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INTRODUCTION

Overview

Mechatronics is the synergistic combination of mechanical engineering, electronic engineering, control engineering, systems design engineering, and computer engineering to create useful products. Mechatronics engineering therefore encompasses many enabling technologies that are considered the key elements of design, operation, and control of modern smart systems. These technologies include signal processing, system interfacing, sensor integration, drive technology, actuation systems, software programming, and motion-control systems. This mechatronics lab however is formulated and prepared in a way that meets those technologies' fields. In doing so, mechatronics lab employs recent equipment and components, different types of sensors, different types of actuators, embedded systems (microcontroller and Arduino) and programs based on mechatronics applications. In addition to that, mechatronics lab employs a large number of electrical and electronic components with different values. The chosen experiments of the mechatronics lab therefore are formulated and designed to meet the basic mechatronics system design and requirements. They are also designed to introduce students to the recent technologies, concepts as well as components of mechatronics system. This mechatronics lab however contains fifteen experiments divided into five main parts as follows:

- **Part I:** Control System and Programing.
- **Part II:** Automation Systems.
- **Part III:** Electrical and Electronics Applications for Mechatronics Systems.
- **Part IV:** Measurement and Transducing.
- **Part V:** Electrical Actuator.

Mechatronics Lab Objectives

The main objectives of this Lab are:

i) To introduce students to the soft and hard elements of mechatronics system.
ii) To conduct different types of experiments that are related to mechatronics system.
iii) To introduce students to the main procedures of running the machines and what the main safety aspects are to be considered when running the machine.
iv) To familiarize students to work harmonically within a group.
v) To introduce students to the main measuring instruments and how to engage them.
vi) To teach students how to interpret and handle data.
vii) To teach students how to handle troubleshooting.

Mechatronics Lab Outcomes:

Upon conducting the experiments of Mechatronics Laboratory, the students should be able to gain the following skills:

i) Ability to apply knowledge of mathematics, science, and engineering (a).
ii) Ability to design and conduct experiments, as well as to analyze and interpret data (b).
iii) Ability to design a system, component, or process to meet desired goals (c).
iv) Ability to function on a multi-disciplinary team (d).
v) Ability to identify, formulate, and solve engineering problems (e).
vi) Understanding of professional and ethical responsibility (f).
vii) Ability to communicate effectively (g).
viii) Recognition of the need for, and be able to engage in, life-long learning (i).
ix) Knowledge of contemporary issues (j).
x) Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (k).

Mechatronics Lab Instructions

The following instructions are very important and to be taken in consideration when conducting mechatronics lab:

- Students are required to formulate their groups with a maximum of three students each.
- Every single person in the group is required to prepare for up-coming experiment (pre-lab) and submit the preparation (pre-lab sheet) to the demonstrator at the start of the lab.
- Students are to be present in the lab 10 minutes before starting the lab and they have to prepare the equipment and components needed for their experiment.
- No student is allowed to join the lab after 10 minutes late from the scheduled starting time (reasonable excuses are looked into).
- No drinks or food allowed in the lab.
- Students can use whatever equipment and components available in the lab only with the permission of the demonstrator or technician.
- Students are to follow the safety requirements labeled on the machine or mentioned by the demonstrator.
- No equipment or component is allowed to be taken outside the Lab without technician or demonstrator permission.
- Any attempt of copying other's report will impose you to withdraw the course.

Note: *Any student who doesn't follow the previous instructions will face formal actions.*

Part I

Control System and Programing

This part is concerned with some topics related to control system as well as program based mechatronics applications. As it is well known, control system is considered the mind of mechatronic system which has the ability to produce commands that match user requirements. Although the concept of control system and its applications' programs are considered very wide and variant, this mechatronics lab presents electronic control of pneumatic circuit based on ladder diagram perception. A study on how to use and how to build mechatronics system using LabVIEW program is then released which helps students to get familiar with LabVIEW program and also explains to the students the importance of using such program. At the end of Part I, an experiment based on Arduino embedded system is then presented as Arduino is considered very powerful tool for learning stage and programming small project.

Experiment # 01

Pneumatic Circuit Control

Section A: Ladder Diagram

This section presents the definition of a ladder diagram, description of how a ladder diagram operates and how it relates to the pneumatic equipment. In addition to that, the rules of drawing ladder diagrams, as well as connection and operation of basic ladder diagrams (using series (And) logic, parallel (OR) logic and control relays are also revealed. Therefore, upon conducting this experiment, students should be able to assemble and operate basic ladder diagrams, and be able to describe the operation of an electromechanical control relay.

Ladder diagram however is considered a type of control system that depends on a graphical representation. Figure 1.1 shows general appearance of the ladder diagram. The vertical lines on the left and right sides of the diagram represent the positive (+) and negative (-) terminals of a DC power supply.

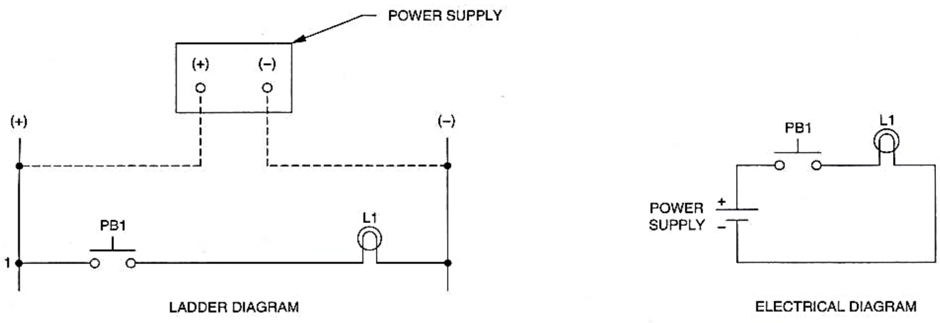


Figure 1.1: Basic Ladder Diagram

The horizontal lines are called rungs. Each rung basically consists of an input element, an output load, and electrical wires. Input elements, such as push buttons and switches, are located on the left side of the rung. Output loads, such as pilot lamps, valve solenoids, and relays coils, are located on the right side.

When the input element on a rung is closed, it forms a continuous path, or closed circuit, to the output load, allowing the current to flow from the positive (+) terminal of the DC power supply to energize the output load. As an example, pressing pushbutton PB-1 in Figure 1.1 causes normally-open (NO) switch contact PB1 in rung 1 to close and pilot lamp L1 to turn on.

Series and Parallel Logic

Two or more input elements can be connected on a rung in series or parallel to form the logic functions AND and OR, as Figure 1.2 shows:

- Rung 1 of the ladder diagram is an example of series (AND) logic. Both switch contacts PB1 and PB2 must close in order for pilot lamp L1 to turn on.
- Rung 2 of the ladder diagram is an example of parallel (OR) logic. Only one of the switch contacts has to close in order for pilot lamp L2 to turn on.

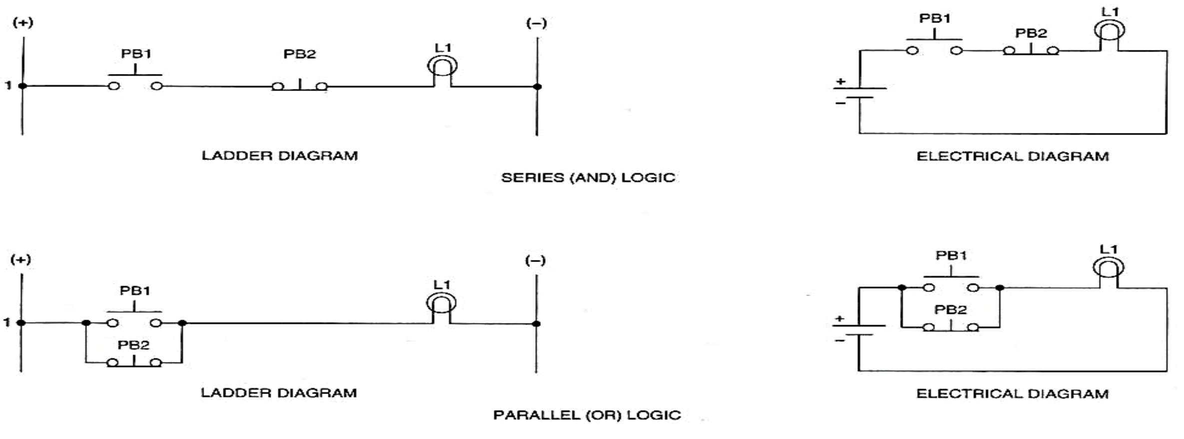


Figure 1.2: Series (AND) and Parallel (OR) Logic

Rules of Drawing Ladder Diagrams

- The ladder diagram presents only electrical control devices, such as switches, relay coils, and solenoids. Pneumatic devices never appear on a ladder diagram, they are drawn on a pneumatic diagram.
- Input elements must be drawn on the left side of the ladder diagram, and output loads must be drawn on the right side. There must be at least one input element and one output load per rung. Input elements should never be connected directly to the negative (-) terminal and load devices should never be connected directly to the (+) terminal of the DC power supply.
- When there are two or more output loads on the same rung, they must be connected in parallel. Loads must never be connected in series on the same rung.
- All ladder rungs must be numbered and each device must be identified with a representative abbreviation. For example, PB is an abbreviation for pushbutton, and CR is an abbreviation for relay coil.
- Contacts operated by a relay coil must be identified with the same abbreviation as the coil which operates them, for example, contacts operated by relay coil CR1 are labeled CR1-A, CR1-B, CR1-C, etc.

Electromechanical Control Relays

Electromechanical control relays are used to perform complex logic functions. As shown in Figure 1.3, they consist of a relay coil, a magnetic core, an armature, and one or more sets of normally-open (NO) and normally-closed (NC) contacts. When current flows through relay coil, the magnetic core and armature attract each other causing the armature to move towards the core. This switches the relay contacts to the activated state. The NO contacts go closed, while NC contacts go open. When the current is removed from the relay coil, the armature is moved back to its original position by spring, which returns the relay contacts to their normal state.

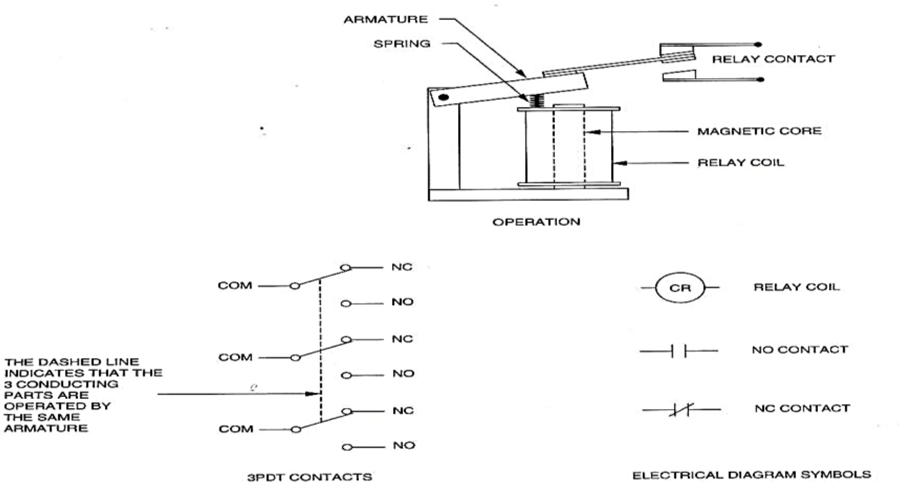


Figure 1.3: Triple-Pole, Double-Throw Control Relays

Parts and Components of Ladder Diagram Experiment:

- DC Power Supply
- Pushbutton Station (2)
- Relay
- Connection Leads
- Pilot Lamp Station

Exercise

- **Basic Ladder Diagram**

  Procedures:

  1. Connect the circuit shown in Figure 1.4

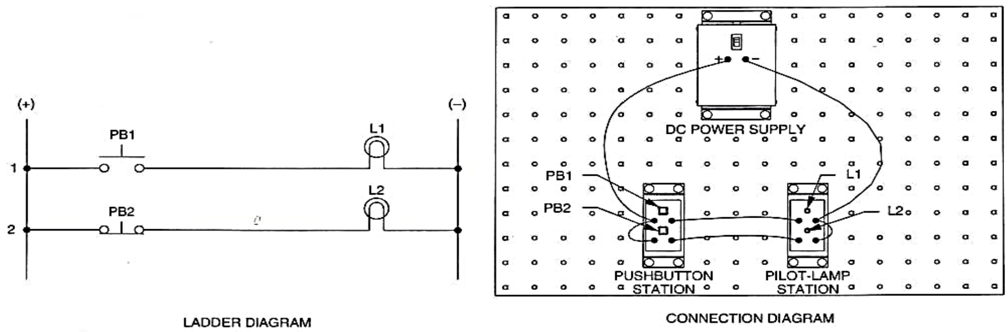


Figure 1.4: Schematic and Connection Diagrams of Basic Ladder Diagram

2. Make sure the power switch on the DC Power Supply is set to the **O** position. Plug line cord of the power supply into an AC outlet.

3. Turn on the Power Supply.
   - Describe the status of each lamp.
   - What happens when you press PB1?
   - What happens when you press PB2?

- **Ladder Diagram Using Series (AND) and Parallel (OR) logic**

  Draw Ladder diagram for series (AND) and parallel (OR) logic and test it.

- **Ladder Diagram Using Electromechanical Control Relays**

  Procedure:

1. Connect the Circuit shown in Figure 1.5

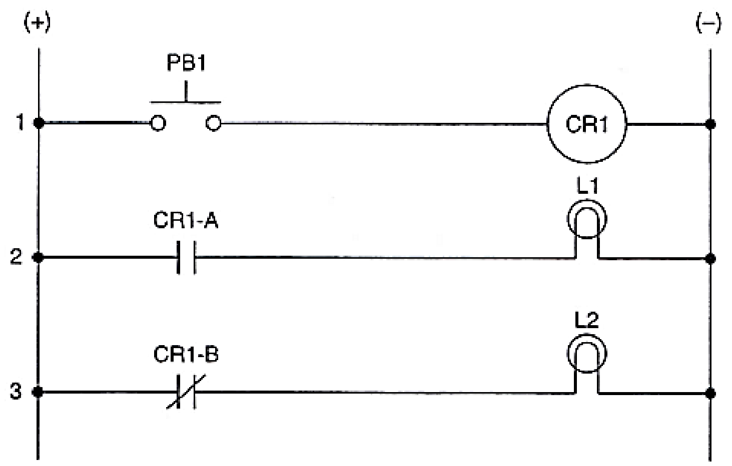


Figure 1.5: Testing a Ladder Diagram Using Electromechanical Control Relays

2. Turn DC power supply on.
   - Is the relay coil CR1 energized at this stage? Why?
   - Depress pushbutton PB1, do not release it at the moment. What happens to pilot lamps L1 and L2? Explain the operation by referring to the ladder diagram.
   - What is the effect of releasing pushbutton PB1? Explain.
   - From your observations, what is the advantage of using a relay coil?

Section B: Basic Electrically Controlled Pneumatic Circuits

The purpose of this section is to introduce students to the concept of cylinder reciprocation, from one side, and to describe the function and operation of quick exhaust valve from other side. It is also required to know the indirect control operation using solenoid-operated directional valves and the function and operation of limit switches as well as magnetic proximity switches.

Cylinder Reciprocation

Many industrial applications require a pneumatic cylinder to be extended and retracted automatically after an operator presses a START pushbutton. This is called cylinder reciprocation. Reciprocation involves a change in the direction of the cylinder. Automatic reversal is achieved by using a sensing device which sends a signal to shift the directional valve when the cylinder becomes fully extended or retracted.

As an example, Figure 1.6 shows a ladder diagram providing one-cycle reciprocation of a cylinder. One-cycle reciprocation means that when started by an operator, the cylinder rod extends, retracts and stops without attention of the operator. Automatic retraction is achieved with a solenoid-operated directional valve activated by the magnetic proximity switch PX1 placed at the end of the extension stroke.

Note: *In the ladder diagram of Figure 1.6, magnetic proximity switch PX1 is shown in activated mode. The side arrow on NO contact PX1 indicates that it is being held in the closed condition before the cycle starts. Magnetic proximity switch PX1 is used to confirm the retracted position of the cylinder rod.*

- Before the operator presses the START pushbutton PB1, the cylinder rod is retracted, as shown in Figure 1.6. Relay coil CR1 is deactivated because an open circuit condition exists in rung 1.
- When pushbutton PB1 is pressed, the current flows from the (+) terminal of the DC power supply, through contacts PB1, PX1, and PX2, to energize relay coil CR1. This closes relay contacts CR1-A and CR1-B. Contact CR1-B causes solenoid SOL-A and pilot lamp L1 to energize. This causes the directional valve to shift and the cylinder rod to extend.

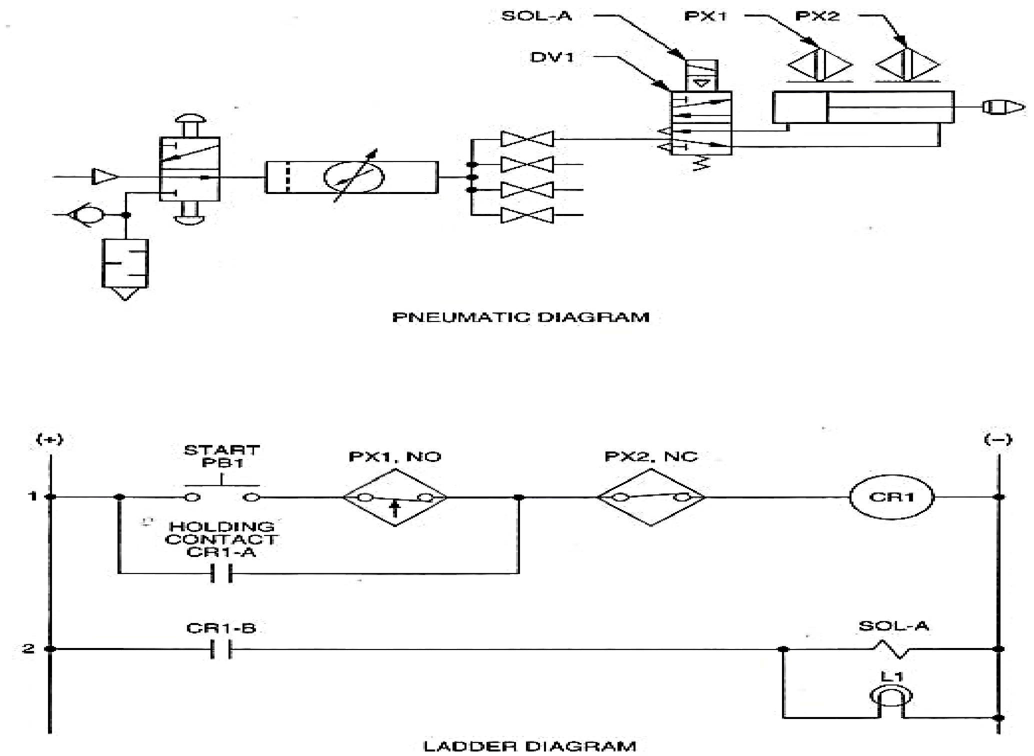


Figure 1.6: One-Cycle Reciprocation of a Cylinder

- When push button PB1 is released, the current continues to flow to relay coil CR1 through the alternate path provided by the holding contact CR1-A being closed. The holding action is obtained by holding current on the coil. Therefore, solenoid SOL-A stays energized and the cylinder rod continues to extend.

- When the cylinder rod is extended, magnetic proximity switch PX2 is activated by the magnetic piston inside the cylinder. This opens NC contact PX2, de-energizing relay coil CR1. This causes relay contact CR1-B to open, de-energizing solenoid SOL-A and pilot lamp L1, causing the directional valve to shift and the cylinder rod to retract. When the cylinder rod is retracted, it stops and waits for the operator to start another cycle.

Magnetic Proximity Switches

In the circuit of Figure 1.6, automatic reversal of the cylinder is achieved by using the electrical signal provided by a magnetic proximity switch when the cylinder rod becomes extended. Magnetic proximity switches are widely used in industrial pneumatic systems to sense the position of a cylinder piston. They can be mounted anywhere within the piston travel range.

The Reed type Magnetic Proximity Switch is shown in Figure 1.7, the switch consist of an internal relay coil controlling a set of NO and NC contacts of the single-pole, double-throw (SPDT) type, and two mechanical reeds (contact point). The (+) and (-) terminals are to be connected to DC Power Supply.

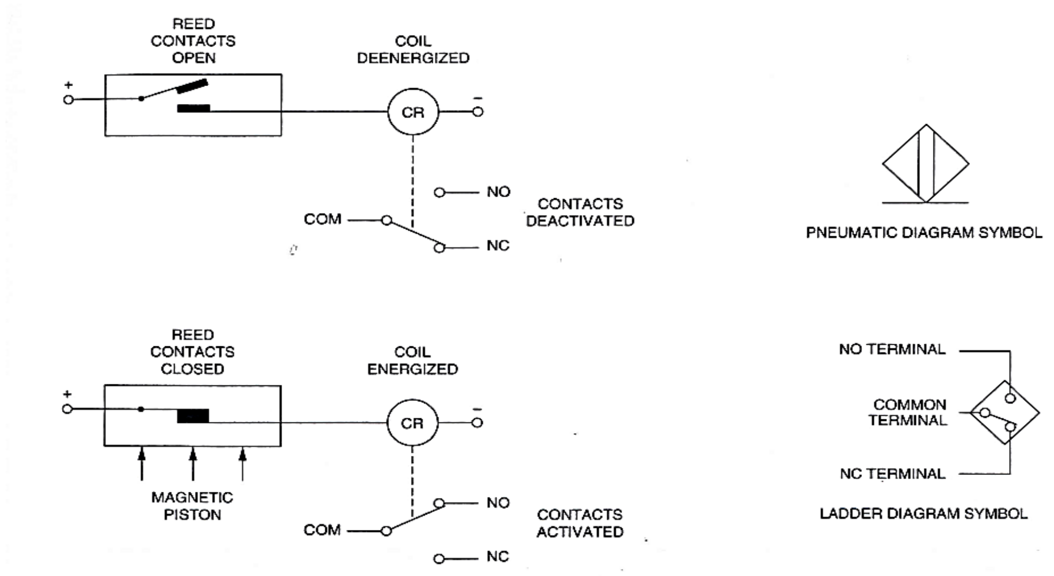


Figure 1.7: Magnetic Proximity Switch of the Reed Type

When the magnetic piston located in the cylinder comes within proximity of the switch, the magnetic field pulls the reed switch contacts together, allowing the current to flow from the (+) terminal to energize the relay coil. This causes the switch SPDT contacts to activate. The NO contact goes closed while the NC contact goes open.

When the magnetic piston moves away from the switch, the reed switch contacts separate, de-energizing the relay coil and the switch contacts return to their normal, deactivated state.

Solenoid-Operated Directional Valves

Solenoid-operated valves have distinct advantages over pilot and manually operated valves that make them an efficient means of actuating directional valves. Solenoid operated valves react almost instantly to the electrical switching signal, while the response time of pilot-operated valves depends on pilot pressure, tubing size, and tubing length.

In the case of a double-solenoid operated valve, it is important to prevent both solenoids from being energized at the same time. One or both solenoids could burn out from excessive current. In the last part of the exercise, you will test an interlocking circuit that prevents solenoids from being energized at the same time.

The solenoid operated valves supplied with your instructor are solenoid-pilot operated type. In this type of valve, the electric current flowing through the solenoid coil produces a magnetic field that move a plunger. Moving the plunger opens a flow path and allows the pilot pressure to act on the valve spool. Note that the spool of the valve will not move if compressed air is not supplied to the valve even though an electric current flows through the solenoid.

As shown in Figure 1.8, the solenoids are equipped with an indicator light and a manual override that allows opening of the flow path without energizing the solenoid.

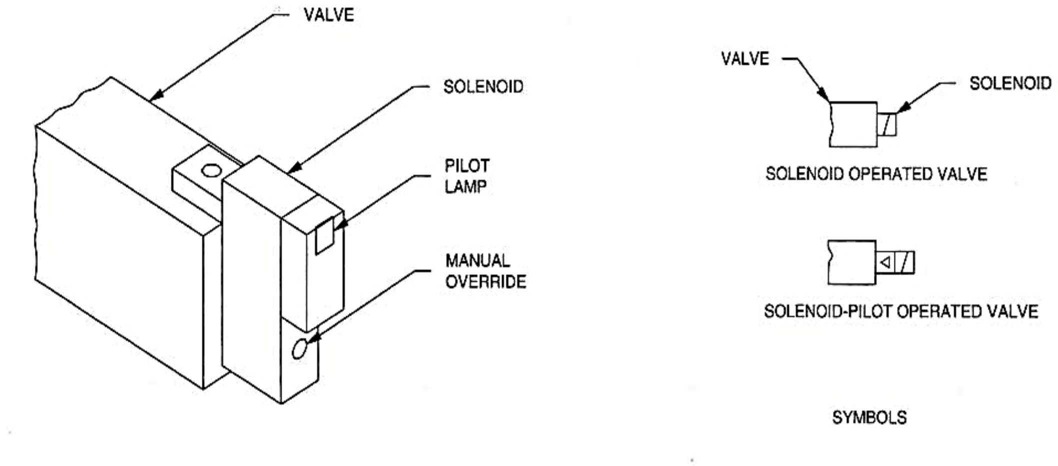


Figure 1.8: Directional Valve Solenoid

Exercise

- **Setting Up The System**

  Procedures:

1. Connect the one-cycle reciprocation circuit shown in Figure 1.12. Screw a tip of the cylinder rod. Do not connect the tubes at the cylinder ports now.

   Note: *The flow Control Valves are used to control the extension and retraction speeds of the cylinder rod.*

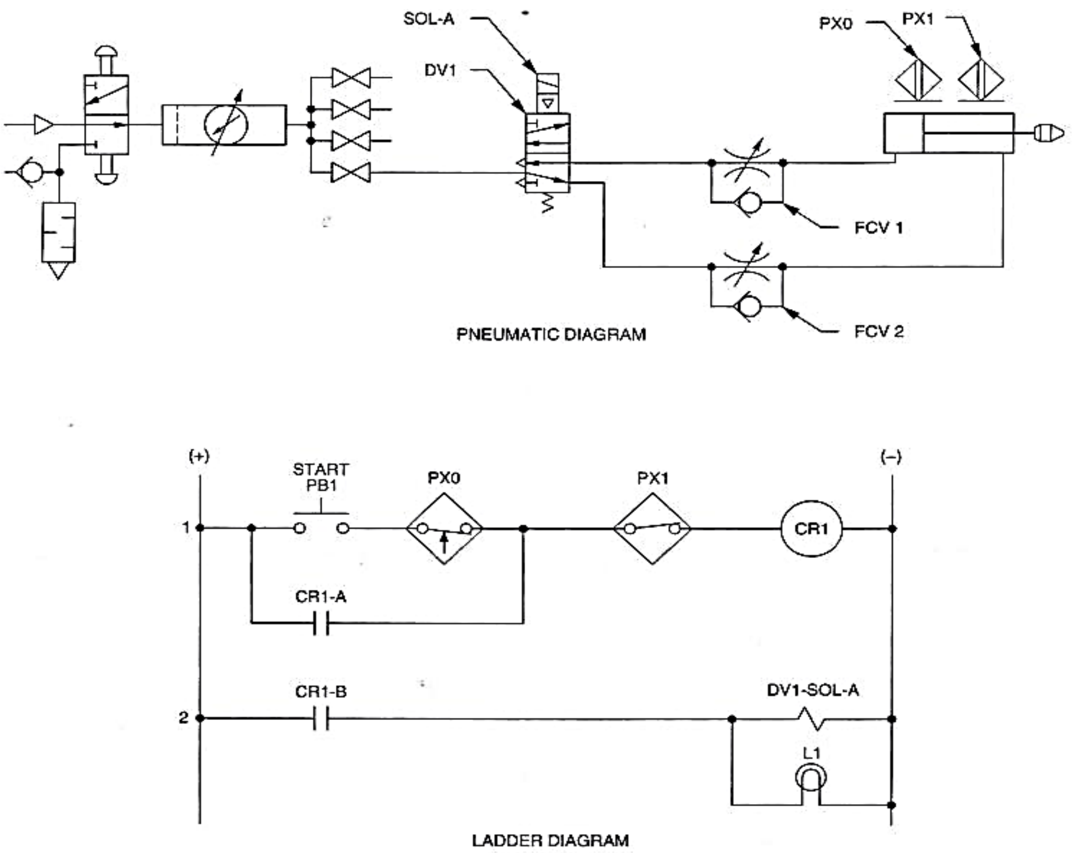


Figure 1.9: Schematic Diagram of a One-cycle Reciprocation System

2. Mount Magnetic Proximity Switch PX1 on the Double-Acting Cylinder so the switch is activated when the cylinder rod is fully extended.

   Note*: Magnetic Proximity Switch PX0 is shown in the activated mode in the ladder diagram of Figure 1.10. The side arrow on NO contact PX0 indicates that it is being held in the closed condition before the cycle starts. Magnetic Proximity Switch PX0 is used to confirm the retraced position of the piston rod.*

- **Testing the Electrical Control Circuit**

  Procedures:

1. Turn on the DC Power Supply. **Do not open** the shut-off valves on the Conditioning Unit at this time
2. Momentarily press the START pushbutton PB1. If the electric circuit is working, pilot lamp L1 should turn on.
3. With your hand. Pull the cylinder rod until it is fully extended. If your circuit is operational, the pilot lamp L1 and the pilot lamp of SOL-A should turn off. Explain why.
4. Retract the cylinder rod and connect the tubes at the cylinder ports.
5. Close the Flow Control Valves by turning the control knobs fully clockwise. Then open each valve by turning the knobs two turns counterclockwise.

- **Testing the One-Cycle Reciprocation System**

Procedures:

1. Verify the status of the trainer according to the procedure given in Appendix B.
2. Open the shut-off valve and the branch shutoff valve at the manifold and set the pressure regulator at 400 kPa (or 60 psi) on the regulated pressure gauge.
3. Start the cylinder cycle by momentarily pressing the START pushbutton PB1.
4. Record what the cylinder rod does and explain what happened by referring to the ladder diagram in Figure 1.12.
5. Does the cylinder rod cycle more than once or does it stop after one cycle? How can you explain that?
6. Start another cycle by momentarily depressing PB1.
7. Is retraction automatic when the cylinder rod becomes fully extended? Explain why, by referring to the ladder diagram in Figure 1.12.
8. Change the position of Magnetic Proximity Switch PX1 to approximately at the middle of the cylinder. Start the cylinder cycle by momentarily depressing PB1 while observing the extension of the rod.
9. From your observations, what can you conclude about the position of the magnetic switch?
10. What would happen to circuit operation is relay contact CR1-A in rung 1 were removed? Would you still be able to fully extend cylinder 1? Explain.
11. Turn off the DC Power Supply.

Limit Switches

A command can also be confirmed using the electrical signal provided by sensing devices which detect the position of the cylinder rod. As an example, the retraction command of the cylinder rod shown in Figure 1.9, could not be executed by PB2 if the rod is not fully extended and its positions confirmed by the limit switch LS2. When LS2 is mechanically activated by the presence of the rod, it's NO contact goes closed, and it is therefore possible to energize CR2 using PB2. Energizing relay coil CR2 causes NC contact CR2-A to go open and relay coil CR1 to de-energize.

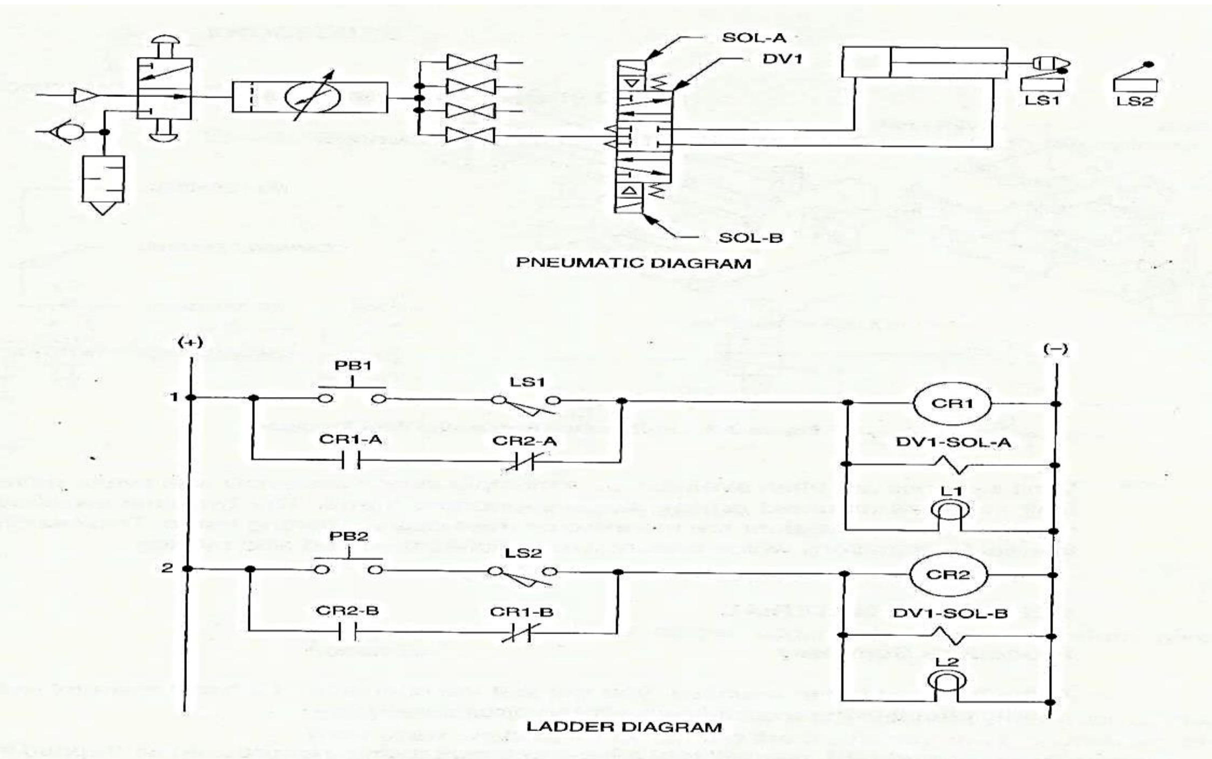


Figure 1.10: Electro-pneumatic Circuit using Limit Switches

Limit switches are used extensively in industrial pneumatic equipment. They are reliable, small in size, simple to use, and generally cheaper than the other types of switches. A limit switch consists of an actuator and one or more set of NO and NC contacts. It is activated when a moving part, such as a cylinder rod or machine member, strikes the actuating mechanism, shifting the contacts to their activated state.

Figure 1.10 shows the limit switch assembly supplied with your trainer. Each switch has a roller-type actuator and a set of SPDT contacts. When the cylinder tip travels across one of the switches, it pushes against the roller, pressing the lever arm. The lever arm acts on an internal plunger, causing the SPDT contacts to activate. The NO contact goes closed while the NC contact goes open. When the cylinder tip moves away from the roller actuator, a spring returns the lever arm and the contacts to their normal condition.

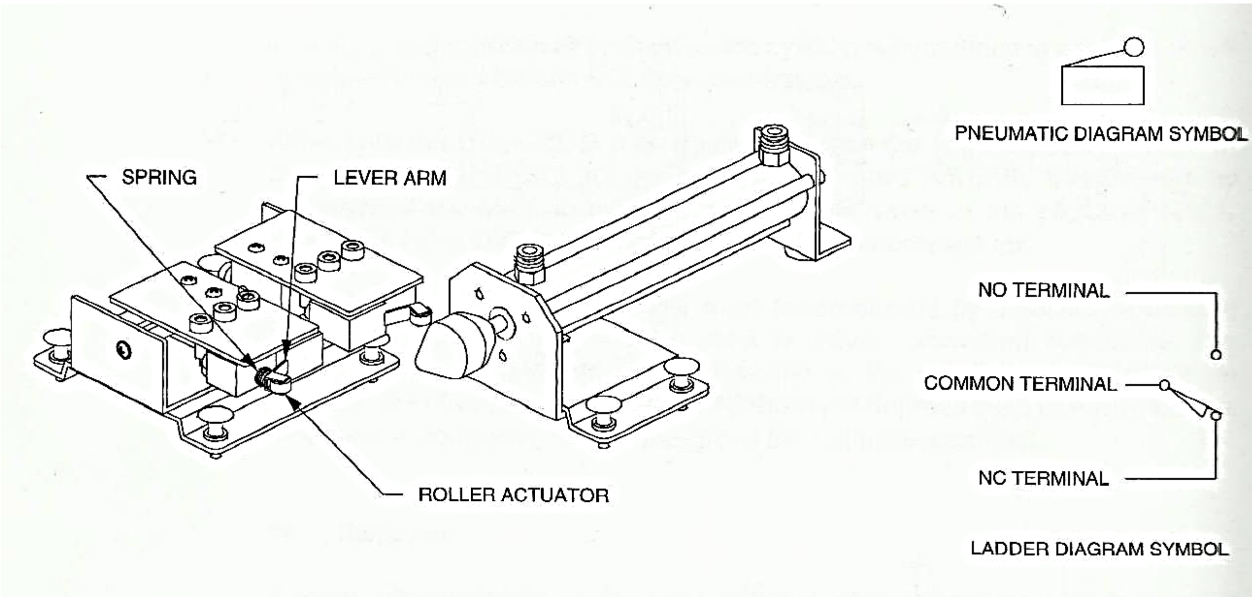


Figure 1.11: Limit Switch with Roller Arm Actuator

Parts and Components of Pneumatic Control Experiment:

- DC Power Supply
- Pushbutton Station (2)
- Relay (2)
- Pilot Lamp Station
- Connection Leads
- Magnetic Proximity Switch
- Conditioning Unit
- Flow Control Valve (2)
- Directional Control Valve, double solenoid operated.
- Directional Control Valve, single solenoid operated.
- Double-acting cylinder.
- Tubing Set
- Limit Switch Assembly
- Directional Valve, pushbutton operated.
- Directional Valve, Double air-pilot operated

- **Mounting of the Limit Switch Assembly**

Procedures:

1. Remove all components except the Double-Acting cylinder from your work surface.
2. Screw the cylinder tip onto the rod of the cylinder.
3. Manually extend the cylinder rod completely.
4. Clamp the limit switch assembly as shown in Figure 1.13.
5. Loosen the limit switch positioning screws. Position the switches side by side at the corner of the support bracket, as shown in Figure 1.13-a. Tighten the limit switch positioning screws.
6. Loosen the support-bracket positioning screws until you are able to slide the bracket over the mounting base as shown in Figure 1.13-b. Adjust the position of the bracket so that the switches are activated when the cylinder tip pushes against the switch arm, and deactivated when the cylinder tip releases the switch arm.
   To test this out, manually extend and retract the cylinder rod, and listen for the "click". Then, tighten the support-bracket positioning screws on the mounting base.
7. Loosen the positioning screw on each limit switch. Adjust the positioning of the switches so that they are activated when the cylinder rod is fully extended and fully retracted, as shown in Figure 1.13-c. To test this out, manually extend and retract the cylinder rod, and listen for the "click". Then, tighten the limit switch positioning screws.
8. Retract the cylinder rod completely as shown in Figure 1.13-d.
9. Your limit switch assembly is now set to detect the fully-extended and fully-retracted positions of the cylinder rod.

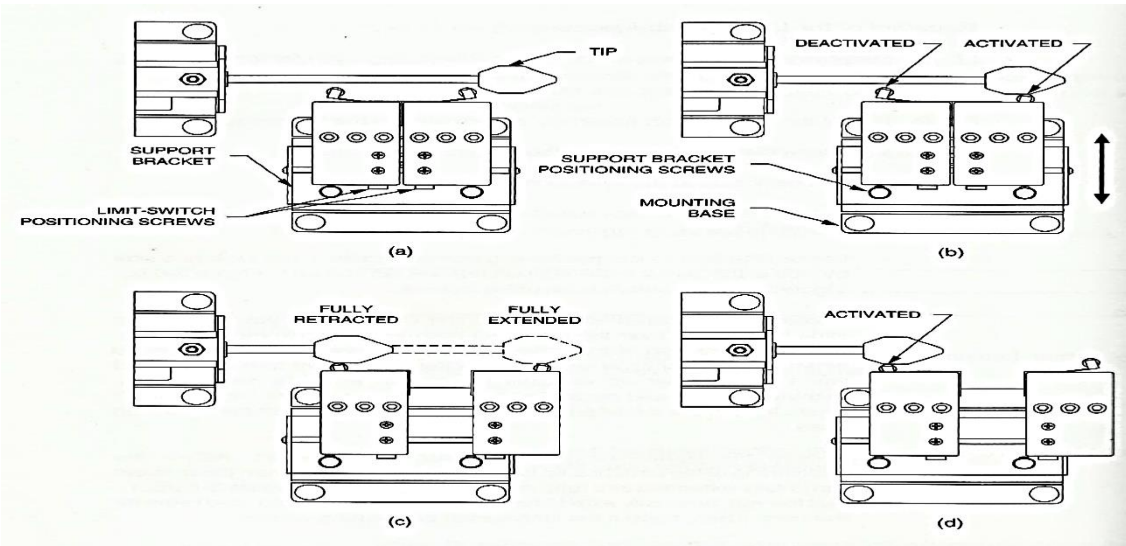


Figure 1.12: Mounting of the Limit Switch Assembly

- **Priority Locking Circuit Using Limit Switches**

Procedures:

1. Connect the circuit shown in Figure 1.14. As you do this, be careful not to modify the mounting of the limit switches LS1 and LS2.

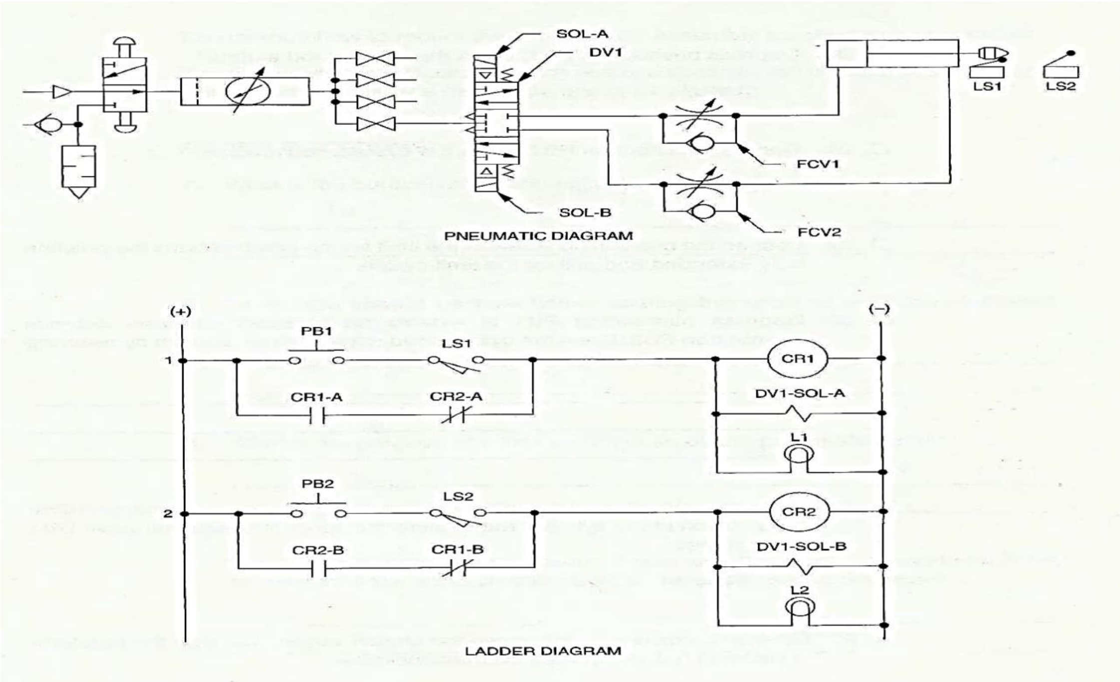


Figure 1.13: Schematic Diagram of a Priority Locking Circuit Using Limit Switches

2. Close the Flow Control Valves by turning the control knobs fully clockwise. Then open each valve by turning the knobs two turns counterclockwise. Refer to the mark on the knob to help you set the correct position.
3. On the Conditioning Unit, open the main shut-off valve and the branch shut-off valves at the manifold. Set the pressure regulator at 400 kPa (or 60 psi) on the regulated pressure gauge.
4. Turn on the DC power supply.
5. Press push-button PB1. Explain what happens.
6. Press push-button PB2. Explain what happens.
7. Loosen the positioning screw of the limit switch which detects the position of fully extended and pull up the limit switch.
8. Press push-button PB1 to extend the cylinder rod, then press the pushbutton PB2.
9. Does the cylinder retract? If not, explain why by referring to the ladder diagram.
10. On the Conditioning Unit, close the shut-off valves and turn the regulator adjusting knob completely counterclockwise.
11. Turn off the DC power supply.
12. Disconnect and store all leads and components.

Section C: Applications on Electrically Controlled Pneumatic Circuits

This experiment concerns with introducing students to the pneumatic sequencing of cylinders, function and operation of sequence valves as well as the cascade circuits used to build electrically pneumatic control.

Pneumatic Sequencing of Cylinders

In many industrial systems, there is a need for two or more cylinders to move in a certain programmed order. A cylinder must reach certain stage before another one can operate to correctly complete the work cycle, these two cylinders are said to operate in sequence. For example, the work cycle of the pneumatic system shown in figure 2.1 involves a cylinder that closes a mold and another cylinder that injects molten plastic into the mold. These two events should occur in a specific order: the clamping cylinder should always operate first.

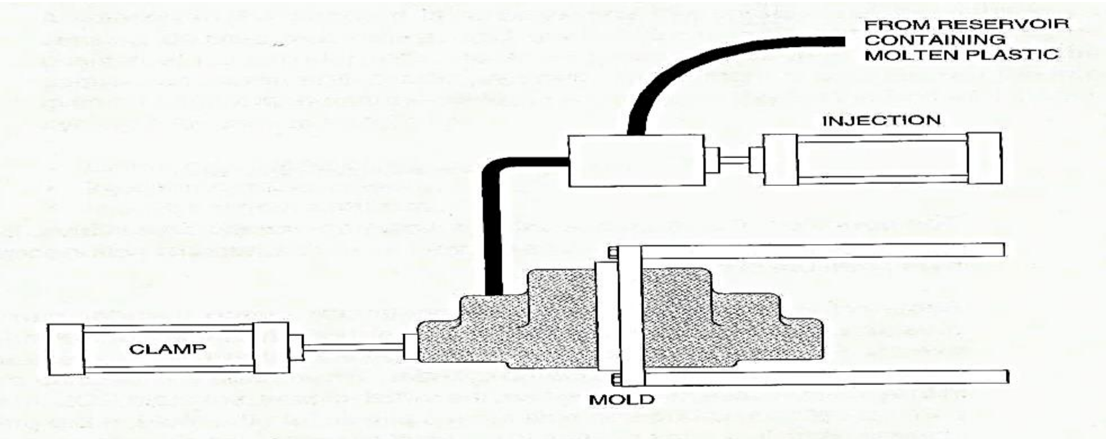


Figure 1.14: Molding Operation

If the clamp cylinder in this system fails to close the mold, molten plastic may leak from the mold, possibly causing damage to the machine. A sequencing circuit will prevent the injection cylinder from operating if the mold is not properly closed. For all sequencing circuits, if the condition necessary to trigger the next event does not occur, the events which normally follow will not occur.

Sequence valves

Sequence valves are considered as devices used to sequence the operation of actuators. In the sequence valve shown in Figure 2.2, the inlet port remains closed to the outlet port until pressure at the inlet port rise sufficiently to compress the adjustable spring which holds the poppet closed. When the poppet opens, air can flow unrestricted through the valve.

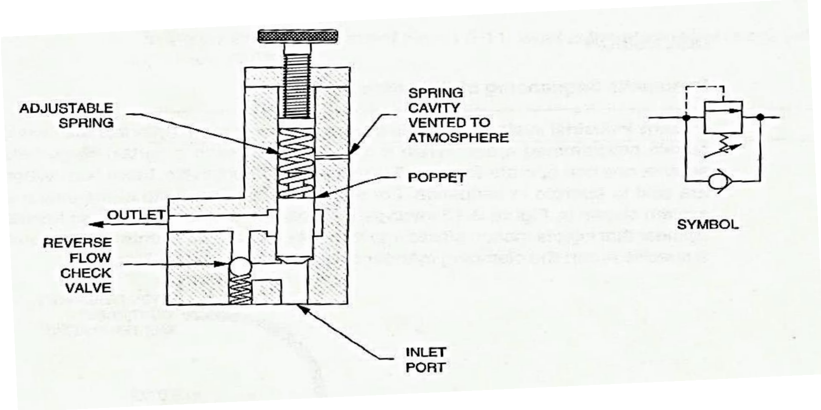


Figure 1.15: Sequence Valve Operation

The operation of a sequence valve is similar to that of a relief valve, but the outlet port of the sequence valve does not vent to atmosphere: it is connected to another high pressure circuit.

Sequencing circuits that include a pneumatic clamp cylinder can also use a pressure switch to energize the electrical branch circuit controlling one of the events. Figure 2.3 shows a sequencing circuit that uses a pressure switch to monitor the pressure in the clamp cylinder. When pressure reaches present level in the pressure switch sensing line, the switch closes, solenoid SOL-A is energized, and the injection cylinder injects molten plastic into the mold. If the pressure level in the sensing line does not rise to the level necessary to close the pressure switch, the injection cylinder will not operate.

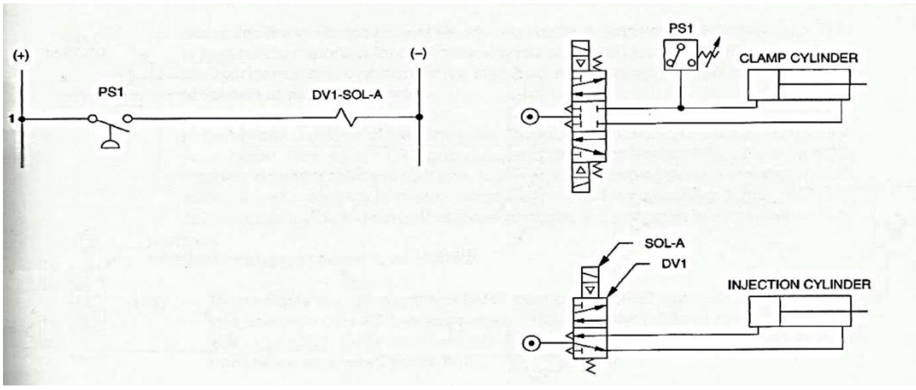


Figure 1.16 Pressure sequencing Circuit using a Pressure Switch

The problem with pressure sequencing is that anything that interferes with the extension of the clamp cylinder can open the sequence valve and start the injection cylinder prematurely.

A solution to this problem is to sequence the operation of the cylinders using sensing devices that detect, and confirm by sending an electrical signal, the position of the cylinder rods. As an example, figure 2.4 shows an electrically sequenced clamp and injection system. The system is designed so the injection cylinder cannot start until the clamp cylinder has activated the limit switch LS1.

The cycling sequence is as follows:

- Clamp cylinder extends;
- Injection cylinder extends;
- Injection cylinder retracts;
- Clamp cylinder retracts;
- The cycle is ended.

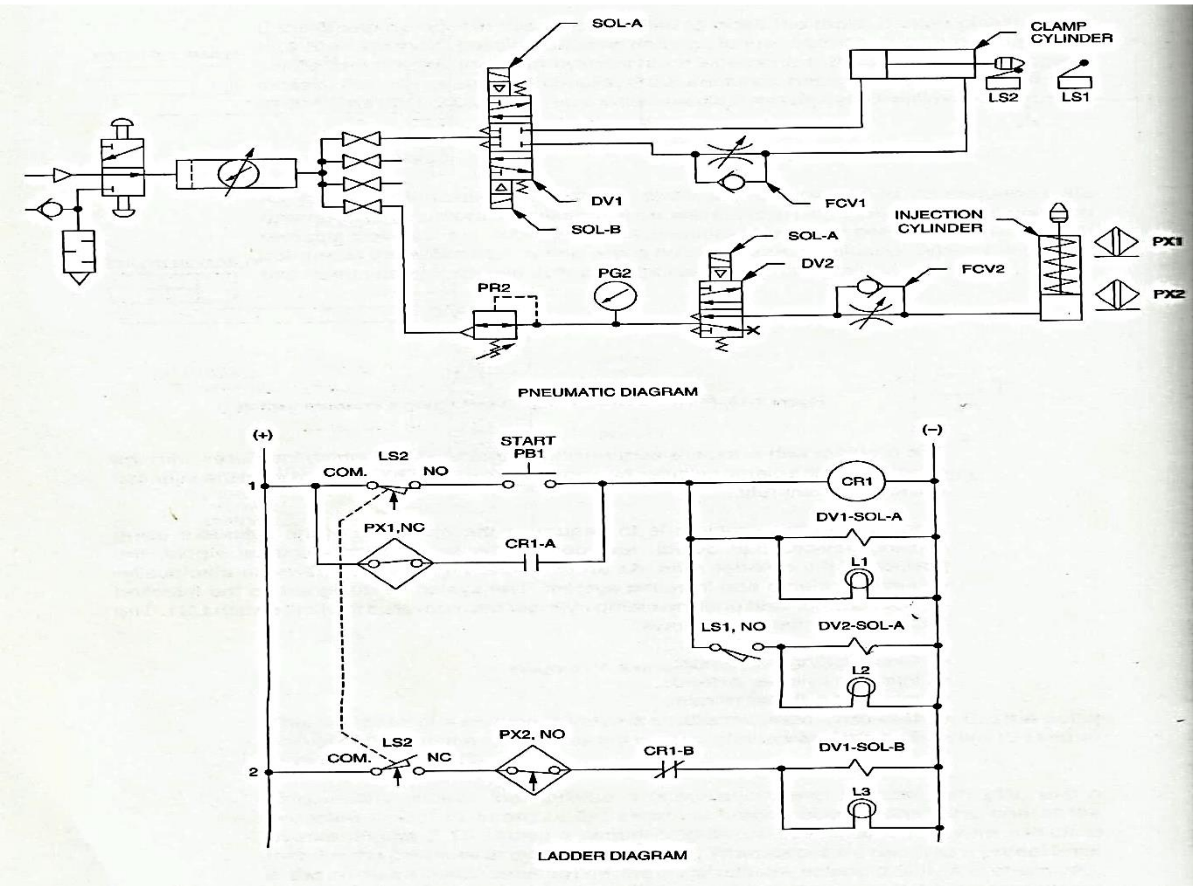


Figure 1.17 Position Sequencing Circuit using Limit Switches

In the circuit shown in figure 2.4, the cylinders not only extend in a definite order, but also retract in a definite order. This sequence is designed so the clamp cylinder keeps the mold closed until the injection cylinder has completely retracted. This is particularly important for applications such as bending, cutting, and milling where the work piece must remain firmly clamped while being worked on and during retraction of the work cylinder.

In the normal condition of the circuit, the clamp and injection cylinders are retracted. As a result, limit switch LS2 and magnetic proximity switch PX2 are activated. Therefore, switch contacts LS2 and PX2 in figure 3-16 are shown in their activated state, as indicated by the side arrows. The dashed line connecting NO and NC contacts of LS2, indicates that these contacts are operated by the same switch.

Electrical circuit action is as follows:

- Momentarily depressing the START push-button, PB1, causes relay coil CR1 and solenoid DV1-SOL-A to energize. Relay contact CR1-A closes to lock in relay coil CR1. Relay contact CR1-B opens to prevent solenoid DV1-SOL-B from being energized at the same time.
- The clamp cylinder extends and after a short travel releases limit switch LS2. This opens NO contact LS2 and breaks the current path through the START pushbutton for the rest of the cycle. The clamp cylinder continues to extend until the mold is completely closed and activates limit switch LS1. This energizes solenoid DV2-SOL-A to start the injection cylinder.
- When the injection cylinder becomes fully extended, it activates magnetic proximity switch PX1. This opens rung 1 by causing the holding circuit of relay coil CR1 to drop out. This de-energizes relay coil CR1 and solenoid DV2-SOL-A. Directional valve DV2 returns to its normal condition and the injection cylinder starts to retract.
- Once fully retracted, the injection cylinder activates magnetic proximity switch PX2. This energizes solenoid DV-SOL-B, causing the clamp cylinder to retract. Once fully retracted, the clamp cylinder activates limit switch LS2. The cycle ends with both cylinders fully retracted.

Parts and Components of Electrical Controlled Pneumatic Experiment

- DC Power Supply
- Pushbutton Station
- Limit-Switch Assembly
- Relay
- Pilot-Lamp Station (2)
- Magnetic Proximity Switch (2)
- Conditioning Unit
- Flow Control Valve (2)
- Directional Valve, Double-Solenoid Operated
- Directional Valve, Single Solenoid Operated
- Pressure Regulator
- Single Acting Cylinder
- Double Acting Cylinder

- Pressure Gauge
- Tees
- Tubing Set
- Connection Leads

Exercise

- **Setting up the system**

1. Connect the electrically sequences circuit shown in figure 2.4. Screw a tip to the cylinder rods.
2. Verify the status of the trainer according to the procedure given in Appendix B.
3. Close the Flow Control Valves by turning the control knobs fully clockwise. Then open each valve by turning the knob two turns counterclockwise. Refer to the mark on the knobs to help you set the correct position.
4. Adjust the position of Magnetic Proximity Switch PX1 to be activated when the injection cylinder rod is fully extended, and PX2 to be activated when the cylinder is fully retracted. Refer to experiment 1 if necessary.

   *Note**:** because of the presence of the spring in the Single-Acting Cylinder, the magnetic piston is located at about two thirds of the cylinder stroke length.*
5. Adjust the position of limit switch LS1 to be activated when the clamp cylinder is fully extended, and LS2 to be activated when the clamp cylinder is fully retracted. Refer to experiment 1 if necessary.
6. Open the shutoff valve and the branch shutoff valves at the manifold and set the pressure at 400 kPa (or 60 psi) on the regulated pressure gauge.
7. Use the Pressure Regulator PR2 to set the pressure at 200 kPa (or 30 psi) on Pressure Gauge PG2.
8. Turn on the DC power Supply
9. Start the system by depressing push-button PB1 momentarily. The system should operate as follows:
   - The clamp cylinder starts to extend first;
   - When the clamp cylinder becomes fully extended, the injection cylinder stars to extend;
   - When the injection cylinder becomes fully extended, it retracts automatically;
   - When the injection cylinder becomes fully retracted, it stops and the clamp cylinder starts to retract;

- When the clamp cylinder becomes fully retracted, it stops. Both cylinders are ready for a new cycle.

10. Repeat the previous step several times to become familiar with the operation of the system.
11. What causes the clamp cylinder to extend when pushbutton PB1 is depressed? Explain by referring to the ladder diagram in figure 2.4.
12. What keeps the injection cylinder from extending during the extension of the clamp cylinder? Explain by referring to the ladder diagram in figure 2.4.
13. What causes the injection cylinder to automatically retract when it becomes fully extended? Explain.
14. Why is solenoid DV2-SOL-A not energized when the injection cylinder releases Magnetic Proximity Switch PX1 during its retraction stroke?
15. What causes the clamp cylinder to automatically retract when the injection cylinder becomes fully retracted? Explain.
16. What causes the cycle to automatically stop when the clamp cylinder becomes fully retracted? Explain.
17. Depress pushbutton PB1 momentarily. When the injection cylinder is retracting, but before it is fully retracted, try to restart the cycle by depressing PB1.
18. Can the cycle be restarted before the clamp cylinder has fully retracted? Explain why.
19. What is the purpose of pressure regulator PR2 in the circuit?
20. On the Conditioning Unit, close the shut-off valves, and turn the regulator adjusting knob completely counterclockwise.
21. Turn off the DC Power Supply.
22. Disconnect and store all leads and components.

Experiment # 02

Arduino

Controllers and Interfacing

A long time ago, before the technology revolution in this field, most of the machines were controlled manually by humans who lead to a problem time wise, since it takes a lot of time to change the inputs and outputs. According to this the control of the system was very complex and not efficient.

This problem didn't last long, after inventing microchips and integrated circuit, the control of a machine became much easier. Nowadays a machine can be controlled either mechanically or electrically without any human interference on control.

There are many types of controllers, people select their controller according to the function its doing and the type of machine it's going to control, taking into consideration the cost of the controller.

Some of the commonly used controllers are: Arduino, PIC microcontrollers, programmable logic controls (PLC's) and Raspberry Pi. These controllers can control systems with very high efficiency and in no time.

Introduction to Arduino

With this device, we can make computers; these computers can sense and control more of the physical world than the normal desktop computer that we all know. These computers are considered as brains; through it, a machine can be controlled. In other words: hardware, one can download any code or sequence he wants on it and it will do the function it's asked to do. The control of the Arduino is easy since it's an open source physical computing platform. This platform is based on a simple microcontroller board.

The Arduino is capable of doing many things, through these function it can control a machine. Arduino is used to develop interactive objects; this is done by taking inputs from a variety of switch or sensors. After it executes the code, the output can be the control of motors, LEDs and other machines. One good thing about Arduino is that it can be stand-alone or can communicate with software running on the computer. So for an Arduino to work properly, both the wiring and the code should be correct and match.

Why is Arduino?

Arduino is not the only microcontroller, there are a lot of different types of microcontroller and microcontroller platform and they all can do the same functions as the Arduino. But according to this project and for the following features of the device, Arduino is going to be used:

- Open source and extensible software.
- Simple and clear programming environment.
- Inexpensive
- Open source and extensible hardware.

Types of Arduino

Arduino come in different sizes and shapes. There are many types of Arduino such as Mega2560, Arduino Uno, Arduino Mini, Arduino Nano and Lilypad Arduino. The Arduino Uno is shown in figure 4.1. Someone can distinguish between them from their size, color and other factors. For example Arduino mega has 256 KB of memory, which is 8 times more than the Uno. Second reason is that it has 54 input and output pins. (16 of them are analog pins and 15 are used for the PWM). In this project Arduino Uno was chosen, because its inputs and outputs are sufficient for this project and taking into consideration the difference in cost between it and other more complicated controllers.

Figure 3. 1: The figure indicates to the Arduino Uno.

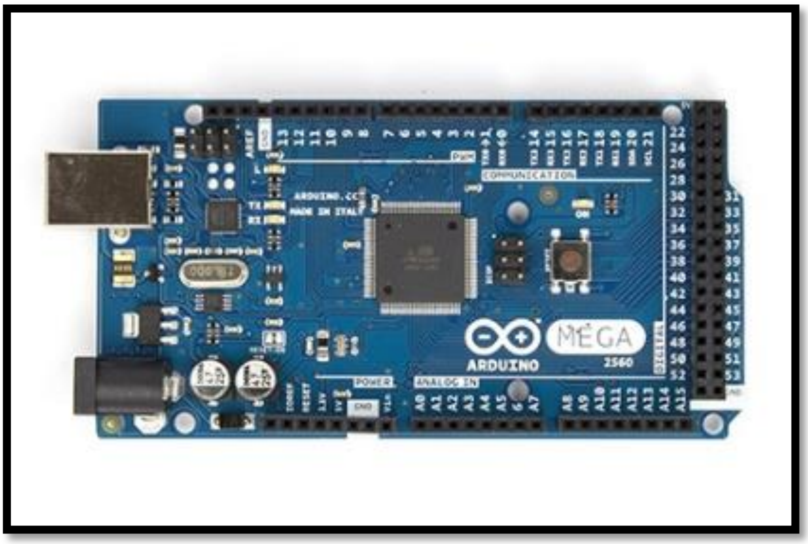


Figure 3. 2: The figure indicates to the Arduino Mega.

Interfacing

Since there are two main aspects in the Arduino (software and hardware) and at a point, interaction between them should be done. This process is called interfacing. For example Arduino can be interfaced with motors using sensors, keypads, other microcontrollers and memory.

The following figure shows the microcontroller interfaces:

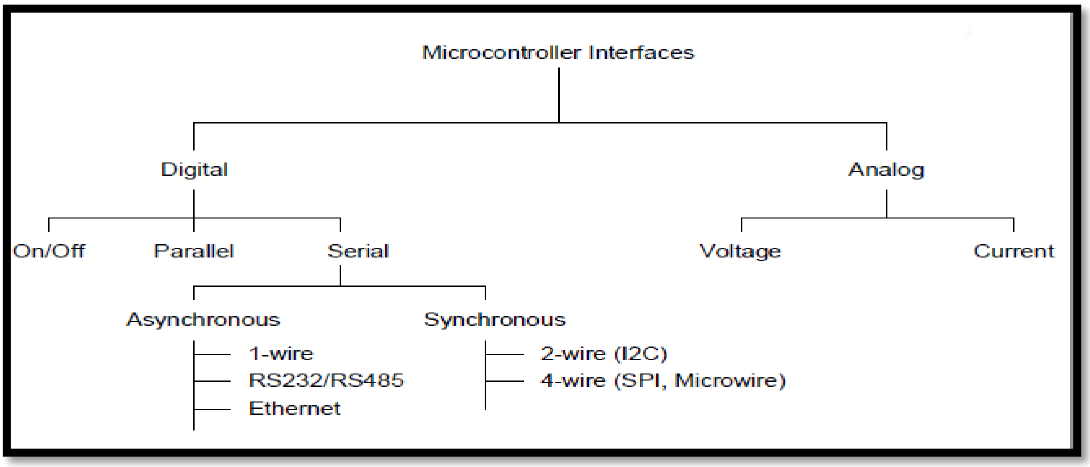


Figure 3. 3: The figure illustrates the interface methods. [16]

Pulse width modulation

To control a DC motor with a variable speed using Arduino, one has to be familiar with Pulse Width Modulation (PWM). PWM is a powerful technique for controlling analog circuits with a microprocessor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. It can be used to control analog and digital machines.

Arduino software

Software programs, called sketches, are created on a computer using the Arduino integrated development environment (IDE). The IDE enables you to write and edit code and convert this code into instructions that Arduino hardware understands. The IDE also transfers those instructions to the Arduino board (a process called uploading).

Arduino Hardware

The Arduino board is where the code you write is executed. The board can only control and respond to electricity, so specific components are attached to it to enable it to interact with the real world. These components can be sensors which convert some aspect of the physical world to electricity so that the board can sense it, or actuators, which get electricity from the board and convert it into something that changes the world. Examples of sensors include switches, accelerometers, and ultrasound distance sensors. Actuators are things like lights and LEDs, speakers, motors and displays. There are a variety of official boards that you can use with Arduino software and a wide range of Arduino-compatible boards produced by members of the community. The most popular boards contain a USB connector that is used to provide power and connectivity for uploading your software onto the board. Figure 4.4 shows a basic board, the Arduino Uno.

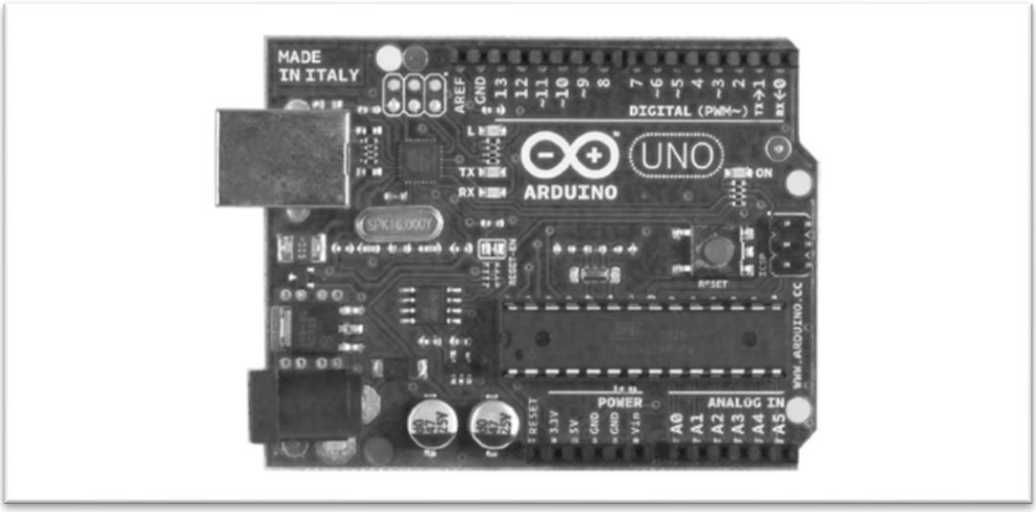


Figure 3.4. Basic Board: the Arduino Uno

You can get boards as small as a postage stamp, such as the arduino mini and pro mini; larger boards that have more connection options and more powerful processors, such as the Arduino Mega; and boards tailored for specific applications, such as the LilyPad for wearable applications, the Fio for wireless projects and the Arduibo pro for embedded applications (standalone projects that are often battery-operated). Many other Arduino- compatible boards are also available, including the following:

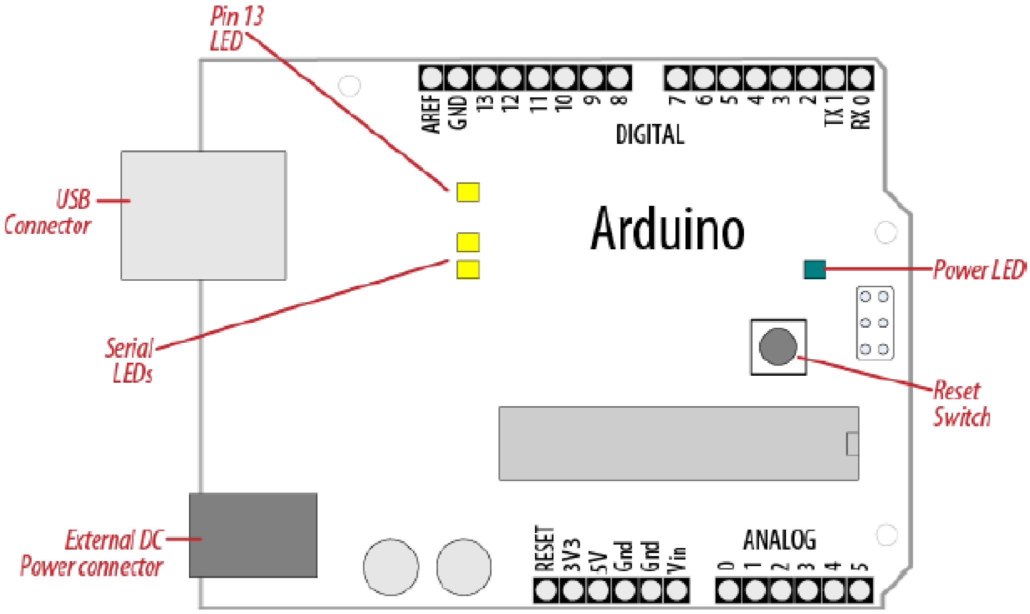
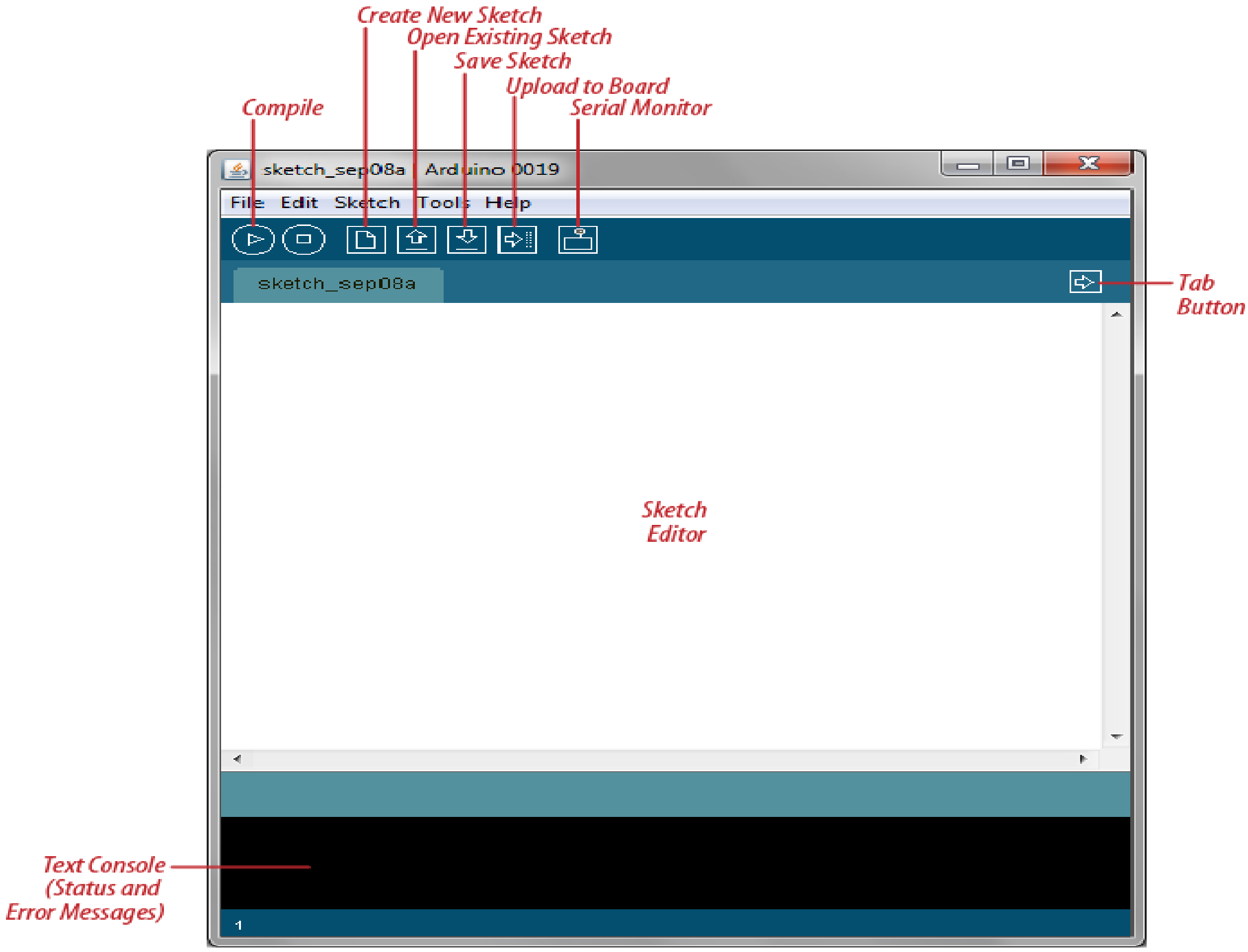


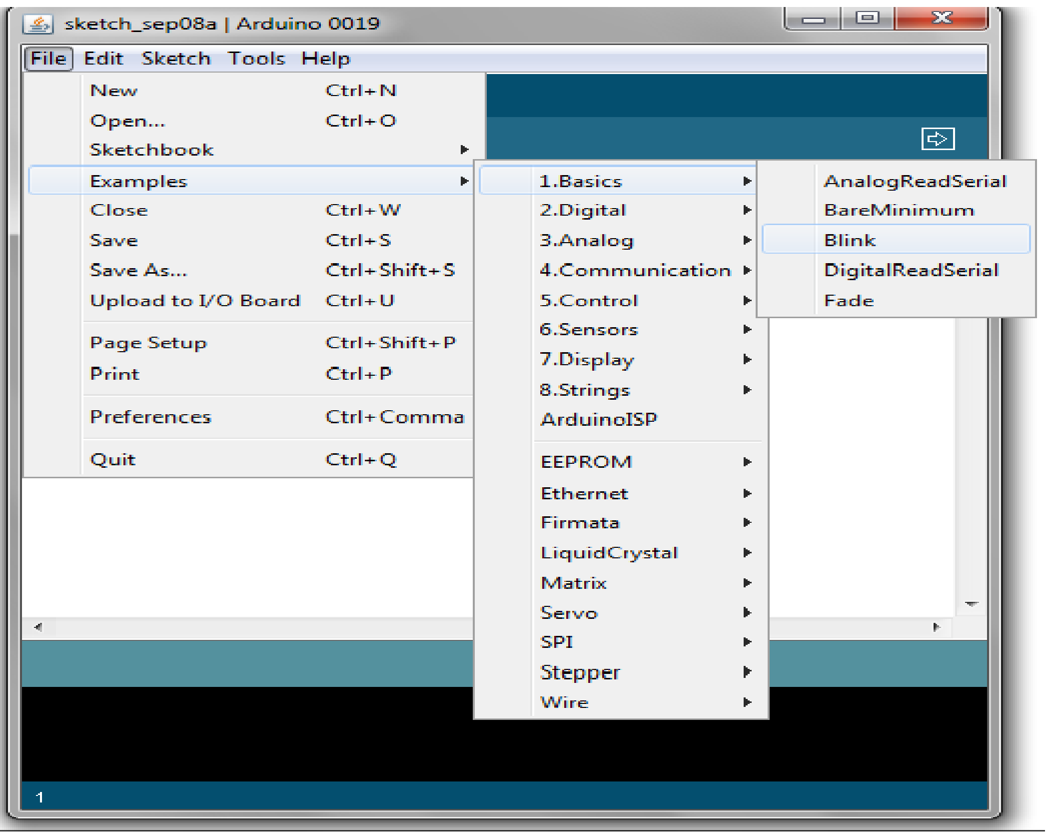
Figure 3.5. Basic Arduino Board (Uno and Duemilanove)

If the power LED does not illuminate when the board is connected to your computer, the board is probably not receiving power.

The flashing LED (connected to digital output pin 13) is being controlled by code running on the board (new boards are preloaded with the bink example sketch). If the pin 13 Led is flashing, the sketch is running correctly, which means the chip on the board is working. If the green power LED is on but the pin 13 Led is not flashing, it could be that the factory code is not on the chip; follow the instructions in Recipe 1.3 to load the blink sketch onto the board to verify that the board is working. If you are not using a standard board, it may not have a built-in LED on pin 13, so check the documentation for details of your board.

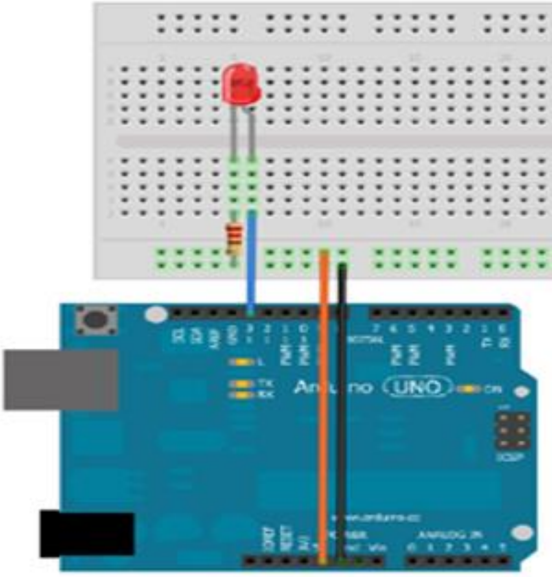


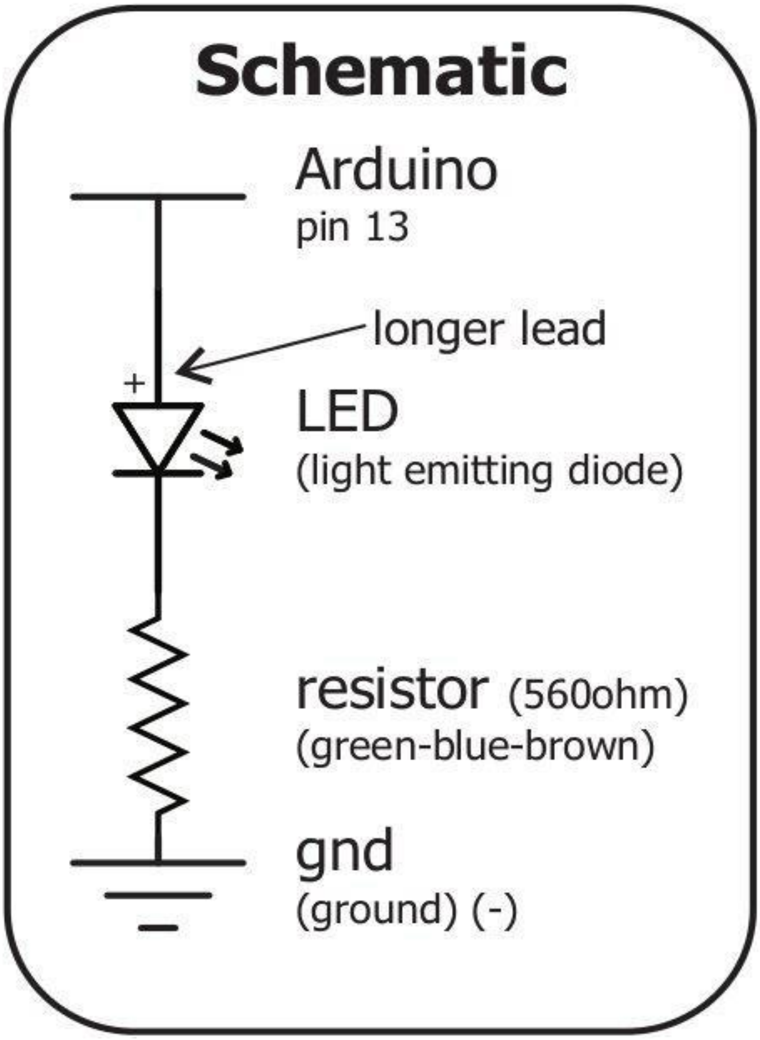
Create New Sketch
Open Existing Sketch
Save Sketch
Upload to Board
Serial Monitor
Compile
sketch_sep08a | Arduino 0019
File Edit Sketch Tools Help
sketch_sep08a
Tab Button
Sketch Editor
Text Console (Status and Error Messages)



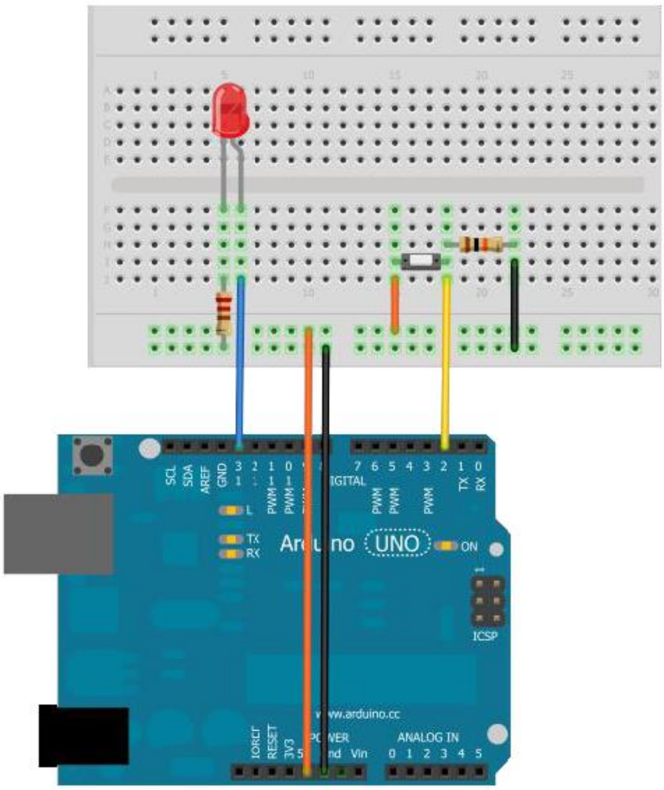
sketch_sep08a | Arduino 0019
File Edit Sketch Tools Help
New Ctrl+N
Open... Ctrl+O
Sketchbook
Examples
Close Ctrl+W
Save Ctrl+S
Save As... Ctrl+Shift+S
Upload to I/O Board Ctrl+U
Page Setup Ctrl+Shift+P
Print Ctrl+P
Preferences Ctrl+Comma
Quit Ctrl+Q
1.Basics
2.Digital
3.Analog
4.Communication
5.Control
6.Sensors
7.Display
8.Strings
ArduinoISP
EEPROM
Ethernet
Firmata
LiquidCrystal
Matrix
Servo
SPI
Stepper
Wire
AnalogReadSerial
BareMinimum
Blink
DigitalReadSerial
Fade

Example 1: Blinking LED

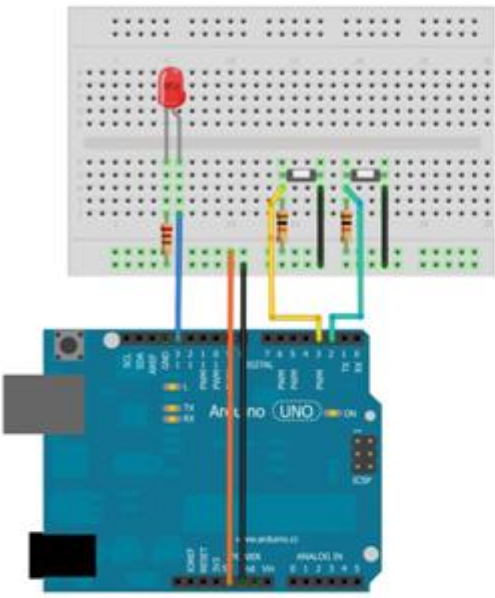


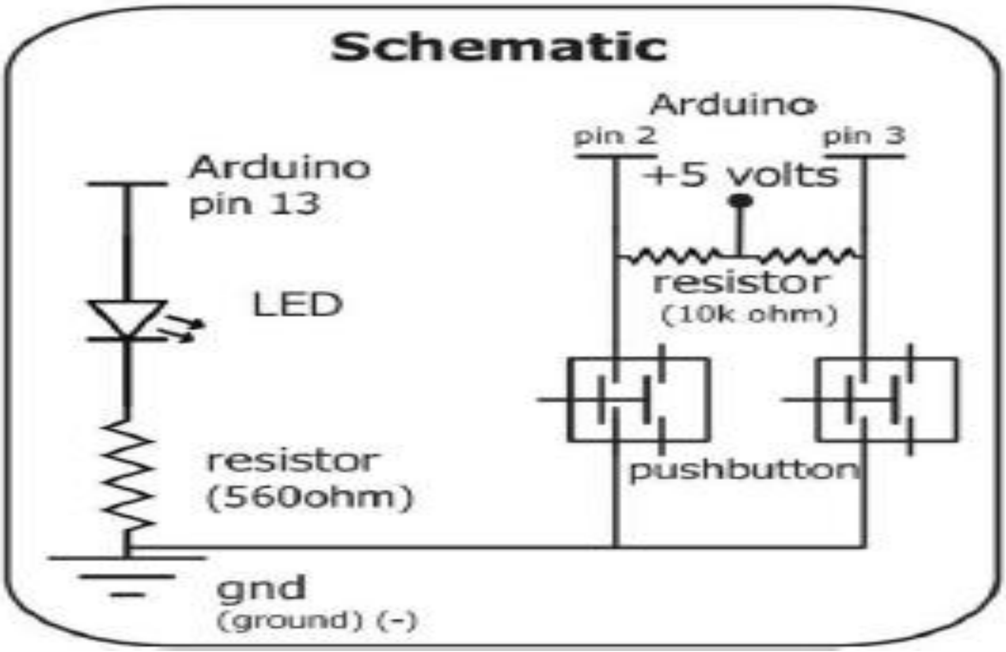


Example 2: Bush Button and LED



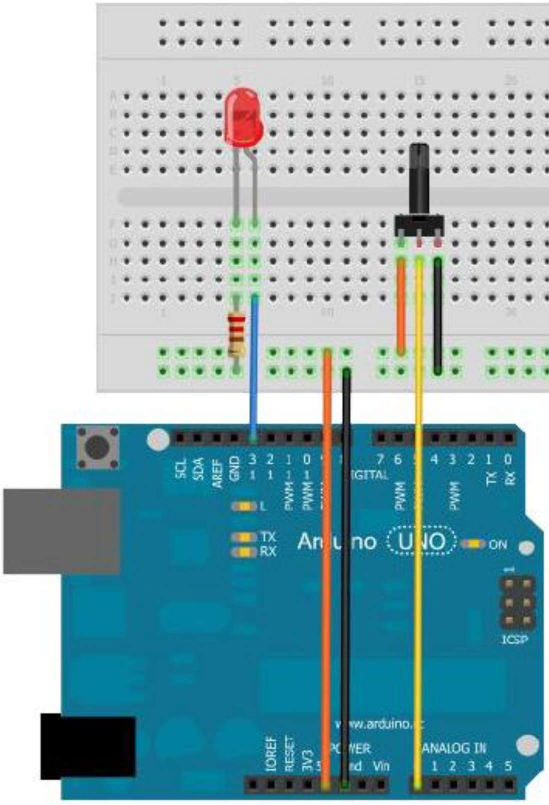
Example 3 : LED and Switches

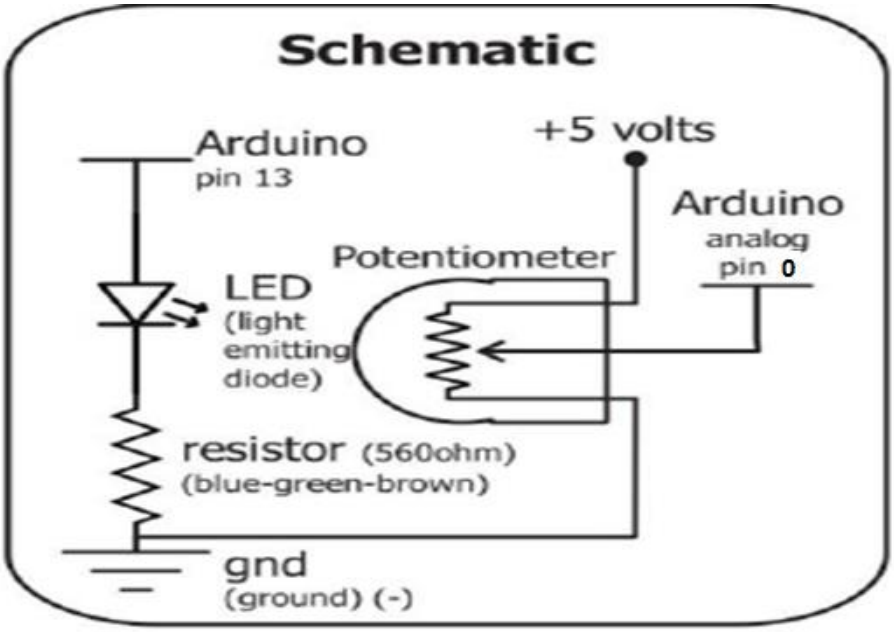





```
const int P1 = 2;
const int P2 = 3;
const int LED =13 ;

void setup() {
 pinMode (P1,INPUT);
 pinMode (P2,INPUT);
 pinMode (LED,OUTPUT);
}

void loop() {
if (digitalRead(P1)==HIGH)
{
  digitalWrite(LED,HIGH);

}
else if  (digitalRead(P2)==HIGH)
{
   digitalWrite(LED,LOW);
}
}
```

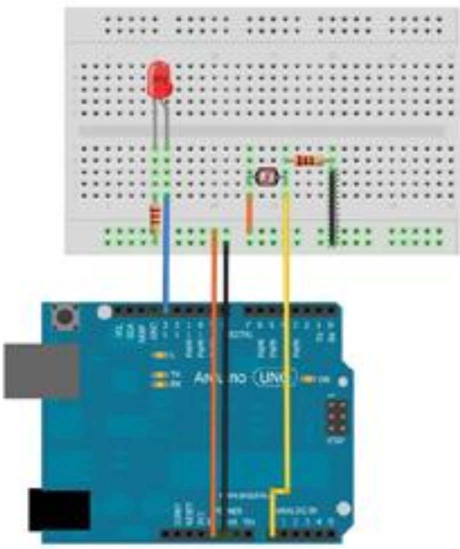
Example 4: Analog Input

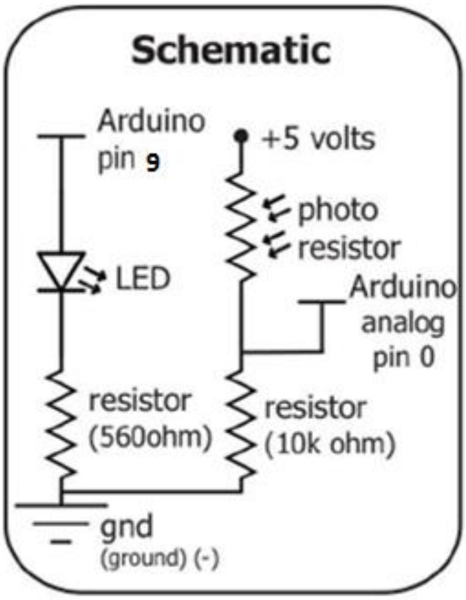


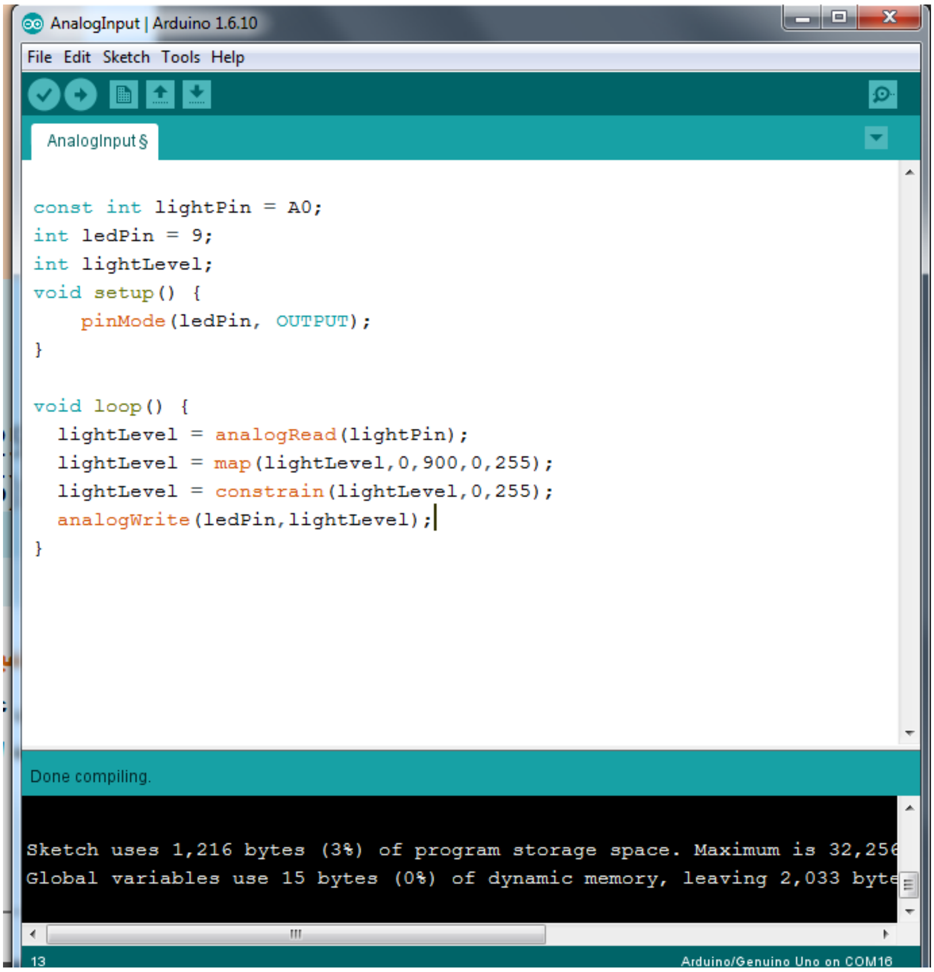



```
int sensorPin = A0;    // select the input pin for the potentiometer
int ledPin = 13;      // select the pin for the LED
int sensorValue = 0;
void setup() {
    pinMode(ledPin, OUTPUT);
}

void loop() {
  // read the value from the sensor:
  sensorValue = analogRead(sensorPin);
  // turn the ledPin on
  digitalWrite(ledPin, HIGH);
  // stop the program for <sensorValue> milliseconds:
  delay(sensorValue);
  // turn the ledPin off:
  digitalWrite(ledPin, LOW);
  // stop the program for for <sensorValue> milliseconds:
  delay(sensorValue);
}
```

Example 5: Photo resistor as light sensor







<u>Task 1:</u> Take the Task from the Supervisor.

<u>Task 2:</u> Take the Task from the Supervisor.

<u>Task 3:</u> Take the Task from the Supervisor.

Experiment # 03

LabVIEW

Introduction

LabVIEW is considered one of the powerful tools for interfacing the system with the computer. It is also considered very important tool for mechatronics engineers as it provides an efficient environment for implementing control algorithm, acquisition data, make signal conditioning and give an interfacing screen for the user. This file provides student valuable information on how to get started with interfacing LabVIEW with the system using Arduino.

Objectives:

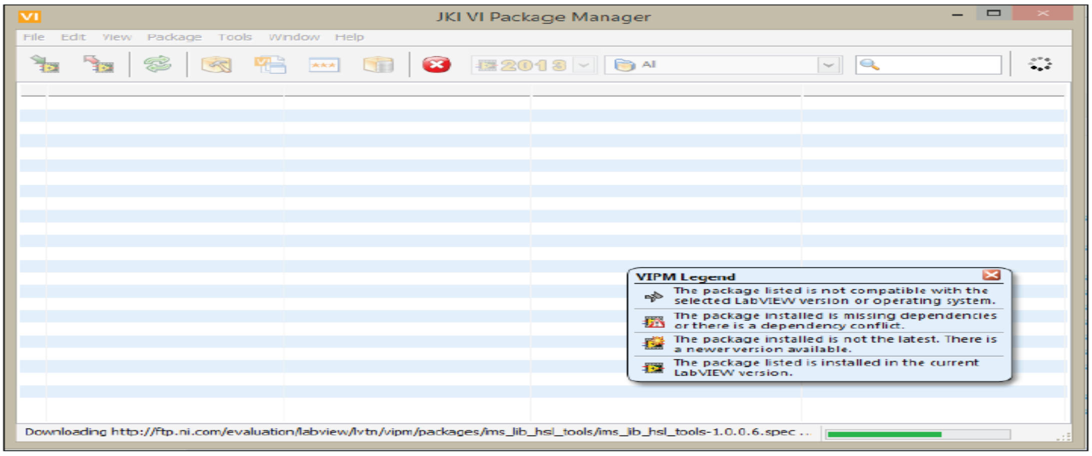
1. To introduce LabVIEW program to the mechatronics students.
2. To learn the principle of interfacing LabVIEW with the system.
3. To learn how to interface LabVIEW with the system.
4. To learn how to control electrical/mechanical components using LabVIEW.

This file contains:

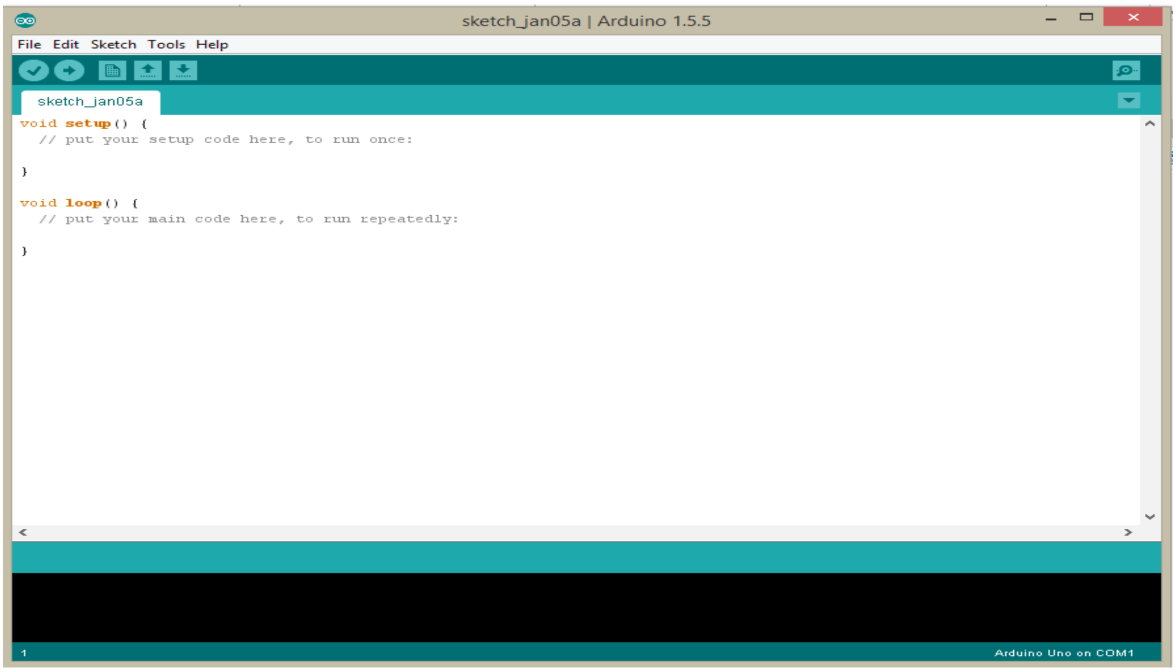
A. Requirements for interfacing LabVIEW with Arduino.
B. Getting started with interfacing LabVIEW with the system using Arduino.
C. Example 1: DC motor control direction.
D. Example 2: servo motor control.
E. Example 3: temperature and photocell sensor indicator.

A. Procedures of interfacing LabVIEW with Arduino:

1. Download LabVIEW program.
2. Download Visual Package Manager (VI package manager) from the internet. This helps you to install additional tools to the main library of the LabVIEW program such closed loop control and tools used to interface LabVIEW with Arduino as LabVIEW library has only basic tools.

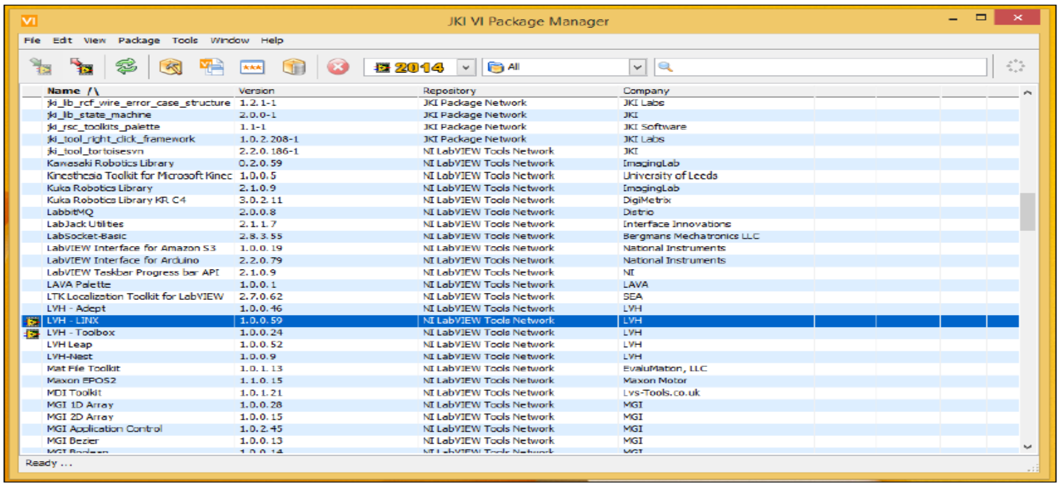


3. Download Arduino from the internet: https://www.arduino.cc/en/main/software then select windows installer, and select all default options.

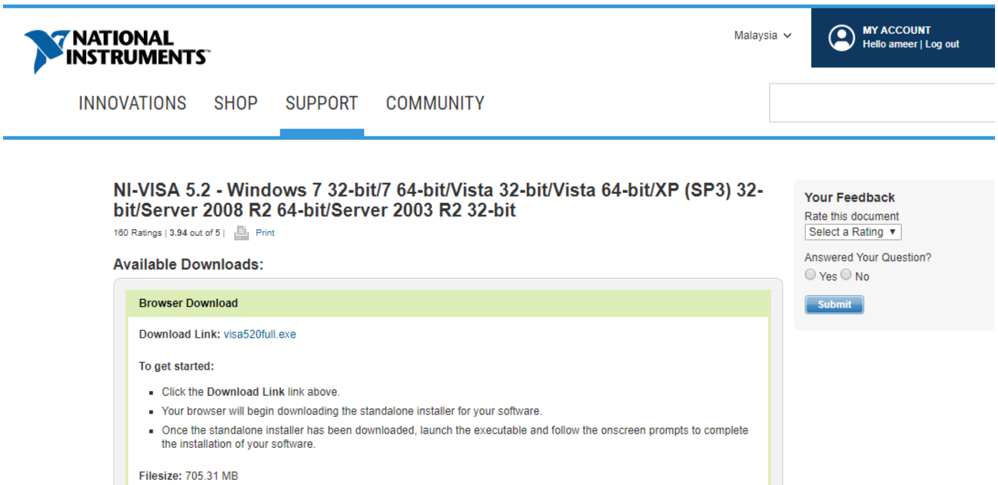


4. Install LINX package (http://sine.ni.com/nips/cds/view/p/lang/en/nid/212478) .

Note: The VI package manager should open automatically and then install LINX package.

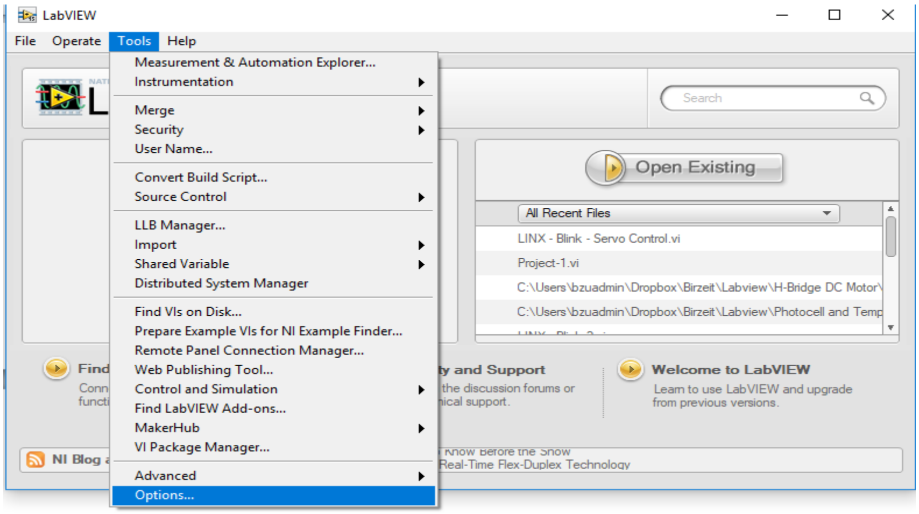


5- Download VISA driver from the internet: http://www.ni.com/download/ni-visa-5.2/3337/en/

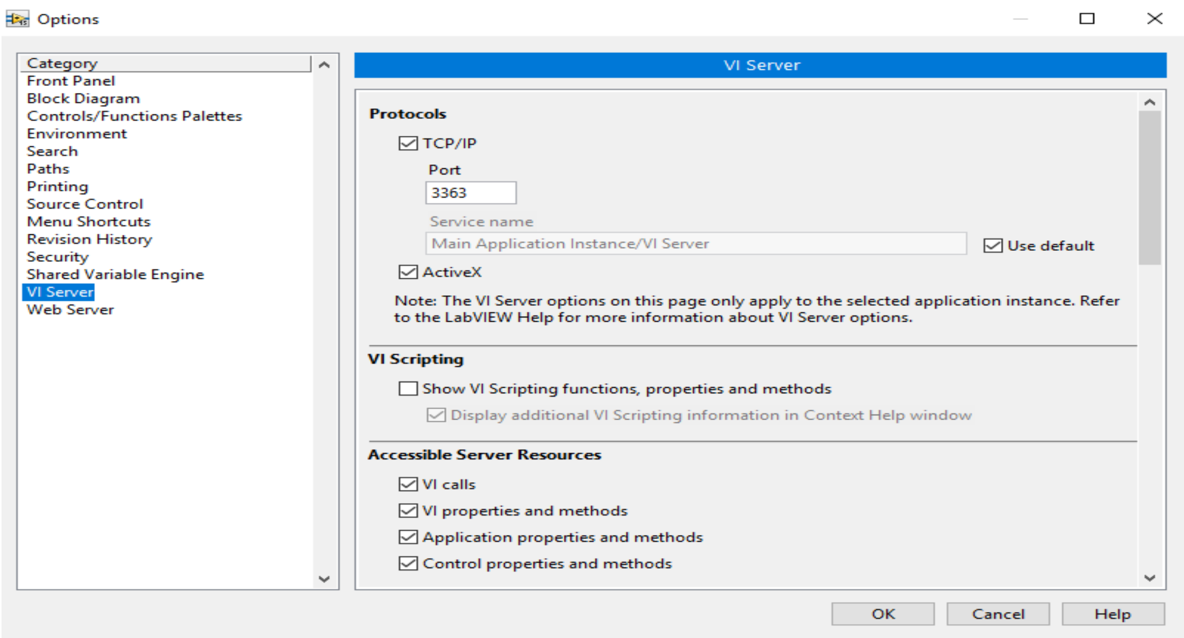


B. **Getting started with interfacing LabVIEW with the systm:**

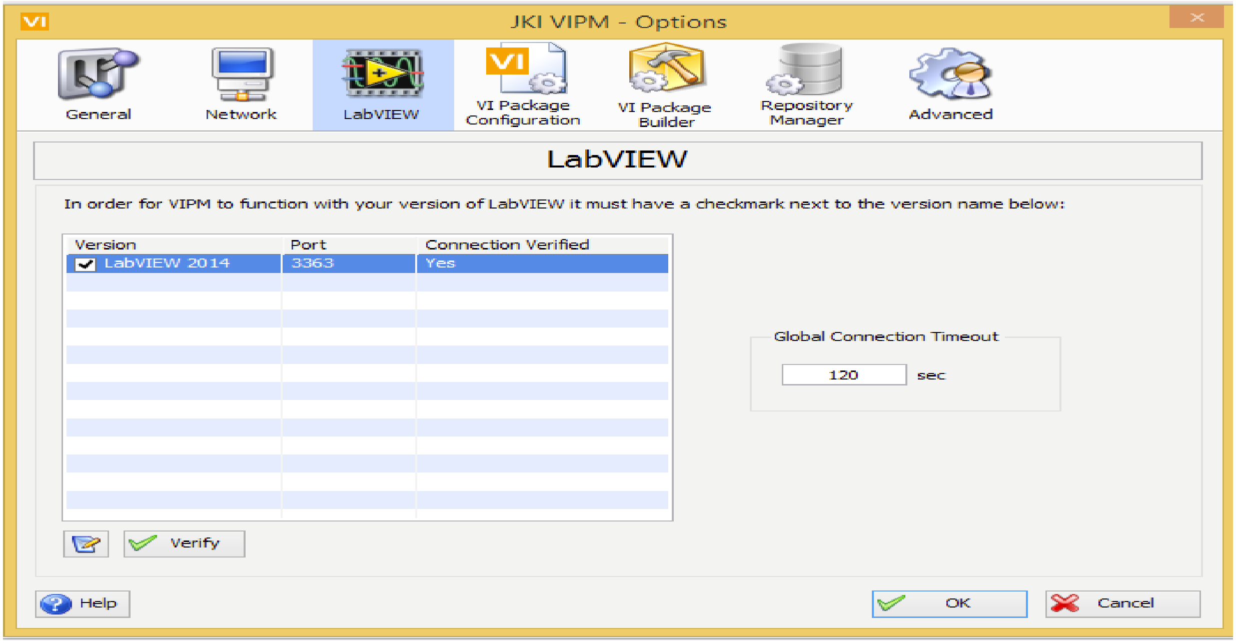
1. First, start LabVIEW, click on Tools and then on Options.



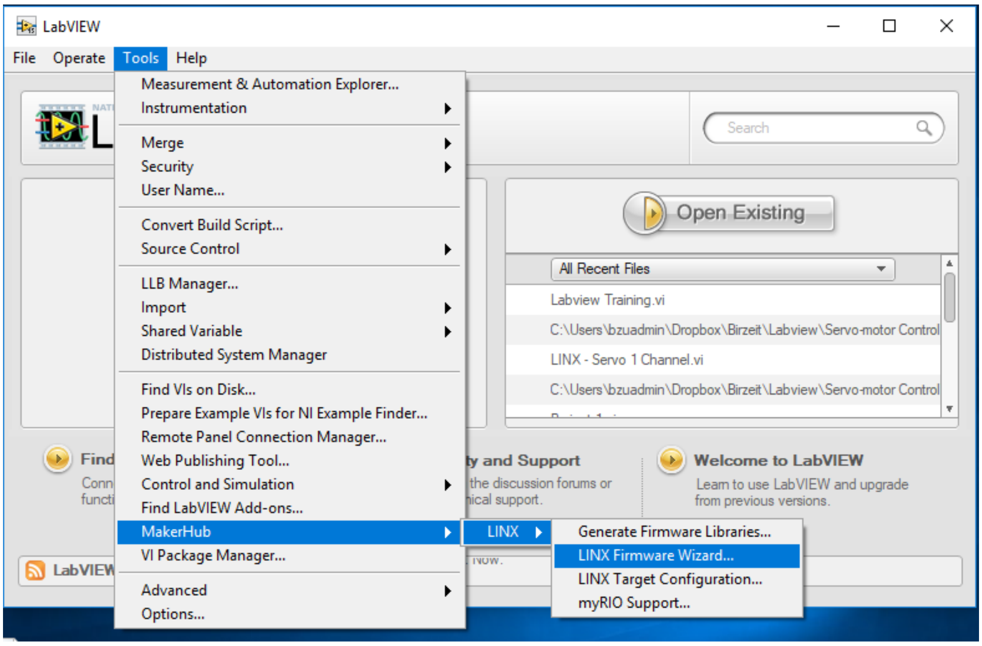
2. You will be taken to the Options window of LabVIEW, where you can set all your preferences. Now, go to VI server menu and then set all the options so that they match the options shown in the following screenshot.



3. After that, you have to do the same on VI Package Manager so that both LabVIEW and Package Manager can talk to each other. On systems like Windows, it was automatically done, but it was not on other system. To do so, open Package Manager, go to the Tools Options menu, and then click on LabVIEW icon. In this menu, make sure that the Port value next to your LabVIEW installation is the same as the one you defined inside LabVIEW. Correct it here if it is not the case, and confirm.

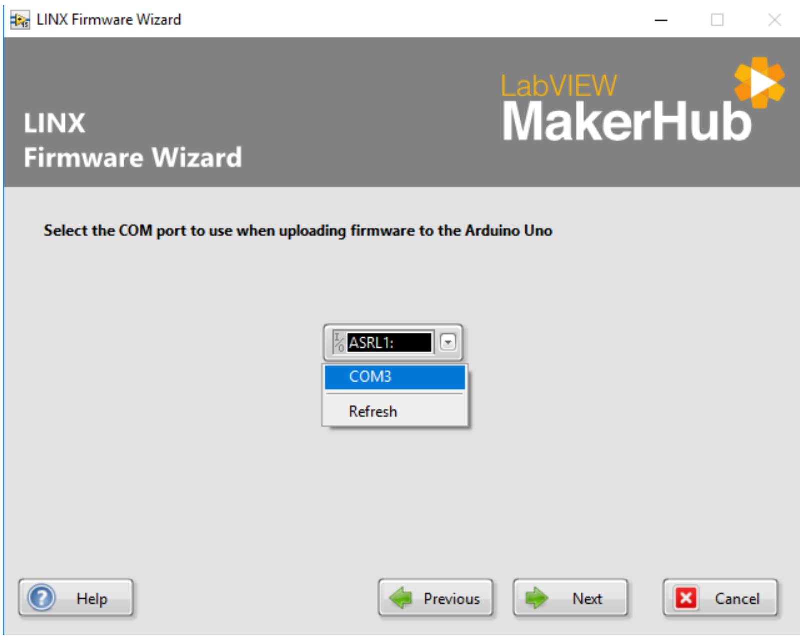


4. Now, you can start interfacing LabVIEW with Arduino by doing the following screenshots:

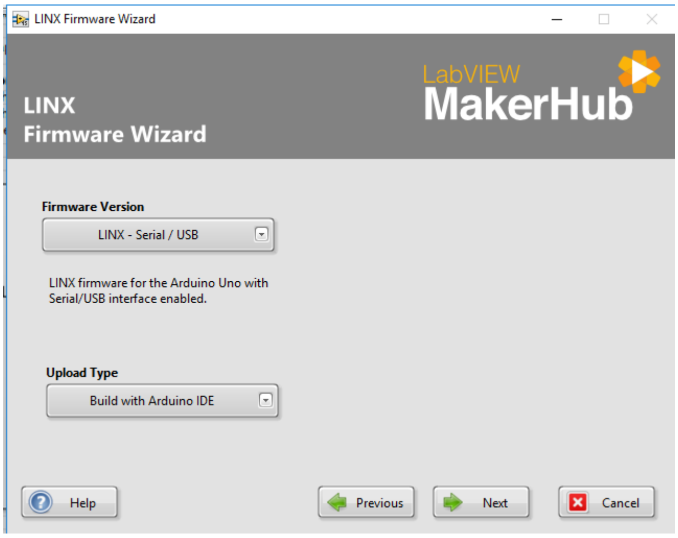


The following screenshot will appear, select from device family your Arduino device type:

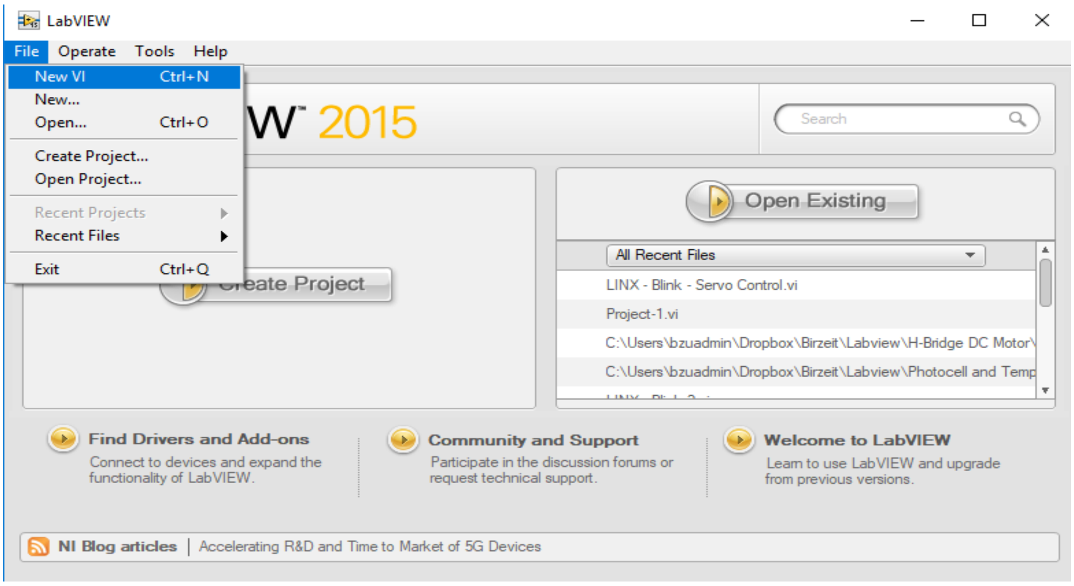
After that, you will be prompted to select the Serial Port on which you want the interface to communicate. As I only had one Arduino board connected at that time, I could only select the port that Windows calls COM4 or COM3. Of course, this will entirely depend on your operating system. A very simple way to find the COM or Serial Port that corresponds to your Arduino board is to look at the list of proposed Serial ports. Then, disconnect your board and see which Serial Port disappeared; this is the one that corresponds to your board. Finally, confirm your choice of Serial Port, and start uploading the firmware on the Arduino board.



This figure will appear, just select next

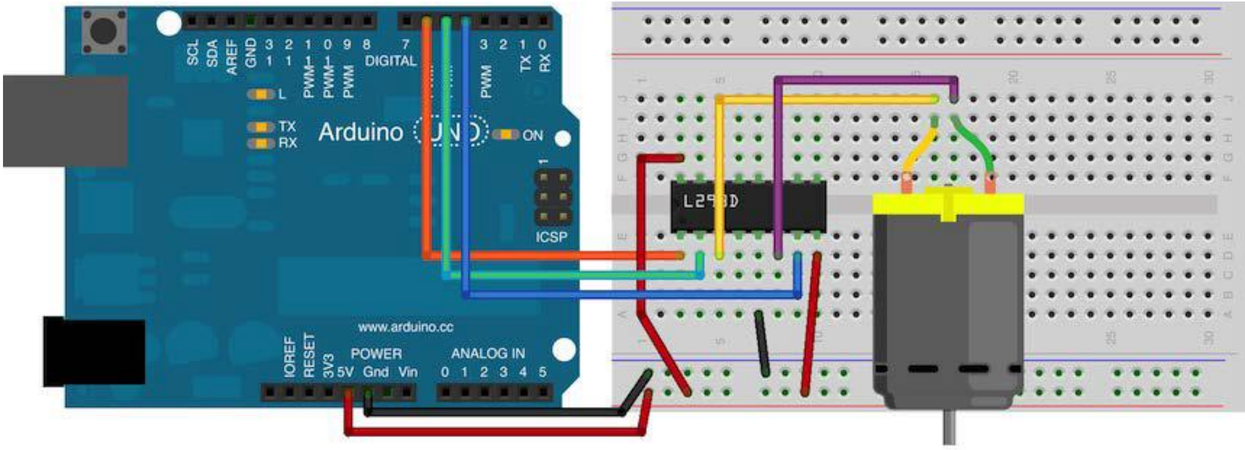


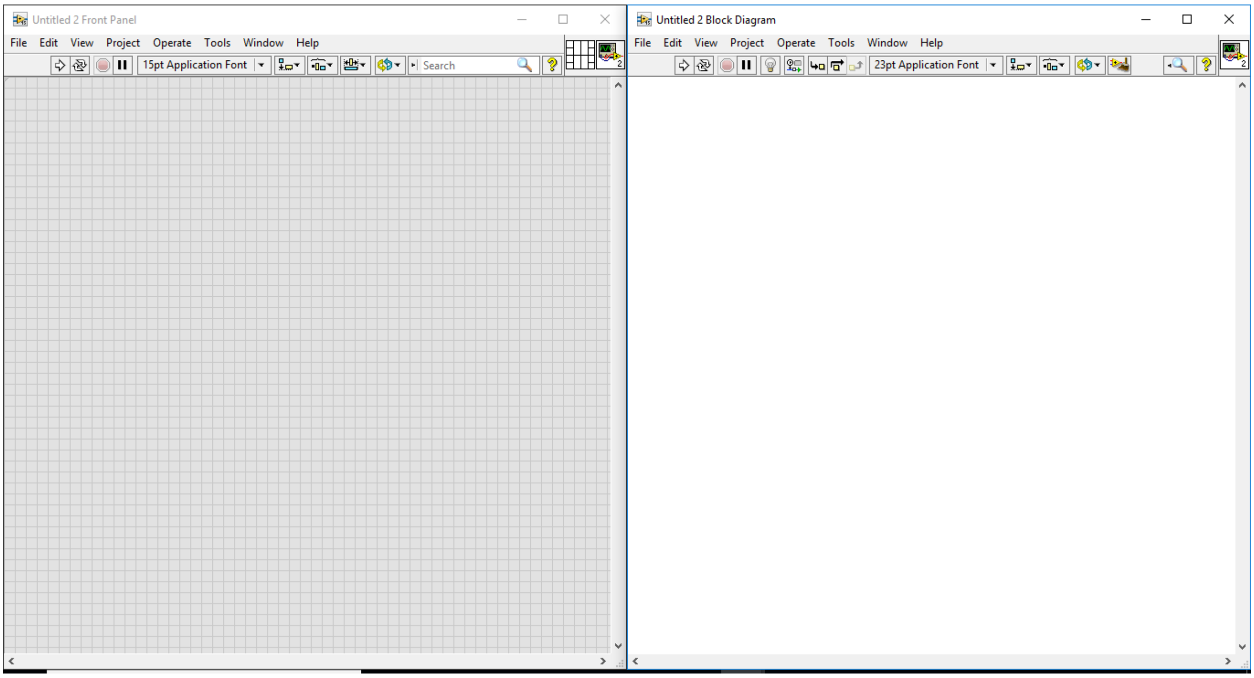
Now, you can create your new interfacing program, go to main LabVIEW file and then select new VI from file as shown in the following screenshot:



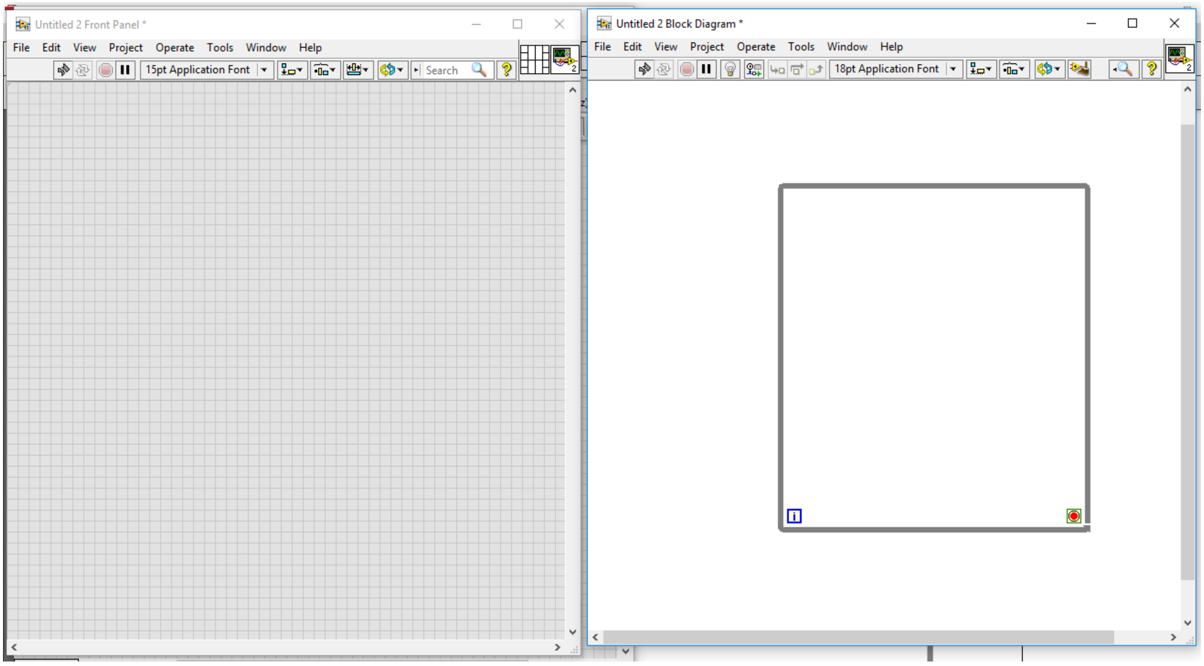
C. Example 1: DC Motor Control Direction.

In this example, a DC motor control direction using LabVIEW program will be presented. In doing so, you are required to assembly the following circuit:



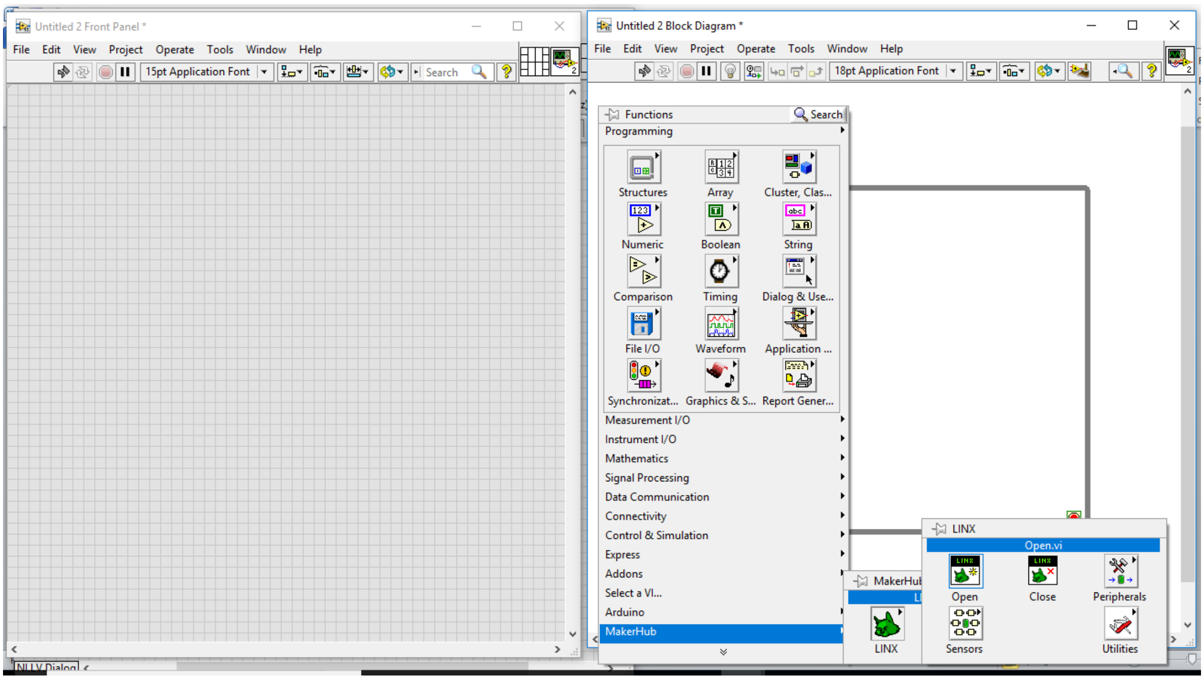


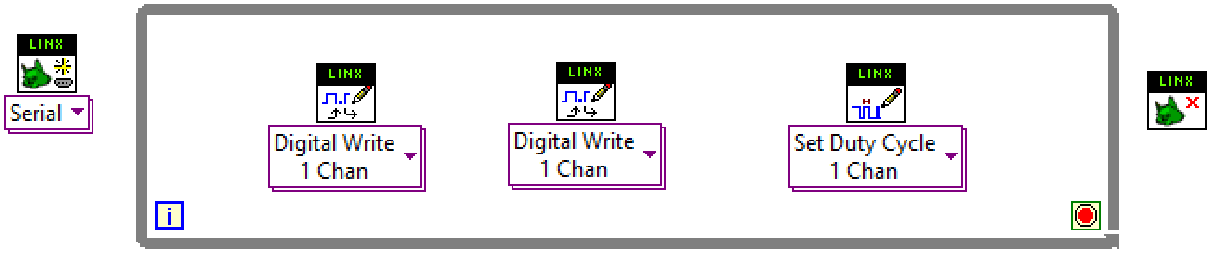
Now, place While Loop that you can just drag-and-drop from the Functions menu (which you can call at any moment with a right-click). The While Loop can be found in the Structures submenu. This loop is required for any Arduino board you want to control via LINX, and all the Arduino commands will need to be placed inside this loop.



After that, place first elements from the LINX package. The first elements we need to place are the LINX initialize and stop elements, which are necessary to tell the software where to start and where to stop. You can find both boxes in the functions panel by going to LabVIEW Hacker submenu.

From the same submenu, place two Digital Write blocks (which will be used to control the motor direction) and one PWM block (which will be used to control the motor speed). Note that you can find these blocks under the Peripherals menu. This is the result:

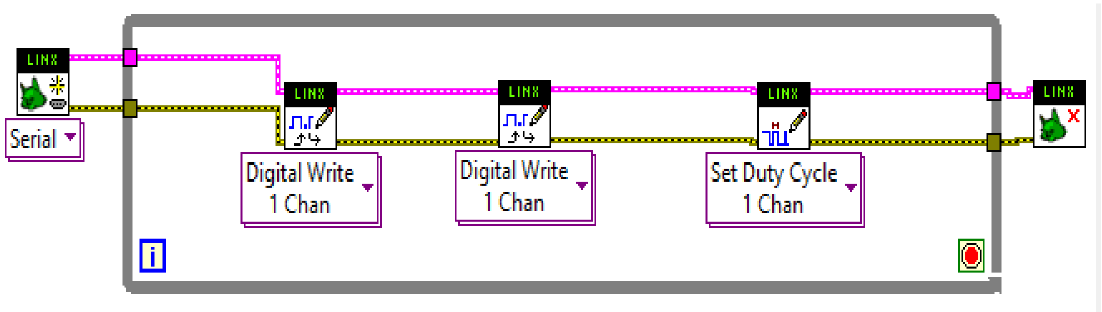




We need a PWM block here to control the speed of the motor. PWM stands for Pulse Width Modulation and is used to control the motor's speed or to fade LEDs, for example. On the Arduino board, it is an output of the board that can be set from 0 to 255 on some pins of the Uno board.

Now, we need some way to tell LabVIEW in which order we want the sketch to be executed. This is where the error and LINX resource come into play. Simply start from the initialize block on the left-hand side and find the error pin on the block.

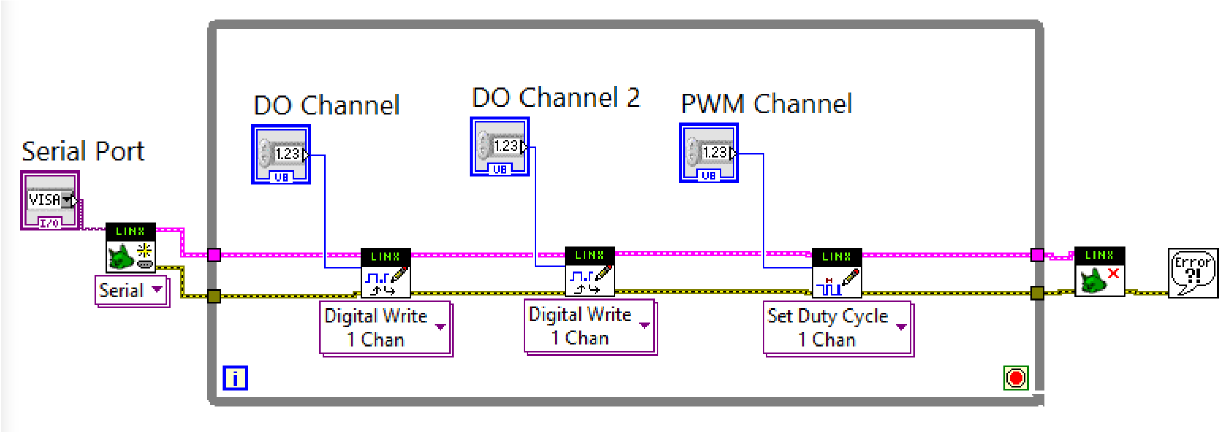
Then, connect the error-out pin of this block to the error-in pin of the first digital block and so on till the end block. After that, do the same with the LINX resource pins. I also added a simple error handler at the end of the VI, just after the stop block. This handler can be found under the Dialog & User Interface menu.



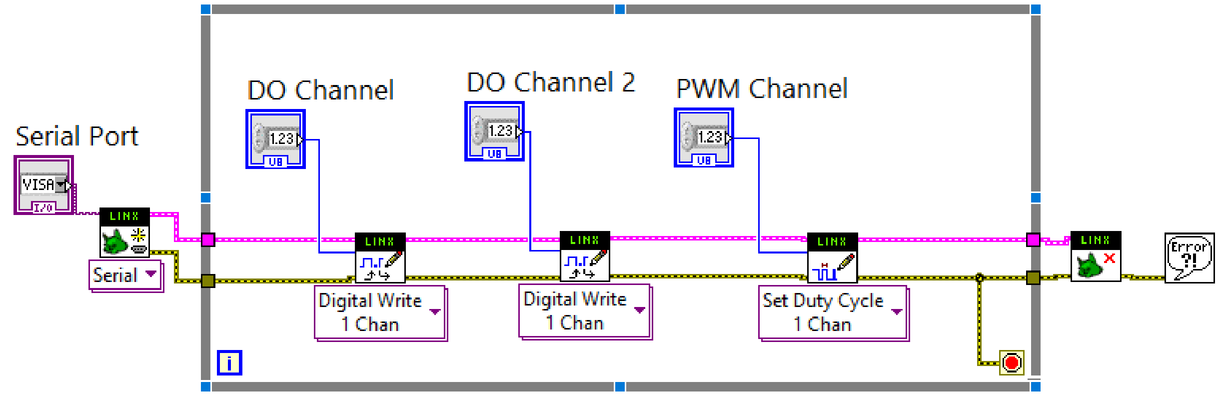
Now that we have the backbone of our project, we will feed the blocks with some inputs. First, add a serial port to the initialize block by going to the serial port pin of the block and right-clicking on it.

Then, go to Create | Control to automatically add a serial port input. You will note that the corresponding control is automatically added to Front Panel as well. Rename this control to `Serial Port` so that we can identify it in Front Panel.

We will also create the same kind of controls for the pins of the blocks we placed earlier. For each block, simply add inputs by right-clicking on the pin's input and then going to Create | Control. Also, rename all of these controls so that we know what they mean later in Front Panel.



We also need to add an end condition for the While Loop. To do so, we need to connect the little red circle that is located in the bottom-right corner of the While Loop. In this chapter, we will simply connect the error wire directly to this red circle. To do so, just select the input pin of the red circle and connect it to the bottom error wire inside the VI.

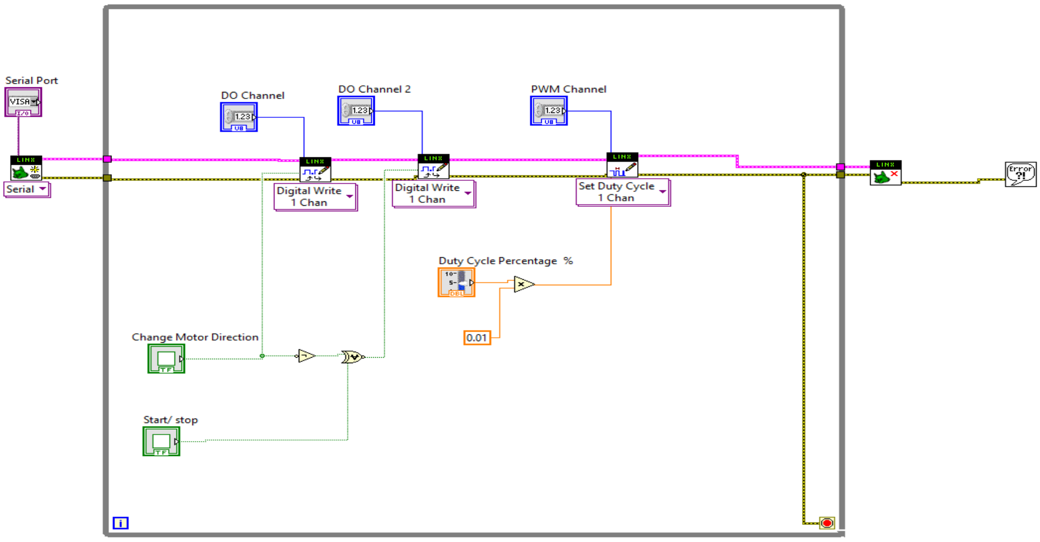


We will now feed the values of the different blocks that we will change from Front Panel to control the motor. At this stage, we will keep it simple: we will have some on/off control for the direction and a simple text box for the speed of the motor.

First, let's set the direction that we need to feed on the two first LINX blocks in our VI. The L293D chip requires to be fed with opposite signals on the two direction pins for the motor to rotate in a given direction. For example, when the first Digital Write block is on, we want the second one to be off and vice versa.

To do so, we will first create a control block on the first Digital Write block, again by right-clicking on the input pin and then going to Create | Control. Then, we will go to the Functions menu, in Booleans, choose a Not element, and use it to connect our control to the second Digital Write channel. This way, we are sure that these two will always be in opposite states.

Finally, also do the same for the PWM block by creating a control for the PWM value. This one will simply be displayed as a text input inside Front Panel. We will also rename this pin as `Motor Speed` so that we know what it means in Front Panel.

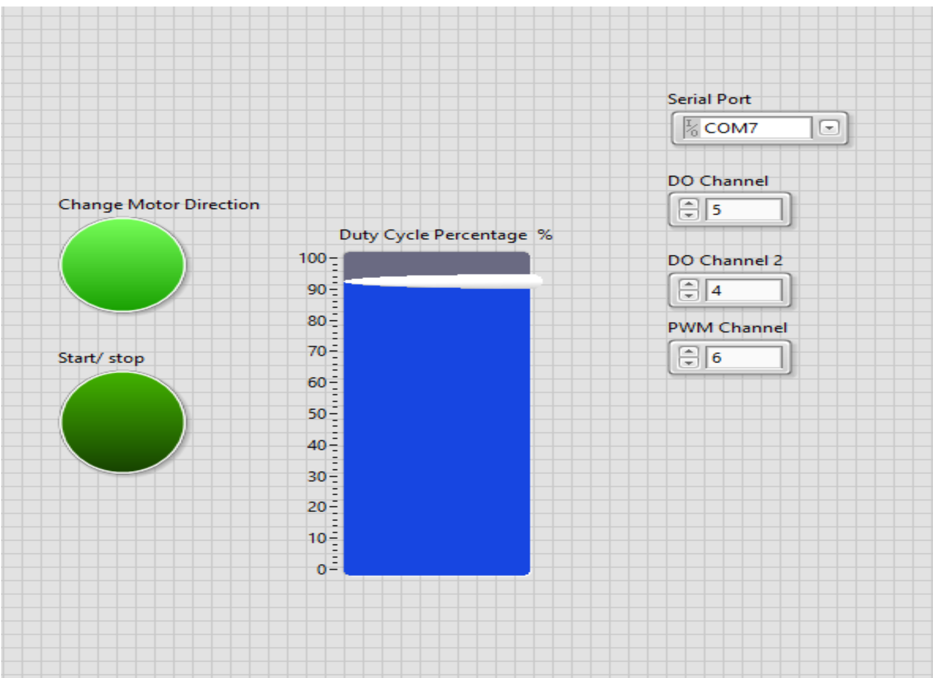


You can now go back to Front Panel and have a look at all the elements that were automatically added for you. Organize them a little bit so that it is easier to control the motor.

I simply arranged the Front Panel so that all the static controls, such as the serial port and pins, are on the left-hand side (we will modify them only once) and the dynamic controls for the motor are on the right-hand side:

It's now time to test the VI. First, set all the correct pins and your Serial Port, as shown in the preceding image. Then, click on the little arrow in the toolbar to start the VI.

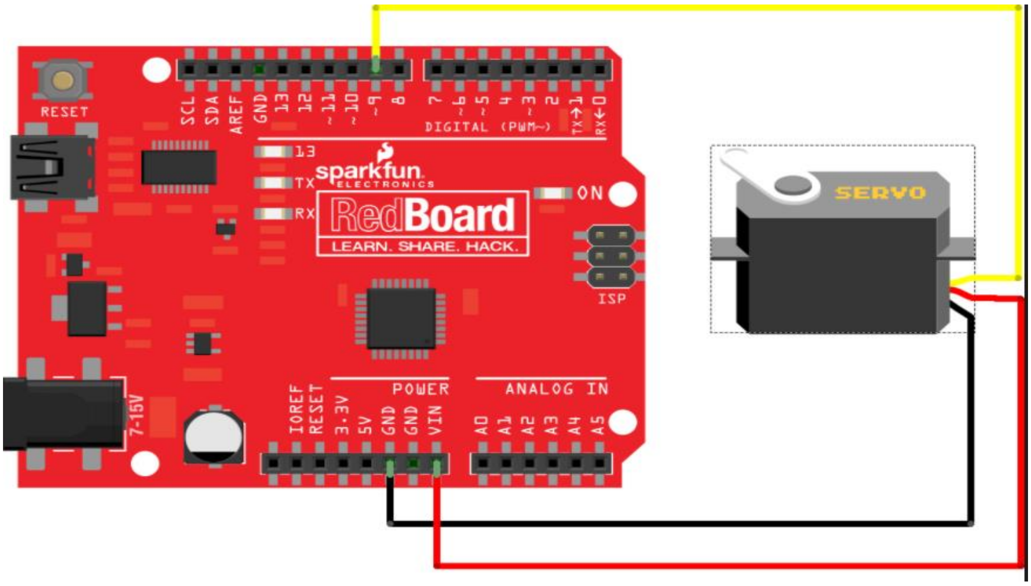
You can now enter a value between 0 and 255 in the Motor Speed input; you will see that the motor starts to rotate immediately. Note that we have to use a value between 0 and 255, as the Arduino Uno PWM output value is coded in 8 bits, so it has 256 values. You can also use the green button to change the direction of the motor.

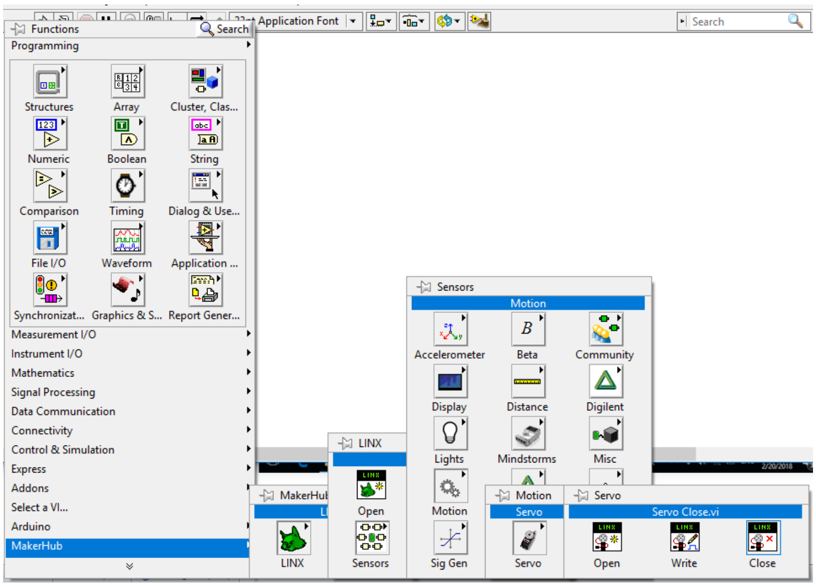


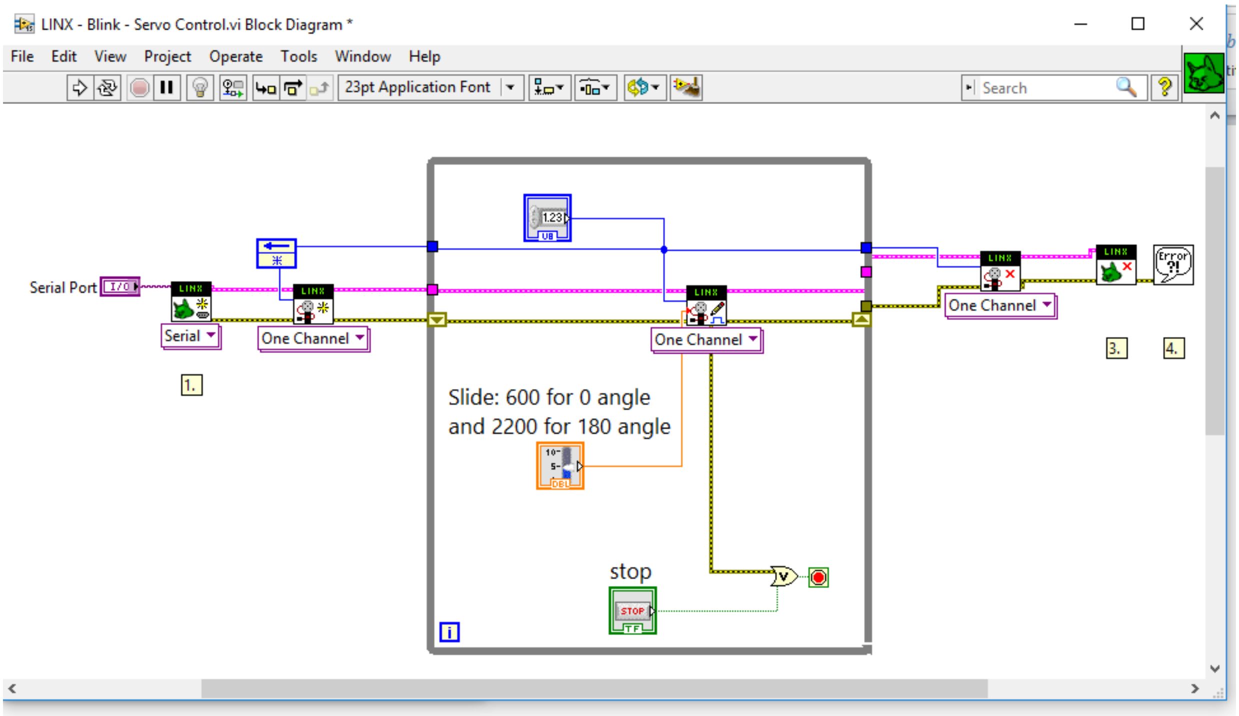
Example 2: Servo Motor Control:

In this example, you will learn how to control servo motor using LabVIEW program.

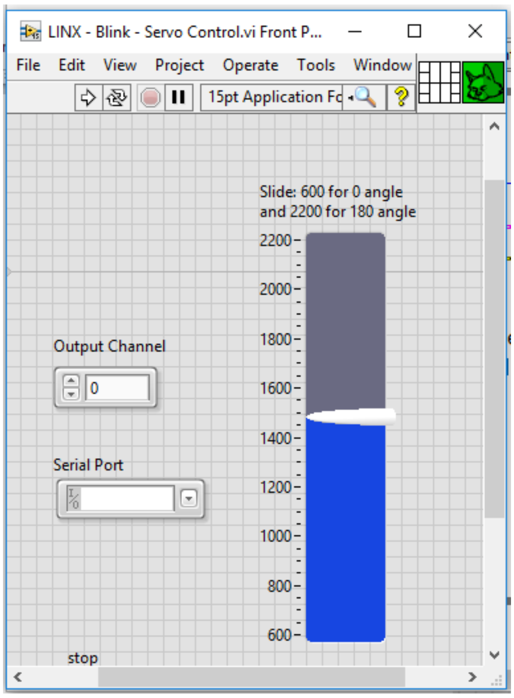
Follow the same procedures done in the previous example and build VI for servo motor control.
Note: some of block diagrams are found in the submenu shown below.





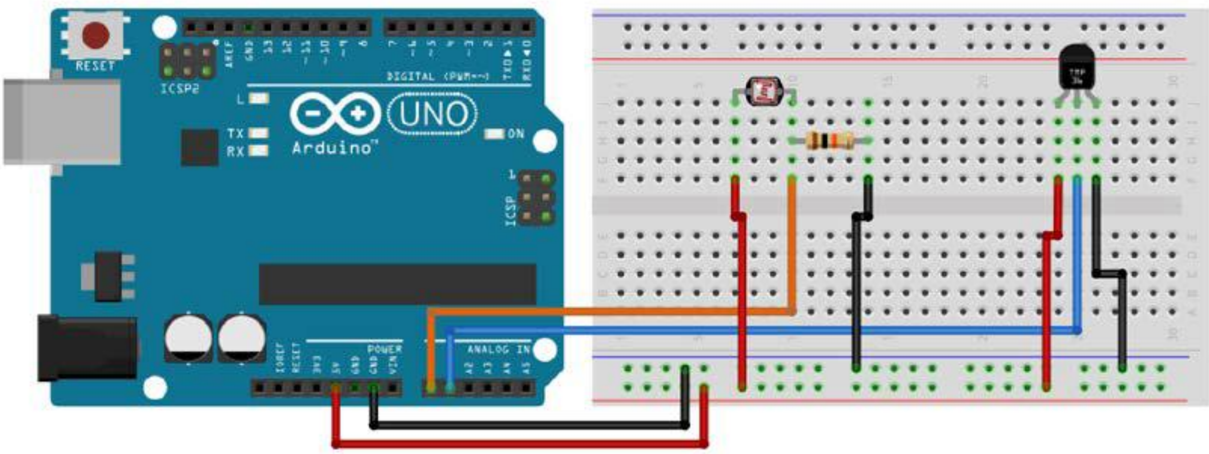


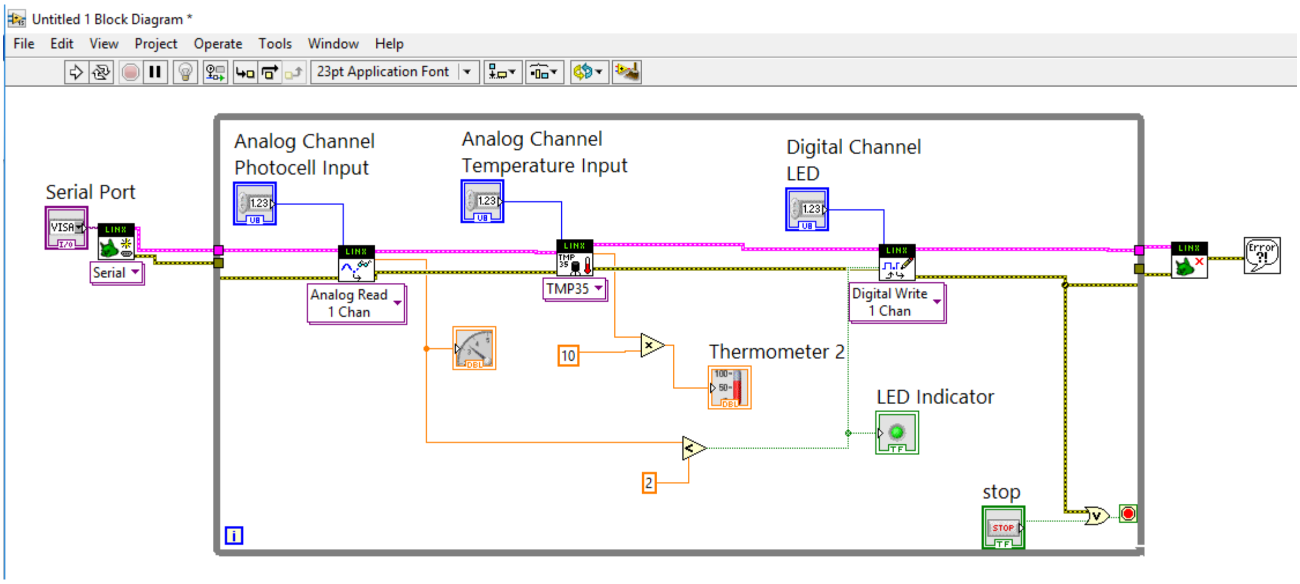
Now, move to interfacing screen, set to serial port (COM 3 or COM 4 based your computer) and also set output channel to the pin number that you connected to Arduino.

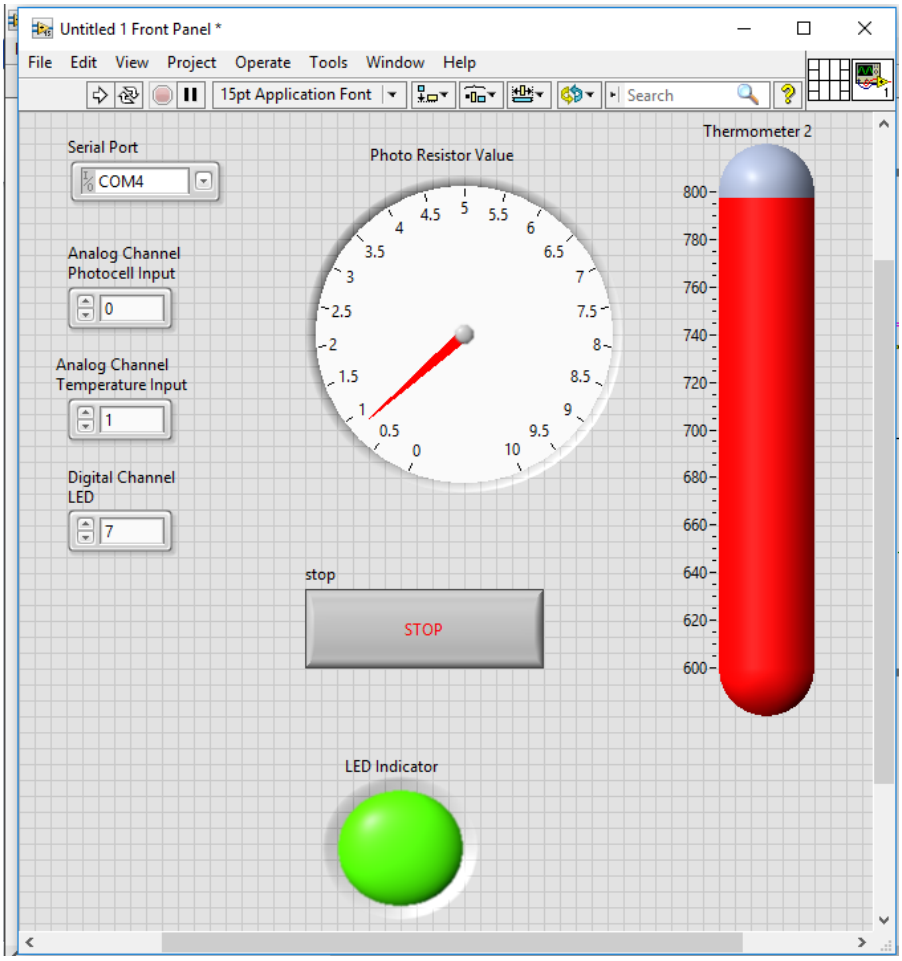


D. Example 3: Temperature and Photocell Sensor Indicator.

In this example, you are required to indicate the value of photocell and temperature sensor on LabVIEW interfacing screen.






Untitled 1 Front Panel *
File Edit View Project Operate Tools Window Help
15pt Application Font
Search
Serial Port
COM4
Analog Channel Photocell Input
0
Analog Channel Temperature Input
1
Digital Channel LED
7
Photo Resistor Value
stop
STOP
Thermometer 2
LED Indicator

Part II

Automation Systems

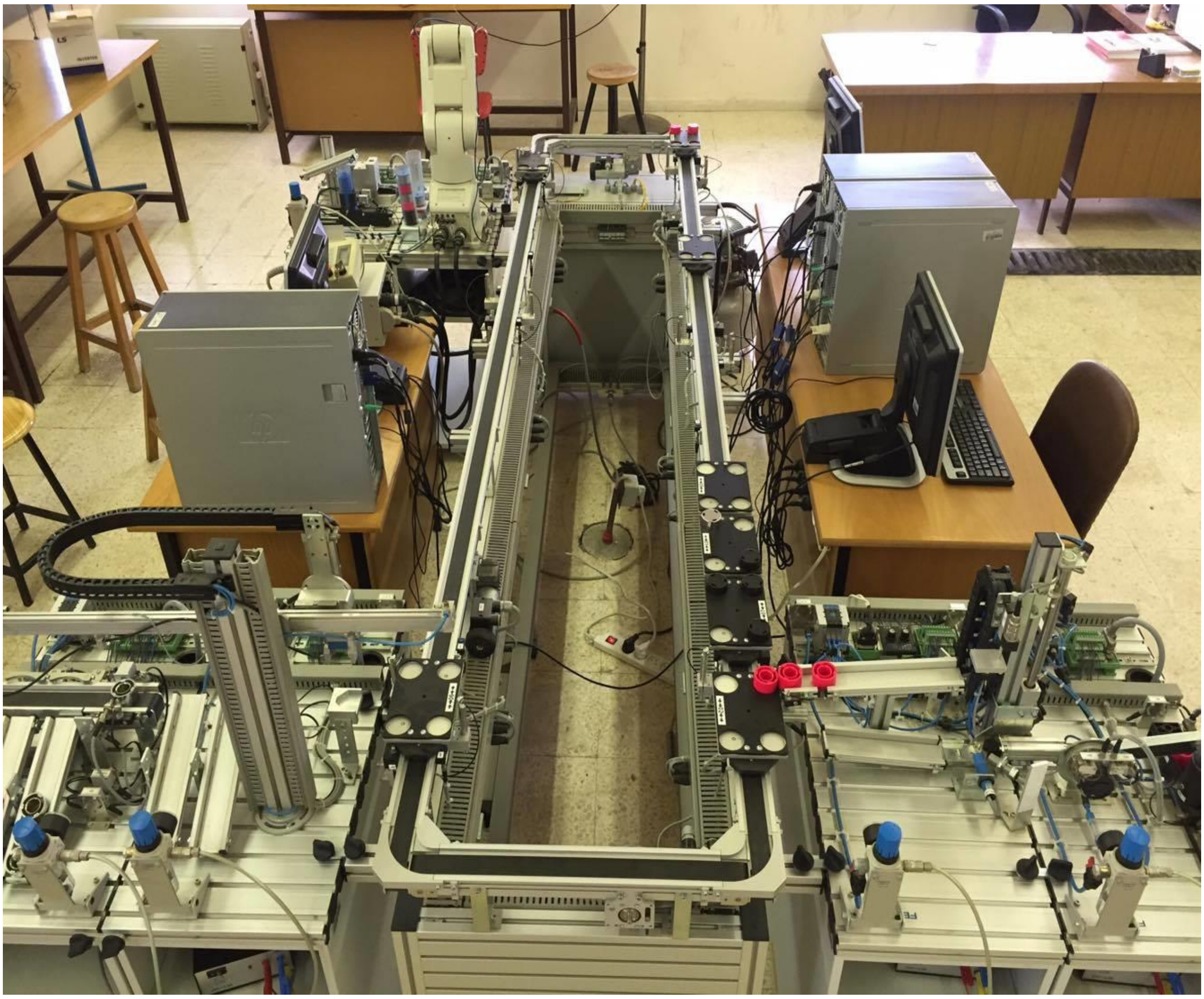


Figure 1. Automation System

This part of mechatronics lab contains different training practices that are related to automation systems. These practices help mechatronics students to be familiar with different engineering procedures to handle an automation operating task such as planning, assembly, programming, commissioning, operation, maintenance and Fault finding. At the start, important instructions and information about the operating automation systems are presented in section A as well as section B. These instructions and information are important to be mastered by the students before conducting the experiments of the automation systems. After that, different types of experiments related to the automation's part are presented.

Section A: General Information

The Training of This Part Covering the Following Subjects:

- Mechanics: Mechanical construction of a station.
- Pneumatics: Piping connections of pneumatic components, Vacuum technology, Pneumatic linear and rotary drives.
- Electrical: Correct wiring of electrical components.
- Sensors: Correct use of limit switches.
- PLC: Programming and use of a PLC, Structure of a PLC program.
- Commissioning: Commissioning of a production system.
- Fault finding: Systematic fault finding on a production system.

Safety Aspects:

When using the automation system there is nevertheless a risk of physical or fatal injury to the user, third parties such a damage being caused to the machinery or other material assets. Therefore, careful procedures have to be followed when operating the automation system to ensure safety aspects for both user and machine. These safety aspects can be summarized as follow:

i) General:

- Trainees must only work on the station under the supervision of an instructor.
- Observe the data in the data sheets for the individual components, in particular all notes on safety.

ii) Pneumatics:

- Do not exceed the permissible pressure of 8 bar (800 kPa).
- Do not switch on the compressor until you have established and secured all tubing connections.
- Do not disconnect air lines under pressure.
- Particular care is to be taken when switching on the compressed air. Cylinders may advance or retract as soon as the compressed air is switched on.
- Do not exceed the maximum operating pressure of the Handling station of 4 bar (400 kPa).

iii) Electrics:

- Electrical connections are to be wired up or disconnected only when power is disconnected.

- Use only low voltages of up to 24 V DC.

iv) Mechanics:

- Securely mount all components on the plate.
- No manual intervention unless the machine is at rest.

v) Drilling machine:

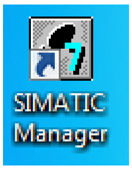
- The drilling machine is operational. Therefore, stay at a safe distance from the rotating spindle.
- The polishing process is merely simulated for reasons of safety.

Table 1. Technical Data

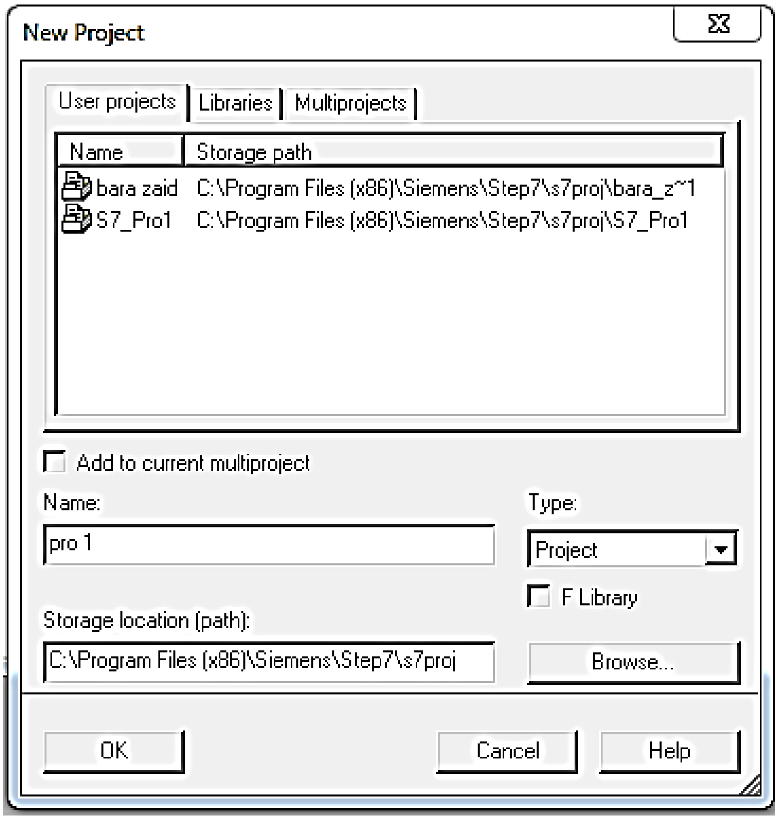
Parameter	Value
Operating pressure	6 bar (600 kPa)
Voltage supply	24 V DC, 4.5 A
Digital inputs	8
Digital outputs	8

Section B: Software Configuration

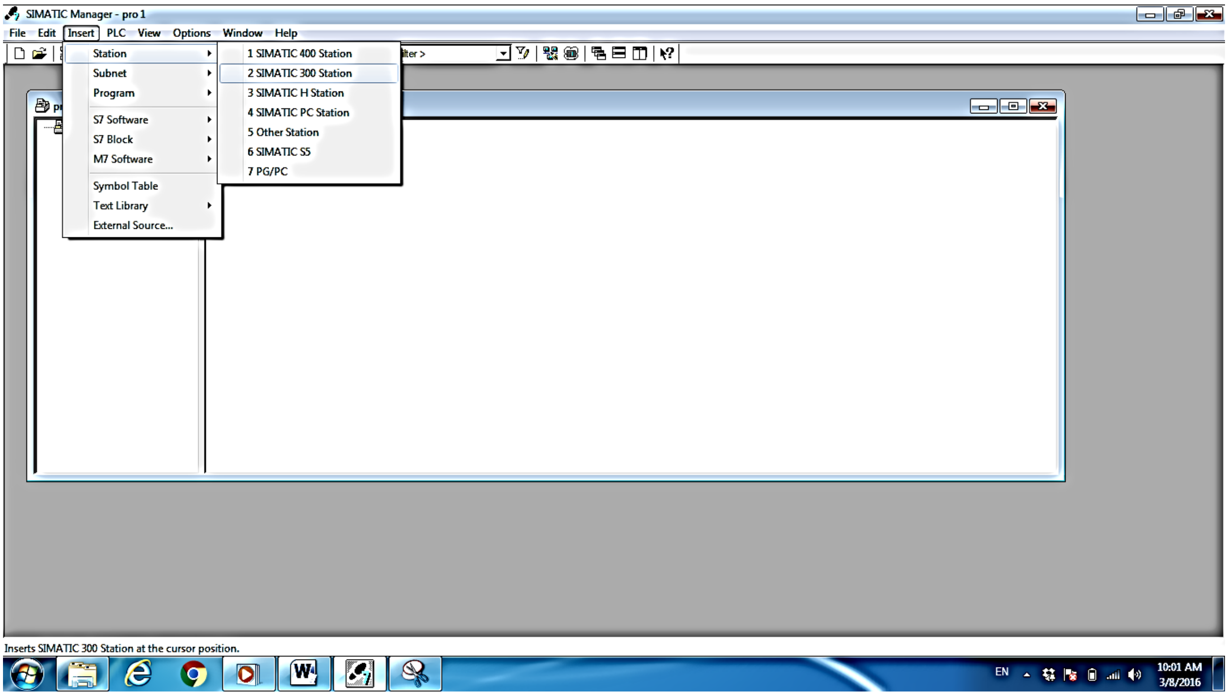
Open SIMATIC Manger from the Desktop



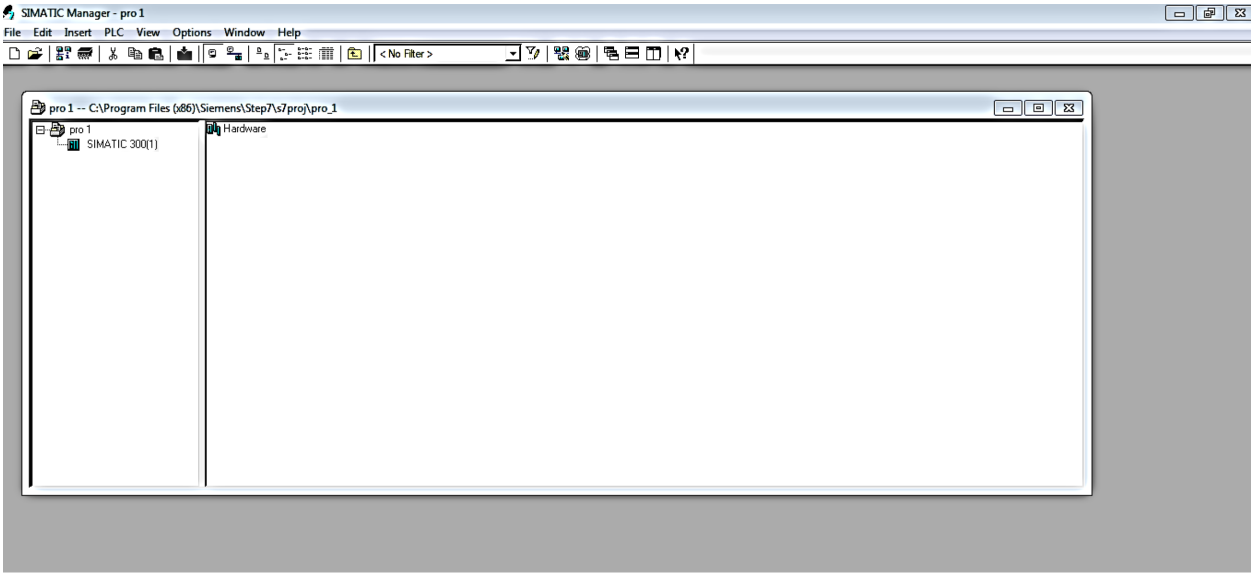
File→ New → (type name: pro 1)→ OK



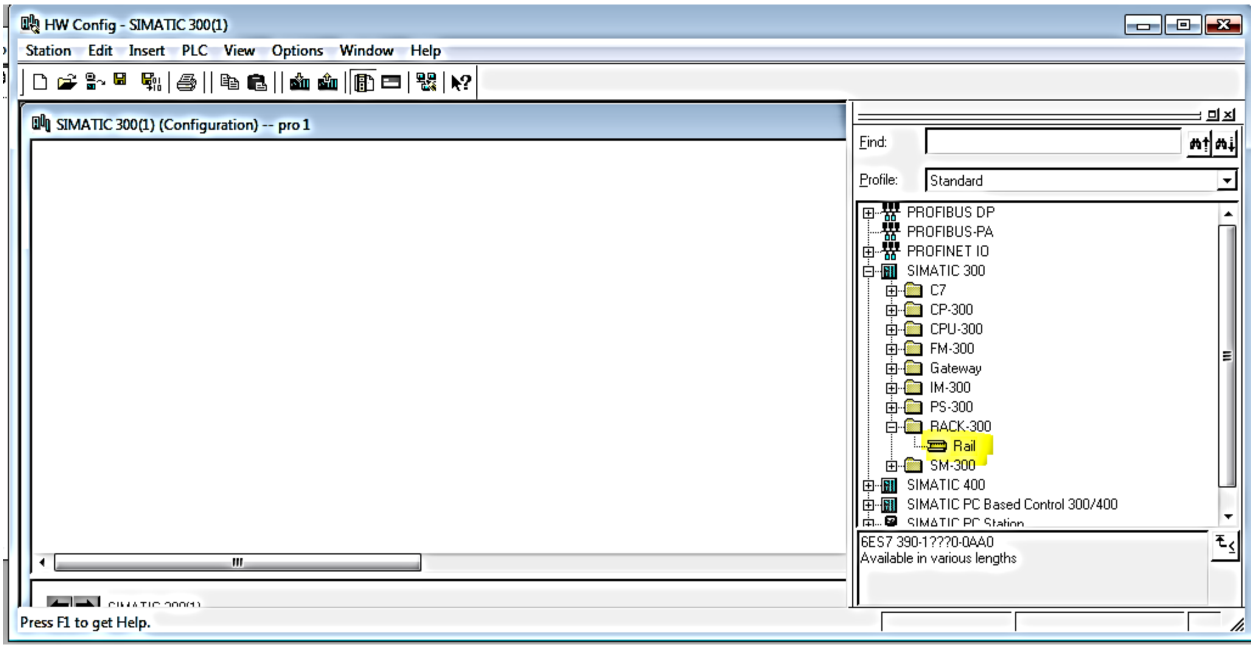
Insert→ Station → SIMATIC 300 Station



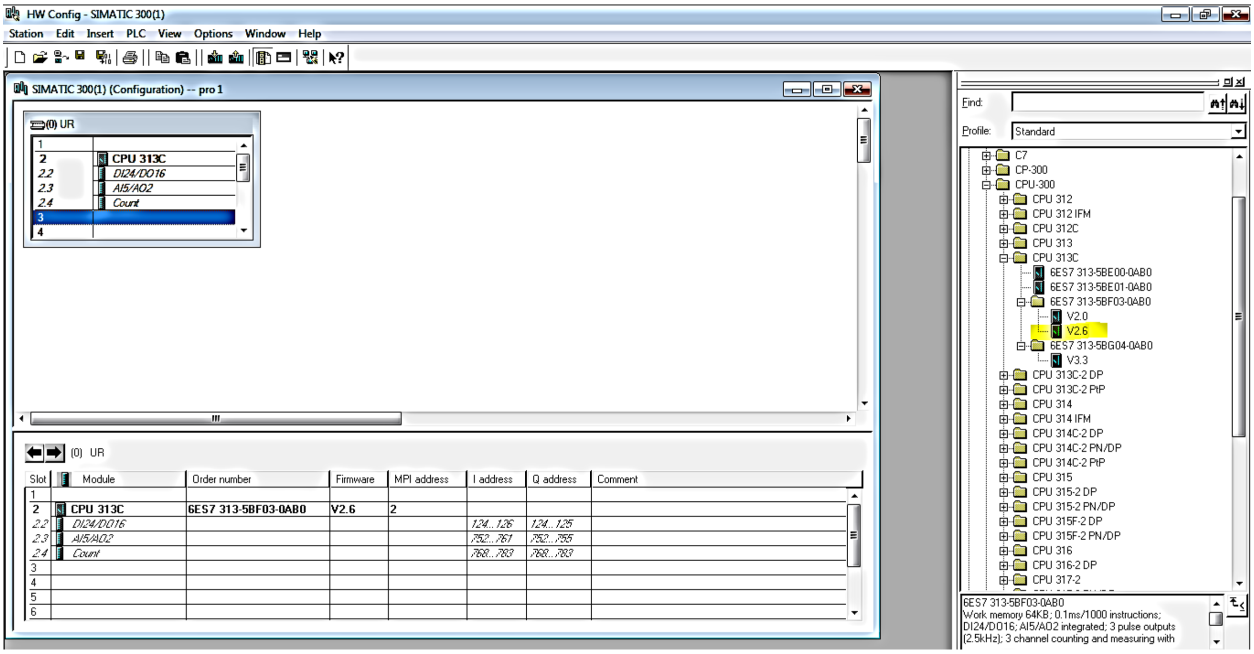
+ pro 1→ SIMATIC 300 (1) ⟶ Hardware (double click)



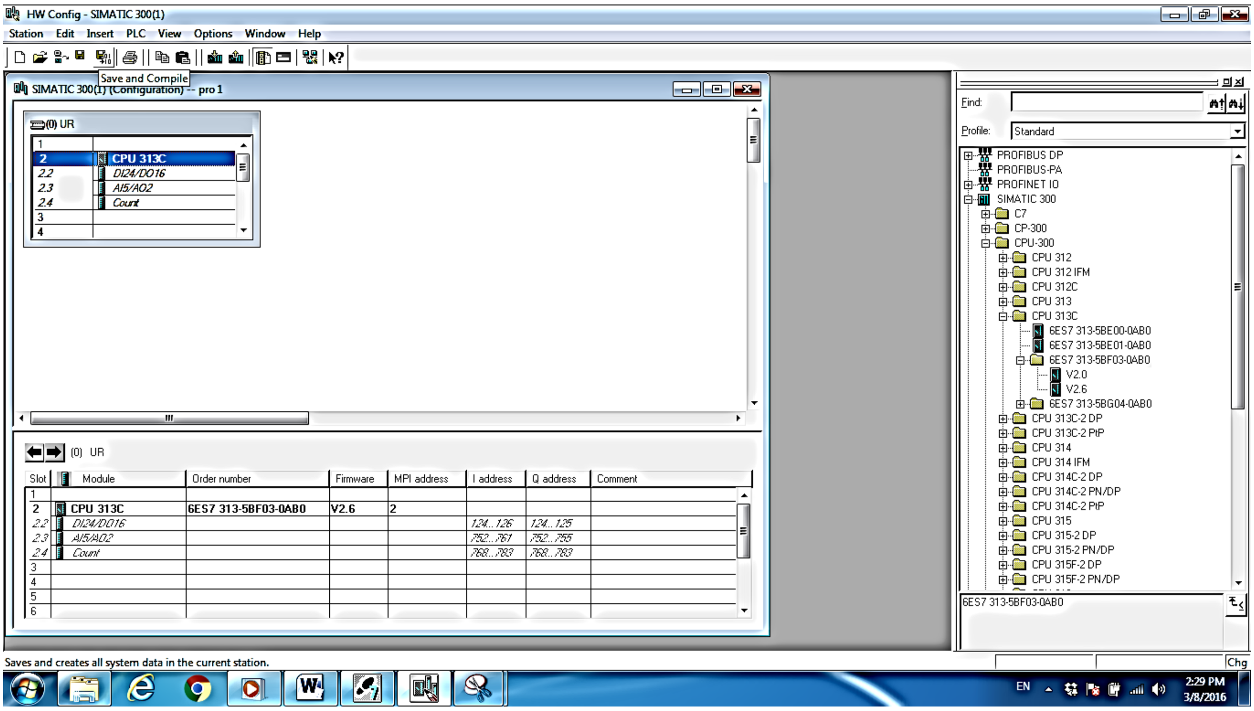
+ SIMATIC 300 → RACK- 300 ⟶ Rail (double click)



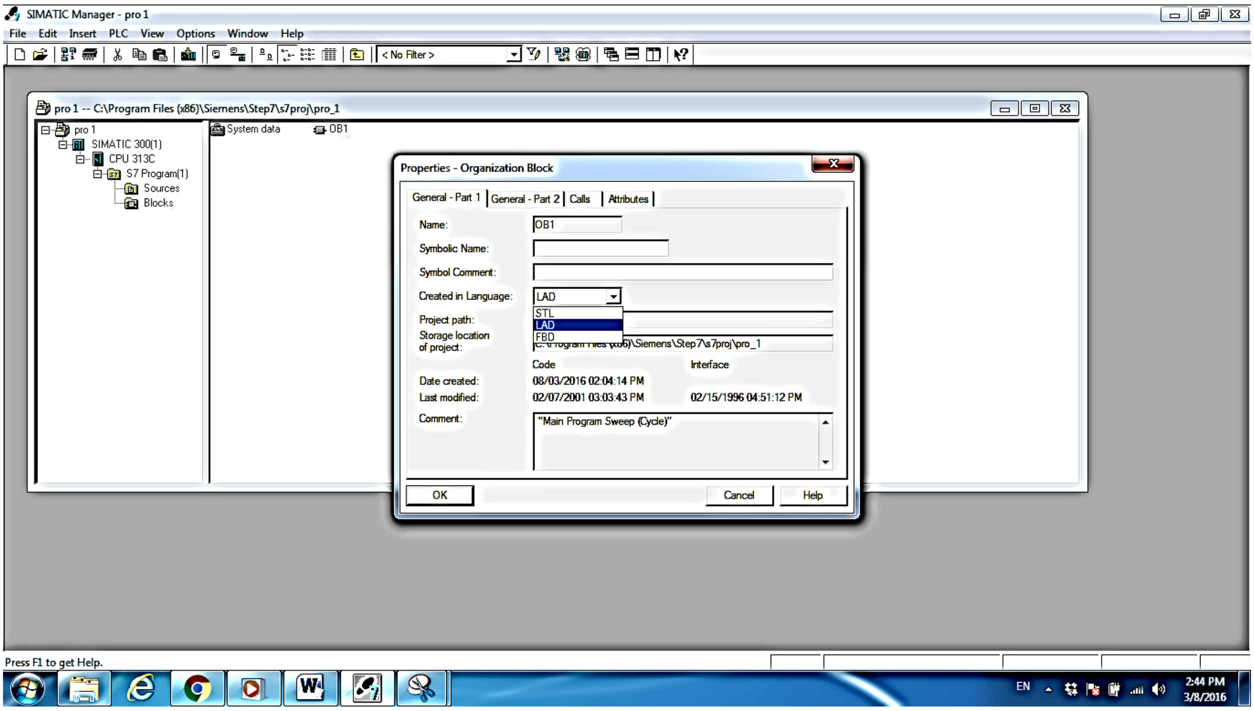
+CPU-300 → +CPU 313C → + 6ES7 313-5BF03-0AB0 (depends on the CPU you use) → drag V2.6 and drop it in row 2 as shown in window bellow



Station → Save and Compile or press Save and Compile Icon or (Ctrl+S)



Return to SIMATIC Manager → CPU 313C → SIMATIC 300 (1) → S7 Program (1) Blocks → OB1



Experiment # 04

Distributing Station

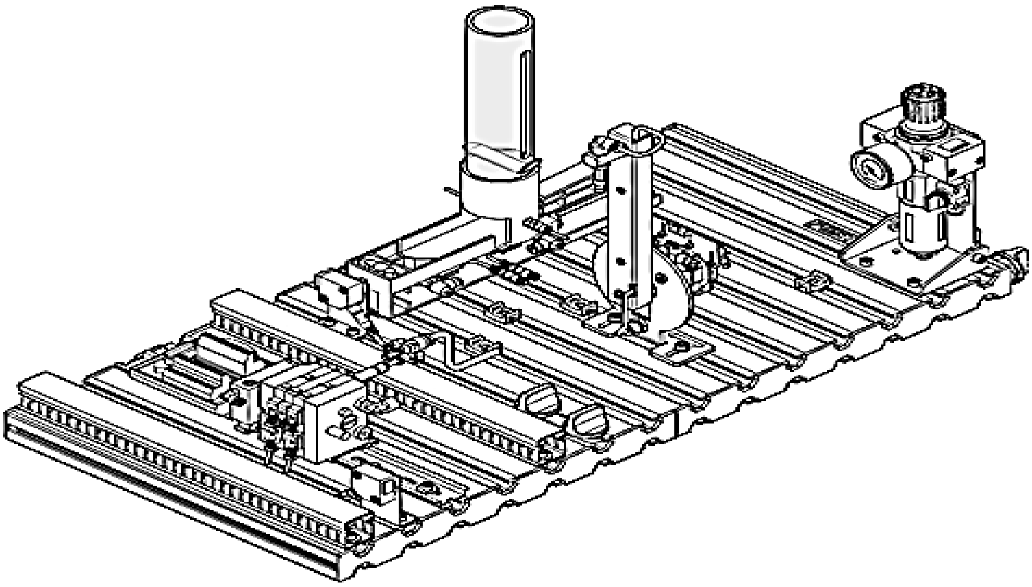


Figure 4.1 Distribution Station

Distributing station is a feed device which is defined as units that fulfill the function of bunkering, sorting and feeding of components. In addition, feed devices can facilitate the sorting of components according to various sorting characteristics of the component (shape, weight etc.).

Figure 4.2 Distributing station with trolley, control console and PLC board

The distributing station separates work pieces from the Stack magazine module. The magazine barrel of the stack magazine holds up to 8 work pieces. The filling level of the stack magazine is monitored by means of a through-beam sensor. A double- acting cylinder pushes out the work pieces individually.

The Changer module grips the separated out work piece using a suction cup. A vacuum switch checks whether a work piece has been picked up. The arm of the transfer unit, which is driven by a rotary drive, conveys the work piece to the transfer point of the downstream station.

The Functions of The Distributing Station are:

- To separate out work pieces from a magazine.
- To transfer work pieces by means of a rotary drive using a suction cup.

Examples of Feed Devices:

- Magazines with feed limiting.
- Vibratory bowl feeder.
- Inclined conveyors.
- Hoppers with sorting devices.

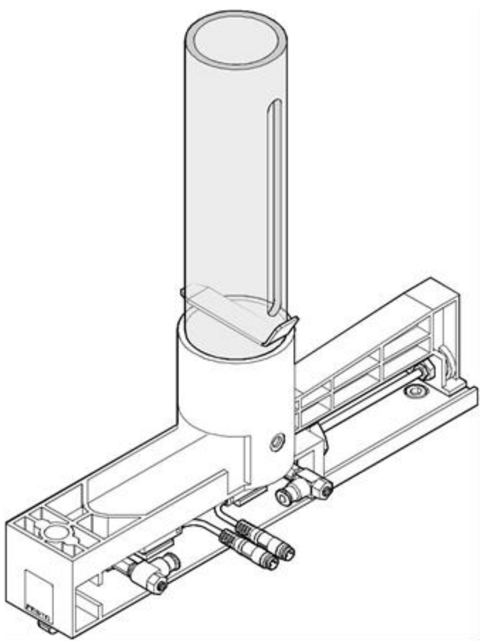
Work pieces handled by feed devices are:

- Electroplated parts.
- Shaped parts made of plastic.
- Punched parts.
- Turned components.

Main Parts and Components of Distributing Station:

i. **Stack Magazine Module**

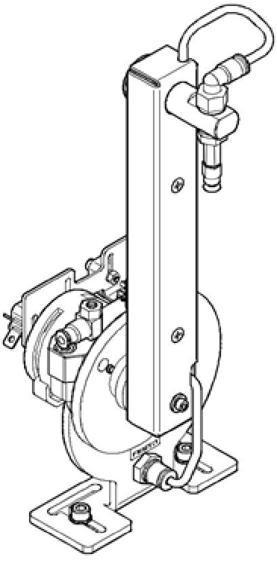
The Stack magazine module separates work pieces from a magazine. Up to 8 work pieces can be stacked in any order in the magazine barrel. The work pieces must be inserted with the open side facing upwards. A double-acting cylinder pushes the lowest work piece from the gravity-feed magazine up to the mechanical stop. This position serves as a transfer point to the next module (e.g. Changer module).



The available work piece in the magazine barrel is detected by means of a through-beam sensor. The position of the ejecting cylinder is sensed electrically via inductive sensors. The advancing and retracting speed of the ejecting cylinder is infinitely adjustable by means of one-way flow control valves.

ii. Changer Module

The Changer module is a pneumatic handling device. Work pieces are picked up using a suction cup and transferred by means of a rotary drive. The swiveling range is adjustable between 0° and 180° by means of mechanical end stops. The end position sensing is effected by means of electrical limit switches (micro switches).



Sensors

i. Proximity sensor (Stack magazine, ejecting cylinder)

The proximity sensors are used for end position sensing of the cylinder. The proximity sensor is sensitive to a permanent magnet mounted on the piston of the cylinder.

ii. Through-beam sensor (Stack magazine, filling level)

The through-beam sensor is used for monitoring the filling level of the Stack magazine. A fibre optic cable is connected to a fibre optic device. The fibre optic device emits visible red light. The work piece interrupts the light barrier.

iii. Micro switch (Changer, swivel drive)

The micro switches are used for end stop sensing of the swivel drive (semi-rotary drive). The micro switches are actuated by adjustable trip cams on the shaft of the swivel drive.

iv. **Vacuum switch (Changer, vacuum suction cup)**

The vacuum switch is used to detect the partial vacuum at the vacuum suction cup. If a work piece is securely picked up, an output signal is generated by the vacuum switch.

Operating Sequence Description

Start prerequisites

- Magazine is filled with work pieces

Initial position

- Ejecting cylinder is extended
- Rotary drive is in position “magazine”
- Vacuum is off

Sequence

- The rotary drive swivels to the position “downstream station” if workpieces are identified in the magazine and the START button is pressed.
- The ejecting cylinder retracts and pushes a workpieces out of the magazine.
- The rotary drive swivels to the position “magazine”.
- The vacuum is switched on. When the workpiece is securely held, a vacuum switch switches.
- The ejecting cylinder advances and releases the workpiece.
- The rotary drive swivels to the position “downstream station”.
- The vacuum is switched off.
- The rotary drive swivels to the position “magazine”.

Starting the Sequence

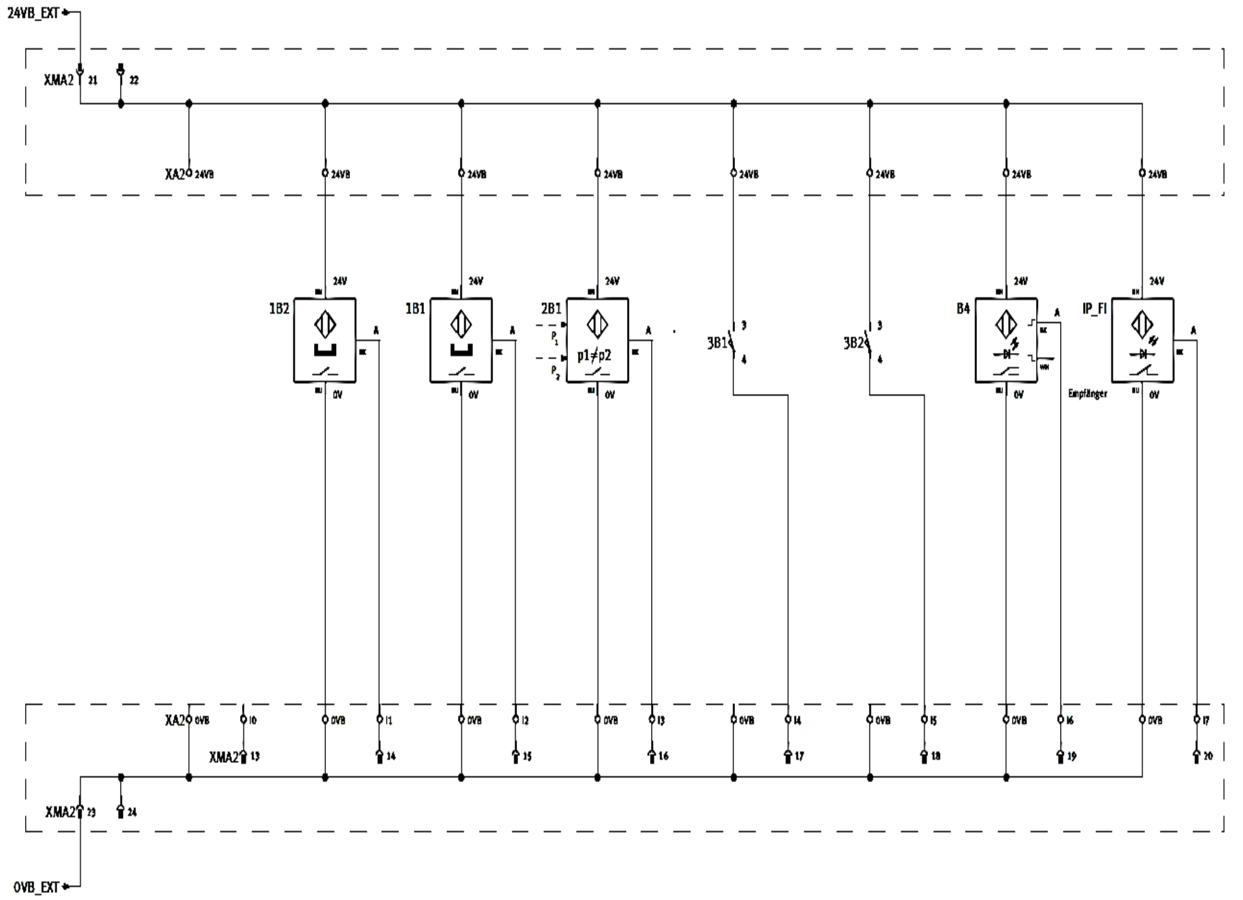
- Fill the magazine with a maximum of 8 work pieces. The opening of the work pieces must point upwards.
- Check the voltage supply and compressed air supply.
- Remove work pieces at the transfer points of modules or stations prior to manual reset.
- Carry out the reset sequence. The reset sequence is prompted by an illuminated
- RESET pushbutton and executed when the pushbutton has been pressed.
- If a work piece is present at the transfer point of the stacking magazine, you will need to remove this manually.
- Start the sequence of the Distributing station. The Start is prompted by the illuminated START button and carried out when the pushbutton has been actuated.

Notes

- The sequence can be interrupted at any time by pressing the EMERGENCY-STOP pushbutton or by pressing the STOP pushbutton.
- With the key-operated switch AUTO/MAN, you can select either the continuous cycle (AUTO) or individual cycle (MAN).
- The following applies in the case of a combination of several stations: The individual stations are reset against the material flow.
- The warning light MAG. EMPTY is illuminated if the stacking magazine does not contain any work pieces. Insert the work pieces and acknowledge by means of pressing the START button.

Input, Output and Pneumatic Circuit Diagrams

i. Station Inputs (Sensor Circuit)



Spannung-versorgung	Ausschiebezylinder ausgefahren	Ausschiebezylinder eingefahren	Werkstück angesaugt	Schwenkzylinder in Position Magazin	Schwenkzylinder in Position Folgestation	Magazin leer	Folgestation frei
Power supply	Ejecting cylinder extended	Ejecting cylinder retracted	Workpiece gripped	Swivel drive in magazine position	Swivel drive in downstream station pos.	Magazine empty	Downstream station free

Figure 4.3 Sensor Circuit

ii. Station Input/output

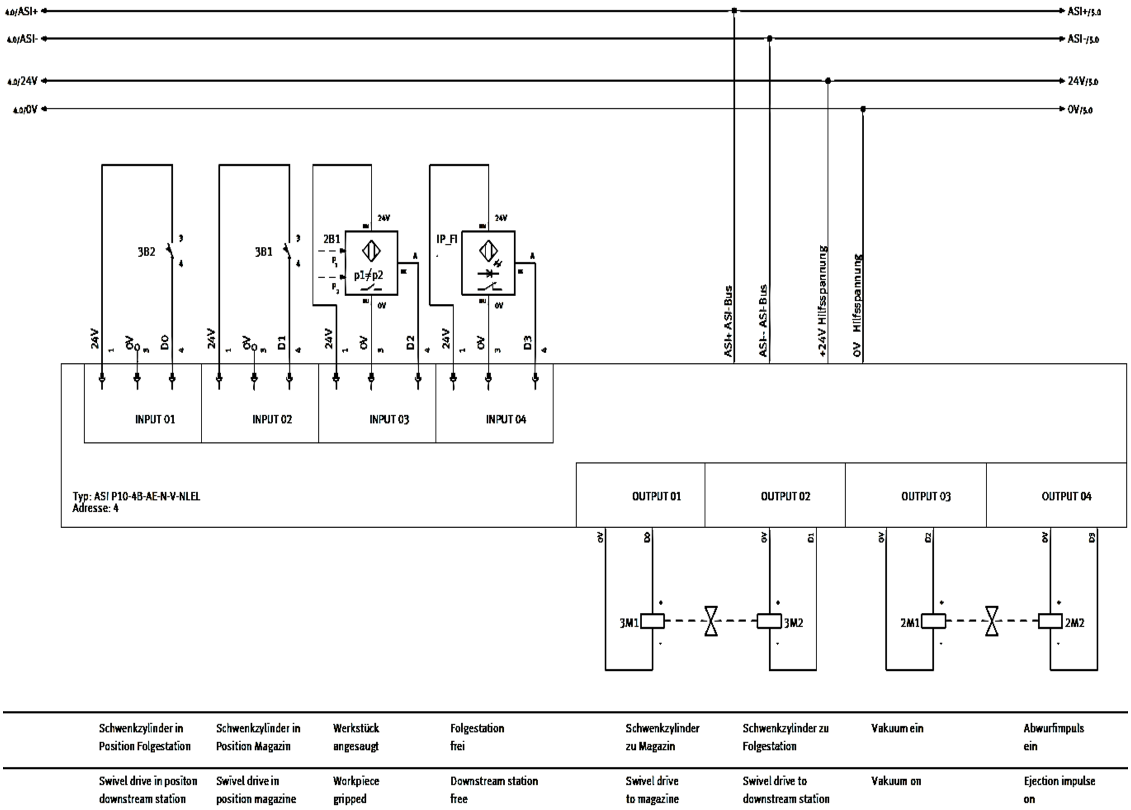


Figure 4.4 (a) Input-Output Circuit

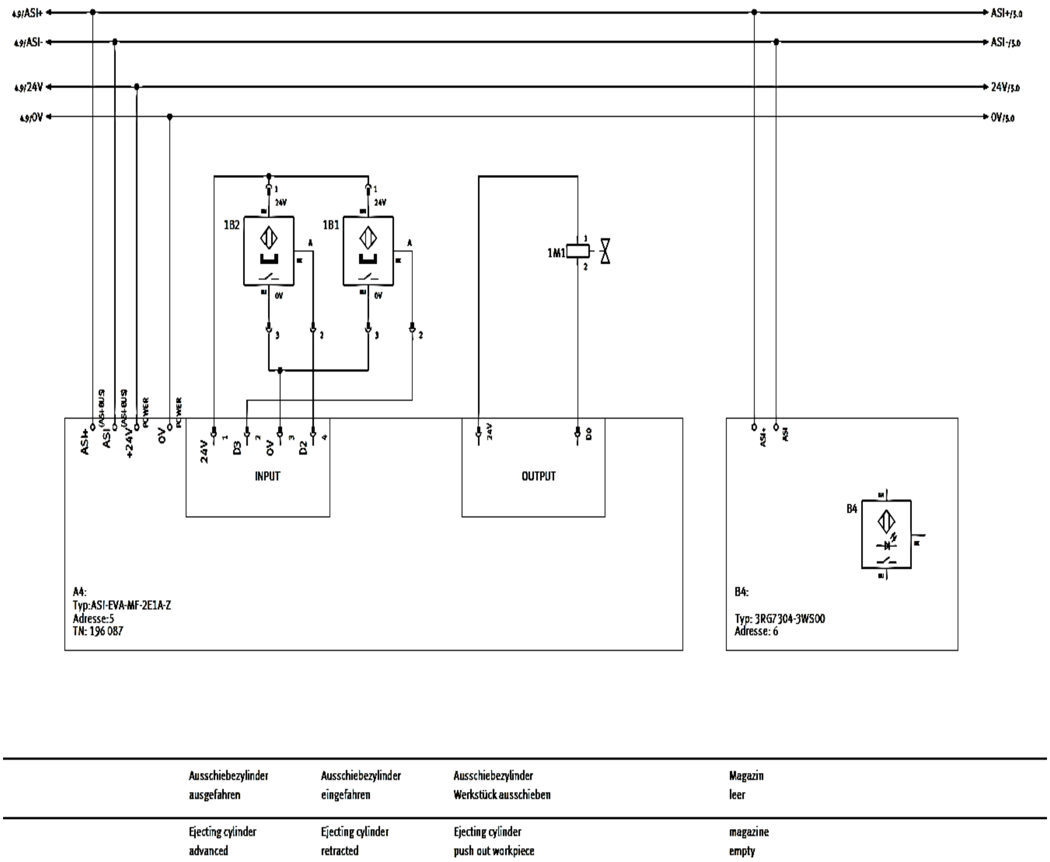


Figure 4.5 (b) Input-Output Circuit

iii. Output Station

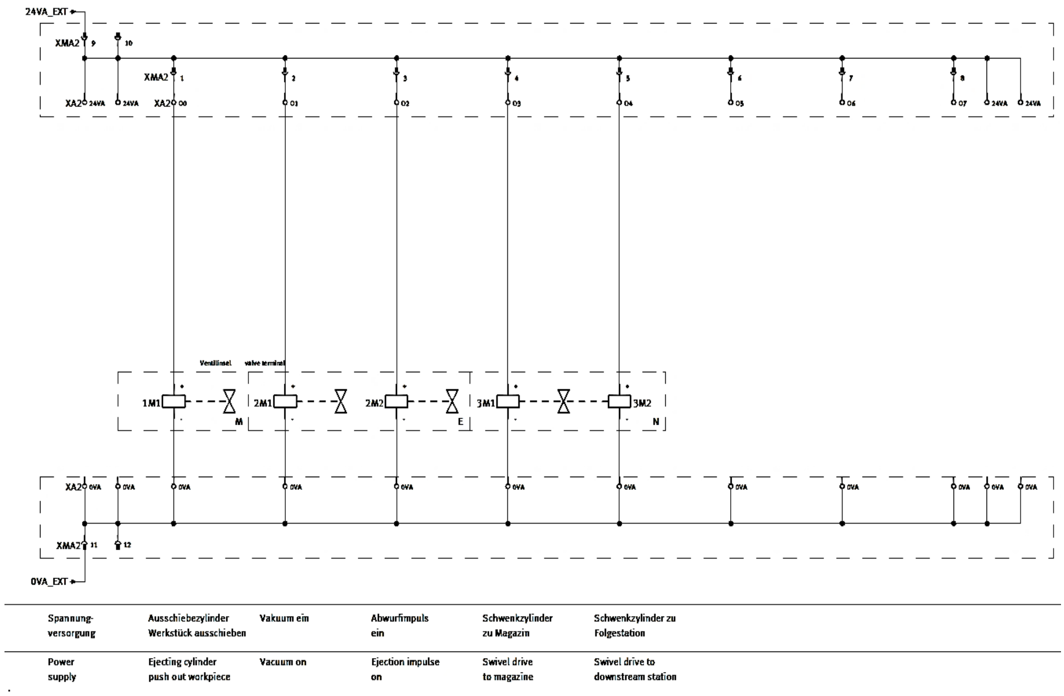


Figure 4.6 Actuator Circuit

iv. Pneumatic circuit

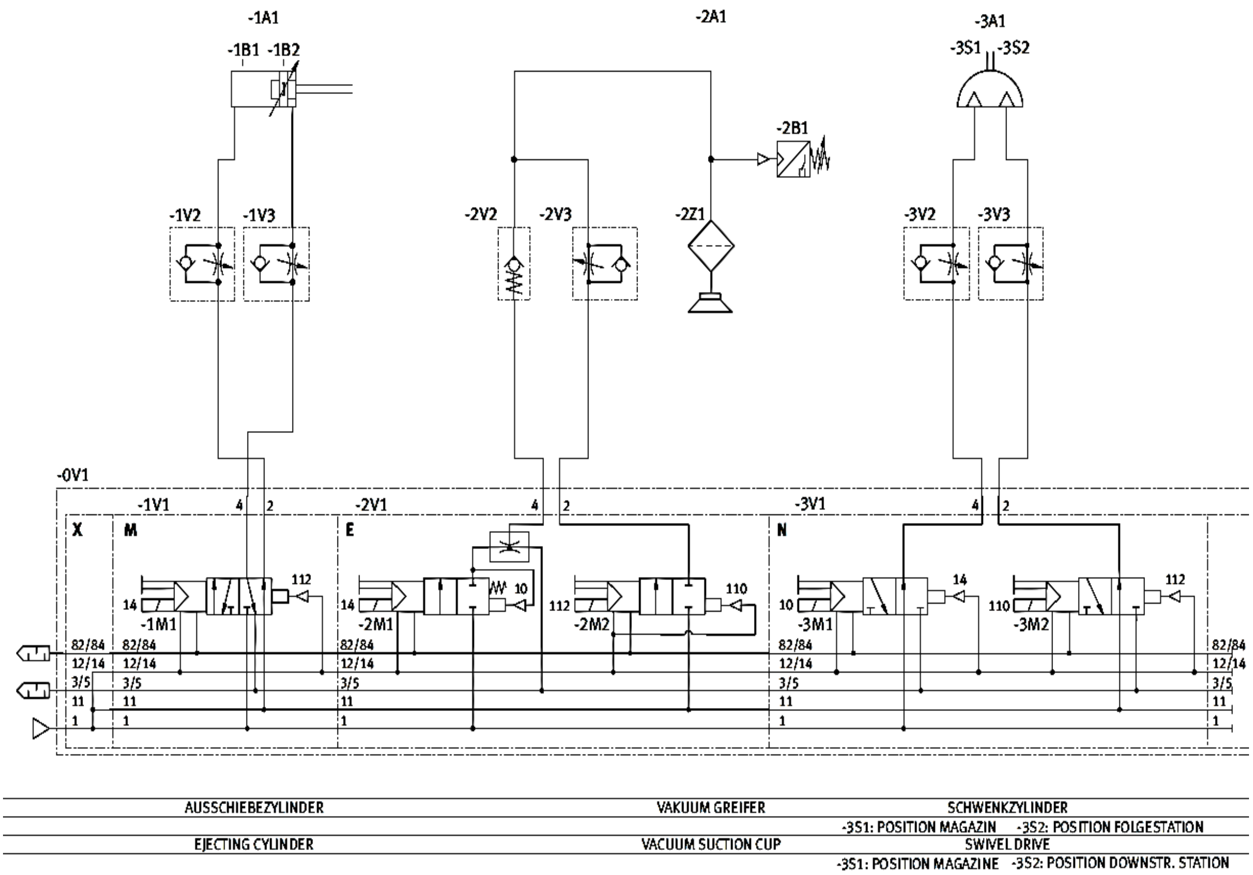


Figure 4.7 (a) Pneumatic Control Circuit

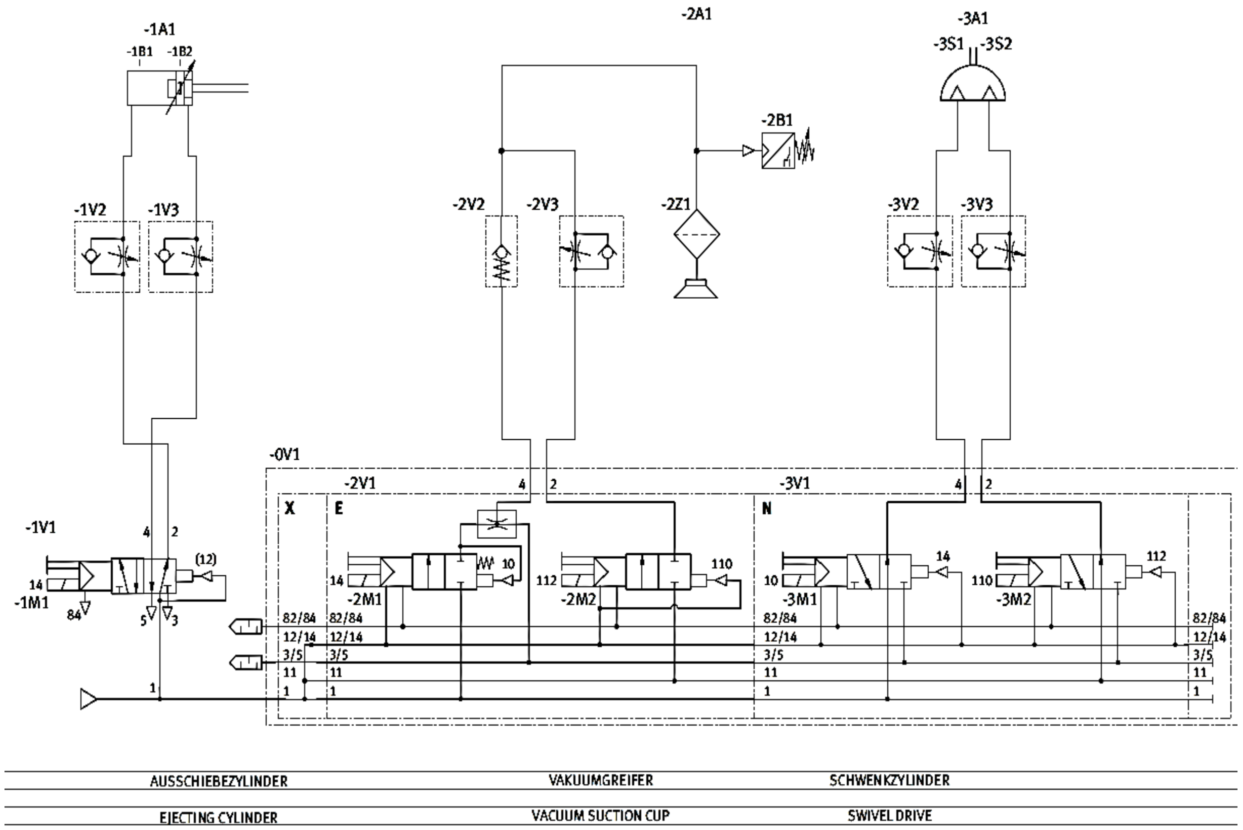


Figure 4.7 (b) Pneumatic Control Circuit

Experiment # 05

Testing Station

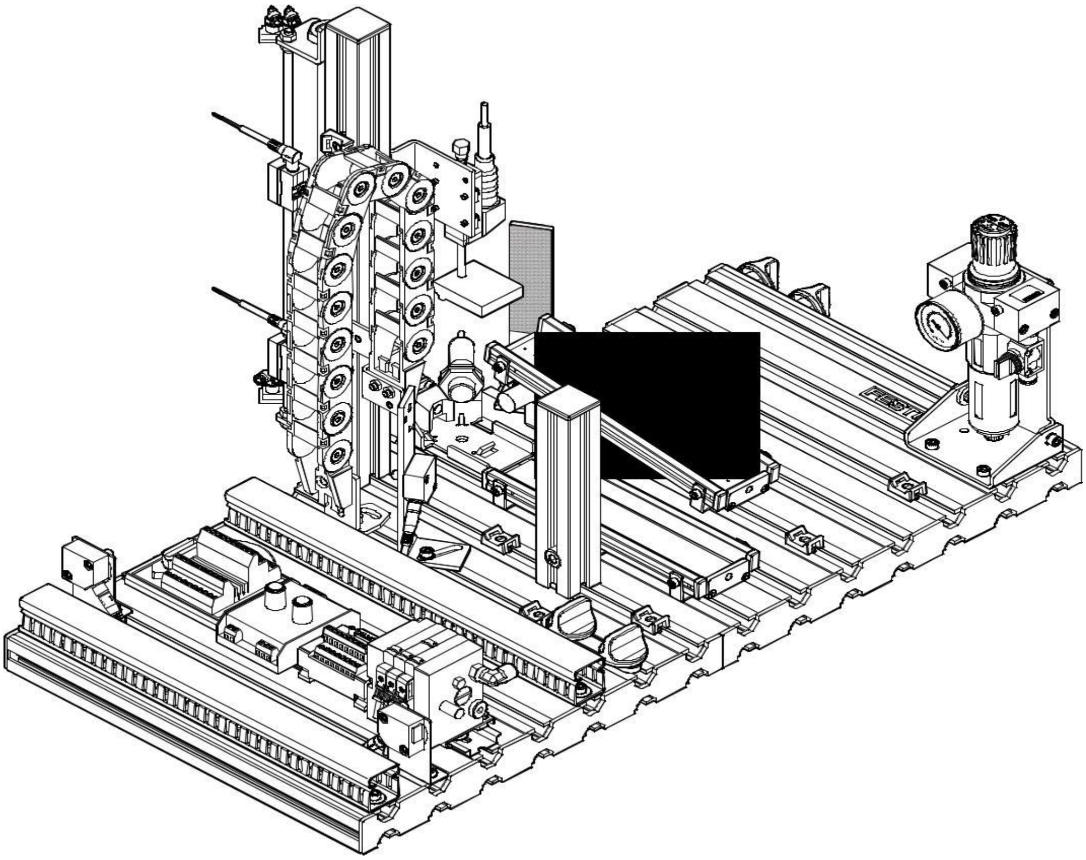


Figure 5.1 Testing Station

In automated production, in contrast with manual production testing assumes a key role. In manual production, reject parts can be immediately rejected, whereas in automated product, reject parts can lead to malfunction of the production process or a halt in production.

The Testing station determines the characteristics of inserted work pieces. The sensing module identifies the color of a work piece and a capacitive sensor detects each work piece irrespective of color. A diffuse sensor identifies metallic and red work pieces. Black work pieces are not detected by the diffuse sensor. A retroreflective sensor monitors whether the working area above the work piece retainer is free before the work piece is lifted by the Lifting module.

The analogue sensor of the measuring module determines the height of the work piece. The output signal is either digitalized via a comparator with adjustable threshold value or can be supplied to a PLC using analogue signal processing via a connection block. A linear cylinder guides the correct workpieces to the downstream station via the upper air cushioned slide. Other work pieces are sorted on the lower slide.

Typical Testing Characteristics Are:

- Availability checking.
- Identity checking.
- Contour checking.
- Size checking.
- Color checking.
- Weight checking.
- Checking the availability of a work piece.

The Functions of the Testing Station are:

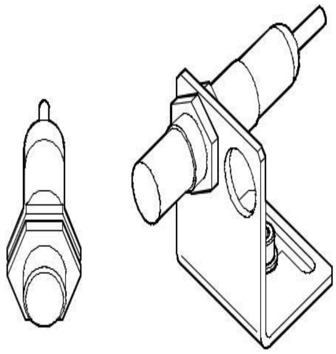
- To determine the material characteristics of a work piece,
- To check the work piece height.
- To either reject a work piece or make it available to a subsequent station.

Figure 5.2 Testing Station with Trolley, Control Console and PLC Board

Parts of Testing Stations:

i. **Recognition Module**

Material or color identification is carried out by means of 2 proximity sensors with digital output (capacitive and optical proximity sensor):

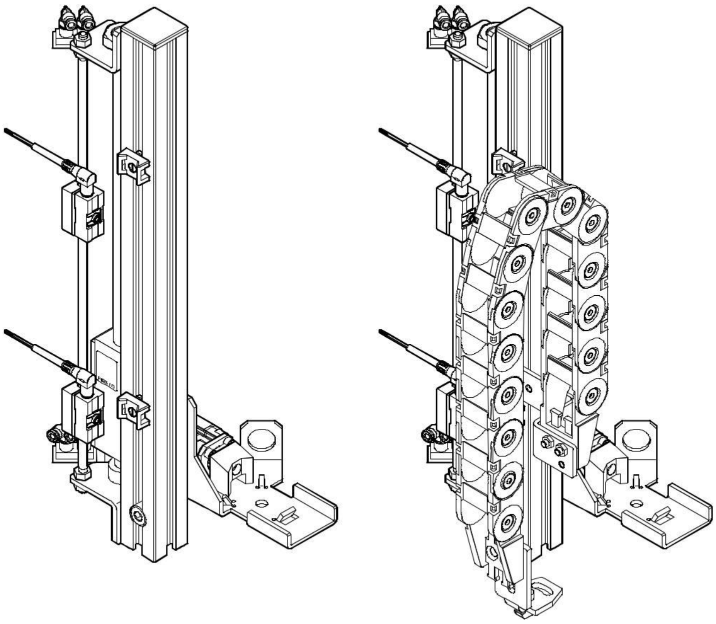


- Capacitive proximity sensor detects silver, red and black work pieces.
- Optical proximity sensor detects silver and red work pieces.

A logic circuit facilitates the assignment of the characteristics silver/red or black to the respective work pieces.

ii. **Lifting Module**

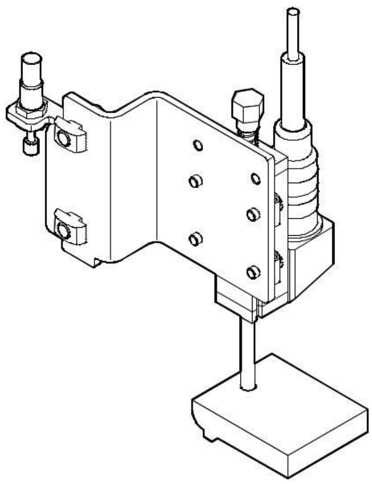
The work pieces are lifted from the Sensing module to the measuring module by means of the Lifting module. The actuators used are a rod less lifting cylinder and an ejecting cylinder. The moving compressed air tubing and electrical cables are routed via the cable guide. The end position sensing of the cylinders is effected by magnetic or inductive proximity sensors.



iii. **Measuring Module**

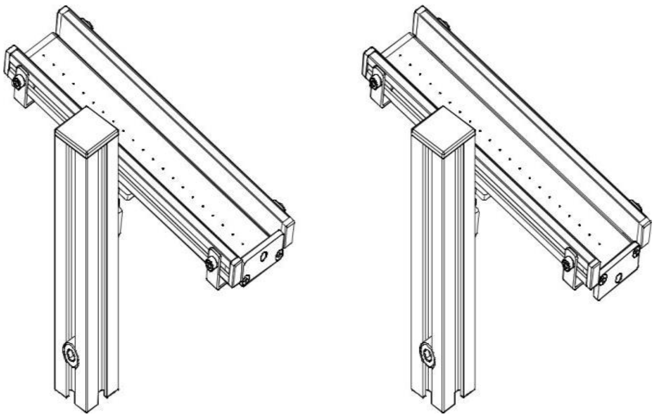
The Measuring module consists of an analogue sensor for the height measurement of work pieces. The operational principle is based on a linear potential meter with a voltage divider tapping. An attached shock absorber affects the cushioned end position approach of the lifting cylinder.

The analogue measured value can be digitalized via a comparator with adjustable threshold values (0/1 signal). The analogue signal can be supplied to a PLC using analogue signal processing via the connection block.



iv. **Air Cushioned Slide Module**

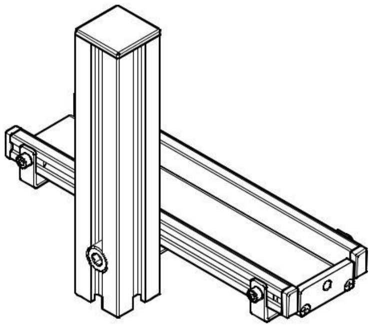
The Slide module with air cushioning is used to transport work pieces. 5 work pieces can be accommodated on the air cushioned slide if the mechanical stopper is fitted. The cushioning minimizes friction between the work pieces and slide surface. The inclination angle of the slide is infinitely adjustable.



If the Testing station is operated using a downstream station, then the mechanical stopper at the end of the air cushioned slide must be rotated by 180°. The height and tilt of the air cushioned slide must be adjusted so as to ensure that the work piece safely slides into the pick-up position of the downstream station.

v. **Slide Module**

The Slide module is used to transport work pieces. 4 work pieces can be accommodated on the slide if the mechanical stopper is fitted. The inclination angle of the slide is infinitely adjustable.



Sensors:

i. **Capacitive proximity sensor (Recognition, detection of work piece)**

The capacitive proximity sensor is used for detection of work pieces. The work piece changes the capacity of a capacitor build in the sensor head. Work pieces are detected independent of color and material.

ii. **Diffuse sensor (Recognition, color detection)**

The diffuse sensor is used for color detection. The diffuse sensor uses infrared light. The diffuse sensor detects the light reflected by the work piece Different surfaces or colors changes the amount of reflected light.

iii. **Retro-reflective sensor (Lifting, working space)**

The retro-reflective sensor is used for monitoring the working space of the Lifting module. If the working space is occupied, it is not possible to move the lifting cylinder. A retro-reflective sensor consists of transmitter and receiver in the same housing. The retro-reflective sensor emits visible red light. The light is reflected by an external reflector. If the light beam is interrupted by an object, the switching status of the retro-reflective sensor changes.

iv. **Proximity sensor (Lifting, lifting cylinder)**

The proximity sensors are used for end position sensing of the cylinder. The proximity sensor is sensitive to a permanent magnet mounted on the piston of the cylinder.

v. **Proximity sensor (Lifting, ejecting cylinder)**

The proximity sensors are used for end position sensing of the cylinder. The proximity sensor is sensitive to a permanent magnet mounted on the piston of the cylinder.

vi. **Linear displacement sensor with comparator (Measuring, height of a workpiece)**

The linear displacement sensor is used for measuring the height of a workpiece. The analogue output signal of the linear displacement sensor is converted to a binary signal (0/1 signal) by means of a comparator.

Adjusting One-Way Flow Control Valves

One-way flow control valves are used to regulate exhaust air flow rates with double-acting cylinders. In the reverse direction, air flows through the non-return valve with full cross-sectional flow.

Uncontrolled supply air and controlled exhaust hold the piston between air cushions (improves motion, even with load changes).

Operating Sequence Description

i) **Starting Prerequisites**

Work piece is in work piece retainer working area free.

ii) **Initial Position**

- Lifting cylinder is lowered.
- Ejecting cylinder is retracted.
- Air cushioned slide is off.

iii) **Operating Sequence Process**

- Determine the color and material of the work piece.
- Lifting cylinder to be raised.
- Measurement of the work piece height.

iv) **Testing Result OK**

- Switch on the air cushioned slide.
- Ejecting cylinder to advance.
- Ejecting cylinder to retract.

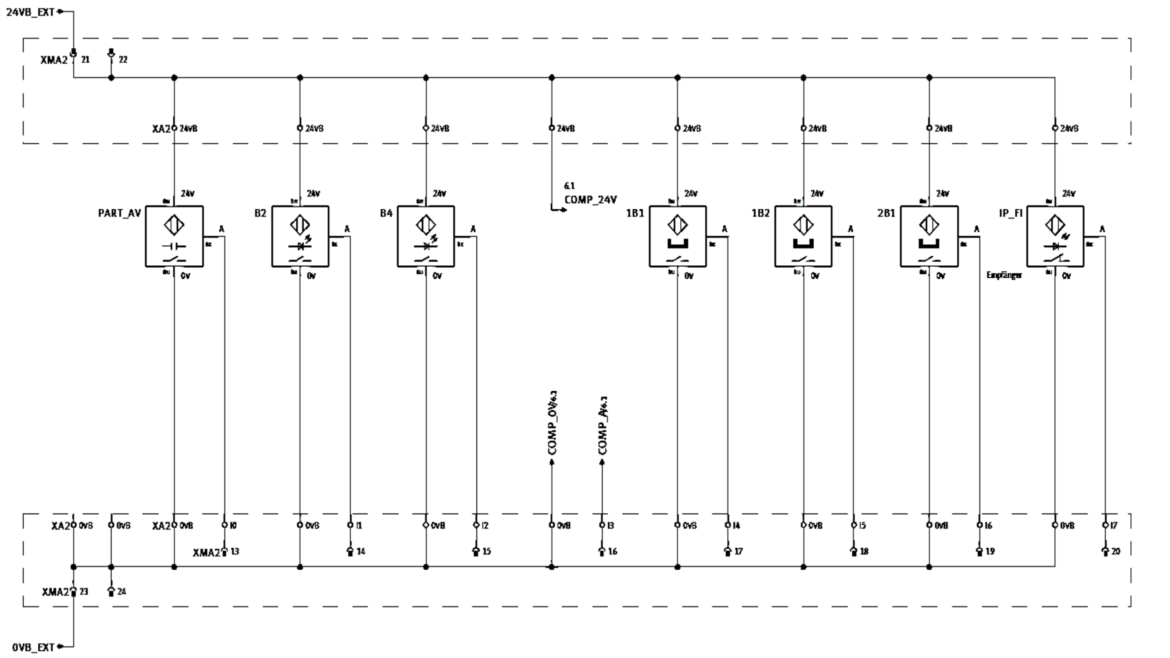
- Switch off the air cushioned slide.
- Lifting cylinder to be lowered.
- Initial position.

v) Testing Result not OK

- Lifting cylinder is to be lowered.
- Ejecting cylinder is to be advanced.
- Ejecting cylinder is to retract.

Electric and Pneumatic Circuit Diagrams:

i. Electric and Pneumatic Circuit Diagram



Spannung-versorgung	Werkstück vorhanden	Werkstück nicht schwarz	Sicherheits-lichtschranke	Komparator Werkstückhöhe korrekt	Hebezylinder oben	Hebezylinder unten	Auswerfzylinder eingefahren	Folgestation frei
Power supply	Workpiece available	Not black workpiece	Safety light barrier	Comparator workpiece height	Lifting cylinder raised	Lifting cylinder lowered	Ejecting cylinder retracted	Downstream station free

Figure 5.3.(A) Electric and Pneumatic Circuit Diagram

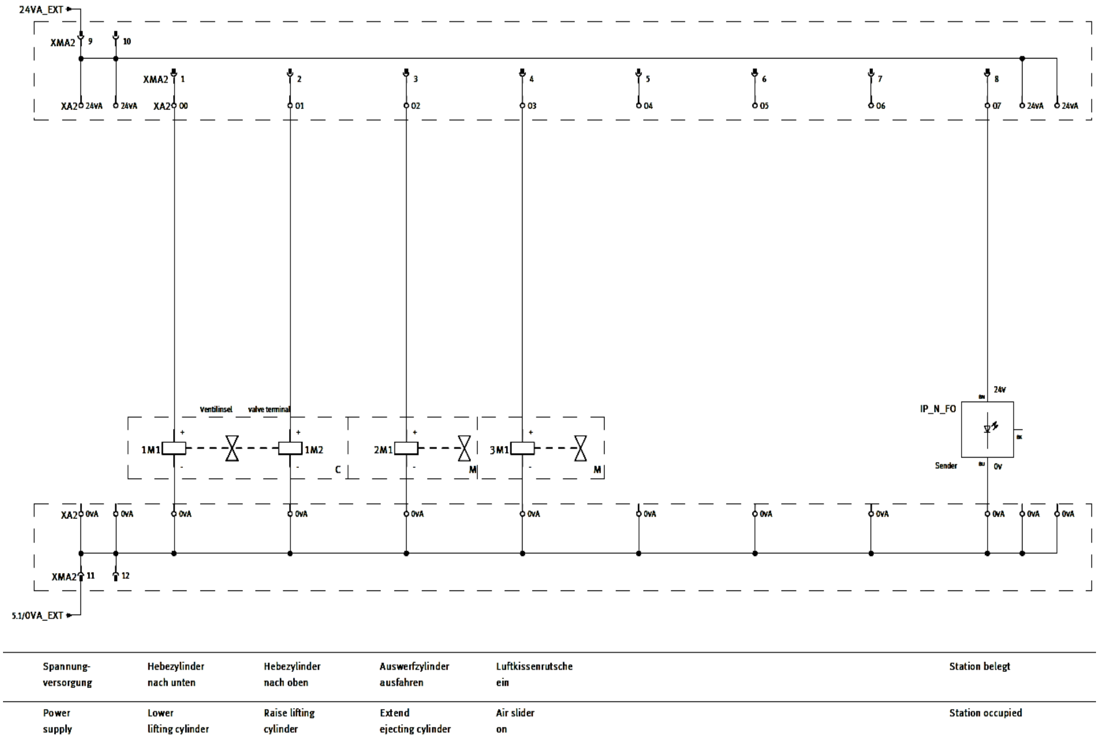


Figure 5.3.(B) Electric and Pneumatic Circuit Diagram

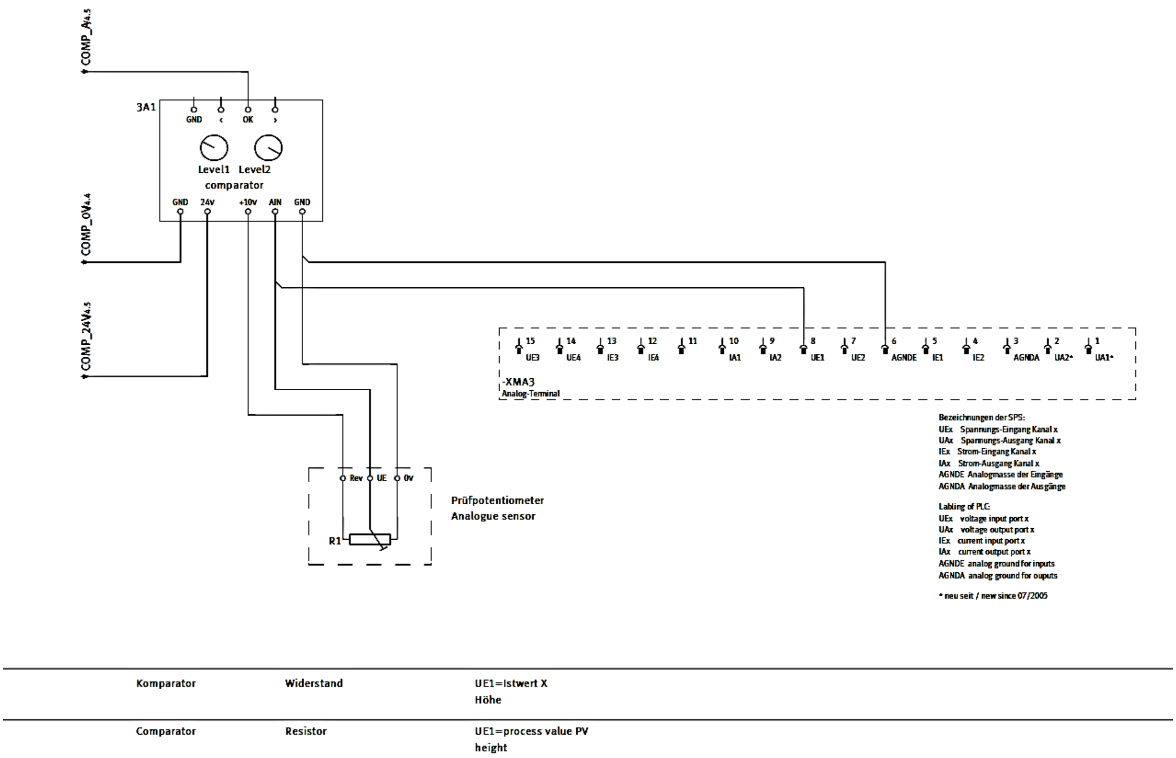


Figure 5.3.(C) Electric and Pneumatic Circuit Diagram

ii. Pneumatic Circuit Diagram Testing

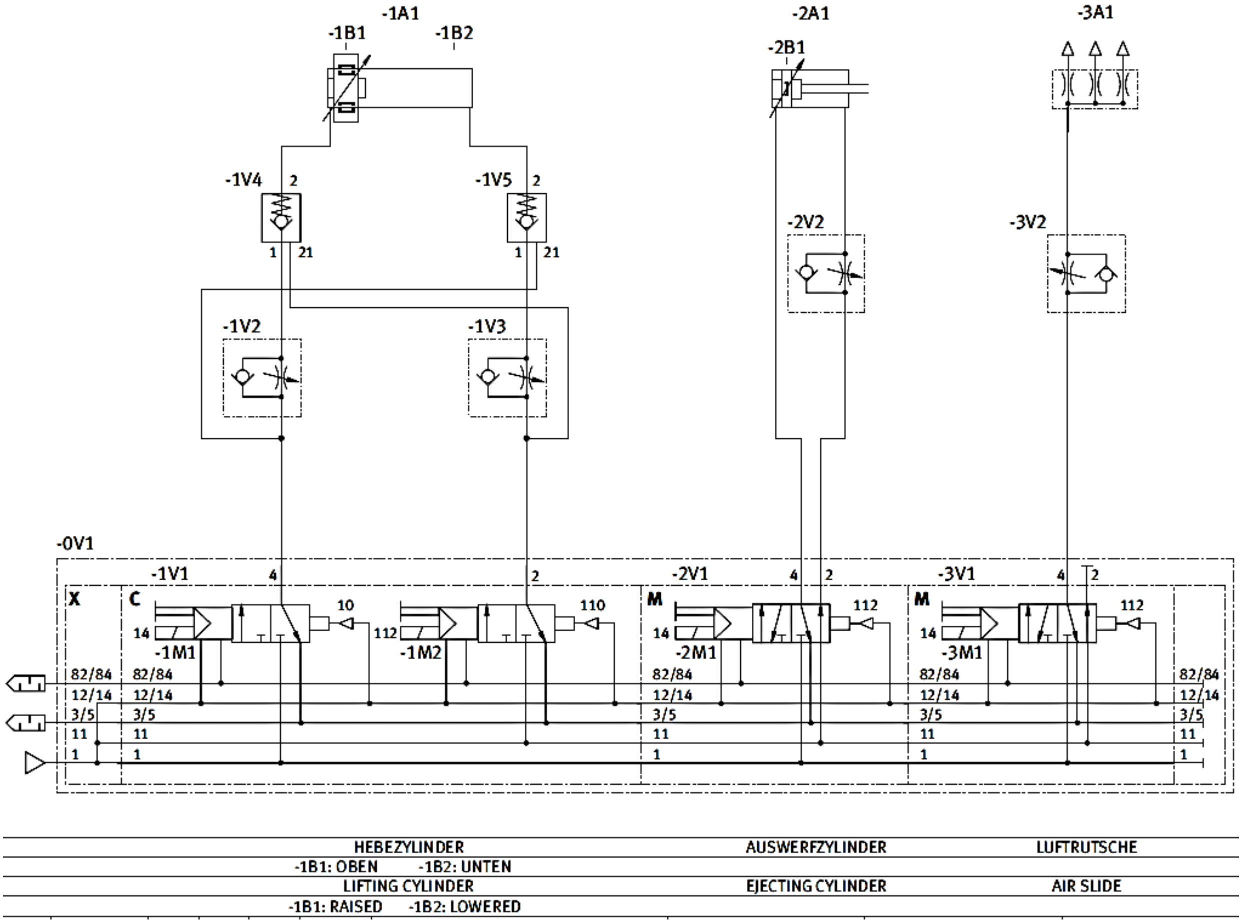


Figure 5.4. Pneumatic Circuit Diagram Testing

Experiment # 06

Processing Station

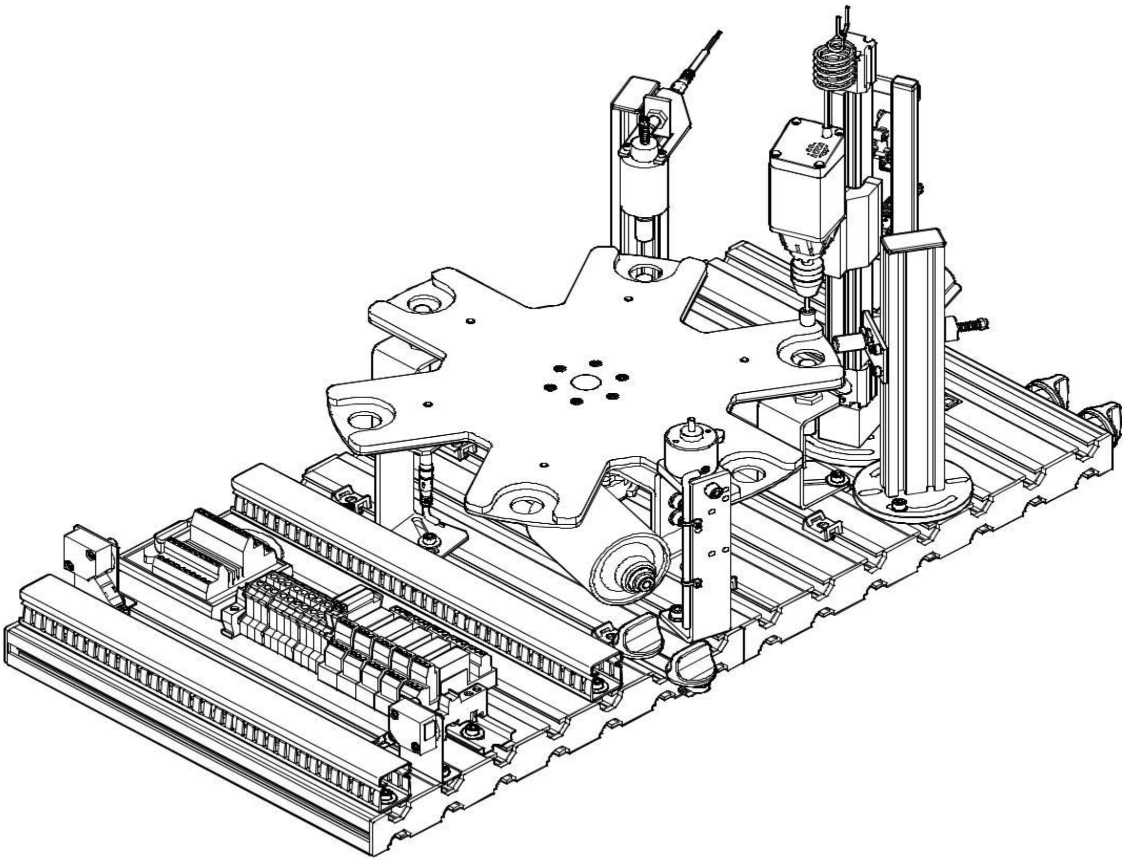


Figure 6.1 Processing Station

Processing is a generic term for production steps such as forming, form change, machining and joining.

- **Forming** is the creation of geometrically determined bodies made of formless substances.
- **Form change** is the changing of geometrical shapes and/or the dimensions of bodies.
- **Machining** is the changing of material characteristics and/or surface finish of bodies.
- **Joining** is the permanent joining of several bodies.

In the processing station, work pieces are tested and processed on a rotary indexing table. The rotary indexing table is driven by a DC motor. The table is positioned by a relay circuit, with the position of the table being detected by an inductive sensor.

On the rotary indexing table, the work pieces are tested and drilled in two parallel processes. A solenoid actuator with an inductive sensor checks that the work pieces are inserted in the correct position. During drilling, the work piece is clamped by a solenoid actuator. Finished work pieces are passed on via the electrical ejector.

Note: *The station uses exclusively electrical actuators.*

The Function of the Processing Station:

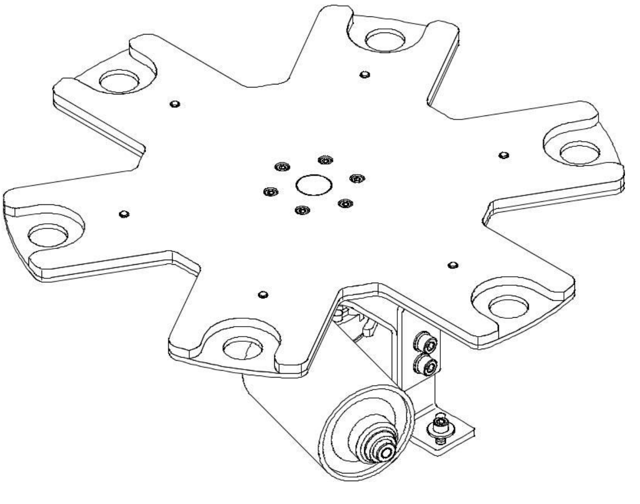
- To check the characteristics of work pieces (correctly positioned, hole).
- To machine work pieces.
- To supply work pieces to a subsequent station.

Figure 6.2 Processing Station with Trolley, Control Console and PLC Board

Parts and components of Processing Station

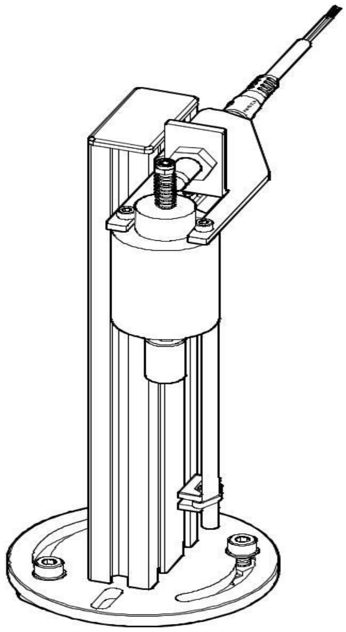
i) **Rotary indexing table module**

The drive of the Rotary indexing table module is operated by a DC gear motor. The 6 rotating plate positions are defined by the positioning screws on the rotary table and sensed by means of an inductive sensor. Each of the 6 semi-circular work piece retainers of the plate is provided with hole in the center to facilitate sensing by means of a capacitive proximity sensor.

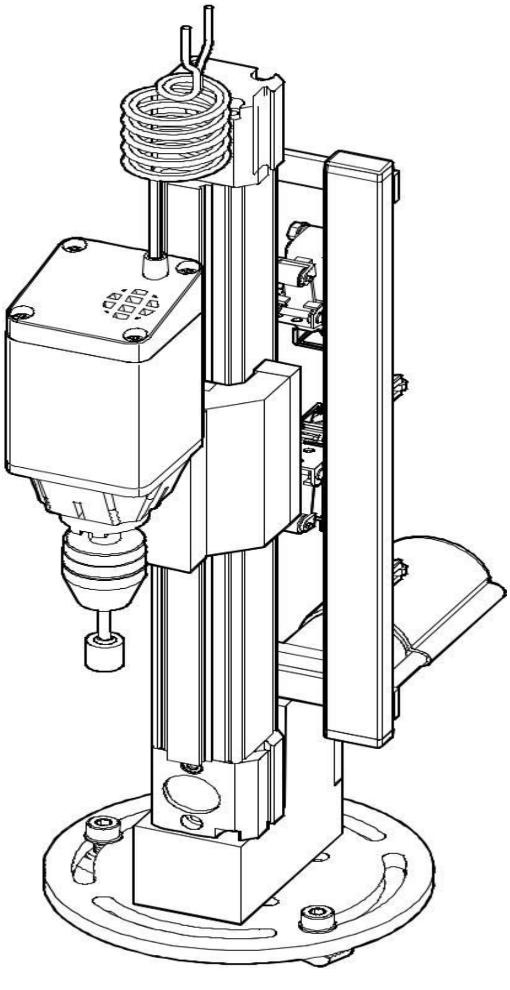


ii) Testing module

An inserted work piece is checked for correct positioning. If the hole points upwards, then the armature of the testing solenoid reaches its end position. An inductive proximity sensor is actuated via a nut at the upper end of the armature.



iii) Drilling module



The Drilling module is used to simulate the polishing of the hole of the work piece. An electrical clamping device retains the work piece. The feed and return actions of the drilling machine are effected by means of a linear axis with toothed belt drive. An electrical gear motor drives the linear axis and a relay circuit is used to activate the motor. The motor of the drilling machine is operated via 24 V DC and the speed is not adjustable. The end position sensing is effected by means of electrical limit switches. Approaching of the limit switches causes a reversal of the direction of movement of the linear axis.

Sensor:

i) **Capacitive proximity sensor (Rotary indexing table, detection of work piece)**
The capacitive proximity sensor is used for detection of work pieces. The work piece changes the capacity of a capacitor build in the sensor head. Work pieces are detected independent of color and material.

ii) **Inductive proximity sensor (Rotary indexing table, Positioning)**

The inductive proximity sensor is used for positioning of the rotary indexing table. Inductive proximity sensors detect metallic objects. The switching distance is a function of material and surface finish.

iii) **Inductive proximity sensor (Testing, orientation of work piece)**

The inductive proximity sensor is used for testing the orientation of the work pieces. Inductive proximity sensors detect metallic objects. The switching distance is a function of material and surface finish.

Operating Sequence Description

i) **Starting prerequisites**
- Work piece is in the work piece retainer material input

ii) **Initial position**
- Rotary indexing table positioned
- Checking solenoid plunger raised
- Drilling machine in raised position
- Drilling machine motor is switched off
- Clamping device retracted
- Electrical branch not actuated

iii) **Operating Sequence**
- The rotary indexing table is rotated by 60°, if a work piece is detected in the work piece retainer 1 and the START pushbutton is pressed.

- The solenoid plunger moves downwards and checks whether the work piece is inserted with the opening facing upwards. The rotary indexing table is rotated by 60° if the result of the check is OK.
- The clamping device clamps the work piece. The motor of the drilling machine is switched on. The linear axis moves the drilling machine downwards.
- When the drilling machine has reached its lower position, it is moved to its upper stop again by the linear axis.
- The motor of the drilling machine is switched off and the clamping device is retracted. The rotary indexing table is rotated by 60°.
- The electrical sorting gate passes on the work piece to a subsequent station.

This sequence describes the passage of **one** work piece through the Processing station. The work piece is in the transfer position to a downstream station. The processing cycle can be started again, once a work piece is inserted in the work piece retainer 1.

Electric Circuit Diagram Processing

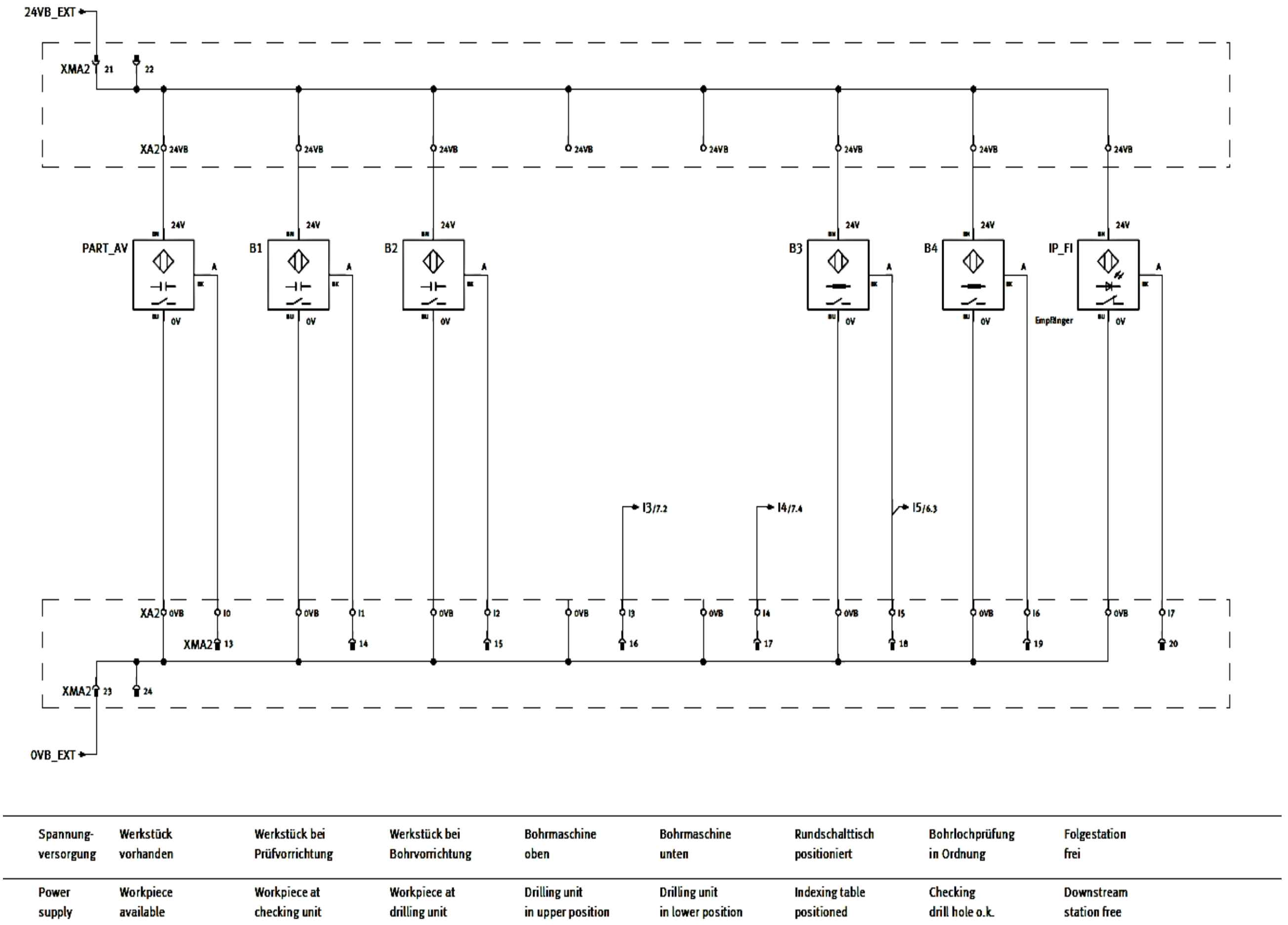


Figure 6.3 (a) Electric Circuit Diagram for Processing Circuit

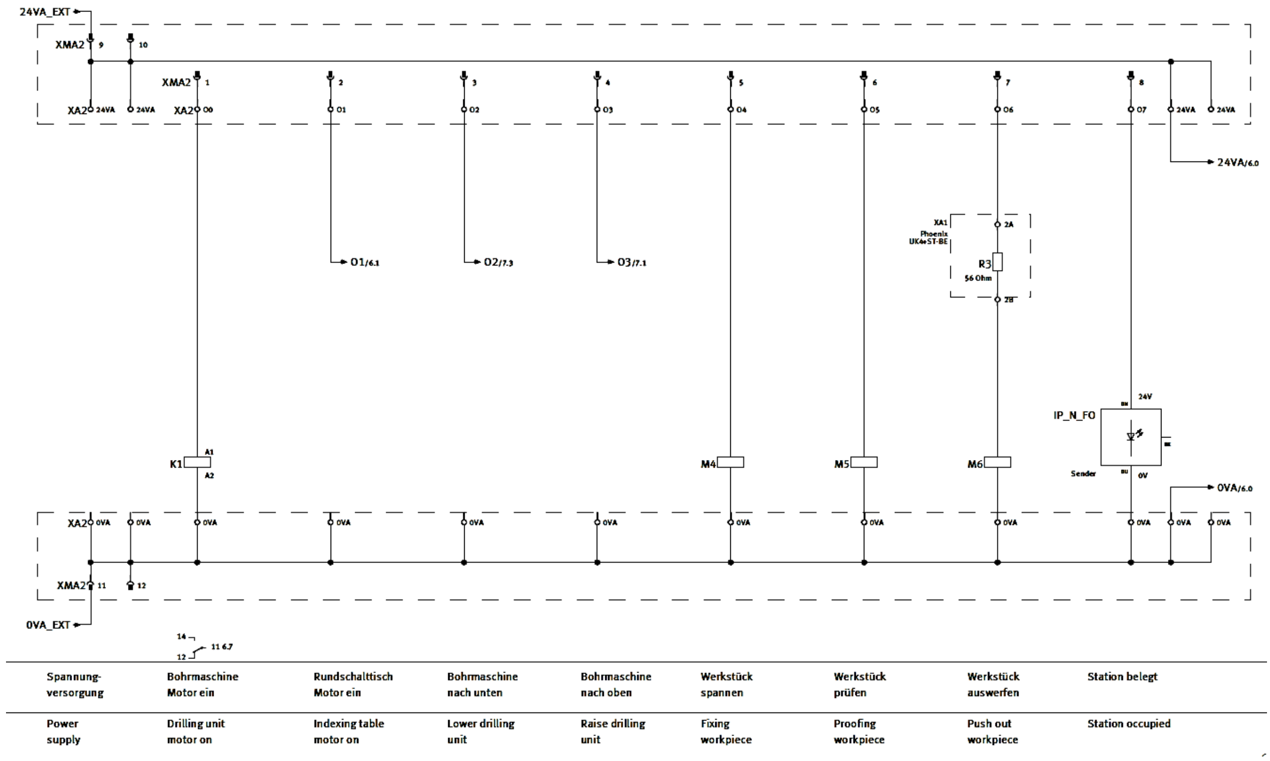


Figure 6.3 (b) Electric Circuit Diagram for Processing Circuit

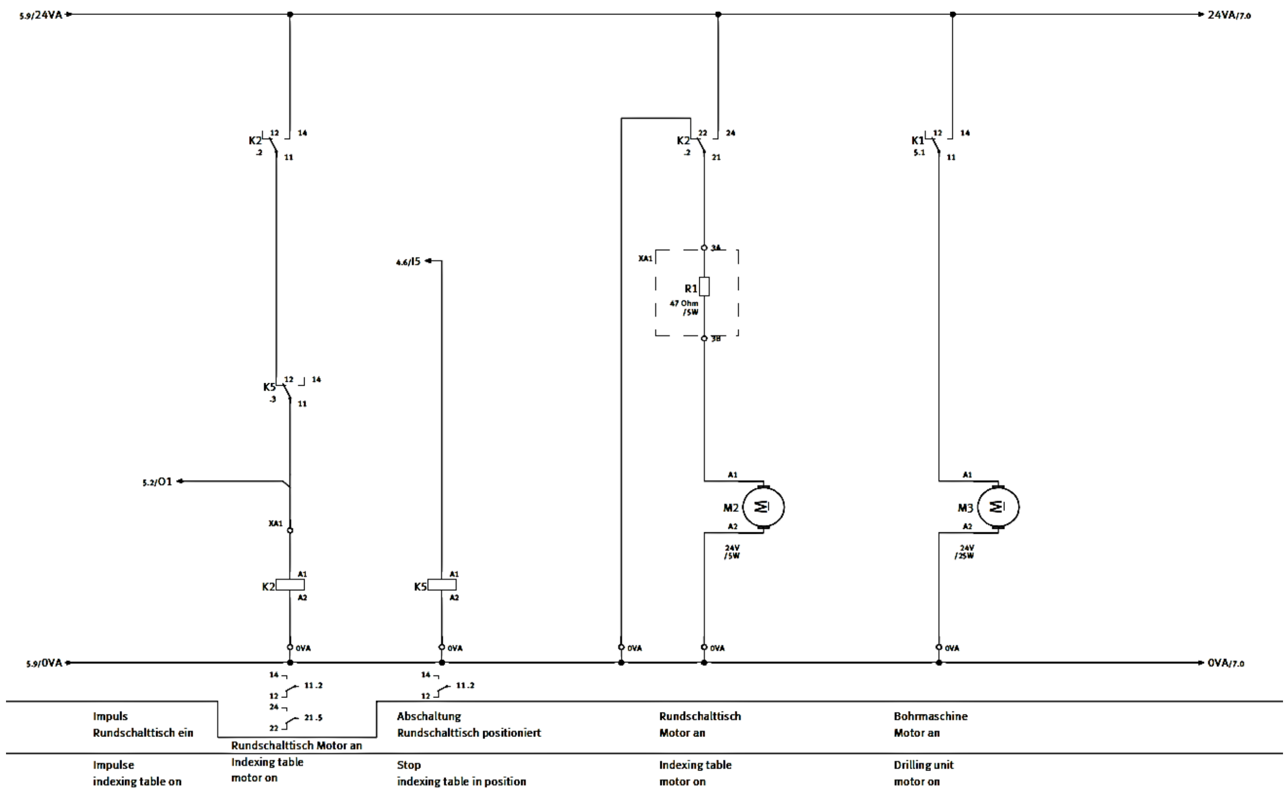


Figure 6.3 (c) Electric Circuit Diagram for Processing Circuit

Experiment # 07

Handling Station

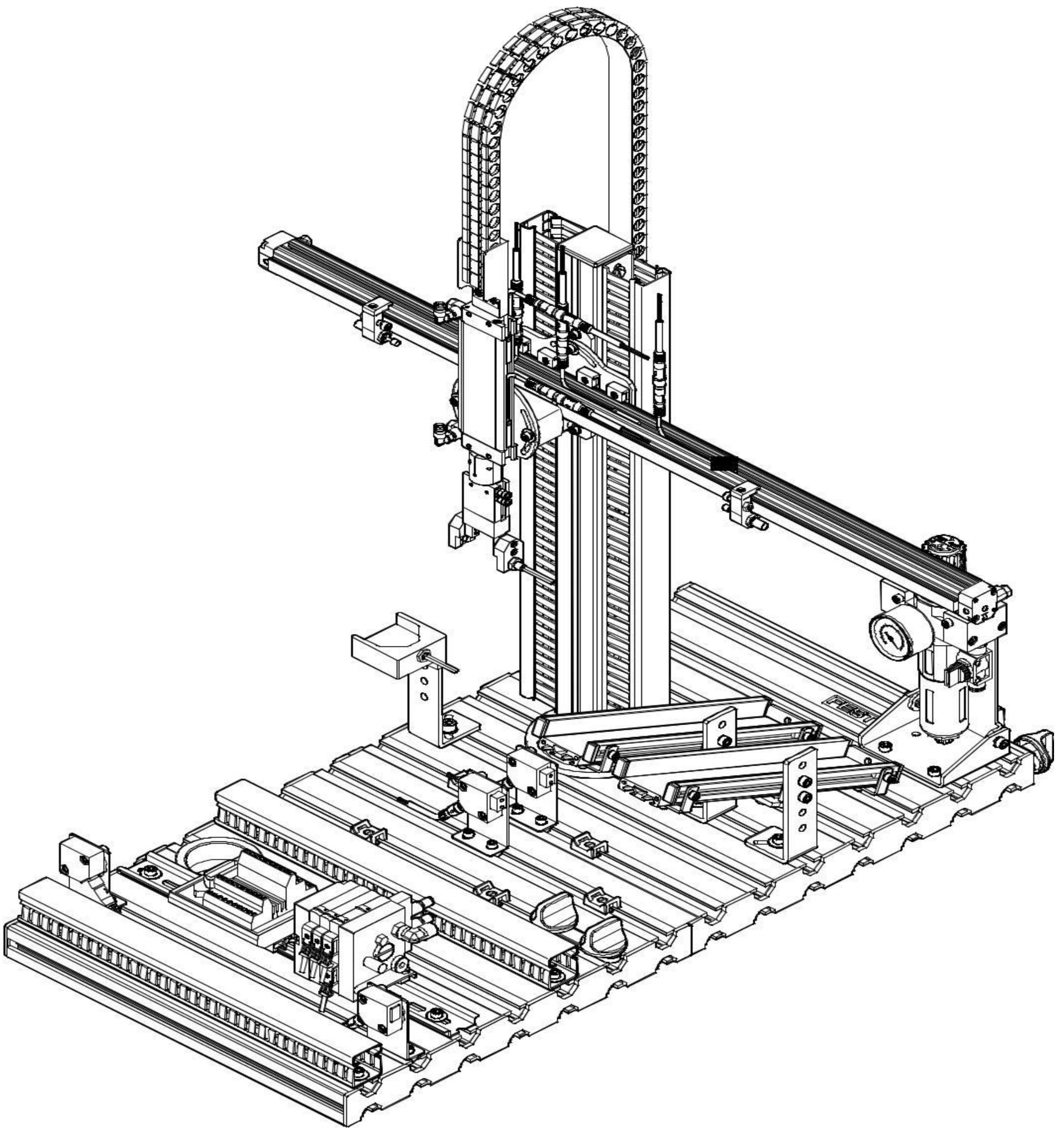


Figure 7.1 Handling Station

Handling is a sub-function of material flow. Additional sub-functions are conveying and storing. Handling is the creation, defined changing or temporary maintaining of a specified spatial arrangement of geometrically determined bodies.

The Handling station is equipped with a flexible two-axis handling device. Inserted work pieces are detected in the retaining device by an optical reflex light sensor. The handling device fetches the work pieces from the retaining device with the help of a pneumatic gripper, which is fitted with an optical sensor. The sensor differentiates between 'black' and 'non- black' work pieces. The work pieces can be deposited on different slides on the basis of these criteria.

Various other sorting criteria can be defined if the station is combined with other stations. By changing the setting of the mechanical end stops, it is also possible to transfer work pieces to a subsequent station.

The Function of the Handling Station Is:

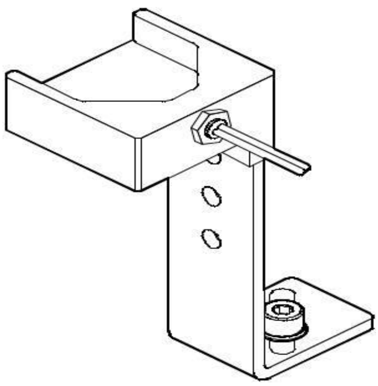
- To determine the material characteristics of a work piece,
- To remove work pieces from a receptacle,
- To deposit the work pieces on the 'metallic/red' slide or the 'black' slide or
- To pass on the work pieces to a subsequent station.

Figure 7.2 Handling Station with Trolley, Control Console and PLC Board

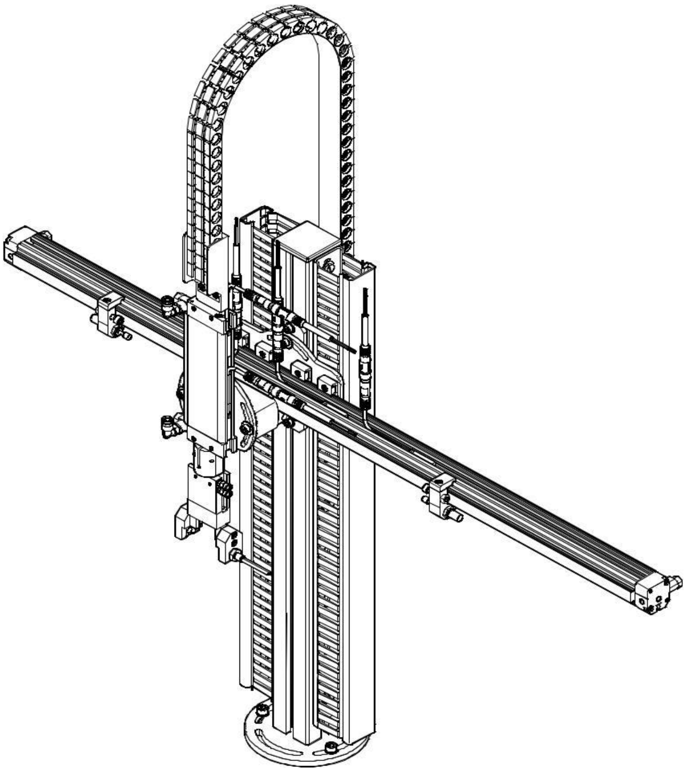
Parts of Handling Station

i) Receptacle Module

The work pieces are inserted manually into the Receptacle module. The work pieces are detected in the receptacle by an optical diffuse sensor.



ii) **PicAlfa Module**

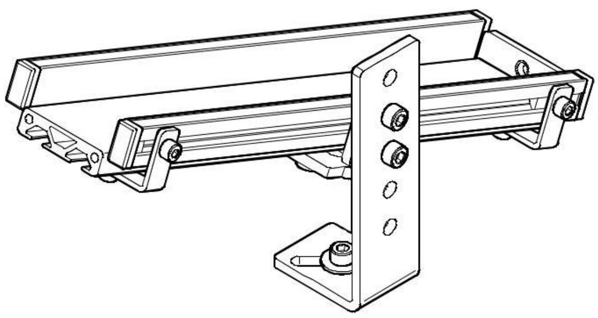


The PicAlfa module uses industrial handling components. Rapid positioning – also at intermediate positions- is effected via a pneumatic linear axis with flexible end position adjustment and cushioning. A linear flat cylinder with end position sensing is used as a lifting cylinder for the Z-axis.

A pneumatic gripper is fitted to the lifting cylinder and an optical sensor integrated into the gripper jaw detects the work pieces.

The PicAlfa module is exceptionally flexible: Stroke length, inclination of the axes, configuration of the end position sensors and the mounting position are adjustable. The module can therefore be adapted to a wide range of different handling tasks without the need for any additional components.

iii) Slide Module



The Slide module is used to transport and store work pieces. The slide can accommodate 5 work pieces. The angle of inclination of the slide is infinitely adjustable. Two slide modules are utilized in the Handling station.

Sensors

i) Diffuse Sensor (Receptacle, Detection Of Work piece)

The diffuse sensor is used for detection of the work pieces. A fiber optic cable is connected to a fiber optic device. The fiber optic device emits visible red light. The diffuse sensor detects the light reflected by the work piece Different surfaces or colors changes the amount of reflected light.

ii) **Diffuse Sensor (Gripper, Color Distinction)**

The diffuse sensor is used for color distinction of the work pieces. A fiber optic cable is connected to a fiber optic device. The fiber optic device emits visible red light. The diffuse sensor detects the light reflected by the work piece Different surfaces or colors changes the amount of reflected light.

iii) **Proximity Sensor (Picalfa, Linear Axis)**

The proximity sensors are used for end position sensing of the linear axis. The proximity sensor is sensitive to a permanent magnet mounted on the piston of the linear axis.

iv) **Proximity Sensor (Picalfa, Lifting Cylinder)**

The proximity sensors are used for end position sensing of the cylinder. The proximity sensor is sensitive to a permanent magnet mounted on the piston of the cylinder.

Adjusting One-Way Flow Control Valves

One-way flow control valves are used to regulate exhaust air flow rates with double-acting cylinders. In the reverse direction, air flows through the non-return valve with full cross-sectional flow.

Uncontrolled supply air and controlled exhaust hold the piston between air cushions (improves motion, even with load changes).

Operating Sequence Description

i) **Starting Prerequisites**

- Work piece in the receptacl

ii) **Initial Position**

- Linear axis in position “upstream station”
- Lifting cylinder retracted (gripper is raised)
- Gripper is open

iii) **Operating Sequence Process**

- The lifting cylinder advances if a work piece is detected in the receptacle and the Start pushbutton is pressed.
- The gripper is closed. The color identification “work piece black” or “work piece non-black” is executed.
- The lifting cylinder is retracted.

iv) Work Piece Black, Deposit On Inner Slide

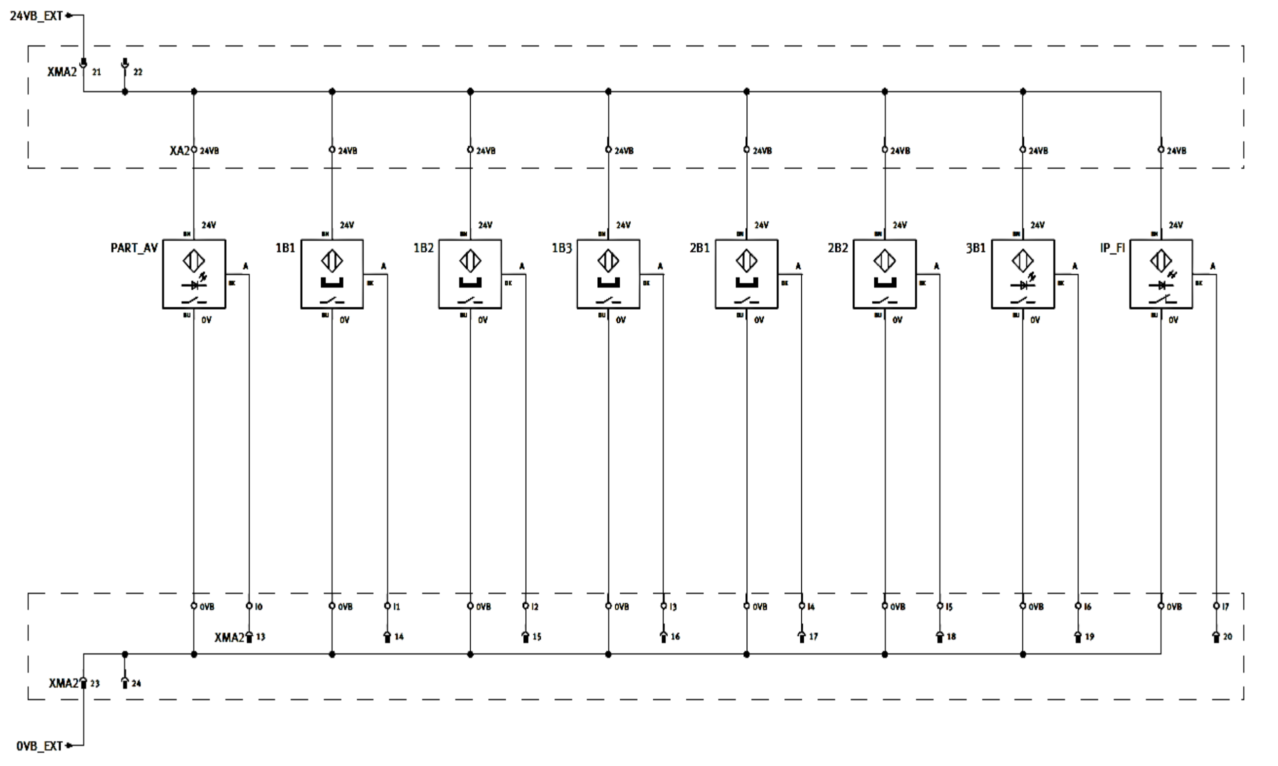
- The linear axis approaches the position “slide 1”.
- The lifting cylinder advances.
- The gripper is opened and the work piece is deposited on the slide.
- The lifting cylinder retracts.
- The linear axis moves into the “upstream station” position.

v) Work piece Red/Silver, Deposit On Outer Slide

- The linear axis approaches the position “slide 2”.
- The lifting cylinder advances.
- The gripper is opened and the work piece deposited on the slide.
- The lifting cylinder retracts.
- The linear axis moves into the “upstream station” position.

Electric and Pneumatic Circuit Diagrams

i) Electric Circuit Diagram



Spannung-versorgung	Werkstück vorhanden	Handhabung bei Vorgängerstation	Handhabung bei Folgestation	Handhabung bei Sortierposition	Greifer ausgefahren	Greifer eingefahren	Werkstück ist nicht schwarz	Folgestation frei
Power supply	Workpiece available	Handling at upstream station	Handling at downstream station	Handling at sorting position	Gripper extended	Gripper retracted	Workpiece is not black	Downstream station free

Figure 7.3 (a) Electric Circuit for Handling Station

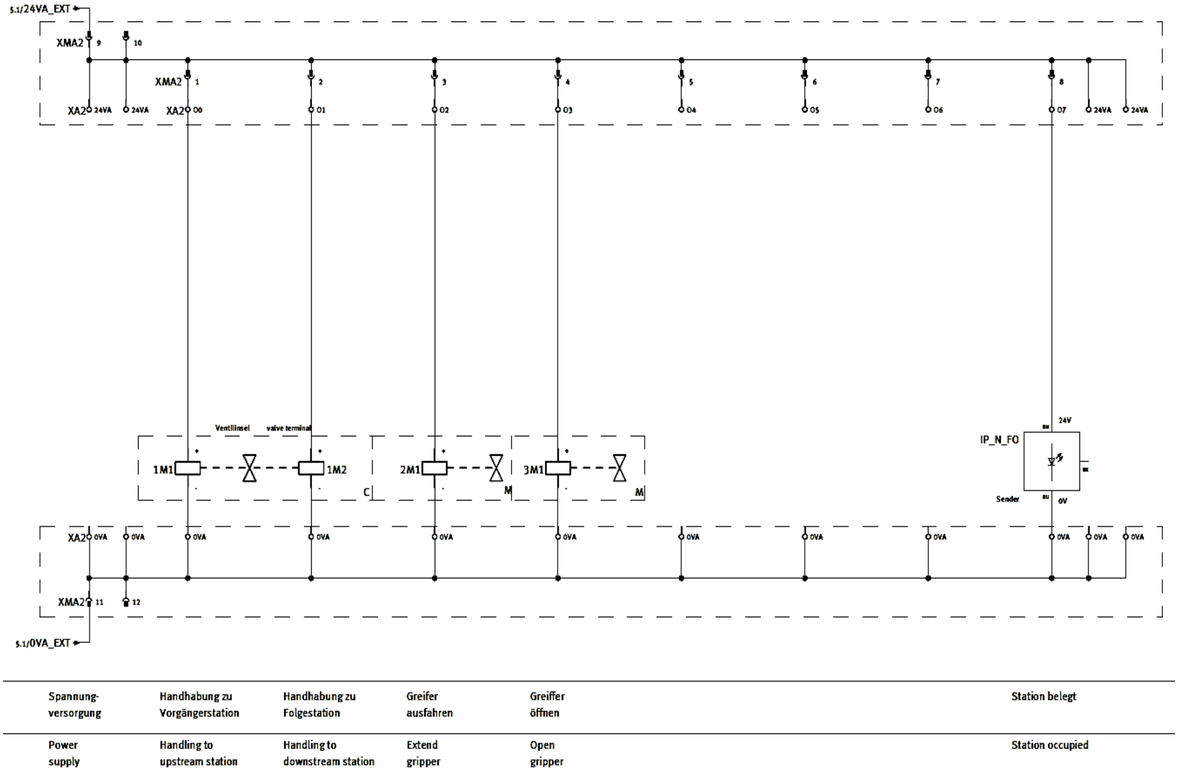


Figure 7.3 (b) Electric Circuit for Handling Station

ii) Pneumatic Circuit Diagram

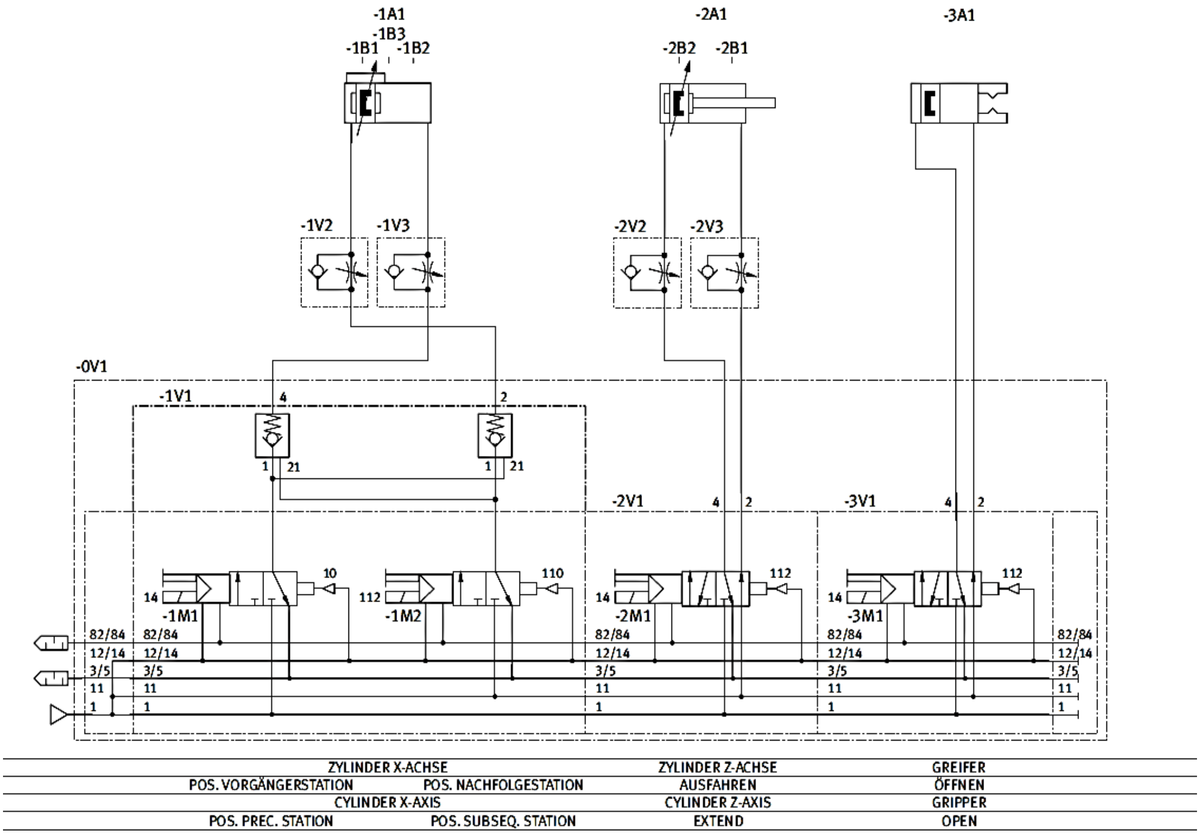


Figure 7.4 Pneumatic Circuit for Handling Station

Experiment # 08

Sorting Station

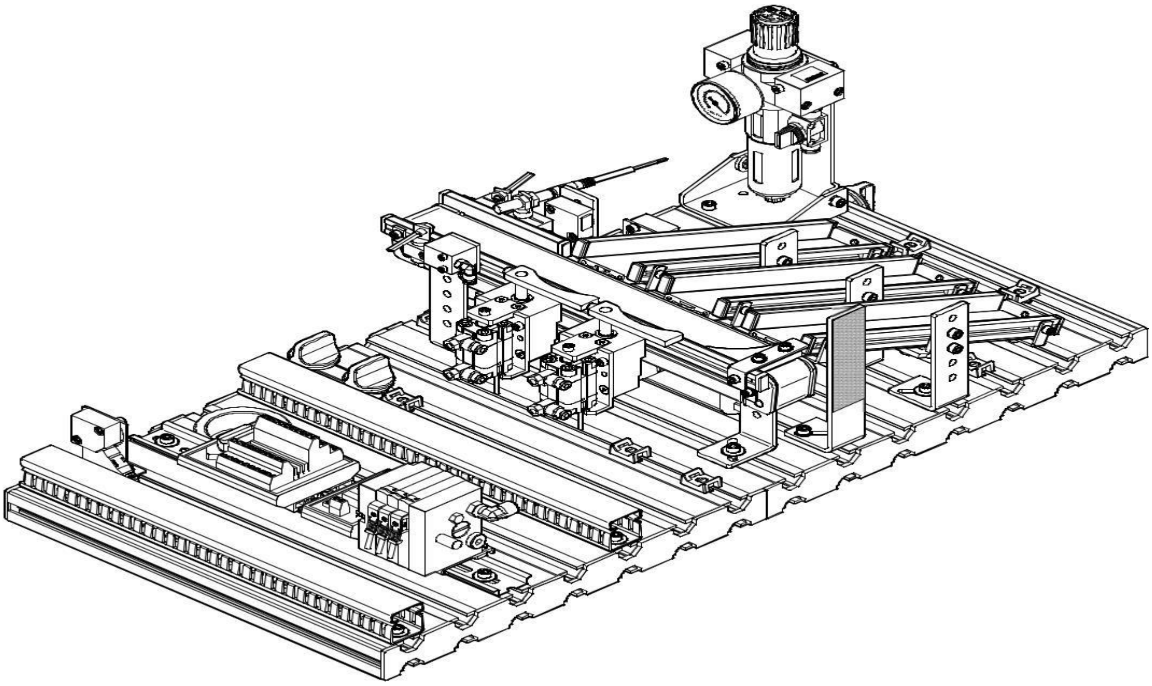


Figure 8.1 Sorting Station

Sorting is considered an important part of the handling function of changing quantities. The conveyor section can be branched off for sorting, whereby the different sorting branches are switched depending on the work piece. The work pieces must proceed individually so as not to impair the switching functions of the branches.

In the sorting station, the symbolic work pieces are sorted according to material and color. The function of the Sorting station is to sort work pieces according to characteristics

Figure 8.2 Sorting station with trolley, control console and PLC board

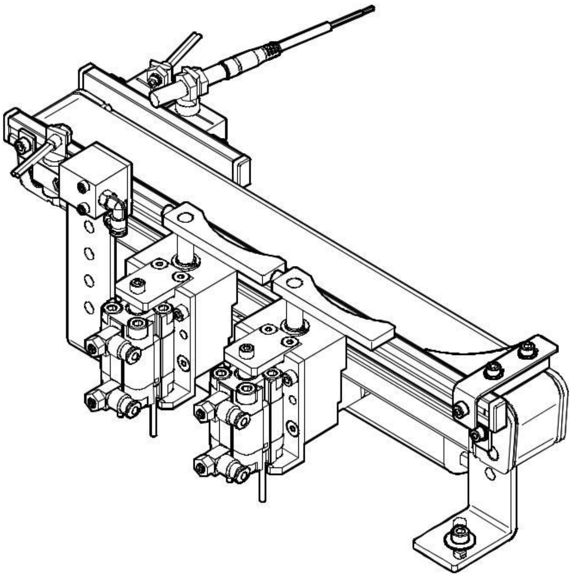
Function

The Sorting station sorts work pieces via 3 slides. A diffuse sensor detects the work pieces inserted at the start of the conveyor. Work piece characteristics (black, red, silver) are detected by sensors in front of the stopper and the work pieces are sorted onto the appropriate slides via branches. The branches are moved by means of short-stroke cylinders using a reversing mechanism. A retro-reflective sensor monitors the filling level of the slides.

Parts of Sorting Machine

i) **Conveyor Module**

The Conveyor module is used to transport and eject work pieces. Two material branches can be switched by means of the attached short-stroke cylinders, whereby the work pieces can be sorted according to their characteristics or type. The drive of the sorting conveyor is operated by means of a DC gear motor.

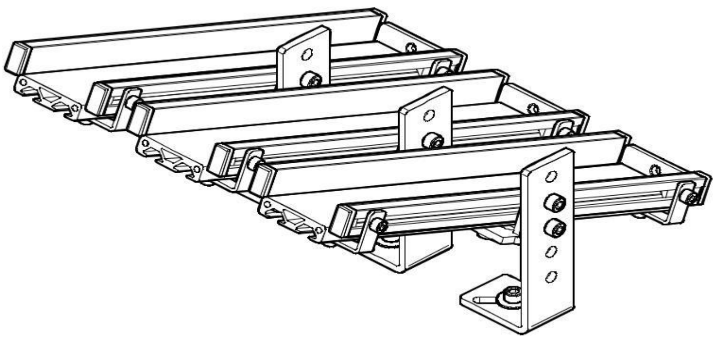


A diffuse sensor detects whether a work piece is available at the start of the conveyor. This causes the program cycle to start and the drive of the sorting conveyor to be switched on.

The work piece is stopped by means of a pneumatic stopper. A diffuse sensor identifies the work piece color (red or black). Metal work pieces are detected via an inductive proximity sensor. Depending on the work piece determined, the appropriate material branches are activated. Once a work piece is released by the stopper, it is then transported to the appropriate slide.

ii) **Slide Module**

The Slide module is used to transport or store the work pieces. This module can be applied universally thanks to its variably adjustable inclination and height. A triple slide module is utilized in the Sorting station. Work pieces arriving from the Conveyor module are stored in the Slide module. A retro-reflective sensor monitors the filling level of the slides.



Sensor

i) **Diffuse Sensor (conveyor belt, detection of work piece)**

The diffuse sensor is used for detection of the work pieces. A fibre optic cable is connected to a fibre optic device. The fibre optic device emits visible red light. The diffuse sensor detects the light reflected by the work piece Different surfaces or colors changes the amount of reflected light.

iii) **Diffuse Sensor (conveyor belt, color distinction)**

The diffuse sensor is used for color distinction of the work pieces. A fibre optic cable is connected to a fibre optic device. The fibre optic device emits visible red light. The diffuse sensor detects the light reflected by the work piece Different surfaces or colors changes the amount of reflected light.

iv) **Inductive Proximity Sensor (Conveyor Belt, Material Recognition)**

The inductive proximity sensor is used for material recognition. Inductive proximity sensors detect metallic objects. The switching distance is a function of material and surface finish.

v) **Proximity Sensor (Conveyor Belt, Branch 1/Branch 2)**

The proximity sensors are used for end position sensing of the cylinder. The proximity sensor is sensitive to a permanent magnet mounted on the piston of the cylinder.

vi) **Retro-Reflective Sensor (Slides, Filling Level)**

The retro-reflective sensor is used for monitoring the filling level of the slides working space is occupied, it is not possible to move the lifting cylinder. A retro-reflective sensor consists of transmitter and receiver in the same housing. The retro-reflective sensor emits visible red light. The light is reflected by an external reflector. If the light beam is interrupted by an object, the switching status of the retro-reflective sensor changes.

Operation Sequence Description

i) **Start prerequisites**

- Work piece at start of conveyor.

ii) **Initial position**

- Stopper advanced.
- Branch 1 retracted.
- Branch 2 retracted.
- Conveyor motor off.

iii) **Sequence**

- Work piece detected.
- Conveyor motor ON.
- Color/material identification.

iv) Black work piece detected, deposit on slide at end of conveyor

- Stopper retracted.
- Work piece ejected.
- Idle step.

v) Silver work piece detected, deposit on slide at center of conveyor

- Branch 2 to advance
- Stopper to retract
- Work piece ejected
- Idle step.

vi) Red work piece detected, deposit on slide at start of conveyor

- Branch 1 to advance.
- Stopper to retract.
- Work piece ejected.
- Idle step.
- Conveyor motor Off Stopper to advance Branch 1 to retract Branch 2 to retract.

Electric and Pneumatic Circuit Diagrams

i) Electric Circuit Diagram

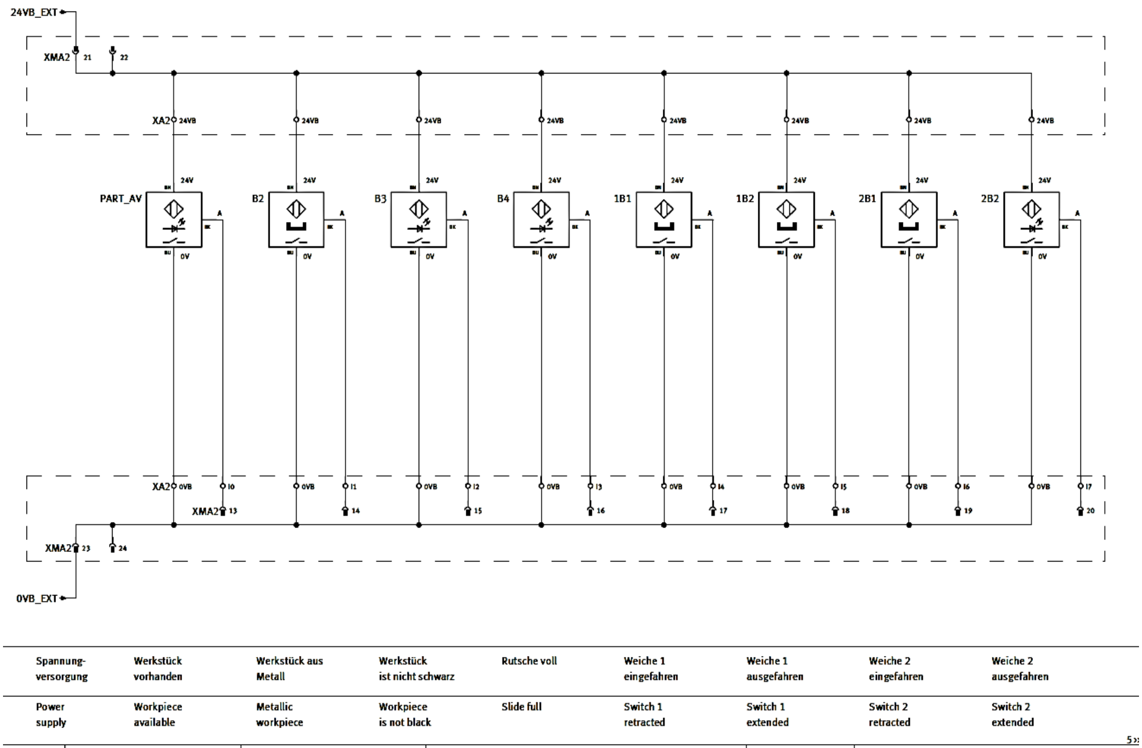


Figure 8.3 (a) Electric Circuit for Sorting Station

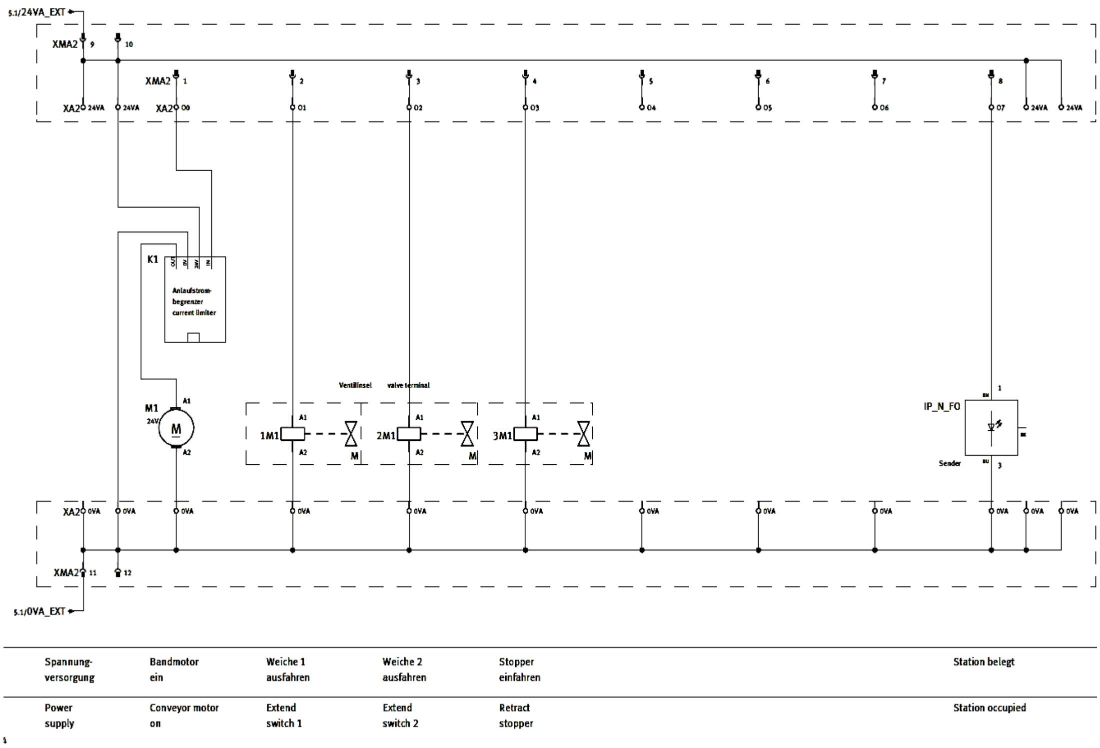


Figure 8.3 (b) Electric Circuit for Sorting Station

ii) Pneumatic circuit diagram

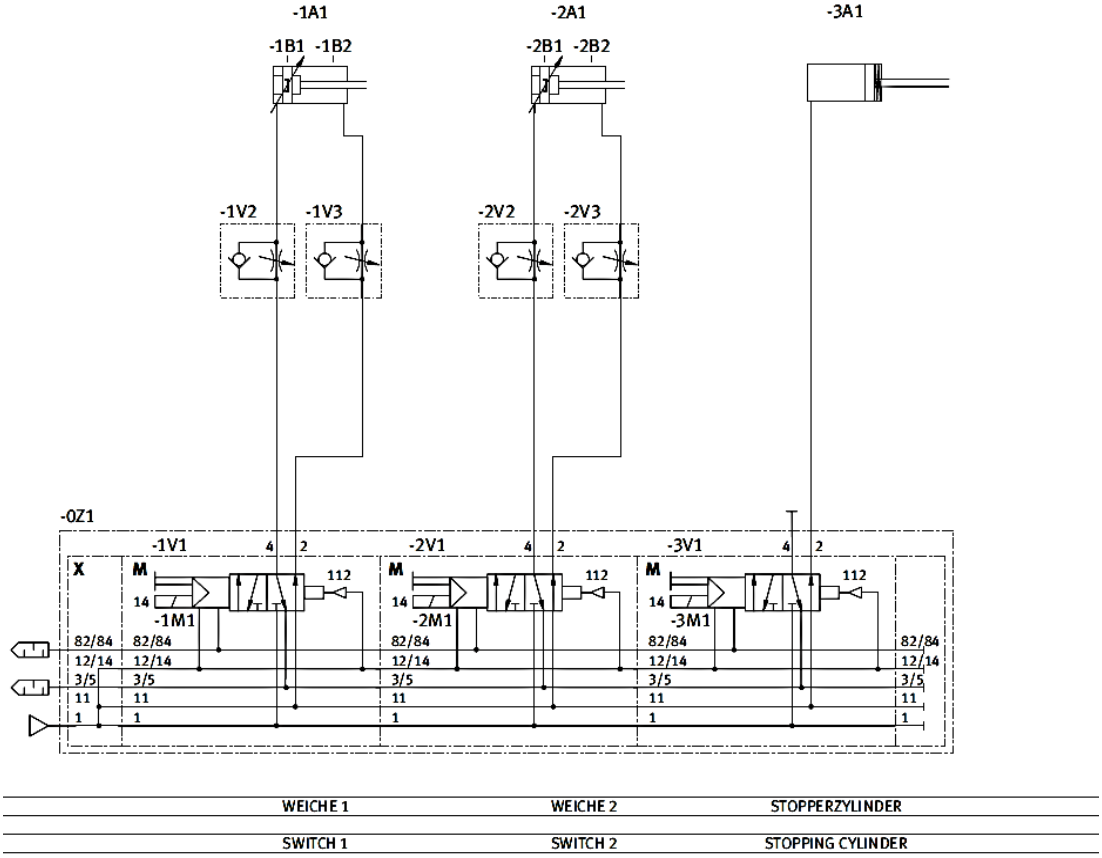


Figure 8.4 Pneumatic Circuit for Sorting Station

Part III

Electrical and Electronics Applications for Mechatronics Systems

Introduction

Virtually every mechatronic device has some forms of electric circuit, and thus, understanding and analyzing electrical circuits is considered very important in mechatronics. Electric circuit however is defined as a closed path through a series of electronic components in which a current flows through. Electric circuits can be of the analog or digital type. In analog circuits, the voltage is continuous and can have any value over a specified range, while in a digital circuit, the voltage signal is usually represented by just two different levels (such as 0 and 5 volts (V)). Analog circuits are more sensitive to noise or disturbances than digital circuits. In an analog circuit, any noise in the circuit is translated into changes in the analog signal or a loss of information, while in a digital circuit, small disturbances have no effect. As long the signal stays within a specified range in a digital circuit, it represents the same information. Digital circuits are used to perform logic operations using hardware instead of software. Two basic quantities in electrical circuits are voltage or electric potential, and current.

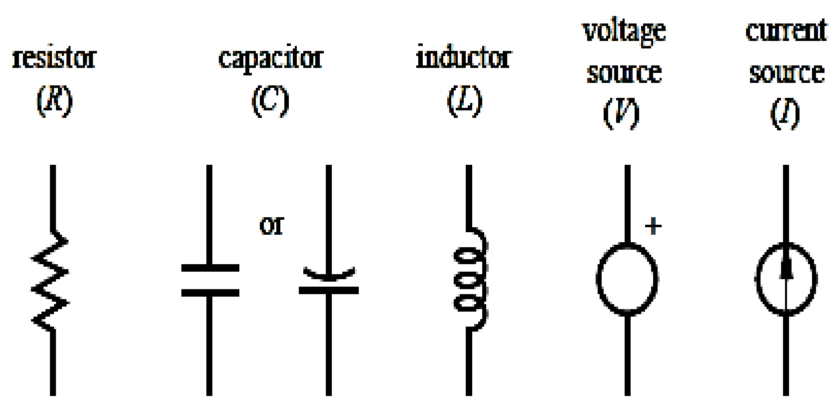


Figure 1 schematic symbols for basic electrical elements.

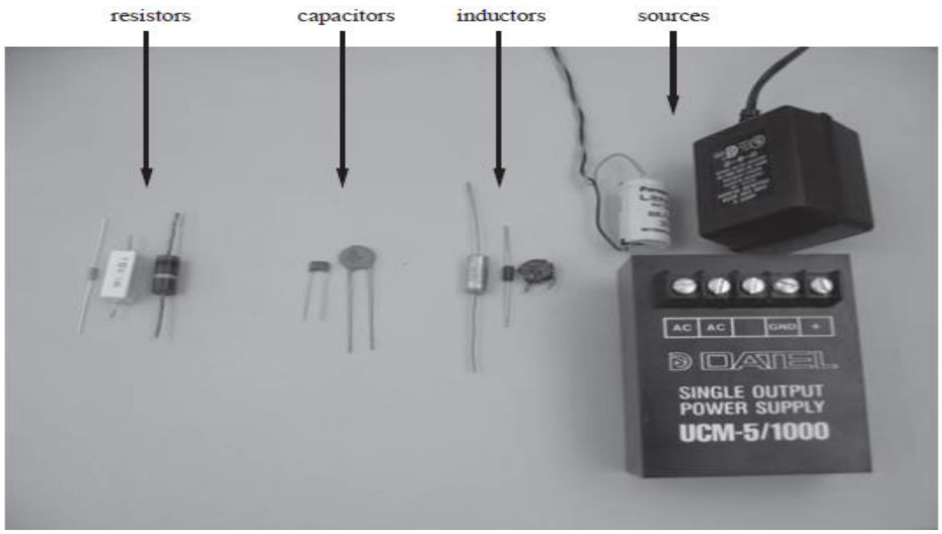
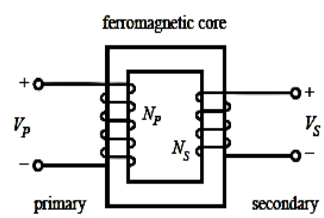


Figure 2. Examples of basic circuit elements.

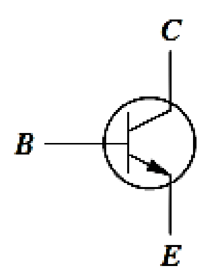
Electrical and Electronics Components

- **Resistor** is a dissipative element that converts electrical energy into heat.

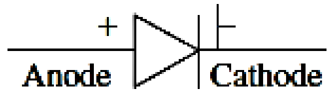
- **Capacitor** is a passive element that stores energy in the form of an electric field.
- Inductor is a passive energy storage element that stores energy in the form of a magnetic field.
- **Transformer** is a device used to change the relative amplitudes of voltage and current in an AC circuit.



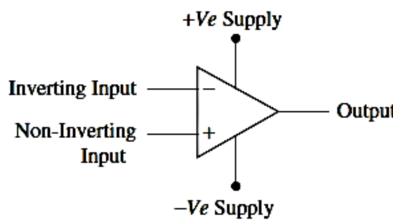
- **Transistor** is a solid-state switch that opens or closes a circuit. Unlike an electromechanical relay, the switching action in a transistor is caused by non-mechanical motion and is due to the change in the electrical characteristics of the device. A transistor is a three-terminal device. One terminal is used as the control input, another is connected to the load voltage, while the third is connected to ground or a constant potential.



- **Diodes and transistors** are examples of solid-state switches. Solid-state switches are devices in which the switching action is caused by non-mechanical motion and is due to the change in the electrical characteristics of the device. A diode is a directional element that allows current to flow in one direction. One common use of diodes is to change AC voltages to DC voltages, which is a process called rectification. Another use of diodes is to limit the range of a signal in a circuit. This is called voltage clamping, and the diode is called a diode clamp when used in such a circuit.



- Operational amplifiers (op-amps) are analog circuit components that require power to operate. They are widely used in amplification and signal-conditioning circuits. A common form is the single op-amp in the form of an 8-pin integrated circuit (IC). An op-amp is constructed from a number of components including transistors, diodes, capacitors, and resistors.



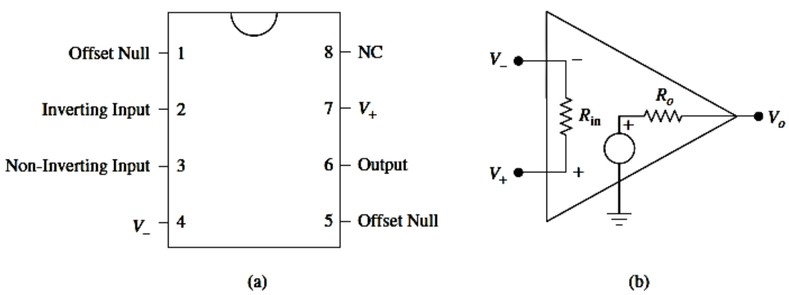


Figure 3. (a) Pin layout for the LM741 and (b) model of an ideal op-amp

Mechanical Switches

Mechanical switches are devices that make or break contact in electrical circuits. There are a variety of mechanical switches available, including toggle, push-button, rocker, and slide.

Figure 4. Mechanical switches (a) toggle, (b) push-button, (c) rocker, and (d) slide

AC Signals

While DC voltages are common in battery-powered devices and laboratory setups, AC voltages are used in power transmission and operation of industrial and residential equipment such as compressors and kitchen appliances. AC voltage signals have the advantage that they are more efficient to transmit over long distances. When an AC voltage signal, such as a sinusoidal voltage signal, is applied to a circuit, the voltage in the circuit will also be sinusoidal with a frequency the same as the applied frequency. Two sinusoidal voltage signals are shown in Figure 2.22. The solid signal is defined by:

$$V = VoSin(\omega t + \theta)$$

While the dashed signal is defined by:

$$V = VoSin(\omega t)$$

Where V_O is the amplitude of the signal, and is the angular frequency in units of radians/second. Theta (θ) is defined as the phase angle and is a measure of the lead/lag in the signal. A positive phase angle (such as that for the solid signal) means that the signal is ahead or leads the dashed signal. The lead time is given by (θ/ω).

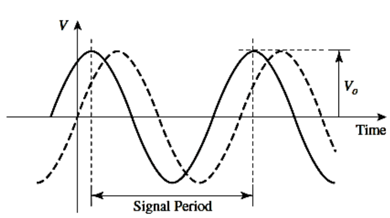
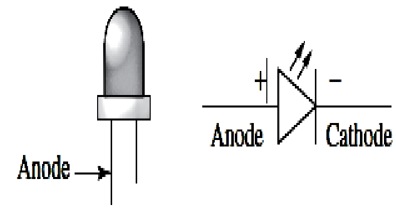


Figure 5. Two Sinusoidal Voltage signals

LED

One common form of a diode is the light-emitting diode (**LED**). These diodes emit light when forward biased, and the amount of light they emit is proportional to the current passing through the LED. They are typically encased in a colored plastic casing. An advantage of an LED over other light sources is that it takes only a few milliamps to light the diode. They also can be powered by a digital power supply (5 VDC), since the voltage drop across the LED when it is on is about 2 V.



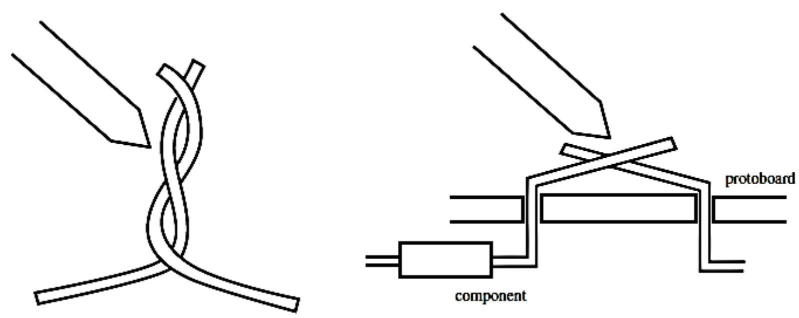
Here is a helpful list of steps you should follow to create a good solder connection:

i) Before soldering, make sure you have everything you need: hot soldering iron, solder, components, wire, protoboard or PCB, tip-cleaning pad, and magnifying glass.

ii) Clean any surfaces that are to be joined. You can use fine emery paper, steel wool, or a metal brush to remove oxide layers and dirt so that the solder can easily wet the surface. Rosin core (flux) solder will enhance the wetting process.

iii) Make a mechanical connection between the wires to be joined, either by bending or twisting, and ensure the components are secure so that they will not move when you apply the iron. Figure 2.42 illustrates two wires twisted together and a component inserted into a protoboard in preparation for soldering.

iv) Heating the wires and metal surfaces to be joined is necessary so that the solder properly wets the metal for a strong bond to result. When soldering electronic components, ractice in heating is necessary so that the process is swift enough to not damage components. Soldering irons with sharper tips are convenient for joining small electronic components, because they can deliver the heat very locally.



(*a*) wires twisted together (*b*) bent leads through protoboard holes

Figure 6. Preparing a Soldered Joint

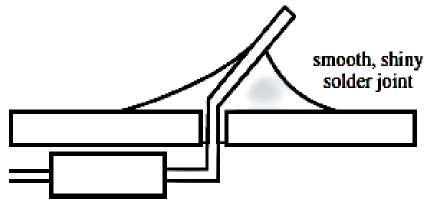


Figure 7. Successful Solder Joint

v) When the surfaces have been heated momentarily, apply the solder to the work (not the soldering iron) and it should flow fluidly over the surfaces. Feed enough solder to provide a robust but not blobby joint. (If the solder balls up on the work, the iron is not hot enough.) Smoothly remove the iron and allow the joint to solidify momentarily. You should see a slight change in surface texture of the solder when it solidifies. If the joint is ragged or dull, you may have a cold joint, one where the solder has not properly wetted the surfaces. Such a joint will not have adequate or reliable conductivity and must be repaired by re-soldering. Figure 2.43 illustrates a successful solder joint where the solder has wet both surfaces, in this case a component lead in a metal-rimhole perforated board.

vi) If flux solvent is available, wipe the joint clean.

vii) Inspect your work with a magnifying glass to make sure the joint looks good.

Experiment # 09

PI Controller Circuit

Experiment # 10

Current Limit Circuit

Part IV

Measurement and Transducer

Introduction and Theoretical Background

Mechatronics systems in automated manufacturing environments require extensive environmental information to make intelligent decisions. Such information relates to the tasks of material handling, machining, inspection, assembly and painting. The environmental information however is collected by devices called sensors and transducers. The extent to which these sensors and transducers are used is dependent upon the level of automation and the complexity of the control system. Complex control systems have introduced a need for fast, sensitive, and precise measuring devices.

Therefore, sensors are used to inspect work, evaluate the conditions of work under progress, and facilitate the higher-level monitoring of the manufacturing operation by the main computing system (sensors transform real-world data into electrical signals). The sensor also called transducer, probe, gauge, detector and pick-up. Moreover, sensor is considered a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).

On the other hand, the transducer (usually accompanying the concept of sensor) is a device that converts one form of energy into another form of energy. Besides, a transducer is defined as a device that converts a signal from one physical form (electrical, mechanical, thermal, and optical) to a corresponding signal, which has a different physical form.

Common Information/Measured Variables:

Acceleration, Density, Velocity, Viscosity, Displacement, Composition, Pressure, Humidity, Torque, Temperature, Force–Weight, Volume, Heat/Light flux, Mass Current, Flow rate, Voltage and Level Power.

Sensor Classification:

Sensors are classified into different categories according to:

i) **Output Signal:**
Analog Signal or Digital Signal

ii) **Power Supply:**
Active Power Supply or Passive Power Supply.

iii) **Operating Mode:**
Null type or Deflection type

iv) **Variables Being Measured:**
Acceleration, Density, Velocity, Viscosity, Displacement, Composition, Pressure, Humidity, Torque, Temperature, Force–Weight, Volume, Heat/Light flux, Mass Current, Flow rate, Voltage and Level Power.

v) **Physical Contact:**
Contact Sensor or Non-contact Sensor.

vi) **Classification By Specifications (most important classification criteria):**
Accuracy, Sensitivity, Stability, Response time, Hysteresis, Frequency response, Resolution, Linearity, Hardness (to environmental conditions, etc.), Construction materials, Input (stimulus) range and Operating temperature.

vii) **Physical Law:**
Photoelectric, Magnetoelectric, Thermoelectric, Photoconductive, Magnitostrictive, Electrostrictive, Photomagnetic, Thermoelastic, Thermomagnetic, Thermooptic, Electrochermical, Magnetoresistive and Photoelastic.

Definition of Important Terms Used in Sensor and Transducer:

- **Analog sensors:** Analog is a term used to convey the meaning of a continuous, uninterrupted, and unbroken series of events such: potentiometers and resolvers.
- **Digital sensors:** Digital refers to a sequence of discrete events. Each event is separate from the previous and next events. Digital sensors are known for their accuracy and

precision, and do not require any converters when interfaced with a computer monitoring system. such a sensor is encoders.

- **Active sensors:** Active sensors require external power for their operation. Typical examples of devices requiring an auxiliary energy source are strain gauges and resistance thermometers.
- **Passive sensors:** In a passive sensor, the output is produced from the input parameters. The passive sensors (self-generating) produce an electrical signal in response to an external stimulus. Such: piezoelectric, thermoelectric, and radioactive.
- **Deflection sensors**: Deflection sensors are used in a physical setup where the output is proportional to the measured quantity that is displayed.
- **Null sensors**: In null-type sensing, any deflection due to the measured quantity is balanced by the opposing calibrated force so that any imbalance is detected.
- **Contact sensor**: a sensor that requires physical contact with the stimulus. Such: strain gauges, most temperature sensors.
- **Non-contact sensor**: requires no physical contact. Such: most optical and magnetic sensors and infrared thermometers, encoders and capacitive
- **Sensitivity** is the property of the measuring instrument to respond to changes in the measured quantity. It also can be expressed as the ratio of change of output to change of input.
- **Resolution** is defined as the smallest increment in the measured value that can be detected. It is also known as the degree of fineness with which measurements can be made
- **Accuracy** is a measure of the difference between the measured value and actual value.
- **Precision** is the ability of an instrument to reproduce a certain set of readings within a given accuracy. Precision is dependent on the reliability of the instrument.
- **Backlash** is defined as the maximum distance or angle through which any part of a mechanical system can be moved in one direction without causing any motion of the attached part. Backlash is an undesirable phenomenon and is important in the precision design of gear trains.
- **Repeatability** is the ability to reproduce the output signal exactly when the same measurand is applied repeatedly under the same environmental conditions.

- **Linearity** is the characteristics of precision instruments are that the output is a linear function of the input.
- **Hysteresis** is the maximum difference in sensor output for the same input quantity is the hysteresis, with one measurement taken while the input was increasing from zero and the other by decreasing the input from the maximum input.
- **Rise Time** is the time it takes the output to change a certain percentage is the rise time.
- **Time constant** is defined as the time it takes the output to reach 63.2% of the final output.
- **Settling time** is the time it takes the output to reach within certain percentage of the final steady–state value is the settling time. A common value is the 2%
- **Bandwidth** is defined the frequency range for which the sensor is designed to operate.
- **Calibration:** the experimental determination of the transfer function of a sensor or actuator. Typically, needed when the transfer function is not known or, when the device must be operated at tolerances below those specified by the manufacturer.
- **Dead band**: the lack of response or insensitivity of a device over a specific range of the input. In this range which may be small, the output remains constant. A device should not operate in this range unless this insensitivity is acceptable. Example, an actuator which is not responding to inputs around zero may be acceptable but one which “freezes” over a normal range may not be.
- **Range:** is the lowest and highest values of the stimulus.
- **Span:** the arithmetic difference between the highest and lowest values of the stimulus that can be sensed within acceptable errors.

Signal Conditioners

A signal conditioner is a device – generally electronic – which converts one physical quantity into another physical quantity. Usually, it is not possible to manipulate the electrical output of a sensor directly. For example, the range of output voltages may not be suitable, the output signal may be too weak, or perhaps the electrical quantity is not the one required for the system. For this reason, the signal conditioner is engaged in the sensor and transducer measurements to draw suitable output signal to be. In most cases, the sensor is built directly into the process itself, so that it is in close contact with the physical quantity to be measured.

Experiment # 11

Ultrasonic, Proximity and Pressure Measurement

Section A: Ultrasonic Sensor

Ultrasonic sensors enable to carry out distance measurements by assessing the time spent by a sound pulse to cover the path between two sound transducers of transmission and reception. The speed of sound however must be known which is approximately equal to 340 m/s for air in the normal conditions.

Transmitter and receiver are placed side by side and oriented in the same direction; the sound detected is the echo reflected by any obstacle met along the path.

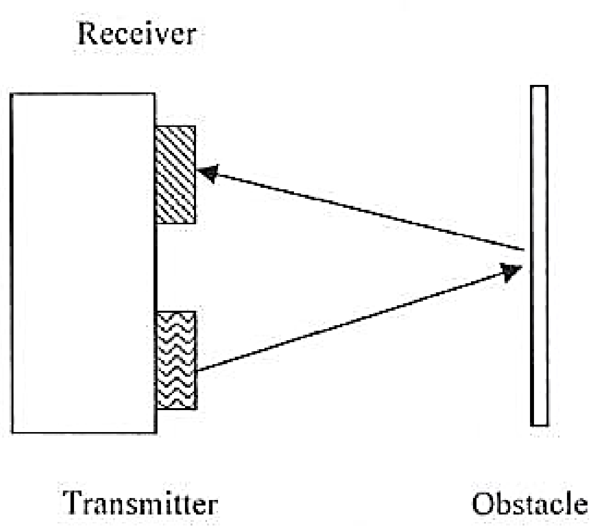


Figure 11.1 Main Components for Ultrasonic Sensor

An ultrasound measuring system is able to detect the surface of most solid and liquid objects, for variable material sensitivity that depends on the type of reflecting material, size of the target and environmental conditions. Measuring accuracy however depends mainly on the precision of knowledge for the speed sound in those particular operating conditions since the time measurement (up to some thousandth of second) does not show any particular problem of accuracy with the current circuit technology.

The same transducer is often used for the production of ultrasound pulses and for the echo detection with the alternation of its operating mode. Consequently, the system can be more compact and alignment within the transmitter and therefore the receiver can be eliminated.

Modulating the carrier with properly coded pulses, usually at a frequency of some tens of Hz, will enable to send ultrasounds. The pulses with a certain frequency are reflected by the target and consequently they are picked up and decoded by the receiving circuit.

The distance from the obstacle is determined on the ground of the time spent; that is of the delay between the transmitted pulse and the pulse received after reflection; if necessary, the variations of temperature and of other environmental conditions must be compensated. As time can be measured with the utmost accuracy and the speed of sound versus the environmental conditions is known, distance could be the result of the following formula:

$$D = \frac{1}{2} T_v C_s$$

Where D is the distance in mm, Tv is the time of flight, that is the time spent from the emission of ultrasound pulse to the reception of echo, expressed in milliseconds, and Cs the speed of sound, expressed in meters per second. Obviously, when the distance of an object is known, the speed of sound in that particular condition can be determined and thus the tabulation of Cs and the need of further sensors for monitoring the environmental conditions can be avoided.

The measurement interval when the sensor can be used depends on several factors such as the emission power of the sound wave, the sensitivity of the receiving circuit, properties of reflection, roughness, shape, inclination of the reflecting surface, influence of environmental condition and the position of the target with respect to the axis of emission. The values indicated in the characteristics of these sensors normally refer to a metallic target of prefixed size, perpendicular and aligned to the axis of ultrasound emission, to a temperature of 25$_o$C and to a relative humidity of 60% in standstill air.

The external unit module for TY40/EV includes two sensors (transmitter and receiver) arranged side by side and oriented in the same direction, as well as a metallic barrier running on slides that can be positioned at a minimum distance of 40 mm (position “0 mm”) up to a distance of 260 mm (position “220 mm”) from the sensors.

The applications using this type of piezoelectric sensors and transducers enable to cover maximum distances not longer than a some meters; consequently they enable to realize ultrasound radars for detecting objects in the range of some meters (detector of parking obstacles for automotive applications, or burglar systems for detecting the passage of people).

Generally, ultrasonic sensors produce output waves of frequencies that exceed 20000 Hz. Moreover, ultrasonic sensors can detect signals of the same type where their range of application is very wide, especially in the measurement and detection of objects.

Ultrasonic sensors are manufactured with the technology of piezoelectric ceramics whose characteristics are very high level that can ensure:

- Very compact and light sensors.
- High sensitivity and production of sound pressures.
- Low power consumption.
- High reliability.
- Joint use of the vibrations of ceramic transducer and of radial base.
- Water-tightness and high resistance to hard environmental conditions; consequently the have the high possibility for outdoor installation since they are enclosed with wholly sealed vessels.
- Transmitters with coupling of piezoelectric vibrations output by particular acoustic adapters (horns) to obtain perfect coupling with the air where ultrasound waves are diffused.
- High frequency and consequently low wavelength and high directionality for high-accuracy measurements of distance.

Sensitivity

The highest sensitivity for both the sensors of transmission and reception can be attained at an operating frequency of 40 kHz.

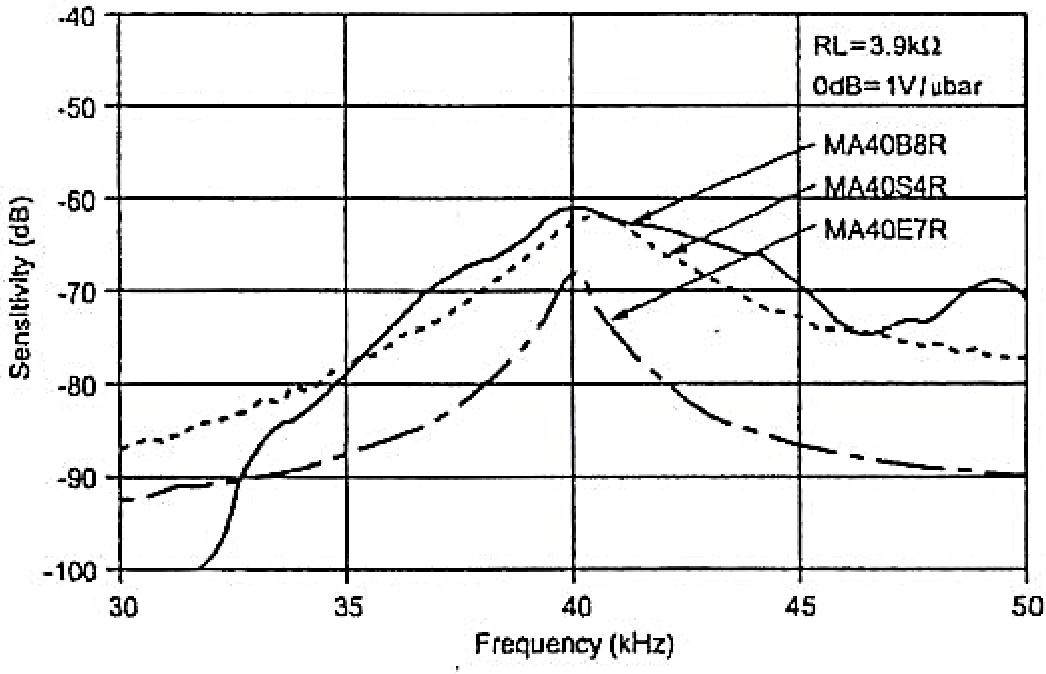


Figure 11.2 Sensitivity vs. Frequency of the receiving sensor

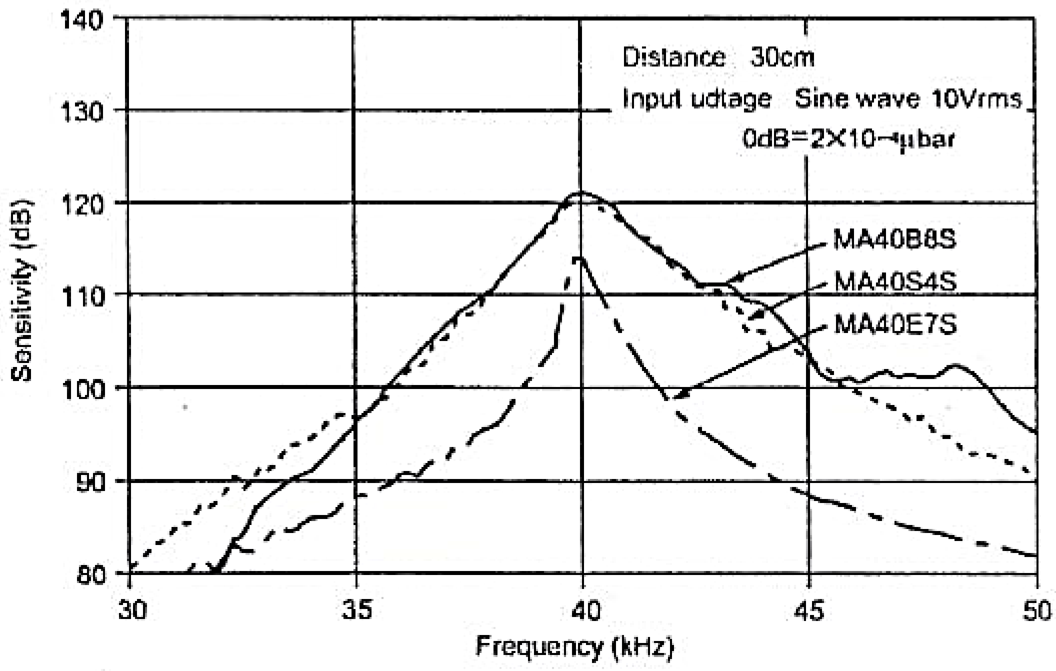


Figure 11.3 Pressure Levels vs. Frequency of Transmitting sensor

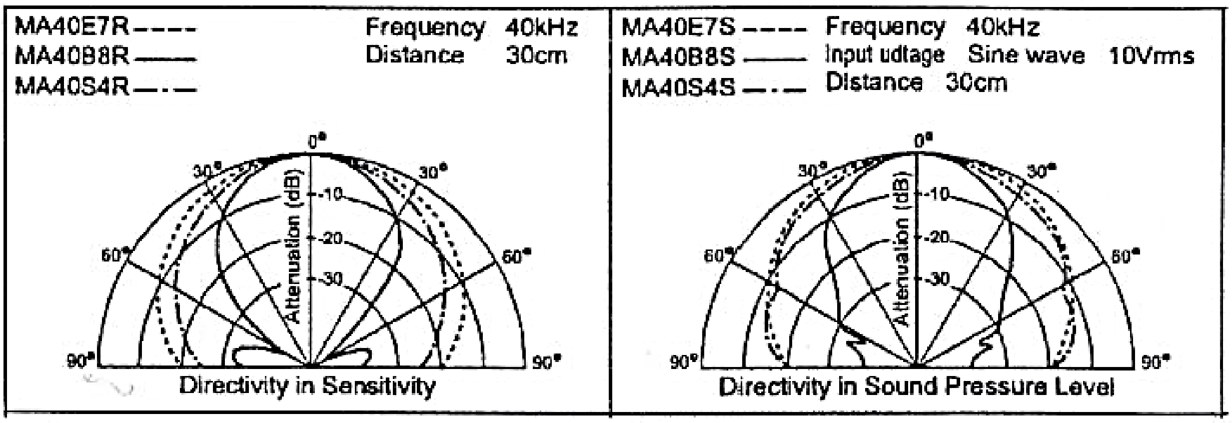


Figure 11.4 Directionality of Receiving and transmitting sensors

Parts and Components of Ultrasonic Sensor Experiment

- G40/EV ultrasonic model which is used to study the photoelectric sensors.

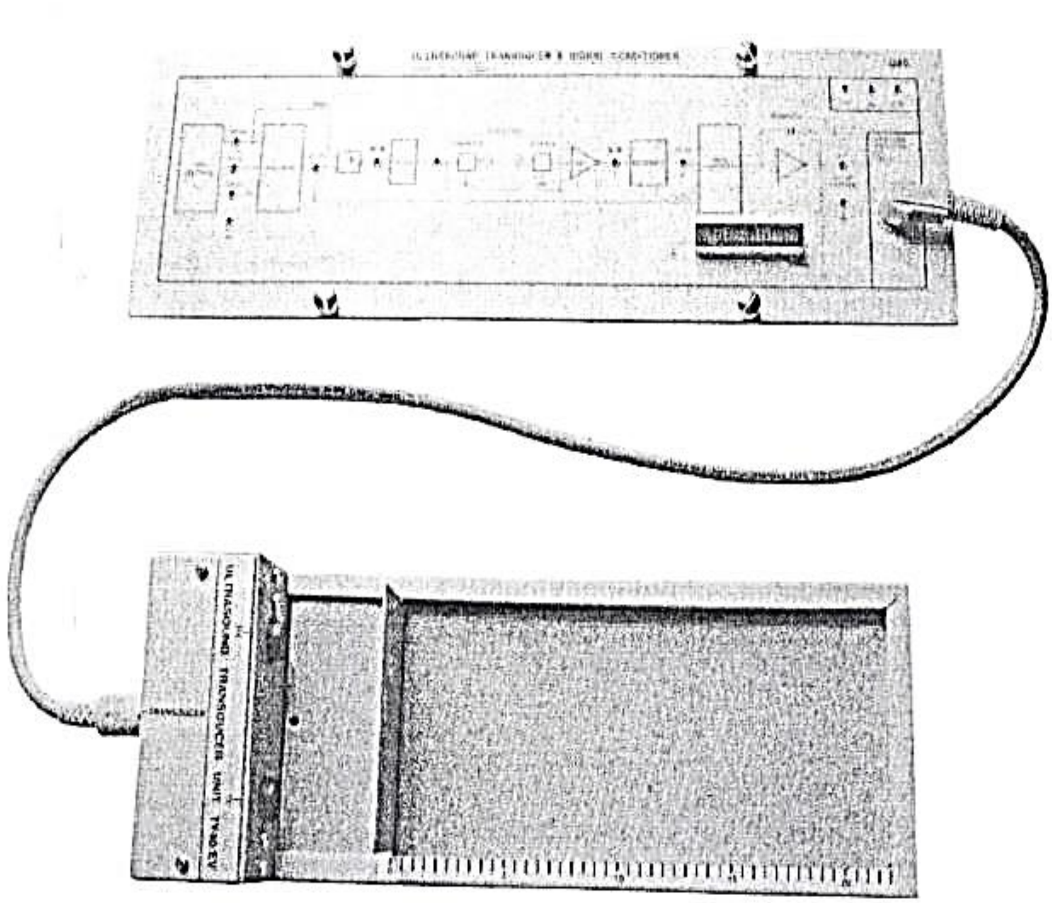


Figure 11.5 G40/EV Ultrasonic Module.

The schematic diagram shown in Figure 11.5 shows the main parts of the G40/EV module which includes the following sections:

i) A particulate section for signal Generator, Modulator, Filter and Transmitter.
ii) A particulate section for reception (Receiver) with amplification and conditioning.

iii) A particulate section for comparison between the signals transmitted and received (Phase Comparator).

iv) A particulate section for the integration of the resulting signal (Integrator) and displaying the distance of the barrier (acting as an obstacle) from the transmitting and receiving sensors.

v) External unit module TY40/EV with installation of two sensors of transmission and reception and system with movable metallic barrier that can be positioned continuously between a minimum distance (0 mm) and a maximum distance of 220 mm from the transducers.

- Multi-meter.
- Dual-trace oscilloscope.

The module is inserted in the module holder module BOX/EV and is powered via the jacks ±12 V and earth (power supply unit module PS1-PSU/EV.

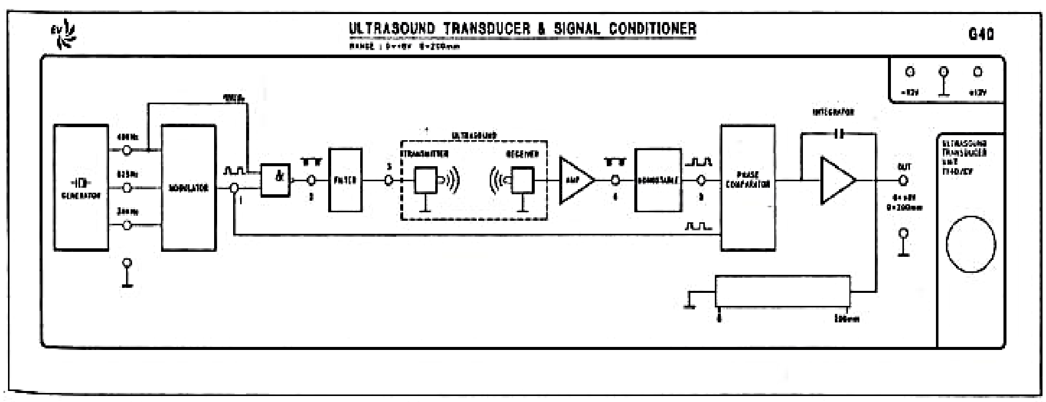


Figure 11.6 Schematic Diagram of the Module G40/EV

Exercises

- **Plotting the "Distance vs. Voltage" line of the module G40/EV**

This part is concerned with plotting the relationship between the distances of the barrier from the ultrasound sensors of the transmission/reception to the voltage available at the output OUT of the module G40/EV. Moreover, it is required to study the effects of the hysteresis of the sensor and calculate the value of linearity of the sensor-conditioner system.

Procedure:

1. Connect the digital voltmeter between the output OUT and the earth.
2. Change the distance of the barrier on the external unit, starting with the distance 0 mm, by steps of 10 mm, and detect the corresponding output voltage measured by the digital voltmeter, until the value of 200 mm. Wait some seconds so that a final stable value can be obtained before detecting the output voltage value on pin OUT because the integration of output signal will take 2 to 5 seconds.
3. Fill in Table 3.1 with the resulting data.
4. Change the distance of the barrier on the external unit, starting with the distance of 200 mm, by steps of 10 mm, until the value goes back to 0 mm. Wait some seconds so that a final stable value can be obtained before detecting the output voltage value on pin OUT because the integration of output signal will take 2 to 5 seconds.
5. Fill in Table 3.2 with the resulting data.
6. Plot on the same graph Vout (V) vs. D (mm).
7. Check if the two curves coincide. If not, what do we call his phenomena? Explain.
8. For the curve representing the data in Table 3.1, find the best fit line connecting the majority of data points.

9. Plot two parallel and equidistant lines with respect to the best fit straight line so that they can include all the data points. Your result will look something like Figur 3.6

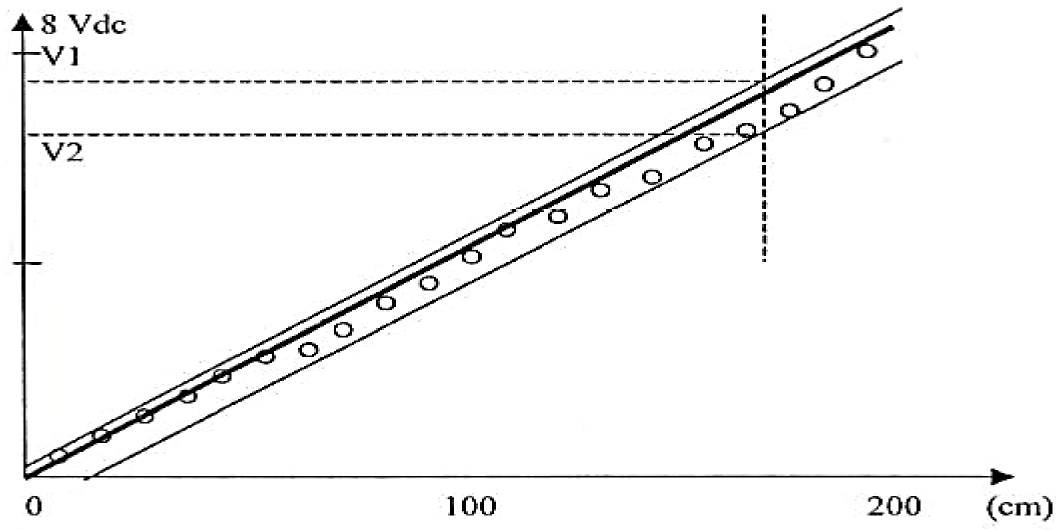


Figure 11.7 Linearity

10. Linearity value referred to the full scale value: $:\pm \frac{1}{2} \frac{V_1 - V_2}{F.S.O}$ Where F.S.O. is the full scale output.

Table 3.1

Distance of Barrier (mm)	V_{Out} (V DC), Pin OUT
0	
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
110	
120	
130	
140	
150	
160	
170	
180	
190	
200	

Table 3.2

Distance of Barrier (mm)	V_{Out} (V DC), Pin OUT
0	
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
110	
120	
130	
140	
150	
160	
170	
180	
190	
200	

Section B: Proximity Sensor

Proximity sensor is considered a very common sensor that is used to measure the small distances between the object and the sensor. There are however different types of proximity sensor which they depend on the internal set-up of the sensor. In this lab, only inductive and capacitive proximity sensors are presented, where a detailed description of the inductive and capacitive proximity sensors are revealed as follows:

Inductive Proximity Sensors

The principle operation of the inductive proximity sensors is based on the damping of an electromagnetic field due to the eddy currents induced within conducting materials placed near the sensors. An oscillating circuit generates a high-frequency electromagnetic field which induces eddy currents within the near metallic actuators.

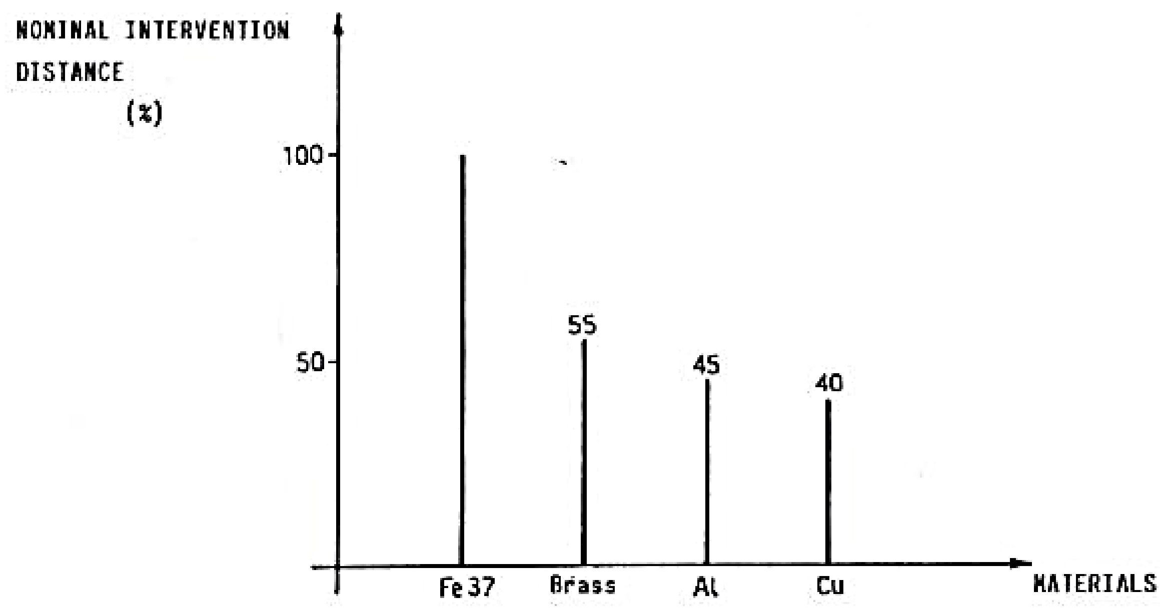


Figure 11.8 Nominal Intervention Distance for some Materials

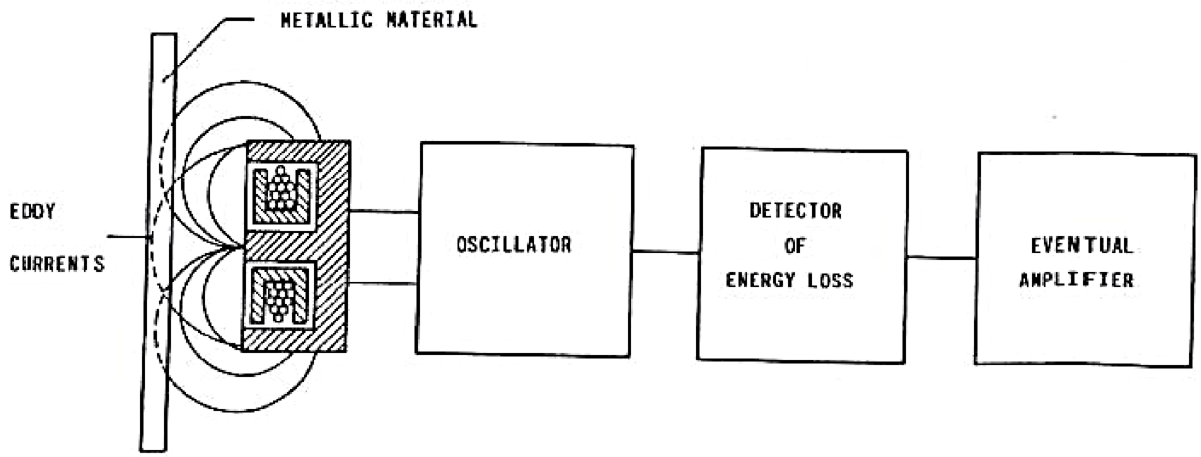


Figure 11.9

Inductive proximity sensor with linear output

The inductive proximity sensors with linear output can generate a variable output voltage, the voltage variation however is directly proportional (linear) to the distance actuator/sensor, within certain limits. The characteristics can be useful when carrying out very accurate positioning for detecting thicknesses, flexures, and vibrations. More generally, it is used to convert distance into voltage, in electro-conducting materials. Figure 3.10 shows the characteristic curve of this type of sensor.

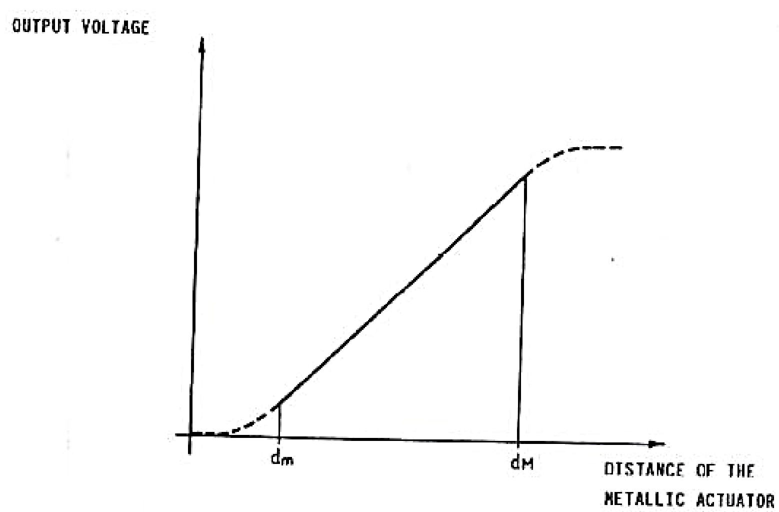


Figure 11.9 Characteristics of Inductive Proximity Sensor

The voltage vs. distance relation is linear only between the two values dm (minimum distance) and dm (maximum distance). The minimum distance dm does not coincide with the null position. However, The output voltage signal of the sensor is normally amplified and shifted so that the signal conditioner can generate a voltage proportional to the distance between the actuator and sensor.

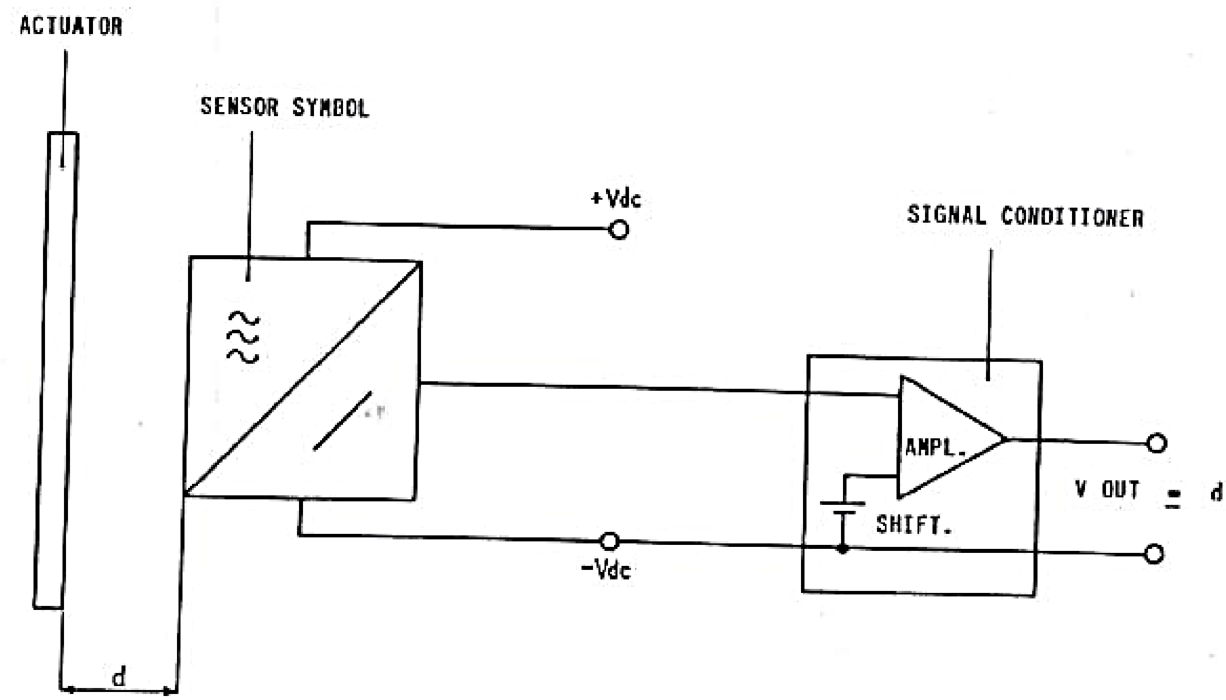


Figure 11.10 Schematic Diagram

Inductive Proximity Sensors with Two-Level Output

The inductive proximity sensors with two-level output deliver two different output current values; according to the position of the metallic actuator. In fact, they can be considered current regulators with two possible output values depending on the distance of the metallic actuator.

The inductive proximity sensors with two-level output however operate at very low electric levels that make them important to be used for installations and systems that operate in an ambient with danger of explosion.

Figure 3.12 shows schematic diagram for the proximity sensor connected with the amplifier (signal conditioner). Generally, the amplifier is physically placed far from the sensor. A sine wave mark however appears at the sensor symbol which indicates the oscillating circuit that generates the magnetic field. On the other hand, there is another mark that indicates the step which is related to the two-level output.

The amplifier mainly consists of a voltage generator connected in series to a resistor. Varying the current, also the voltage drop across the resistor varies, so that the ON-OFF (voltage) signal is generated at the output. This signal indicates whether the distance of the actuator is shorter or longer than the switching distance.

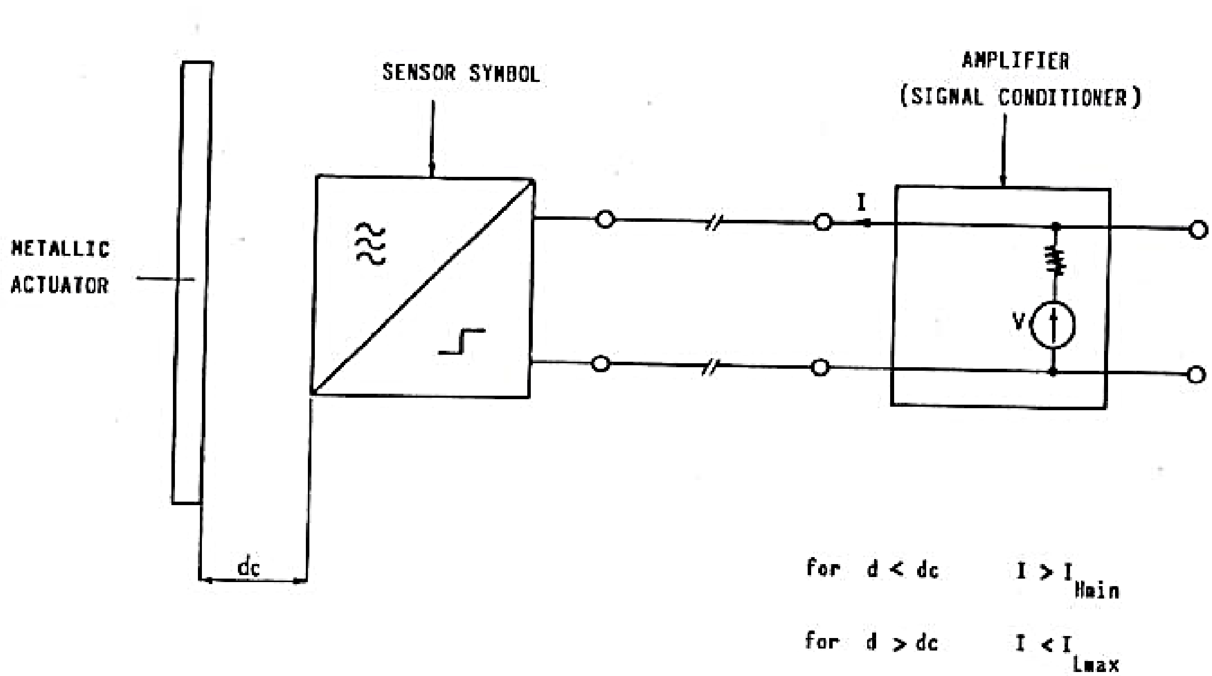


Figure 11.11 Schematic Diagram

Capacitive Proximity Sensor

Capacitive proximity sensor is used to detect metallic and non-metallic objects such as wood, liquids, and plastic materials. The principle operation of the capacitive proximity sensors is based on the variation of stray capacitance generated between the sensor and the object to be detected. At a certain distance of this object from the sensitive surface of the sensor, a circuit starts oscillating; the starting or ending of this oscillation is perceived by a threshold detector which controls an amplifier for driving an external load. Figure 3.13 shows the block diagram of this device.

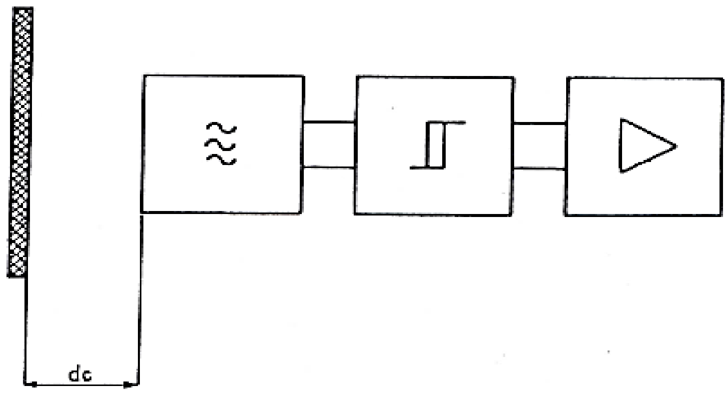


Figure 11.12 Block Diagram

Capacitive Proximity Sensor Classification

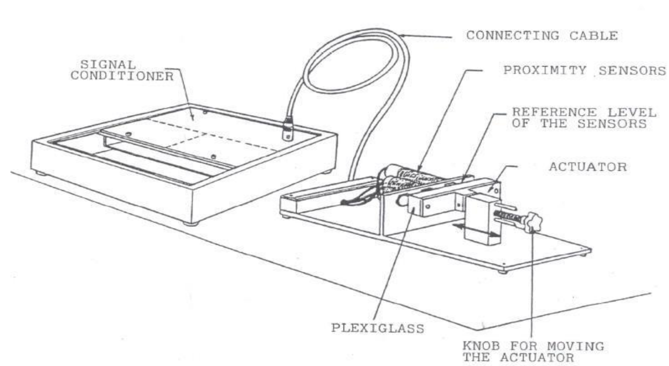
The capacitive proximity sensors are classified according to the operating voltage as:

- Direct-current capacitive proximity sensors where their output types are sorted according to:
  i) Polarity: NPN and PNP.
  ii) Output function: normally closed, normally open, ambivalent or exchange.
- Alternating-current capacitive proximity sensors where the output actuator is a SCR with the relevant driving circuit and it can be normally closed or normally open.

Parts and Components of Proximity Sensor Experiment

- **TY29 Module**

  This Model consists of two main parts: the panel which includes the signal conditioners (G29/EV) and the device which generates



linear displacement (TY29).

- **Inductive sensor with linear output, inductive sensor with two-level output and capacitive sensor with DC output.**

Exercises:

Part I: Inductive Proximity Sensor with Linear output

- **Distance and Voltage Relationship for the Sensor:**
  This part of the experiment concerns with the determining the relationship (curve) between the distance range (actuator/sensor) and the output voltage of the sensor (terminal 1).

Procedure:

1. Insert the voltmeter between terminal 1 and the ground.
2. Change the distance of the actuator through the proper knob, starting from a distance of 1 mm, by steps of 0.5 mm, then measure the corresponding actual distance with the gage reading the value of the output voltage on the digital voltmeter.
3. Fill in Table 3.3

Table 3.3

L (mm)	V_{out}(mV)
1.0	
1.5	
2.0	
2.5	
3.0	
3.5	
4.0	

- **Distance and Voltage Relationship for the Sensor and Conditioner.**

For this part of the experiment, the curve that is corresponding to the distance range (actuator/sensor) and voltage which is measured at the proportional output of the conditioner (terminal 3) is required to be determined.

Procedure:

1. Carry out the same operations of exercise 2.2 changing the scale of the output voltage from mV to V.
2. Fill the data in table 3.4.
3. Using the resulting data, it is possible to plot the characteristic curve of the sensor + conditioner.
4. Compare between the results of exercise 2.2 and 2.3.
5. For the curve representing the data in Table 3.3, find the best fit line connecting the majority of data points.
6. Plot two parallel and equidistant lines with respect to the best fit straight line so that they can include all the data points. Calculate the linearity of the system.
7. Linearity value referred to the full scale value: $:\pm \frac{1}{2} \frac{V_1 - V_2}{F.S.O}$

Table 3.4

L (mm)	V_{out}(mV)
1	
1.5	
2	
2.5	
3	
3.5	
4	

Part 2: Inductive Proximity Sensor with Two-Level output

- **Measurement of the current with and without the actuator**

It is required to check whether the values of the current crossing the sensor (with and without the actuator) correspond to those of the data sheets.

Procedure:

1. Insert the digital voltmeter between terminals 5 and 6, measure the voltage value across R1, with and without the actuator.
2. Knowing that R1 is equal to 2200, calculate the values of the two currents and compare them with the values of the data sheets. (Data sheets are found in Appendix C)

- **Intervention Distance and Hysteresis**

Determining the distance in mm between the actuator and the sensor S2, at which the output 9 switches from the high state (led out) to the low state (led on).

Procedure:

In this exercise you can either measure the voltage at the output of the conditioner or visualize the led connected to the output of 1C1.

1. Place the actuator 10 to 15 mm away from the sensor (led out).
2. Approach the disk slowly to the sensor S2 until the led starts emitting light.
3. Measure the distance between the actuator and sensor with the gage, compare this value to the value indicated in the data sheets found in Appendix C.
4. Move the actuator slowly away from sensor S2 until the led stops emitting light.
5. Measure the distance between the actuator and sensor with the gage.
6. Compare the values of distance measured in steps 3 and 5. Is there a difference between them? If yes, what do we call this phenomenon? Explain.

Part 3: Capacitive Proximity Sensor with two-level output

- Repeat exercise 2.5 with the same modes for this type of sensor.
- Screwing the plexiglass plate supplied with the unit TY29 on the actuator, this will cause the operating sensor to be the capacitive one.

Section C: Pressure Sensor and Transducer

Pressures in liquids and gases may be measured electrically using an infinite variety of pressure sensor. Pressure sensor however is categorized into:

i) Absolute pressure transducer: a device containing a reference vacuum for the measurement of the absolute pressure of the ambient or of the pressure source connected to it by a tube.

ii) Differential pressure transducer: A device for the measurement of differential pressure between two pressure sources connected to it by a tube.

iii) Gage pressure transducer. A differential pressure transducer in which the pressure source consists of the local atmospheric pressure, while the other source is connected to it by a tube.

There are also other terminologies that are utilized for pressure sensor such Barometric sensor, Altimetric sensor and Vacuum sensor. Independently of their classification within these groups, pressure transducers consist basically two main parts: the first part converts a pressure p(t) into a movement; the second part converts this movement x(t) into an electric signal v(t).

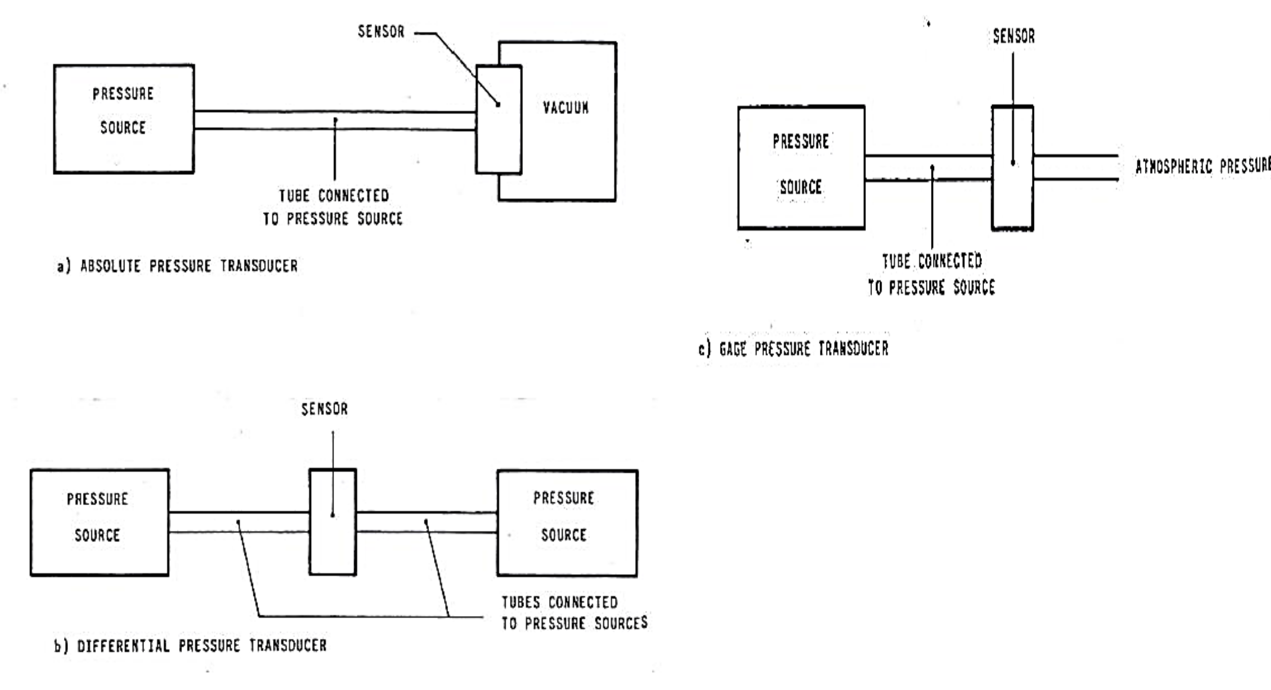


Figure 11.13 Categories of Pressure Transducers and Connections to Pressure Sources

Comparative Analysis of Different Types of Pressure Transducer

The table below shows the principal characteristics of different types of pressure transducers. Note that the operating range may vary significantly for transducers of the same type; this clearly affects their cost.

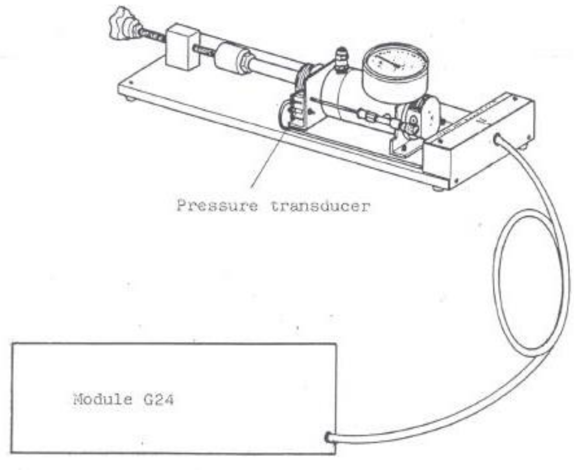
Table 4.4 Characteristics of Different Types of Pressure Transducers

Characteristics / Transducer	Accuracy	Cost	Electronic Interface	Principal Advantages	Principal Disadvantages	Use
LVDT	Fair	Average	Complex	-	Expensive if a high level of accuracy is required	Low-precision apparatus
Potentiometric	Fair	Low	Simple	Low Cost	Low accuracy and reliability	-
Strain-Gage	Excellent	High	Simple	High Precision	Very Expensive	Precision industrial uses: nuclear and oceanography
Monolithic Capacitive	In theory: Excellent	Relatively High	Complex	Excellent Stability and Low Temperature Dependence	Distance between the two electrodes is critical	Industrial
Monolithic Piezoresistive	Good	Relatively High	Simple	Temperature Stability and Excellent Linearity	-	Industrial
Monolithic Semiconductor	Good	Low	Complex if heat-compensating	Small Size	Highly sensitive to Temperature	Industrial
Piezoelectric	Excellent	High	Charge Amplifier	High Precision	Very Expensive	Precision measurement: Sound Measurement

Parts and Components of Pressure Sensor Measuring Experiment

- **Pressure Transducer**

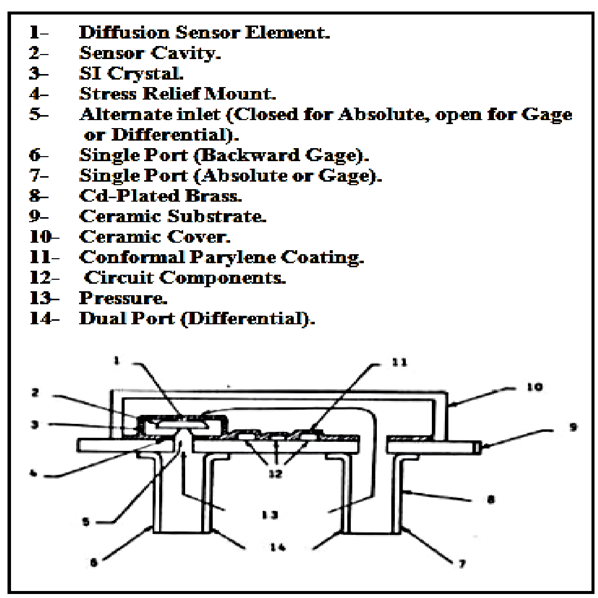
Pressure sensor is based on the phenomenon of piezoresistivity. That is the ability of a certain number of materials to change their resistance when it is subjected to a deformation.



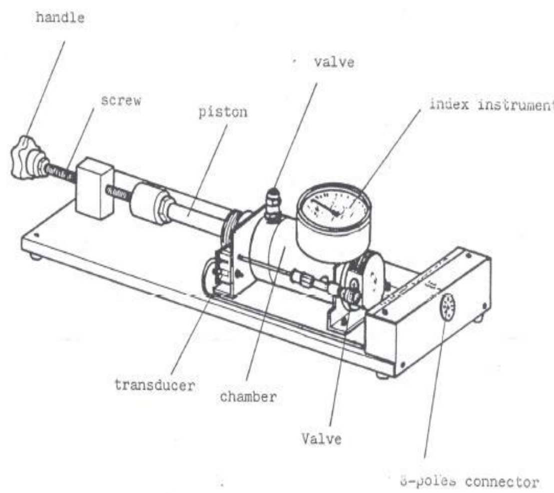
The advantages of such a sensor are its size (about one tenth of other monolithic transducers), excellent electrical characteristics and the intrinsically low cost of the sensitive element. On the other hand, it is considered to have a high sensitivity shift with temperature, and the fact that the fluid being tested comes into contact with the sensitive element. These limitations are often circumvented by fitting laser- trimmed resistors for close null and sensitivity tolerances. In order to reduce sensitivity shift with temperature, some sensors are fitted with thermistors (temperature-compensated).

- **Sample Pressure Generation Device**

In order to study the characteristics of the pressure transducer and the signal conditioner, a sample pressure must be made available. For this purpose a device, called Pressure Transducer Unit Ty24, has been manufactured, which is able to generate pressures from 0 to 2 bar.



- **Pressure Generator**



It consists of a piston, controlled by a handle by means of a screw, which can be inserted into a chamber. By varying the position of the piston, you vary the pressure inside the chamber.

A differential type transducer is fitted beside the chamber, and this has an input connected to the pressure of the chamber and the other part is left free (so at ambient pressure); in this way we obtain the relative pressure (gauge).

Over the chamber there are an exhaust valve and an index instrument, which operate as reference for the pressure inside the same chamber. Besides, the availability of an exhaust valve gives the possibility to obtain a zero value of pressure (atmospheric pressure) for each position of the piston. The connection to the module is obtained by the 8 poles connector fitted on the side of unit TY24.

Exercises

- **Setting Up Signal Conditioner:**

The purpose of this exercise is to adjust signal conditioner so that a pressure of 0 atm corresponds to an output voltage of 0 V and a pressure of 2 bar corresponds to an output voltage of 8 V.

- **Tracing The "Output Voltage/Pressure" Curve Of The Transducer/Conditioner:**

The purpose of the exercise is to plot the curve which represents the relationship between the pressure applied to the transducer and the output voltage of the signal conditioner. Also, it is required to find the best fit straight line which perfectly represents the relationship between the pressure applied to the transducer and the output voltage of the signal conditioner. Additionally, it is desired to calculate the linearity of the sensor/transducer.

Procedure:

1. After setting up the signal conditioner, connect the digital voltmeter to the output marked OUT.
2. Starting from 0, vary the pressure of the sample generator in steps of 0.1 bar.
3. The data gathered in this way should be listed in table 4.1.
4. For the curve representing the data in Table 4.1, find the best fit line connecting the majority of data points.
5. Plot two parallel and equidistant lines with respect to the best fit straight line so that they can include all the data points. Calculate the linearity of the system.
6. Linearity value referred to the full scale value: $\pm \frac{1}{2} \frac{V_1 - V_2}{F.S.O}$

Table 4.1

P (bar)	V_{out} **(Volt)**
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1	
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	
1.7	
1.8	
1.9	
2	

- **Studying The Effect Of Transducer's Temperature On The Measurement Process**

  In this part of the experiment, it is required to analyze the effect of the temperature on the measuring process to observe the variation in measurement as the temperature of the transducer varies.

Procedure:

1. Heat the transducer using an incandescent lamp and measure the new characteristics following the procedure in 5.2.
2. Compare your results with the results of 5.2.

Table 4.2

P (bar)	V_{out} (Volt)
0	
0.1	
0.2	
0.3	
0.4	
0.5	
0.6	
0.7	
0.8	
0.9	
1	
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	
1.7	
1.8	
1.9	
2	

Experiment # 12

Temperature Measurement

When energy is provided to a physical system in any form, the state of the system inevitably changes and the temperature in this case is considered one of the important indicators that represents the state of the system. In the International System, *kelvin* (K) is considered the standard unit for the temperature where the absolute zero corresponds to 0 K. Two other temperature scales are normally used: the Celsius or centigrade scale (°C) and the Fahrenheit scale (°F). The relationship between these temperature scales is shown in Figure 12.1.

°K	°C	°F
0	-273,1	-460
273,1	0	+32
373,1	100	+212
1273	1000	1832

Figure 12.1 Relationship between Celsius, Fahrenheit and kelvin

Conversion from Centigrade to Fahrenheit is based on the following equation:

$$°\mathrm{F} = \frac{9}{5} \, . \, °\mathrm{C} + 32$$

Centigrade scale however is used in this handbook which is perhaps the most practical of the three, as 0 °C corresponds to the temperature of melting ice and 100 °C correspond to the boiling-point of water at sea-level. In industrial and domestic applications, temperature is measured by numerous different types of transducers of varying complexity and accuracy.

The most commonly used are semiconductor transducers, thermo-resistances and thermocouples, as these transducers offer a high degree of accuracy together with simple construction and ease of use. These types of transducers can also be very small, and are therefore easy to insert directly into the process.

Transducers Types Used To Measure Temperature:

i) Semiconductor Temperature Transducers

Semiconductor temperature transducers are based on the degree of sensitivity of the semiconductor materials to the temperature. The temperature coefficient of a semiconductor temperature transducer is much higher than that of a thermo-resistance, and it is much cheaper to produce. Its main disadvantages lie in a limited temperature range and lower linearity.

Devices of this type may have one or two terminals, and are classified as follows:

- Semiconductor resistive block.
- Junction between two semiconductors doped P and N (diodes).
- Integrated circuit.

This type of devices is considered the most simple in structural terms, and may have a positive or negative temperature coefficient of approximately 0.7%/ ℃ and linearity of +_0.5% within a temperature range of –65 ℃ to +200 ℃.

The law by which resistance varies with temperature is, in approximate terms, as follows:

$$R_T = R_0 (1 + \alpha T)$$

The transducer and the signal conditioner are generally connected by two wires. As the temperature to which these wires are subjected varies, the overall resistance of the transducer and wires also varies. However, the measurement error caused by the wires is, in most cases, negligible. In rare cases, three-or four-wire devices are used as in the classic connection with two constant-current generators (see Figure 12.2).

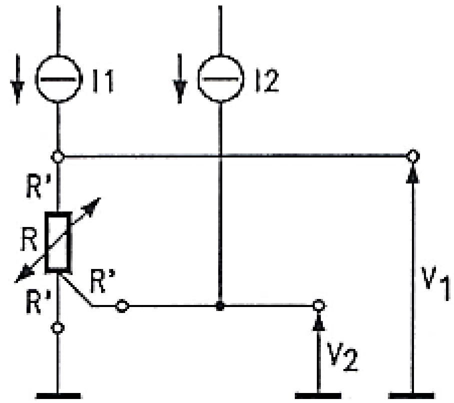


Figure 12.2

The wires which carry the transducer output are always made using the same material and are always of the same length, and their resistance R' is therefore identical. As a result, using a differential amplifier, it is possible to obtain a voltage which varies only with the resistance R. The nominal resistance at a temperature of 25 °Cis between 10Ω and 10KΩ, with a tolerance of between 1% and 20%; in physical terms, their form in that of a ¼ W resistance or a signal diode.

As the characteristics are specified for null power dissipation (i.e. without any appreciable current circulating in the device), care must be taken to prevent overheating caused by the measurement current. For this reason, the transducer is not generally powered with currents in excess of 10 mA.

The transducer examined in this experiment is the Philips KTY83-110, whose main characteristics are as follows:

- Nominal resistance: 1000Ω (25oC, 1 mA)
- Temperature range: -55oC / +175oC
- Maximum tolerance: 1%
- Temperature coefficient: +0.75%/oC (P.T.C.)

ii) **NTC Thermistors**

Thermistors are considered resistance variation transducers constructed with materials of high temperature coefficient, and with very cheap manufacturing processes. Moreover, these types of temperature sensors are categorized as semiconductor RTDs (Resistance Temperature Detectors) and can determine negative (NTC) or positive (PTC) temperature coefficients; according to their composition.

The resistance of NTC thermistors depends on the absolute temperature which is given by:

$$R(T) = R_0 \cdot \exp\left(\frac{b}{T}\right)$$

PTC thermistors have a constant thermal coefficient in a limited temperature range, showing a fairly good sensitivity. In addition to that, PTC thermistors have a positive temperature coefficient and their characteristic increases as temperature rises. On the other hand, NTC thermistors have a negative temperature coefficient and their resistance/temperature characteristic decreases as temperature rises.

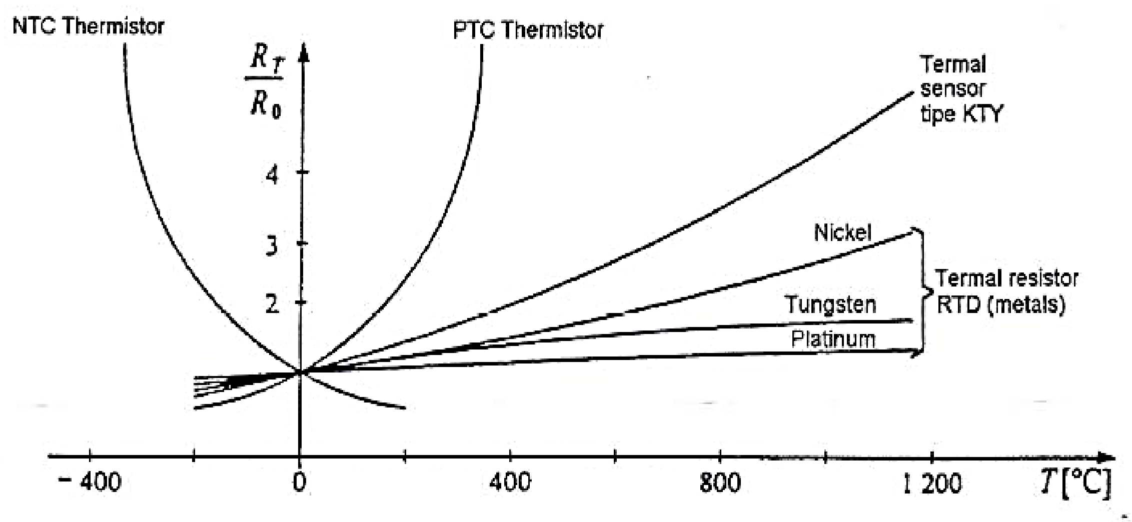


Figure 12.3

NTC thermistors can use various circuits to reduce their nonlinearity that it under goes (e.g.: a resistor bridged with the sensor and another one series connected with it); or using a microprocessor which leads to digital linearization with interpolation of the calibration curve. Resistance and temperature of a NTC thermistor will vary according to the following formula:

$$R_T = A \, . \, e^{\frac{B}{T}}$$

Where:

- R_T is the resistance of the material at the generic temperature T.
- *A* and *B* are constants depending on the material with 200K < *B* < 5500K
- *T* is the generic temperature expressed in Kelvin degrees.

The main relation between resistance of the thermistor R_T and temperature *T* is given by:

$$R_T = R_{Ta} \, . \, e^{B.\frac{Ta-T}{Ta.T}}$$

Where:

- Ta is the reference temperature Ta = 293K (Ta =20 °C).
- $R_{Ta}$is the resistance of the thermistor at the temperature Ta.
- *B* is a constant depending on the material 200K < *B* < 5500K.

The transducer examined with the module G34/EV shows the following characteristics:

- R_{Ta}= 12.09 kΩ.
- *B* = 3435K ± 1%.

The characteristic of NTC thermistors however can be linearized through a bridged resistance calculated with the following formula:

$$R_L = R_{Tmed} \cdot \frac{B - 2 \cdot T_{med}}{B + 2 \cdot T_{med}}$$

Where:

- R_L is the value of the bridged resistance for linearization.

- R_{Tmed} is the resistance of NTC thermistor corresponding to the mean temperature T_{med}.
- B is the dimensional constant of the thermistor.

Considering a range of temperature between 0 ℃ and 80 ℃, set the linearization resistance of the thermistor examined in the module G34/EV, according to the following table:

T_{min} = 20 ℃ R_{Tmin} = 12.09 kΩ

T_{med} = 40 ℃ R_{Tmed} = 5827 Ω

T_{min} = 80 ℃ R_{Tmax} = 1668 Ω

Applying the formula $R_L = R_{Tmed} \cdot \frac{B- 2 \cdot T_{med}}{B+2 \cdot T_{med}}$ will lead to:

$$R_L = R_{Tmed} \cdot \frac{B- 2 \cdot T_{med}}{B + 2 \cdot T_{med}} = 5827 \text{ X } \frac{3435-2 X 40}{3435 +2 X 40} = 5560 \ \Omega$$

The bridged resistance used for linearization, being equivalent to the same resistance, RL shows a slight nonlinearity; reducing the range of use will also progressively reduce this nonlinearity.

iii) **Thermoresistances**

Thermoresistances measure temperature by detecting variations in the resistance of an electrical conductor. The law by which resistance varies with temperature is, in approximate terms, as follows:

$$R_T = R_o(1 + \alpha T)$$

where the temperature coefficient α is the average value over the measurement range.

Thermoresistances are also known as Resistance Temperature Detectors (R.T.D.), and have the following electrical symbol:

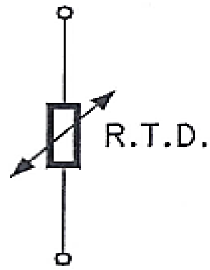


Figure 12.4

This type of transducer has the following main characteristics:

- Long-term invariability of characteristics
- Reproducibility of characteristics
- Good resistance variation with temperature

Two types of thermoresistance are generally accepted as standard: the nickel thermoresistance and the platinum thermoresistance.

The nickel thermoresistance has a temperature coefficient $\alpha = 6.17*10^{-3}\ C^{-1}$, and can be used at temperatures between -60 and $+150^{o}$C. The platinum thermoresistance has a temperature coefficient $\alpha = 3.85*10^{-3}\ C^{-1}$, and can be used at temperatures between -220 and $+750^{o}$C. The characteristic curves are shown in Figure 12.5.

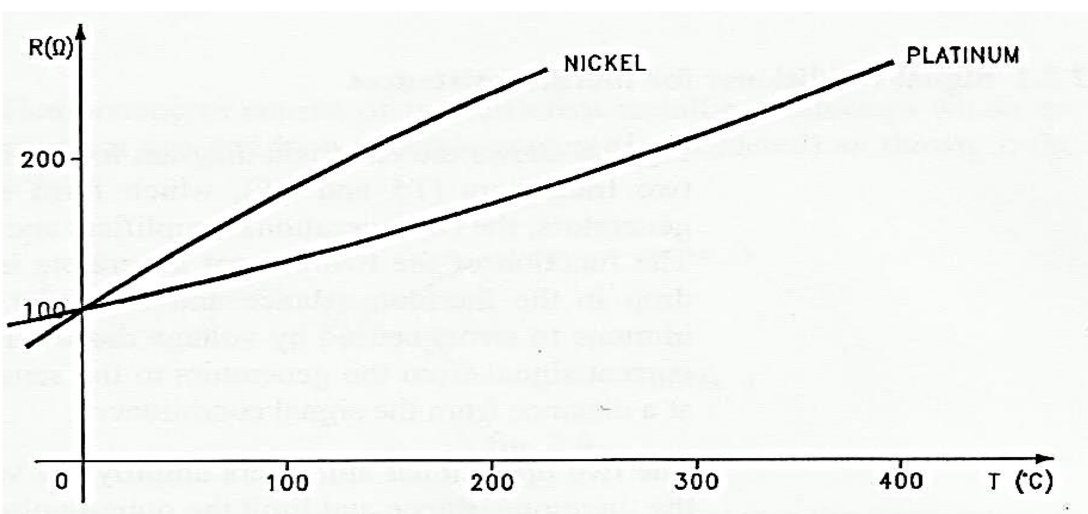


Figure 12.5 Characteristic Curves Of Thermoresistance And Platinum Thermoresistance.

The most commonly used thermoresistances have a resistance of 100 Ω at 0_oC and a tolerance of $\pm 0.1_oC$.These normally consist of a wire (platinum or nickel) which is wound on an insulating cylindrical or flat support. The support is in a material which withstands high temperatures (ceramic, glass, etc.)

This structure results in a fairly high thermal constant. In other words, thermoresistances are relatively slow to follow the variations in the process temperatures.

The thermoresistance and the signal conditioner are normally connected by two wires. In order to reduce the influence of these wires on the measurement as the ambient temperature varies, the three- or four-wire connection in used together with a special electronic circuit, as in the semiconductor temperature transducer.

The overheating generated by the measurement current causes an error whose entity depends on the transmission of heat between the sensitive element, the protective sheath, and the ambient. For this reason, the measurement current is not normally in excess of 10 mA. These experiments use a Pt-100 3-wire platinum thermoresistance, which has a temperature range of 0 to 250_oC, excellent linearity, and a low tolerance.

iv) **Thermocouples**

Thermocouples consist of two different metallic conductors which are joined at one end by a galvanic contact (i.e. soldered) as shown in Figure 12.6.

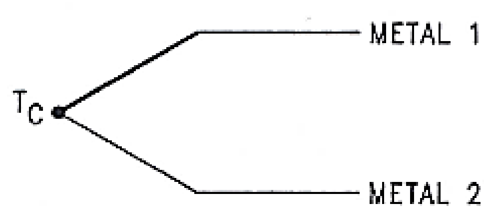


Figure 12.6

The thermocouple (or hot junction) is introduced into the temperature to be measured (e.g. inside an oven) and the conductors are brought to the point of measurement (cold junction), which is at a different temperature as seen in Figure 12.7. This circuit generates a thermoelectric e.m.f. (electromotive force) which varies according to the difference between T_C and T_F (Seebeck effect).

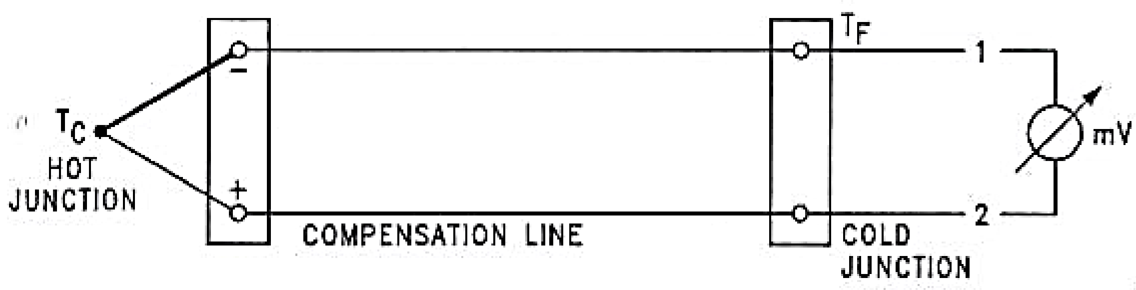


Figure 12.7

By measuring this electromotive force, and as the temperature T_F is a known quantity, it is possible to calculate the value of T_C. Since it is necessary to know the value of T_F in order to calculate T_C, it is necessary to extend the wires of the thermocouple with compensating wires to a point at which the temperature is constant and known.

The most important of the thermocouples available on the market are as follows:

- Fe-Constantan (type J)
- Ni-NiCr (type K)
- Cu-Constantan (type T)

Figure 12.8 shows the e.m.f./temperature curves for these types of thermocouples.

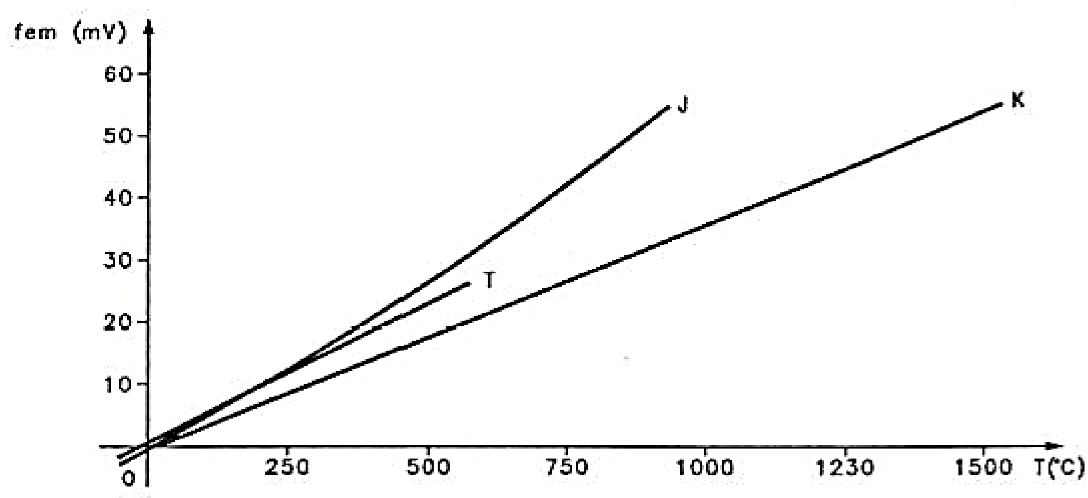


Figure 12.8

The e.m.f. of the Fe-Constantan thermocouple is much greater than that of the other types; its linearity is good, and it is inexpensive. One disadvantage is that the maximum temperature is limited by the iron element (700 – 800$_o$C). The e.m.f. of the Ni-NiCr thermocouple is less than that of the Fe-Constantan type, but its operating temperature is significantly higher (in excess of 1500$_o$C). Its linearity is good, especially in the high temperature range, although it is slightly more expensive to produce than the Fe-Constantan thermocouple. The main disadvantage of the Ni-NiCr thermocouple is that it is vulnerable to reducing gases, and therefore requires protection.

The temperature range of the Cu-Constantan thermocouple is lower than that of the Fe-Constantan type (500 – 600$_o$C), but its linearity is better while it is not more expensive. This type of thermocouple is used mainly for low temperatures. The compensation wires must have the same thermoelectric characteristics as the thermocouple up to 150 – 200$_o$C, and they must be inexpensive.

The thermocouple examined in this case is of the Fe-Constantan type (type J), and has the following main characteristics (see data sheet for further details):

• Transduction constant: 53 V/$_o$C

• Error: ±2.2$_o$C in the 0 – 270$_o$C range

±0.75% in the 270 – 760$_o$C range

• Protected against atmospheric agents by metallic sheath

Temperature Process

1. **Heating a body**

   The physical process of heating a body is described below. The body is assumed to be a heat conductor with a mass m and a specific heat c. If a quantity of heat Q is applied to such a body, its temperature increases by δT, which is given by the following equation:

$$\delta T = \frac{Q}{m \cdot c}$$

The quantity of heat *Q*, in the International System, is expressed in Joules, and may be calculated by multiplying the value of the power supplied to the heating element (which is assumed to be constant, and is expressed in Watts) by the time (in seconds) for which this power is applied. In approximate terms, therefore, the heating process is an integrating process which, in the time domain, will have a response with a delay of τ. The process may take place in a crucible, a tank containing chemical reagents, an oven etc.

In the TY34/EV temperature unit, the process takes place on an aluminum plate. This makes it possible to achieve high temperatures (up to 250_oC) with a relatively low heating power (100W max), and to bring the process to operating temperature extremely quickly.

The temperature unit also features the thermal actuators: a two-element electrical resistance (2 x 50W/24VAC) and a fan (170 m_3/hr/24VDC/4.5W). The fan makes it possible to cool the aluminum plate very rapidly, so that a series of experiments can be carried out without delays between one and the next.

The aluminum plate features wells for the three different types of industrial temperature transducer supplied with the temperature unit (PTC, thermoresistance and thermocouple). The unit also includes a mercury thermometer, which is used to provide the reference temperature. The thermometer, too, is inserted into a special well in the aluminum plate. The temperature unit is illustrated in Figure 12.9. The temperature unit can operate with the following temperature range:

$T_{amb} \rightarrow 250_oC$

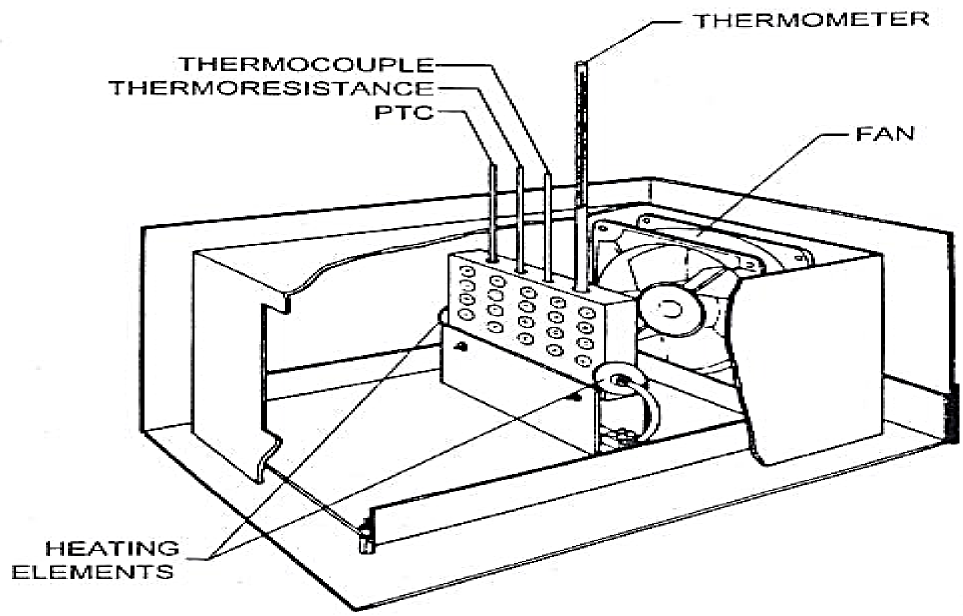


Figure 12.9

2. **Control Of The Temperature Process**

Automatic temperature control systems are widely used in industrial and domestic applications. The block diagram shown in Figure 12.10 illustrates a typical temperature process control system.

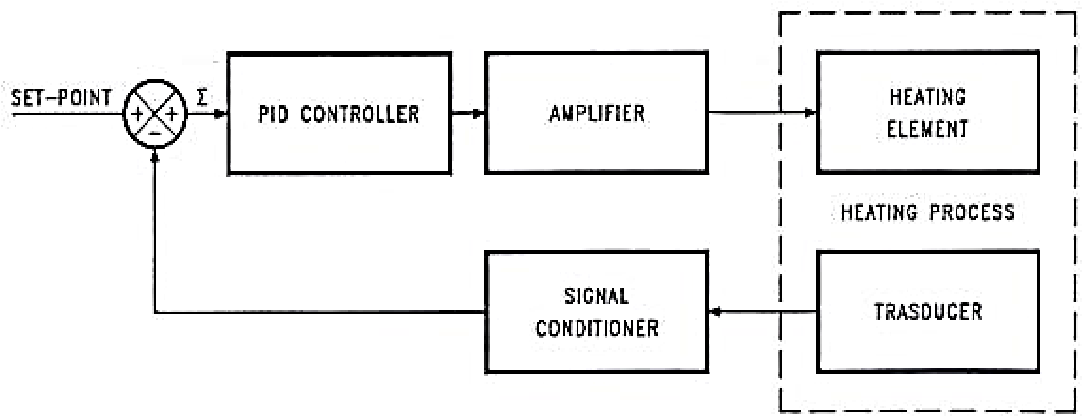


Figure 12.10

The fundamental elements in a temperature control system are as follows:

- Power amplifier: amplifies the output signal from the control loop, and applies the amplified signal to the actuator (heating element)

- Temperature transducer: one of the three types may be used. The transducer is accompanied by a signal conditioner which converts the signal from the transducer into one suitable for comparison with the set-point or reference signal.
- Set-point and comparison block.
- Controller: PID-type variable-configuration controller with adjustable parameters.

3. **Regulation by means of P-type controller**

Refer to fig. 5.11. The error signal obtained by comparing the signal from the signal conditioner with the reference signal is amplified by a factor K_P.

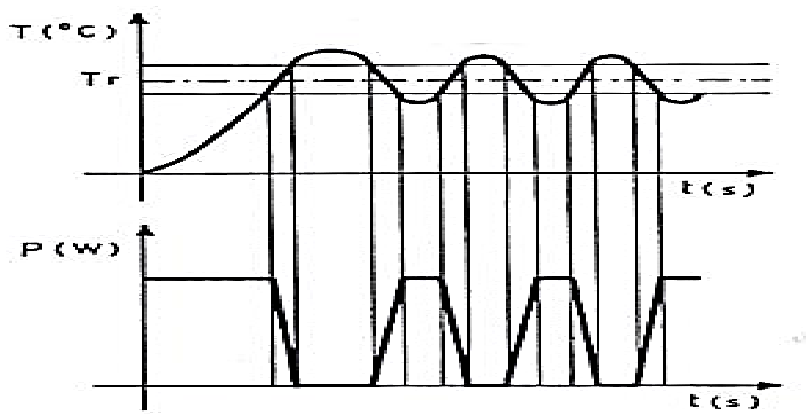


Figure 12.11

Outside the proportional band, the controller determines an ON/OFF power signal, while, within the proportional band, the power is modulated. Once the system reaches steady state, the power supplied by the amplifier to the actuator depends on the thermal dispersion of the heating element.

Note that, at steady state, when the controller operates in the center of the proportional band, the error is not null, but depends on the coefficient K_P and, as a result, on the value of the proportional band itself. Different temperature vs. time curves can be obtained, depending on the proportional band entered. Figure 12.shows the different temperature curves caused by:

a) PB too wide

b) PB correct

c) PB too narrow

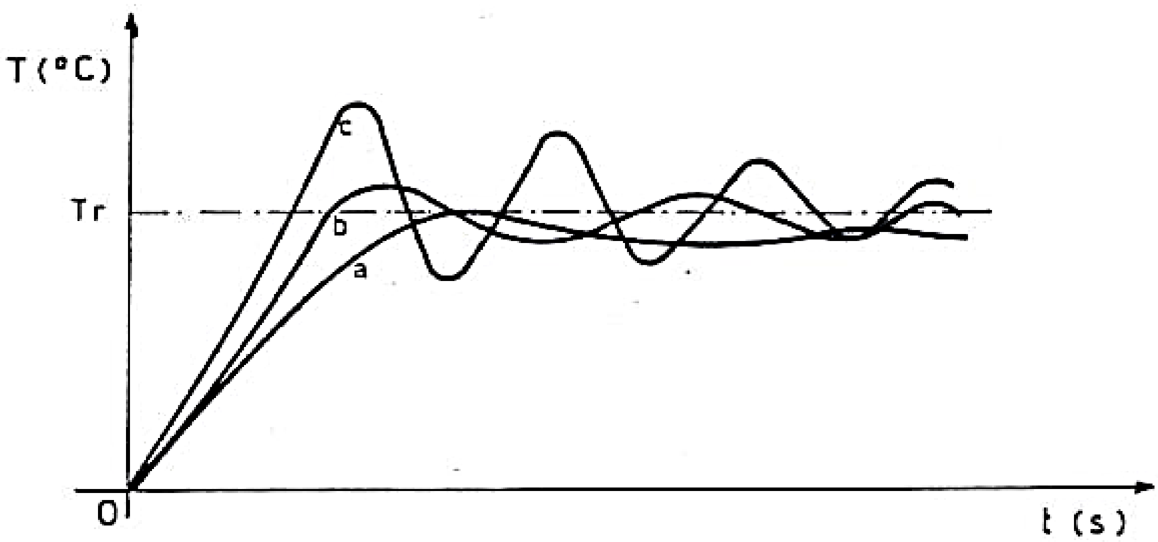


Figure 12.12

4. **Regulation by means of PI and PID controllers**

The integrating action can be used to reduce the steady-state error to zero and improve the response of the controlled system so that the operating temperature can be reached more quickly.

The integrating action is particularly effective in compensating step variations in the controlled temperature. However, it may occur that the thermal inertia of the system (i.e. the interval between the application of power to the actuators by the POWER AMPLIFIER and the actual heating of the body) is high; therefore, the proportional

band must be extremely wide. In this case, the integrating action must be greatly reduced in order to prevent the occurrence of oscillations, and compensation of the temperature variations requires a relatively long time.

In order to avoid this problem, a derivative action is added to the proportional-integrating action; this gives the system more effective initial control.

As the process evolves, the derivative action is reduced, and the integrating action takes over in order to reduce the control error to zero with respect to the steady-state value.

Exercise

- **Characteristics of the silicon transducer**

It is required to plot the characteristic curve of the silicon transducer (with the relative signal conditioner) on a graph.

Procedure:

1. Connect the silicon transducer to the corresponding signal conditioner.
2. Connect the output of the SET-POINT block terminal 2 to the SET-POINT input of the ERROR AMPLIFIER block terminal 3.
3. Connect the output of the PID CONTROLLER to the input of the HEATER AMPLIFIER.
4. Connect the HEATER output of the POWER AMPLIFIER to the heating elements of the oven.
5. Connect the COOLER output of the HEATER AMPLIFIER to the fan on the TY34/EV unit.
6. Set up the connection of the power supply for alternating voltage (24+24V AC) to the POWER AMPLIFIER block.
7. Connect the output of the signal conditioner to the feedback input of the ERROR AMPLIFIER block.
8. Short-circuit jacks 5 and 6 and set potentiometers P2 and P3 on the PID CONTROLLER to the half–way position (these potentiometers are positioned externally on the panel).
9. Connect the multi-meter to the output of the signal conditioner, and set to 20V DC. If the Y-t plotter is available, connect the Y input to the same output.
10. The above connections form the circuit illustrated in fig.5.13.

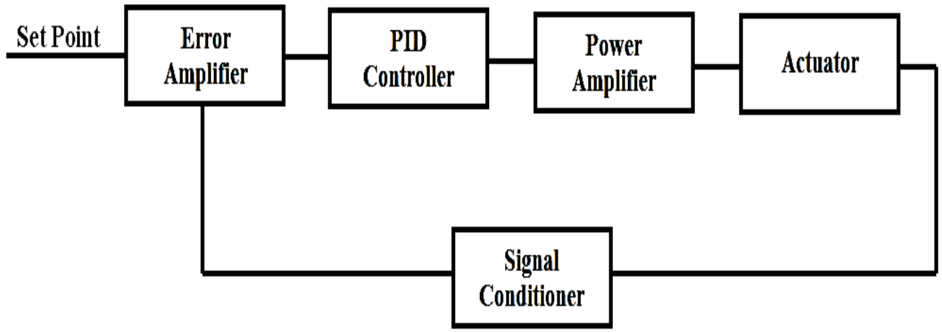


Figure 12.13

11. Power the circuit and check that the voltage supplied to the power supply is 24+ 24V AC.
12. Starting from ambient temperature, adjust the Set-Point knob in order to increase the temperature of the oven in 10ºC steps (i.e. bring the voltage on jack 2 to a value which corresponds to the ambient temperature, then increase this voltage by a quantity which corresponds to a 10oC temperature increase). Measure the output voltage of the signal conditioner as soon as the temperature is stabilized. The reference temperature is given by a precision mercury thermometer (Centigrade scale).

13. N.B. Be careful to avoid exceeding the maximum temperature that the transducer can withstand (175ºC). For safety, do not exceed 150ºC. Write your results in table 5.1.
14. Make a table listing the values measured and use these measurements to plot a graph with the temperature on the x-axis and the output voltage of the transducer on the y-axis.
15. Study the linearity of the transducer following the steps described in pages 39 and 40 of this manual.

Table 12.1

T (C)	Vout (V)

- **Characteristics of the NTC Thermistor**

It is required to determine the characteristic curve of the NTC thermistor with the respective signal conditioner, and transferring it into a Cartesian coordinate system.

Procedure:

1. Prearrange the equipment as it has been described in the exercise 3.1, and replace the signal conditioner for STT with the signal conditioner for NTC thermistors.
2. Starting from the ambient temperature increase the temperature in the oven turning the Set-Point knob by steps of 10ºC (i.e.: lead the voltage across the jack 2 to a value corresponding to the ambient temperature; then increase of a quantity corresponding to a temperature variation of 10ºC) and measure the output voltage of the signal conditioner as soon as temperature has stabilized. When exceeding the temperature of 110ºC, remove the NTC thermistor from its own seat not to damage. The reference measurements are carried out with mercury thermometer.
3. Arrange a Voltage vs. Temperature table (use table 5.2) and plot the characteristic curve on a chart.
4. Study the linearity of the transducer following the steps described in pages 39 and 40 of this manual.

Table 12.2

T (C°)	**V_{out}(V)**

- **Characteristics of the thermoresistance**

The purpose of this exercise is to plot the characteristic curve of a thermoresistance (with the relative signal conditioner).

Procedure:

1. Set up the apparatus as described in paragraph 3.1, replacing the signal conditioner for the PTC thermistor with the signal conditioner for the thermoresistance.
2. Starting from ambient temperature, adjust the Set-Point Knob to increase the temperature of the oven in 10ºC steps (i ,e. bring the voltage on jack 2 to a value which correspond to ambient temperature, then increase this voltage by a quantity which corresponds to a 10ºC temperature increase). Measure the output voltage of the signal conditioner when the temperature is stabilized. If the temperature exceeds 150ºC, remove the semiconductor transducer in order to avoid the possibility of damage.
3. The reference temperature is given by a precision mercury thermometer (Centigrade scale)
4. Arrange a Voltage vs. Temperature table (use table 5.3) and plot the characteristic curve on a chart.

5. Study the linearity of the transducer following the steps described in pages 39 and 40 of this manual.

Table 12.3

T (C°)	V_{out}(V)

- **Characteristics of the Thermocouple**

The purpose of this experiment is to plot the characteristic curve of a J- type thermocouple (with the relative signal conditioner)

Procedure:

1. Set up the apparatus as described in the previous experiments, replacing the signal conditioner for the thermoresistance with the signal conditioner for the thermocouple.
2. Starting from ambient temperature, adjust the Set-Point knob in order to increase the temperature of the oven in 10º steps (i,e. bring the voltage on jack 2 to a value which corresponds to ambient temperature, then increase this voltage by a quantity which corresponds to a 10ºC temperature increase). Measure the output voltage of the signal conditioner as soon as the temperature is stabilized. If the temperature exceeds 150ºC, remove the semiconductor transducer in order to avoid the possibility of damage. The reference temperature is given by a precision mercury thermometer (Centigrade scale).
3. Arrange a Voltage vs. Temperature table (use table 5.4) and plot the characteristic curve on a chart.

4. Study the linearity of the transducer following the steps described in pages 39 and 40 of this manual.

Table 12.4

T (C°)	**V_{out}(V)**

- **Determining the time constant of temperature transducers**

In this experiment, it is required to determine the time constant of the transducer's temperature. This is necessary for the subsequent study of automatic process control systems.

Not that, in reality, this experiment determines the time constant of the transducer and signal conditioner together. However, as the time constant of the signal conditioner is extremely small in relation to that of the transducer, the measured constant will be, for all practical purposes, the time constant of the transducer.

Start with the semiconductor transducer, and then repeat the experiment for the thermoresistance and the thermocouple.

Procedure:

1. Set up the apparatus as described in paragraph 3.3 for the experiment with the thermoresistance.
2. The purpose is to create a closed-loop control system using the thermoresistance, and then to measure the response speed of the silicon transducer by moving it from an area in

which the temperature is known and stable into an oven, For the moment, remove the silicon transducer from its well so that it remains at ambient temperature.

3. Adjust the Set- point to a temperature of 100ºC ,
4. Measure the output voltage of the thermoresistance signal conditioner while the temperature of the oven stabilizes at 100ºC
5. Connect the semiconductor transducer to the relative signal conditioner, prepare to measure the voltage on jack 23, and introduce the transducer into the oven.
6. Measure the temperature indicated by the transducer over a period of time, and compile a time, temperature table. (Use table 5.5)
7. Plot these values on a graph and determine the time required to bring the transducer to a temperature of 63 ºC (see fig. 5.14) This measurement delay is referred to as the time constant of the transducer.
8. Repeat this experiment with the other types of transducers. The closed –loop circuit should use a transducer which is different from the type whose response time is being determined.

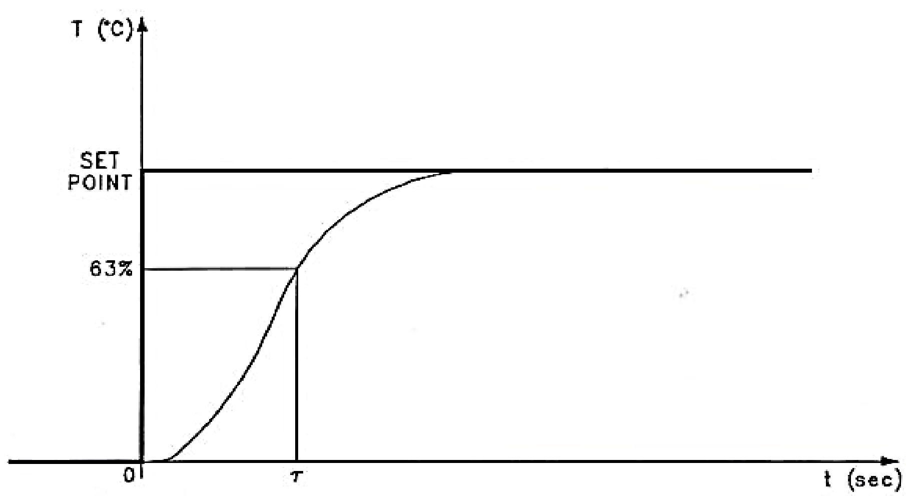


Figure 12.14

Table 12.5

Time (s)	Semiconductor Transducer	Thermoresistance Transducer	Thermocouple Transducer
0			
5			
10			
15			
20			
25			
30			
35			
40			
45			
50			
55			
60			
65			
70			
75			
80			
85			
90			
95			
100			
105			
110			
115			
120			
125			
130			
135			
140			
145			
160			
165			
170			
175			
180			
185			
190			
195			
200			

- **Characteristics of the temperature process**

Procedure:

1. Power the logic section of module G34/EV (±12V)
2. Connect the SET-POINT output (jack 2) to the input of the POWER AMPLIFIER block (jack 11).
3. Connect the HEATER and COOLER outputs of the POWER AMPLIFIER block to the corresponding inputs on the TY 34/ EV.
4. Adjust the Set-point potentiometer to the maximum setting (+8V)
5. Connect the power supply (2x24V AC).
6. Fill in table 5.6.
7. For the sake of simplicity, it is assumed that the thermal constant of the thermometer is negligible with respect to the thermal constants of the transducers, and that the thermal characteristic measured for the process may therefore be considered as a real time value.
8. Plot the time (in minutes) and the temperature (oC) on a graph.
9. Draw a curve which best approximates the plotted values and determine the rise time of the process.
10. Adjust the Set-point suddenly to zero, and set the switch on the COOLER POWER AMPLIFIER to MAN. (Manual cooling). Continue filling Table 5.6
11. Plot the time (in minutes) and temperature (oC) on a graph. This graph may be plotted as a continuation of the previous graph.
12. Draw a curve which best approximates the plotted values and determine the descent time of the process.

Table 12.6

	Heating	Cooling
Time (min.)	Temperature (℃)	Temperature (℃)
0.0		
0.5		
1.0		
1.5		
2.0		
2.5		
3.0		
3.5		
4.0		
4.5		
5.0		

Part V

Electrical Actuator

Experiment # 13

Pulse Width Modulation Speed Regulator of DC Motor

This experiment is an example of the application of PWM techniques in the control of separate-excitation DC motor. As well as the PWM amplifier, the experiment includes a closed-loop control system for control of both speed and current. The motor is fitted with an adjustable mechanical brake, which facilitates the execution of tests and experiments under various load conditions.

Section A: Pulse Width Modulation (PWM)

The major reason for using pulse width modulation in DC motor control is to avoid the excessive heat dissipation in linear power amplifiers. The heat dissipation problem often results in large heat sinks and sometimes forced cooling. PWM amplifiers greatly reduce this problem because of their much higher power conversion efficiency. Moreover the input signal to the PWM driver may be directly derived from any digital system without the need for any D/A converters.

PWM regulator:

In PWM regulators, power control is carried out by a transistor which operates as a switch at a suitably high frequency as seen in Figure 13.1. The power is regulated by varying the ON and OFF time of the transistor.

V_a

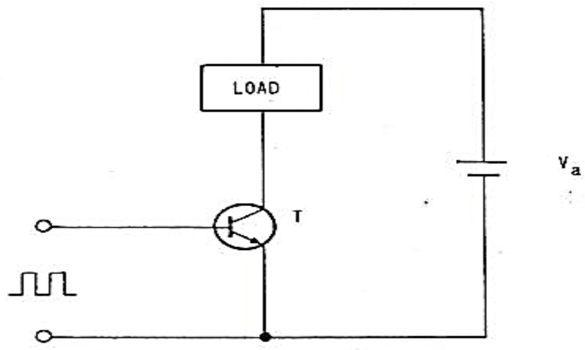


Figure 13.1 Power Control circuit

The power transistor therefore operates in saturation or in cut-off; the dissipated power will thus be very little. In this type of operation, the transistor can be shown as a switch which is closed or opened at a fixed frequency as seen in Figure 13.2

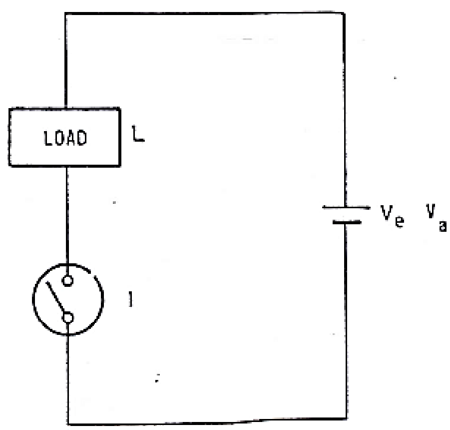


Figure 13.2 Transistor Act as a Switch at a Fixed Frequency

The load L will be powered by the entire voltage V_a for the time period T_{on} during which I is closed, while it will not be powered for time period T_{off} ; the sum of T_{on} and T_{off} is equal to the period of the square driver wave. The power supplied to load L is proportional to the ratio T_{on}/T_{off}. This ratio is the ***duty cycle*** which gives:

$$\boldsymbol{P_u = \frac{T_{on}}{T} \cdot P_{max}}$$

Where: duty cycle = $\boldsymbol{\frac{T_{on}}{T}}$, $\boldsymbol{P_{max}}$ is the power absorbed by the load if it is powered at a voltage V_a

Voltage and current in PWM systems

In the case of a pure resistive load (RL), measurement of a voltage at the load terminals using average value and effective value voltmeters will give two different results. If the duty-cycle is referred to as D.C

$$\boldsymbol{D.C.} = \frac{T_{on}}{T} = \frac{P_u}{P_{max}} = \frac{{V_{u\,eff}}^2}{R_L} * \frac{R_L}{{V_a}^2} = \frac{{V_{u\,eff}}^2}{{V_a}^2}$$

i.e.

$$V_{u\,eff} = V_a * \sqrt{D.C.}$$

And since :

$$V_m = V_a\, D.C.$$

Therefore

$$V_{u\,eff} = \frac{V_m}{\sqrt{D.C.}}$$

As D.C. is always < 1, the average voltage is lower than the effective voltage.

As the load is resistive, the same considerations also apply to the current. The power on the load (expect the losses) can also be measured using a standard voltmeter and ammeter. Connected as shown in Figure 13.3

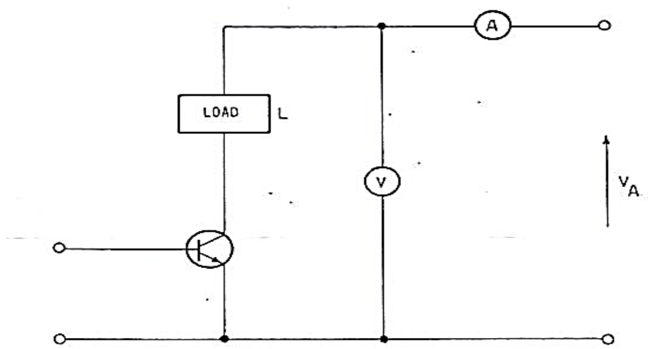


Figure 13.3 Power on the load measurement

This gives: $P_u = \frac{T_{on}}{T} \cdot P_{max} = V_a \cdot I_a \frac{T_{on}}{T} = V_a\, I_m$

The students are expected to carry out the PWM circuit on an external breadboard

Section B: Separately- Excited DC motor

Transfer function of the DC motor

The block diagram of the DC permanent magnet motor is shown in Figure 13.4.

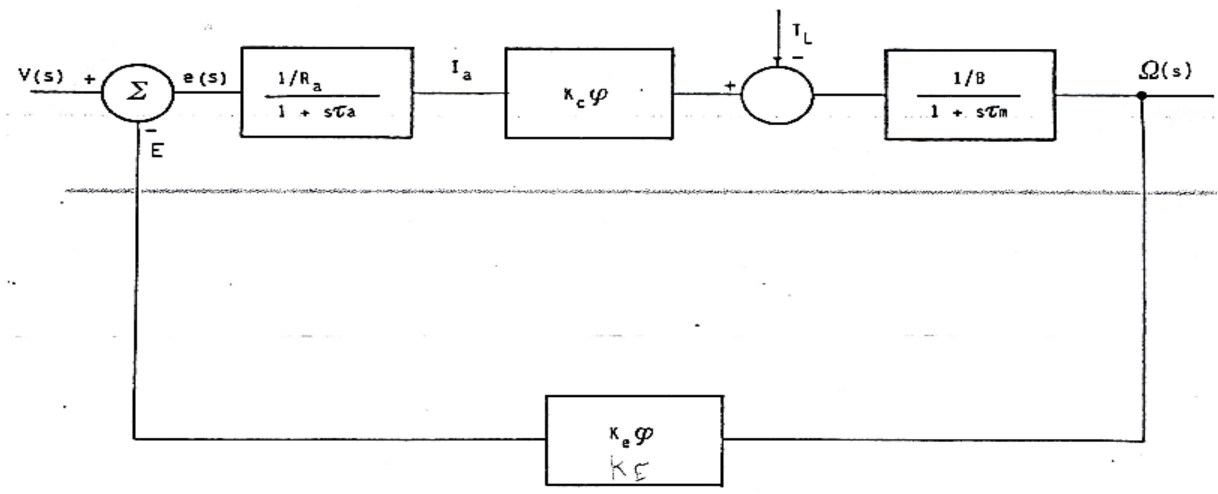


Figure 13.4 DC Motor Model

Where:
Ra : armature resistance
E(s): armature e.m.f (electromotive force)
Va (s): armature voltage
KE: voltage constant
KT: torque constant
Ta: electrical time constant
τm : mechanical time constant
The characteristics of the DC motor used in the apparatus, according to the manufacture

Torque constant KT	0.06 N.m/A
Rotor resistance (Ra)	8 Ω
Rotor inductance (La)	7.6 mH
Rotor inertia (J)	350 . 10-7 m2/Kg
Mechanical time constant (τm)	0.17

The students are expected to derive the equations that yield to the model shown in fig 13.4

Related formula:

$\tau_a = \frac{L_a}{R_a}$; L_a: armature inductance.

$\tau_a = \frac{J}{B}$; J; Inertia of the rotor

From the block diagram shown in figure 13.4, find the transfer function of the motor

$$\boldsymbol{G_m}(\mathbf{s}) = \frac{\boldsymbol{\Omega}\ (\boldsymbol{s})}{\boldsymbol{V_a}\ (\boldsymbol{s})};\ \text{assume that } T_L = 0 \text{ and } K_T = K_E$$

Find Ω(s) as a function of I(s), then find the transfer function. We do that because the speed transducer in our system depends on the absorbed current by the motor

$$G_m(s) = \frac{I_a\ (s)}{V_a(s)}$$

Speed Transducer

The speed transducer circuit for the system is shown in figure 7.5 and is based on the principle that the armature e.m.f in a separate excitation motor is proportional to the angular velocity.

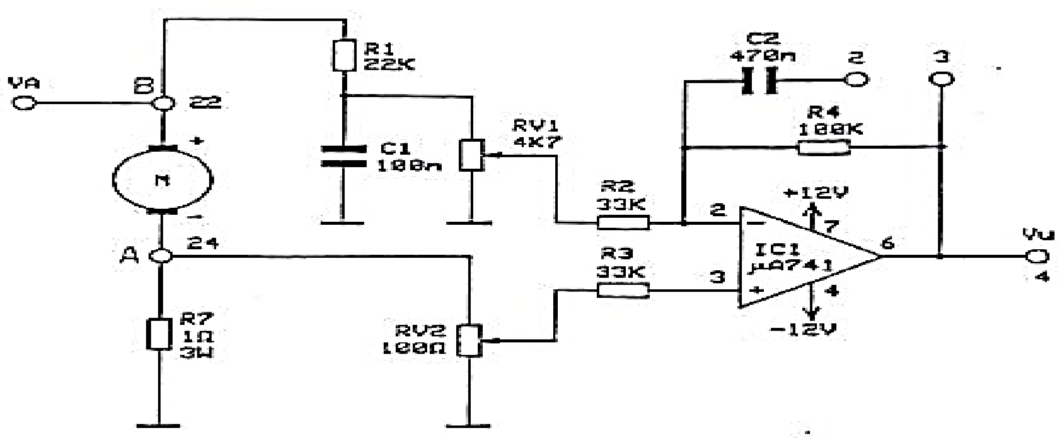


Figure 13.5 Speed Transducer

Control circuit for DC motor

The simplest control system is the open-loop circuit shown in Figure 13.6.

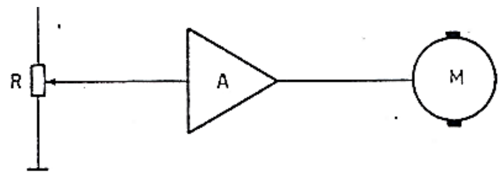


Figure 13.6 Open-loop control circuit for DC motor

The armature voltage, and therefore the motor speed, is adjusted by potentiometer R through power amplifier A. Generally, control is based on the calibration of R into speed values, so that each position of R corresponds to a given speed. There is no way of checking whether the speed set using R will remain constant as the load and power supply change.

In the closed-loop control systems, a regulation circuits compares the set speed and the actual speed. The error signal ε, suitably amplified, controls the circuit which drives the motor. See Figure 13.7.

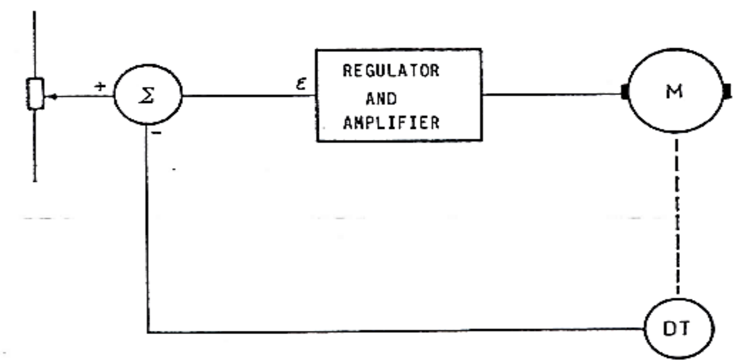


Figure 13.7 Closed-loop Control Circuit for DC motor

Exercises:

i. Measurement Of The Open Loop Speed:

1. Connect point 1 to 18 and 22 to 23
2. Connect all necessary supplies to the module.

3. Switch the power supply.

4. Connect the voltmeter between terminal 1 and ground and change the value of setpoint from 1-8 volt.

5. Use multimeter to take the value of the output voltage from transducer, after that use the relationship between voltage and speed to detect the speed of the motor.

6. Fill the result in Table 13.1

Table 13.1

Set Point (Volt)	V_{out} (volt)	Speed (RPM)
1		
2		
3		
4		
5		
6		
7		
8		

ii. Voltage Duty-Cycle Speed Curve Of The PWM Regulator:

1. Connect point 1 to 18 and 22 to 23.

2. Connect the oscilloscope to the output of the PWM regulator (point 20).

3. Switch on the power supply.

4. Connect the voltmeter between point 18 and ground and measure the voltage of the PWM regulator (V_{in}).

5. Vary P1 from zero to +8v.

Carry out the measurements in order to complete the Table 13.2.

6. Measure the signal duty-cycle using the oscilloscope

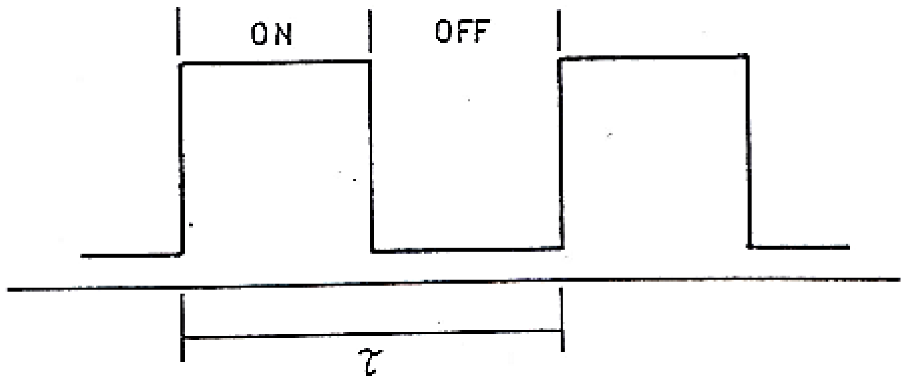


Table 7.2

V_{in}	Duty Cycle (μs)		Speed (RPM)
	On	Off	
			500
			1000
			1500
			2000
			2500
			3000
			3500

iii. Measurement Of The Closed Loop Speed:

1. Connect the instrument to the terminals on the panel and connect between terminal 22 and 23.
2. Carry out the block diagram of the figure (7.8)

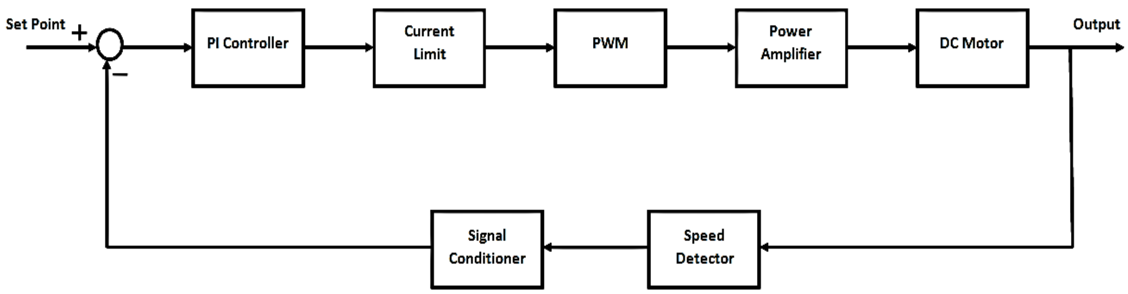


Figure 13.8 Closed Loop System

3. Switch on the power supply.

4. Change the value of the setpoint as shown in table 3 by the knob, and use the multimeter to check the value.

5. Use multimeter to take the value of the output voltage from transducer, after that use the relationship between voltage and speed to detect the speed of the motor.

6. Fill the result in Table 13.3.

7. Measure the speed of the motor from the relationship between volt and speed (0-8) volt →(0 – 3500) rpm.

8. Compare between closed-loop and open-loop system.

Table 7.3

Set Point (volt)	Output Voltage (volt)	Speed (rpm)
1		
2		
3		
4		
5		
6		
7		
8		

Experiment # 14

Angular Position, Speed Transducing And Control of DC motor

Section A: Speed Transducers

The strong motorization of industrial machines, have determined the parallel development of angular speed transducers. The international unit of measurement for angular speed is the radian per second (rad/s, but the use of the revolution per minute (RPM) is also available, where one revolution corresponds to any 2.n radian.

The most used transducers for this variable are the following:

- Tacho-generators
- A.C. Tacho-generators
- Digital Transducers

The main difference between the first couple is in the supplied waveform, which is continuous in the first type and alternating in the second, both with amplitude variable with speed. The A.C. tacho-generator has no commutator and therefore it requires less maintenance. However, it has strong defect for it needs a rectifier/ leveller unit at the output. This is the reason why tacho-generator is the most used in industry.

As far as concerning with digital transducers, they are considered very simple and economic to construct from one hand and they can give very precise output from other hand. In contrast, they supply a pulse output (ON/OFF type) which cannot be directly used in closed-loop analog control system and consequently it requires signal conditioners which can be quite complex.

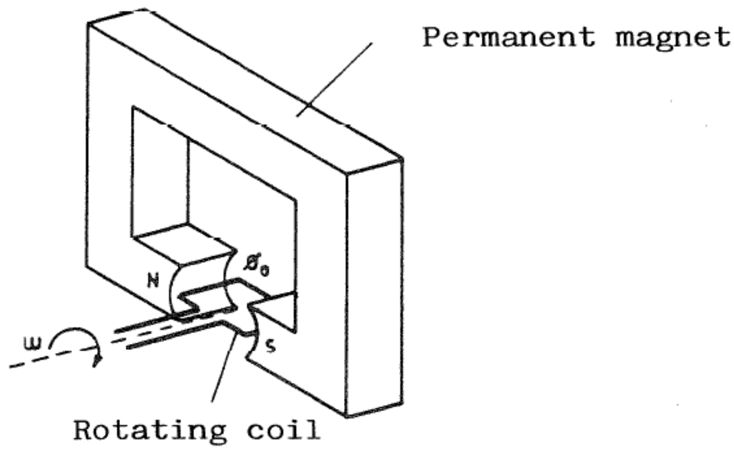
In case of DC electric motors, the armature feedback of the same motor is often used as the counter electromotive force developed is directly proportional to the rotating speed.

Parts and Components of DC Angular Velocity Control Experiment

- **Module G36A/EV.**

  This Module consisting of:

i) **Tacho-generator**



As shown with the accompanying figure, the magnetic field is created by U-type permanent magnet whose polar expansions face each other's.

In order to understand its operation, let's consider a coil with angular speed rotation = ω. This coil is influenced by a flow variable according to the following relation: $\theta = \theta_o \cdot \cos(\omega.t)$ and hence, the voltage across the coil is: $e = \theta_o\, \omega \sin(\omega t)$ whose max. value is proportional to the angular speed.

In fact, a tacho-generator consists of a stator, on which a permanent magnet is inserted and of a rotor, on which N turns are wound, spaced among each other by an angle of 2π/N. The N turns are connected to a commutator and the induced sine voltage is separated by two brushes for a time of 2π/N ω. Figure 14.1 represents two shapes of the output voltage at angular variations. Note that the amplitude as well as the ripple is functions of ω.

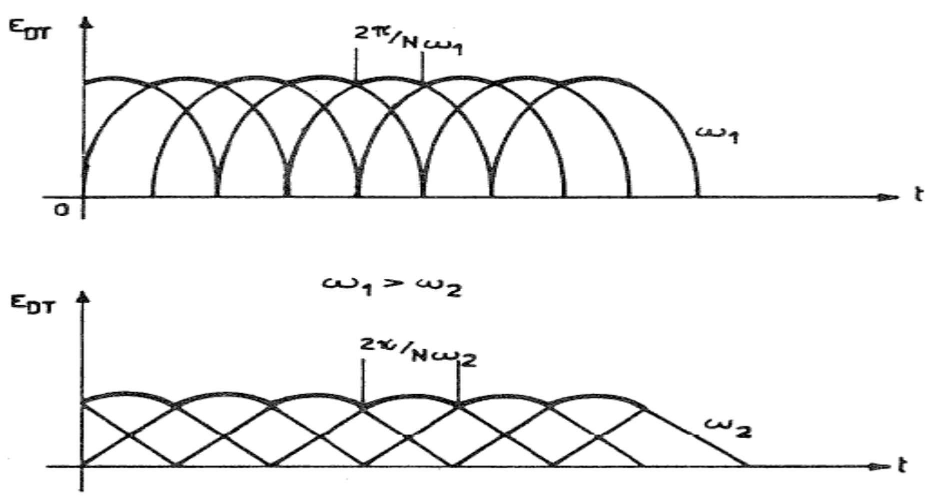


Figure 14.1 Output voltage of tacho-generator at different speed

An A.C. component, with frequency proportional to ω and amplitude inversely proportional to Nω, is generated together with D.C. component (proportional to ω). This A.C. component is an error, called ripple, which is usually very small in respect to the output voltage. Due to the commutation, a set of pulses with frequency slightly superior to the ripple overlap the induced voltage. The noise can be eliminated with a low-pass filter, but the same cannot be said as far as concerns the ripple.

The fundamental parameter of a tacho-generator is the "tacho-constant", which gives the relation among the output voltage and the rotation speed: this is measured in volt (rad. s^{-1}).

It is expressed by the relation: $K_T = E_{DT} / \omega a$. The tacho constant is often expressed with V/rpm. The relation among the two tacho constants is the following:

K_T [V/ rad. s^{-1}] = (2 Π /60) .K_T [V/rpm]

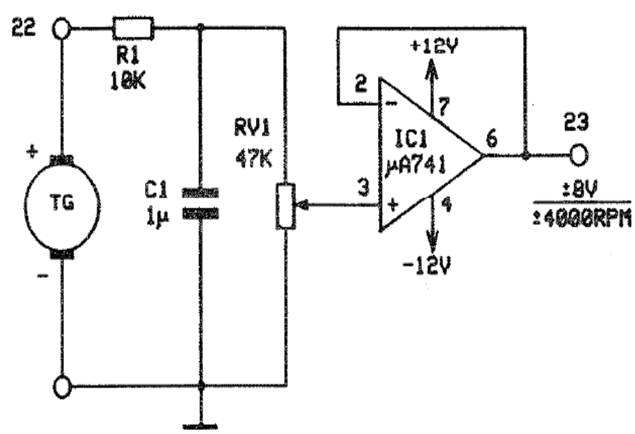
The precision is more accurate the less current is circulating; for a relation = 100 among load impedance and inner impedance, the precision is ±0.5%. In this experiment, the characteristics of the utilized tacho generator are:

- No. of poles : 2
- Tacho constant : 3 mV/rpm
- Max. current : 30 mA

ii) Signal Conditioner for Tacho-generator

The tacho-generator can supply a D.C. output voltage proportional to the angular speed with no help from any external component. However, in order to be adapted to the other modules and to ease measurements, the tacho-generator is supplied with its own signal conditioner, whose diagram is shown below.

The output voltage from the tacho-generator can be measured directly between terminal 22 and



the ground without the help of signal conditioner.

Rl and RV1 form a resistive separator for the tacho-generator output signal while the condenser C1 operates a filtration to reduce the influence of the residual ripple.

Note that the trimmer RV1 is activated by the switch fitted in the lower side of the Tacho-Gen Conditioner block.

Care must be taken not to load the tacho-generator too much, it will cause variations on the tacho constant: which is why the output signal of the signal conditioner has been buffered. The buffer has been carried out by means of an operational amplifier connected as voltage detector.

iii) Armature Feedback

Consider the following relation which gives N = rotation speed (rpm) of a DC motor as function of $\boldsymbol{V_a}$ = voltage armature, of $\boldsymbol{I_a}$ = armature current, of $\boldsymbol{R_a}$ = armature resistance and of Kθ = magnetic constant:

$$N = \frac{\boldsymbol{E}}{\mathbf{k}\,\boldsymbol{\Phi}} = \frac{\boldsymbol{V_a} - \boldsymbol{R_a} \cdot \boldsymbol{I_a}}{\mathbf{k}\,\boldsymbol{\Phi}}$$

where $\boldsymbol{E}$ is the electromotive force.

If Kϕ is kept constant (as obtained in D.C. motor speed controls acting only on the armature current =Ia) we must get Ra.Ia and subtract it from the Va, in order to determine N. These operations are performed by the signal conditioner for armature feedback which, in module G36/EV, is fitted in the block called SPEED DETECTOR.

iv) Signal Conditioner for Armature Reaction

It is generally easy to carry out a circuit with the above mentioned operations; the circuit of Figure 14.2 can be used, reporting the electrical diagram of the components contained on in the block SPEED DETECTOR. This block consists of two operational amplifiers (IC1A and IC1B). IC1A is used in the classical differential configurations the output voltage is equal to the difference among the input signals (called A and B and taken across the motor) multiplied by the ratio R4/R1. The two condensers C1 and C2 are used to filter the input signals and have an output signal proportional to the mean voltage present across the motor.

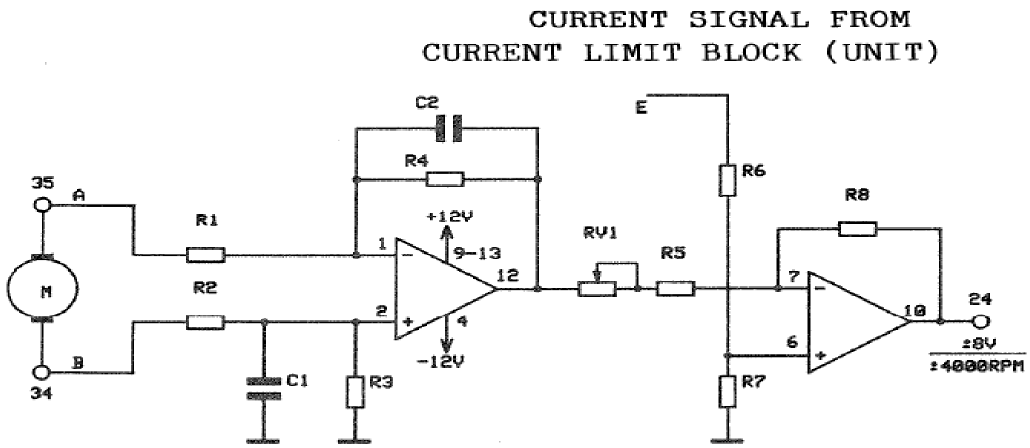


Figure 14.2 Signal Conditioner for Armature Reaction

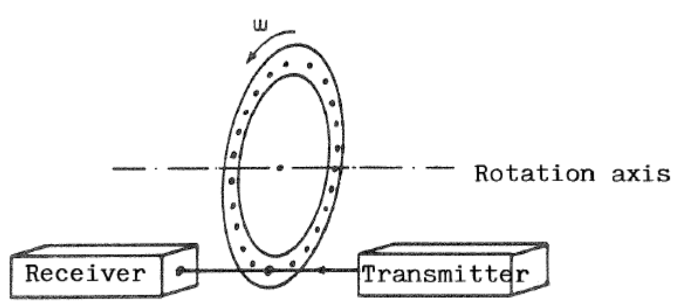
The second operational amplifier, IC1B, is connected to the differential configuration, too; a signal (signal E coming from CURRENT LIMIT), which is the current value of the motor and which is subtracted from the output signal of IC1A, is applied to the non-inverting signal. With the potentiometer RV1, it is possible to change the gain of IC21B in a way that a fixed voltage corresponds to each angular speed.

v) Digital Speed Transducers

This definition includes all transducers that generate pulse outputs that relates frequency variable with speed. Pulses are usually sent to counters which, if the measurement in carried out in a due time, give the value of speed directly in rpm. Photoelectric transducers, based on masked or perforated disc systems or on reflection systems, are the most popular digital speed transducers.

The first type essentially consists in a disc, which is made to rotate on the axis of which we must know the angular speed as shown in the accompanying Figure.

The disc rotation produces a shuttering effect on the track

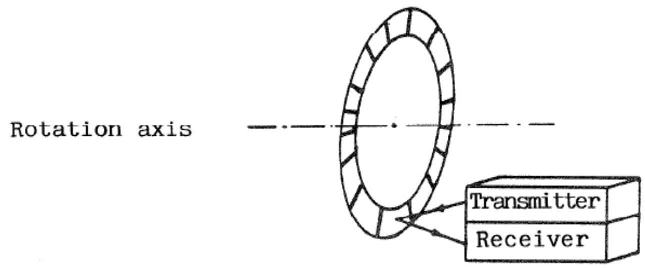


of the light source to the light sensor, so that there is a pulse corresponding to each hole or to each section.

However, to increase the accuracy of the measured physical value, particularly at low speed, it is required to increase the number of holes (or of the sections).

The reflection photoelectric transducer uses a transmitter and a receiver in the same container, instead of a projector and a receiver separately as shown in the second Figure.

A mask with reflecting and opaque segments is used instead of the perforated disc.



When the light emitted from the transmitter tracks a reflecting surface is sent back to the receiver as shown in the attached Figure. The advantage of using this system is that it is sufficient to apply reflecting masks on the moving part, instead of using a special disc.

Module G36A/EV uses a transparent disc on which 30 not transparent black zones are applied. The used emitter/phototransistor diode operates in the infrared range.

vi) Signal Conditioner for Photoelectric Speed Transducer

Photoelectric speed transducers do not supply signals which can be directly inserted in a regulation analogue loop and do not give angular speed. In order to get this measurement, it is necessary to use a frequency/voltage converter, a frequency meter or a counter. In this case a frequency meter is used, as it can supply very accurate information. The measured error is ± 1 rpm on the mean angular speed calculated over the counting interval (2 s).

The electric diagram of the whole DIGITAL RPM METER block is as shown in Figure 14.3, where you can see that the component marked with OC1 contains the photodiode-phototransistor couple and generates the pulse signal proportional to the rotating speed. This signal is squared by an inverter and applied to the counter input.

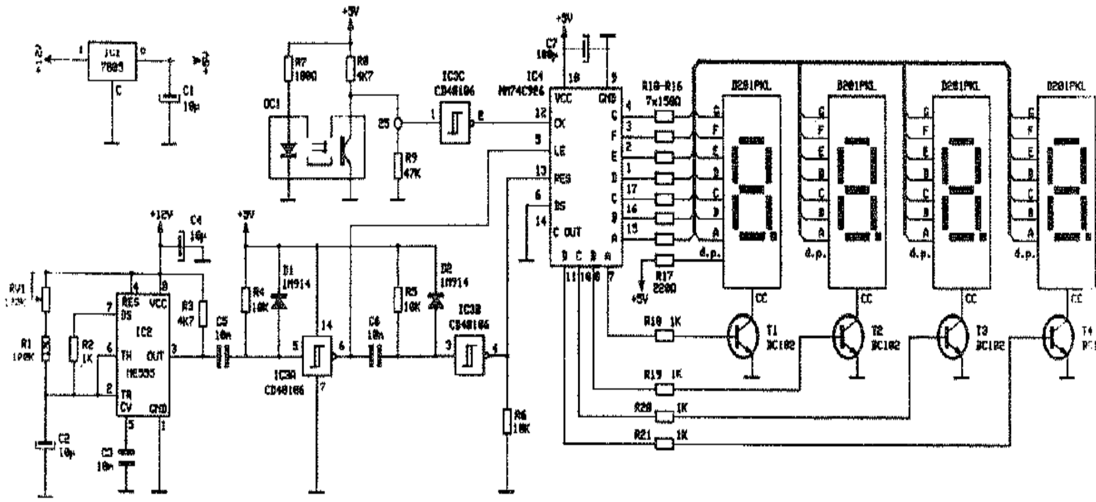


Figure 14.3 Digital Rpm Meter Electric Diagram

The integrated circuit 1C4 (MM74C926) is composed by a counter with 4 decimal ciphers followed by a register where the counter measurements can be stored. The outputs can control a 7-segment display and besides there are 4 signals to enable the display of the 7 segments.

IC2 is a timer supplying the time lapse of the pulse counting (2 seconds). At the end of this lapse, two signals are generated: the first is the LATCH ENABLE (LE) which enables the output data from the counter to be transferred to the output register and the second is the RESET (RES) which resets the counters. After resetting, the cycle starts again.

Section B: Position Transducers

The position transducers are used to detect the position of the movement of an object from a reference point. The movements can be linear or angular; consequently linear or angular transducers have been carried out according to the type of movement. Module G36A/EV analyses one of the most common angular position transducers: the potentiometric transducer.

Potentiometric Transducer

The potentiometric angular position transducer is at the same time very simple and accurate enough. It consists in a resistive potentiometer whose shaft is mechanically connected to the motor axis. The two terminals of the resistor which are the electrical part of the potentiometer are connected to the two reference voltages (± 8 V). Movements of the motor shaft make the position of the potentiometer cursor vary and consequently also its voltage value. The angular position of the cursor and consequently of the motor shaft can be detected from the voltage value obtained.

Signal Conditioner for Potentiometric Transducer

In this case, too, a signal conditioner must be used to obtain a signal fitting our needs. In this case the signal conditioner amplifies the signal of the potentiometer to obtain a voltage of -8V for a 0_o angle and a voltage of +8V for a 360_o angle. With reference to Figure 14.4, a voltage proportional to the position is applied to the non-inverting input of the operational amplifier by means of the potentiometric cursor.

R3 and C1 create a low-pass filter to erase disturbances connected to the movement of the same cursor. The amplifier is connected to the non-inverting configuration and so its gain G is:

G = 1 + (R2 + RV1) / R1 acting on the trimmer RV1, it is possible to obtain a voltage ±8 V for an angle of 0 - 360_o.

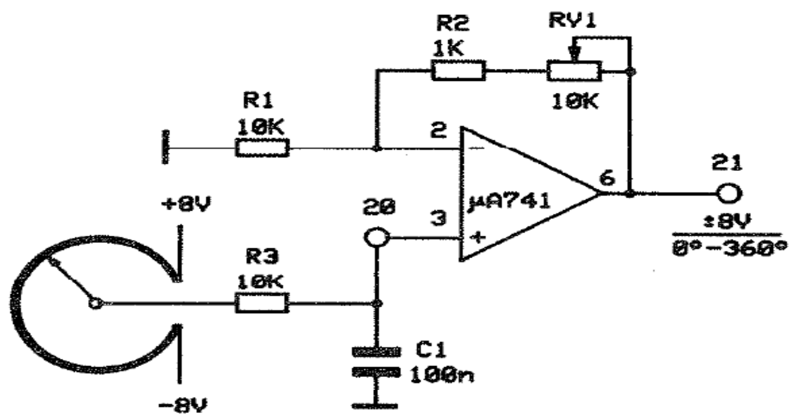


Figure 14.4 Signal Conditioner for Potentiometric Transducer

Section C: Angular Position and Speed Process

The angular position and speed process unit provided with module G36A/EV (Unit PY36A/EV) is shown in Figure 14.5. It consists of a permanent magnet and bidirectional D.C. motor with function of process actuator. There is a tacho-generator fitted on the motor shaft, and an alternating opaque and translucent disk, which, together with a U-shaped photo-coupler constitutes an incremental encoder. On the other side, a motoreducer which reduces the speed to a factor 50 is also mounted on the motor shaft: this means that a turn of the shaft toward the motoreducer is equal to 50 on the tacho-generator side. The shaft of the motoreducer controls the red pointer which is on the graduated scale.

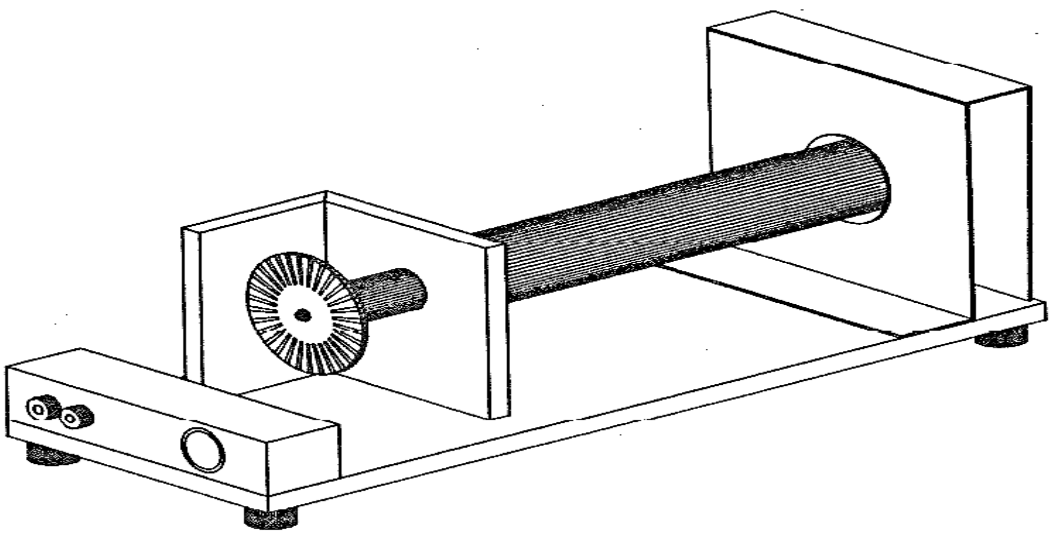


Figure 14.5 Angular Position and Speed Process

The position of the motoreducer shaft is transmitted to the potentiometer (which is the position transducer) through two gear wheels which ratio is 1:2.

So, the ±180° shifting of the motoreducer produces a ±90° shifting on the potentiometer.

The potentiometer has the characteristic of continuous rotation without damaging: this allows its connection during speed exercises where the motor rotates with continuity. In addition to that, the unit also consists of a mechanical brake (which can be controlled from the side knob) to apply variable loads to the motor.

The Range of The Angular Speed Process is:

- Range : -4000 - 4000 RPM
- The range of the angular position process is:
- Range : 0o- 3600o

Speed Control Process

The speed control process supplied with module G36A/EV is shown in the block diagram of Figure 14.6.

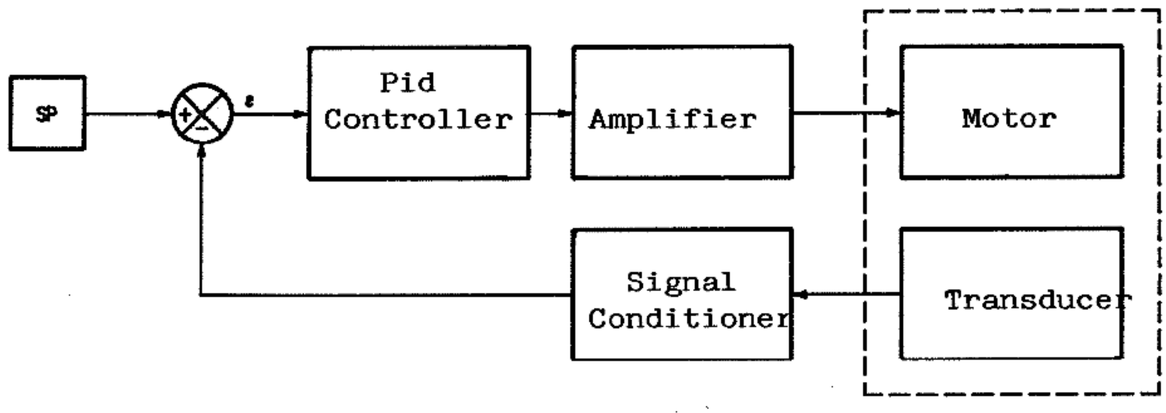


Figure 14.6 Speed Process Control Diagram

Parts and Components of speed control Experiment

- Set-Point: it is the block by which the desired output variable can be set
- The comparison block: it consists in the section ERROR AMPLIFIER and it compares the obtained output variable with the set input one.
- The controller: PID type which can be configured in different ways: the three actions (proportional, integrative and derivative) can be controlled and inserted separately.
- Power amplifier: it is an electric circuit which "doses the input electric power in order to give it to the actuator (electric motor)
- Speed transducer: it can be one of the three available transducers: tacho—generator, armature feedback and photoelectric detector.
- Current limit: its function is to limit the maximum current across the motor.

Control of the position process:

The position process control of the module G36A shown in the block diagram of Figure 14.7

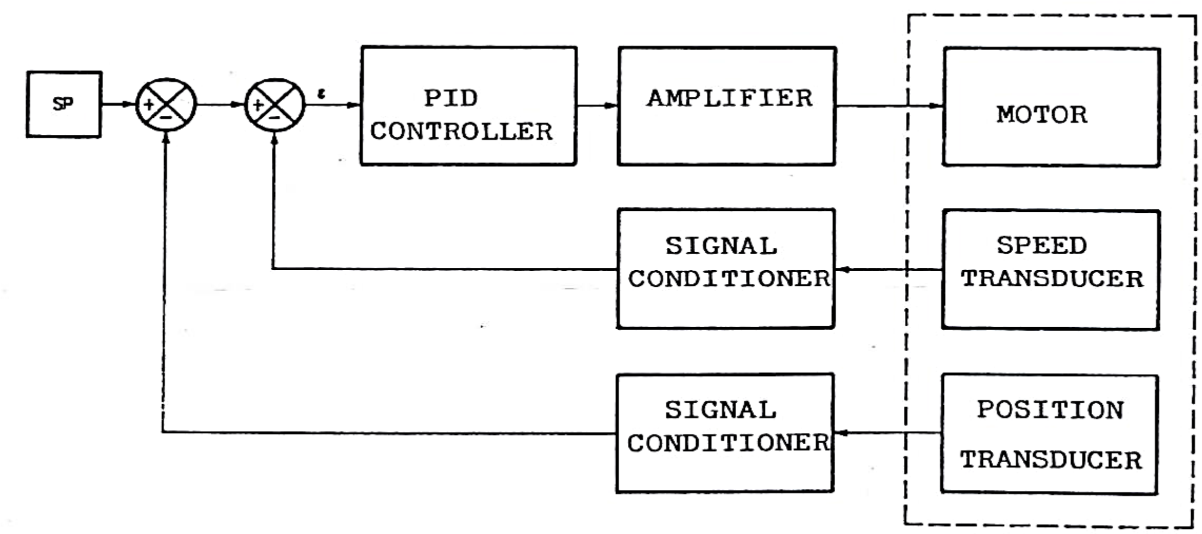


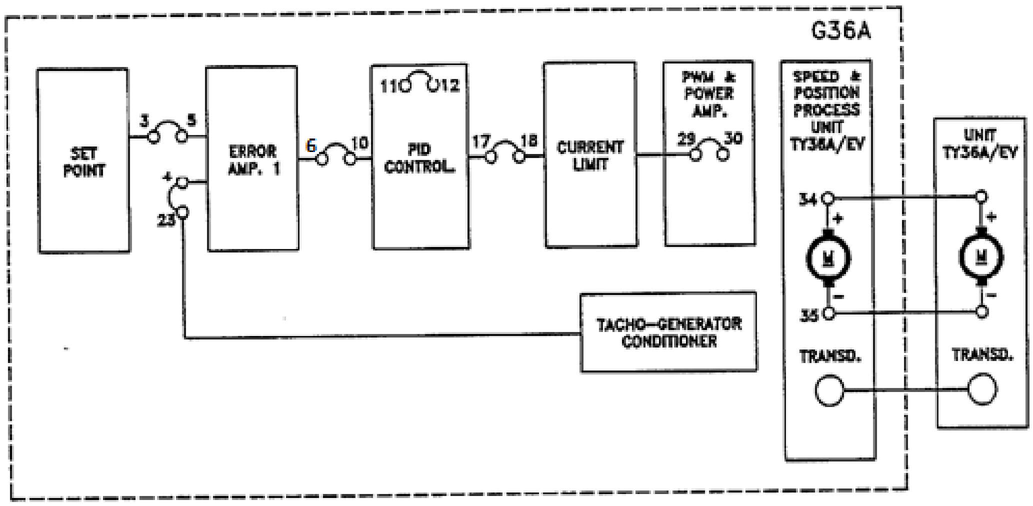
Figure 14.7 Speed Process Control Diagram

Exercises

- **Plotting Characteristic Curve for Tacho-generator**

  Procedures:

  1. Carry out the following circuit



2. On the PID CONTROLLER block, turn the PROPORTIONAL knob to the max. Value.
3. Connect all the necessary power lines to the module
4. Set the multimeter for DC voltage measurements and insert it between terminal 22 and ground.
5. Switch on the power supplies.
6. Turn the set-point knob completely clock-wise
7. Act on the knob of the TACHO-GEN CONDITIONER block until the display of the DIGITAL RPM METER reaches 4000 RPM
8. Acting on the Set-Point knob, set the speed values written on table 2.1, appearing on the 4-digit display of the photoelectric transducer (DIGITAL RPM METER).
9. With a multimeter, measure the voltage supplied by the tacho-generator across each of the set values.
10. Fill table 6.1 with the measured voltage values of the tacho-generator at each set speed.
11. Plot a Cartesian graph, where speed is on the x-axis and voltage is on the y-axis.
12. Plot the best fitting straight line and determine the tacho-generator linearity.
13. Repeat the above operations for Set-Point negative values, i.e. for the motor opposite rotating speed.

Table 6.1

RPM	Voltage
0	
500	
1000	
1500	
2000	
2500	
3000	
3500	

- **Plotting Characteristic Curve for DC Motor Armature Feedback**

Procedure:

1. Carry out the following circuit

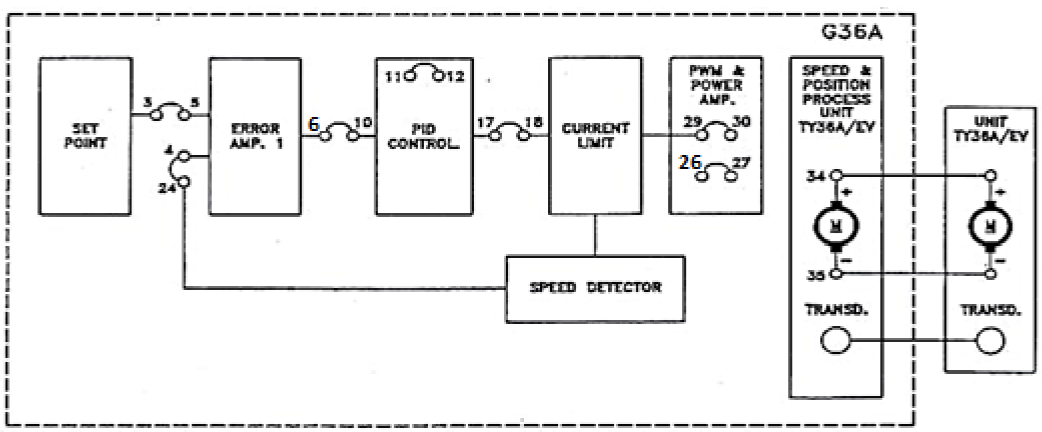


Figure 14.8

2. On the PID CONTROLLER block, turn the PROPORTIONAL knob to the max. value.

3. Connect all the necessary power lines to the module

4. Set the multimeter for DC voltage measurements and insert it between terminal 24 and ground.

5. Switch on the power supplies.

6. Act on the Set-Point knob to obtain the speed values written in table 1.2, and shown in the 4-digit display of the photoelectric transducer (DIGITAL RPM METER)

7. With a multimeter, measure the voltage supplied by the SPEED DETECTOR at each set values.

8. Fill table 6.2 with the measured voltage values of SPEED DETECTOR at each set speed.

9. Plot a Cartesian graph, where speed is on the x-axis and voltage is on the y-axis.

10. Plot the best fitting straight line and determine the armature feedback linearity.

11. Repeat the above operations for Set-Point negative values, i.e. for the motor opposite rotating speed.

Table 6.2

RPM	Voltage
0	
500	
1000	
1500	
2000	
2500	
3000	
3500	

- **Photoelectric Transducer Analysis**

  The purpose of this exercise is to analyze the signals supplied by the speed photoelectric transducer and signal conditioner.

  The following instruments are necessary for this exercise:

  - Oscilloscope
  - Digital frequency meter
  - Standard revolution counter

  Procedures:

  1. Carry out the diagram of Figure 6.12

  2. Connect one probe of the oscilloscope to terminal 25 of the signal conditioner for photoelectric transducer (DIGITAL RPM METER) and switch on the power supply.

3. Change the motor speed and observe the signal variations displayed on the oscilloscope.

4. Connect a frequency meter to terminal 25 and confront its indication (in Hz with 30 pulses per revolution) with the one supplied by the 4-digit display (in RPM): if there are differences it depends on the different time bases of the two frequency meters.

5. Determine the error of this transducer and of its signal generator with standard revolution counter.

- **Plotting of the Characteristic Curve of the Potentiometric Transducer**

1. Carry out the diagram of Figure 14.9

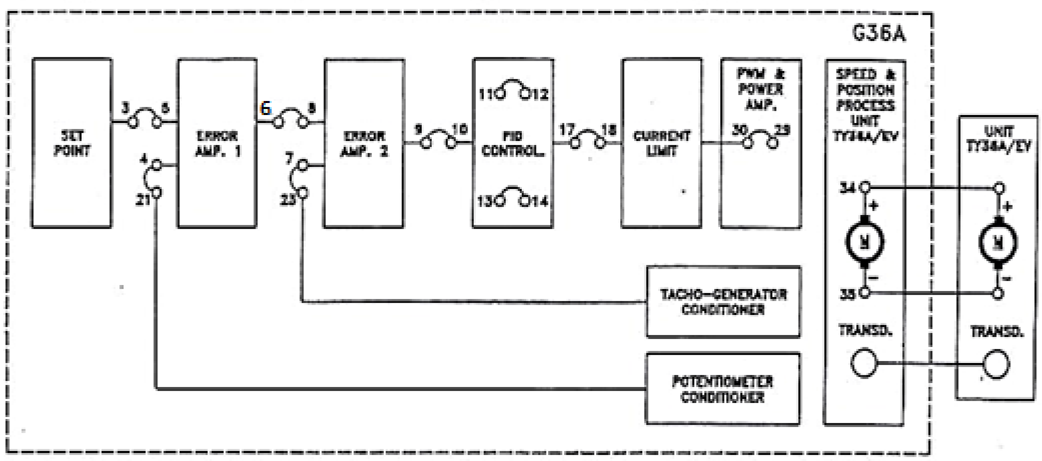


Figure 14.9

2. On the PID CONTROLLER block, turn the PROPORTIONAL and the INTEGRATIVE knobs to the maximum value.

3. Connect all the necessary supplies to the module

4. Set the multimeter for DC voltage measurements and insert it between terminal 21 and ground.

5. Switch the power supplies

6. Turn completely anti-clockwise the set-point knob

7. Acting on the Set-Point knob, set the angular position values shown in table 1.3 and displayed by the pointer indicator of unit TY36A/EV.

8. With a multimeter, measure the voltage supplied by the potentiometric transducer/signal conditioner unit and corresponding to each set value.

9. Fill table 6.3 with the output voltage values of the POTENTIOMETER CONDITIONER block corresponding to each set angular position.

10. Plot a Cartesian graph, where the position is on the X-axis and the voltages are on the Y-axis.

11. Write on the graph the points whose coordinates are on the table

12. Plot a curve which approximates this set of points at best; it will be the characteristic curve of the potentiometric transducer/ signal conditioner unit.

13. Plot the best fitting straight line and determine the potentiometric transducer linearity.

Table 6.3

Angular Position	**Voltage**
30	
60	
90	
120	
150	
180	
210	
240	
270	
300	
330	
360	

Experiment # 15

Stepper Motor

A stepping motor translates digital information into proportional mechanical movements. On other words, stepping motor is considered an electromechanical device whose shaft rotates at discrete steps. Its simplicity of use, due to the fact that it does not need feedback, precision and the positioning rapidity make stepper motor very common in the industry particularly for the following applications:

- Computer terminals such as printers, punch- readers, plotters, etc.
- Machine tools;
- Movie devices for transferring films and opening lens;
- Medical devices;
- Industrial automation (textile, pharmaceutical and electronic industries);
- Process controls;
- Office machines;
- Measure instruments.

The diffusion of stepping motors is linked to the fortune that digital and microprocessor controls have met in these last years.

Principle of Operation

Based on Figure 15.1, the position of the shaft of a stepping motor depends on the relation between number of stator, Poles and rotor. Since the rotor is a permanent magnet, its poles are fixed. On the contrary, the stator is constituted by several windings and its poles are determined by the current circulating into its windings.

By powering the windings one by one, a magnetic rotating field is created which is followed by the rotor. The rotation speed is determined by the speed which the windings are switched with, and by the rotation direction of the switching sequence.

There are two driving methods for stepping motors according to the way to reverse the current in their windings:

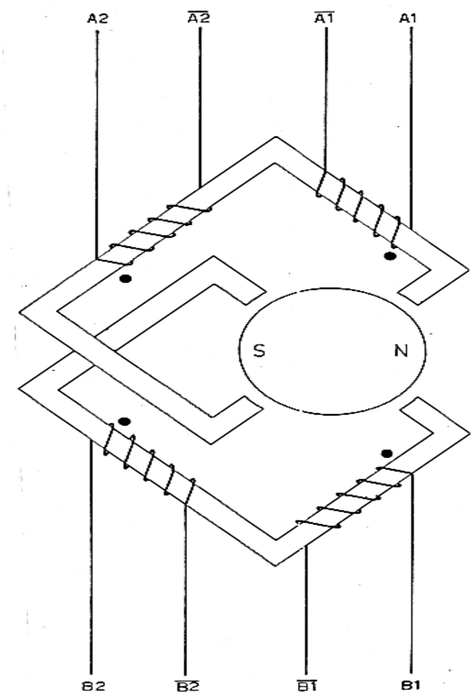


Figure 15.1 Stator, Poles And Rotor For General Stepper Motor

i) Unipolar Driving Method.

Referring to Figure 15.1, connect ends A1, A2, A3, A4, to the common point of a current generator and switch the current on the other ends according to the diagram of Figure 15.2.

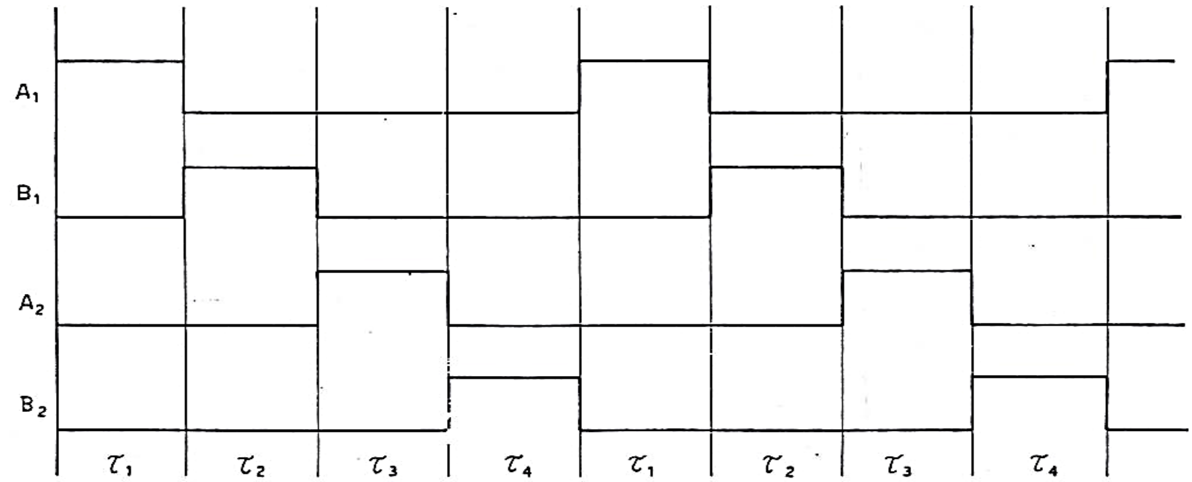


Figure 15.2 Time Interval for Driving the Unipolar Driving Method

Note that the sequence repeats each 4 time intervals. During these 4 intervals, the rotor positions are those of Figure 15.3.

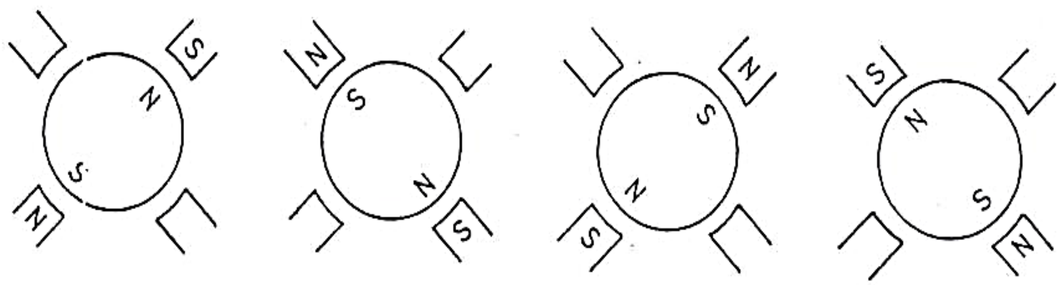


Figure 15.3 Rotor Position of the Unipolar Driving Method

Note that the rotor fully rotates every 4 intervals; this is how wave unipolar driven. The term unipolar however refers to the fact that current crosses the windings in one direction only. However, Figure 15.4 shows a 2- phase driving.

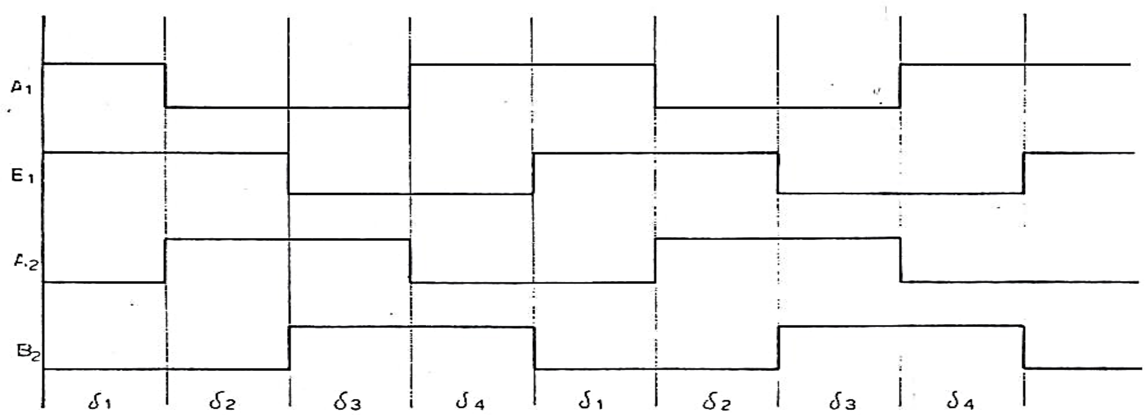


Figure 15.4 2-Phase Driving Of the Stepper Motor

Even here the rotor rotation defines in 4 steps (see Figure 15.5).

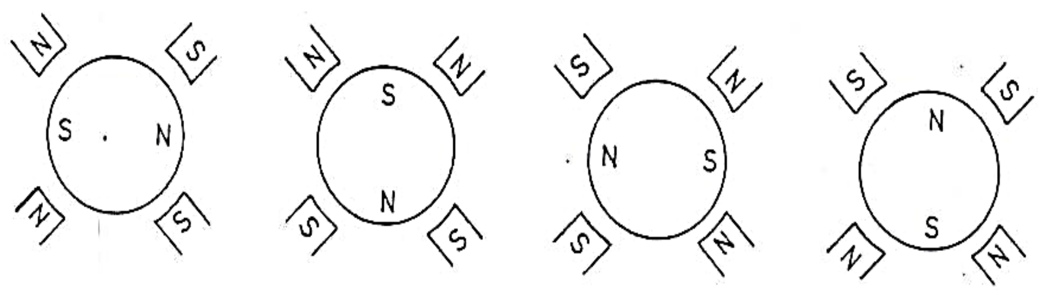


Figure 15.5 4-Steps Rotor Rotation

With respect to the previous case, per each interval, 2 windings are interested and then the torque is increased, and consequently the dissipated power increased. If the windings of the stepping motor are powered according to the sequence of the wave driving, after each step, which is after each passage from a balancing position to the other, rotor and stator poles are aligned.

On the contrary, in the 2- phase driving, rotor poles set between the two poles of the stator. Therefore, alternating the two driving system, we have the half-step operation as shown in Figure 15.6.

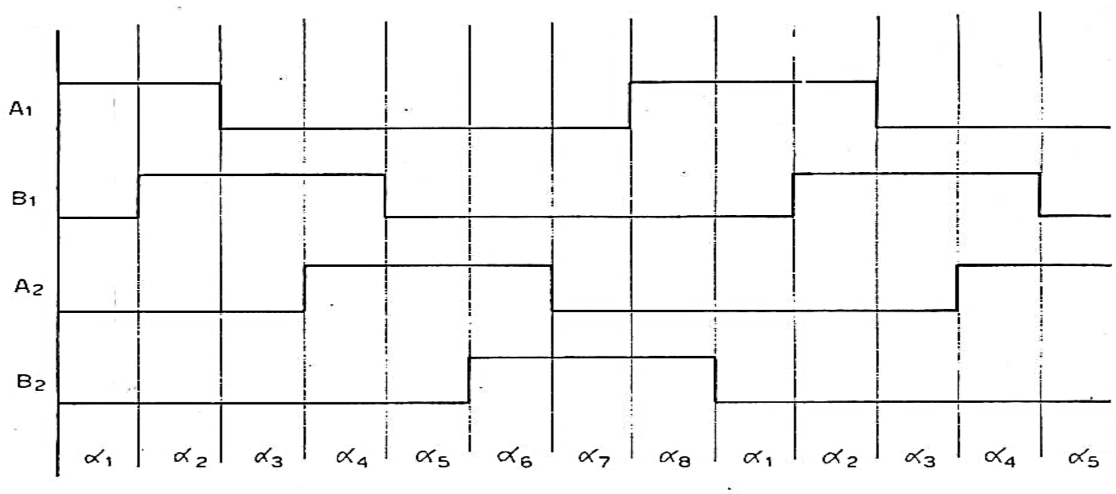


Figure 15.6 Half-Step Operation For 2- Phase Driving

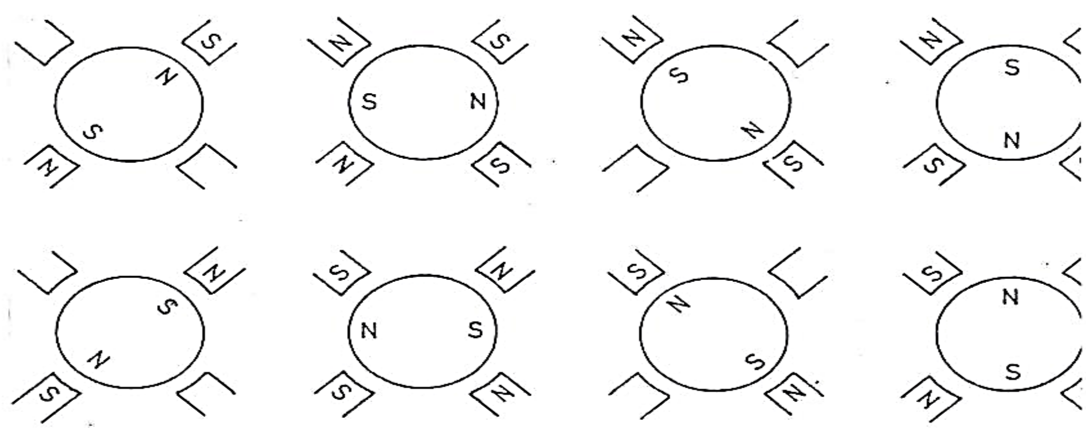


Figure 15.7 Rotor Balancing Positions.

ii) Bipolar Driving Method.

Using the 2-phase driving, operation characteristics are improved with respect to those of a wave operation because two windings on four, instead of one four are interested at the same time.

A further improvement is obtained interesting all four windings. This is possible with a bipolar driving which sends alliteratively current in the two winding directions. Figure 15.8 shows the current diagram for a 2-phase bipolar driving.

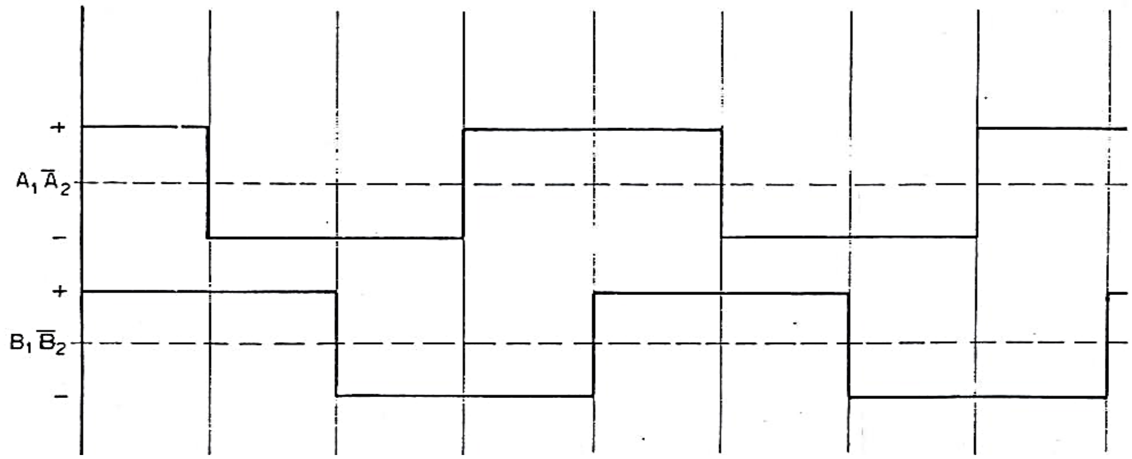


Figure 15.8 2-phase bipolar driving.

Connect the circuit as per Figure 15.9.

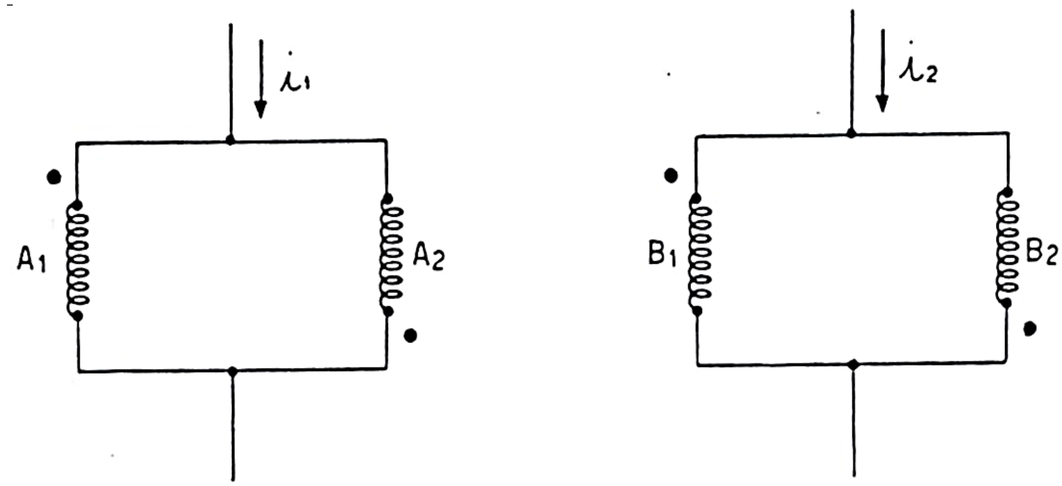


Figure 15.9

Figure 15.10 shows the rotor positions

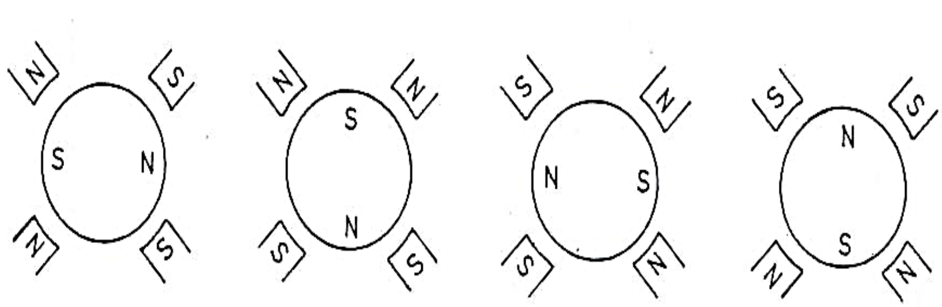


Figure 15.10 Rotor Positions for Bipolar Driving

The half- step bipolar driving keeps the same parallel connection of the windings, but currents must respect to the diagram of Figure 15.11.

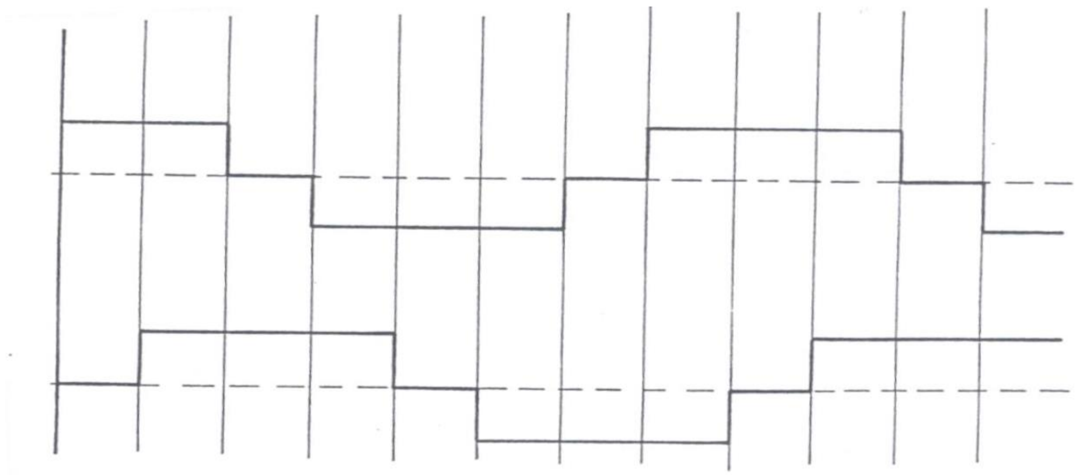


Figure 15.11

Figure 15.12 shows the rotor positions.

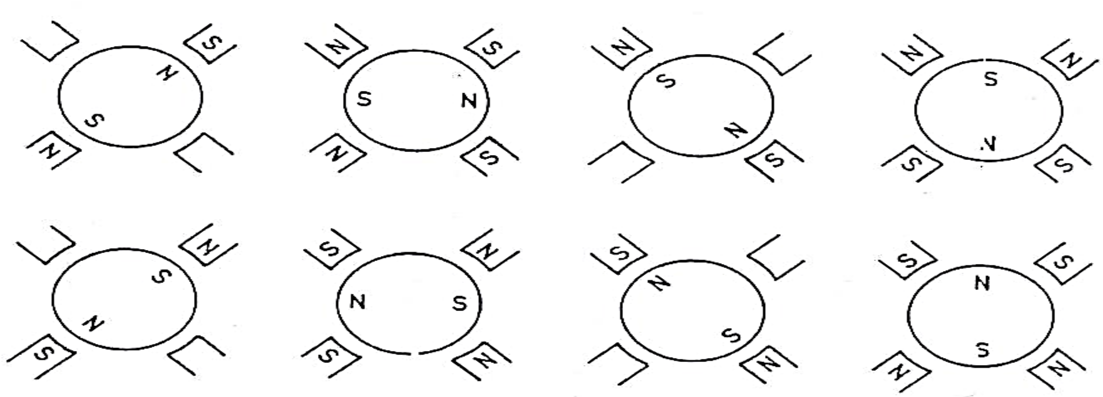


Figure 15.12 Rotor Position

Exercises:

- **Unipolar Full Step Driving (1 – phase)**

  Procedure:

  1. Connect terminal 3 to the output signal of the block GENERATIOR (terminal 1), or to the signal generated via the MANUAL CLOCK (terminal 2).
  2. Via the 4 cables, connect the output signals A1, B1, A2 and B2 of the block UNIPOLAR- FULL STEP (1- PHASE) to the proper terminals of block the POWER DRIVERS.
  3. Connect module G16 to the external unit TY16/EV (stepper motor) Power the module.
  4. Set switches
     - I1 to the position UNIPOLAR
     - I2 to the position FULL- STEP
     - (I3 determines only the rotating direction).
  5. Draw the time diagram of the 4 intervals and draw the rotor positions.

- **Unipolar Full Step Driving (2 – phase)**

  Procedure:

  1. Connect terminal 3 to the output signal of the block GENERATIOR (terminal 1), or to the signal generated via the MANUAL CLOCK (terminal 2).
  2. Via the 4 cables, connect the output signals A1, B1, A2 and B2 of the block UNIPOLAR- FULL STEP (2- PHASE) to the proper terminals of block the POWER DRIVERS.
  3. Connect module G16 to the external unit TY16/EV (stepper motor)
  4. Power the module.
  5. Set switches
     - I1 to the position UNIPOLAR
     - I2 to the position FULL- STEP
     - (I3 determines only the rotating direction).
  6. Draw the time diagram of the 4 intervals and draw the rotor positions.

- **Unipolar Half Step Driving**

  Procedures:

  1. Connect terminal 3 to the output signal of the block GENERATIOR (terminal 1), or to the signal generated by the MANUAL CLOCK (terminal 2).
  2. Via the 4 cables, connect the output signals A1, B1, A2 and B2 of the block UNIPOLAR- HALF STERP to the proper terminals of the block POWER DRIVERS
  3. Connect module G16 to the external unit TY16/EV (stepper motor)
  4. Power the module
  5. Set switches
     - I1 to the position UNIPOLAR
     - I2 to the position HALF- STEP
     - (I3 determines only the rotating direction)
  6. Draw the time diagram of the 4 intervals and draw the rotor positions.

- **Bipolar Full Step Driving**

  Procedure:

  1. Connect terminal 3 to the output signal of the block GENERATOR (terminal 1), or to the signal generated by the MANUAL CLOCK (terminal 2).
  2. Via the 4 cables connect the output signals A1, B1, A2 and B2 of the block BIPOLAR – FULL STEP to the proper terminals of the block POWER DRIVERS.
  3. Connect module G16 to the external unit TY16/EV (Stepper motor)
  4. Power the module
  5. Set switches
     - I1 to the position BIPOLAR
     - I2 to the position Full- STEP
     - (I3 determines only the rotating direction).
  6. Draw the time diagram of the 4 intervals and draw the rotor positions.

Experiment #16:

Pressure Control

Overview

This experiment aims at understanding an example of a closed loop control system (Pressure Control System) and the different effects of P, PI, and PID controllers on this system.

Introduction

Closed Loop (Feedback) Control Systems:

The generic architecture of a closed-loop system is shown in figure 16.1.

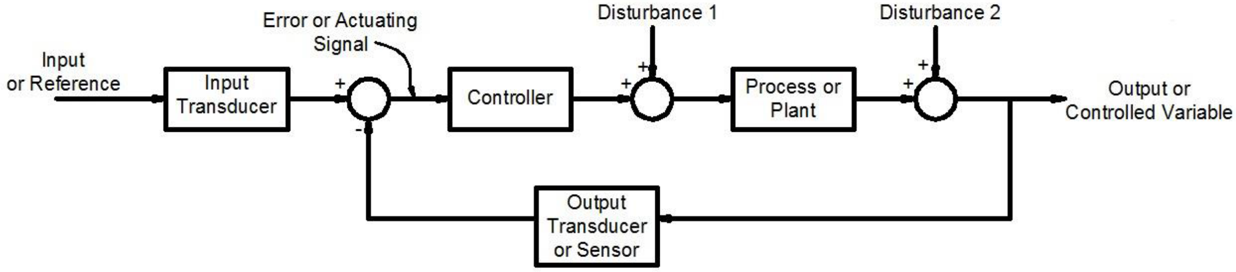


Figure 16.1

- The input transducer converts the form of the input to the form used by the controller.

- An output transducer, or sensor, measures the output response and converts it into the form used by the controller.

- The first summing junction algebraically adds the signal from the input to the signal from the output, which arrives via feedback path. In figure 3.1, the output signal is subtracted from the input signal. The result is generally called the *Actuating Signal* or the *Error*.

- The closed loop system compensates for disturbances by measuring the output response, feeding the measurement back through a feedback path, and comparing that response to the input at the summing junction. If there is any difference between the two responses, the control system drives the plant, via the actuating signal, to make a correction. If there is no difference, the control system does not drive the plant to make a correction, since the plant's response is already the desired response.

- Via closed-loop systems, transient response and steady-state error can be controlled more conveniently and with greater flexibility, often by a simple adjustment of gain in the loop and sometimes by redesigning the controller. We refer to the redesign process as "compensating the system" and to the resulting hardware as "a compensator".

Pressure Control System

In this experiment, we will study the pressure control system supplied with module G35 (TY35/EV). Let us look in detail at the basic parts of the system.

1. Pressure Process

1.1 Description

Refer to figure 8.2, which illustrates the pressure unit supplied with module G35 (TY35/EV). The unit consists essentially of a process tank and a compressor with an electric motor. The compressor provides the gas (i.e. air) required to generate and maintain the pressure.
The actuator consists of an electrically-controlled proportional valve fitted to the outlet. A pressure transducer fitted on the tank side provides the feedback signal.
A pressure gauge is fitted on the top of the unit.
A manually operated restrictor valve on the tank side enables the user to vary the pressure load.
The unit is completed by a safety pressure valve fitted on the delivery line. This valve prevents the pressure in the tank from building up to dangerous levels and blocking the compressor.
The TY35/EV unit can operate with pressures between 0 and 2 bar.

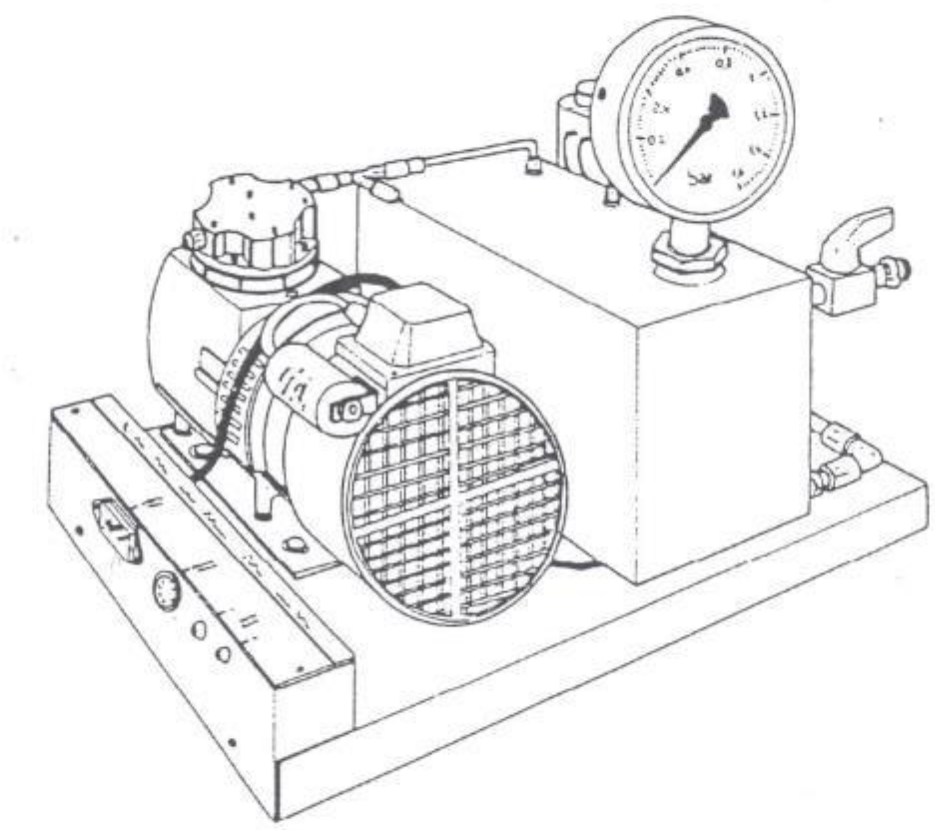


Figure 16.2: TY35/EV Unit

1.2 Automatic Pressure Control

Automatic pressure control systems are widely used in industry. These systems are essentially identical to those used for the automatic control of other physical quantities, such as temperature, velocity, etc.

Obviously, the actuator used in pressure control systems is different. In this case, the actuator is a proportional valve, and therefore requires a suitable amplifier.

Pressure control systems can be used to carry out the following types of control functions:

a. Proportional (P)

b. Proportional + Integral (PI)

c. Proportional + Integral + Derivative (PID)

2. Pressure Transducers

2.1 Semiconductor pressure transducers

The operating principle of this type of transducer is based on the piezo-resistivity (i.e. the property of materials whose resistance changes as a function of mechanical distortion) of a silicon support.

Four resistors, connected as a Wheatstone bridge, are applied to a silicon diaphragm (See Figure 16.3). The diaphragm is then soldered to a glass support ring.

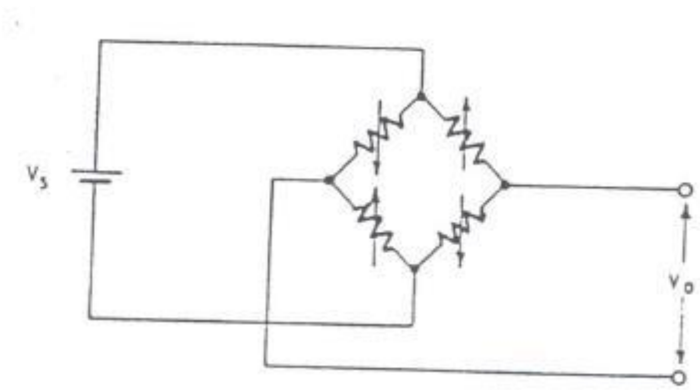


Figure 16.3

One diagonal of the bridge is powered by a constant voltage generator, while the opposite diagonal carries a voltage which varies proportionally with the pressure exerted on the diaphragm.

The transducer used is of the differential type. If one of the ports is left open, the transducer can be used as a differential transducer.
The structure of the transducer is shown in Figure 16.4.

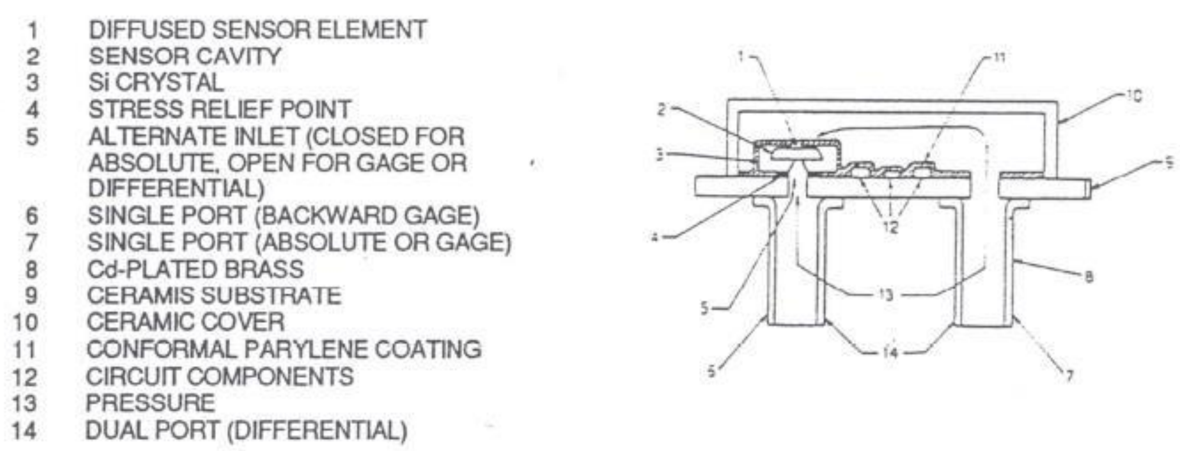


Figure 16.4

This transducer is manufactured by the HONEYWELL MICROSWITCH DIVISION and is designed for operation in air.
The most important characteristics of this transducer are as follows:
a. Range: 0 – 30 psi (0 – 2 bar approx.)

b. F.S.O: 195 mV.

c. Linearity: 0.25% F.S.O.

2.2 Signal Conditioner for Semiconductor pressure transducer

This type of transducer requires a particularly stable signal generator (8V). For this reason, this type of circuit is fitted to the signal conditioner.
The transduced signal is then amplified (which is a simple operation, as this type of device has a high output signal) in order to make the measurement signal easier to handle. An offset nulling circuit is then added (repeater block). A further amplifier ensures that the output signal is within the correct range.
Here, too, the various circuits are filtered so that the signal conditioner is less susceptible to ambient noise.
Figure 8.5 shows the diagram for a signal conditioner.

3. PID Controller

The electrical diagram for the module is shown in figure 16.5, which also shows the test points (located on the front panel) and the value of each component.

3.1 Description of the circuit

The controller module performs Proportional, Integral and Derivative operations in closed-loop processes. Refer to figure 8.5. For all three operations performed by the PID controller, the active component is an operational amplifier (IC1) connected in inverting configuration.

Before describing the functions carried out by the controller, let us examine those performed by the circuit consisting of R4, R5, R6 and P1. As the inverting input is a virtual ground, and assuming that jacks 6,7 and 8 are left unconnected, then if the input voltage applied to R1 is Vi, a current equivalent to passes through resistor R1. As the input resistance of the operational amplifier is, in theory, infinite, resistor R4 carries a current, and therefore the voltage at the ends of R5 is .

As resistor R4 is connected to a virtual ground, the circuit can be simplified by replacing R4 and R5 with a single resistor whose value is equal to the value of R4 and R5 connected in parallel (R4//R5). Seen from the output of IC1 (jack 13) the voltage at the ends of R5 (and, therefore at the ends of R4 also) is:

$$\frac{V_o \cdot R_4//R_5}{R_4//R_5 + R_6 + P_1}$$

Application of the equivalent values gives:

$$\frac{V_o}{V_i} = -\frac{R_4}{R_1} \cdot \frac{R_4 \cdot R_5 + (R_6 + P_1)}{R_4 \cdot R_5}$$

If the equivalent feedback resistance is referred to as R_{eq}, it may be stated that

$$\frac{V_o}{V_i} = \frac{R_{eq}}{R_i}$$

$$R_{eq} = R_4 \cdot \left(1 + \frac{R_6+P_1}{R_5} + \frac{R_6+P_1}{R_4}\right)$$

With components used, R_{eq} varies from 11 MΩ to 231 MΩ. This circuit is designed in order to obtain such high resistance values using normal resistors.

In the PID controller, the proportional action is given by R1 and R_{eq}; when the value of P1 is varied, the gain increases and, as a result, the error decreases. You should keep in mind that a higher gain improves the accuracy and speed of operation, but reduces stability.

The integral part of the controller consists of resistors R1 and R7 and capacitors C4, C5 and C6. The three capacitors can be used separately or in various combinations; the range of regulation is therefore wide. When the capacitance is varied, the time constant of the integral controller, too, varies.

In this type of controller, when the input signal (error) is integrated, the output varies until the error signal is null. Therefore, using this type of controller, it is possible to achieve a zero error condition (which is not possible with proportional controllers). However, in this case too, as the integral action increases, the system becomes less stable; this may lead to permanent or damped oscillations in which the ring time is unacceptably long.

The derivative part of the controller consists of resistors R2 and R_{eq} and capacitors C1, C2 and C3. In this case too, the capacitors can be used separately or in different combinations, and the resulting range of education is wide.

The derivative action encounters major problems in giving a null output in the presence of a constant non-zero error signal. For this reason, derivative action is never used by itself, but in combination with an integral and/or proportional action.

However, the derivative action is used because it increases stability. In fact, this type of action is able to stabilize a system which has lost its stability due to the use of extensive gain levels or extensive integral actions

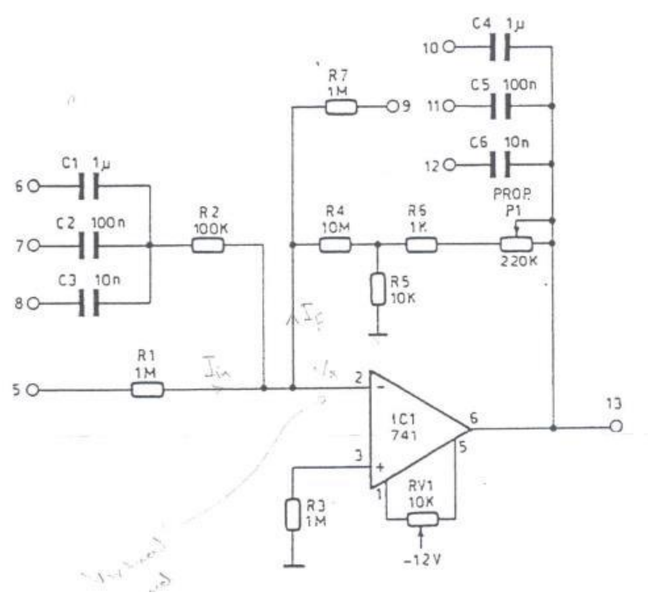


Figure 16.5

4. Exercises:

4.1 Measuring the characteristic curve of the pressure transducer

Objectives:
To determine the characteristic curve of the transducer/ signal conditioner used to measure relative pressure.
Procedure:
1. Power the circuit with the ±12 V voltage.
2. Connect the output of the set-point to the input of the power amplifier (jack 14).
3. Connect the output of the pressure transducer of the TY35/EV unit to the input of the signal conditioner.
4. Connect the appropriate power supply (+24 V DC) to the module.
5. Adjust the set-point so that the pressure inside the tank rises gradually, and measure the output voltage of the Conditioner block.
6. List the increasing pressure levels and the corresponding output voltages of the conditioner block in table 16.1.
7. Plot a graph with the pressure on the x-axis and the corresponding output voltage on the y-axis.
8. Draw a curve which best approximates the points plotted on the graph. This is the characteristic curve of the transducer/signal conditioner.

Table 116.1

P (bar)	P (kPa)	Vout (V)
0	**0**	
0.2	**20**	
0.4	**40**	
0.6	**60**	
0.8	**80**	
1.0	**100**	
1.2	**120**	
1.4	**140**	
1.6	**160**	
1.8	**180**	
2.0	**200**	

4.2 Plotting the best fit line of the pressure transducer and checking its linearity

Based on the results you found in the previous section, draw the best fit line and check the linearity of the system. Revise Experiment 3 if you need.

4.3 Automatic Pressure Control with proportional action

Procedure:

1. Connect all the power supply connectors.

2. Connect the output of the set-point input of the error amplifier.

3. Connect the proportional valve to the power amplifier.

4. Connect the pressure transducer on the TY35/EV unit to the input of the signal conditioner.

5. Connect the output of the conditioner block (jack 21) to the feedback input of the error amplifier module.

6. Power the compressor with the main voltage (220V AC, 0.75A, 80W).

7. Close the discharge valve of the tank.

8. Connect the control and power voltages.

9. Use the set-point to set a pressure of one bar.

10. Use potentiometer P1 to set the gain of the controller to minimum level and determine the pressure by measuring the output of the signal conditioner.

11. Reduce the error between the set pressure and the actual pressure by gradually increasing the gain (Adjust P1 to do this)

12. If the system becomes unstable, reduce the gain slightly until stability is regained.

13. Fill your data in Table 16.2.

14. Comment on your results.

Table 16.2

RUN	Gain	Pressure (bar)	Vin (V)	Vout (V)	Error=Vin-Vout
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					

4.4 Automatic control using a PID controller

Procedure:

1. Set up the system as described in the previous exercise.
2. Bring the proportional action to the limit of stability, then add the integral action by connecting jack 9 to or more of jack 10,11 and 12.
3. Vary the time constant of the integral action by varying the equivalent value of the connected capacitance, and see how the system reacts. Record your observations and explain them.
4. Add the derivative action (here too, the time constant should be varied) and check the effect on the system.
5. Explain what happens and comment on your results and their accuracy.