ = possible (enabled by using FUNC/DATA), ○ = possible (enabled by using △ ▽)

| Function code No. | Name | Setting range | Unit | Min. unit | Factory setting | Change during operation | User setting |
|---|---|---|---|---|---|---|---|
| o02 | Selection of operation in error occurrence | 0: Er8 trip with eight continuous communication errors or check sum errors<br>1: Er8 trip after the time (o03) set in the timer elapses with eight continuous communication errors or check sum errors<br>2: Er8 trip if communication does not recover until the time (o03) set in the timer elapses<br>3: Retry and operation continuation with communication or check sum error | - | - | 0 | △ | |
| o03 | Selection of time set in timer | 1 to 60s | s | 1 | 2 | △ | |
| o04 | Transmission rate | 0: 19200bps 1: 9600bps<br>2: 4800bps 3: 2400bps<br>4: 1200bps | - | - | 1 | △ | |
| o05 | Data length selection | 0:8bits 1:7bits | - | - | 0 | △ | |
| o06 | Parity bit selection | 0: No parity 1: Even parity<br>2: Odd parity | - | - | 0 | △ | |
| o07 | Stop bit selection | 0:2bits 1:1bit | - | - | 0 | △ | |
| o08 | Communication discontinuation detection time | 0: No detection,1 to 60s | s | 1 | 0 | △ | |
| o09 | Response interval | 0.00 to 1.00 | s | 0.01 | 0.01 | v | |
| o10 | RS485 command selection (frequency setting) | 0: Selection of frequency setting selected with F01<br>1: Selection of frequency setting from RS485 | - | - | 0 | X | |
| o11 | RS485 command selection (operation command) | 0: Selection of operation command selected with F02<br>1: Selection of operation command from RS485 | - | - | 0 | X | |

Table 5-1-1 Table of Function Selection List

**Note:** For details on "o01" to "o11", refer to the instruction manual that came with the optional RS485 serial communication unit.

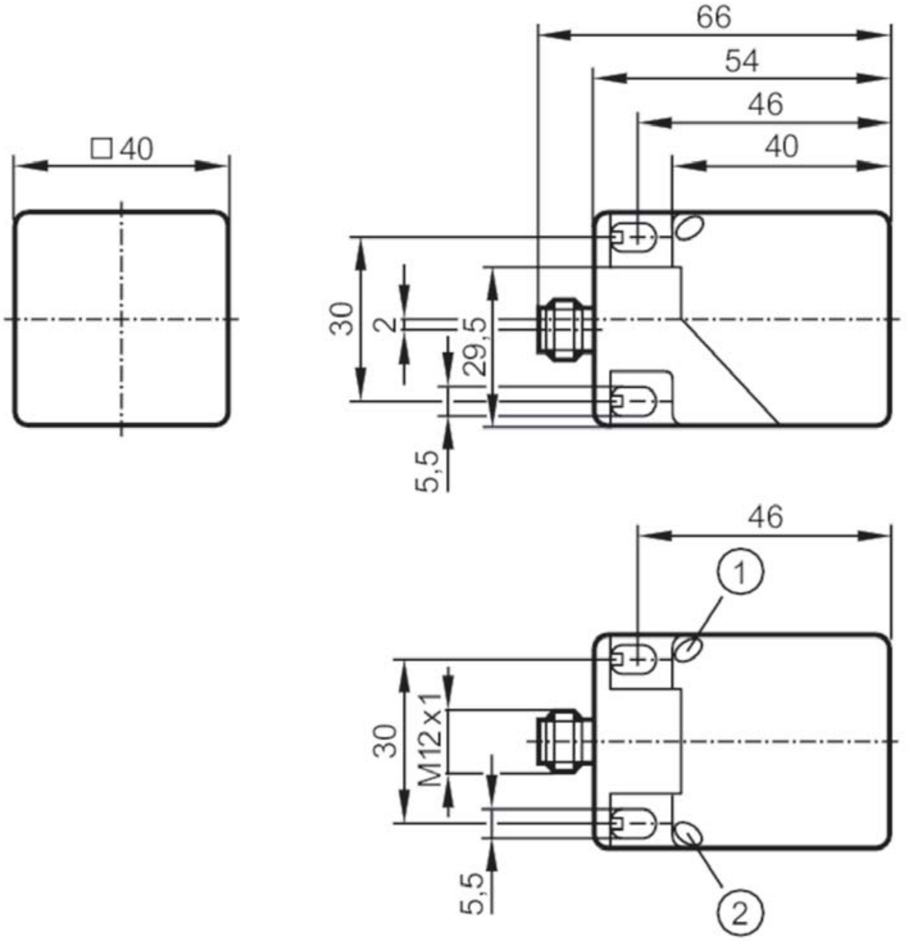
Change during operation: X = impossible, △ = possible (enabled by using FUNC/DATA), ○ = possible (enabled by using △ ▽)

# Appendix C
## “Sensor Datasheet”

# IM5129

## Inductive sensor

**IMC3040UBPKG/K1/SC/US-100-DPS**




1 LED yellow
2 LED green

Made in Germany

| | |
|---|---|
| **Application** | |
| Special features | Correction factor K = 1 |
| Magnetic-field immune | yes |
| **Electrical data** | |
| Operating voltage [V] | 10...36 DC; ("supply class 2" to cULus) |
| Current consumption [mA] | < 20 |
| Protection class | II |
| Reverse polarity protection | yes |

# IM5129

## Inductive sensor

IMC3040UBPKG/K1/SC/US-100-DPS

| | | |
|---|---|---|
| **Outputs** | | |
| Output function | | normally open |
| Max. voltage drop switching output DC | [V] | 2.5 |
| Permanent current rating of switching output DC | [mA] | 200 |
| Switching frequency DC | [Hz] | 200 |
| Electrical design | | PNP |
| Short-circuit protection | | yes |
| Type of short-circuit protection | | pulsed |
| Overload protection | | yes |
| **Range** | | |
| Sensing range | [mm] | 40 |
| Real sensing range Sr | [mm] | 40 ± 10 % |
| Operating distance | [mm] | 0...32.4 |
| **Accuracy / deviations** | | |
| Correction factor | | steel: 1 / stainless steel: 1 / brass: 1 / aluminium: 1 / copper: 1 |
| Hysteresis | [% of Sr] | 1...20 |
| Switch point drift | [% of Sr] | -10...10 |
| Correction factor K = 1 | | yes |
| **Operating conditions** | | |
| Ambient temperature | [°C] | -25...70 |
| Protection | | IP 67 |

**Tests / approvals**

| | | | |
|---|---|---|---|
| EMC | | EN 61000-4-2 ESD | 8 kV CD / 6 kV AD |
| | | EN 61000-4-3 HF radiated | 10 V/m |
| | | EN 61000-4-4 Burst | 2 kV |
| | | EN 61000-4-5 Surge | 0,5 kV line to line, Ri: 2 Ohm |
| | | EN 61000-4-6 HF conducted | 10 V |
| | | EN 55011 | class B |
| MTTF | [years] | 1161 | |

| | | |
|---|---|---|
| **Mechanical data** | | |
| Weight | [g] | 130.6 |
| Housing | | rectangular |
| Sensing face | | 5 positions selectable |
| Mounting | | non-flush mountable |
| Dimensions | [mm] | 40 x 40 x 54 |
| Materials | | housing: PA anti-spatter; plug: stainless steel |

**Displays / operating elements**

| | | |
|---|---|---|
| Display | switching status | 1 x LED, yellow |
| | operation | 1 x LED, green |

| | |
|---|---|
| **Remarks** | |
| Pack quantity | 1 pcs. |

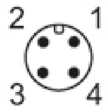
# IM5129

## Inductive sensor

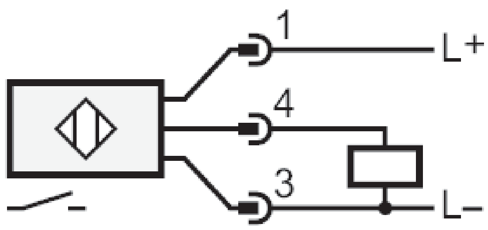
**IMC3040UBPKG/K1/SC/US-100-DPS**

## Electrical connection - plug

Connector: 1 x M12; Locking: locking, rotatable



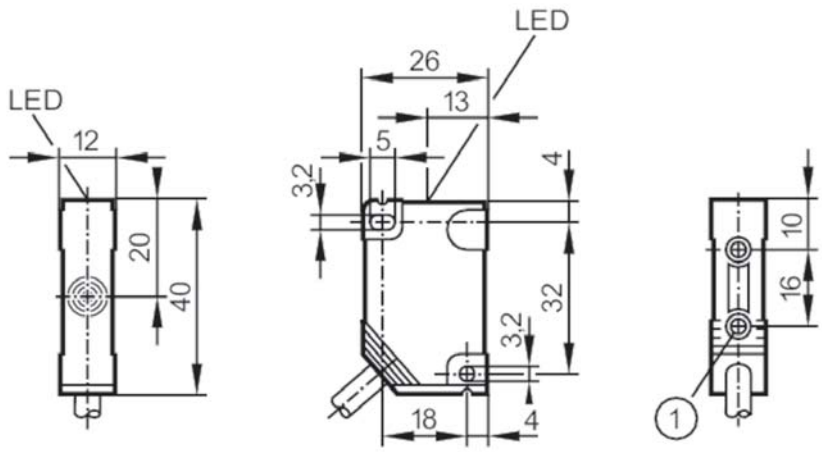

## Connection



# MN5200

## Magnetic sensor

MN-3060-BPKG/0,15M/AS




1 threaded bush M3 Depth 5.8 mm
Tightening torque maximum 1.2 Nm screw fixing class 8.8
when brass insert in contact with counterpart

CE

Made in Germany

| | | |
|---|---|---|
| **Electrical data** | | |
| Operating voltage | [V] | 10...30 DC |
| Current consumption | [mA] | < 10 |
| Protection class | | III |
| Reverse polarity protection | | yes |
| **Outputs** | | |
| Output function | | normally open |
| Max. voltage drop switching output DC | [V] | 2.5 |
| Permanent current rating of switching output DC | [mA] | 200 |
| Electrical design | | PNP |
| Short-circuit protection | | yes |
| Type of short-circuit protection | | pulsed |
| Overload protection | | yes |
| **Range** | | |
| Sensing range | [mm] | 60; (referred to magnet M 4.0) |
| **Accuracy / deviations** | | |
| Hysteresis | [% of Sr] | 1...10 |
| **Operating conditions** | | |
| Ambient temperature | [°C] | -40...75 |
| Protection | | IP 67 |

# MN5200

## Magnetic sensor

MN-3060-BPKG/0,15M/AS

| Tests / approvals | | |
|---|---|---|
| EMC | EN 61000-4-2 ESD | 4 kV CD / 8 kV AD |
| | EN 61000-4-3 HF radiated | 10 V/m |
| | EN 61000-4-4 Burst | 2 kV |
| | EN 61000-4-5 Surge | 0,5 kV line to line, Ri: 2 Ohm |
| | EN 61000-4-6 HF conducted | 10 V |
| | EN 55011 | class B |
| | noise immunity according to DIN ISO 11452-2 | 100 V/m |
| MTTF [years] | 1961 | |

| Mechanical data | |
|---|---|
| Weight [g] | 29.8 |
| Housing | rectangular |
| Dimensions [mm] | 40 x 12 x 26 |
| Materials | housing: PBT |

| Displays / operating elements | | |
|---|---|---|
| Display | switching status | 1 x LED, yellow |

| Electrical connection | |
|---|---|
| Connection | plug |

| Remarks | |
|---|---|
| Pack quantity | 1 pcs. |

## Electrical connection - plug

Cable: 0.15 m, PUR; 3 x 0.34 mm²

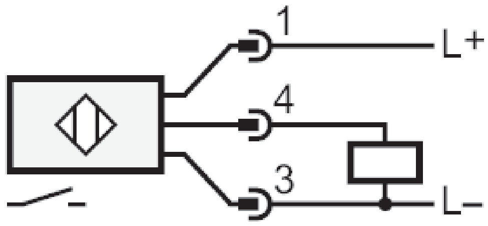
Connector: 1 x M8; Locking: knurled nut, rotatable

# MN5200

## Magnetic sensor

**MN-3060-BPKG/0,15M/AS**

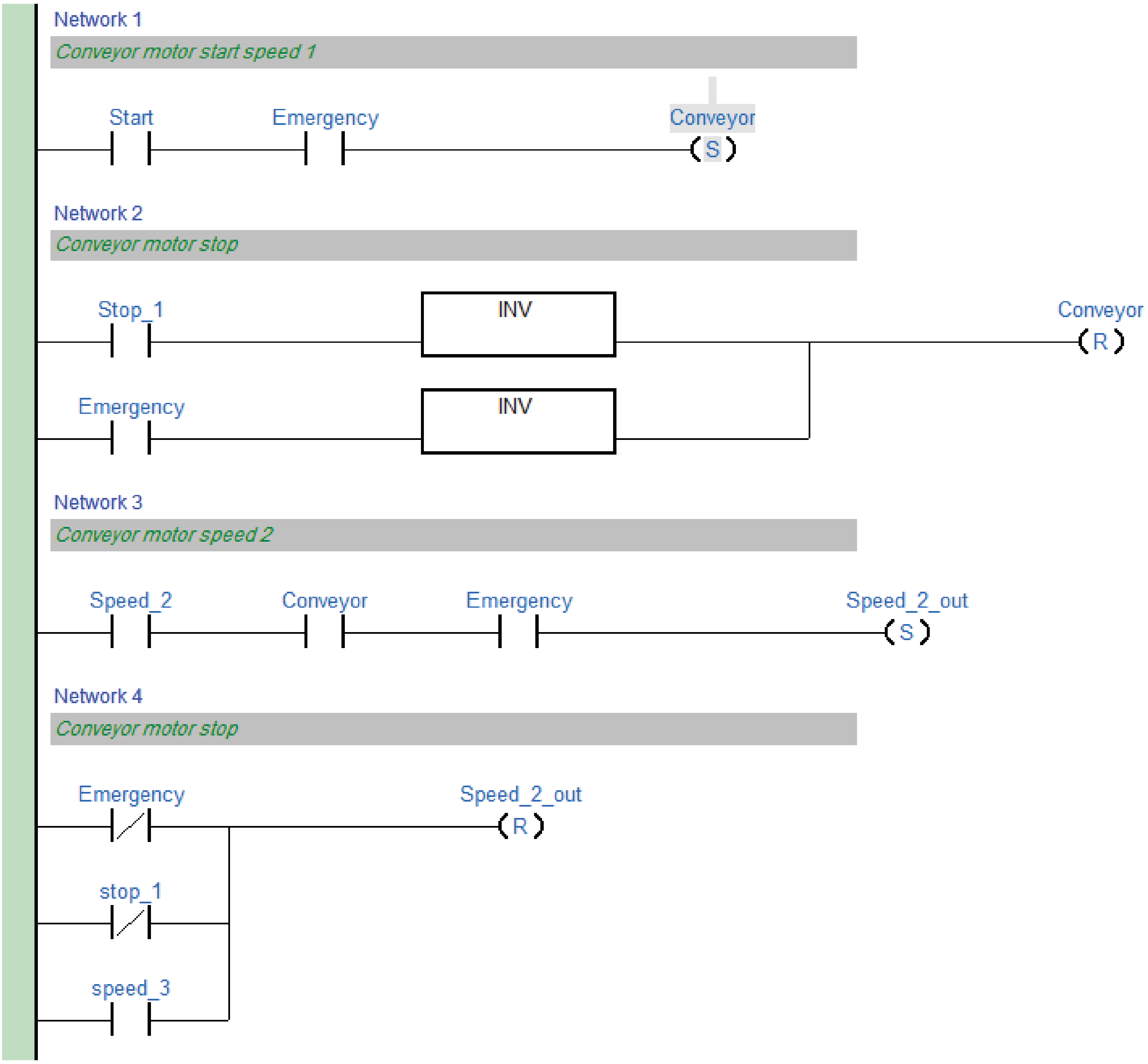
## Connection

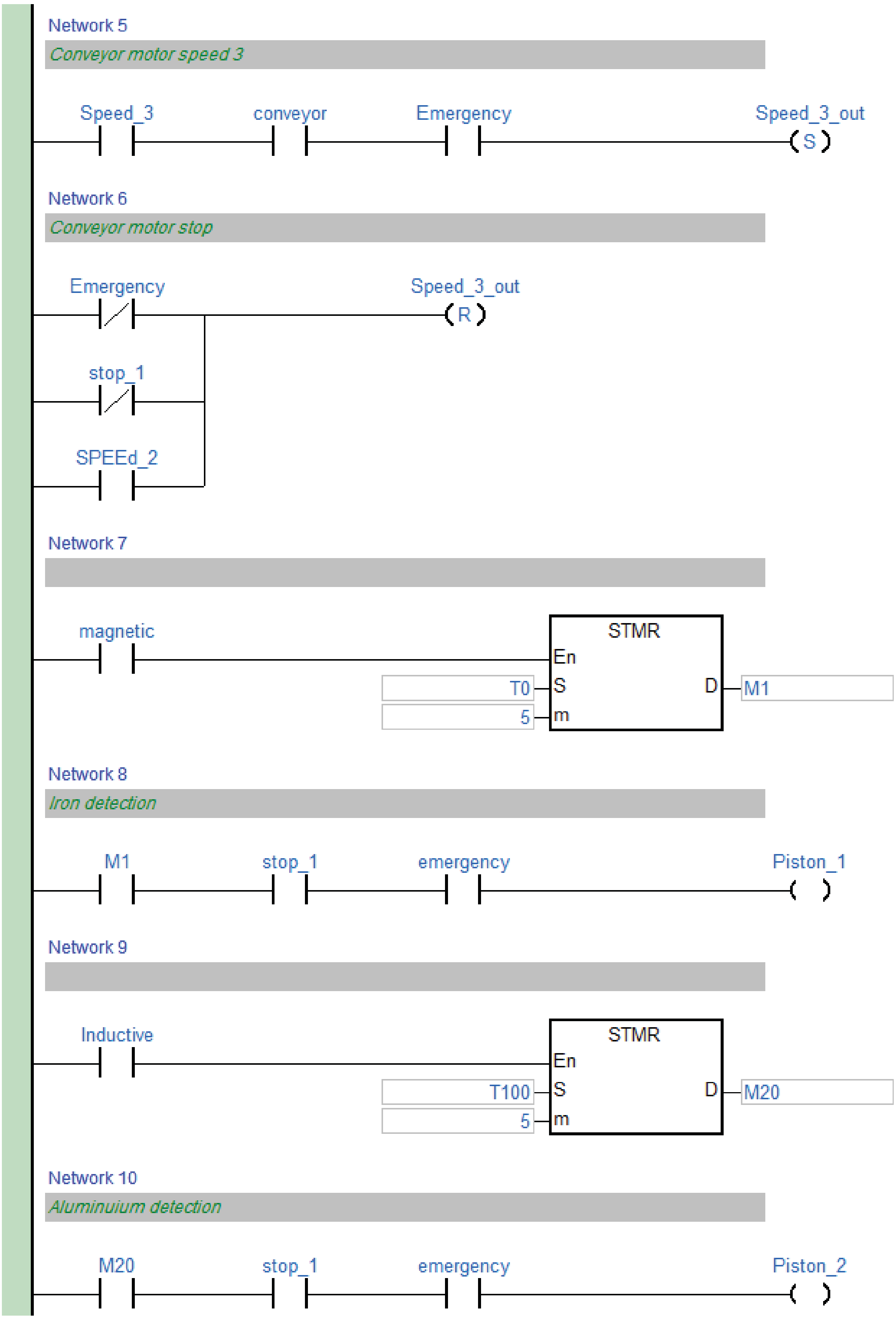


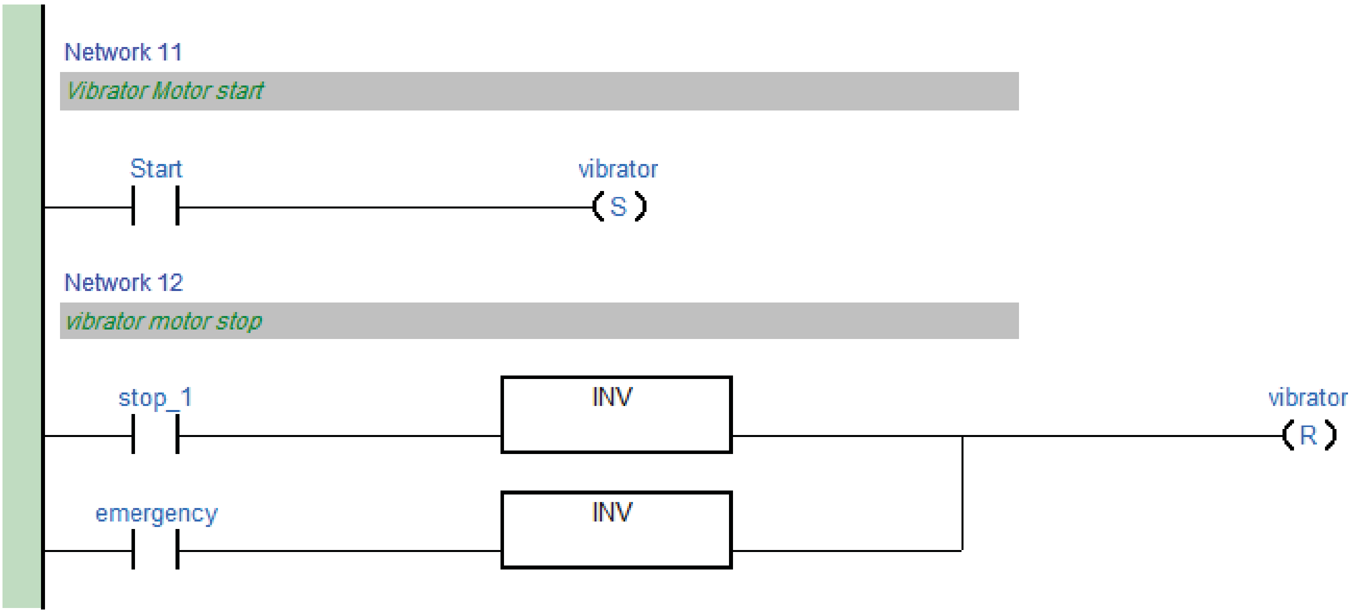
# Appendix D

## “PLC code”

| Declaration Type | Identifiers | Address | Type | Initial Value | Identifier Comment |
|---|---|---|---|---|---|
| VAR | Speed_3 | X0 | BOOL | FALSE | |
| VAR | Stop_1 | X1 | BOOL | FALSE | |
| VAR | Emergency | X2 | BOOL | FALSE | |
| VAR | Speed_2 | X3 | BOOL | FALSE | |
| VAR | Start | X4 | BOOL | FALSE | |
| VAR | Magnetic | X5 | BOOL | FALSE | |
| VAR | Inductive | X6 | BOOL | FALSE | |
| VAR | Conveyor | Y0 | BOOL | FALSE | |
| VAR | Speed_2_out | Y1 | BOOL | FALSE | |
| VAR | Piston_1 | Y2 | BOOL | FALSE | |
| VAR | Piston_2 | Y3 | BOOL | FALSE | |
| VAR | Speed_3_out | Y5 | BOOL | FALSE | |
| VAR | Piston_3 | Y6 | BOOL | FALSE | |
| VAR | Vibrator | Y7 | BOOL | FALSE | |




Network 5
Conveyor motor speed 3
Speed_3
conveyor
Emergency
Speed_3_out
S
Network 6
Conveyor motor stop
Emergency
Speed_3_out
R
stop_1
SPEEd_2
Network 7
magnetic
STMR
En
T0
S
D
M1
5
m
Network 8
Iron detection
M1
stop_1
emergency
Piston_1
Network 9
Inductive
STMR
En
T100
S
D
M20
5
m
Network 10
Aluminuium detection
M20
stop_1
emergency
Piston_2



Network 11
Vibrator Motor start
Start
vibrator
S
Network 12
vibrator motor stop
stop_1
INV
vibrator
R
emergency
INV