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Design and Development of PLC Controlled Pneumatic Pressing System

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***Abstract* - This article discusses about the design and development of an efficient, cost effective, and automatic pneumatic pressing system. The pressing machine consists of a three pneumatic cylinders namely Feeder, Ram, and Pusher respectively and three double solenoid directional control valves. These cylinders are selected based on requirement for pressing the object. The directional control valves are controlled by a programmable logic control (PLC). Ladder logic is developed in the PLC which controls the actuation of the DCVs. This makes the machine completely automatic with no manual intervention which increases the accuracy of the machining and the quality of the obtained product. The electro pneumatic circuits of the pressing machine are simulated using the automation studio software and the system is modelled using modelling software. Further, the simulation and the modelling provided the optimum design of the machine, which can be implemented on to the physical model to obtain an efficient operation which gives a good quality product.**

Keywords: Pressing machine, Feeder, Ram, Pusher, PLC, and Automation Studio.

I. INTRODUCTION

Programmable Logic Controllers, commonly known as PLCs, are integral components of industrial automation systems. These electronic devices are designed to control and automate various industrial processes and machinery. They play a crucial role in enhancing efficiency, accuracy, and safety within manufacturing, production, and other industrial settings.

PLCs were originally developed as replacements for traditional relay-based control systems. They provide a more flexible and versatile approach to process control by utilizing digital logic and programming [11].

A. Function and Purpose

PLCs are designed to monitor and control a wide range of processes and equipment, including assembly lines, robotic systems, pumps, motors, conveyors, and more. They receive input signals from sensors and other devices, process these inputs using a user-defined program, and then generate output signals to control actuators and devices that influence the process being automated.

Ladder Logic is the most common programming language used for PLCs. It mimics the appearance of traditional relay logic diagrams, making it easy for electricians and technicians to understand. However, PLCs can also be programmed using other languages like Structured Text

(similar to programming languages like C) and Function Block Diagrams.

B. Operation

The operation of a PLC involves a cyclical process:

Scan Cycle: The PLC scans its inputs, reads their statuses, and updates the corresponding memory values. Execution Phase: The PLC processes the control logic program using the input data and updates the output values accordingly.

Output Update: The updated output values are sent to the connected devices (actuators) to control the industrial processes.

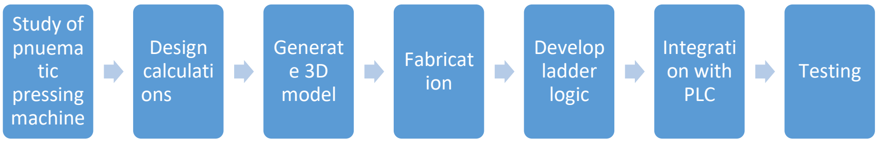
Repeat: The entire scan cycle repeats at a high speed, typically measured in milliseconds, ensuring real-time control and responsiveness.

II. LITERATURE SURVEY

Duc Thinh Pham et.al, (2022) [1] evaluates experimentally the position control ability of a pneumatic cylinder by using pneumatic systems and the PLC. PID controller is used to define the accurate position.

Chengxiang Li et.al, (2018) [2] discussed about the design of osculum type pneumatic unloading manipulator based on PLC control. Osculum type pneumatic unloading manipulator a device or system that uses pneumatic (compressed air) power to control a manipulator, which is a mechanical arm or device designed to handle, move, or manipulate objects.

Paul G. Harris et.al, (2012) [3] discusses about a model and an identification method appropriate for typical industrial, open-loop controlled, pneumatic systems. Open-loop pneumatic control using a PLC is suitable for simple tasks or processes where a predefined sequence of actions is sufficient, and precise positioning or feedback is not critical. However, for applications requiring greater



accuracy, stability, and error correction, a closed-loop control system with feedback mechanisms is typically employed.

Michell Idrovo Urgilés et.al,(2018)[4] analyzes the different solutions of remote laboratories (RL), specifically in the area of pneumatics and electro-pneumatics. Ranjeeta Singh et.al, (2017) [5] discusses about the design and development of a PLC-based controller for pneumatic pressing machine, which performs the most critical operation in an engine bearing manufacturing plant. The paper firstly overviews the manufacturing process of engine bearing and then discusses the need of automating the pneumatic press. The PLC program was emulated on RSLogix Emulate-500 and the operations of the pneumatic press were simulated on FluidSIM-P. The results of simulation validate the design of PLC- based controller in general and digital input-output connections of the PLC and PLC program in particular. A PLC-based controller offers flexibility, reliability, and the ability to easily modify and expand the control logic as needed. It allows for precise control over the pneumatic pressing process and can integrate various safety features to meet regulatory requirements and ensure the well-being of operators. Kelaginamane et.al,(2015)[6] describes about the design and fabrication of automatic sheet metal punching machine controlled by Programmable Logic Controller (PLC). It also describes the working principle and the hardware structure of the system. By automating the punching system one can have greater control over the whole process. This system can replace existing manual feed and operated punching machines. By interfacing PLC, it is possible to get good results in the form of increased safety of the worker.

A. Problem Statement

The precision and repeatability of the pressing process depends on the skill and experience of the operator. Closed feedback system is quite difficult in semi-automated system. Collection of data and analysis are usually manual and time-consuming. Safety measures may rely on physical barriers and operator vigilance. Emergency stops and safety protocols are dependent on human response. So by incorporating PLC controlled system the problems mentioned above can be overcome.

B. Objectives

Design and development of pneumatic controlled pressing machine through PLC and mechatronics system. Simulation of the pressing machine using automation studio software.

C. Methodology

III. MATERIALS AND METHODS

A. Pneumatic Cylinder

A pneumatic cylinder as shown in fig.1 converts compressed air energy into a reciprocating linear motion. They are simple to use and are a cost-efficient solution to move loads linearly, making them commonly used in the automation of machines and industrial processes. Double-acting pneumatic cylinders allow for complete control of the piston's movement. Double-acting pneumatic cylinders allow for complete control, extended piston stroke length, and a constant output force through the entire stroke. Since they use compressed air in both directions, they use more energy. They can also operate at higher cycling rate [9].

Fig 1: Double acting pneumatic cylinder

B. Directional Control Valve

Directional control valves as shown in fig 2 are extensively used in industries for the passage of fluid in the system. It is difficult to adjust manually every control valve at the right time. It controls the fluid flow in a hydraulic or pneumatic system by changing the position of its internal components. It permits or restricts fluid flow to the actuator by opening and closing its ports. A 5/2 way double solenoid valve, commonly known as a 5-port, 2-position double solenoid directional control valve, has one input, two output, and two exhaust ports. There is no spring return function on the double-solenoid valve. The position is attained by activating the coils in this sort of valve. When voltage is delivered to a solenoid coil, the double solenoid valve is reversed and remains in this switching state until an opposing signal is applied[10].

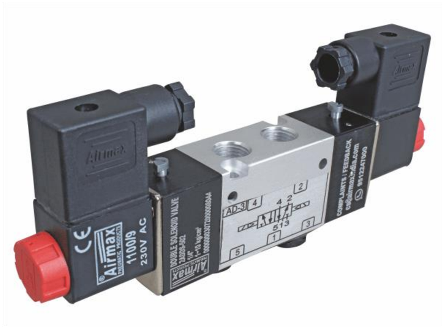


Fig 2: Directional Control Valve

C. Air Compressor

A common application is to compress air as shown in fig 3 into a storage tank, for immediate or later use. When the delivery pressure reaches its set upper limit, the compressor is shut off, or the excess air is released through an overpressure valve. The compressed air is stored in the tank until it is needed. The pressure energy provided by the compressed air can be used for a variety of applications such as pneumatic tools as it is released. When tank pressure reaches its lower limit, the air compressor turns on again and re-pressurizes the tank. A compressor is different from a pump because it works on a gas, while pumps work on a liquid.

Fig 3: Air Compressor

D. Filter, Regulator and Lubricator unit

Filter, regulator, and lubricator (FRL) as shown in fig 4 units in compressed air systems deliver clean air at a fixed pressure. They are lubricated, if necessary, to ensure proper pneumatic component operation, which increases their operational lifetime. The air supplied by compressors is often contaminated, over-pressurized, and non-lubricated, meaning an FRL unit is required to prevent damage to equipment. Filters, regulators, and lubricators can be bought individually or as a package depending on the need for components to meet the proper air specifications for downstream equipment.

Fig 4: FRL Unit

E. Magnetic Reed Switch Sensor

A magnetic reed switch sensor as shown in fig 5 is a type of proximity sensor that detects the presence of a magnetic field. It is composed of two ferromagnetic, reed-like metal contacts encased in a glass or plastic tube that is filled with an inert gas (such as nitrogen). The contacts are normally open (separated) when no magnetic field is present, and they close (make electrical contact) when exposed to a magnetic field.

Fig 5: Magnetic Reed Switch Sensor

IV. DESIGN CALCULATION FOR PRESSING MACHINE.

The feeder, pusher and ram has been designed based on the below calculations.

A Feeder and Pusher

Operating pressure = 6 bar

Bore diameter = 25 mm

Stroke = 100 mm

Forward direction,

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Force = Pressure * Area

$$\text{Force} = \frac{6*10^5 * \pi *(25*10^{-3})^\wedge 2}{4}$$

Force = 294.524 N

Force = 30.022 kg

In reverse direction,

$$\text{Area} = \frac{\pi * d^2}{4} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$= \frac{\pi *(25*10^{-3})^\wedge 2}{4}$$

$\mathbf{A_p = 0.00049087\ m^2}$

Piston diameter = 12 mm

$$\text{Area} = \frac{\pi * d^2}{4}$$

$$= \frac{\pi *(12*10^{-3})^\wedge 2}{4}$$

$\mathbf{A_r = 0.0001130\ m^2}$

Area = Ap - Ar

= 0.00049087 – 0.0001130

Area = 0.0003778 m²

Force = Pressure * Area

$= 6 * 10^5 * 0.0003778$

Force = 226.28 N

Force = 23.066 kg

Velocity,

Forward direction,

$$V = \frac{Q}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

$$V = \frac{0.5}{0.00049087}$$

V= 1018.599 m/s

For reverse direction,

$$V = \frac{Q}{A}$$

$$V = \frac{0.5}{0.0003778}$$

V= 1323.451 m/s

B. Ram

The pressing force can be calculated by using the formula,

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$F_p = l*t*\tau$ …………………………..(4)
Where, F_p is the pressing force
l is the pressing profile length [mm] = 10 mm
t is the material thickness [mm] = 0.7 mm
τ is the material shearing resistance [kgf/mm^2]. = 7 kgf/mm^2
Therefore,
$F_p = l\ t\ \tau$
$= 10\times0.7\times7$
F_p = 49 kgf
F_p = 480.69 N

To calculate the force applied by the dead weight that is mounted on the pressing piston head,
P.E = weight × gravitational force × height ……(5)
Here weight is 2.5 kg, gravitational force is 9.8m/s^2 and height is 0.1m.
Therefore,
P.E = 2.5 × 9.8 × 0.1
P.E = 2.45 J

The force exerted by the pneumatic system is added with the force exerted by the dead weight to get the total pressing force.
Therefore,
Total pressing force = P + P.E …………….(6)
Where P is pressing force
P.E is potential energy.
Here the value of pressing force is 49kgf and the value of potential energy is 2.45 J. Then
the equation will be
Total pressing force = 49 + 0.245
= 49.245 kgf
= 483.03 N

V. MODELLING

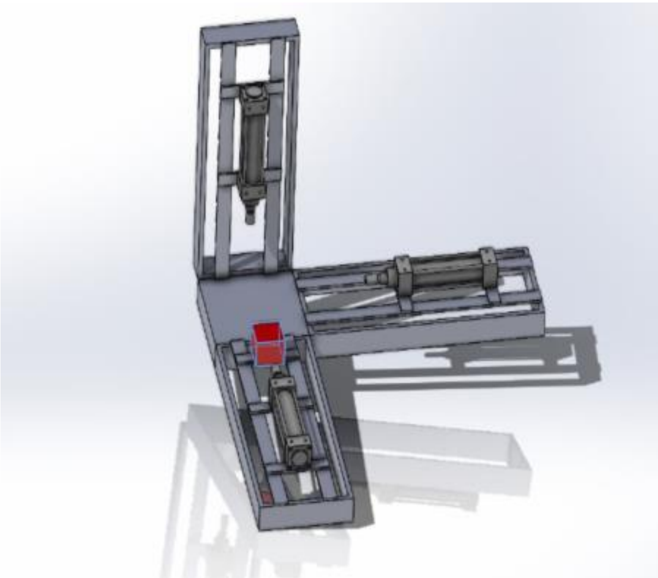

Fig 6: 3D model of pressing system

A. Working of the pressing system

The main function of the pressing machine is to press the work piece which is fed by the feeder. This pressing operation is carried out by the ram. Initially, when the object is placed in the specified position. The function of the feeder is to feed and hold the work piece until the ram cylinder presses the work piece. All three cylinders is two sensors to sense the position of the piston inside the cylinder. The work piece is placed manually in front of the feeder. The position of piston of cylinder A at the bottom dead center is sensed after which a signal is sent for Solenoid 1 of the cylinder A to actuate the piston. The feeder feeds the work piece and places the work piece in the position where it has to be pressed. Then the sensor 3 is senses the piston in BDC of Ram cylinder. Then the signal is sent to the solenoid 3 which actuates the piston which presses the work piece which fed through the piston. Then the sensor 4 will sense the piston in TDC and the signal is sent to the solenoid 4 which will actuate the piston back to the BDC. The feeder cylinder piston will be in TDC so that the sensor 2 senses that and the solenoid 2 is actuated and it also sends back the piston to the BDC. Then the sensor 5 senses the piston in BDC of the pusher cylinder and actuate the piston of pusher cylinder, which pushes the work piece out of the platform. Then the sensor 6 senses the piston in TDC of the pusher cylinder. The solenoid 6 which sends back the piston to the BDC of the pusher cylinder. Then the cycle repeats.

The flow chart of the operation is shown in the flow chart, this gives the clear idea of steps carried in the operation. In this system the sensors mounted on the cylinders is considered as the input and output of this system is considered as the solenoid in order to actuate the cylinder for the pressing operation.

B. Flow chart

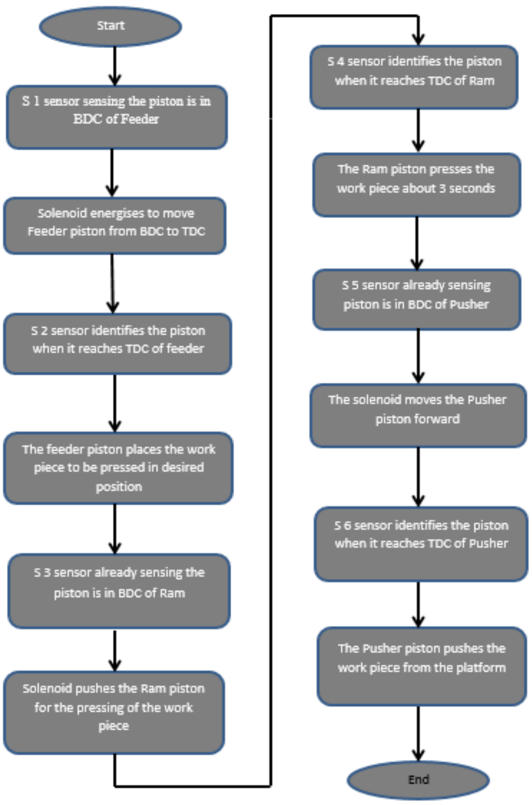

Fig 7: Flow chart of the working of Pressing System

VI. WORKING IN AUOMATION STUDIO

A simulation model of the pressing machine is built in the Automation Studio software. As shown in the above figure double acting cylinders connected to the pressure source through the double solenoid 5/2 directional control valve. The DCV connected to the feeder cylinder has two solenoids, Sol1 and Sol2. The feeder cylinder has two position sensors Sen1 and Sen2, which detect the position of the piston in the cylinder at the bottom dead center and top dead center respectively. The DCV connected to the Ram cylinder has two solenoids, Sol3 and

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Sol4. The cylinder has two position sensors Sen3 and Sen4, which detect the position of the piston in the cylinder at the bottom dead center and top dead center respectively. Similarly Pusher cylinder has two position sensors Sen5 and Sen6, which detect the position of the piston in the cylinder at the bottom dead center and top dead center respectively. The PLC input and output cards are placed where the input card is connected to the contact switches of the sensors and the output card is connected to the solenoids. This is because, the output from the sensors is taken as an input to the PLC and using this input, the output is given to the solenoids which actuate the pistons in respective cylinders.

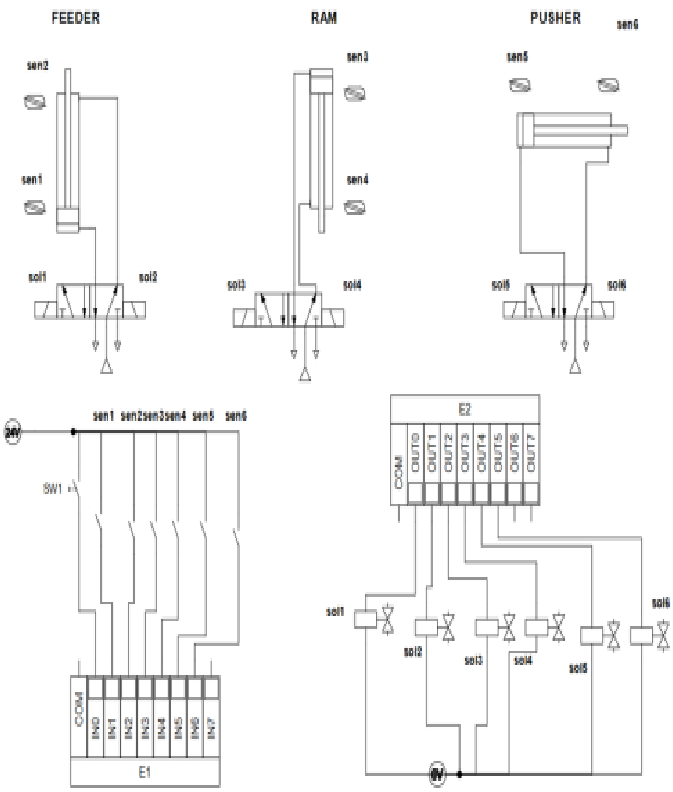

Fig 8: Simulation using automation studio software

VII. PLC LADDER LOGIC

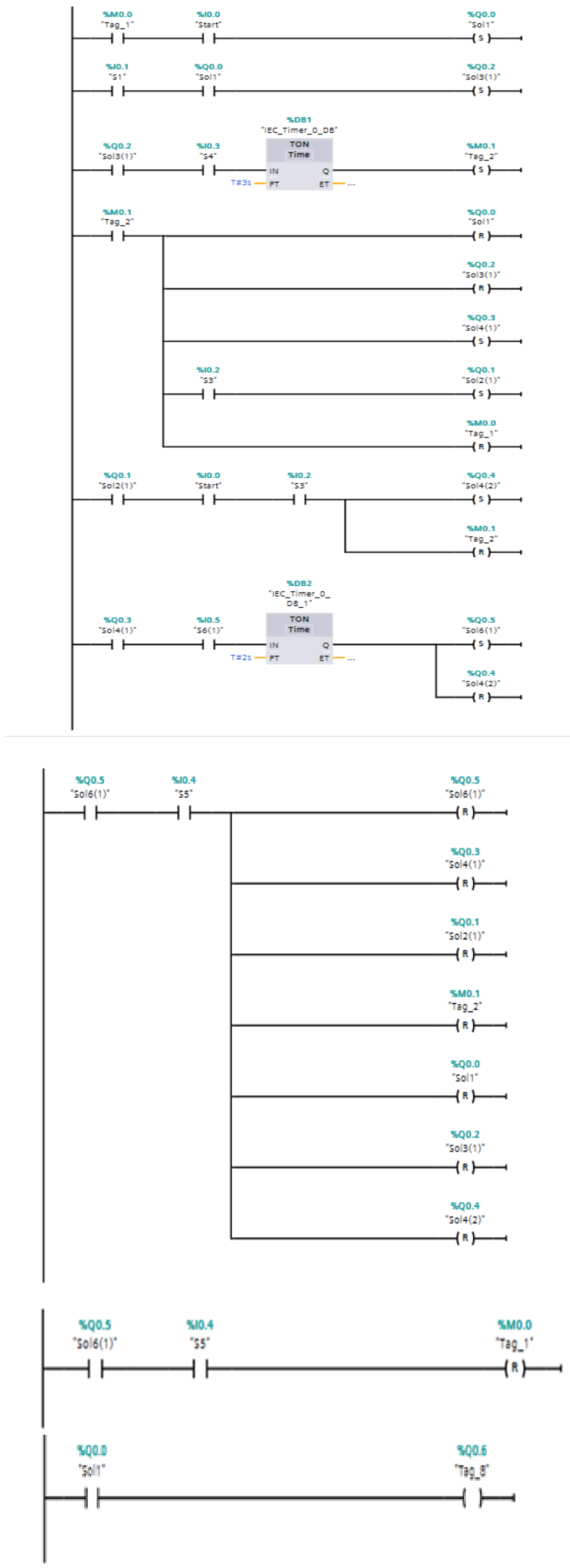

Fig 9: PLC Ladder Logic Diagram

The figure 9 shows the ladder logic diagram for the control of pneumatic pressing system. The PLC ladder logic is used to control the actuation of the cylinders. In the PLC ladder logic, I stands for input terminal, Q stands for output terminal and 0.0, 0.1, 0.2 stand for the first, second and third terminals and so on. This ladder diagram can be interpreted as when the process starts the sensor 1 which is mounted on feeder cylinder senses the piston and the output is from solenoid 1 which will feeds the work piece to be pressed. Then the sensor 3 of the ram cylinder already sensing the piston of the Ram cylinder in BDC and the output from the signal to the solenoid 3 which presses the work piece. Then the sensor 4 senses the piston in TDC while pressing the work piece and after 3 seconds, the solenoid 4 which pushes back the cylinder piston to BDC after pressing. The feeder piston is in the TDC position, the sensor 2 sensing the piston in TDC the solenoid 2 energizes and sends back the piston to the BDC. The sensor 5 of the pusher cylinder sensing the piston the solenoid 5 pushes the pusher cylinder piston to push the work piece outside the platform. Then lastly the sensor 6 senses the piston and after 2 seconds the solenoid 6 energizes which pushes back the piston to the BDC of the pusher cylinder. The process will continue as per the same cycle.

VIII. FABRICATED MODEL

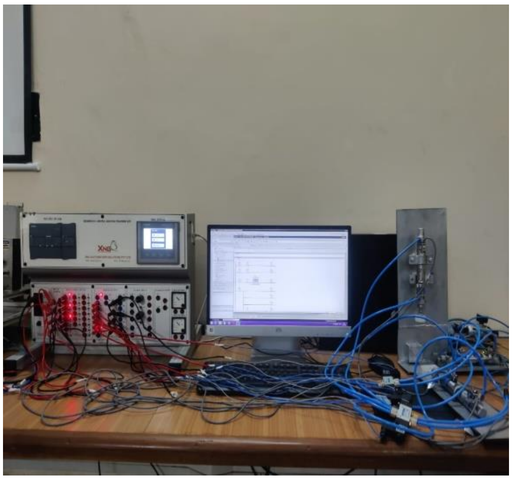

Fig 10: Pressing System Integrated with PLC

The integration of the pressing system to PLC can be done by connecting the sensors and actuators to the PLC's input/output modules. The sensor is connected to the PLC as the input, and the 5/2 double solenoid valves are connected to the PLC as the output. These modules act as interfaces between the physical components and the PLC. Connecting the control valve and other relevant pneumatic components to the PLC's output modules. This allows the PLC to control the flow of compressed air and the pressing action. Utilize the PLC's capability to collect data from sensors and provide real-time feedback on the pressing process's progress. The PLC program can store data about pressing cycles, force applied, success/failure status, and other relevant metrics. Integrating a pressing system with a Programmable Logic Controller (PLC) can enhance the automation, control, and monitoring of the pressing process [7][8].

IX. CONCLUSION

The primary objective of this project, the successful fabrication of pressing machine and integration with PLC has accomplished. All stages of the development process have been thoroughly documented.

The key takeaways from the adoption of a PLC controlled pressing machine include

- It combines the flexibility of programmable logic controllers (PLCs) with the precision and power of pneumatic systems, resulting in improved efficiency, accuracy, and safety in various production processes
- One of the main advantages is it's cost-effectiveness. Since there is an abundance of air, pneumatic systems which use air as fuel, do not demand extra cost for other fuels such as hydraulics which uses oil as its fuel.
- The PLC control ensures unparalleled precision and consistency in the pressing process. Parameters such as pressure, force, and time are meticulously controlled, resulting in uniform and high-quality output. This level of accuracy significantly reduces defects and rejects, ultimately contributing to improved product quality.
- The ability to reconfigure and fine-tune parameters through the PLC program enables quick changeovers, reducing downtime and facilitating seamless transitions between different pressing operations.
- Real-time data monitoring and logging capabilities has achieved which will gives valuable insights to the pressing system.

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