Design & Fabrication of Electro-Pneumatic Gantry Type Sorting Robot

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Abstract - *Automation is one of the main priorities of various industries to achieve better efficiency and less error in the process which are carried out within the industry. Today industries are trying to move toward automation to increase production and quality of product. So, by taking this point into consideration and by taking it as an opportunity to contribute in this domain we tried to make demonstration model for educational use. In this project automatic electro pneumatic gantry type sorting conveyor system has been used for sorting the object based on its parameter such as metallic properties and colour. For this purpose, we have used the PLC (Programmable Logic Controller) which is controller that is used for controlling the various processes required to sort the material. In order to give the input and check the process and various parameter while the system is running, we have integrated the PLC with HMI (Human Machine Interface). The various sensors and relays are used in this project and the sensors are connected to the PLC. PLC controls the process and carries out the sorting of material with the help of actuators.*

***Key Words*: Automation Production, Electro pneumatic Gantry type Sorting robot, Conveyor System, PLC (Programable Logic Control), HMI (Human Machine Interface).**

1. INTRODUCTION

A worker who has been performing a repetitive task undergoes fatigue. Worker fatigue on assembly lines can result in poor quality control, reduced performance and sometimes it can be harmful for that worker or surrounding people. But machines can perform highly repetitive tasks much better than humans. So, by integrating automation in industry may help to improve product quality and efficiency of manufacturing system. So, by taking these points into consideration and by taking it as an opportunity to contribute in this domain we developed demonstration model of electro pneumatic sorting system as a setup in which we can get hands on experience on industrial automation aspects such as product designing, working of different types on sensors, integrating sensors with actuators, Operating the system using programable logic controller and interfacing programable logic controller with human machine inter- face. In this chapter, we identify the problem statement, objectives, methodology and main component that will be used in the project. The electro-pneumatic automatic sorting machine consists of some sensors, actuators which are controlled by program- able logic controller (PLC).

1.1 PROBLEM STATEMENT

To make a prototype of Electro-Pneumatic pick and place gantry type sorting robot using pneumatic components and sensors and interfacing them with PLC and HMI.

1.2 OBJECTIVES

Our objective is to design system so that material handling process facilitate easy, cheap, fast and safe loading and unloading without or with least human interference.

- To study the operating condition of sensors and actuators used in sorting system.
- To design and fabricate gantry system on conveyor belt for pick and place operation.
- To develop automated system for event-based control, Interlocking and Sequencing of operation.
- To perform experimentation and validation of Electro-pneumatic pick and place gantry type sorting robot.

1.3 SCOPE

This project will help to learn all the insides of an Industrial Automation and Material Handling system.

- It will help to learn various aspects of automation like PLC, HMI and Sensor etc.
- It will also help to learn PLC programming as well as the integration of all the elements in the system with the PLC.
- It will help to learn how to display and set all the processing data on to the HMI (Human Machine Interface) screen can be learned.

By understanding the robot's operation and programming one can able to design and fabricate actual working robot for the industrial application.

1.3 METHODOLOGY

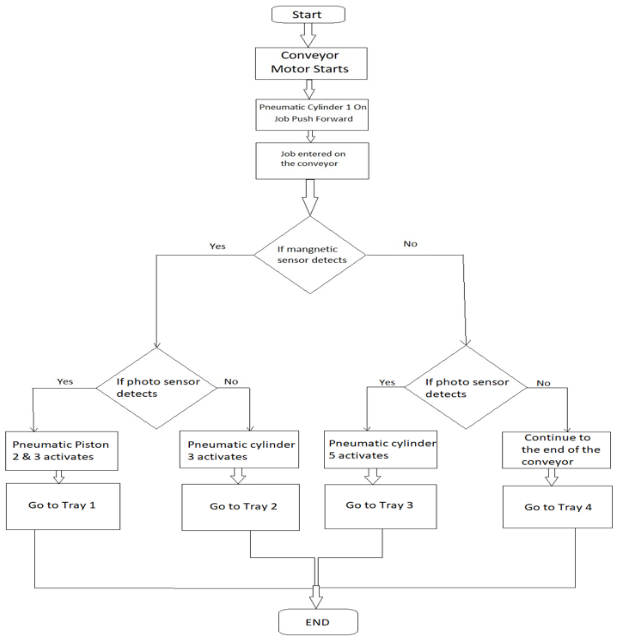


Chart -2: Machine Flow Chart

Chart -2 shows the steps and decisions that are needed to perform sequential sorting process. This will allow anyone to logically follow the process from beginning to the end and will help during making logic for the ladder programming.

Chart -3 shows the block diagram that represents the principal parts of the system and the relationship between them.

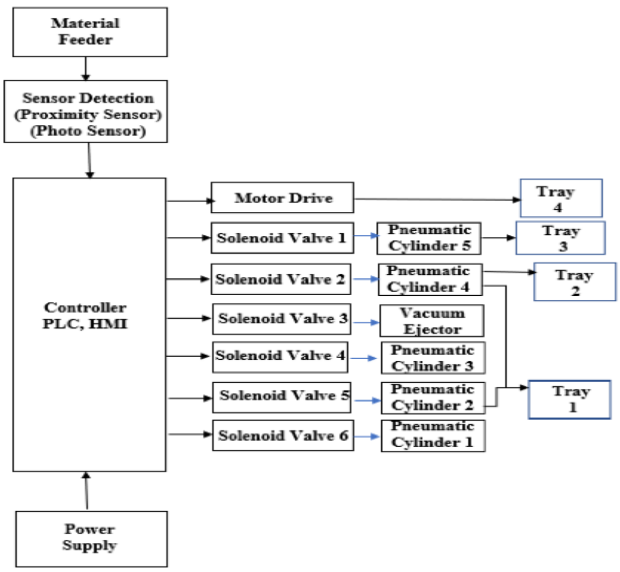


Chart -3: Working Principle Block Diagram

1.4 SORTING SYSTEM COMPONENTS

1.4.1 Conveyor Belt

A conveyor belt is the carrying medium of a belt conveyor system.

Fig -1: Conveyor Belt

1.4.2 Sensors

A. Inductive type proximity Sensor

Inductive proximity sensors are used for non-contact detection of metallic objects. Their operating principle is based on a magnetic field is generated.

B. Photo Electric Sensor

Photoelectric sensor consists of a built-in emitter and receiver unit. The photoelectric sensor is normally open and PNP type, the basic working principal is reflection of light. The emitter emits the light beam on to the material, the light gets reflected from the material surface and is received by the receiver. Based on this signal it gives corresponding output to the PLC. In this project we have used two types of sensor i.e. E3FA-DP12 sensor with plastic housing and E3FB-DP12 sensor with metal housing, although the all the other parameters are identical. The sensitivity of the sensor can be adjusted using the sensitivity adjuster screw.

1.4.3 Controllers

A. Programmable Logic Controller

A Programmable Logic Controller (PLC) is an industrial computerized control unit/controller which continuously monitors the signals of input devices and makes decisions based upon a custom program according to the application, to control the signals of output devices. The PLC-type that will be used is DELTA-DVP14SS211R that has 8 inputs and 6 outputs, additionally we used DELTA-DVP16SP11R extension module which has 8 inputs and 8 output. We chose Delta PLC because of its good quality, easy to be programmed, has accepted the price and meet the required purpose.

A. Human Machine Interface (HMI)

A The HMI (Human Machine Interface) system represents the interface between the worker (operator) and machine (process/plant).The actual unit which controls all the processes is PLC. Hence, there is an interface requirement between the worker (operator) and HMI device and an interface requirement between HMI device and the PLC. In this project we used DOP-B035211 Delta HMI which has 4.3 inch touch display.

1.4.4 Protection System

B. Emergency Stop Switch

Emergency Stop Button 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.

C. Circuit Breaker

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit. The main function of circuit breaker is to protect the electrical devices and humans 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).

D. Fuse Terminal Block

Fuse terminal Blocks are intended to protect motors, controllers and branch-circuit conductors against excessive heating due to long motor over current 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.

1.4.5 Pneumatic System

A. Double Acting Cylinder

A double-acting pneumatic cylinder is one where the thrust, or output force, is developed in both extending and retracting directions. Double-acting cylinders have a port at each end and move the piston forward and back by alternating the port that receives the high-pressure air, necessary when a load must be moved in both directions such as opening and closing a gate.

B. Solenoid Valves

The solenoid valve is an electro-mechanical 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.

C. Vacuum Generator

A vacuum ejector, or simply ejector is a type of vacuum pump, which produces vacuum by means of the Venturi effect. In an ejector, a working fluid (liquid or gaseous) flows through a jet nozzle into a tube that first narrows and then expands in cross-sectional area. The fluid leaving the jet is flowing at a high velocity which due to Bernoulli's principle results in it having low pressure, thus generating a vacuum.

D. Air Compressor

An air compressor is a pneumatic device that converts power into potential energy stored in pressurized air (i.e., compressed air). By one of several methods, an air compressor forces more and more air into a storage tank, increasing the pressure. When the tank's pressure reaches its engineered upper limit, the air compressor shuts off. The compressed air, then, is held in the tank until called into use

2. CALCULATIONS

2.1 Gantry Design

In this sorting mechanism we used gantry to pick and place objects in their respective trays. As shown in Figure 3.1, Gantry has motion in x and y-direction and supported by roller wheels. In total 12 roller wheels are used for x-direction motion and 6 wheels are used for y-direction motion. So we need to find the force required to move the gantry.

A) Weight of Gantry:

$W = m.a_g$

$= 5 * 9.81$

$= \mathbf{49.05\ N}$

Where:

W: Weight of the body (N)

m: Mass of body (Kg)

ag: Acceleration due to gravity (m/s2)

B) Rolling Resistance:

F_r= c * W

= 0.057 * 49.05

= 2.796 N

Where:

Fr: Rolling resistance or rolling friction(N)

c: Coefficient of rolling friction

C) Total Force

Force Required to push the Gantry = Pulling force

Pulling Force (P) = rolling resistance

= 2.796 N

But we are using 12 wheels

Total Force (F_t) = 12 * 2.796

= 33.55 N

To push the Gantry we are using Pneumatic piston.

2.2 Selection of Conveyor Motor

PROPERTIES	VALUE
Aluminium Density	2710 Kg/m^3
Belt Density	1000 Kg/m^3
Belt Thickness	0.0015 m
Belt Width	0.14m
Diameter of Pulley	0.050 m
Friction of Coefficient	0.5

Table -1: Mechanical Properties

Conveyor belts are elastic/flexible machine elements that 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 pulleys. Fig 9 shows a flat belt geometry.

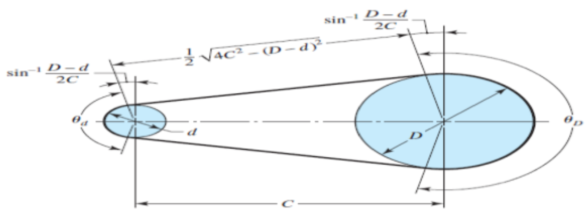


Fig -9: Flat Belt Geometry

A) Length of Conveyor Belt

Length of Conveyor Belt = 2 * (CD) + 2 * (π.r)

= 640 + 640 + 2 + 3.14 * (53/2)

= 1280 + 166.5

= 1446.5 mm

B) Weight of Belt

Weight of Belt = Length * Thickness * Width * Density

= 1.4465 * 0.0015 * 0.140 * 1000

= 0.303 kg

C) Torque required

Assuming, External force = 100 N

Max. Weight of Object- 0.2 Kg

Torque required to drive the conveyor belt(T)

= 0.5 * D*[F + (μ * W * g)] Nm

= 0.5 * 0.053 * [100+(0.5 * 0.2 * 9.8)]

= **2.675 Nm**

Were

D = Roller Dia. (m)

W = Load Mass (Kg)

g = Gravitational Acceleration (m/s2)

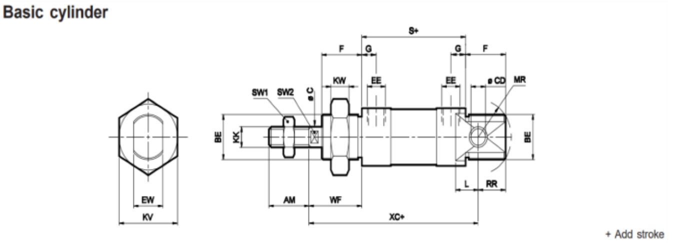
F = External Force (N)

μ= Friction Coefficient

Generally, due to manufacturing defaults, misalignments and other various factors theoretical values varies from actual values therefore we will select conveyor motor which has more torque than calculated torque.

2.3 Selection of Pneumatic Cylinder

Pneumatic cylinders were used in this system to push and pull gantry, to lift com- ponents from conveyor belt, to feed components to the conveyor belt and to reject components from conveyor belt. Due to time constraints we selected standard double acting pneumatic cylinder from market, these cylinder having bore diameter ranging from 12mm to 25mm, and stroke length ranging from 10 mm to 300mm. According to our application we selected two double acting cylinder having bore length 12 mm and stroke length 250 mm, and three double acting cylinder having bore length 12 mm and stroke length 100 mm. Now to check whether this cylinders can lift the load we performed following calculations, for reference see Chart -



Cylinder bore Ø	MR	BE	F	CD H9	RR	L	G	EE	S	KW	C	SW1	SW2	KK	AM	WF ±1.2	XC ±1	EW d13	KV	Stroke tol 10 - 100	Stroke tol Above 100
12	17	M16x1.5	17	6	15	9	6	M5x0.8	$51^{\pm 0.5}$	8	6	10	5	M6x1	16	22	75	12	24	+ 1.5 + 0	+ 2.5 + 0
16	17	M16x1.5	17	6	15	9	6	M5x0.8	$58^{\pm 0.5}$	8	6	10	5	M6x1	16	22	82	12	24		
20	20	M22x1.5	20	8	16	12	8	G1/8	$67^{\pm 0.7}$	10	8	13	7	M8x1.25	20	24	95	16	32		
25	21	M22x1.5	22	8	17	12	8	G1/8	$71^{\pm 0.7}$	10	10	17	9	M10x1.25	22	28	104	16	32		

Chart -1: Cylinder Specification

B) Pull Force

Theoretical pull force is:

F = π (D²/4 – d²/4) P

$$F = \pi (D^2/4 - d^2/4) P$$

= 3.14 * (0.0122/4 - 0.0062/4) * 500000

= **42.39 N**

were,

F = force, N

D = cylinder bore, m

P = pressure, N/m2

d = piston rod diameter, m

For sliding gantry, required force was 33.55 N. Therefore, selected cylinder will satisfy the requirement.

A general rule of thumb is that for vertical and high-friction applications, the required force should be twice the load to be moved.

Therefore,

$$\mathbf{F_{effective} = 21.195\ N}$$

For lifting the objects (having max weight, 1.962 N) from the conveyor belt, required force is 1.962 N. Therefore, selected cylinder will satisfy the requirements.

2.4 Control Design

A) Programmable Logic Controller

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.

PLC Input-Output table

Table 2 and 3 shows the PLC I/O's

Input Mapping	
X0	Emergency Stop
X1	Fault Reset
X2	Cycle Start
X3	Proximity Sensor
X4	Photo Sensor 1
X5	Photo Sensor 2

Table -2: Input Mapping

Output Mapping	
Y0	Fault Reset
Y1	Cycle Start
Y2	Job Pushes Forward (PC1)
Y3	Gantry Slide X-direction (PC2)
Y4	Job Pickup (PC3)
Y5	Suction Activate
Y20	Gantry Slide Y-direction (PC4)
Y21	Job Rejects (PC5)
Y22	Conveyor Motor Start

Table -3: Output Mapping

B) PLC Control Circuit

FIG 10 shows PLC control circuit of machine.

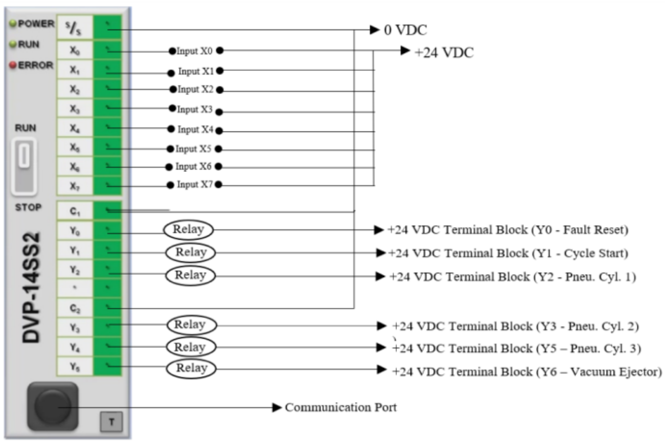


Fig -10: PLC Connections

2.5 Pneumatic Power Circuit

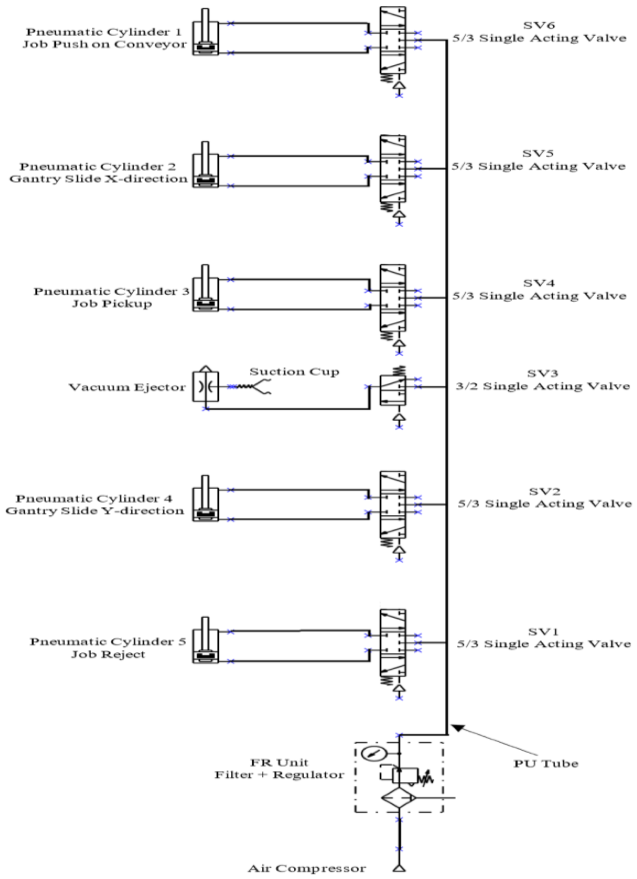


Fig -11: Pneumatic Power Circuit

3. EXPERIMENTAL VALIDATION

This Section provides work implementation, which is divided into three subsystems

3.1Mechanical System:

3.1.1 Conveyor

According to Chapter 2, after calculating necessary values we build the modular conveyor by using aluminium extrusions. We used 20*20 profile aluminium extrusions for conveyor body and designed housing for bearings and conveyor rollers. We purchased conveyor belt from local vendor according to our needs and finally assembled conveyor system.

3.1.2 Gantry Frame

We used 30*60 profile aluminium extrusion for building gantry frame. For gantry movement we used twelve T-slot roller wheels, see figure 4.3. We fixed the gantry frame on 1200 mm*720 mm*7.5 mm wooden board using 30*30 profile corner brackets. And as shown in figure 4.4 we assembled conveyor, gantry frame and collecting trays on wooden board.

3.2 Electrical System

3.2.1 Conveyor Motor

After calculating torque needed to run the conveyor, we purchased Orange MG555 12V 10 RPM Square Gearbox DC motor and attached the motor to conveyor by using flexible coupling. This motor has higher torque than that we calculated in chapter 2, still we selected this motor because it was available at the time and also it was cheaper

3.2.2 Sensors

In this system all the sorting process is done after collecting data from sensors. In this model we used Orange 8mm PNP Inductive Proximity Sensor and Omron Photoelectric Sensor E3FA-DM13.

3.2.3 PLC

Since we were using two sensors, emergency stop switch, fault reset switch, cycle start switch, six solenoid valves and one DC motor we needed total 9 output and 6 input ports but our main PLC module DVP14SS211R has only eight input and six output ports, so we purchased Extension Input output module DVP16SP11R to meet our requirements. After installing PLC in control panel, we tested them and they worked successfully

3.2.4 HMI

We purchased DOP- B03S211 HMI which has 4.3-inch touch display for easy access to system overview. We fixed HMI in control panel, and it worked successfully but in latter stage due to some technical fault HMI wasn't properly communicating with PLC. So, in future we planning to rectify that problem and will try to interface HMI with PLC.

3.2.5 Control Panel

After testing all the components, we assembled them on the DIN rails in control panel. After assembling, we done proper wiring of all components and finally tested the control panel by supplying AC current. Then we fixed the control panel in the cabinet which will protect electrical components from dust and moisture

3.3 Pneumatic System

3.3.1 Double acting Cylinder

Since system needed 5 pistons and according to calculations from chapter 2, we purchased the required pistons and fixed them on gantry frame.

3.3.2 Solenoid Valve

In this model we build Automatic Sorting System so we needed automatic operation of pistons so we used solenoid valves to drive the pistons. Solenoid valves further connected to relays which when received signal from PLC activates the pneumatic cylinders. In total we used six solenoid valves.

3.3.3 Vacuum Ejector and Suction Cup

To lift the components from the conveyor belt, we used vacuum ejectors to generate vacuum and with the help of suction cup the system can lift the components and place them in their respectively trays. We use 22 mm diameter suction cup.

4. VALIDATION

We successfully integrated conveyor system with gantry frame and integrated all the electrical and mechanical components with each other. PLC program was correctly compiled and is running successfully. System is running on designed cycle. Every object is being sorted in their respective tray.

Following results were obtained,

Total working space of gantry	0.0625 m^2
Total Time taken by system to complete 1 cycle	91 sec
Total time taken by gantry to place block in Tray 1	07 sec
Total time taken by gantry to place block in Tray 2	05 sec
Total Time taken by system to sort JOB1 (Metal Black)	25 sec
Total Time taken by system to sort JOB2 (Metal White)	24 sec
Total Time taken by system to sort JOB3 (Non-Metal Black)	23 dec
Total Time taken by system to sort JOB4 (Non-Metal White)	19 sec
Total Time taken by conveyor to complete 1 rotation	41 sec

5. CONCLUSIONS

Conclusions of project work as follows:

- We successfully designed, built and integrated conveyor system with gantry frame for efficient material handling (synchronous working of conveyor and gantry).
- We designed control panel box for mounting the electronic components like SMPS, relay board, HMI, PLC etc. and connected all the components together.
- We programmed the PLC by using WPL Soft Software with ladder programming. The program was compiled successfully and the program is successfully performing event-based control, interlocking and sequencing of operations.
- As compare to manual sorting, automatic sorting is more efficient and faster method and also it reduces the human efforts.
- By doing this project we learned the electronic aspects in automation like circuit design, wiring, panel designing and working of various electronic components.

FUTURE SCOPE

- In future student can modify various component in the system to learn and develop this model further.
- This kind of model can also be used for small scale industries by making some changes in it.
- In future this project can be used for educational purposes by allowing student to change or modify various sensor and interfacing them with PLC.
- Computer Vision can be integrated in this model to enhance and increase the sorting capacity

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