Design and Applied Technology

(Secondary 4 - 6)

Learning Resource Materials

Automation

Elective Module 1

Programmable Control Systems

Robotics

Basics of Control Systems

Pneumatics

Design and Applied Technology

(Secondary 4 – 6)

Elective Module 1
Automation

[Learning Resource Materials]

Resource Materials Series
In Support of the Design and Applied Technology Curriculum
(S4 –6)

Technology Education Section
Curriculum Development Institute
Education Bureau
The Government of the HKSAR

Developed by
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PREFACE

A set of curriculum resource materials is developed by the Technology Education Section of Curriculum Development Institute, Education Bureau for the implementation of the Design and Applied Technology (Secondary 4-6) curriculum in schools.

The aim of the resource materials is to provide information on the Compulsory and Elective Part of the DAT (Secondary 4-6) to support the implementation of the curriculum. The resource materials consist of teacher's guides and student's learning resource materials of each Strand and Module of the DAT (Secondary 4-6) arranged in eight folders.

All comments and suggestions related to the resource materials may be sent to:

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INTRODUCTION

Automation is happening around us in our daily life - from early morning “snooze” of an alarm clock to boarding the MTR through an automatic door. Both of them are examples of industrial automation application and involve different levels of automation. An alarm clock is basically a timer. The “snooze” function is in fact a sequential control with preset time variables. An automatic door is a typical application of Pneumatic/Electro-pneumatic systems. The duration of door opening is another example of a sequential control with delay function. Sometimes the MTR driver performs the “Manual Override” function for emergency, which is, to re-open the doors when a passenger is clamped between the closing doors.

Students will be introduced to the basic control systems, pneumatics/electro-pneumatics systems, programmable control systems and robotics. After completing this module, students will have an integrated knowledge in understanding, interpreting and appraising basic automation systems, such as washing machine, traffic lights, buggy, air conditioner, production line, automatic door and fire alarm system etc.

New topics like electro-pneumatics, micro-controller, PLCs and robotics, will also be introduced in this module. For better understanding, four thematic learning tasks will be assigned to students. With the experience after the tasks, students will be technologically competent to solve practical design problems in different scenarios. Our students will gain some hands-on experience from these tasks.

From the application point of view, this module will be very challenging to the students who have desires in pursuing innovative design and advanced technology. This module will provide students who have interest in logics, electronics, computer control and system engineering with a lot of opportunities to explore and unlimited space for their innovation.

CHAPTER 1 – BASICS OF CONTROL SYSTEMS

This chapter covers topics on:

1.1 Open-Loop, Closed-Loop and Sequential Control Systems
1.2 System and Sub-systems
1.3 Operation of a Washing Machine
1.4 Operation of Traffic Lights
1.5 Control of Fluid Level in a Tank
1.6 Application of Control Systems in a Buggy
1.7 Application of Control Systems in Air Conditioner

These topics include learning materials that facilitate you to:

- Identify Open-Loop, Closed-Loop and Sequential control system
- Identify input, process, output, state output diagram and time-phase diagram
- Understand some control basics in washing machine, traffic lights, water level, buggy and air-conditioner

1.1 OPEN-LOOP AND CLOSED-LOOP CONTROL SYSTEM

(I) Basic terminology of control system

1. Controlled elements are defined as those which are involved in realizing automatic controlling tasks. Commonly they are referring to electrical motors, pneumatic cylinders, and hydraulic pumps in machines, equipment and industrial production processes.
2. Controllers are defined as those used to make the controlled elements to perform their controlling tasks.
3. Controlled values are referring to those physical properties that are to be controlled according to the desired value by an automatic control system. Commonly they are the temperature, speed and displacement.
4. References (Set points) are referring to the values of input signals required by an automatic control system to control the controlled elements.
5. Disturbances are referring to those which make the controlled values deviated from the desired value in an automatic control system. For those disturbances that are come from the control system itself are called the Internal Disturbance. Those come from the surrounding environment are called the External Disturbance.
6. Automatic Control System is composed of controlled elements and controllers which work together according to a preset program so that the controlled elements can perform the controlling tasks.

(II) Open-Loop Control System

Open-Loop control is the most basic automatic control system and is composed of controller and controlled element. It involves the forward function of the control system but without the "feedback control". The block diagram shows their relationship.

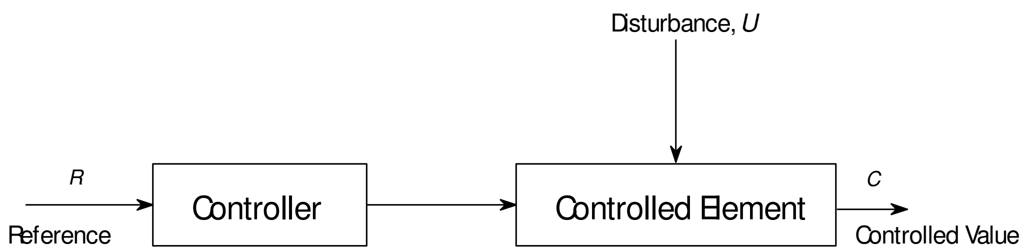


Figure 1.1 Block diagram of Open-Loop control system

Taking a furnace temperature control as an example for the Open-Loop control system:

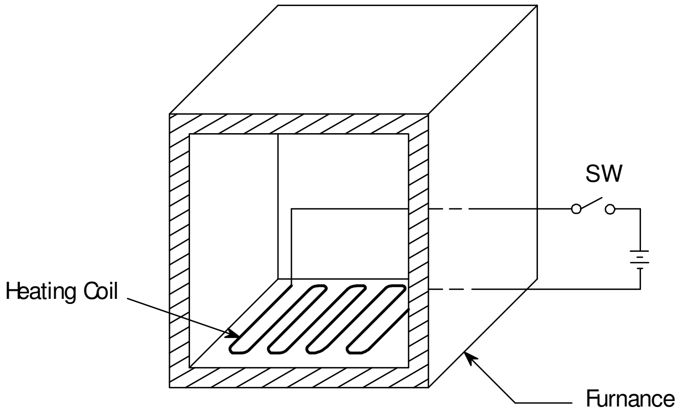


Figure 1.2 Open-Loop control system of Furnace Temperature (Controlled value)

In this case, the controlled element is the furnace, or more specifically referring to the heating coil. U is the control value that determines the power (voltage, current) to the heating element. The furnace temperature, c, is the controlled value. The SW is the switch that is controlled by an electromechanical relay. The switch will be turned ON or OFF in a pattern according to the timed sequence. The timed sequence is used to maintain the temperature inside the furnace within a controllable range.

The **Disturbance** in this case is the frequency at which the furnace door is opened. If the door is opened so often, the furnace temperature will drop and the controlled value c becomes deviated (lower) from the desired value. However, the SW in an Open-Loop control system will not be closed to give power to the heating coil to restore the temperature. The ON/OFF time of this switch has been preset and will not be changed with the furnace temperature in this case.

In an Open-Loop control system, the controlled value will not influence the value of input signal. Therefore, there is no need to measure the furnace temperature (controlled value). The control system becomes simple but the accuracy and stability is usually not high. The only way to increase the stability is to make sure that every component used in this system is of high quality and accuracy but it is usually unpredictable. This system cannot deal with the disturbance, such as frequent opening of the furnace door.

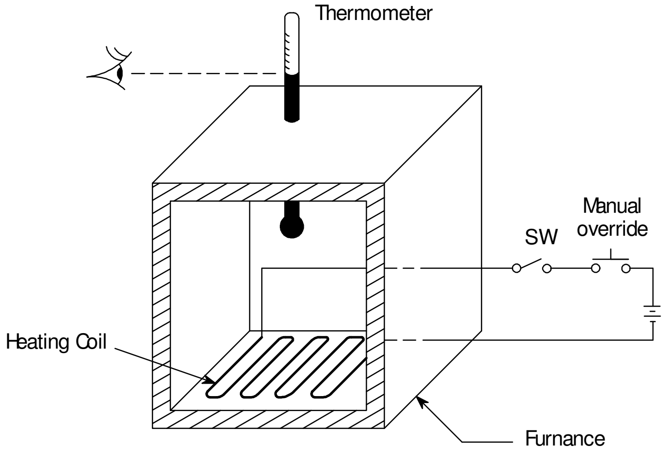


Figure 1.3 Human interrupt control of the Open-Loop control system

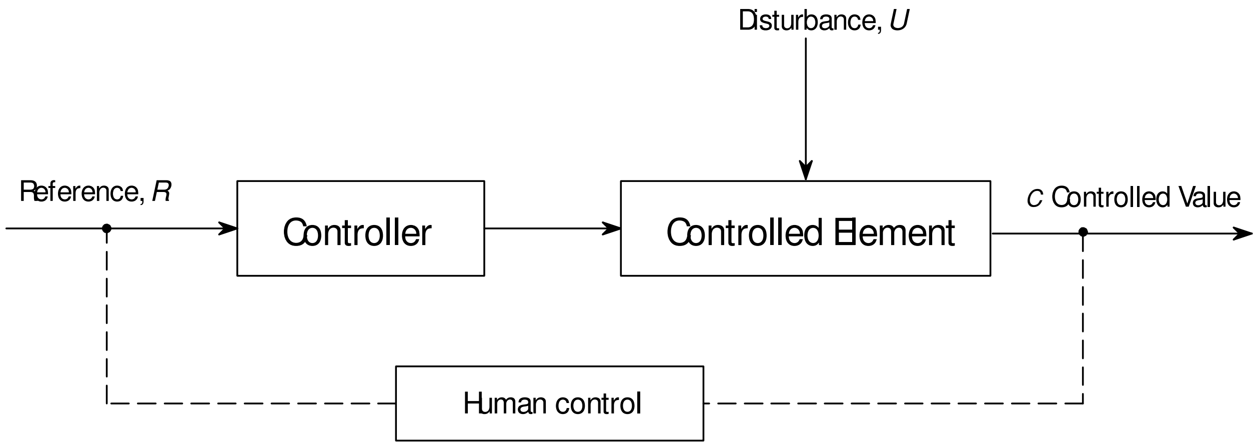


Figure 1.4 Block diagram of Human override in Open-Loop control system

The above problem can be solved by the use of manual override to the electromechanical switch. A thermometer is used to measure the actual furnace temperature for visual monitoring. If the controlled value is deviated from (usually lower than) the desired value, the operator will close the switch in order to give power to the heating coil. The furnace temperature can hence be more closely stabilized within the controlled range. It is an immediate solution that the controlled value can be used ‘back” to control the system, however, it is by no means an automatic control system. If we use some sort of sensor and electrical circuit to measure the temperature and provide the “feedback” of controlled value to the system, the system becomes a Closed-Loop Control system.

(III) Closed-Loop Control System

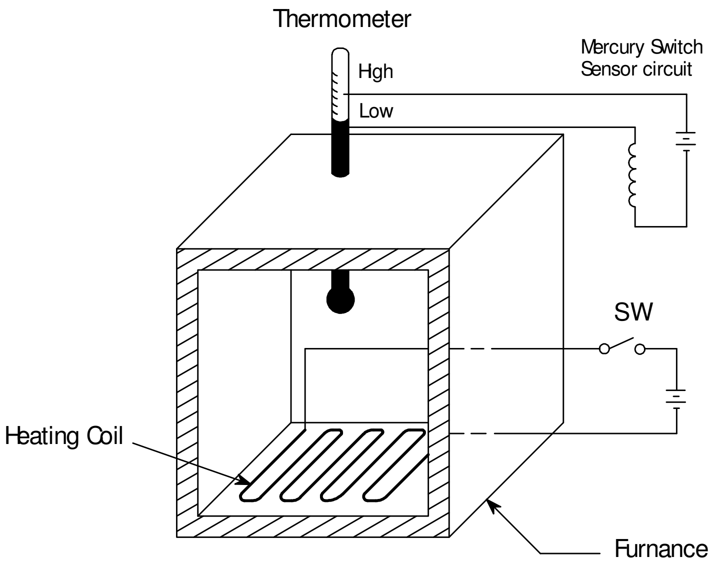


Figure 1.5 Closed-Loop control system of furnace

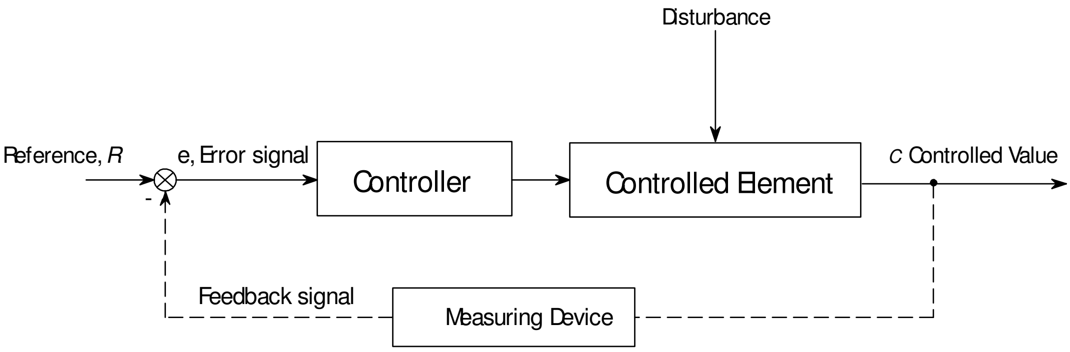


Figure 1.6 Block diagram of Closed-Loop control system

The main difference between Closed-Loop system and Open-Loop system is the Feedback function. The controlled value is measured and used to compare with the input signal (Reference). An error signal is then generated by this comparison. The error signal is amplified and converted to be used to change the controlled value in an opposing way so as to delete or at least minimize the deviation from the desired value. It is called the Feedback control.

If the feedback signal is used to enhance the controlled value and make it go beyond the desired value, it is known as **Positive Feedback**. If the feedback signal is used to reduce the deviation of the controlled value from the desired value, it is known as **Negative Feedback**. Most of these control systems are negative feedback, so the word “negative” is usually omitted for simplicity.

The advantage of Closed-Loop control system is that the reference is changed in accordance with the level of disturbance. The error signal generated can compensate and oppose the effect of disturbance. Therefore, the controlled value can go back to the level before the disturbance is interfered.

(IV) Sequential Control System

Sequential control means one operation or process must be completed before the next one is initiated. The execution of next operation or process depends on the execution of the preceding one. It will continue in a stepwise order until a termination command is met. Sequential control is usually referring to automatic and mostly used in engineering and industry, as most of the processes in production line are sequential in nature. Take a lift as an example. The lift can only move up or down after the door has closed properly and the door will only open when the lift is level with the building floor. It implies that automatic sequential control usually work with sensory feedback mechanism.

We will explore the application of sequential control system by exploring the operation of a washing machine, traffic lights, and the control systems in a buggy in topics 1.3, 1.4 and 1.6 respectively.

1.2 System and Sub-systems

Systems are actually everywhere in our daily life, from the universe solar system to home entertainment systems, from Automatic Teller Machine (ATM) to missile defense systems. In laymen terms, people say everything goes smoothly when “the system works” but disaster comes when “the system fails”.

The definition in dictionary for system is that a system is as a whole but with inter-related parts and emphasizing on internal structure. The system approach means, in engineering sense, integrating analysis and synthesis. Let’s take automobile as an example.

When driving a car in a normal situation, it works as a whole. However, when it is tugged to a garage, it is obviously a system composed of many inter-related subsystems, such as transmission, ignition, steering, braking, lubricating, suspension, and more. Each of these subsystems is in turn made up of many parts, such as the clutch, stick shift, and gear box for transmission. The gear box again in turn consists of many components, such as gear, shaft and a lot of nuts and bolts.

In engineering system approach, when engineers want to design a car, they do not start with a bunch of bolts and nuts. They start with a conception of the intended car as a whole with a set of functional requirements. Then, they decompose the concept car into a number of functional sub-systems, most importantly, with proper interface design for assembly in later stages. For example, there are sub-systems for Power and the subsystem for Transmission. Interfacing is the connection of two sub-systems to work together. Then, engineers further analyze the sub-systems into their inter-related components. Finally, they come to the specifications of manufacturing a single part in details under the component level.

After thousands of individual parts are made, they will be tested, brought together and assembled into a number of sub-systems. The sub-systems will be brought together again and assembled into larger sub-systems. Finally, they are assembled together into a car (a system) for test drive.

The sub-systems approach at different intermediate levels is crucial for engineers and any personnel involved in managing a large complex system. Through division of sub-systems according to their functions, engineers can make a detailed design (less complex) and physical assembly (in a manageable scale) at a time. The sub-system approach is also related to the concept of Modularity which is widely adopted in today’s civil construction and manufacturing. The system approach can be visualized by the Vee model.

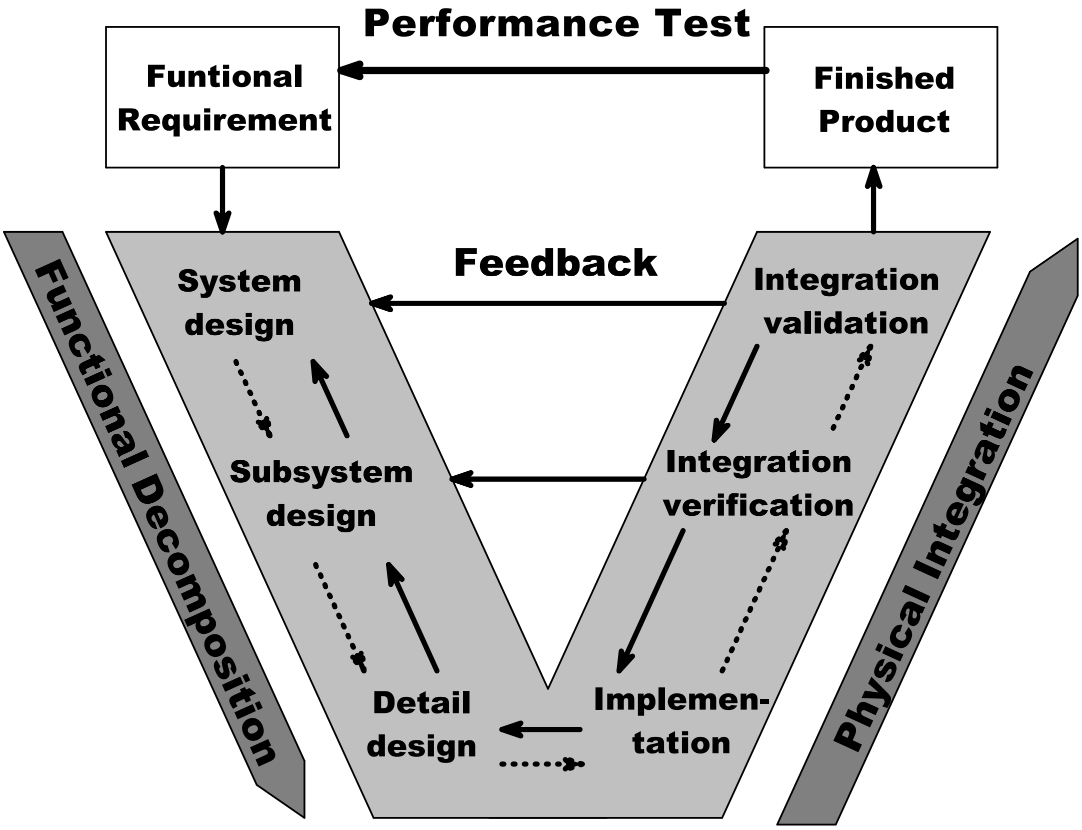


Figure 1.7 Vee Model of System and Sub-system approach

1.3 Operation of a Washing Machine

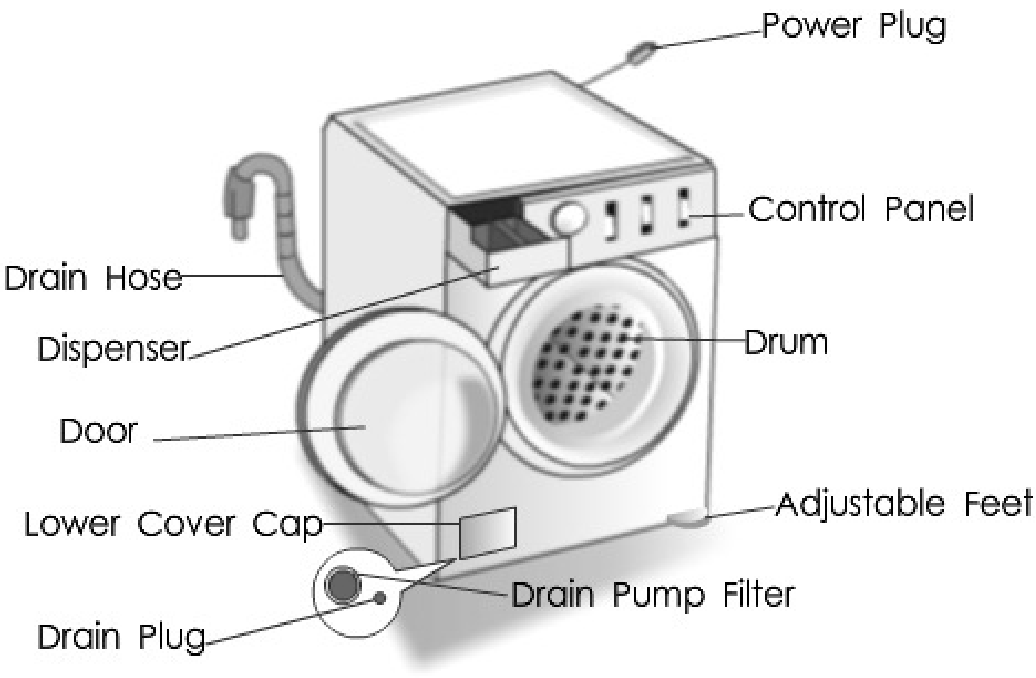


Figure 1.8 Typical structure of a washing machine

A washing machine has a rotating drum for holding laundry and water. The amount of fabrics and the amount of water in the drum may vary. Power is supplied from an inverter to an A.C. motor which drives the rotating drum. A speed control regulates the drum's rotating speed within a selected range.

During the tumble-wash phase, the motor works at low speed and high torque. Although power consumption during the tumble-wash phase is comparatively low, this phase lasts much longer than the spin-dry phase. Therefore, driving the drum motor efficiently during the tumble-wash phase can reduce the total power consumption. Balancing the load before fast spinning is very important because it reduces power consumption during acceleration. In order to achieve a rapid, power-saving spin-dry phase, maximum drum speed is required.

S T O P A N D T H I N K
Why A.C. motor, not D.C. motor, is used to drive the washing machine? State your reasons.

(I) Timing diagram for the Washing - Drying operation

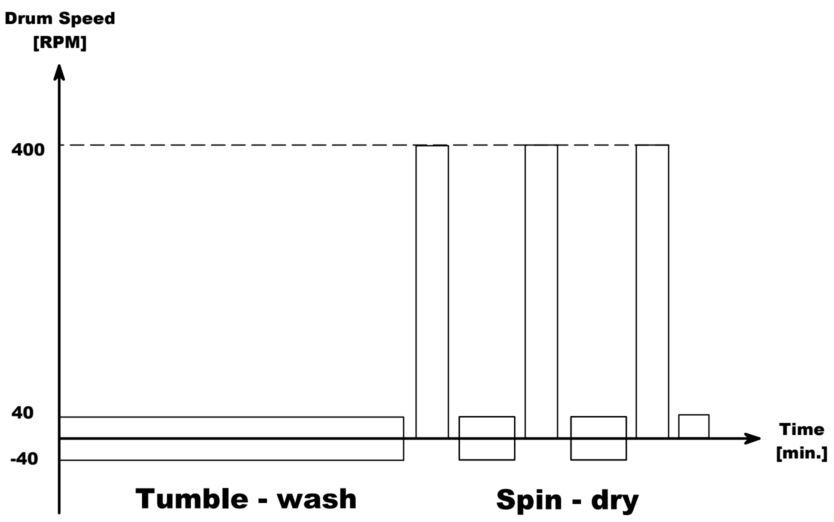


Figure 1.9 Timing diagram for washing processes

During the spin-dry phase, the washer drum rotates at high speed, typically 400rpm for brief intervals as shown in the Time-phase diagram in Figure 1.9, Between these high-speed intervals, the drum rotates at low speed for longer intervals. Regarding the diagram, the drum rotates for 1 min at 400 rpm, and then rotates at low speed for about 3 minutes in both directions. Then, there is a second 400-rpm spin (1-min long) followed by another low-speed spin for 3 minutes in both directions. Finally, there is a high-speed spin for 1 minute, followed by a low-speed spin for another 1 minute in a single direction.

(II) Timing diagram for Tumble-wash phase

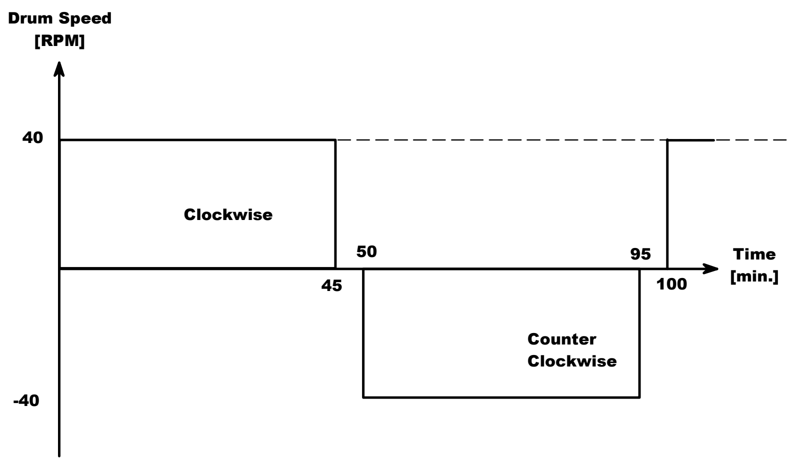


Figure 1.10 The timing phase diagram for tumble-wash phase

The tumble-wash phase is typically three to four times longer than the spin-dry phase. When the scale of the time-phase diagram is enlarged as in Figure 1.9, It can be found that during the tumble-wash phase, the drum rotates slowly, typically at 40 rpm, first turns clockwise

(CW), and stops, then turns counter clockwise (CCW), and stops, and so on. Rotation time interval varies and depends on the nature of laundry, such as delicate, light, heavy or mixed according to the manufacturer's specifications. The diagram shows that there is a 90-percent rotation time in a 100-sec interval.

S T O P   A N D   T H I N K

Why the tumble-wash cycle is not 100 percent continuous rotating and needs to be stopped for a while (10 percent time) before reversing in direction?

(III) Flow diagram analysis of washing machine operation

Flow diagrams are widely used to explain decision making processes in a logical manner. They are particularly useful for converting sequential events into a series of 'Yes' or 'No' operations to each decision to be made. Flow diagram is also used for understanding a process to be controlled before producing a ladder diagram in PLC programming. Here are some major symbols used in flow diagrams.

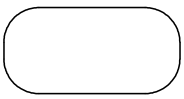
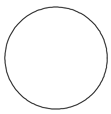
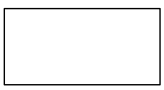
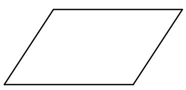
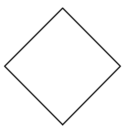
Symbol	Function
	Elongated circle/Terminator Represent the start or end of a process
	Connector
	Rectangles Represent process and action to be taken
	Input/Output
	Diamond/Decision Represent what decisions that must be made

Table 1 Main symbols for Flow diagram

Steps of constructing a simple flow diagram

1. Start the flow chart by drawing an elongated circle/terminator, and label it with "Start".
2. Draw a rectangle or diamond to represent the first process or action. Write the key word of action or question down, and then draw an arrow (connector) from the "Start" to this shape.
3. Represent the actions and decisions of the whole process and in the order of their occurrence. Using arrows (connectors) to indicate the flow of the process.
4. Draw a diamond to indicate where a decision needs to be made, using arrows leaving out of the diamond to indicate the possible outcomes.
5. Use an elongated circle labeled with "Finish" to indicate the end of the process.
6. Review the flow chart from step to step to see if the flow diagram represents the sequence of actions and decisions involved in the process and in a good order.

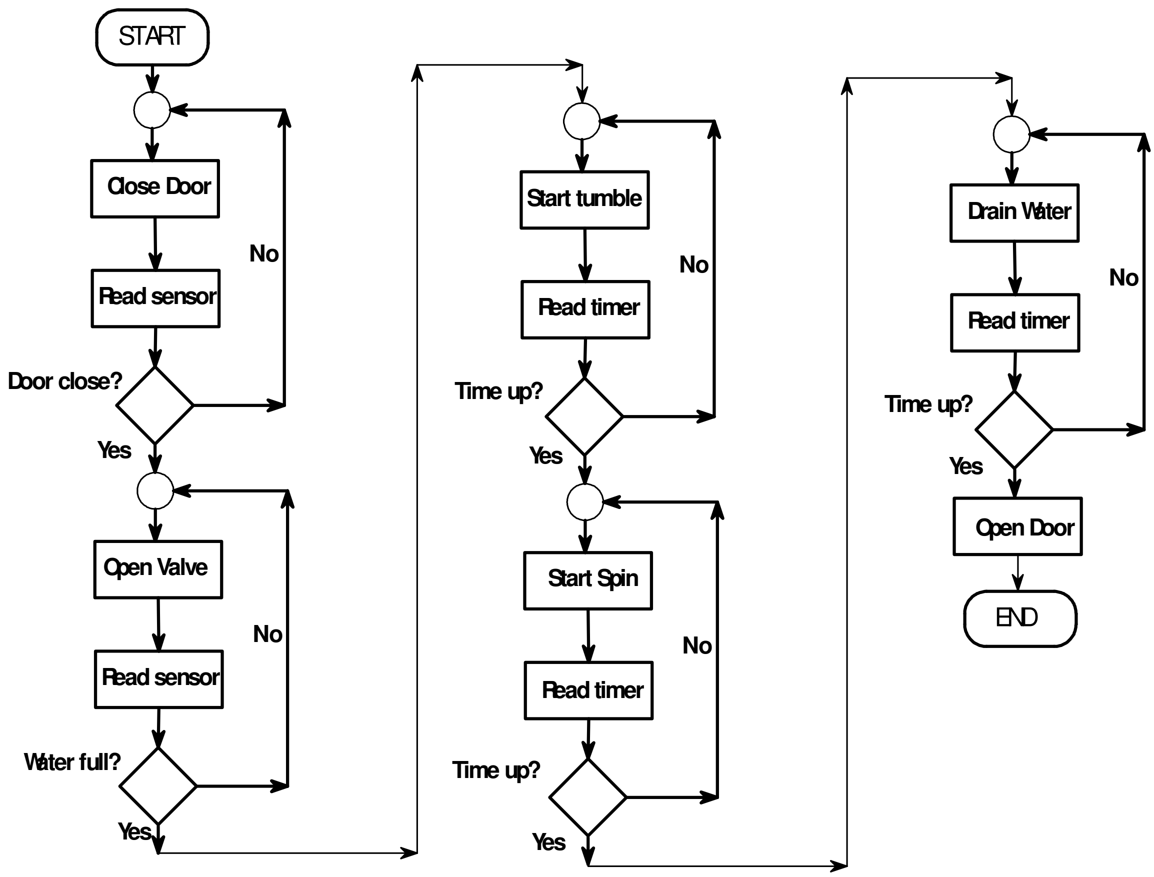


Figure 1.11 Flow diagram for a classical washing machine

The operation of washing machine may vary according to type, price and country of origin. Some washing machine controls may be highly sophisticated and use artificial intelligence to improve washing efficiency, water consumption, acoustic noise, electromagnetic interference (EMI) and the power consumption. The example above is the flow diagram for a classical washing machine (human operation is included in this case).

1.4 Operation of Traffic Lights

Traffic lights become an integral part of a modernized city. The proper operation of traffic lights can smooth the flowing traffic and boost the economic growth. Proper operation means precise timing, cycling through the states correctly, and responding to outside inputs like Walk signals. Traffic lights are at least come in pairs and need to be synchronized for proper operation. Below is a typical 3-lamp, 4-state traffic light signals.

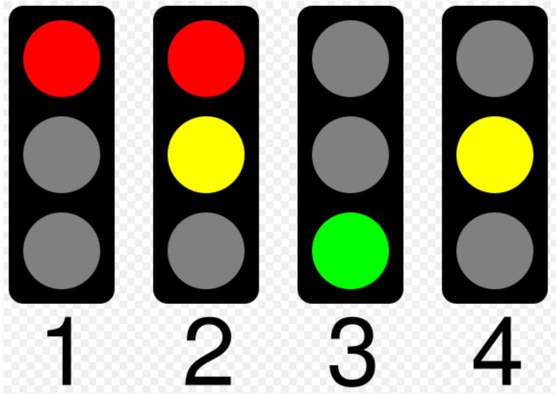


Figure 1.12 A typical 3 lamps traffic light sequence

When considering the design and implementation of traffic light control at an intersection, it is typically between a busy (Main) road and a less busy (Side) road. Both streets have the ordinary (Red, Amber, Green) signal lights. The intersection is sometimes fitted with a sensor to detect the vehicle for the side- road traffic condition and with a walk request button controlled by pedestrians.

A single 3-lamp traffic light has three states, Red, Yellow, and Green, which are also the outputs. A single input for the traffic light is values 0 for no change and 1 for state change. This input is connected to the output of a countdown timer, which outputs a value of 1 when it counts down to zero. Thus for a single light, we can draw the state transition diagram as below.

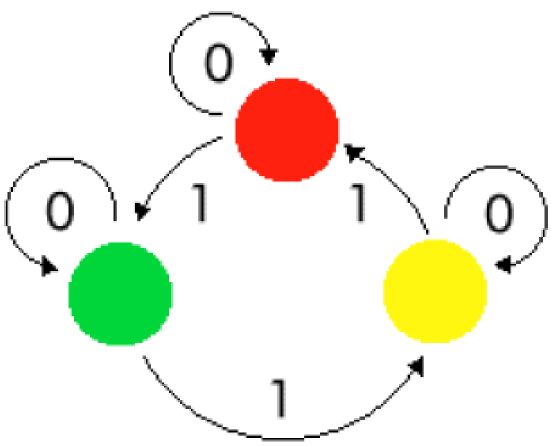


Figure 1.13 A State diagram of traffic signal sequence (a single light)

(I) Three important parts of Traffic Light Control System

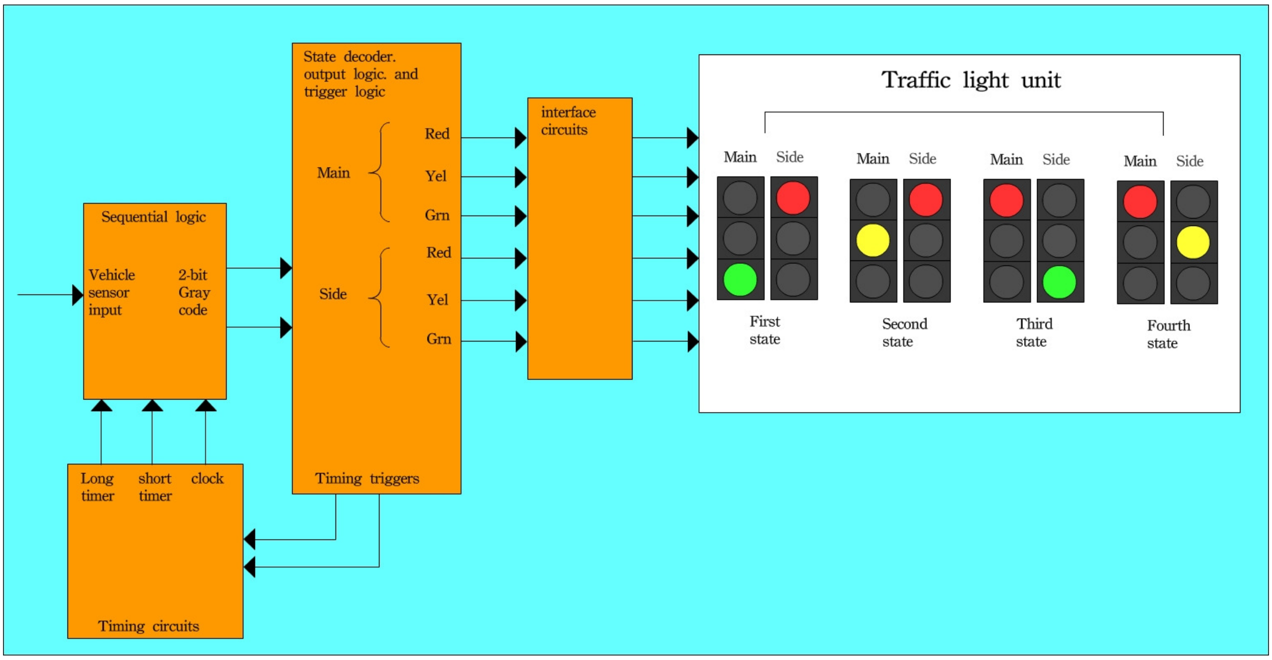


Figure 1.14 A Block Diagram of Typical Traffic Control system

The first part is the controller, which represents the brain of a traffic system. It consists of a computer or a programmable logic controller (PLC) that controls the selection and timing of traffic lights in accordance to the varying demands of traffic loads.

The second part is the traffic light unit or "signal face". Signal faces are used to provide controlling signals to the traffic in a single direction. It consists of 3 signal states and operates in synchronization with the sequence of other traffic lights. The lamps are conventionally comprised of red, amber and green lights.

The third part is the detector or sensor to indicate the presence of vehicles. The detector consists of wire loops placed in the pavement at intersections. They are activated by the change of electrical inductance caused by a vehicle passing over or standing over the wire loop. For a more recent technology, it uses the video detection system for the indication of vehicles on the road. A small camera is fixed in the traffic light pole to "see" if any vehicle is present.

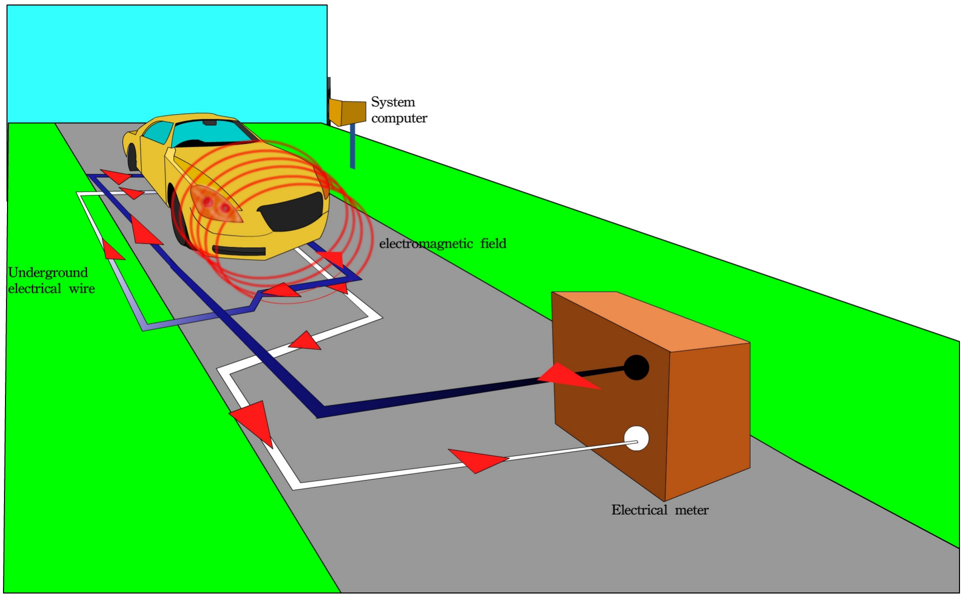


Figure 1.15 A diagram of Induction loop traffic sensor.

(II) A timing diagram to traffic control

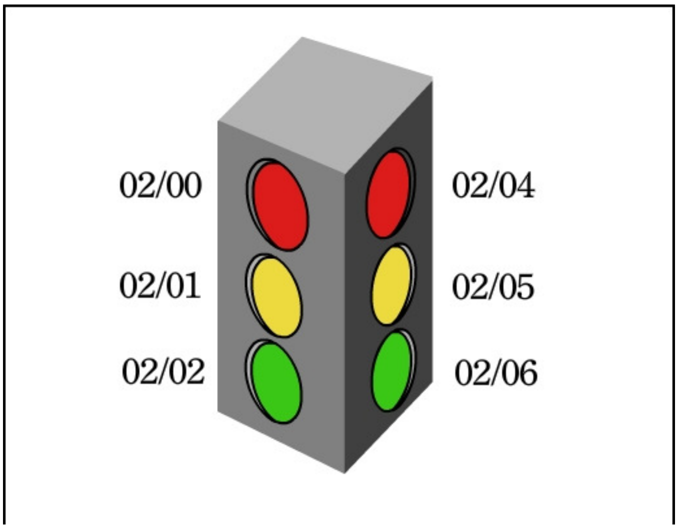


Figure 1.16 A diagram of a pair of traffic signal unit

The sequence of traffic light operation and timing duration can be analyzed or represented by a timing diagram. The code O represents an output signal. The codes are O:2/00 and O:2/04 for Red; O:2/01 and O:2/05 for Amber and O:2/01 and O:2/05 for Red. A 1 second delayed period for RED lights on both directions to be illuminated is for road safety reason. 1 second delayed period lets drivers from both directions have a brief for readiness and let the vehicles on the junction be cleared off.

<table>
<tr><td colspan="3">Red = O:2/00</td><td>Green = O:2/02</td><td>Amber = O:2/01</td></tr>
<tr><td>Green = O:2/06</td><td>Amber = O:2/05</td><td colspan="3">Red = O:2/04</td></tr>
<tr><td>8 Sec.</td><td>4 Sec.</td><td>1</td><td>8 Sec.</td><td>4 Sec.</td></tr>
</table>

Figure 1.17 A diagram of a pair of traffic signal unit

1.5 Control of Fluid Level in a Tank

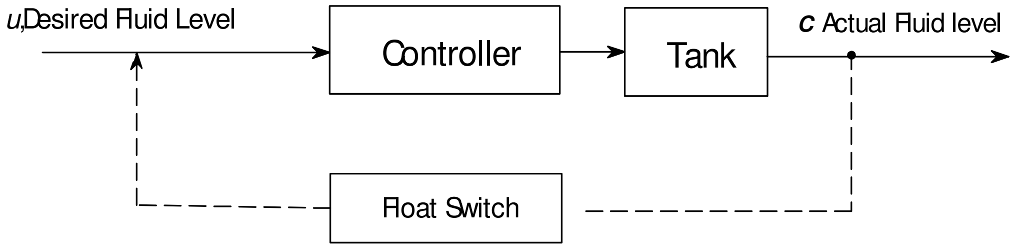


Figure 1.18 Block diagram of fluid level control system

A cold water tank is supplied with water via a float operated control valve ‘F’. A manual globe valve ‘V’ is on the outlet pipe. Both valves are assumed to have same size in term of flow capacity (mass flow rate) and flow characteristic (pressure drop) along the pipe. The desired water level in the tank is set at the point B. This is equivalent to the set (desired) point of a Closed-Loop control system.

Here, the tank is the controlled element. The float switch is the measuring device which provides the feedback to the controller. The controlled value is the fluid level and the control value is the mass flow rate.

(I) When Loading is 50% (Half-open)

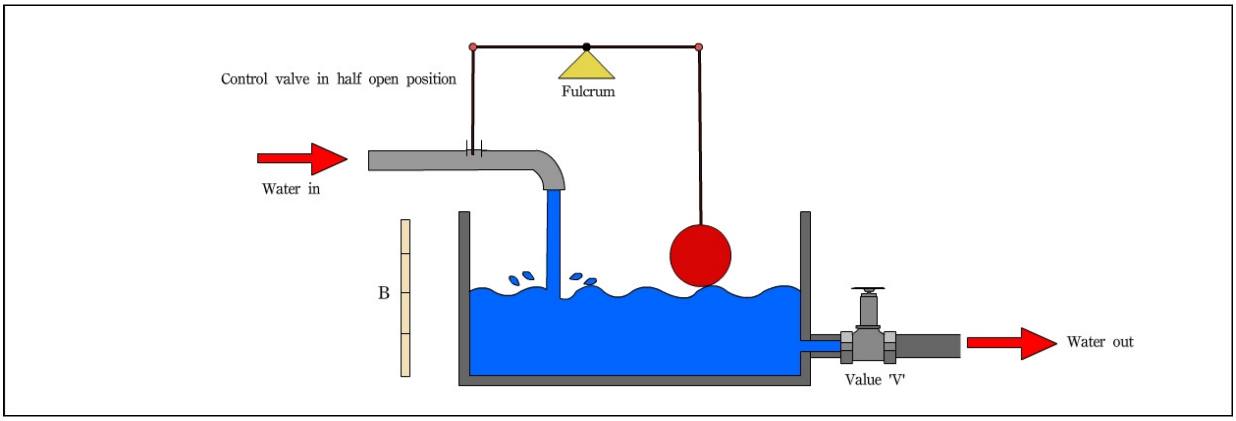


Figure 1.19 Valve at 50% open

It can be assumed that, with valve ‘V’ half open (50% load), the flow rate of water entering via the float operated valve is equal to that leaving the discharge pipe via globe valve “V”, Water level can be maintained in the tank at point B.
The system can be said to be in equilibrium, under control and in a stable condition. It means that the flow rate of water entering and leaving the tank is the same and, therefore, the level is not varying. The water level is precisely at the desired water level (B) and giving the required outflow.

a. When the loading is 0% (Fully closed)

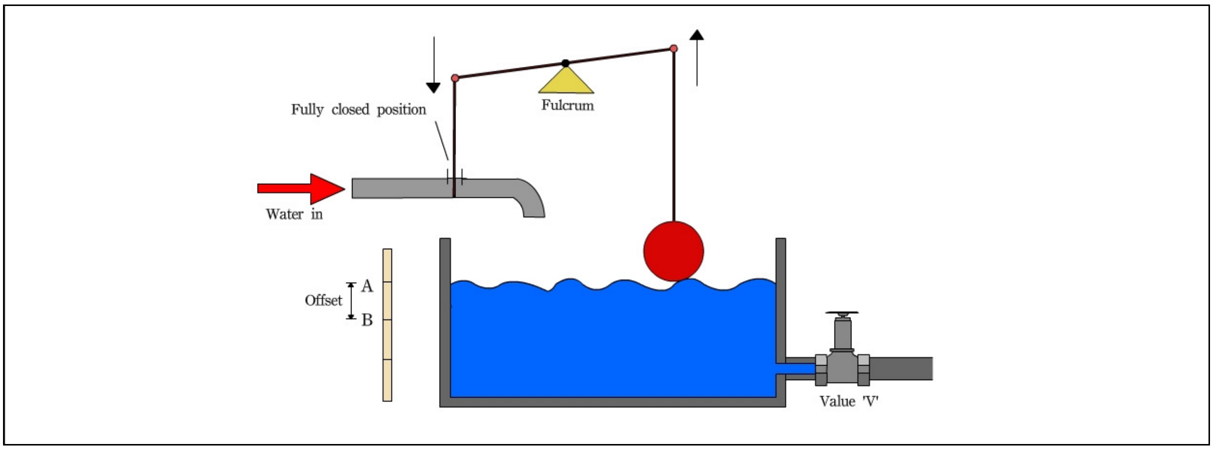


Figure 1.20 Valve fully closed

With the globe valve 'V' is fully closed, the level of water in the tank rises to point A. The float operated valve cuts off the water supply.

The system is still under control and stable but the water level is above level B. The difference between level B (set point) and the actual level A is the proportional band of the control system.

If globe valve 'V' is half open to give 50% load, the water level in the tank will return to the desired level, point B.

b. When the loading is 100% (Fully open)

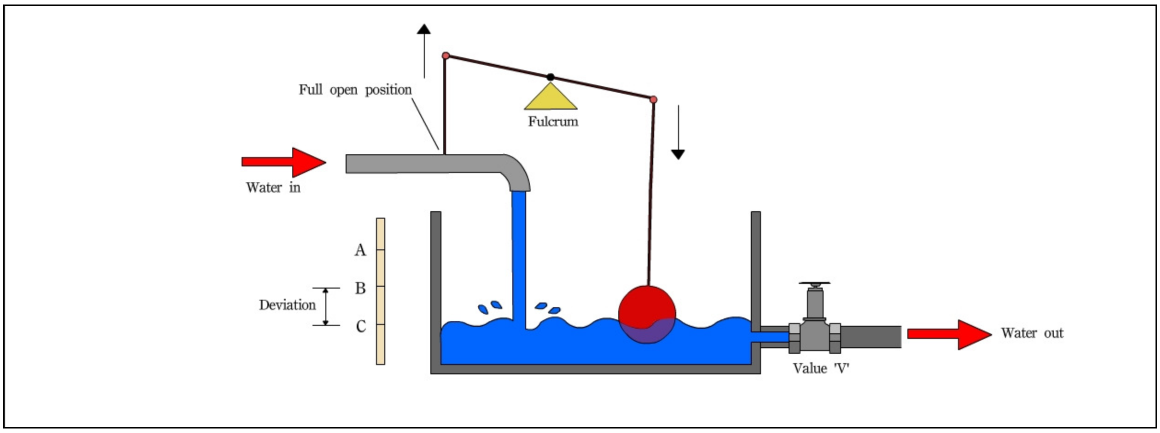


Figure 1.21 Valve fully open

The globe valve 'V' is fully opened (100% load). The float operated valve will be dropped to widely open the inlet valve. This allows a higher flow rate of water to meet the increased demand from the discharge pipe. When it reaches level C, enough water will be entering to meet the discharged needs. The water level will be maintained at point C.

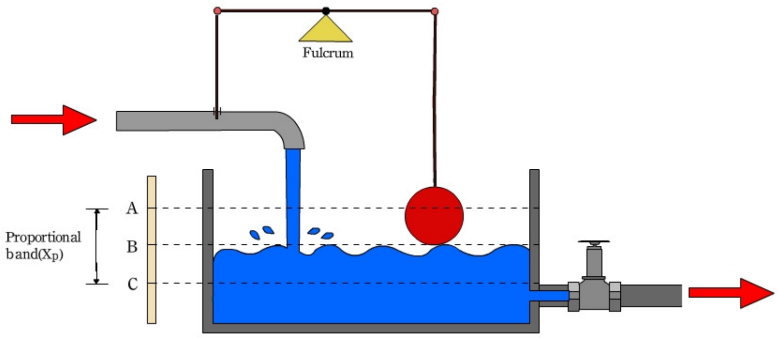


Figure 1.22 Proportional band

The system in this case is still regarded as under control and stable, but there is an offset that is the deviation in level between points B and C. The difference in levels between points A and C is known as the Proportional Band, It is the change in level for the float operated control valve to move from fully close to fully open.

c. Level Control Basics

The above water level control case illustrates several basic and important concepts, such as feedback and proportional control:

1. The control valve is triggered in proportion to the error (offset) in the water level from the set point. (level A and C)
2. The set point can only be achieved at certain load level (50% in this case).
3. A stable control state will be achieved between points A and C (proportional band). Any load (disturbance) causing a difference in level other than that of B will be the offset.

1.6 Application of Control Systems in a Buggy

The buggy is an obstacle-avoiding robot comprised solely of two motors, two wheels, two contact (bump) switches, and a few discrete electronic components. This obstacle-avoiding robot is designed to illustrate the basic knowledge of a sequential (Open-Loop) control system.

This buggy is entirely an analog circuitry without any integrated circuit. The block diagram illustrates how the bump sensor is connected to the motor–driven wheel (actuators). Signal will be created when the bump sensor comes into contact with obstacles. This signal is sent to the motor-driver circuitry – the signal amplifier for each wheel, signaling the robot to back up. An adjustable timer is the RC circuit that is associated with each motor driver to determine how long each wheel should reverse.

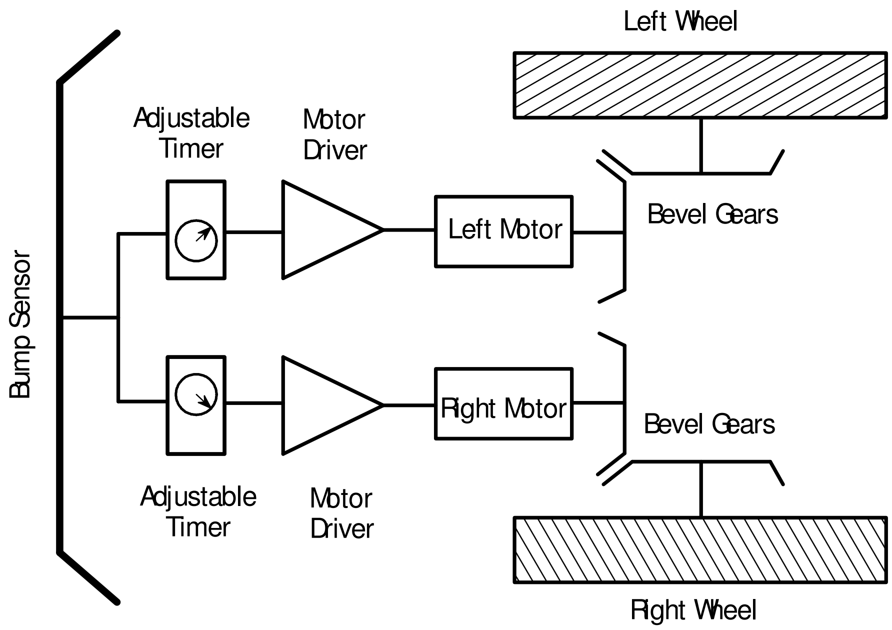


Figure 1.23 The block diagram shows two motors, two wheels, a bump sensor and two potentiometers for programming the time events.

The diagram illustrates the sequence of actions when the obstacle-avoiding buggy strikes an obstacle. The robot is initially moving forward. When it strikes the obstacle, both motors are switched to reverse and the buggy moves straight backwards.

How the buggy makes a turn? The right motor reverses for a longer time period than the left motor, causing the robot to turn to right. After a certain period, the right motor stops reversing and both motors go forward, leading the robot off in a new direction. If the robot bumps into obstacle again, the process repeats the sequence of actions until the obstacle clears off from its way.

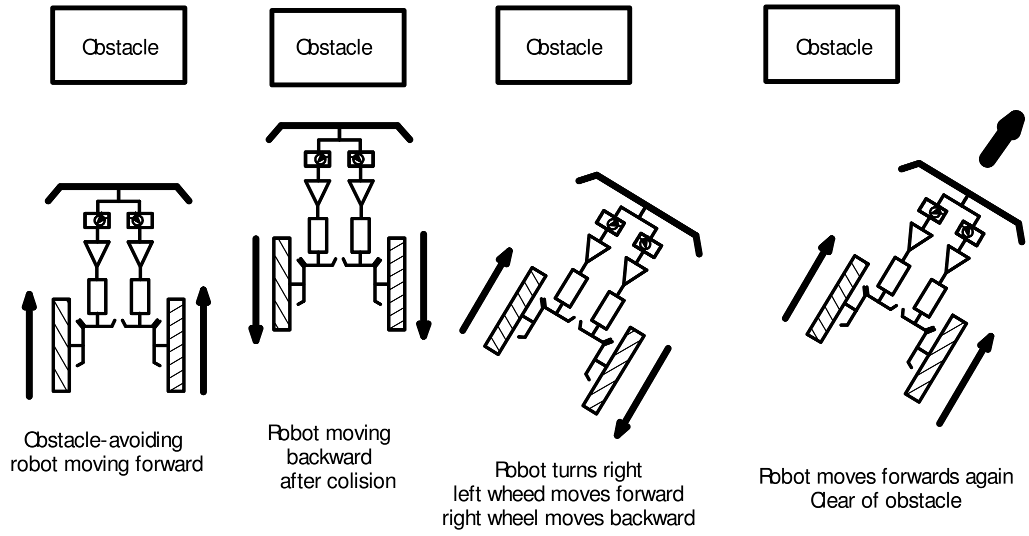


Figure 1.24 The basic operation of the obstacle-avoiding buggy

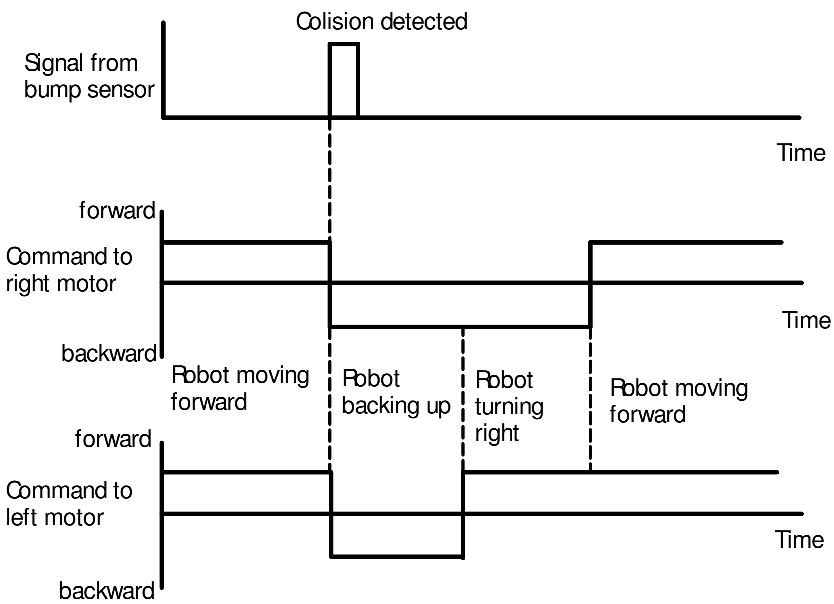


Figure 1.25 Timing sequence illustrating the obstacle-avoiding buggy's backing up behavior.

The sequence of actions can be illustrated in timing diagrams. Figure1.25 depicts the signal generated by the front bumper sensor. Figure 1.26 illustrates the signals sent to the right and left drive motors.

Initially, both motors receive signals to go forward. If a collision occurs, the bumper sends a binary signal to the adjustable timers, low (0) for no contact, high (1) when an obstacle is struck. The timers, in turn, provide a binary signal to the motor drivers – high (1) for reverse rotation, low (0) for forward rotation.

Assume that the timers are set for delays of TR seconds and TL seconds for the right and left motors respectively (TR > TL) for reversing. After encountering an obstacle, the buggy will backup for a time TL. The left motor turns forward after TL, the right motor stays in reverse for a time TR - TL. It will then resume moving forward. Therefore, the buggy will move in a different direction and avoid the obstacle. The buggy will repeat the sequence until it can totally avoid the obstacle.

1.7 Application of Control Systems in Air Conditioner

(I) Temperature Control

Air conditioning systems are essential in most of our daily lives though we are facing a critical issue of global warming. With a view of that, an effective control that can improve the cooling efficiency will save the power consumption. A simple air conditioning system is shown in Fig 1.26. The only control task in this system is temperature. There are two adjustable valves to regulate the temperature.

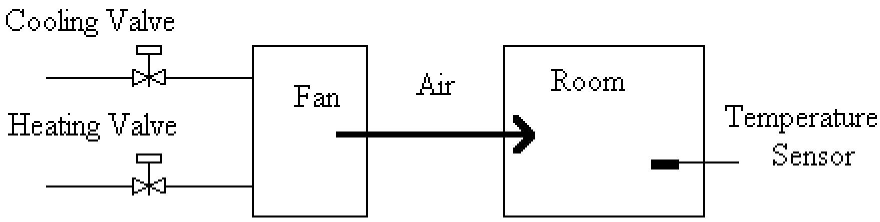


Figure 1.26 Block diagram of temperature feedback control system

The temperature sensor provides the feedback to the Closed-Loop control system.

If temperature measured Tm is lower than the set point Ts, open heating valve Hv fully and close the cooling valve Cv fully to restore the temperature.

If temperature measured Tm is higher than the set point Ts, open cooling valve Cv fully and closes the heating valve Hv fully to restore the temperature.

State	Action
$T_m \quad < T_s$	C_v *Low (0),* H_v *High (1)*
$T_m \quad > T_s$	C_v *High (1),* H_v *Low (0)*

Table 1.1 Relationship of control and controlled valve

(II) Humidity control

In the real world, however, it is usually not enough to manage an air conditioning system with temperature control only. We need to control humidity as well. A modified air conditioning system is shown in Fig 1.27. There are two sensors in this system: one is to monitor temperature and another is to monitor humidity. There are three control elements: cooling valve, heating valve, and humidifying valve (water spray nozzle), to adjust temperature and humidity of the air supply.

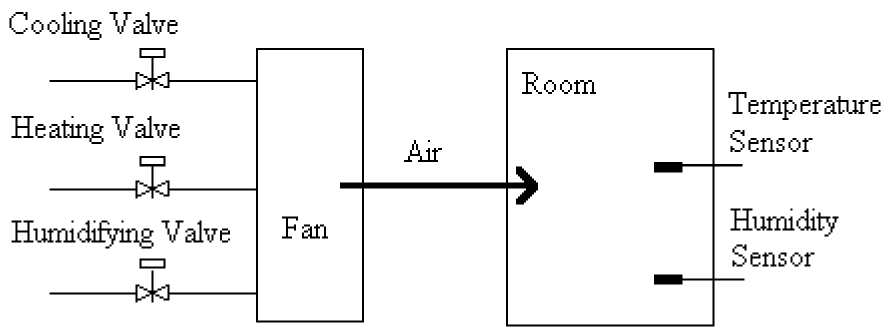


Figure 1.27 Block diagram of temperature and humidity control system

The humidity sensor provides the feedback to the Closed-Loop control system. If humidity measured HUm is lower than the set point HUs, open humidifying valve HUv fully to restore the humidity. If humidity measured is HUm higher than the set point HUs, close humidifying valve HUv fully to reduce the humidity.

State	Action
$HU_m < HU_s$	HU_v, *High (1)*
$HU_m > HU_s$	HU_v, *Low (0)*

Table 1.2 Relationship of control and controlled valve

S T O P A N D T H I N K

1. Suggest any disadvantage of this type of temperature and humidity control.
2. Suggest any method which can improve this control system.

QUIZZES (CHAPTER 1)

1. Why automated control systems are so important in industry?
2. State the differences between Open-Loop and Closed-Loop control system.
3. Give one daily example in Open-Loop control system and Closed-Loop control system. Draw the block diagrams for the examples.
4. Suggest and name the types of sensors used in a washing machine.
5. What is the meaning of set point?
6. What is the meaning of proportional band?
7. What is the meaning of error signal?
8. What is the meaning of offset?
9. Describe how an RC circuit functions as a timer.
10. What sensors can be used as a bump switch for an obstacle avoiding buggy?

CHAPTER 2 – PNEUMATICS

This chapter contains topics on:

2.1 Pressure
2.2 Pneumatics Components and Symbols
2.3 Understanding Pneumatic Components
2.4 Pneumatic Circuitry
2.5 Electro-pneumatic Systems

These topics include learning materials that facilitate you to:

- Understand the characteristics of pressure
- Identify pneumatics and electro-pneumatics components
- Understand design of pneumatics and electro-pneumatics circuits
- Understand the industrial application of pneumatics.

2.1 Pressure

(I) Units

The atmosphere exerts a pressure on earth surface. As a standard, pressure is measured at sea level. This pressure can be described as a force per unit area. The metric unit of pressure is Pascal (Pa).

1 Pa = 1 N/m^2 (Newton per square meter)

The force exerted by the atmosphere at sea level is 100,000 Pa. 1 standard atmosphere is approximately 14.696 psi or 1.01325 bar or 1.03323 kgf/cm2. In English, pressure is expressed in psi, or pounds per square inch. It is also defined as a ratio of force to area.

1 MPa =10 bar or 145 psig

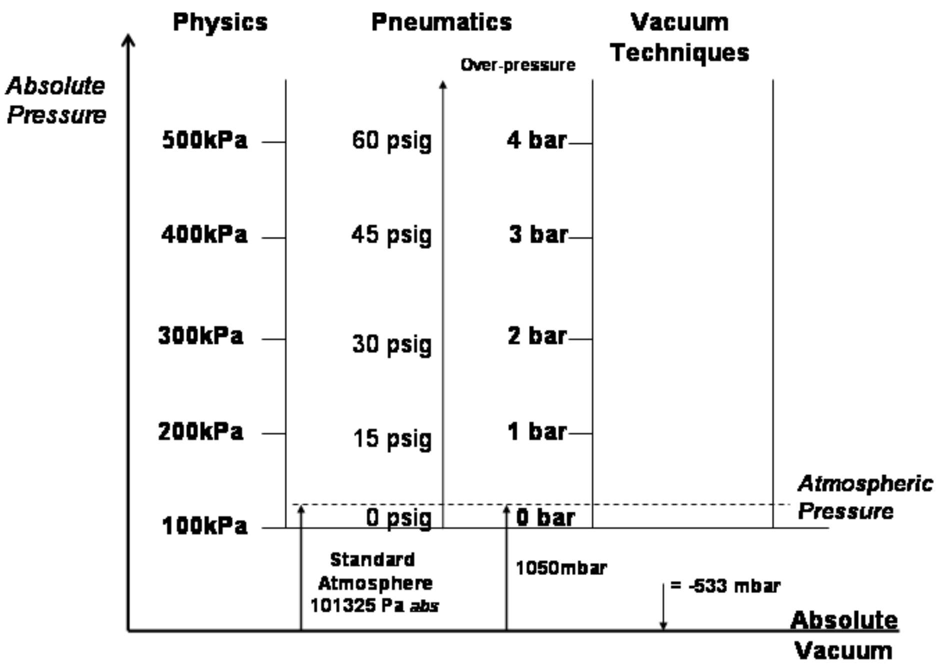


Figure 2.1 The various systems of pressure notation

In the application of pneumatics, pressure is usually referring to gauge pressure (GA or psig). As the pressure is always above atmospheric pressure, it is also regarded as over-pressure. For gauge pressure in pneumatics application, the atmospheric pressure is referenced as zero pressure.

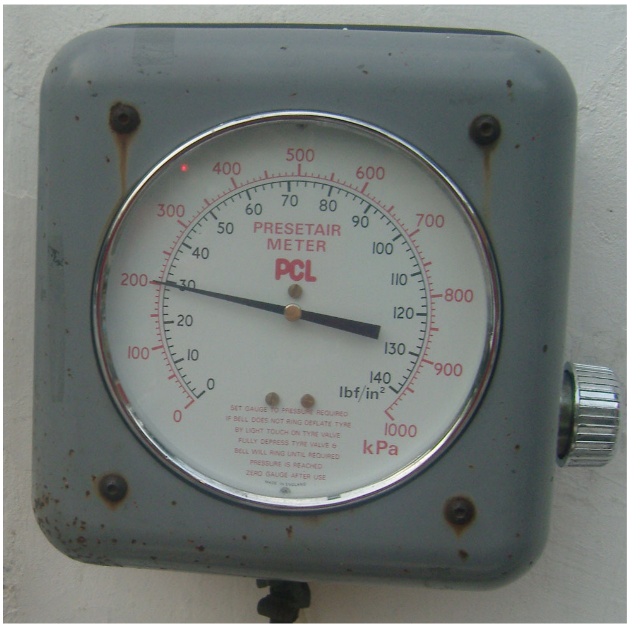


Figure 2.2 Gauge Pressure dial

In a full vacuum scenario, pressure can be expressed as absolute pressure (Pa $_{ABS}$ or psia). In vacuum technology, a pressure is always below atmospheric and in a state of under pressure. The actual atmospheric pressure is 1.013 bars. Disregarding the decimals, the standard atmospheric temperature is referenced to 1 bar.

(II) Pressure and Flow

The most important relationship in pneumatics is pressure and flow. If there is no flow, pressure over the entire system will be the same at every point. However, once there is a flow from one point to another, pressure will be decreasing along the path. This difference in pressure is called pressure drop. Pressure drop depends on three factors:

1. Initial pressure
2. Volume of flow
3. Flow resistance

2.2 Pneumatics Components and Symbols

(I) Air Handling Units (AHUs)

a. Why needs Air Handling Unit?

All atmospheric air carries dust and moisture. After compression, moisture will condense in the air. Dust and moisture combine with other contaminants, such as pipe scales and worn sealing materials, will cause detrimental effect to the pneumatic system. Therefore, AHU is the primary element in a pneumatic system to provide clean, regulated, and/or lubricated compressed air in all industrial applications.

The function of an AHU is to prolong the life of pneumatic tools, devices and valves, and hence reduce the maintenance and downtime costs. AHU is also known as Air Preparation Unit (APU). It is usually composed of Filter, Regulator and/or Lubricator.

b. Filter

A standard filter consists of two units: water separator and filter. Water separator will collect a considerable quantity of water and the filter will prevent contaminants, such as dust and rust particles from entering into the pneumatic system. Water collected can be drained off through a manual drain cock or an automatic drain. The time required to replace a filter can be alerted by excessive drop of pressure across the filter.

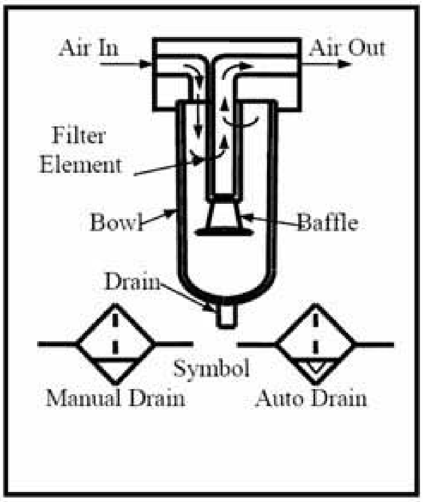


Figure 2.3 Typical structure and symbol of a Filter with Drain

c. Regulator

Pressure regulator has a diaphragm to balance the output pressure against an adjustable spring force.

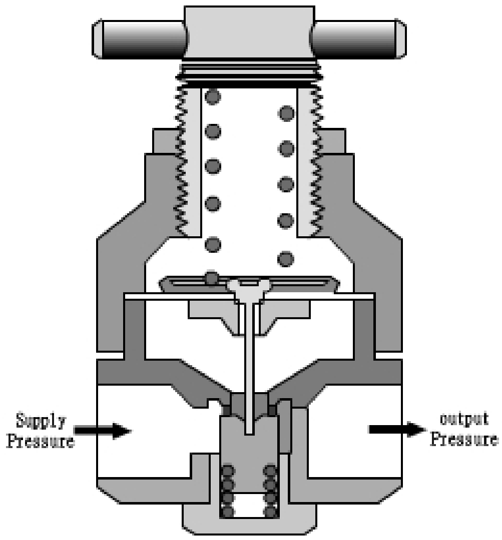
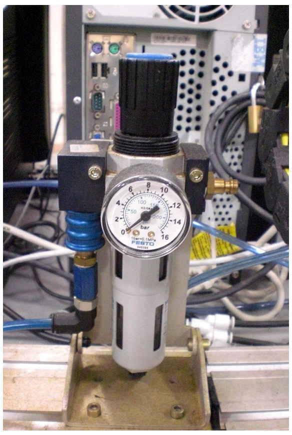


Figure 2.4 Regulator sectional diagram

If the consumption required by the pneumatic system increases, the output pressure will decrease accordingly. This decreases the force acting on the diaphragm and against the spring poppet force. The diaphragm and the poppet will lower until the spring force to be balanced again. This will increase the air flow through the orifice until it meets the increased consumption of compressed air.

If the consumption rate drops, output pressure slightly increases. This increases the force acting on the diaphragm and valve will then lift until the spring force is equaled again. The air flow through the valve will then be reduced until it matches with the reduced consumptions rate. The output pressure can be maintained.



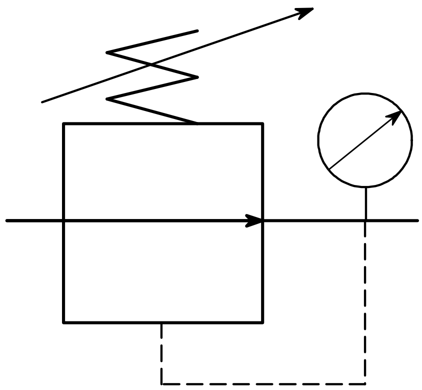


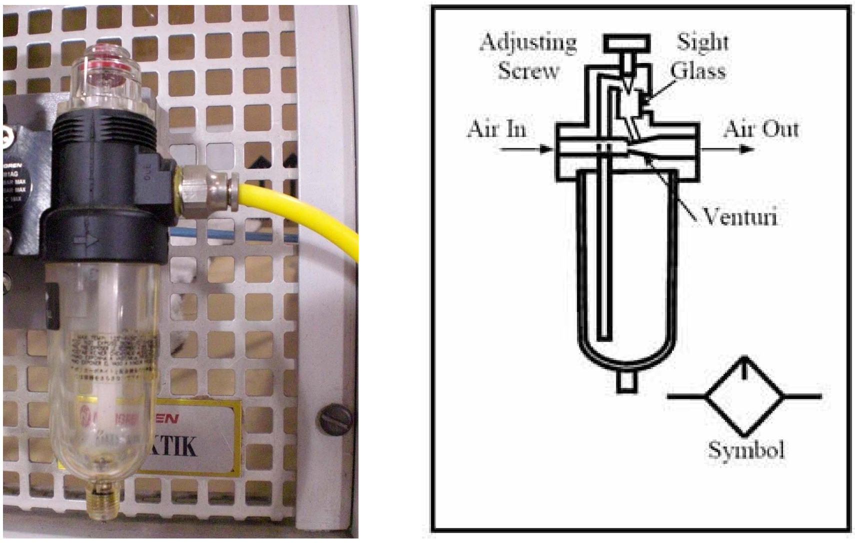
Figure 2.5 Structure and symbol of a Pressure Regulator

S T O P A N D T H I N K
Why the output pressure will increase when the consumption flow rate drops and vice versa? Can you explain this phenomenon?

d. Lubricator

It is designed to dispense a certain amount of lubrication oil continually to the compressed air. Some pneumatic devices need lubrication to run at peak efficiency. However, some pneumatic applications will omit the lubricator for the following reasons:

1. Clean and hygienic environment for food and pharmaceutical application
2. Oil free, healthier and safer working environment
3. Reduce cost of additional lubrication equipment, lubricating oil and maintenance.



Structure and symbol of a Lubricator

In most applications, especially for those used in school and vocational training, a combined unit or modular design of filter, pressure regular and lubricator is commonly used.

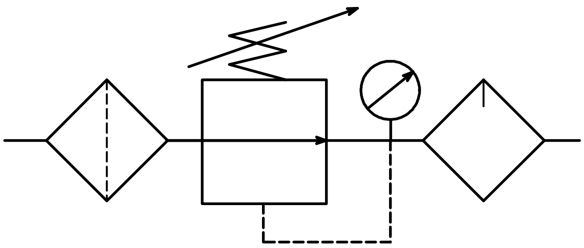


Figure 2.6a Structure and symbol of a combined APU

S T O P A N D T H I N K
What are the advantages of a combined APU?

2.3 Understanding Pneumatic Components

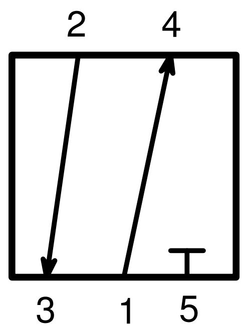


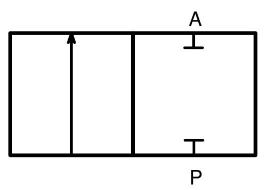
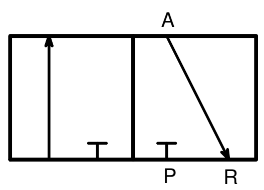
Figure 2.6b Position or box details

When looking at the box in details, the number of ports is determined by the number of end points in a given box and only counted in one box per symbol. In this example, there is a total of 5 ports. In practice, the exhaust port sometimes goes directly to atmosphere with no physical port exists. It can be noted that the actual ports line will extend beyond the box, while the exhaust port is blocked with a symbol **T**.

(I) Directional Control Valves

The function of a directional valve is used to determine the direction of compressed air flow through its ports by changing its internal connections. The descriptions of directional valves are described by the following parameters:

1. The number of ports
2. The number of switching positions
3. The normal (non-operated, initial) position
4. The method of operation or actuation.

Directional Valves symbols	Switching function	Major application
	2/2 ON/OFF without exhaust	Pneumatic tools
	3/2 Normally closed NC	Single acting cylinders (push type)

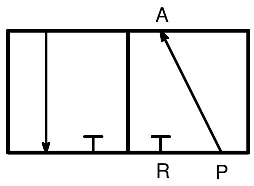
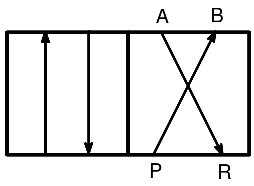
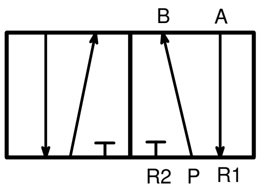
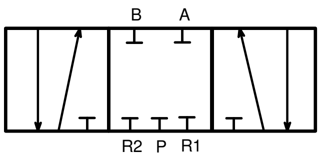
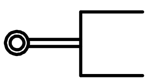
Directional Valves symbols	Switching function	Major application
	3/2 Normally open NO	Single acting cylinders (pull type)
	4/2 Switching between output A and B ports with common exhaust R	Double acting cylinders
	5/2 Switching between output A and B ports with separate exhaust R	Double acting cylinders
	5/3 Switching between output A and B ports with mid-position fully sealed	Double acting cylinders, with neutral position for stopping all cylinders action

Table 2 Symbols (ISO) of common direction valves

Remarks: P is inlet port of working air line; A is the outlet port of working air line; R is the exhaust port.

(II) Valve actuator

The directional valve can be controlled directly by manual control or automatically by mechanical, electrical and air actuation. Below are some common actuator symbols:

Symbols (ISO)	Actuator type
	Spring return
	Roller type (2 directional)

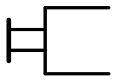
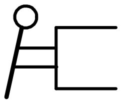
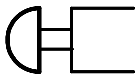
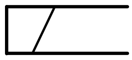
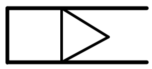
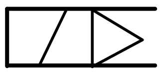
	Manual control
	Lever type manual control
	Push button manual control
	Direct Acting Solenoid
	Air Pilot
	Pilot Assist Solenoid

Table 2.1 Symbols for common valve actuator

Take a typical 5/2 directional valve as an example. It shows the method of actuation, the number of positions, the flow paths and the number of ports. Here is a brief illustration of how to read a symbol:

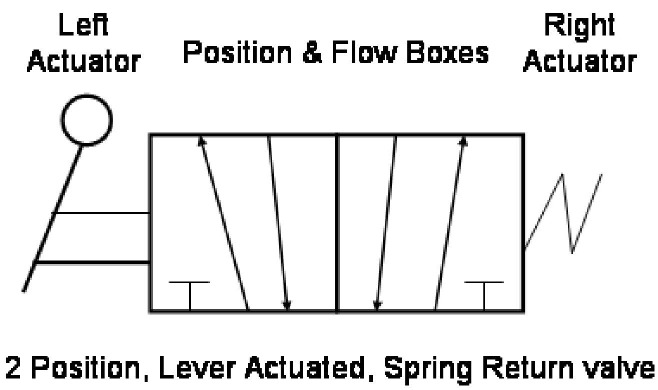


Figure 2.7 Directional Valve symbol
(2 position, lever actuated and spring return)

The left actuator is manually controlled by a lever. It is used to shift the valve from right to left when actuated. This directional valve has at two positions (boxes) and each position has three flow paths.

When the lever is not activated, the spring return actuator in the right side will take control of the valve and the right box will be in operation. When the lever is actuated, the box next to the lever is then in control of the valve. A valve can only be in one “Position” at a time. It should be reminded that there is no external movement occur and only switching of internal connections taking place within the valve housing.

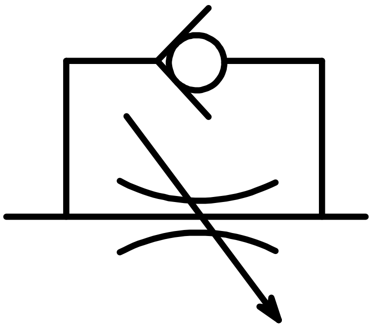
The number of boxes in a valve symbol indicates the number of positions the valve has. Flow direction is indicated by the arrows in each box. The number of arrows represents the number of flow paths the valve has when it is in that position. The position is depending upon which actuator is taking control of the valve at that time.

In practice, the exhaust port goes directly to atmosphere and no physical port exists. The exhaust port is indicated with symbol **T.**

(III) Adjustable speed control of air flow

A speed control valves consists of a check valve and a variable throttle valve in one housing to restrict the air flow in one direction.

The air can flow freely from left to right direction to the cylinder but the air has restricted flow for speed regulation in reverse direction to the cylinder.



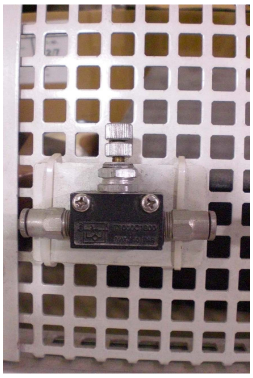
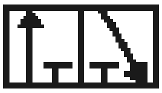


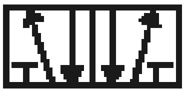
Figure 2.8 Structure and symbol of flow control Valve

S T O P A N D T H I N K

Would you describe briefly the following two valves to see how much you understand at this stage?



(a)



(b)

HIGHLIGHT

1. Cylinder Sizing Calculation

The air cylinder size calculation steps are as follow:

1. Calculate the area of the cylinder piston
   Area = Pi x r^2

2. Multiply the piston area by the air pressure to be used
   Area x Pressure = Force Output

The real force output of a cylinder will be less than the theoretical output because of internal friction and external loading. It is best to use a cylinder that will generate, from 25% to 50% (safety factor). more force than theoretically needed.

2. Cylinder Bore Size Selection

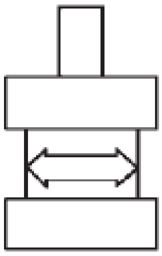


Figure 2.9 Cylinder bore Size

Four easy steps:

1. Determine the force needed to move the load. Add 25% (safety factor) for friction and to provide enough power for the cylinder rod to move at a reasonable rate of speed
2. Find out how much air pressure will be used and maintained in the system.
3. Calculate the power factor by the formula (Air pressure x Power factor = Cylinder force required).
4. Once the power factor is found, the bore diameter can be checked from the table below. For safety sake, the higher approximate value in the table will be chosen for the determination of the bore size.

Power Factor Table											
Bore Diameter	$^3/_4$	1	$1^1/_8$	$1^1/_2$	2	$2^1/_4$	$2^1/_2$	3	$3^1/_4$	4	6
Power Factor	0.4	0.8	1.0	1.8	3.1	4.0	4.9	7.1	8.3	12.6	28.3

Table 2.2 Power Factor Table

Example:
Estimated force needed is 900 N (25% safety factor included). Air pressure to be used is 80 N:

80 (N) x Power Factor = 900 (N).
Power Factor = 900 N / 80 (N) = 11.25

The power factor just above 11.25 is 12.6. Therefore, a bore diameter of 4cm cylinder should be used.

(IV) Factors affecting the performance of cylinder

There are many factors that affect the performance of a cylinder.
Some of these factors are:

1. Quantity and type of fittings leading to the cylinder
2. Hose tube length and capacity
3. Cylinder operating load
4. Air pressure.

(V) Single Acting Cylinder

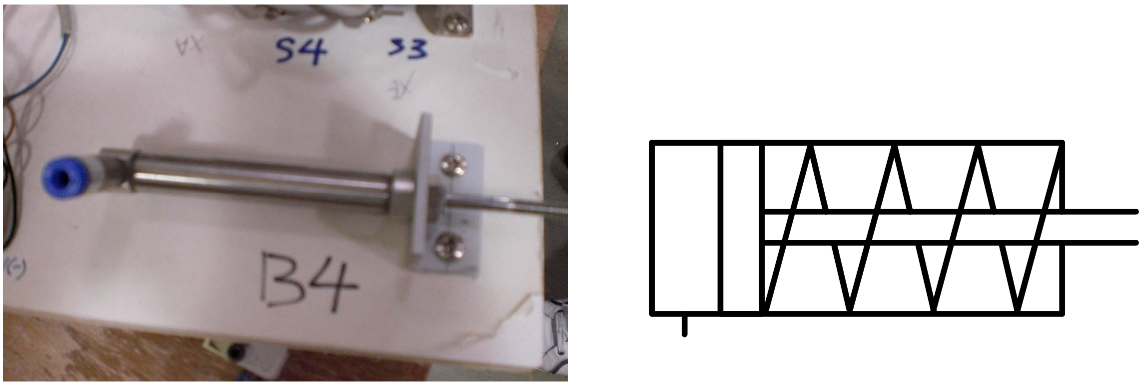


Figure 2.10 Structure and symbol of Single acting cylinder

A single-acting cylinder has one air inlet to provide power to the "extend" stroke. The piston rod is returned by an internal spring. Single-acting cylinders use theoretically one-half as much air as double-acting cylinders. It is operated by a 3-way valve.

(VI) Double Acting Cylinder

Double-acting cylinders have two inlets to provide power to both the "extend" and "retract" stroke. It requires four ways or five ways directional control valves to control.

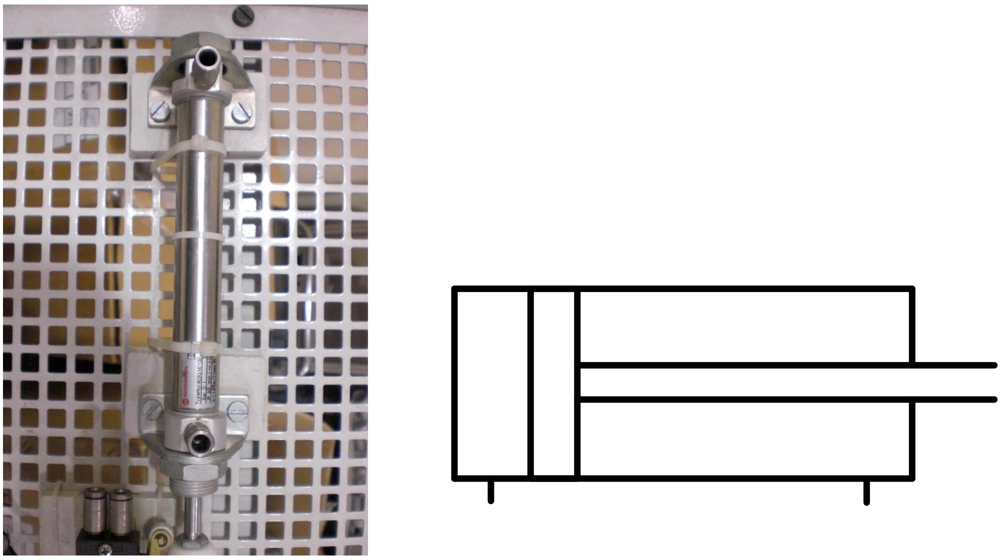


Figure 2.11 Structure and symbol of Double acting cylinder

(VII) Single and Double Rod

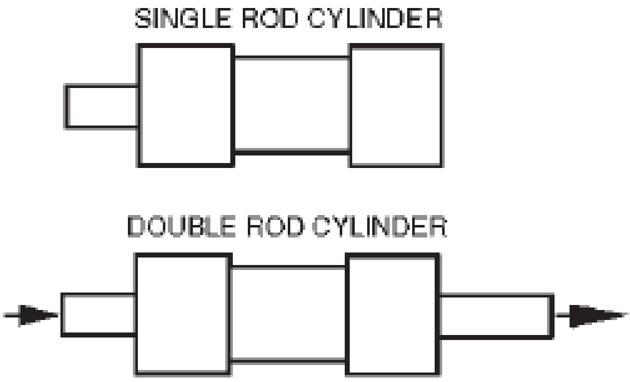


Figure 2.12 Single acting (above) and Double acting cylinder (below)

Single-rod cylinder has a piston rod protruding from only one end of the cylinder. Double-rod cylinder has a common rod, driven by a single piston, protruding from both cylinder ends. When one end retracts, the other end extends.

Double-rod cylinders are excellent for providing an adjustable stroke and additional rigidity. Also, a double-rod with attached cam may be used to trip a limit switch.

2.4 Pneumatic Circuitry

When constructing a pneumatic circuit, it is drawn from bottom to top and from left to right. The circuit layout basically consists of 4 layers. The bottom layer is Air Supply Unit; the second layer is Signal Level; the third level is Control or Logic Level; and the top level is Power level.

Pneumatic circuits are the assemblies of valves and a collection of elementary sub-circuits to perform control functions. These functions are usually consist of the followings:

1. Control output actuators, such as single-acting, double-acting cylinders, rotary actuator and slide unit
2. Operate another valves, such as remote control and safety interlocks
3. Perform logic control functions, such as AND, OR and NOT.

(I) Number notation in pneumatic circuits

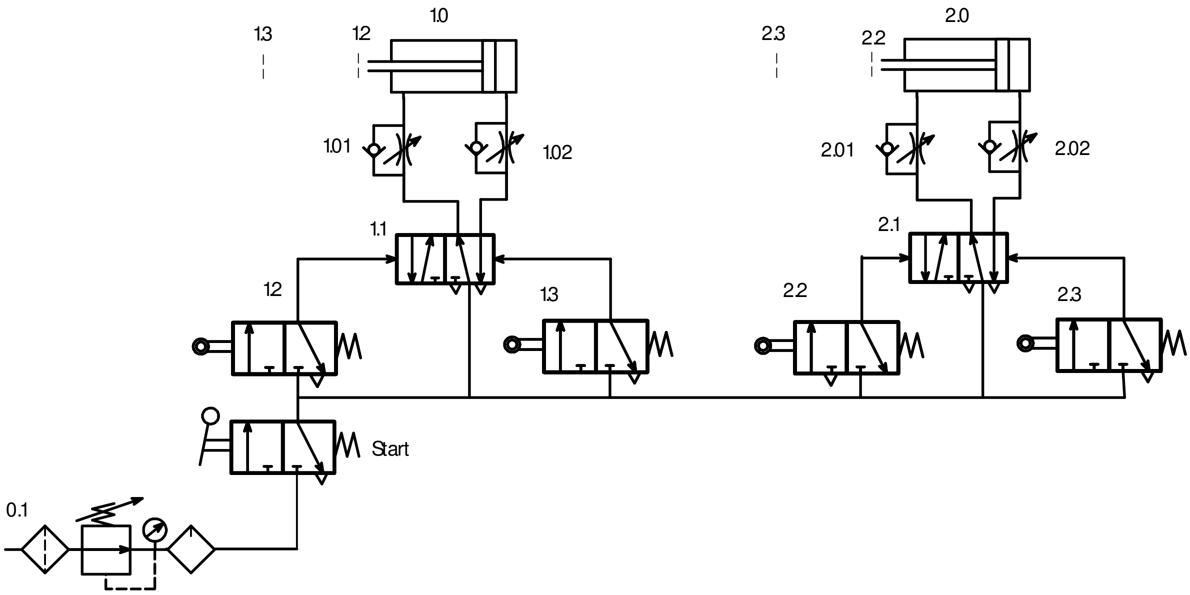


Figure 2.13 Pneumatic circuit with number notation

Pneumatics Components	Numbering Notation	Remarks
Top level: Working components	1.0, 2.0,3.0, ……	Mark the actuators.
	1.01,1.02,2.01,2.02, 3.01,3.02,…….	Mark the auxiliary components, i.e. flow restriction valve.
Third level: Control components	1.1, 2.1, 3.1,…..	Mark the components connected to working components, i.e. 3/2 directional valve to the single acting cylinder; 5/2 directional valve to the double acting cylinder.
Second level: Signal Components	1.2,1.4,1.6, ….. 2.2,2.4,2.6, ….	Mark the signal components responsible for the outstroke of cylinder, i.e. 3/2 NC valve
	1.3,1.5,1.7, …… 2.3,2.5,2.7, ……	Mark the signal components responsible for the retraction of cylinder, i.e. 3/2 NC valve
Bottom level: Air Supply Components	0.1, 0.2, 0.3, ……..	Mark the elementary air supply unit to pneumatic circuit. i.e. AHUs

Table 2.3 Numbering notation in pneumatic circuit

(II) Elementary functions

a. Flow amplification and remote control

A large power rating cylinder is needed for most industrial application. Thus a large directional valve with sufficient air capacity is required. However, it is dangerous to operate a large valve directly or in close proximity by an operator. A small manually operated valve is used to control a large pilot-operated valve at a remote distance. The large capacity valve can be installed close to the cylinder.

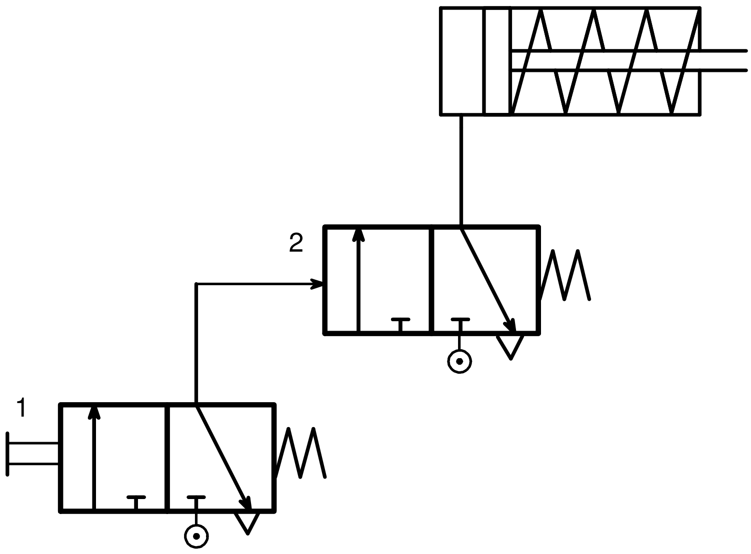


Figure 2.14 Flow amplification and remote control of cylinder

b. Signal Inversion

A 3/2 normally closed valve (NC) is connected to the 3/2 normally open valve (NO). When the NC valve is pressed, the NC changes position and pressure releases.

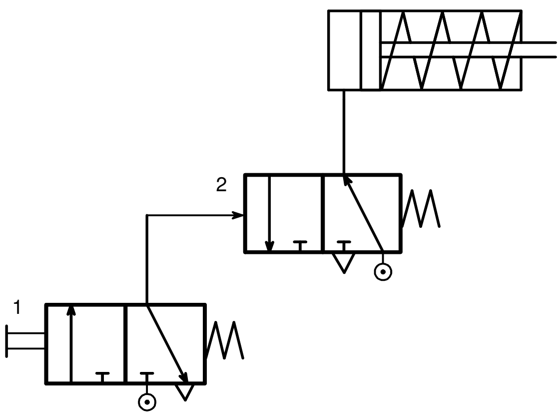


Figure 2.15 Circuit diagram of Signal inversion

c. Mono-stable circuit

A 3/2 manual operated NC valve is used to control a 5/2 valve which actuates a double acting cylinder. This circuit has two functions: (1) one is for flow amplification, (2) Another is the control of double acting cylinder with one 3/2 NC valve.

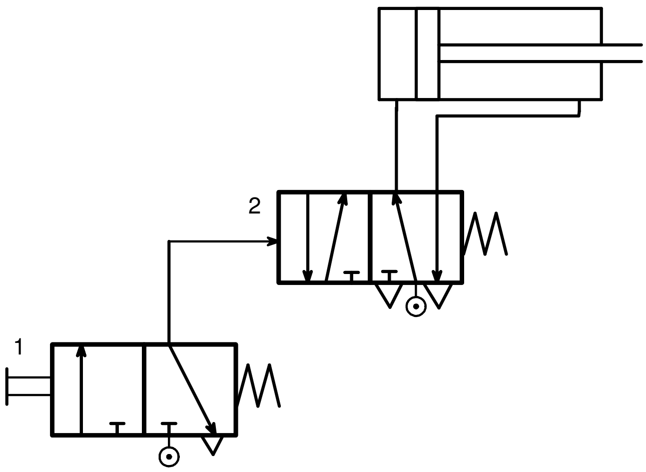


Figure 2.16 Switching of two circuits with one manual operated valve

d. Bi-stable Circuit

Two normally closed 3/2 valves are used to control a 5/2 directional valve which is used for actuating a double acting cylinder. When the left valve is pressed momentarily, the cylinder will retract and hold its position until the right 3/2 valve is pressed. When the right 3/2 valve is pressed momentarily, the cylinder will extend. This circuit has two functions: (1) flow amplification (2) memory function.

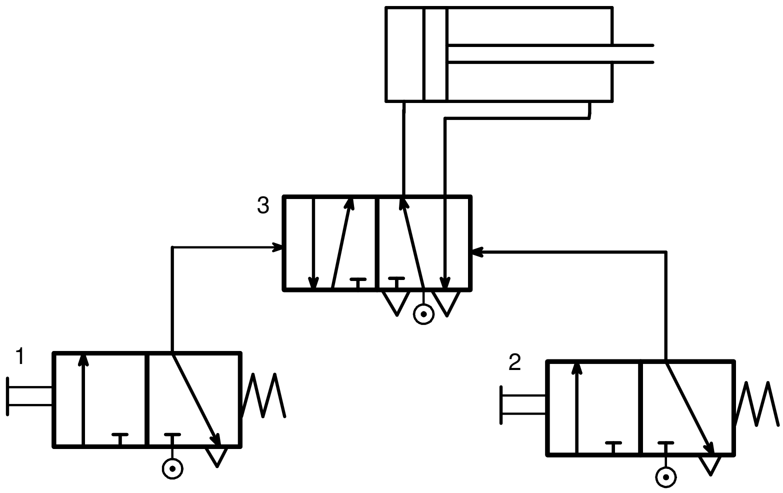


Figure 2.17 Switching of two circuits with one manual operated valve

e. Timing Circuits

A 3/2 NC valve is used to control another 3/2 NC valve. A flow restriction valve is connected in the pilot line and in a direction that the ON signal is delayed. When the valve 1 is pressed, the air flow is restricted to the directional valve. The cylinder will extend after a certain time delay. When the valve 1 is released, the exhaust air flows freely. The cylinder retracts immediately.

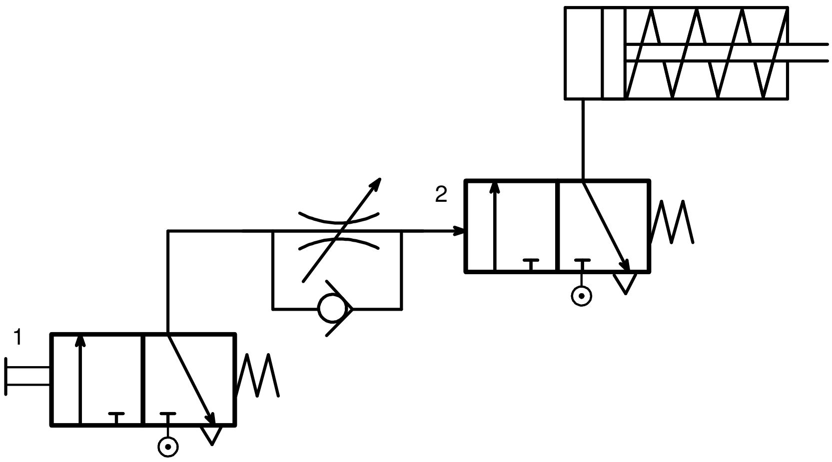


Figure 2.18 Delayed switching ON circuit

A 3/2 NC valve is used to control another 3/2 NC valve. A flow restriction valve is connected in the pilot line and is in a direction that the OFF signal is delayed. When the valve 1 is pressed, the air flow freely to the directional valve. However, when the valve 1 is released, the exhaust flow is restricted. Therefore, the cylinder retracts after a delay.

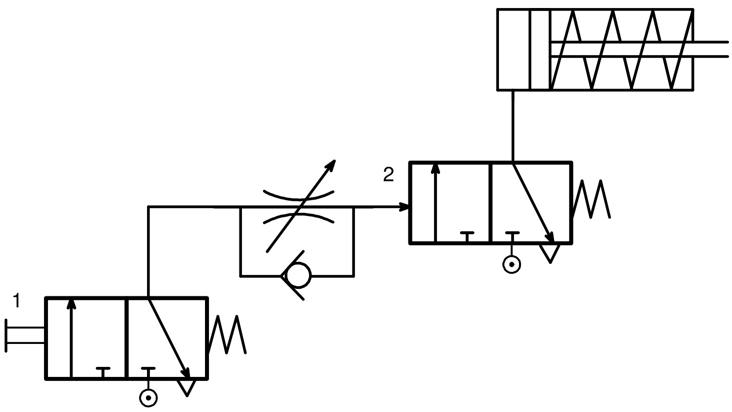


Figure 2.19 Delayed switching OFF circuit

STOP AND THINK

Why the air pressure fluctuates within the plants? Please list any 4 points.

(1) ____________________

(2) ____________________

(3) ____________________

(4) ____________________

f. Direct operation and speed control of single acting cylinder

A manual operated 3/2 NC valve is used to directly control a single-acting cylinder. A flow restriction valve is connected in the pilot line. The circuit can control the speed of the cylinder outstroke. The cylinder is returned by a spring force once the valve is released. No flow restriction in the return stroke.

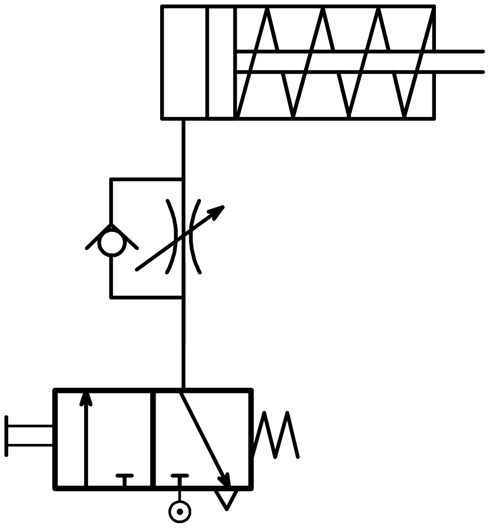


Figure 2.20 Direct control of a single acting cylinder

(III) Logic Circuits

a. Logic OR function for a single acting cylinder

With a shuttle (OR) valve connected for the operation of a single acting cylinder, the outstroke of the cylinder can be actuated by either of the two 3/2 valve. If the shuttle valve is absent in practicality, the air from one valve will escape directly through the exhaust port of another valve. A flow restriction valve is added to regulate the speed of the outstroke.

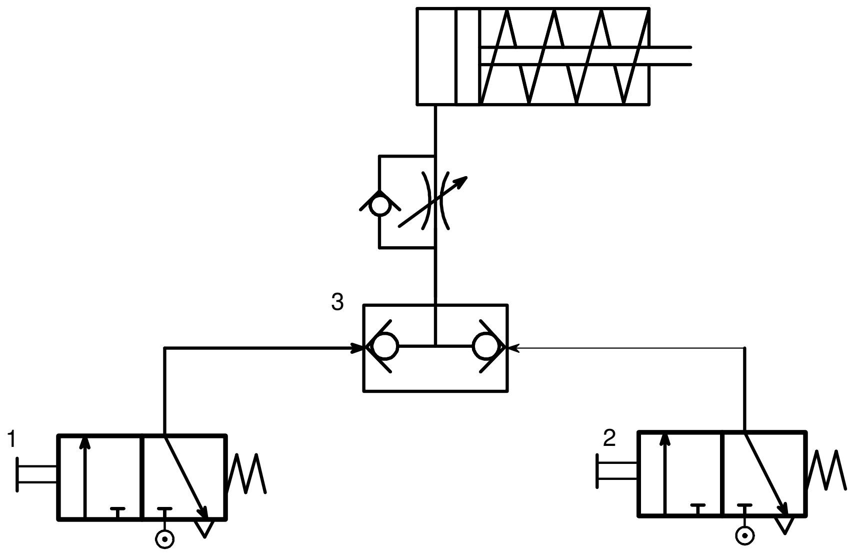


Figure 2.21 "OR" Operation of a single-acting cylinder

b. Logic AND function for a single acting cylinder

This function is commonly known as an interlock function for safety purpose. Two 3/2 NC valves are connected in series. Both valves need to be pressed together for the outstroke operation of a single acting cylinder. The first valve can be a mechanical plunger operated valve to make sure that the safety door is in place for common machine operation. Then, the second valve may be the manual switch pressed by the operator. The outstroke of single acting cylinder can be made only when?? both valves are actuated.

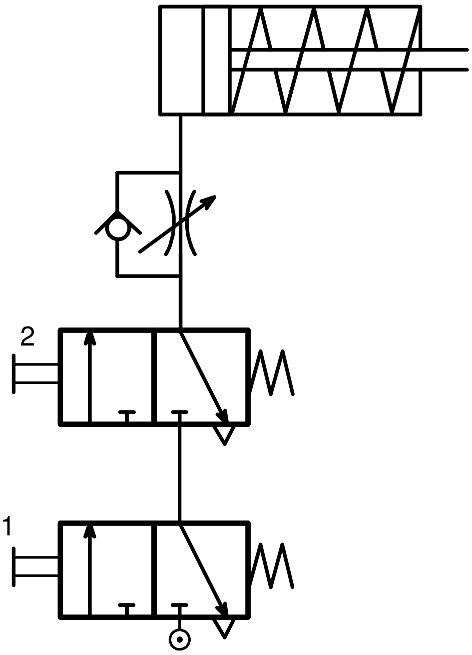


Figure 2.22 Interlock and "AND" function of a single-acting cylinder

c. Inverse Operation NOT function

A 3/2 manual actuated NC valve is used to control a 3/2 NO valve for the inverse operation of single acting cylinder. The cylinder is in an outstroke condition as an initial position. When the NC valve is pressed momentarily, the cylinder will retract at a regulated speed, and a flow restriction valve is connected in the exhaust line. It may be used for an unlocking function of some mechanical devices.

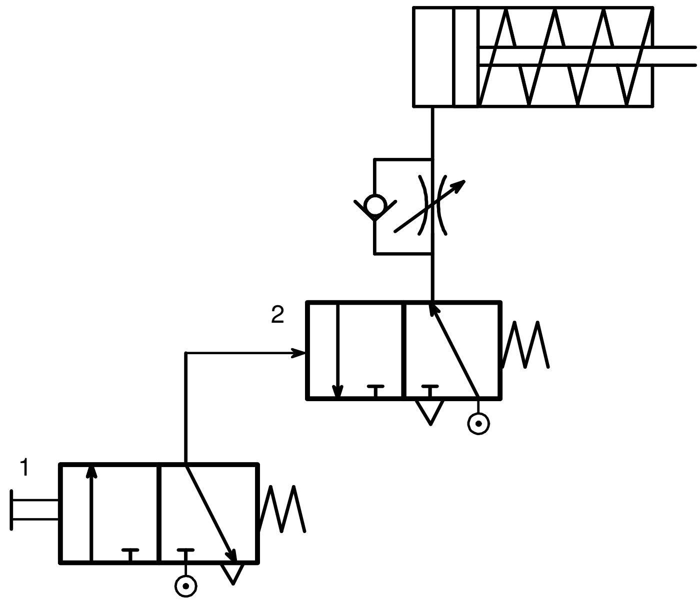


Figure 2.23 Signal inversion of a cylinder

d. Direct control of a double acting cylinder

A 5/2 directional valve is used for a basic operation of a double acting cylinder. The cylinder is in a retracted position when the spring takes the control of that valve. Once the valve is pressed momentarily, the cylinders will outstroke. The speed of both directions can be regulated independently by two flow restriction valve.

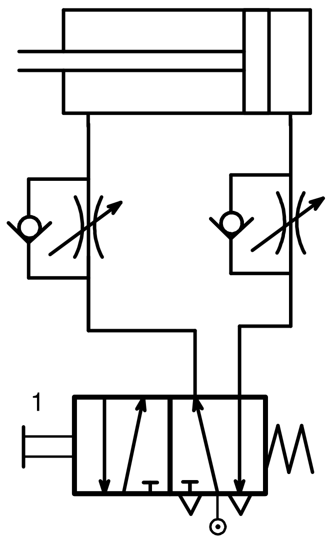


Figure 2.24 Direct control of a double acting cylinder

e. Bi-stable control of a double acting cylinder

Two 3/2 NC valves are used for the control of 5/2 valve and in turn control the double acting cylinder. When valve 1 is pressed momentarily, the cylinder will extend and hold its position even the valve is released. The cylinder will retract until the valve 2 is pressed momentarily. The speed of both directions can be regulated by two flow restriction valves. This circuit is also known as a “memory” function.

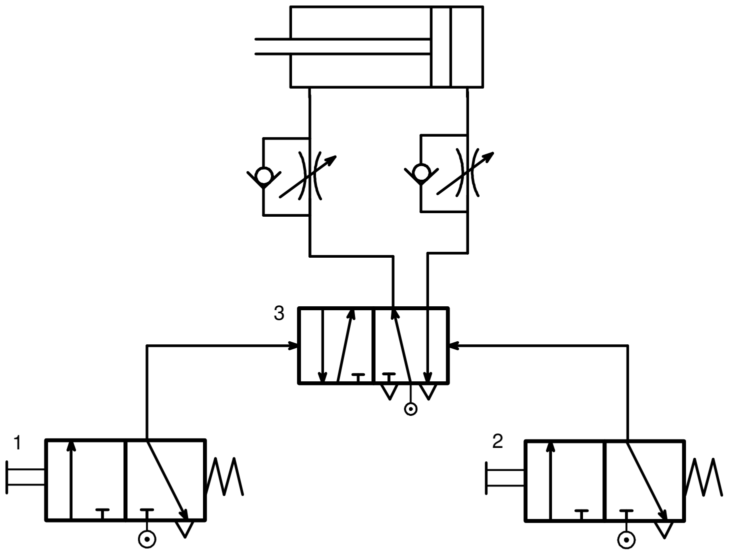


Figure 2.25 Memory function of double acting cylinder control

f. Automatic return of double acting cylinder

One of the two manual operated 3/2 NC valves is replaced by a roller actuated valve and is put to the position at the end of the cylinder outstroke. When the valve 1 is pressed momentarily, the cylinder extends. When the cylinder rod trips the valve 2 at the end of outstroke, the cylinder will retract automatically.

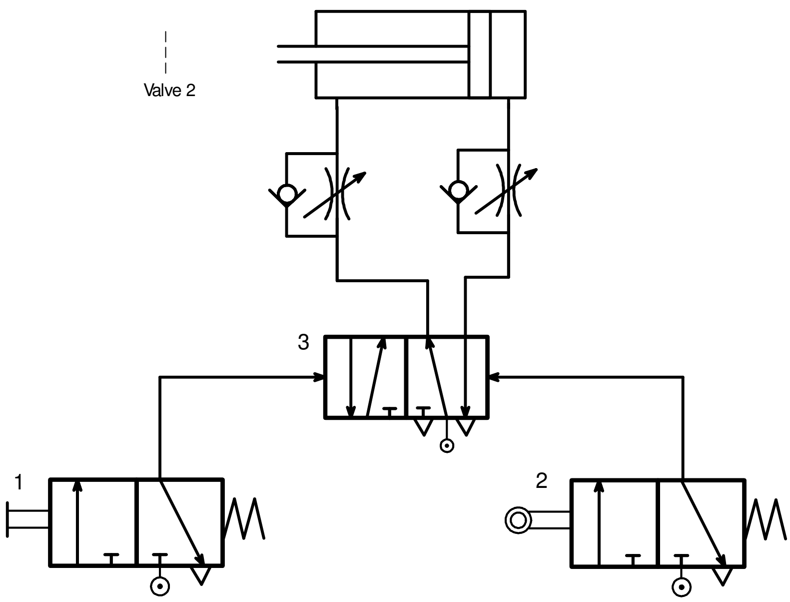


Figure 2.26 Automatic control of a double acting cylinder

S T O P   A N D   T H I N K

1. What will happen in the above circuit if valve 1 is still pressed even when valve 2 is tripped at the end of the outstroke?
2. Would you suggest any modification to the circuit to improve this situation?

g. Reciprocating strokes

Repeating strokes of a double acting cylinder can be designed by two roller-actuated 3/2 NC valves. They are at both ends of stroke. A 3/2 manual operated valve is connected in series with one of the roller-operated valve to perform an interlock (AND) function as a "manual" switch to start the automatic reciprocating stroke.

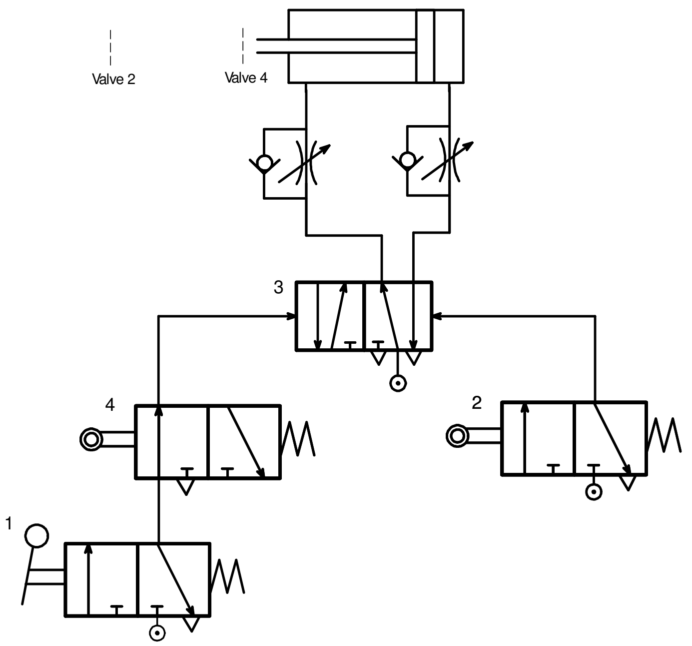


Figure 2.27 Reciprocating stroke of a double acting cylinder

H I G H L I G H T

Working principle of electromagnetic relay

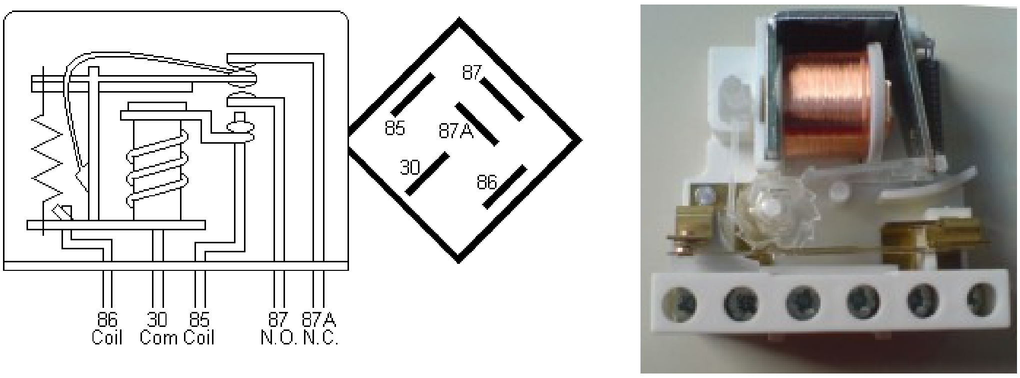


Figure 2.28 Schematic diagram of electro-mechanical relay principle.

An electromagnetic relay is an electrical switch that can be actuated indirectly by another switch. When the coil is energized, current flows through the coil and generates an attractive electromagnetic force. The armature is pulled down, causing the lever arm to close the contacts. When the coil is de-energized, the spring pulls the lever arm down and opens the contacts. Electromagnetic relay can be designed with normally open contacts or with normally closed contacts. It is a commonly used device in electro-pneumatics and PLC applications.

1. Functions of Electromagnetic relay

- It is an electrical switch with a high current rating that is indirectly operated by a low control current
- It acts as an interface between the low signal levels (5-12V) from controllers to high current rating devices
- It can provide contact points for one to many
- It can provide contact points from normal close to normal open or vise versa

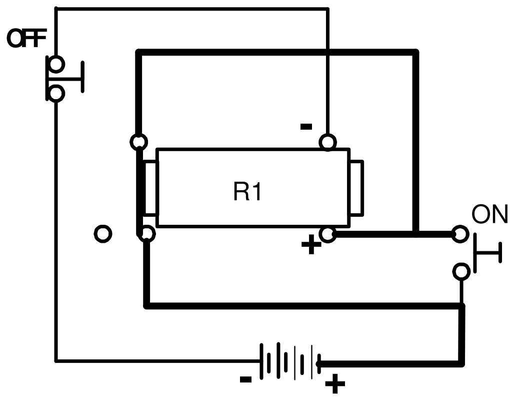
2. Limitations of Electromagnetic relay

- It contains moving parts and electrical contacts; it has limited operating speed, reliability and lifespan
- It is big in size and requires large mounting racks in application
- Each relay can only provide a small number of contacts
- It is very difficult to change the control function of a relay system once it is connected up. A complete re-wiring may be necessary for changing control tasks
- Due to limited lifespan, the replacement and maintenance involves high cost

3. Latching function of Electromechanical relay

It can be connected to an electro-pneumatic circuit for the control of solenoid valves and the control function of Programmable Logic Controller (PLC), an automatic pneumatic system can be realized.

The latching function of electromagnetic relay can be done by connecting the power line to one of the contact pins. Once the coil is energized, the contact closes and allows power to the coil. When the ON switch is turned off, the coil remains energized by the power line. An OFF switch is connected to "reset" the relay.



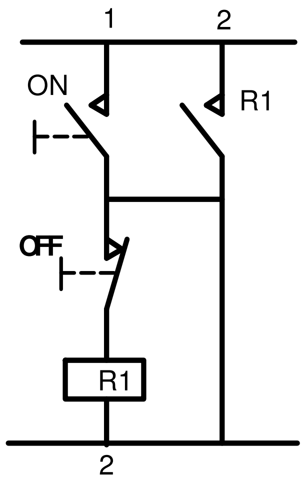


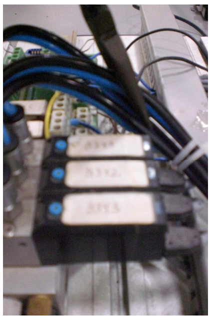
Figure 2.29 (left) Electrical circuit diagram; (right) Electro-pneumatic circuit of "latch" relay

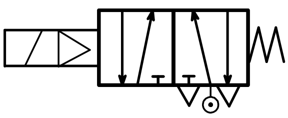
(IV) Electro-pneumatic

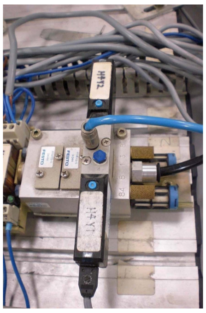
a. Solenoid valve

For electro-pneumatic applications, there are two types of solenoid valve: double solenoid and single solenoid.

For double solenoid valve, the cylinder will extend if one of the solenoid is energized. The extended cylinder will hold its position by either leaving the solenoid in the energized state or un-energized state. When energizing the opposite solenoid, the cylinder will retract.
For a single solenoid valve, the valve will shift back to its original position and the cylinder will retract when power is turned off.







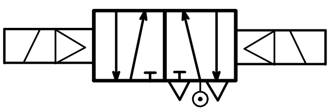


Figure 2.30 (left) single solenoid valve; (right) double solenoid valve

b. Major symbols for Electro-pneumatic circuit

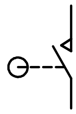
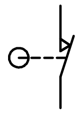
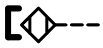
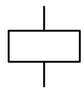
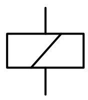
Operation	ISO Symbol
N.O. spring return ,2 points contact	
N.C. spring return ,2 points contact	
N.O. roller-operated, spring-return contact	
N.C. roller-operated, spring-return contact	
N.O. Solenoid controlled proximity contact	
Control relay	
Solenoid	

Table 2.4 ISO symbols of Electro-pneumatic circuit

c. Electro-pneumatic circuit

(i) Manual control

Manual control (push button) of a double-acting cylinder can be done by using solenoid valves and a 5/2 valve respectively. When pressing the pushbutton, it energizes the solenoid to extend the cylinder. Once the pushbutton is released, the cylinder retracts by the spring force.

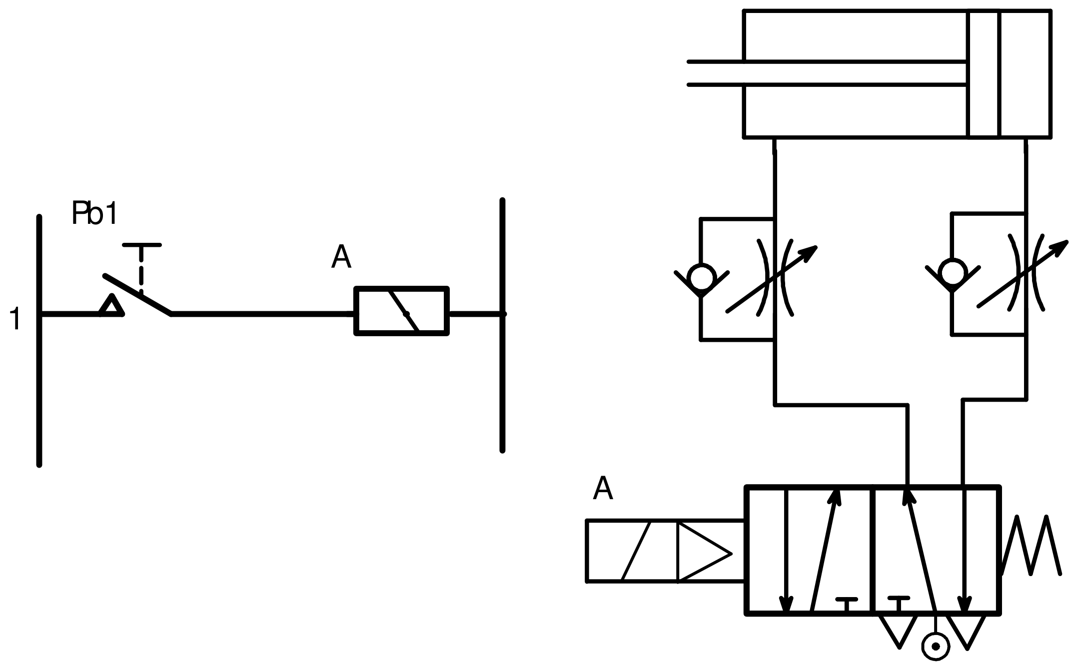


Figure 2.31 Manual operation of a double-acting cylinders

(ii) "OR" control

For electro-pneumatic system, two or more pushbuttons can be used to control the actuation of cylinders through an "OR" logic control without the problem of air leakage through switches as in pneumatic system.

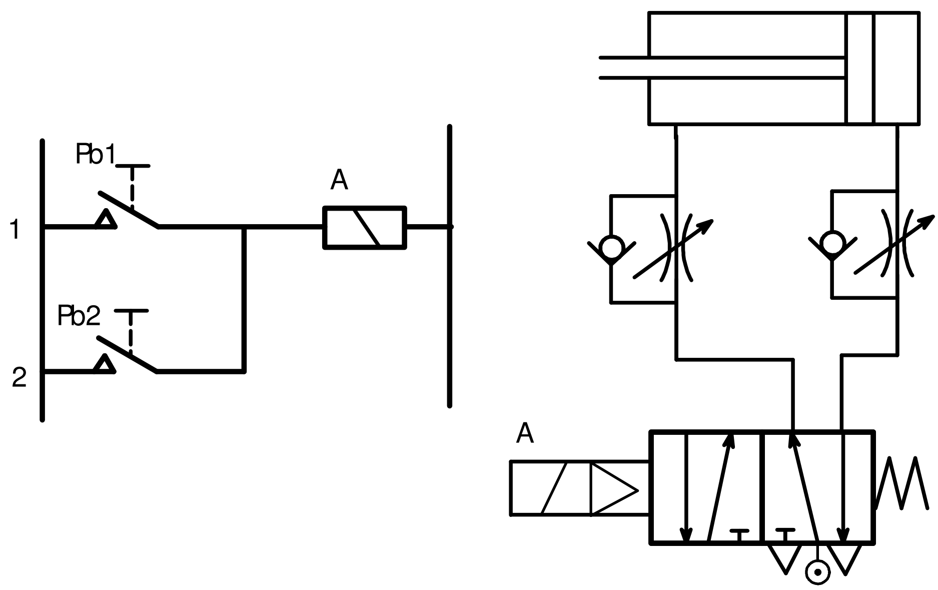


Figure 2.32 "OR" operation of double-acting cylinders

(iii) Multiple contacts

When pressing either the pushbutton of pb1 or pb2, the solenoid will be energized and the lamp will be turned on as shown in Figure 2.33

In Figure 2.34, when pb1 is closed, it energizes control relay R1 which will then turn on the lamp and solenoid valve (A) to extend the cylinder. When pressing pb2, only the solenoid (A) is energized to extend the cylinder but it does not turn on the lamp.

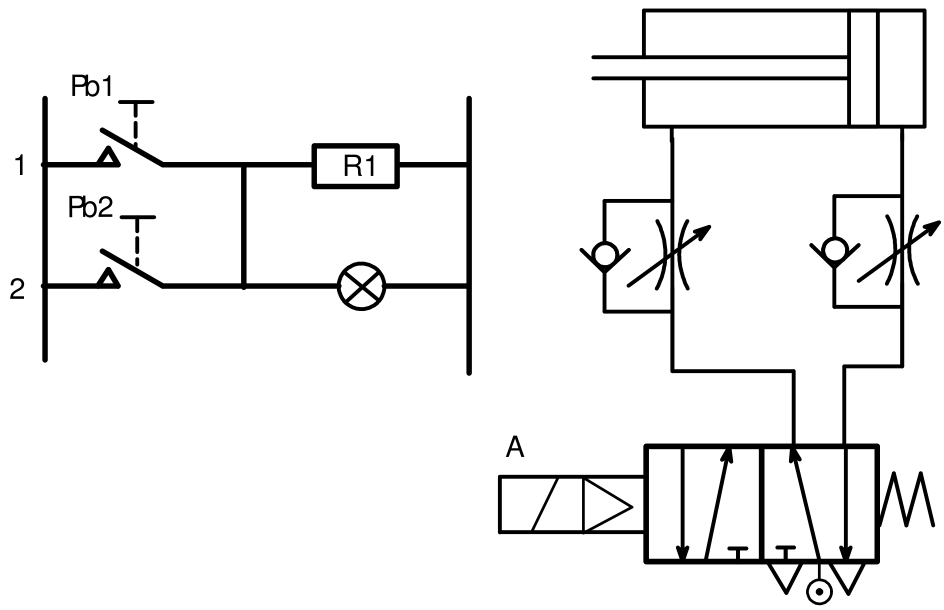


Figure 2.33 Control of cylinder and lamp by either pb1 or pb2

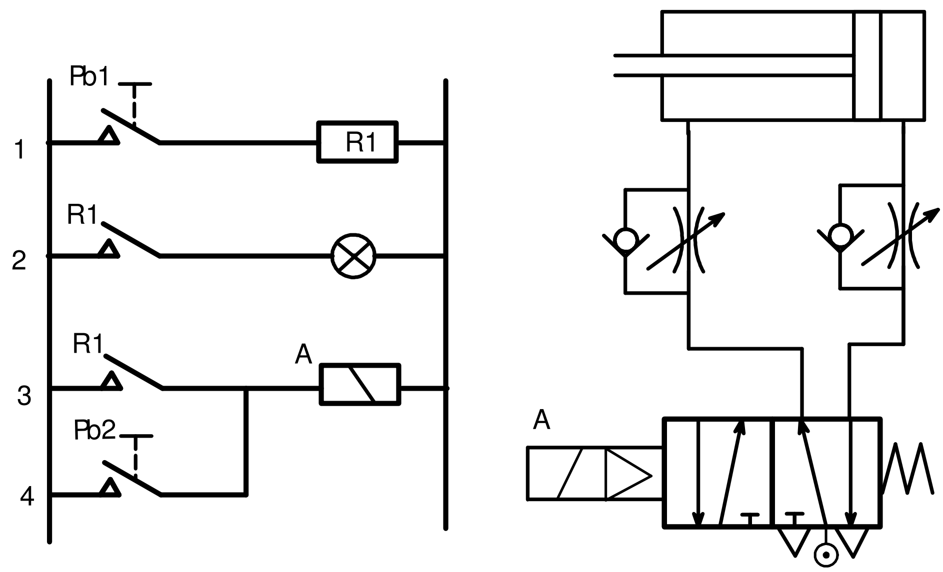


Figure 2.34 Control of cylinder and lamp by pb1; pb2 for controlling cylinder only.

(iv) Control of Slide Unit

Double solenoid valve has a bi-stable characteristic. When Pb1 is pressed, the slide moves from left to right and is held in that position until Pb2 is pressed.

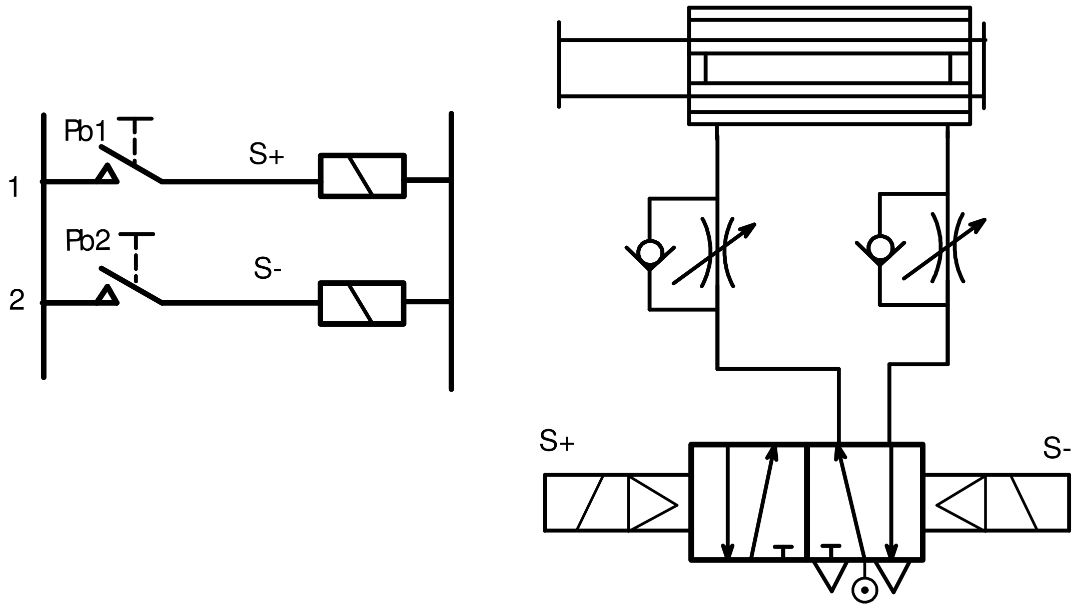


Figure 2.35 Control of Slide unit movement.

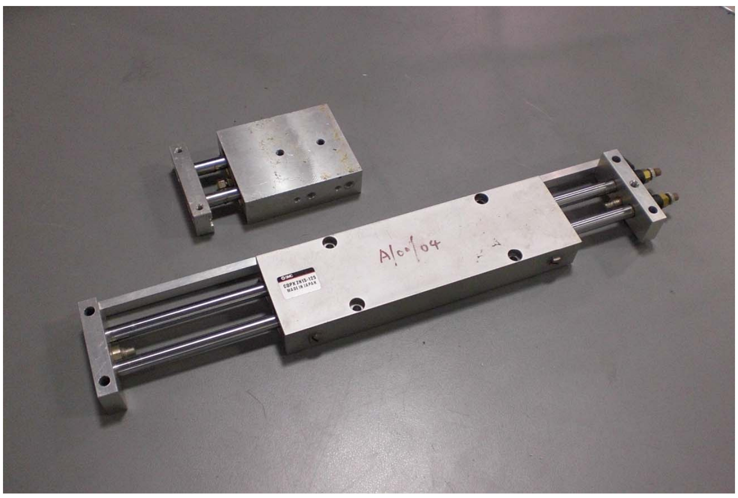


Figure 2.36 Slide Unit

(v) Control of rotary actuator

The rotary actuator has a built-in positional switch at the limit. When the START (pb1) button is pressed, it energizes solenoid S+, the rotary actuator turns from left to right and is held in that position. Once the START button is released, the "triggered" positional switch a1 energizes the solenoid S- immediately and the rotary actuator returns to the left automatically.

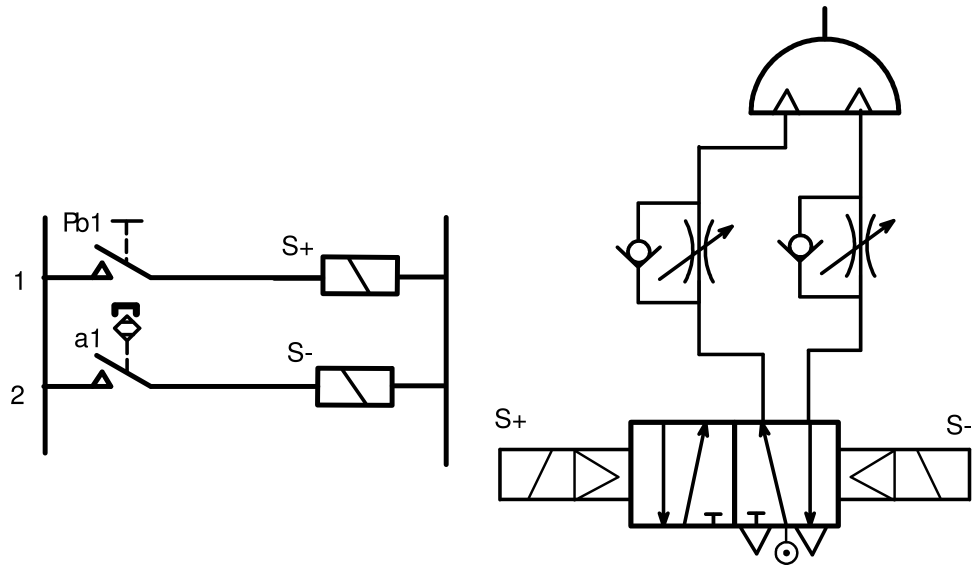


Figure 2.37 Automatic return of rotary actuator

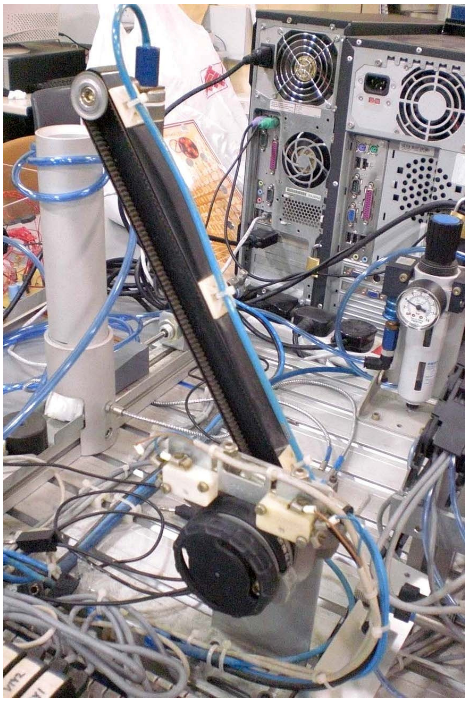


Figure 2.38 Rotary Actuator

(vi) Reciprocating movement of linear drive

Slide actuator usually has positional switches at the ends of movement limit. When the START button is pressed and held in this position, the side will move back and forth because of the alternate switching of positional switches ao and a1. ao and a1 are used for energizing the S+ and S- solenoids for controlling the forward and backward movements respectively.

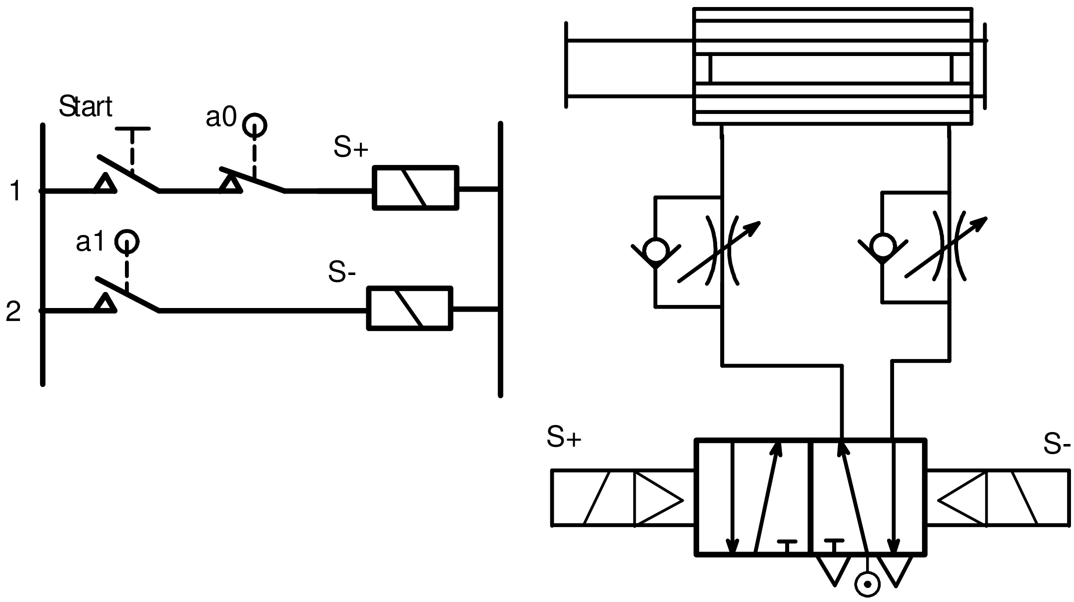


Figure 2.39 Reciprocating movement of Linear drive

(vii) Time delay circuit

A double acting cylinder can be reciprocating. The time of action can be adjusted by delay on timer. In case of power failure, the cylinder will keep on moving to the end and held in this position until the power resumes.

The double acting cylinder has two built-in positional switches, a0 and a1, at both ends of its stroke. In Figure 2.40, the normal open a0 is closed in the initial position. When the START button is pressed, the timer T1 is energized. The timer will in turn energize the solenoid S+ to extend the cylinder when the preset time is over.

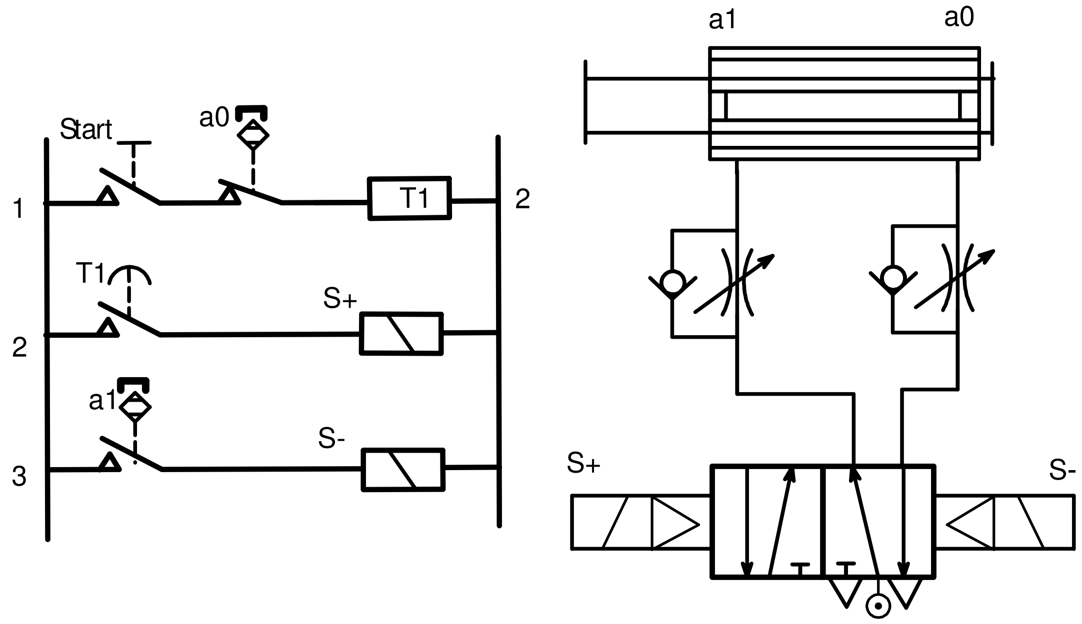


Figure 2.40 Double acting cylinder with delay on timer in extend stroke

In Figure 2.41 a0 is closed in the initial position as it is triggered in the retract stroke. When START button is pressed, T1 is energized and cylinder will extend after a certain time of delay. When the cylinder rod is fully extended, a1, as a positional switch, will be triggered. It will energize another delay on timer. After a preset period of time, the solenoid S- will be energized. The directional valve will move to the right and the cylinder rod will retract.

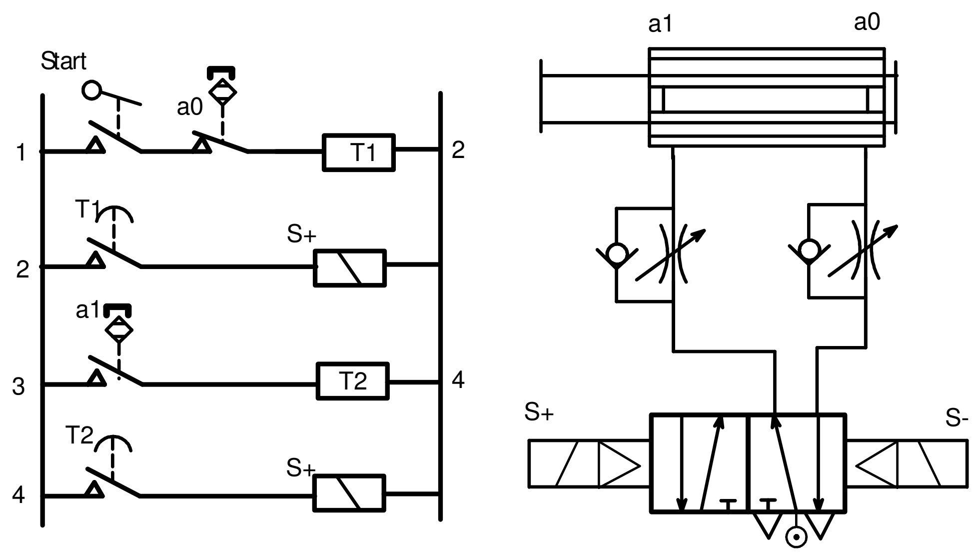


Figure 2.41 Double acting cylinder with delay-on timer in both extend and retract stroke

(viii) Sequential control of electro-pneumatic system

For simplicity, cylinder is omitted in the illustration. R1 is a normal close control relay. When START button is pressed, T1 is energized and the LED is on. After the preset period, R1 is energized by T1 in line 3, the normal close R1 become open. The LED will then be turned off. At the same time, control relay R1 in line 4 is closed and T2 is energized. After the preset duration of T2, T2 opens and de-energize R1 in line 1, R1 in line 1 backs to its NC state and the LED turns on again. This sequential operation repeats itself.

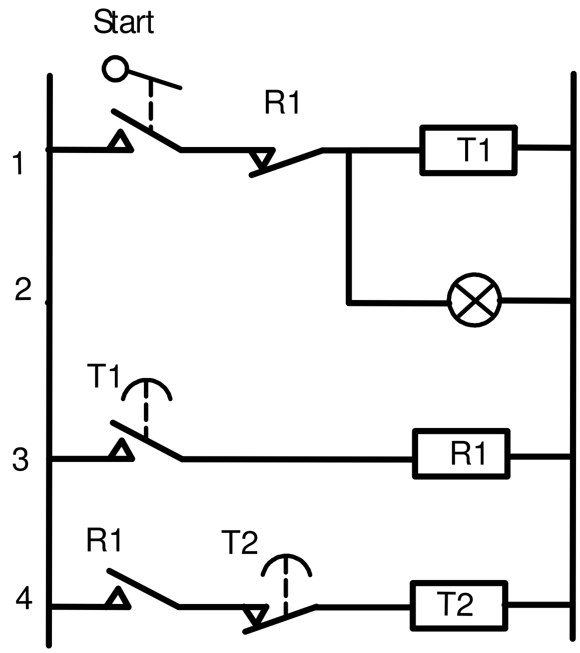
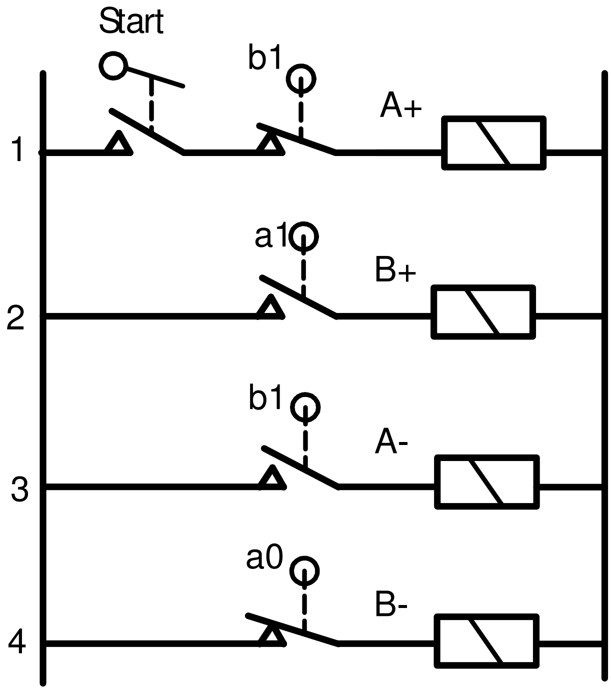


Figure 2.42 Control of bi-stable LED flashing

E X A M P L E
Take a game kiosk in an amusement park as an example, a pneumatic 2-fingers gripper is installed in a double acting slide. The actions are as follow: 1. A 2-fingers gripper is open in initial position 2. The gripper is attached to the double acting slide 3. The gripper and the slide are driven by pneumatic but controlled by PLC 4. The slide moves to the right from left when the START button is pressed 5. When it moves to the preset position, the gripper will close and try to pick up a toy 6. The slide will move to the initial position with the gripped closed 7. At the end of the return stroke, the gripper finger will open and drop the toy.

For simplicity, the downward movement of gripper for picking up a toy is omitted. a0, a1, b0 and b1 are positional switches for slide and gripper respectively. bo is closed in its initial state and the gripper is in open position. When the START button is pressed, A+ is energized and the slide extends to the left. At the end of extend stroke, a1 is triggered and energizes the solenoid B+. With the energizing of B+, the 2-fingers gripper closes. When b1 is triggered by closing the gripper, it in turn energizes A-. The slide is then retracted. After it is fully retracted, a0 is closed and in turn energizes B- to open the 2-fingers gripper.



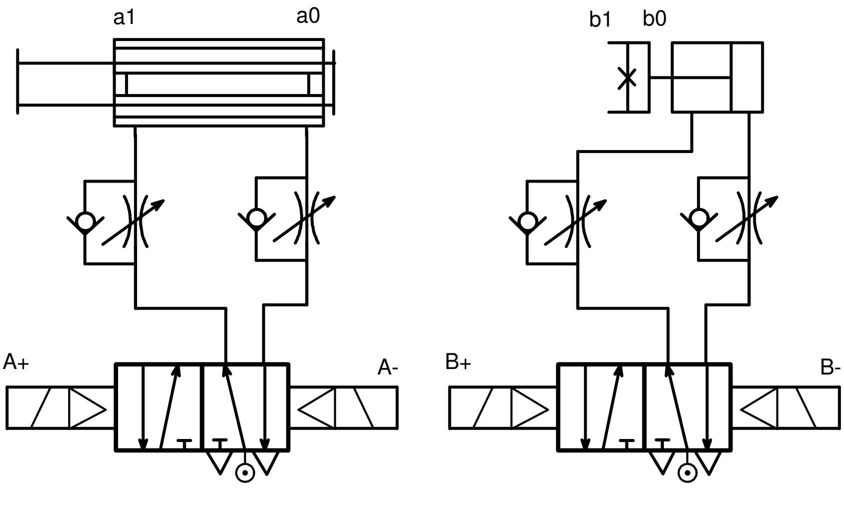


Figure 2.43 Sequential controls of pneumatic slide and gripper

2.5 Electro-pneumatic Systems

This section introduces the use of electro-pneumatics parts that can be controlled by Programmable Logic Controller (PLCs). This will also be discussed in Chapter 3.
When the electro-pneumatic solenoid receives an electrical signal from the electronic controller, which can be either PC or PLC. Practically, the input signal can be accepted in form of 0 - 20mA DC or 0-10V DC. With this input, the unit regulates the high pressure air supply to the final control element, such as control valve, to give a corresponding displacement.

(I) Applications of pneumatic/electro-pneumatic systems

Pneumatic and Electro-pneumatic control systems are widely adopted in process control and the production line automation in manufacturing industry.

a. Materials Transfer

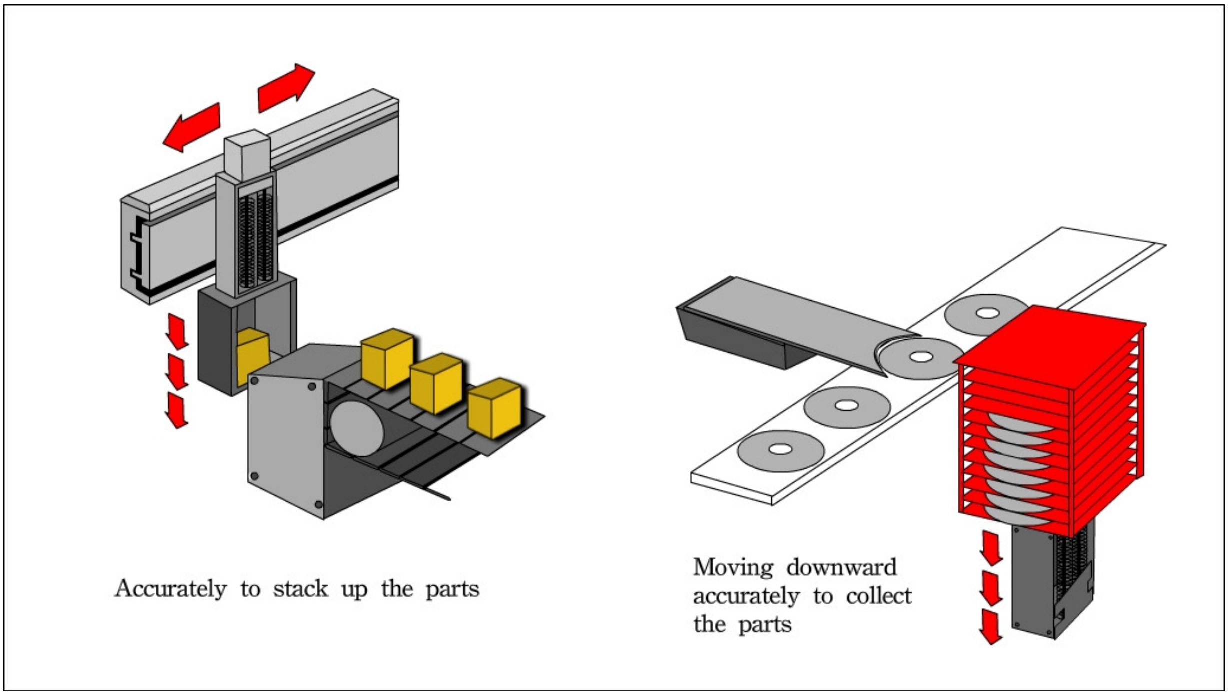


Figure 2.44 Examples of material transfer application

In Figure 2.44 (left) a tailor-made container is attached to the end of the cylinder rod to collect the pre-cut work pieces that are coming progressively from the conveyor belt. As the work pieces fill up the container, the cylinder has to move down (extend) progressively to collect the new coming work pieces at an appropriate height. The timing of the cylinder displacement must synchronize with the conveyor speed. This is achieved after careful calculation and a number of trial runs in the production line. The cylinder is fixed to an electro-pneumatic slide unit that moves back and forth to serve other conveyor belts.
For figure 2.44 (right), it is a CD production line. There are two cylinders in this transfer

mechanism. One cylinder steadily pushes the CD from the conveyor belt to the material magazine. Another cylinder that connects to the magazine needs to vertically move down (retract) progressively to allow each CD feed to the empty slot every time.

S T O P   A N D   T H I N K

For the two cases above, please suggest with reasons for (a) what types of cylinder to be used? (b) Should air-piloted or solenoid control valves be used in this application?

b. Testing of limit switch

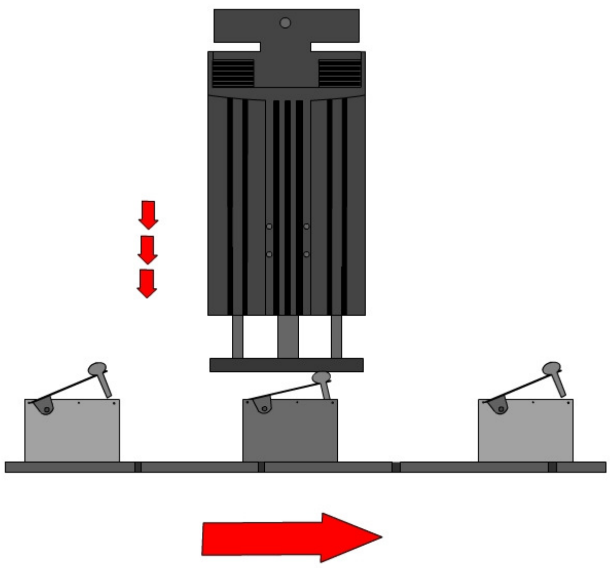


Figure 2.45 Testing of limit switches

The pneumatic systems above are used for the automatic testing and transfer mechanism. The linear drive on the left is used to trip the limit switch for functional or failure test. Limit switches are moved along the conveyor belt. This action is tedious and requires constant magnitude of force for testing. Only automation can do this job at a standard and efficient way.

c. Work piece ejection in punching machine

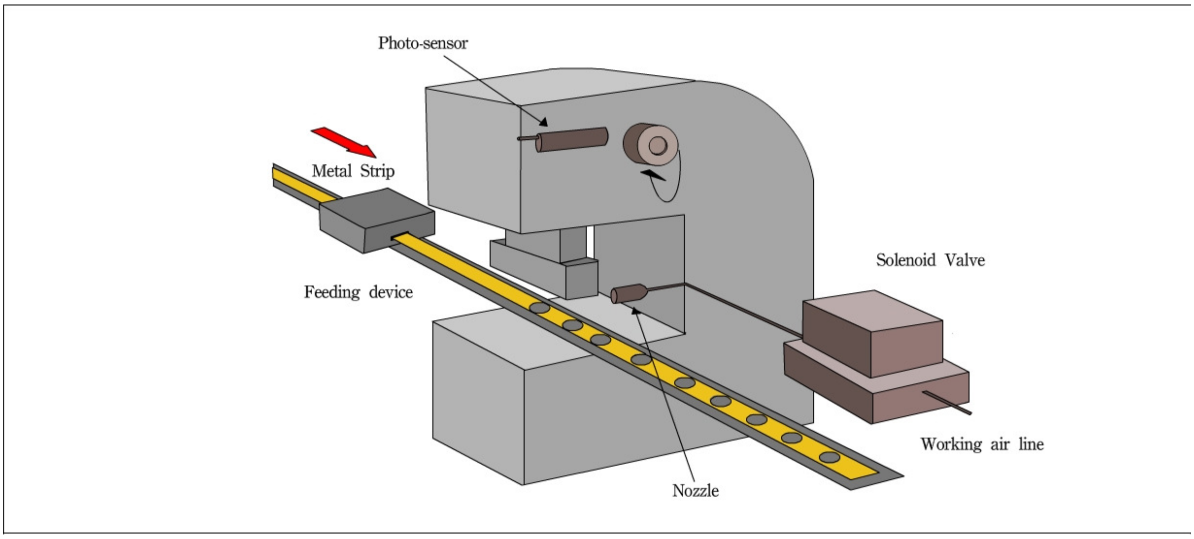


Figure 2.60 Punching Machine Accessory Function

For a conventional metalworking punching machine, a continuous supply of compressed air is needed to "blow" the finished work pieces off the way. It will cause wastage of compressed air if it is supplied continuously during the punching action. To improve this situation, a 2-way solenoid valve and an opt-electrical switch will work together. The control valve will actuate only when the dies are open, the compressed air will then "blow" out of the nozzle to push the finished parts out of the way for collection. That will save 50% volume of compressed air.

S T O P A N D T H I N K

One of the advantages of pneumatic system is theoretically of no cost at all as the supply of air is free in the atmosphere. Therefore, in the above case, why engineers need to design an automatic system to reduce the wastage of compressed air?

(I) Safety Consideration of Pneumatic systems

1. Contaminants of solid particles may come from damaged pump and valve sealing
2. Liquid contamination may come from oil, water, or cleaning solvents
3. A loose fitting or damaged hose allowing contaminants into the system by-passing the filter
4. Worn out, misused, or incorrectly routed hoses
5. Use the right voltage for solenoid valve
6. Calculate the correct air pressure to activate your device
7. Use pressure relief valves

8. Repair air leaks immediately
9. Wear safety glasses when working with pneumatic cylinders
10. Protect equipment and patrons with a good safety envelope.

(II) Advantages of Pneumatics

1. High efficiency. A relatively small compressor can fill a large storage tank to meet intermittent high demands for compressed air
2. Unlike hydraulic systems, no return lines are required. The used compressed air can be released through the exhausted ports to atmosphere without harm
3. High reliability, because of fewer moving parts
4. Low cost, easy installation and maintenance
5. Availability of components of wide range of standard sizes and ratings
6. Air devices create no sparks in explosive atmospheres. They can also be used under wet conditions with no electrical shock hazard
7. The design problems involved are usually not too difficult to solve, and equipment selection procedures are relatively simple and straightforward. Installation is relatively simple because of relatively low power and light duty.

(III) Limitations of Pneumatics

1. Difficult to perform speed control in pneumatics cylinders. Load line and return (exhaust) line will be required in this case as flow restriction devices are installed. Usually no return line is needed in pneumatics circuits as compressed exhaust air can release into working environment with no harm and damage
2. Additional drying and filtering systems are needed as dust and moisture needed to be removed before entering into the pneumatic systems. Dust and moisture will accelerate wearing of pneumatic devices
3. Compressed air will inevitably cause noise pollution. It will be a concern if it is used in laboratory or clinical applications
4. Leakage of air is unavoidable in compressed air system. Routine maintenance and troubleshooting are required for pneumatic systems
5. The compressed air is compressible. The accuracy, say, the stroke of cylinder, will be deteriorating and varied over times. Adjustment needs to be done after certain period of servicing
6. The power rating is limited as the compressible nature of air. Some critical situation, the pneumatics systems will not be applied, such as the life-saving ladder in a fire engine. The power rating and the speed cannot reach the requirement.

Quizzes (chapter 2)

1. What are the limitations of using Pneumatics?
2. Why elevator in fire engine cannot be driven by Pneumatics?
3. What are the limitations of using a single acting cylinder?
4. Suggest methods to detect the leakage of compressed air in a manufacturing plant.
5. What are the major reasons of using Electro-pneumatics?
6. Describe the differences between Solenoid and Electromechanical relay.
7. Why some application prefer to use a non-lubricated pneumatic system?
8. Why two 3/2 NC and spring return valve cannot be used to directly control a double acting cylinder?
9. Why a shuttle valve must be present to perform a OR logic function?

CHAPTER 3 - PROGRAMMABLE CONTROL SYSTEMS

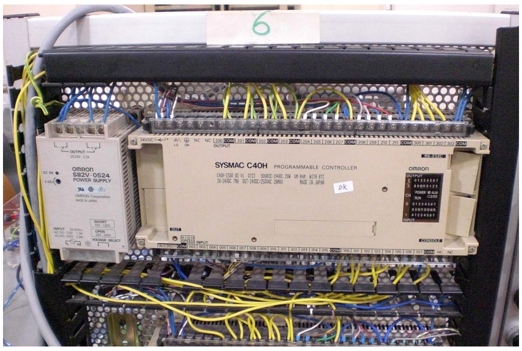
This chapter contains topics on:

3.1 What is Programmable Logic Controller (PLC)?
3.2 Programming the PLC
3.3 Application of Ladder Logic Diagram
3.4 Programmable Interface Controller
3.5 Stepper Motor and Servomotor

These topics include learning materials that facilitate you to:

- Understand the operation of PLCs
- Understand the Ladder Logic Function
- Understand the programming of PLCs
- Understand the use of PLCs in control.

3.1 What is Programmable Logic Controller (PLC)?



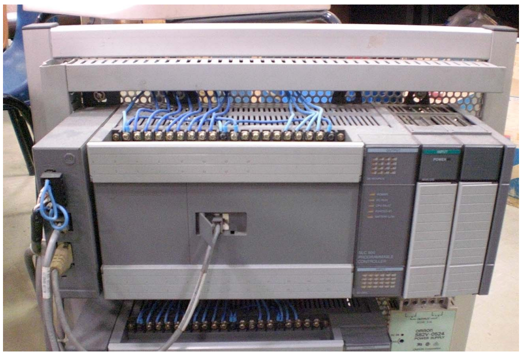


Figure 3.1 PLCs of different brands

A programmable logic controller is defined by the National Electrical Manufacturers Association (NEMA) as:

A digitally operating electronic apparatus which uses programmable memory for the internal storage of instructions for implementing specific functions such as logic, sequencing, timing, counting, and arithmetic to control, through digital or analogue input/output modules, various types of machines or processes.

(I) Why Programmable Logic Controller (PLC) is needed?

Basically system automation and process control require at least an "on/off" control in modern commerce and industry application. These control systems are no longer built from electromechanical relays, switches, timers, counters and other discrete logic gates to perform sequential control. It is because they are all hard-wired for specific purpose or controlling specific machines. These types of dedicated systems are of no flexibility. Therefore, digital devices, which can be *programmed* to do a variety of logical functions, play an important part in our daily industrial automation.

The **P**rogrammable **L**ogic **C**ontroller (**PLC**) was invented in 1960s to replace the sequential relay circuits that were commonly used in machine control. PLC is a solid-state, electronic device that controls the operation of a machine. It uses logic functions, which can be programmed into its built-in memory via software. This program can be changed or modified when necessary.

(II) Basic component of the PLC

A typical Programmable Logic Controller contains the following major components:

- Input module
- Output module
- Processor
- Memory

- Power supply
- Programming device

A schematic diagram is shown below:

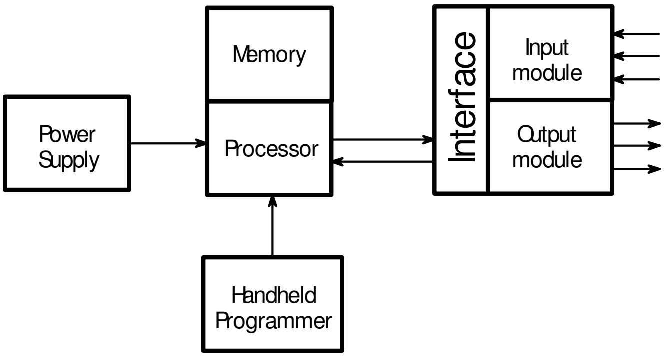


Figure 3.2 Schematic diagram of the basic Programmable Logic Controller

a. Inputs devices

The inputs to the controller are signals from limit switches, pushbuttons, proximity sensors, and any other digital (binary) or analog (continuous) devices.

b. Output devices

The outputs from the controller are on/off signals to the operating motors, cylinders, relays, solenoid valves and any other actuators.

c. Input and output module

Input and output modules are the I/O connections to the industrial process that is to be controlled.

d. Processor

The processor is the Central Processing Unit (CPU) of the programmable controller. It executes various logic and sequencing functions.

e. Memory

It consists of input, output and flag memory. Its storage capacity may ranges from 1K to 48K. It contains the program of logic, sequencing and other input/output operations.

f. Power supply

A power supply of 115Vac or 220Vac is typically used to drive the PLC. The components of industrial process that are controlled by PLC can have a higher voltage and power rating than the PLC.

g. Programming device

The programming device is usually detachable from the PLC cabinet. It may be either a hand-held programmer, similar to those used in robotics, or a computer-based programming package, using PC to input program into the PLC memory.

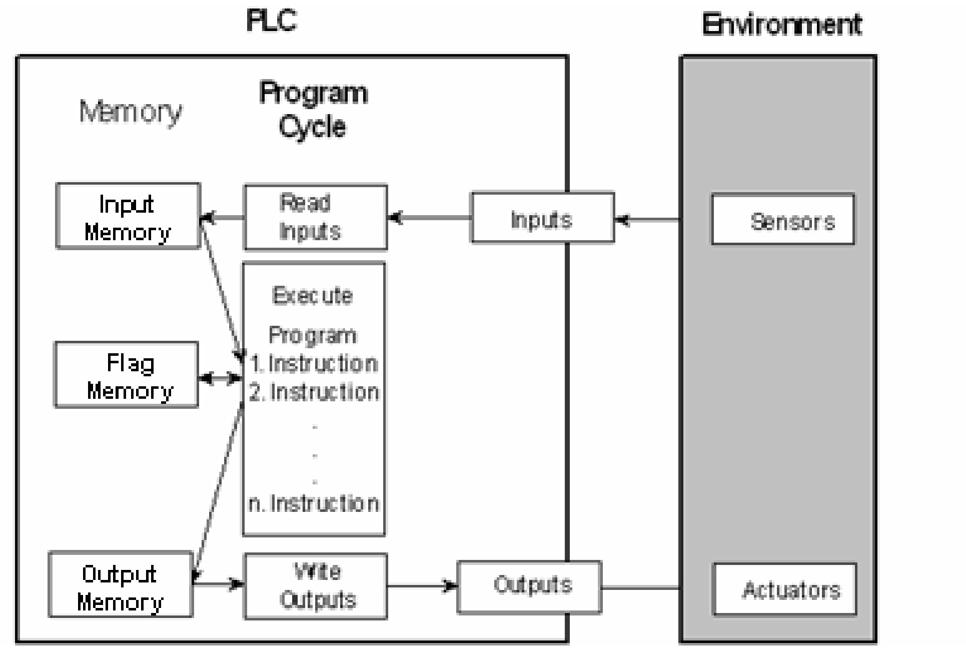


Figure 3.3 Functionality of PLC components

(III) How the PLC operate

Programmable Logic Controllers (PLCs) work by continually scanning a program. This scan cycle consists of 3 important steps: (1) checking input status, (2) executing the program, and (3) updating output status.

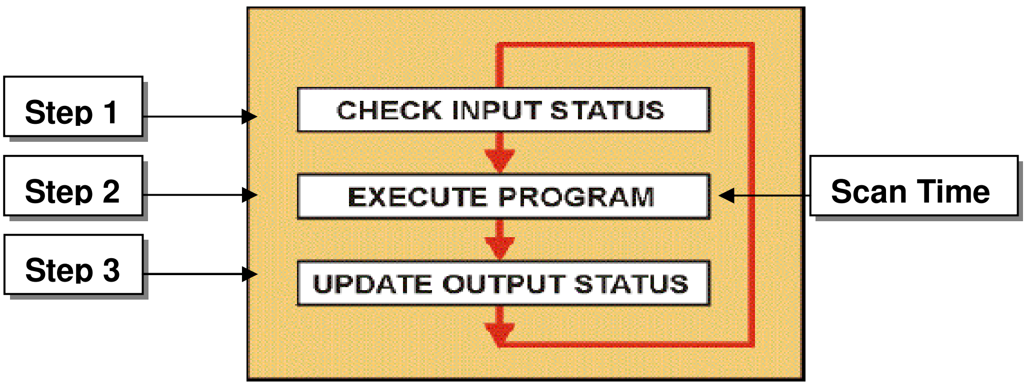


Figure 3.4 Scan cycle of PLC

Step 1—Check Input Status

Firstly, the input signals to the PLC, through the input module, are sampled by the processor. The contents are stored in the input memory.

Step 2—Execute Program

The control program is executed by the processor. The input values stored in the input memory are used in the control logic operation to determine the values of outputs.

Step 3—Update Output Status

Finally, the PLC updates the status of the outputs which is based on the input values and the results of executing the control program.

Scan and Scan time

A "scan" is referred to the cycle of reading the inputs, executing the control program and updating the outputs.

A "scan time" is referred to the time taken to complete one scan. The time vary from 1 to 100ms. It depends on the number and complexity of control functions to be performed for each scan cycle. This means it depends on the number of rungs in the ladder diagram and the complexity of the logic operation to be carried out on each rung.

S T O P   A N D   T H I N K
What will happen if the value of input changes immediately after it has been sampled during a scan cycle?

(IV) Advantages of Programmable Logic Controller

- Programming the PLC is easier than wiring the relay control panel.
- The PLC can be reprogrammed. Conventional controls must be rewired.
- PLCs take less floor space than relay control panel.
- Maintenance of PLC is easier and reliability is greater.
- The PLC can be connected to digital systems more easily than relays.

Below is the comparison between Relays logic control and PLC.

Relays	PLCs.
Large complicated systems that take up a lot of space.	One PLC can control a large system. Takes up less floor space than a relay-based system.
Hard-wired devices are used to configure relay ladder.	Only the input and output devices are hard-wired. The inner configuration of PLC is solid-state.
Difficult to modify or update a program	By the programming software, it becomes simple to write a new program (or modify an existing one), and download it into the PLC.
Limited service of life for mechanical devices.	The PLC is a solid-state device which has the characteristic of long service life and little maintenance
Require separate hard-wired timers and counters	Counters and timers are internal solid-state devices

Table 3 Comparison between Relays and PLCs

H I G H L I G H T

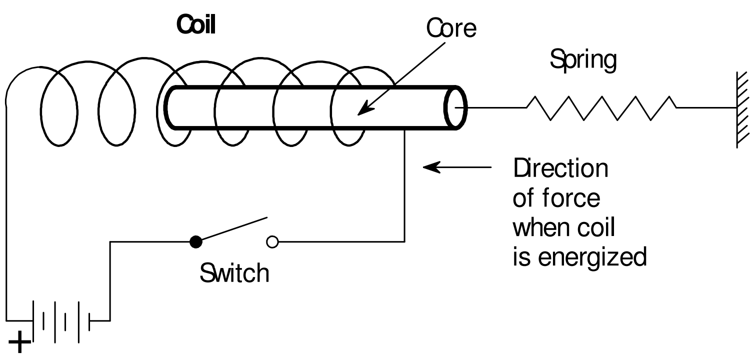


Figure 3.5 Working principle of solenoid

A solenoid is an electromagnetic actuator that can be used to open and close a valve, electrical contact, or other mechanical devices. The solenoid operates by means of an electrical current flowing through a wire coil to produce magnetic field inside the coil. A mechanical spring causes the core to be retracted out of the coil when the electrical current is turned off.

STOP AND THINK

What will happen to the above solenoid design in case of power failure during the course of control? Would you suggest any modification to alleviate this problem?

3.2 Programming the PLC

PLCs is relatively easy to program. The programming language is designed to resemble ladder logic diagram. It is designed for an industrial electrician or electrical engineer who is accustomed to reading ladder logic schematics in electromechanical control relay. The learning curve becomes short for programming a PLC to perform the same logic control functions.

(I) Constructing a Ladder Logic Diagram

The power (e.g.110V AC) to the components is provided by two vertical rails. The left rail is the power rail and the right rail is the ground bus. The horizontal line is the “rung”. It is common to locate inputs and outputs to the left and right of each rung respectively. Power flows through a series of normally open or normally closed contacts. It powers a coil from left to right and top to bottom over a ladder diagram.

(II) Symbols of components in ladder diagram

Normally open contacts are symbolized by two vertical lines along a horizontal rung. Normally closed contacts are shown by a diagonal line across a normally open contact. Both types of contacts represent ON/OFF inputs to the ladder logic. These inputs can be limit switches, relays, photo-detectors and any binary contact devices.

The output loads can be represented by circles in the rung. The output loads are motors, lights, alarms, solenoids and any other electrical components.

The timers and counters are symbolized by squares on the right of a rung. When the input signal is received, the timer waits the specified delay time before switching on the output signal. The timer is reset by turning off the input signal.

Counters require two inputs. The first is a pulse train that is counted by the counter, The second is a signal to reset the counter and restart the counting procedure.

Resetting the counter means zeroing the count for a count-up device, and resetting the starting value for a count-down device. The accumulated count can be stored in the flag memory for use if required by the application.

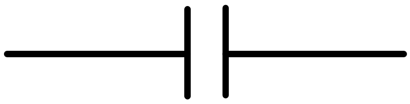
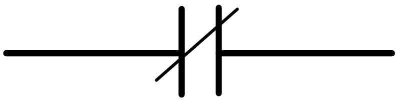
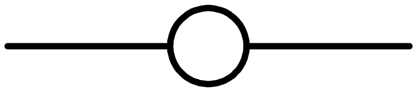
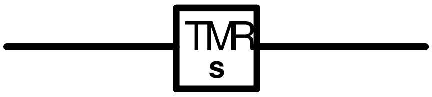
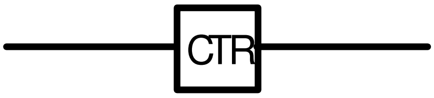
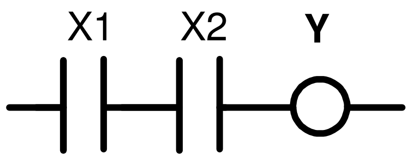
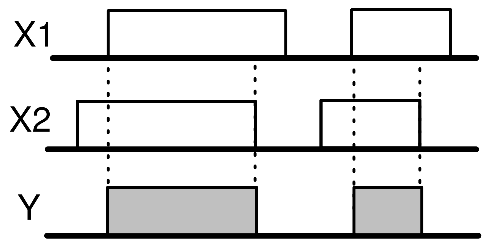
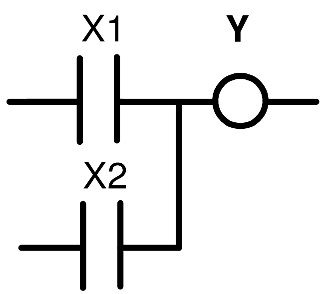
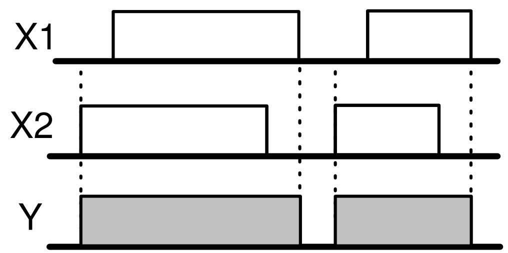
Ladder Symbol	Functions
	Normally open contacts (switch, relay, other ON/OFF devices)
	Normally closed contacts (switch, relay, other ON/OFF devices)
	Output loads (motor, lamp,. Solenoid, alarm, etc)
	Timer
	Counter

Table 3.1 Symbols of common components in ladder diagram

(III) Ladder control logic

Input contacts can be arranged to conduct logic functions in the ladder diagram.

<table>
<tr><th>Function</th><th>Ladder</th><th>Truth Table</th><th>Time Chart</th><th>Boolean</th></tr>
<tr><td>AND</td><td>
</td><td><table><tr><th>X1</th><th>X2</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td><td>
</td><td>X1 AND X2
(X1.X2)</td></tr>
<tr><td>OR</td><td>
</td><td><table><tr><th>X1</th><th>X2</th><th>Y</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td><td>
</td><td>X1 OR X2
(X1+X2)</td></tr>
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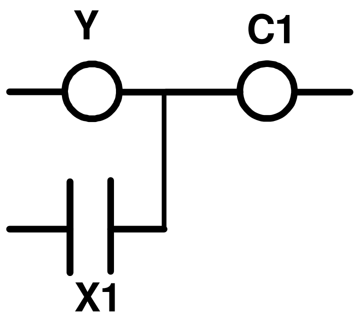
<td>
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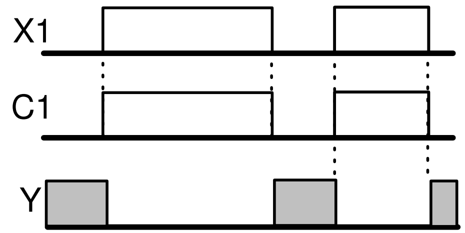
<td>
</td>
<td>NOT X1</td>
</tr>
<tr>
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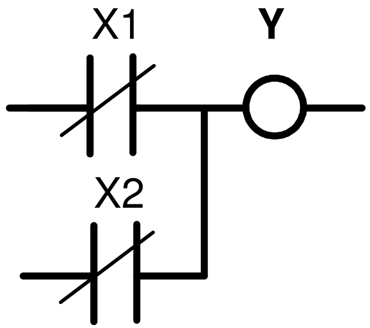
<td>
</td>
<td>
<table>
<tr><th>X1</th><th>X2</th><th>Y</th></tr>
<tr><td>0</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>1</td><td>1</td></tr>
<tr><td>1</td><td>0</td><td>1</td></tr>
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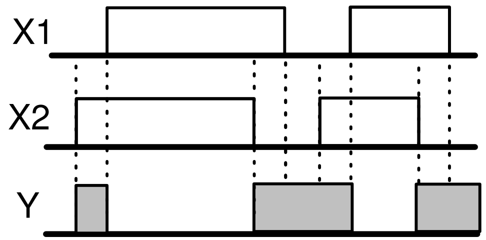
<td>
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(X1.X2)</td>
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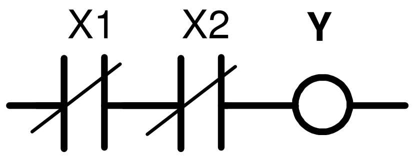
<td>
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<td>
<table>
<tr><th>X1</th><th>X2</th><th>Y</th></tr>
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<tr><td>0</td><td>1</td><td>0</td></tr>
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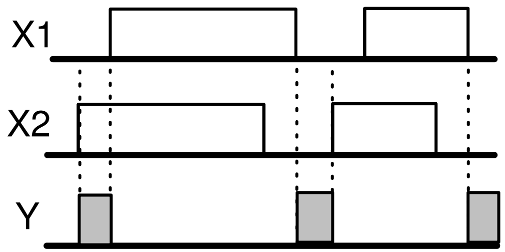
<td>
</td>
<td>X1 OR X2
(X1+X2)</td>
</tr>
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Figure 3.6 Ladder logic diagram

3.3 Application of Ladder Logic Diagram

(I) Starting and stopping an electric motor

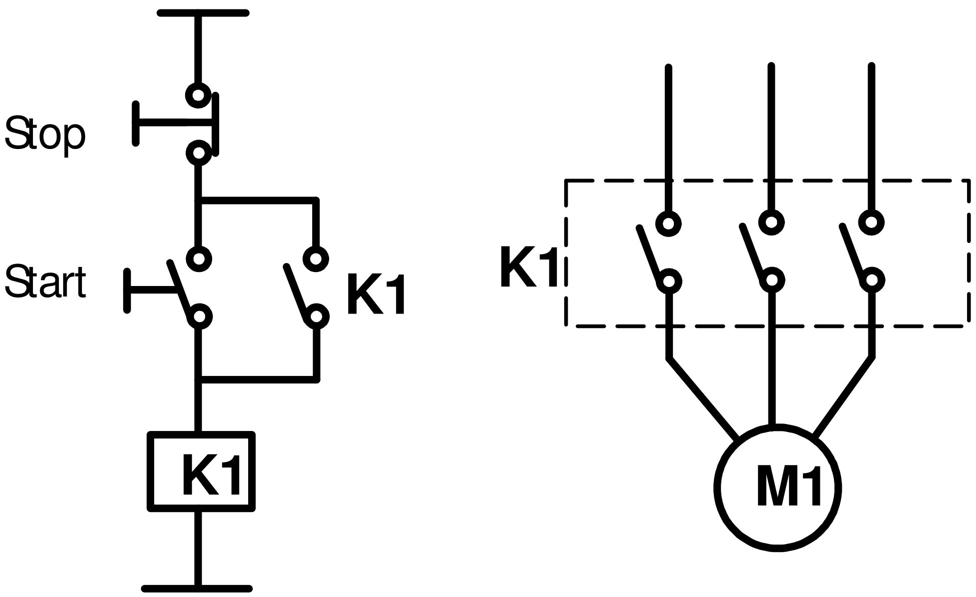


Figure 3.7 Motor ON/OFF control (Industrial 3 phase motor)

Pushbutton is used for starting and stopping an electric motor - one for START and the other for STOP. When the Start button is pressed momentarily by a human operator, power is supplied and maintained for the motor until the STOP button is pressed.

The operation logic is as follow:

START	STOP	MOTOR
0	0	0
0	1	0
1	0	1
1	1	0

Table 3.3 Truth table of Motor ON/OFF control

X1 and X2 are input contacts for START and STOP respectively and K1 is the output load to represent MOTOR. Y serves as a latch function to maintain the power to motor when the START button is released.

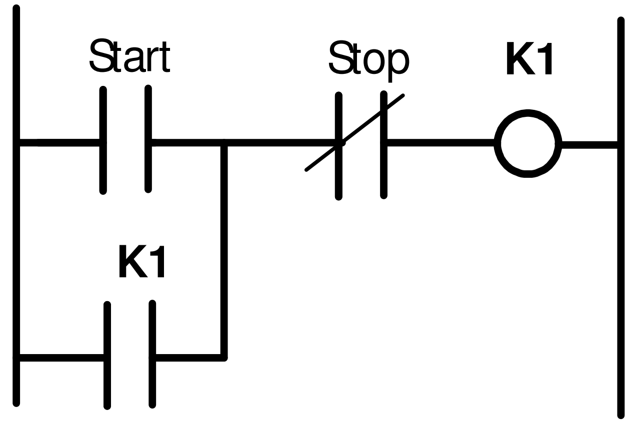


Figure 3.8 Ladder diagram of motor ON/OFF control

For a better understanding on the differences between hard-wired logic control and programmable control, a logic circuit design for the same motor ON/OFF control application is provided below for comparison.

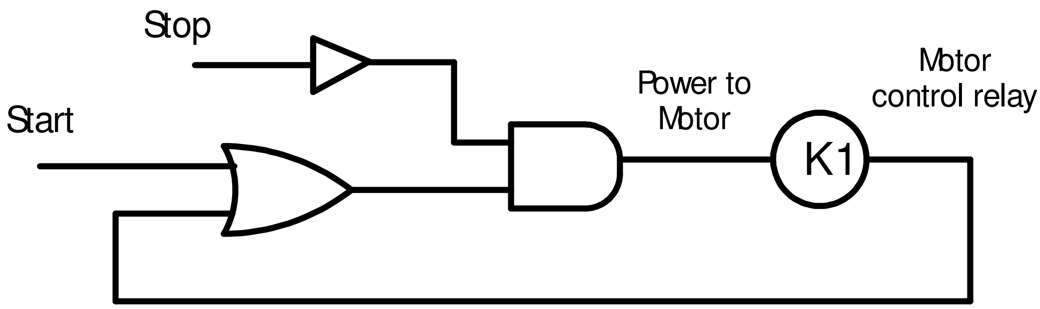


Figure 3.9 Hard-wired logic circuit for the same motor ON/OFF control

(II) Use of control relay for alternate switching of motors

A relay can be used to control ON/OFF actuation of a powered device at remote location. A control relay in different rungs of a ladder diagram is used to serve multiple logic function. The output load (control relay, C) on one rung in a ladder diagram can be inputs for other rungs.

When the normally opened contact X is open, the relay is not energized. The output motor Y1 in the second rung is connected to the power line. The motor Y1 turns on. When the contact X is closed, the normally closed control relay in second rung will open and the normally opened contact in third rung will close. The motor Y1 and Y2 will turn off and on respectively.

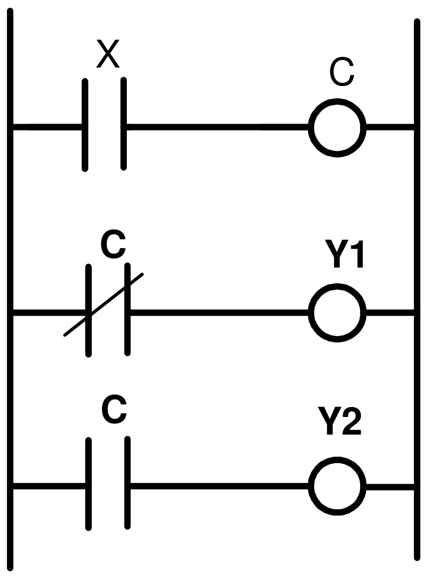


Figure 3.10 Use of control relay for multiple logic function

(III) Level control in sewage treatment tank

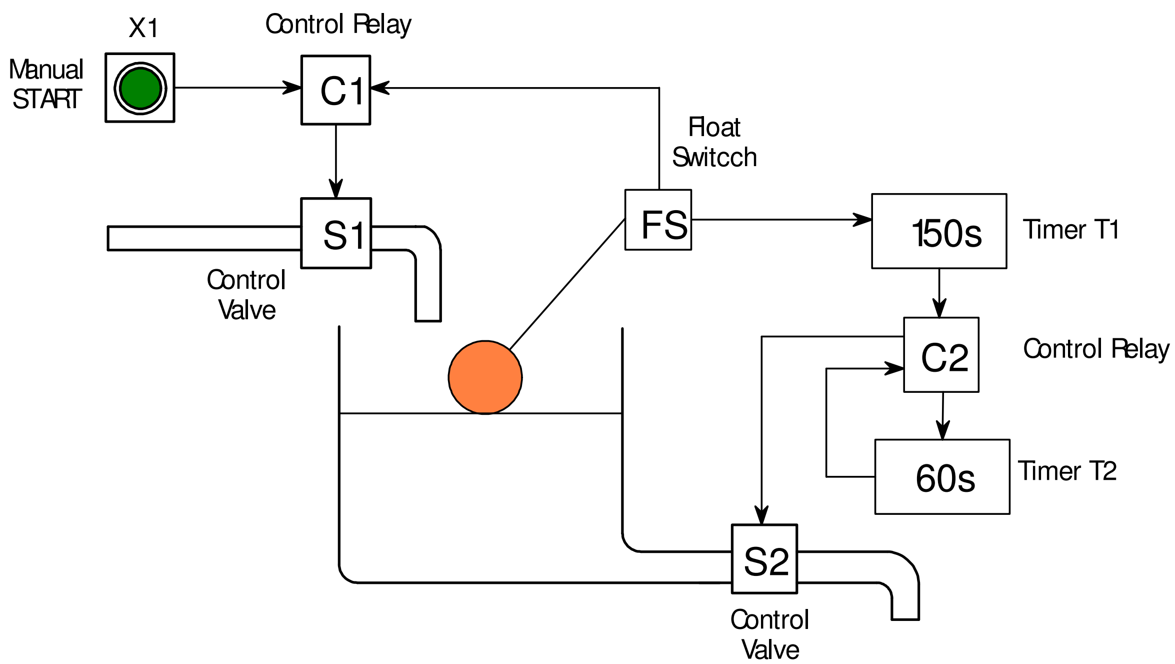


Figure 3.11 Schematic diagram of fluid level control

When the START button X1 is pressed, it energizes the control relay C1. C1 in turn energizes the solenoid S1 which is used to actuate a motorized valve, allowing sewage flows into the storage tank. When the level rises to a certain level, the float switch FS will close. This will open C1 and in turn de-energize S1 to stop the sewage from flowing in.

FS also energizes other control relay C2 which in turn energizes a timer T1 to provide a 150s time delay for the chemical reaction to take place. At the end of time delay, C2 powers the solenoid S2 which actuates another motorized valve to drain the tank. At the same time, C2 also initiates another timer T2 to allow a delay of 90s for the drainage to complete. At the end of 60s, T2 opens and de-energizes C2 and thus de-energizes solenoid S2 and stops the out flow.

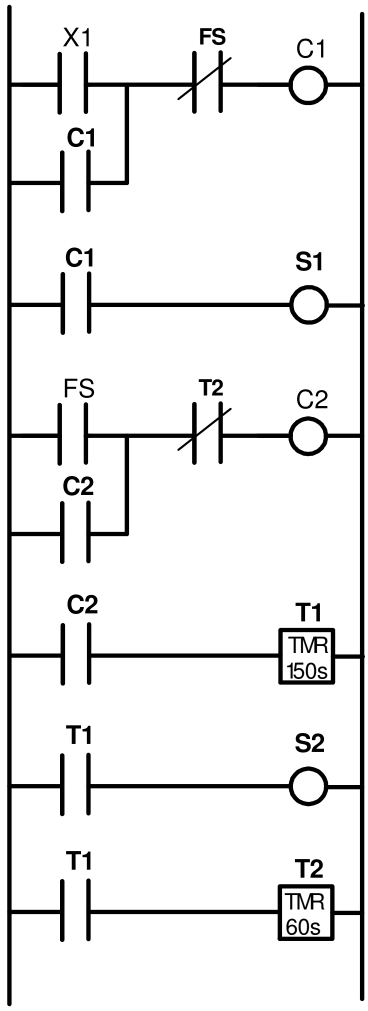


Figure 3.12 Ladder logic diagram for fluid level control

Exercise 1 : Sequential control of drill automation

The upper limit switch L1 (normally opened contact) is closed at the beginning of the drilling cycle. The START (normally open contact) button is pressed momentarily to start the drilling cycle. At the same time, the output load motor M1 starts rotating the drill and the other motor

M2 starts to descend the drill. The drill (M1) will stop at the lower limit switch L2. At this time, the motor M2 starts to reverse and ascend the drill.

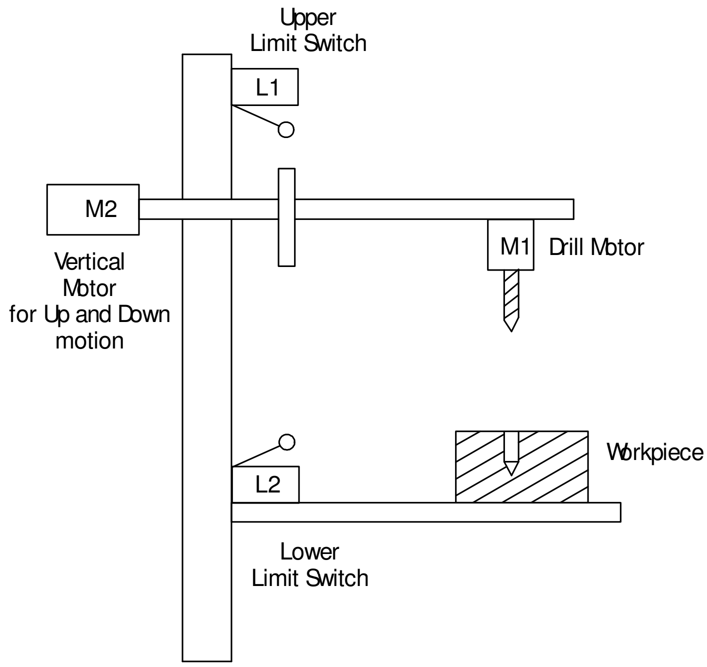


Figure 3.13 Schematic diagram of automatic drilling system

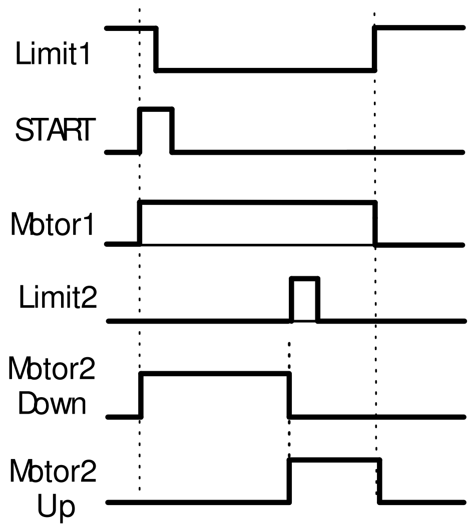


Figure 3.14 Timing diagram for sequential control of automatic drilling system

Exercise 2: Control of traffic light

Pushbutton S1 is pressed momentarily to start a traffic light cycle. The Red signal will be ON for 5s. Then, followed by the Yellow signal for 2s. Final, the Green will be ON for 8s. The cycle will be reset and wait until the start button is pressed again.

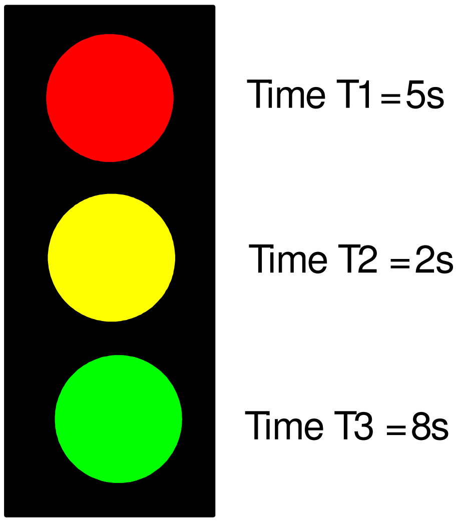


Figure 3.15 Traffic light control

(IV) Entry of ladder logic diagram into the PLC

The ladder logic diagram is directly entered into the PLC memory. It requires PC-based application software or a handheld programmer with limited graphics user interface to display the symbols in the ladder diagram. The ladder diagram is inputted to the PLC memory rung by rung. Below is an example of ladder logic program entry by a handheld programmer to a typical PLC.

Figure 3.16 Handheld Programmer for PLCs

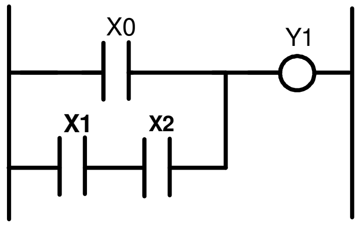
Ladder Diagram	Boolean		Handheld Programmer
	Address	Instruction	
	0	ST X0	ST.ST.0.WRT
	1	ST X1	ST.ST.1.WRT
	2	AN X2	AN.ST.2.WRT
	3	OR	OR.STK.WRT
	4	OT Y1	OT.AN.1.WRT

Table 3.4 Example of inputting ladder diagram into PLC

Remarks: Command button ST is START, AN is AND, OR is OR,OT is Output, STK is Stack, WRT is Write.

3.4 Programmable Interface Controller (PIC)

Programmable Logic Controllers are usually used for industrial and electrical application. They are rather bulky and expensive for use in school. An alternative solution is to introduce a controller based PIC for controlling tasks in student projects.

(I) Introduction of PIC

A Programmable Interface Controller or PIC, contains a microprocessor and EEPROM. PIC can be provided with 8, 18 and 28 pin configurations which provide a variety of outputs and digital/analogue inputs.

The chips use reprogrammable 'flash memory' which can be written and rewritten. Constructing a working controller involves connecting the chip to power, interfacing input, output components and adding a capacitor, resonator and a reset switch.

'Flash memory' is EEPROM (Electrically Erasable Programmable Read Only Memory). It means that the PIC is capable of being re-programmed over 10,000 times.
The most commonly used PIC is the 16F84 shown below. This is a 18-pin device which has 8 outputs and 5 inputs.

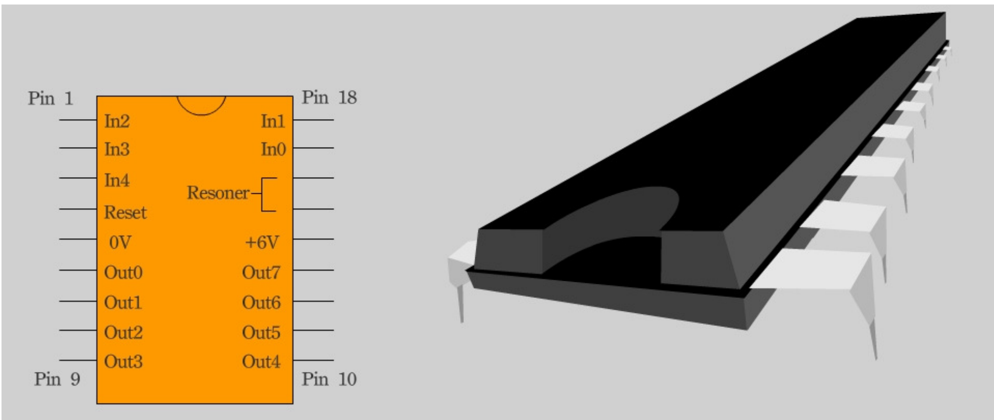


Figure 3.17 Pin layout diagram of PIC 16F84

S T O P A N D T H I N K
Why EEPROM memory is used for PIC?

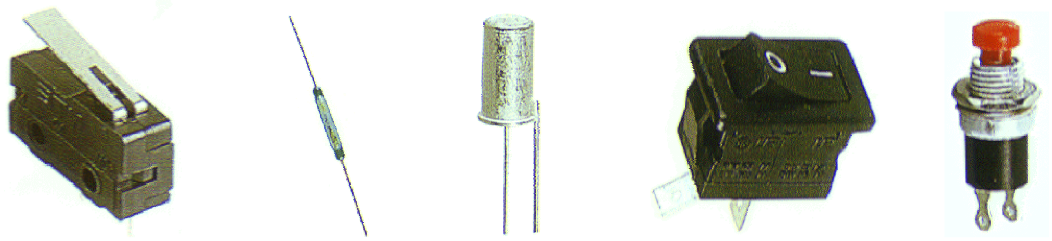
(II) Configuration of PIC 16F84

The 16F84 requires a 6V DC supply. This can simply be provided by 4 x AA cells. A 4MHz ceramic resonator must also be connected as shown below. The 16F84 provides an internal clock pulse. The resonator is used to regulate the speed of the clock pulse (4MHz).Pin 4 (reset) and must be connected via a 4k7 resistor to +V.

(III) Interfacing Input and Output Devices

a. Digital input sensors

Common input devices are Micro-Switches, Reed Switches, Tilt Switches and Push Switches. They can all be directly connected to any input pin of PIC 16F84. Care should be taken to add 10k resistor to prevent short circuit and the 1k resistor to protect the input pin. The digital input will trigger from logic 0 to logic 1 when the switch is pressed.



Limit switch   Reed Switch   Tilt Switches   Toggle and Push Switches

Figure 3.18 Common digital input device to PIC

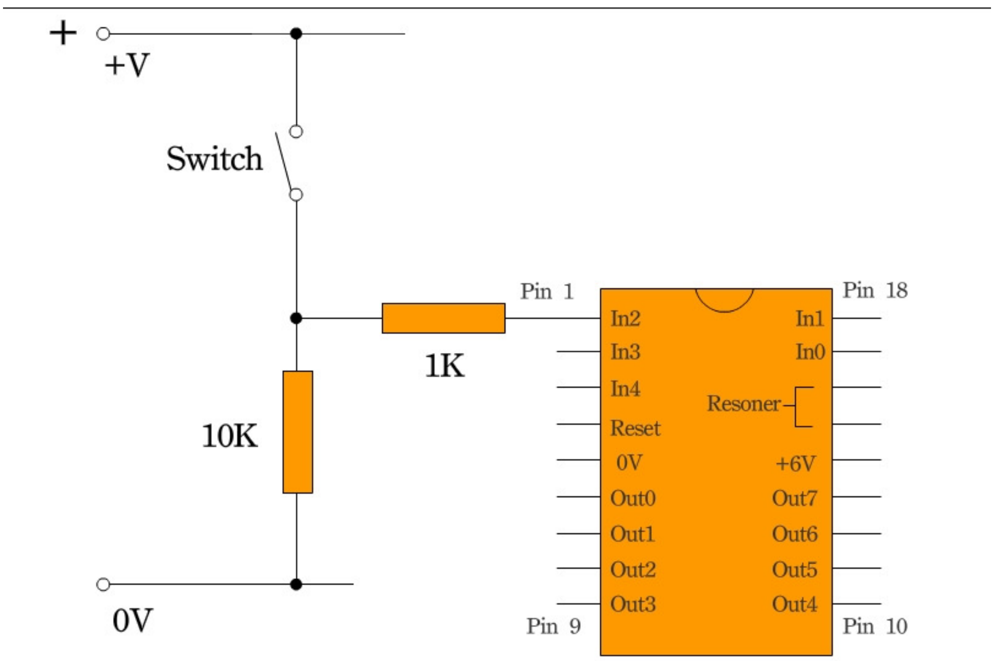
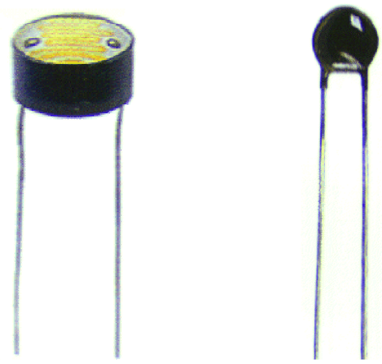


Figure 3.19 Circuit diagram for connecting input device

b. Analogue input sensors

Although the 16F84 does not have analogue input pins, an analogue sensor can also be used by connecting them via a potential divider and a transistor interfacing circuit. A phototransistor can be used to switch the input directly.



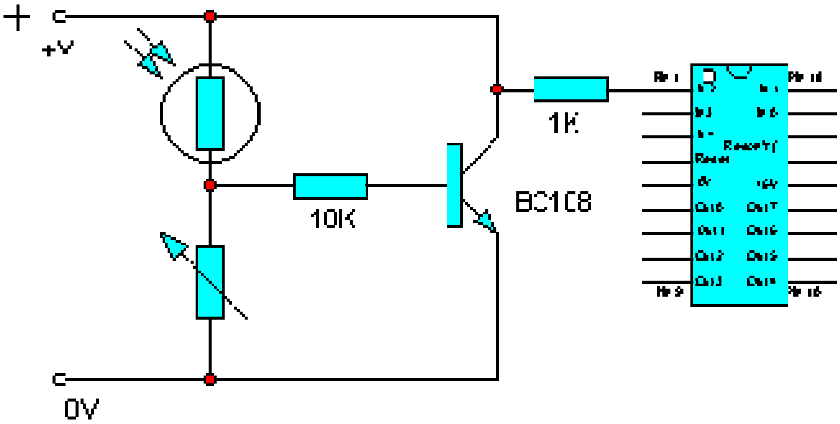


Figure 3.20 Interfacing circuit for analogue photo-sensors

c. Output devices

Buzzer Light bulb Solenoid

Figure 3.21 Common output devices

Common output devices are LED, 7 segment display, Piezo sounder, speaker, light bulb and solenoid.

An LED can be driven directly from any output. The 330k resistor serves the functions of protecting the input pin from the risk of short circuit in the event of LED blows and prevents the LED from blowing out by the over-current.

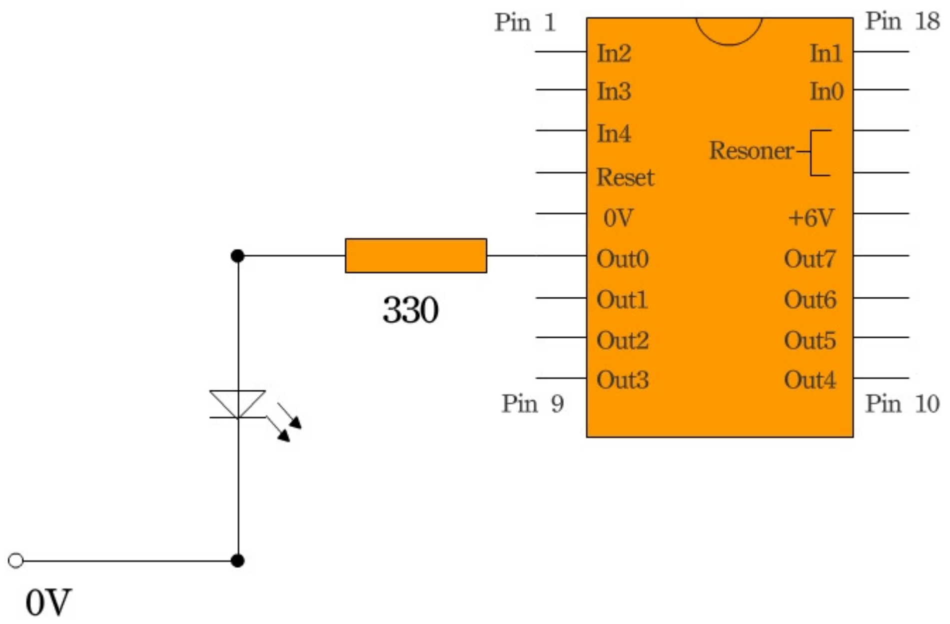


Figure 3.22 Output circuitry for LED

7 segment displays can display the number from 0 to 9 by outputting logic 1 or high signal to the display segment in correct sequence.

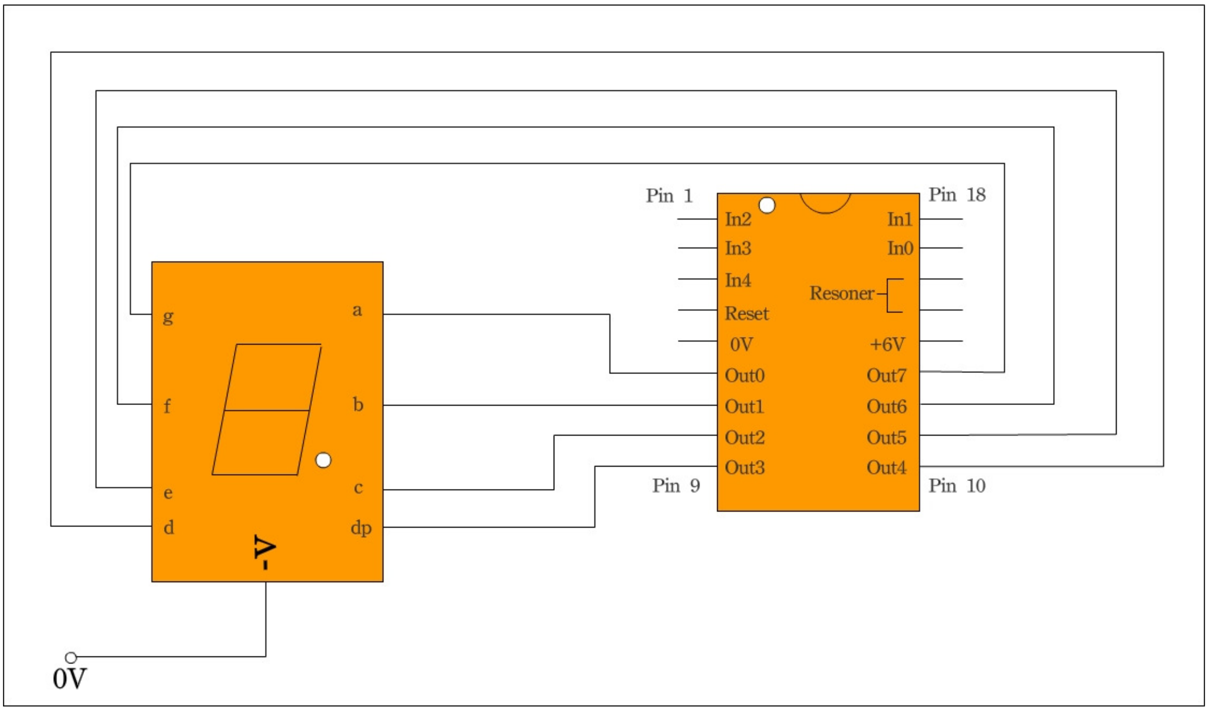


Figure 3.23 Output circuitry for 7 segment display

A Piezo speaker can be directly connected to the output pin to produce a range of sounds because of its high internal resistance. The sounds are produced by the output signals that are in form of pulses and at a variety of frequencies. The frequencies can be generated by the programmed instructions.

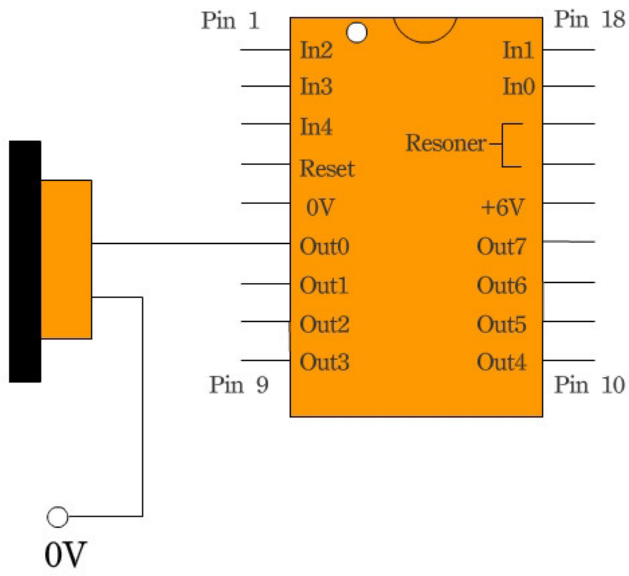


Figure 3.24 Output circuitry for Piezo speaker

Higher current devices cannot be driven directly by the output signal from PIC which is usually as low as 6V DC. It requires a simple transistor-to- transistor pair switching circuit (the Darlington driver) to amplify the current rating. It is significant when the PIC is required to control electrical actuators in industrial application, the power rating is usually higher, say 24V DC or more. A relay is also a common device used to do this type of switching to drive the output load of different or higher voltage and current rating.

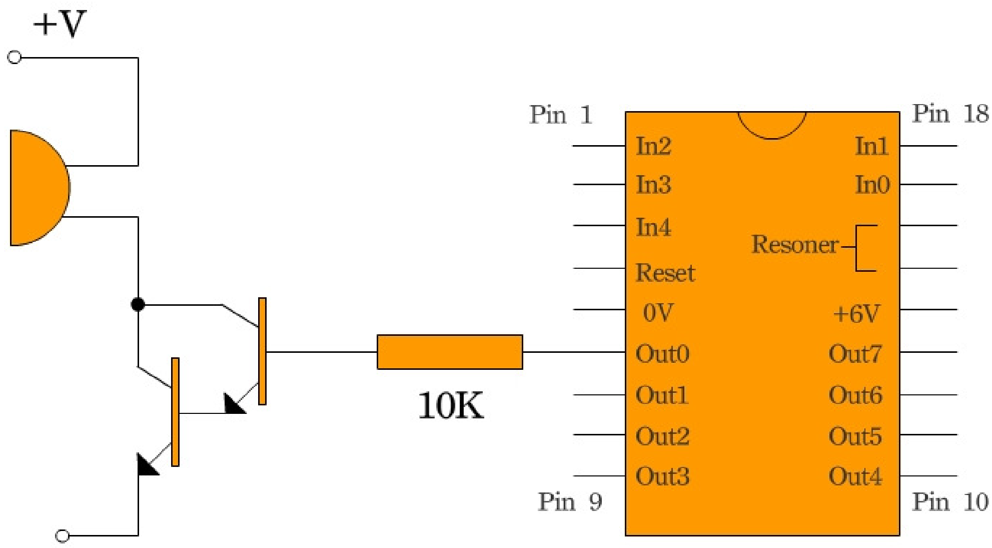


Figure 3.25 Output circuitry for buzzer

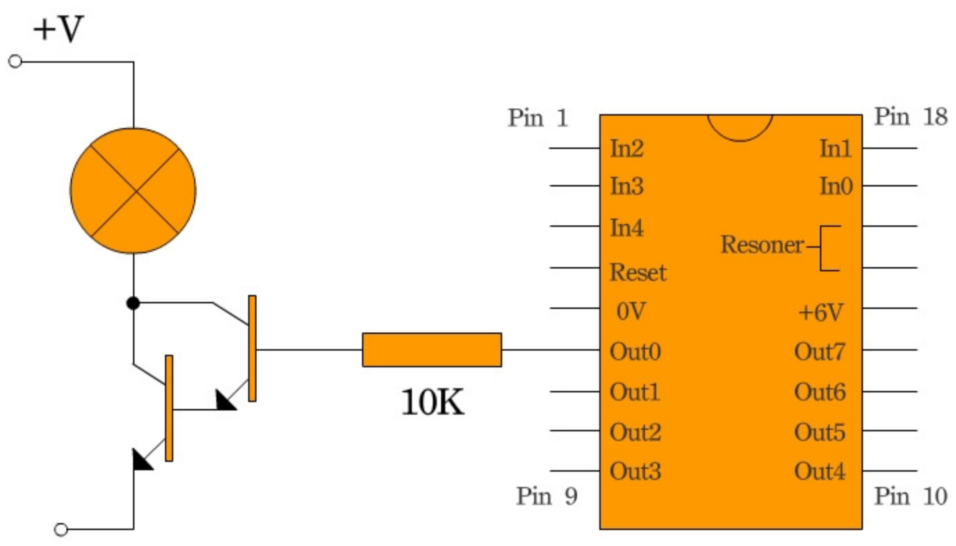


Figure 3.26 Output circuitry for Light bulb

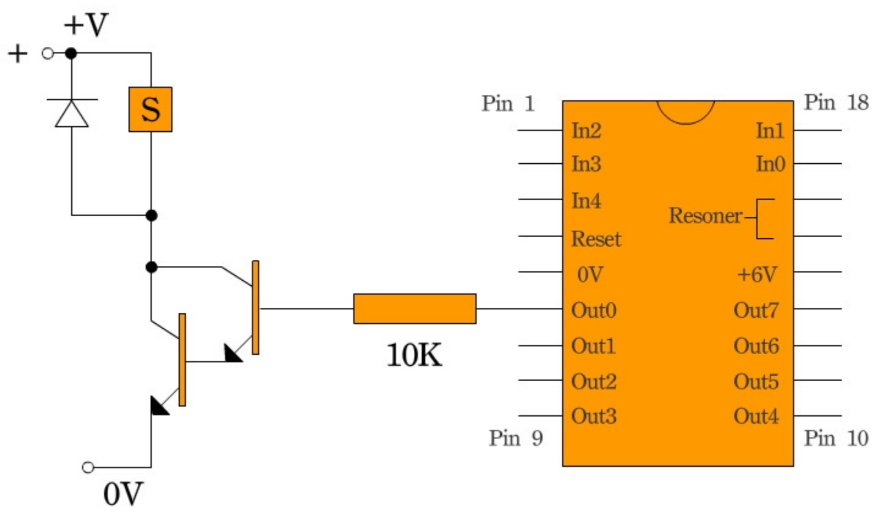


Figure 3.27 Output circuitry for Solenoid

(IV) Programming PIC

The PIC is programmed using a "compiler" or "assembler" which is a high-level programming language. However, they are still not easily to be understood by senior secondary students. It can be made easier to program this PIC by a program editor which uses flowchart approach. The editing software has graphical user interface and adopts "drag and drop" operation for programming. The software will convert the flowchart into BASIC or Assembly language which will be downloaded to the PIC.

3.5 Stepper Motor and Servomotor

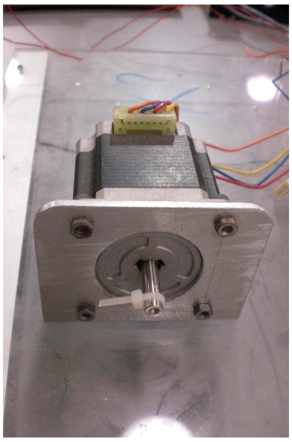
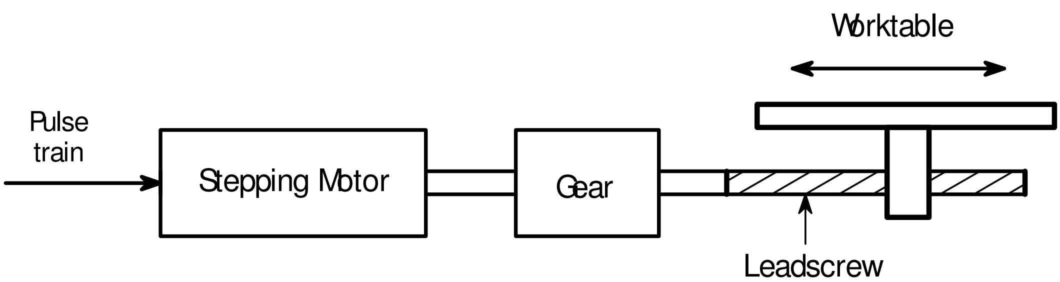


Figure 3.28 Photo of a typical stepping motor

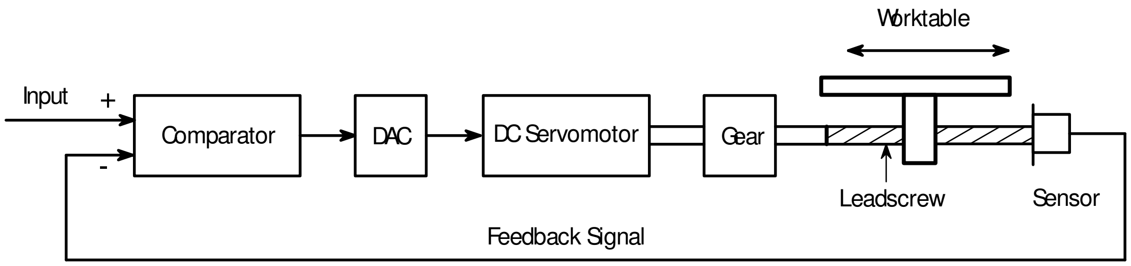
Stepping motor is an electric motor without commutators. All the windings in the motor are the stator and the rotor is either a permanent magnet or a toothed block of magnetically soft material. All commutations are handled externally by a motor controller.

The motor is designed so that it can be held in any fixed position or being rotated bidirectionally. Most stepping motors can also be spinned quickly at audio frequencies.
Both stepping motor and servomotor can be used for precise positioning in industrial application but they are different in working principle:

- Servomotors require analog feedback control systems. This usually involves a potentiometer to provide feedback about the rotor position. External circuits are needed to drive a current through the motor proportional to the difference between the desired position (set point) and the actual position.
- Stepping motors can be used in Open-Loop control system. This is generally adequate for systems that operate at low acceleration with static load.



(a)



(b)

Figure 3.29 (a) Closed loop control of servomotor (b) Open loop control of stepping motor

(I) Stepping Motor Principle

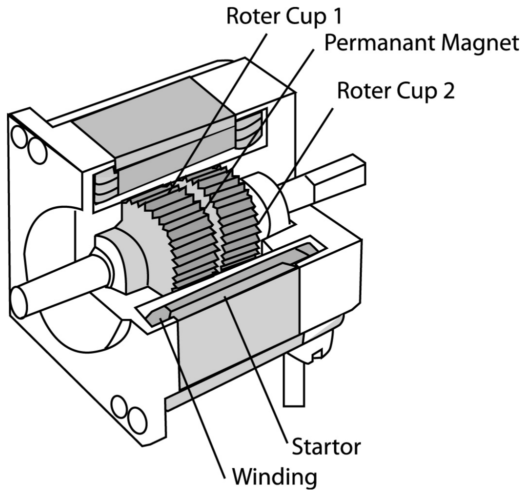


Figure 3.30 Exploded view of a typical stepping motor

Stepping motor divides a revolution into discrete steps. It can be held standstill in a motor position when not rotating and without the need for a positional feedback sensor. The steps are created by sequentially energizing the stator electromagnets causing the rotor to line up each time with the resultant magnetic field. The shaded area in the diagram indicates the position of the energized magnets and the wedge indicates the angle rotated according to the resultant magnetic field.

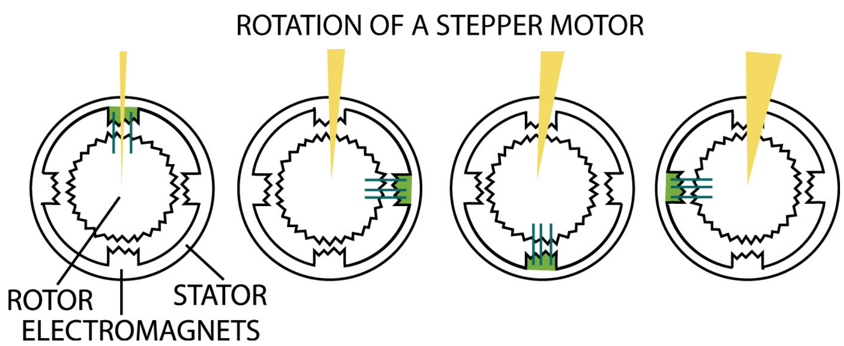


Figure 3.31 Alternate energizing stator for the rotation of rotor.

Stepping Motors can achieve a short and precise movement with quick acceleration. No brush maintenance is required. This greatly reduces its cost compared with any other brushed motors. However, the rapid energizing of electromagnets is inefficient at high speed condition. Any excessive loads can cause the motor to skip its sequence and stall in the worst case.

H I G H L I G H T

Control of stepping motor by PIC

Unipolar stepping motors have four coils which must be switched on and off in the correct sequence to make the motor turn as shown in previous section. The table below shows the correct sequence.

Step	Coil 1	Coil 2	Coil 3	Coil 4
1	1	0	1	0
2	1	0	0	1
3	0	1	0	1
4	0	1	1	0
5	1	0	1	0

Table 3.5

The ULN 2003A is a Darlington driver IC used to drive the stepping motor. The PIC (6V) and stepping motor (12V) have different supply voltages but they must be common to ground 0V.

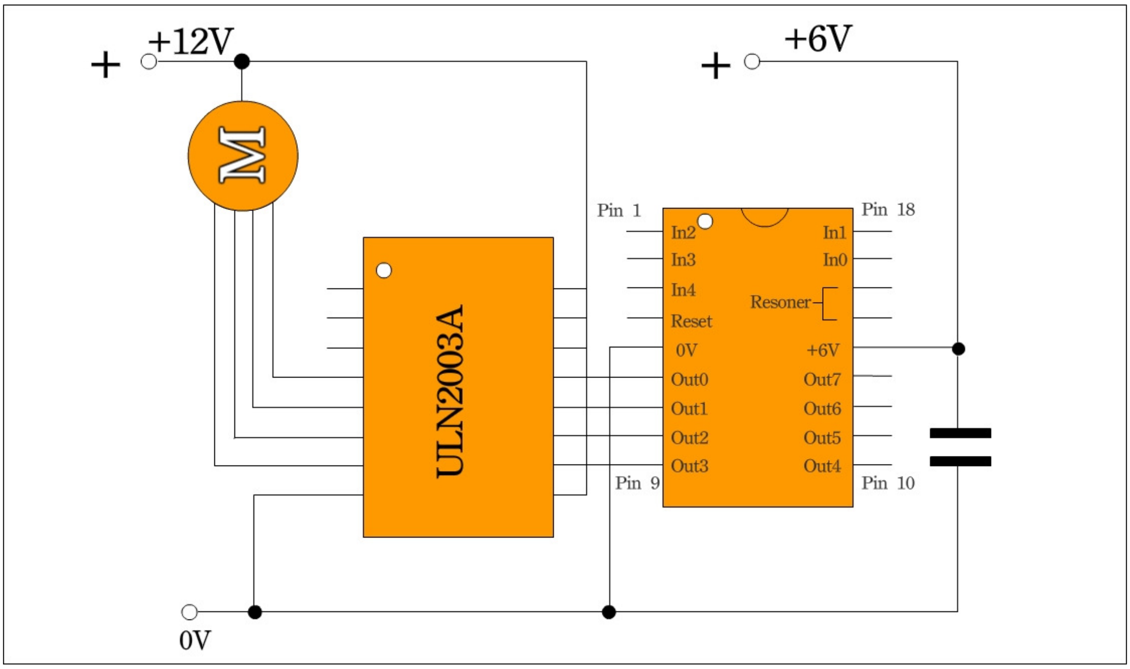


Figure 3.32 Control circuitry for stepping motor by PIC 16F84

(II) Advantages of Servomotors

Figure 3.33 Servomotor with integrated feedback device

Servomotor has the following advantages when compared to other motor technologies:

- fast positioning
- high peak torques
- wide speed ranges
- high controllability

In general, servomotor is common in positioning applications. It provides a wide range of power output that will be suitable for a variety of industrial applications, such as packaging, material handling, laser trimming and automation where high throughput is of concern.

a. High peak torque and High productivity

Servomotor of same power rating offers peak torques of 200-400 percent over the continuous duty torque. Higher peak torques, in practical terms, mean that the motor can accelerate and position the load faster.

b. Light weight and Energy savings

Servomotors can fit in a tight and compact location. Smaller motor size means less weight. It is significant in some applications where a load includes the motor itself, such as the joint in robotic arm.

c. High controllability

Servomotors can offer excellent controllability. Servomotors are used with closed loop motion controllers and can position accurately. Servos can position up easily to a diameter of one hair.

d. Fast Response and Reliability

A measure of controllability is bandwidth. This is an indication of response time. The higher bandwidth, the faster the response. Comparing to other motor technologies, servos have the highest bandwidth. This means that if there is a disturbance in loading, servos can make corrections faster.

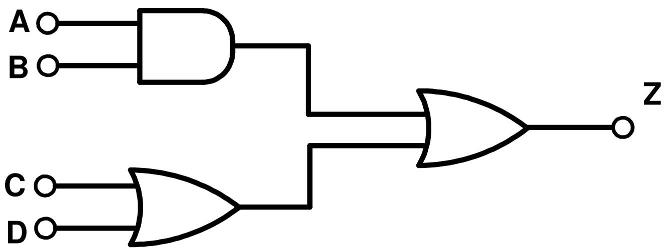
e. Motor speed, voltage and current

Speed is directly proportional to the amount of voltage applied; the more voltage, the faster the motor will operate. The torque delivered is directly proportional to the current. Just like a conventional DC motor, the more the current, the more the torque to be delivered. Both characteristics are very predicable, thus servos become easy to apply in any application.

S T O P   A N D   T H I N K
Can you suggest one application of (I) servomotor and (II) stepping motor with an appropriate reason?

Quizzes (Chapter 3)

1. Name the 6 major components of a typical PLC.
2. What are the three main steps of each scan cycle performed by a PLC?
3. What are the drawbacks of using electromechanical relays in automated control?
4. Give a brief description of what a PLC is.
5. Can PLC be regarded as a computer? If not, why?
6. What is the history of PLCs?
7. Why PLCs are more commonly used for industrial applications than computers?
8. Convert the following logic diagram into a ladder diagram and write a Boolean expression for it?



9. What are the usage of Tilt switch and Reed switch?
10. List three advantages for stepping motors and servomotors?

CHAPTER 4 – ROBOTICS

This chapter contains topics on:

4.1 Definition of Robots
4.2 Mechanical Structure of Industrial Robotic Arms
4.3 Robot Anatomy
4.4 Robot Control Systems
4.5 Applications of Robots

These topics include learning materials that facilitate you to:

- Identify different mechanical structure of industrial robots
- Identify different robot anatomy
- Understand different robot control methods
- Understand various applications of robots.

4.1 Definition of Robots

Robot is officially defined by the Robot Institute of America as *"A re-programmable, multi-functional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks"*.

Figure 4.1 Typical industrial robotic arm.

Variations of robots are available for use in industrial applications. They are used to carry out repeated actions with high accuracy and without any variation. Robots require a control program to govern its velocity, direction, acceleration, deceleration and the distance of movement at any time.

An Industrial Robot (IR), which is usually referring to a robotic arm, consists of several links connected in series by linear, revolute or prismatic joints. At one end the robot is fixed to a supporting base while the other end is equipped with a tool and manipulated into position to perform tasks.

However, the definition of robots by Robot Institute of America seems to be focused on industrial application, robots nowadays are quite popular for leisure and some of them are for innovative purposes, such as humanoid and military purpose.

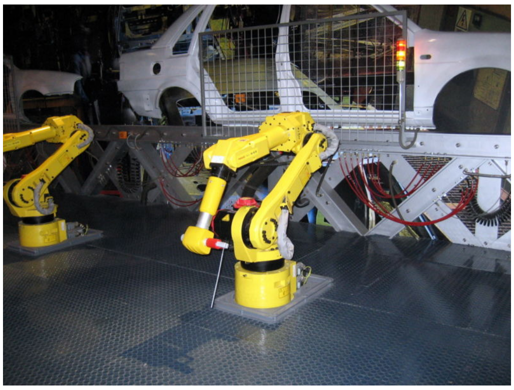


Figure 4.2 Examples of different types of robotic applications

Therefore, robot can also be defined as **"Human made semi or fully autonomous (self-controlled) object or cooperating objects (with common objectives) with intelligence which is programmable"**.

S T O P A N D T H I N K
Please state your reasons for the following questions. 1. Are movable machines, such as cars, "Robot"? 2. Are computers "Robot"?

4.2 Mechanical Structure of Industrial Robotic Arms

Since 80's of last century, there was a rapid growth in the application of robotic arms in industry, especially in the car manufacturing and welding process. Identifying different types of mechanical robotic structures seem to be an effective and visual way of classifying robots and are a good starting point for learning robotics.

(I) Cartesian Coordinate Robot

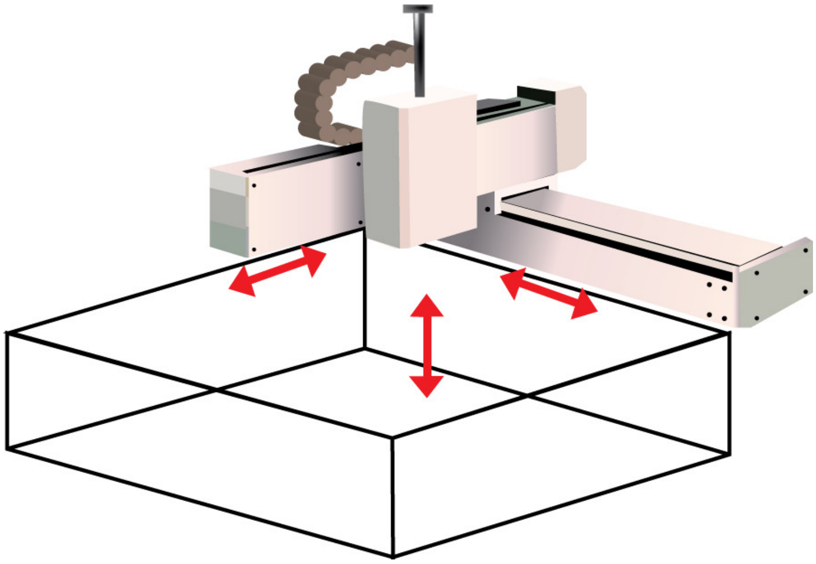


Figure 4.3 Typical Cartesian Robot

Cartesian robot is formed by 3 prismatic joints, which axes are coincident with the X, Y and Z planes. A Cartesian Coordinate robot with the horizontal member supported at both ends is sometimes called Gantry robot. It can be quite large in size. Cartesian robot uses 3 perpendicular translational slides along the x, y , z axes, and it is also called the xyz robot or rectilinear robot. It has a rectangular work volume. The joint types are obviously LLL.

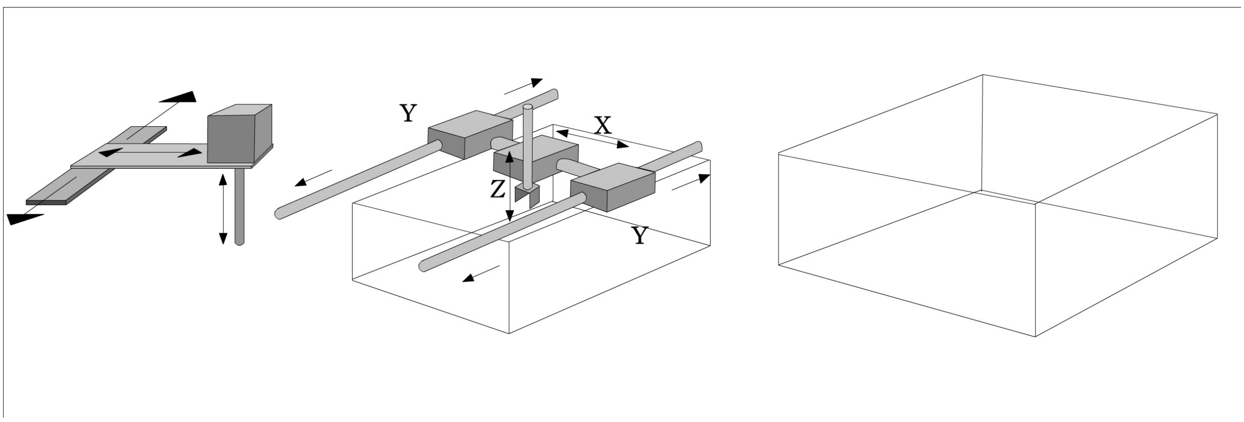


Figure 4.4 Schematics diagram of Cartesian robots

Advantages:

- The rigid structure can support large robots and heavy payloads:
- Easily controlled/programmed movements
- High accuracy
- Accuracy, speed and payload capacity are constant over entire working range
- Control system simplicity
- Familiar X, Y, Z coordinates can be easily understood
- Inherently stiff structure
- Large area coverage
- Structural simplicity, offering good reliability
- Easy to expand in modular fashion

Drawbacks:

- The workspace is limited within the robot size. A big robot will require a very large area if it works for a large work piece, such as a car
- Work piece underneath is out of reach by this type of robot
- Prismatic joints are easily contaminated with dust, especially in folds around the flexible bellows

(II) Cylindrical Robot

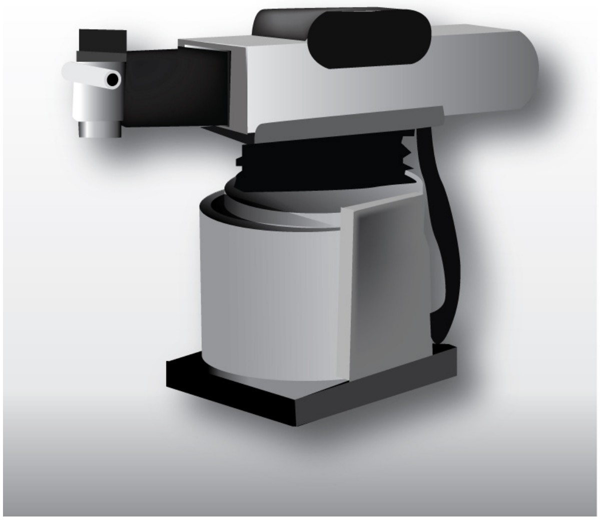


Figure 4.5 Typical Cylindrical Robot

Cylindrical robot is able to rotate along its main axis forming a cylindrical work space. It has two linear axes and one rotary axis around its base.

Advantages:

- Base rotation gives high speeds
- Can reach under objects (compared with Cartesian robots)
- Easily controlled/programmed movements
- Control system simplicity
- Good accuracy
- Fast operation
- Good access to front and sides
- Structural simplicity, offering good reliability

Drawbacks:

- Dust contamination around the flexible bellows is hard to avoid for prismatic joint
- Relatively small workspace (compared with Cartesian robot)

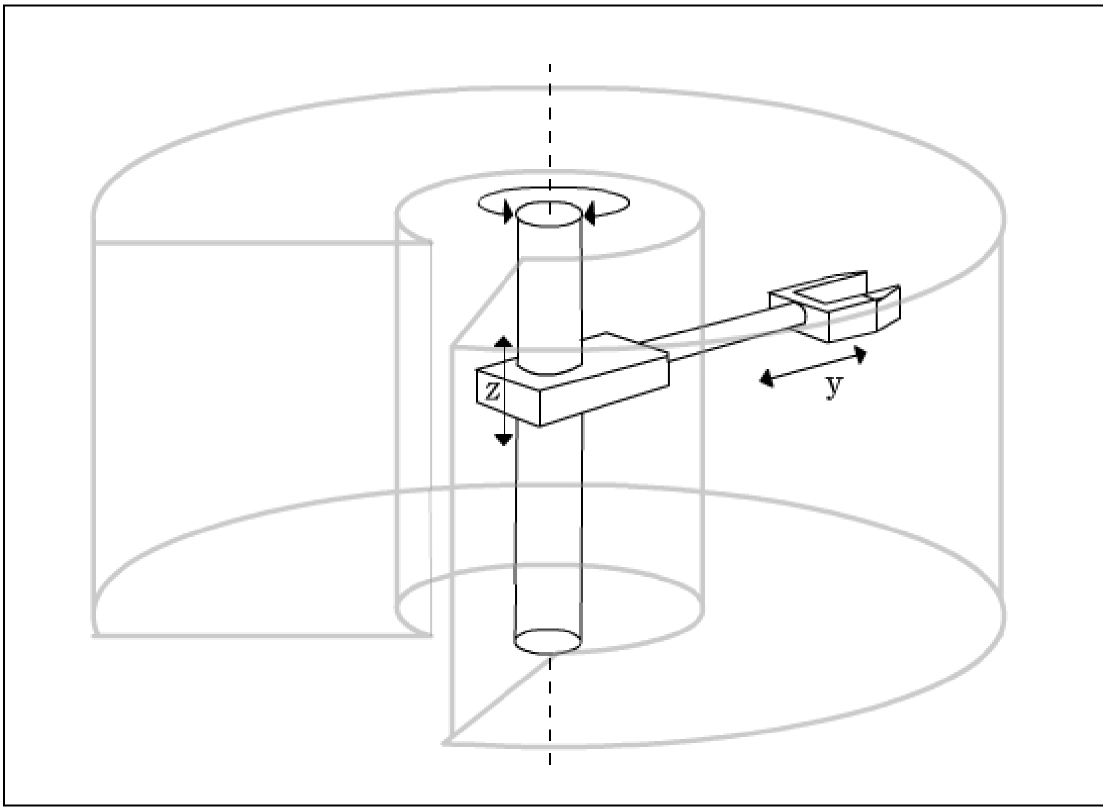


Figure 4.6 Schematics diagram of Cylindrical Robot

Cylindrical robot can move up and down and around the column, and the arm can be telescopic. It has a cylindrical work volume. The joint types are usually LTL or TLL.

(III) Spherical / Polar Robot

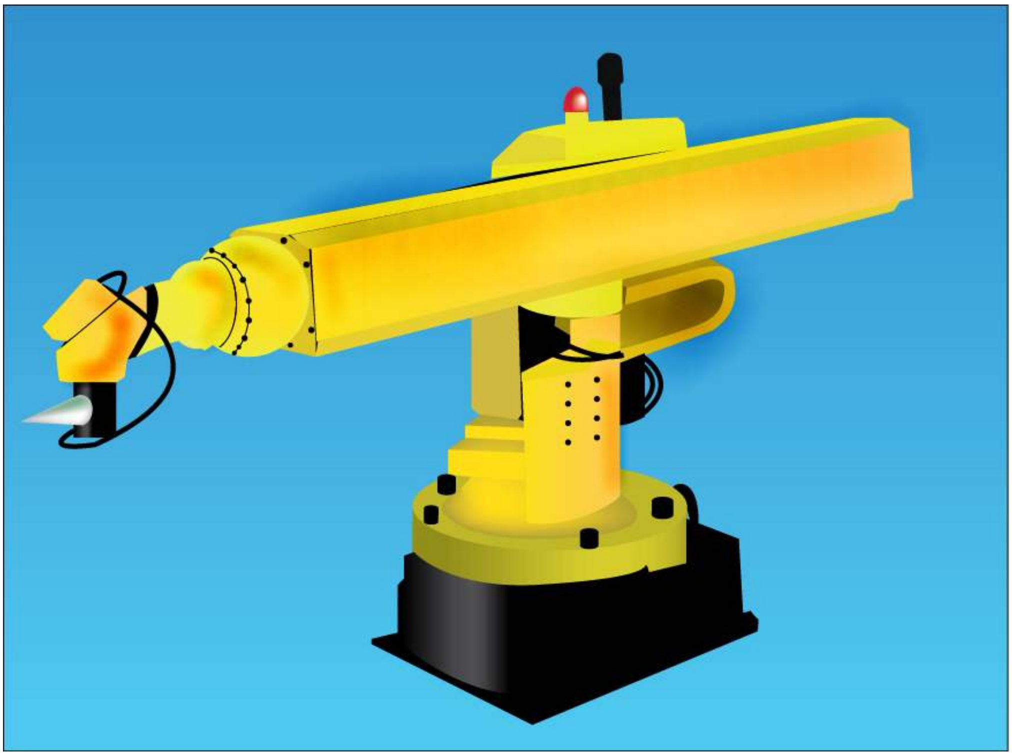


Figure 4.7 Typical Polar Robot

A Polar Robot has one linear axis and two rotary axes. It is able to rotate in two different directions along its main axes and the third joint moves in translation forming a hemisphere or polar coordinate system. The joint type is usually TRL

Advantages:

- Has a large workspace, and can reach below its base
- Easily controlled/programmed movements
- Familiar polar coordinates easily understood
- Large payload capacity
- Fast operation
- Accuracy and repeatability at long reaches

Drawbacks:

- Resolution is relatively low, and is variable over the workspace
- The resolution is lower when the end effector is around the base - small change in angle produce a large movement

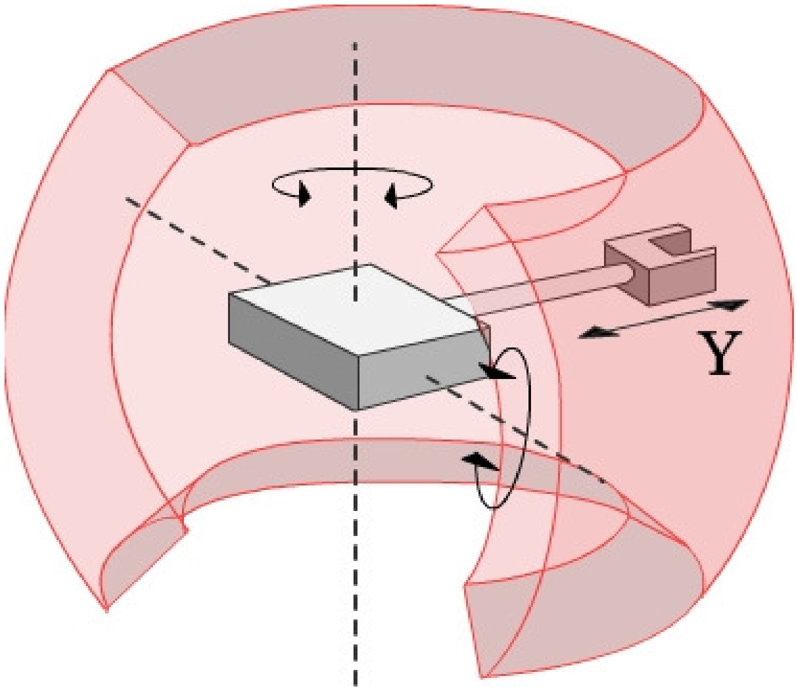


Figure 4.8 Schematics diagram of Polar robot

(IV) SCARA Robot

Figure 4.9 Typical SCARA Robot

SCARA (Selective Compliance Assembly Robot Arm) is a particular robot design developed in the late 1970's in Japan. It is a version of articulated robot, where shoulder and elbow joints rotate about vertical axis, and there is a prismatic joint at the shoulder for elevation.
The basic configuration of a SCARA is a four d.of.f robot with horizontal positioning, much like a shoulder and elbow held perfectly parallel to the ground.

Advantages:

- Fast cycle times and fast operation
- Excellent repeatability and high accuracy
- Relatively high payload capacity due to stiff structure in the vertical direction
- Extremely good maneuverability and access within its programmable area

Drawbacks:

- Difficult to program offline
- Highly complex arm in mechanical structure

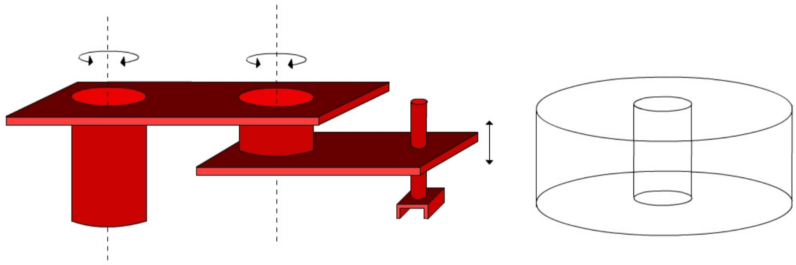


Figure 4.10 Work space of polar robot

(V) Parallel Robots

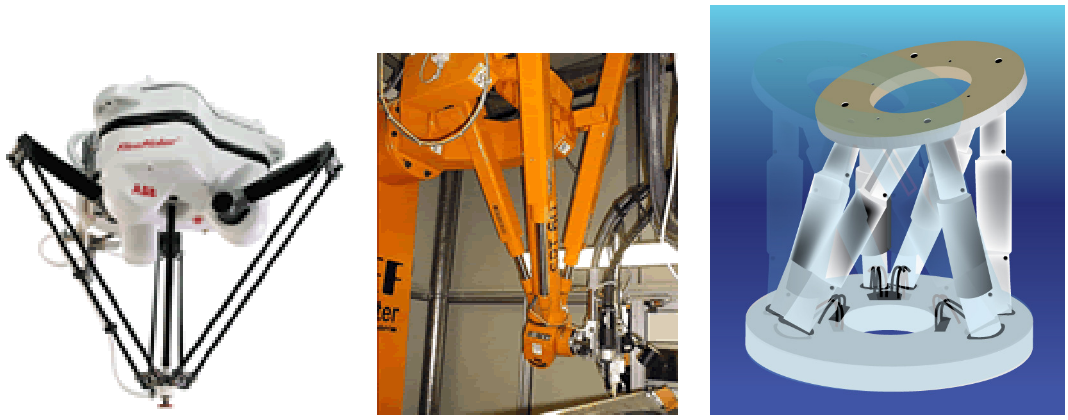


Figure 4.11 Delta type (left); triceps type (mid) Hexapod type (right) **Parallel** Robots

Parallel robot uses three parallelograms to build a robot with three translational and one rotational degree of freedom. The parallelograms ensure consistent orientation of one end of a link with respect to the other. The rotational axis can only be provided by the end effector. As the arms are parallel with each other, the weight of load is distributed over all three links. Good examples of application are flying simulator and 4-D cinema.

Advantages:

- Increased stability and arm rigidity
- Faster cycle times than serial linked robots
- End-of-arm errors are averaged over parallel link structure

Drawbacks:

- Relatively large footprint-to-work space ratio
- Small range of motion

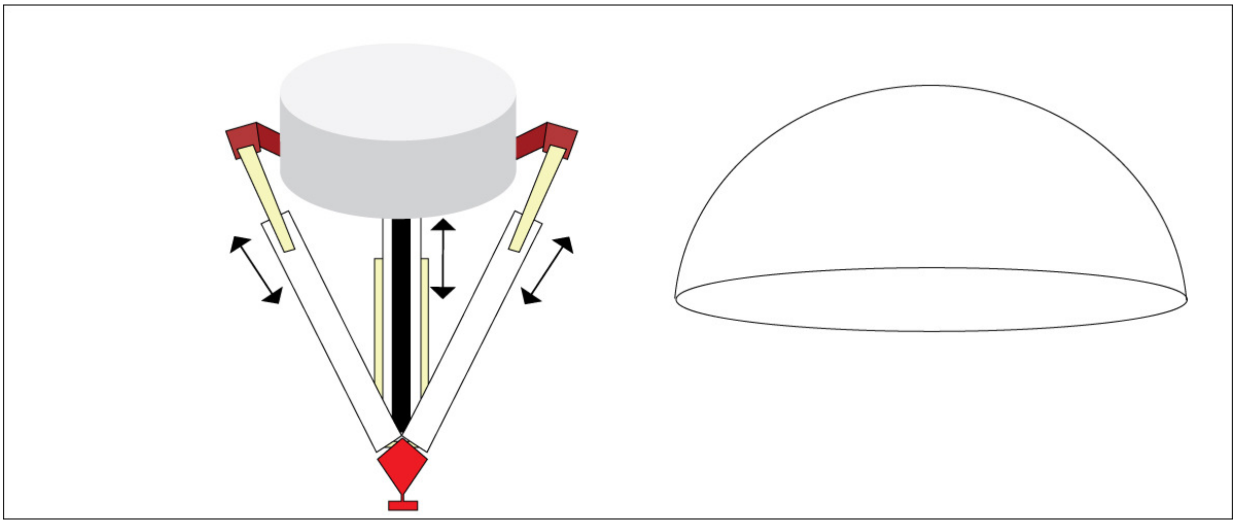


Figure 4.12 Schematics diagram of Parallel Robot

(VI) Articulated/ Revolute Robots

Articulated or Joint-Arm Robots are the most versatile robots available. It closely simulates the natural form of human arm. **Articulated robots** are mechanical manipulator that looks like an arm with at least three rotary joints. One joint is around the base (A1) and the others are on the joints A2 and A3. In terms of a human arm, these can be compared to the shoulder, bicep and forearm. A six-axis jointed robot includes the axis of the wrist (A4, A5 & A6), known as pitch, roll and yaw respectively. With these extra axes added, this robot can move the end effector to any point at any orientation in the workspace. The joint types used are TRR.

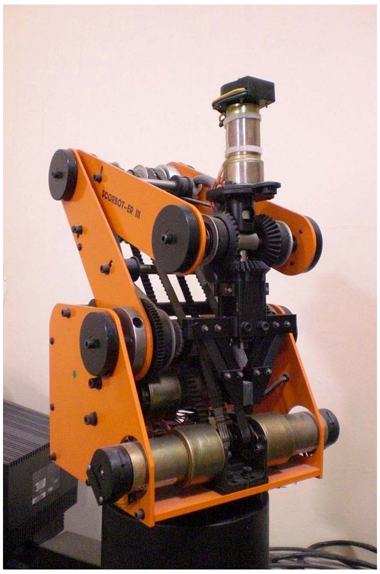


Figure 4.13 Typical **Articulated Robots** for material handling application

Advantages:

- The wrist can reach any position and orientation within the work envelope
- It can reach areas that are difficult to be reached by other robots

- It is compact and provides the largest work envelope relative to their size
- Extremely good working ability
- Ability to reach over obstructions
- Easy access to front, sides, rear and overhead
- Large reach for small floor area
- Slim design allowing easy integration into restricted workplace layouts
- Fast operation due to rotary joints
- Ability to traverse complex continuous paths

Drawbacks

- Not easy to control
- The motion of robot from one point to another can be difficult to visualize, as the robot will move each joint through the minimum angle required
- Accuracy is decreased due to the accumulation of joint errors
- Control of motion is difficult due to the gravitational loading
- Resolution control varies and has less increment at full reach

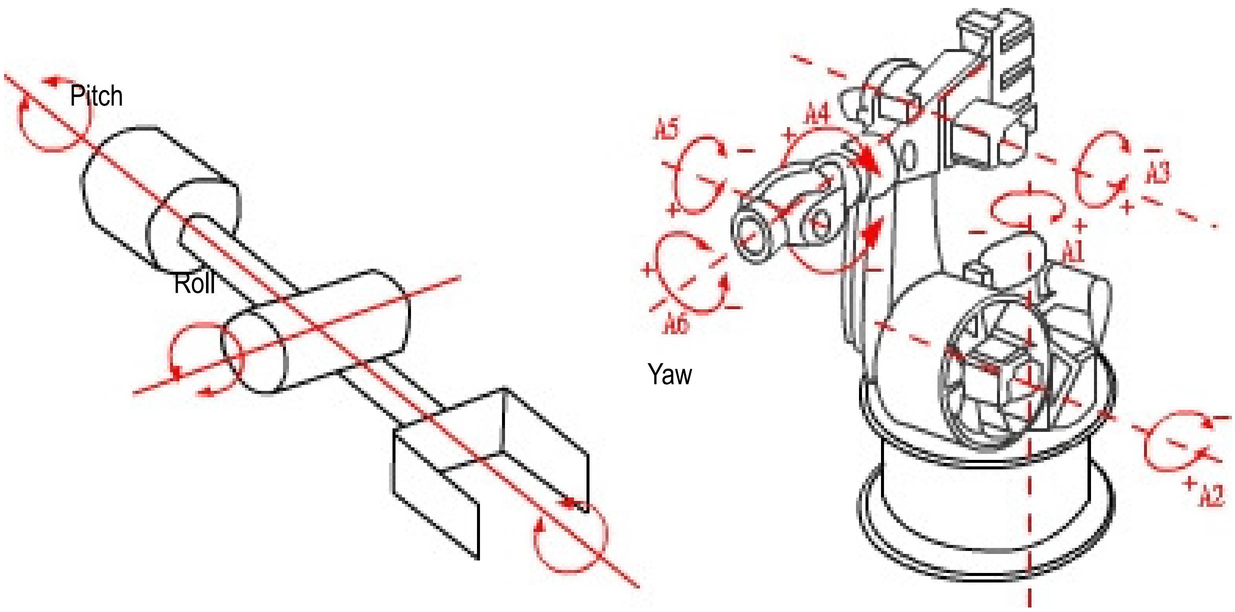


Figure 4.14 Schematic diagram of Articulated Robots

STOP AND THINK
1. Why Articulated robots are commonly used in welding process in industrial application? Please state your reasons. 2. What are the limitations of Cartesian robots used in this application?

4.3 Robot Anatomy

Robot Anatomy is to examine matters including types, sizes of joints, links and any other aspects of a robot.

(I) Degree of Mobility, Degree of Freedom

A joint of an industrial robotic arm, especially the articulated robot, is quite similar to a human arm. It provides relative motion or links between two parts of the robot.
Each link-joint pair is known as **Degrees of Mobility (DOM).**
Degrees of Freedom (DOF) is the number of independent movements the arm can make, referring to the point of view of the end effector (e.g. a grasping hand).

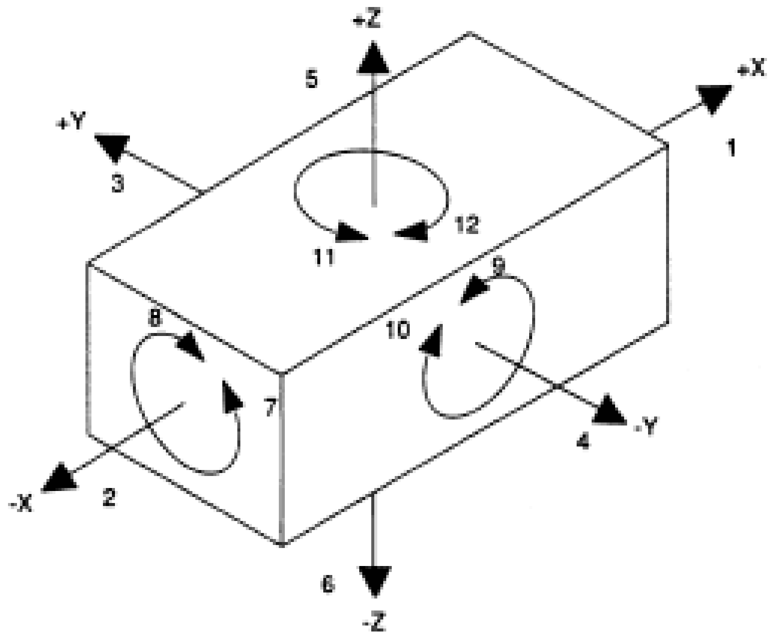


Figure 4.15 Total 12 Degree of Freedom of an object

Each joint enables the robot with a certain number of Degree of Freedom (DOF) of motion. Each joint can provide more than one DOF. For an industrial robot, there are commonly less than or equal to 3 DOF in the body-arm assembly and up to 3 in the wrist assembly but it is possible have any number of DOM. Another DOF may come from the end effector, such as open and close of gripper.

DOF of an arm can be a combination of vertical, radial and translational movements

- Vertical - ability to move up and down (z-axis motion)
- Radial - extension and retraction (in-and-out or y-axis motion)
- Rotational - rotation about the vertical axis (x-axis motion or swivel about the vertical axis at the base)

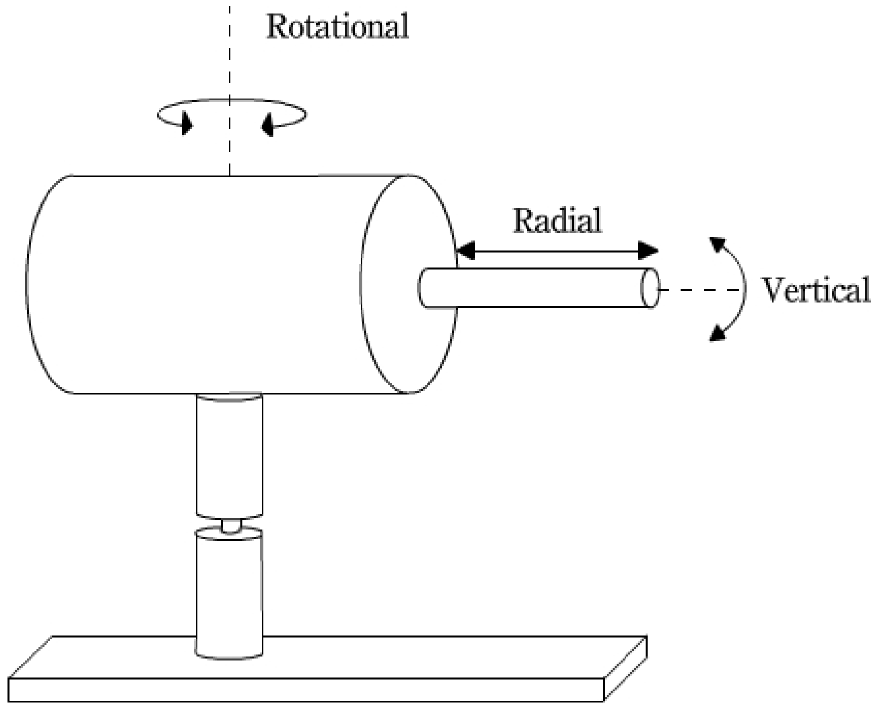


Figure 4.16 Combination of vertical, radial and translational movements

It is important to identify the number of DOF of a robot because the most important specifications and criteria of selecting robots is to state the number of degree of freedom that the robot possesses.

To establish the orientation of the object, the wrist assembly may have the following 3 typical DOF configurations:

- Pitch – type R joint for up-and-down motion of the object
- Yaw – type R joint for right-to-left rotation of the object
- Roll – type T joint to rotate the object about the arm axis

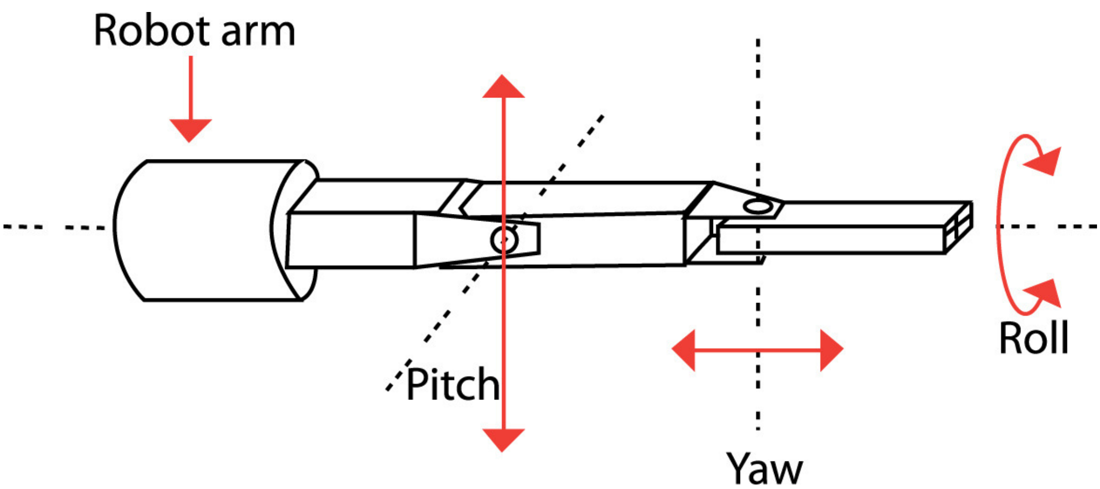


Figure 4.17 A typical wrist would have 3 DOF

S T O P   A N D   T H I N K

1. What will be the number of mobility (DOM) and number of freedom (DOF) for a telescopic arm which has 4 steps of extension?

DOM = _____

DOF = _____

(II) Joints and links

Links are considered to be rigid components of robots. There will be two links connected to each joint: the input link and output link. The purpose of each joint is to provide controlled relative movement between the input and output link.

There are five types of mechanical joints in industrial robots. Two of them provide the linear motion whilst the other three types provide the rotary motion. They are listed below:

a. Linear (prismatic) joint - type L joint

The relative movement between the input link and the output link is a linear sliding motion, with the axes of the two links parallel to each other.

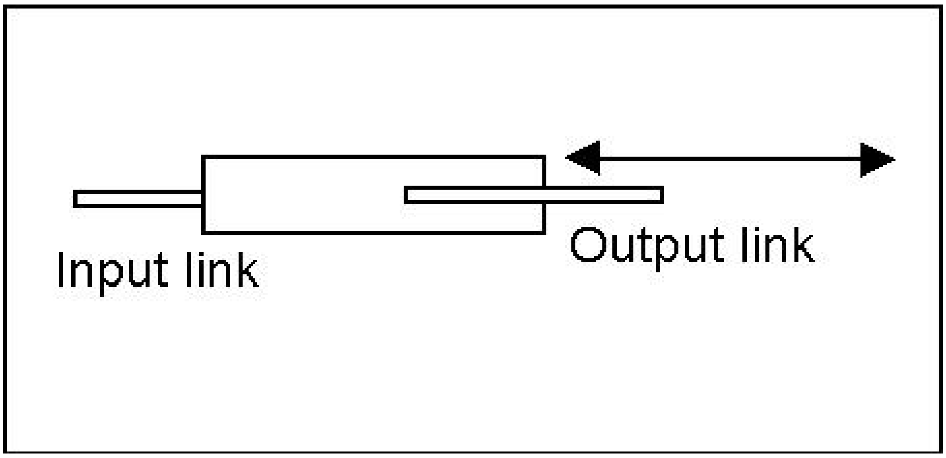


Figure 4.18 Radial, sliding, or translational movement – Type L

b. Orthogonal Joint – type O joint

The relative movement between the input link and the output link is a linear sliding motion, with the axes of the two links are perpendicular to each other.

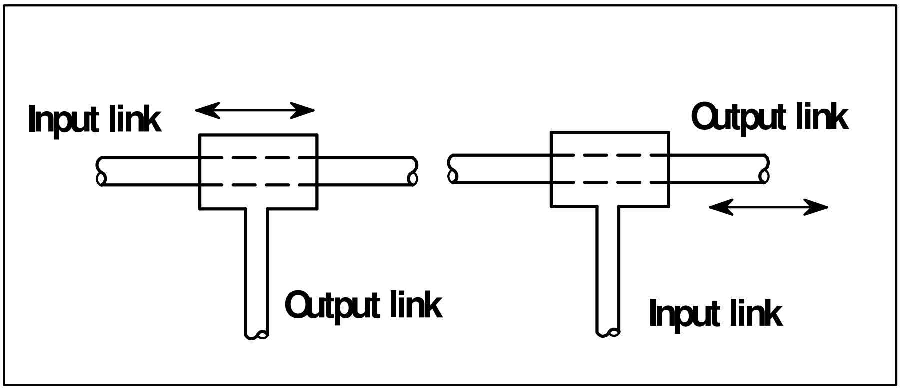


Figure 4.19 Two types of orthogonal joint are also known as Type O

c. Rotational Joint – type R joint

The relative movement between the input link and the output link is rotational, with the axes of rotation perpendicular to the axes of the input and output links.

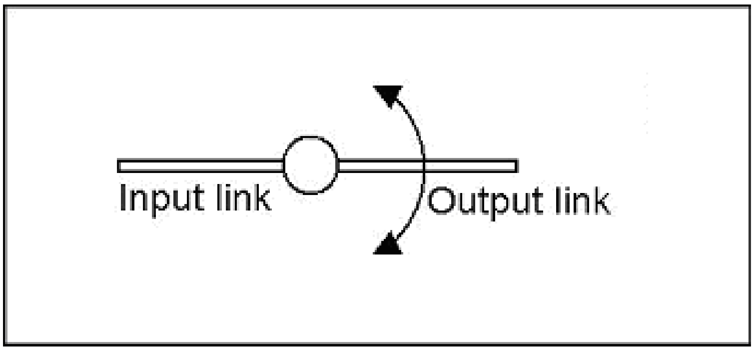


Figure 4.12 Axis of rotation is perpendicular to axis of the 2 connecting links – Type R

d.Twisting joint – type T joint

The relative movement between the input link and the output link is a rotary motion, with the axes of rotation parallel to the axes of the input and output links.

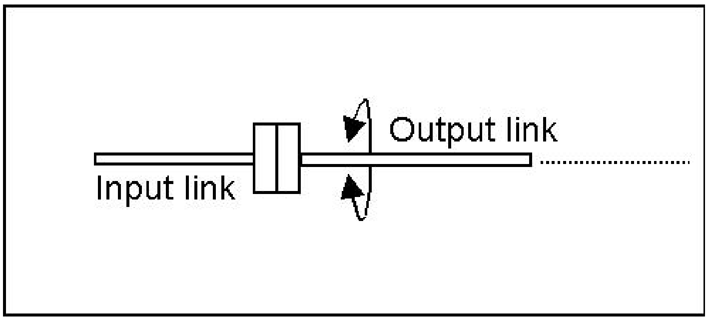


Figure 4.21 Axis of rotation is parallel to the links – Type T

(III) Revolving joint – type V joint

The axis of output link is perpendicular to the axis of rotation, with the axis of rotation of the joint parallel to the axis of input link.

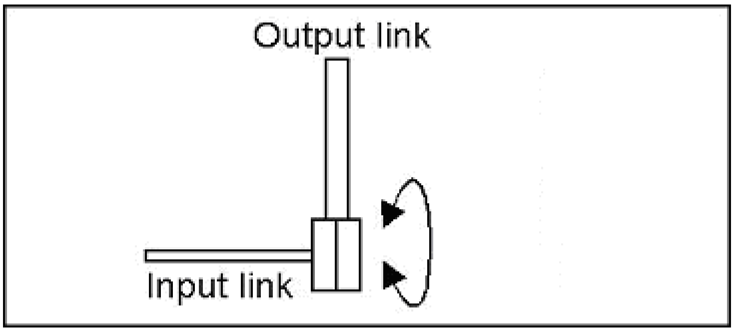


Figure 4.22 Output link is perpendicular to the input joint, but parallel to the axis of rotation – Type V

(IV) Joint notation scheme

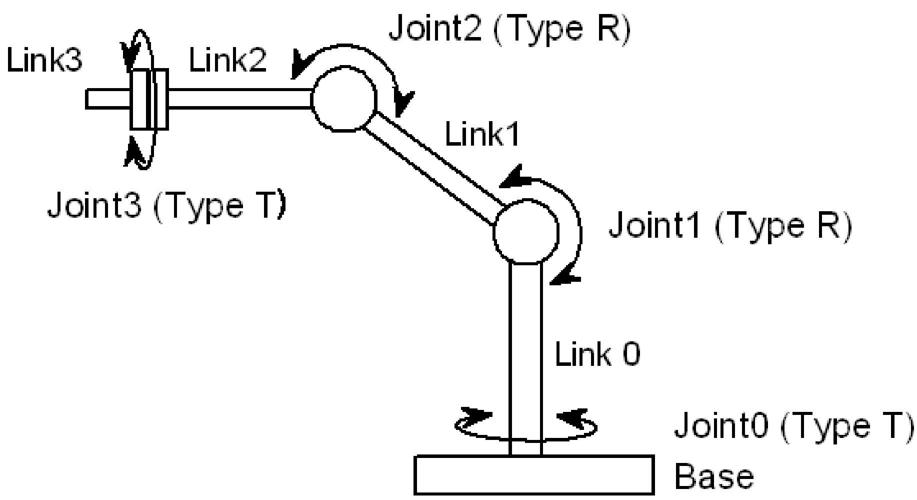


Figure 4.23 Joint and link nomination in an Articulated robot

For a typical robotic arm, it can be divided into 2 main sections:

- a body-and–arm assembly
- a wrist assembly.

Joint notation scheme is that a robotic arm that can be described in terms of the type of joints (L O R T V) it has, which is listed in the order from the base to the end effector.
5 joints types can be labeled with L.O.R.T and V for the linear, orthogonal, rotational, twisting and revolving joints respectively. They are commonly used in joint notation system to describe a robotic arm.

E X A M P L E

We can use TRR as an example to explain the joint notation scheme of TRL.

A TRR represents a 6 DOF robot where (1) the Body-and-Arm assembly is made up of 3 joints: a twisting joint (Type **T**) at the Base, rotational joint (Type **R**) at Joint 1 and linear joint (Type **R**) at Joint 2; (2) the Wrist assembly consists of 3 joints: a twisting joint (Type **T**) for Rolling, rotational joint (Type **R**) for Pitching and rotational joint (Type **R**) for yawing. A colon is used to denote the Body-and-Arm assembly from the Wrist assembly.

Adopting this joint notation system to identify the 6 configurations of robots is listed below:

Robot Type	Joint Notation Scheme
Cartesian Robot	LOO
Cylindrical Robot	TLO
Polar Robot	TRL
SCARA Robot	VRO
Parallel Robot	TRL
Articulated Robot	TRR

Table 4.1 Joint types for different robot configurations

(V) End Effector

A device which is attached to the wrist of the robotic arm to perform specific tasks, such as grippers for material transfer, welding torches for joining, and spray guns for surface finishing, etc. They are mainly divided into two categories by functions:

- Grippers - To hold and move objects
- Tools - To perform work on a part. A tool can be held by collets, making the tools changeable and more flexible

a. Grippers

Vacuum or Suction cups
Vacuum or suction caps are appropriate when the objects to be handled have a flat, smooth, clean surface, e.g. for lifting glass.

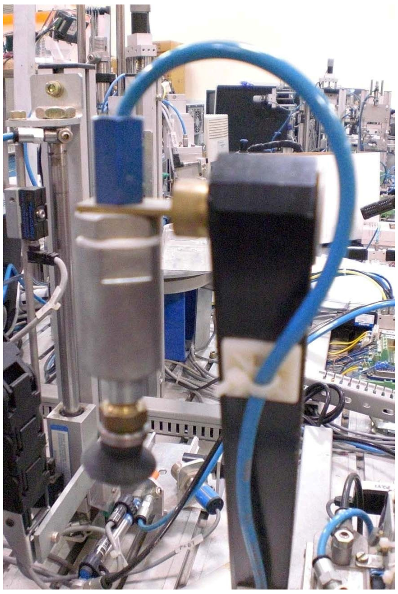


Figure 4.24 Vacuum gripper

Advantages:

- simple in mechanically design
- gentle force can be applied to lift objects without causing damage
- reliable
- light weight
- can be used on a wide range of materials

(VI) Magnetic

Useful only for ferrous materials (containing iron). Objects of different shapes can be picked up quickly. It can pick up parts with holes and irregular surface. It is inevitable to picks up dirt, rubbish or unwanted objects during operation. In addition, slippage may occur and handling will not very precise.

Figure 4.25 Articulated robot per permanent magnetic gripper

It can be powered electromagnetically or use a permanent magnet. Dropping an object is easy for an electromagnetic one by simply powering off the gripper. However, it may be dangerous in the event of power failure. For a permanent magnetic one, it needs specific mechanism to unload the object from the gripper.

Other gripper designs may use adhesives, hooks, scoops, etc, They are specially designed for picking up parts of particular shapes.

(VII) Mechanical gripper

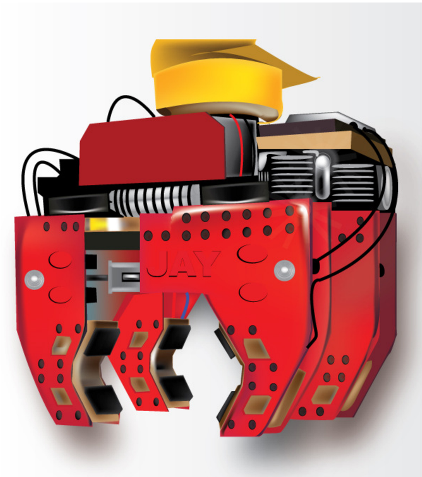


Figure 4.26 Mechanical gripper of fingers type

It uses fingers / jaws - usually 2 fingers, with 2 positions - open and closed, making control relatively simple. Detachable fingers allow worn fingers to be replaced, and is interchangeable between different types of fingers.

It can have **hard fingers** which allow precise handling but may damage delicate materials. The finger may not be versatile or effective for picking up objects of different shapes. The other can be **compliant fingers** which have some "allowance" for dealing with some unpredictable shapes.

Sensors on grippers can provide information to the robot control system that an object has been picked up and allow fingers to apply appropriate force to grasp the object. Sensors can be force sensors, pressure sensors, strain gauges and touch sensors

S T O P A N D T H I N K

Can you use the Joint Notation Scheme to describe the following robots - (1) 6 DOF Articulated robot (2) 6 SCARA?

(i) Body and Arm assembly : (1) _______ ; (2) _________

(ii) Wrist assembly : (1) ________ ; (2) _________

(iii) Joint notation scheme : (1) ____:____ ; (2) ____:_____

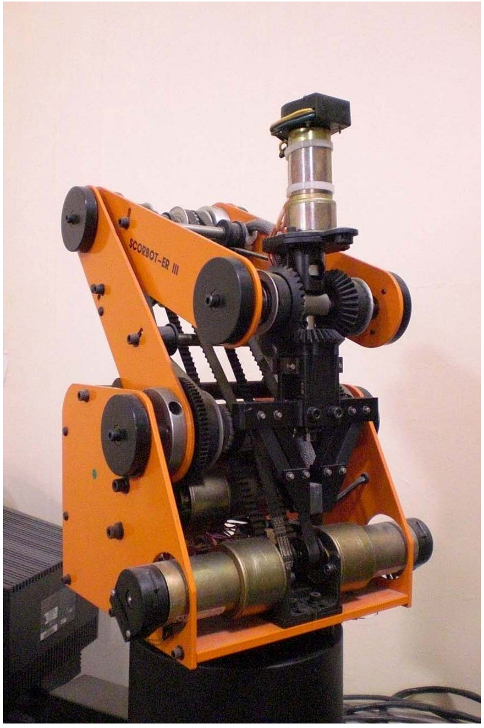


Figure 4.27 (a) Articulated robot (b) SCARA robot

(VIII) Work Space

Work space is also called Work volume or work envelope. It is defined as the space within which the robot can manipulate by the end of its wrist. It is determined by the following factors:

1. The number and types of joints in the manipulator (body-and-arm and wrist assembly)
2. The physical size of each joints and links
3. The ranges of each joint

Cartesian robot has a rectangular work space. Polar robot has a partial spherical work envelope and a cylindrical robot has a cylindrical work volume.

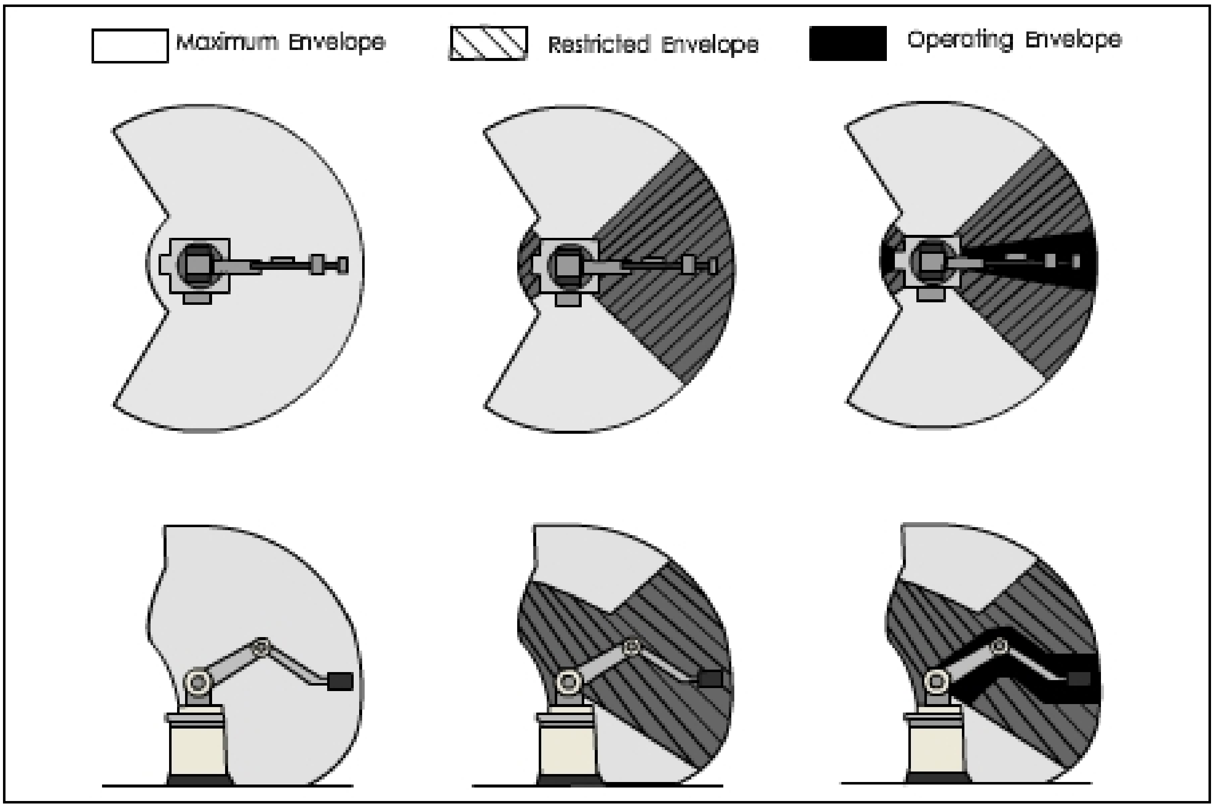


Figure 4.28 Diagrams show the work envelopes of an articulated robot

- **Maximum envelope** is the envelope that encompasses the maximum designed movements of all robot parts, including the end effector, work piece and attachments.
- **Restricted envelope** is a portion of the maximum envelope which a robot is restricted by some limiting devices.
- **Operating envelope** is the restricted envelope that is used by the robot while performing its programmed motions.

S T O P A N D T H I N K
What is/are the use(s) of knowing the work envelope for a robot?

4.4 Robot Control Systems

(I) Drive Systems

Usually there are three main classifications of power drive for robots - electric, pneumatic and hydraulic. They are used to drive robots through the use of actuators

a. Electric

For electrical driven robots, four major types of electric drive can be used:

(i) **Stepping Motors**: These are used mainly for simple pick and place mechanisms, especially when low-cost is the more important consideration than power or controllability.

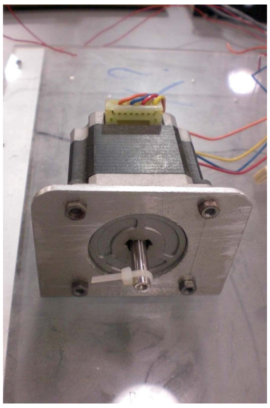


Figure 4.29 Stepping motor

(ii) **DC Servos:** For the early electric robots, the DC servo drive was used extensively. It provides good power output with a high degree of speed and position control.

(iii) **AC Servos:** In recent years the AC servo has taken over from the DC servo as the standard drive. These modern motors give higher power output and are almost silent in operation. They have no brushes in structure. They are very reliable and require almost no maintenance in operation.

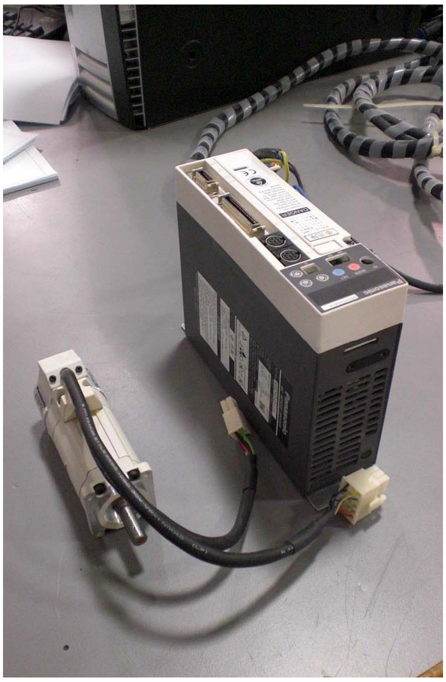


Figure 4.30 AC Servos with controller

(iv) **Solenoids Actuator**: A major advantage of solenoid actuator is their quick operation. Also they are much easier to install than pneumatic or hydraulic actuators. However, solenoid can only have fully open (extend) or closed (retract) function. They cannot bear much loading.

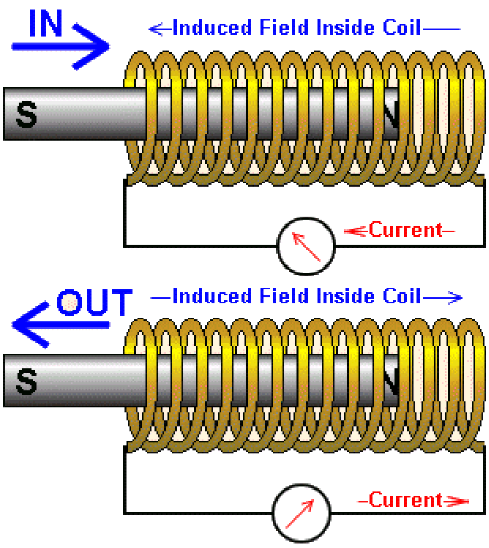


Figure 4.31 Operation of solenoid actuator

b. Pneumatic

Robots, that use compressed air, may come in a wide variety of sizes. Most of the simple pick and place arms are driven by pneumatics. This makes the system low in cost. However, it has the disadvantage of being difficult to control with high accuracy.

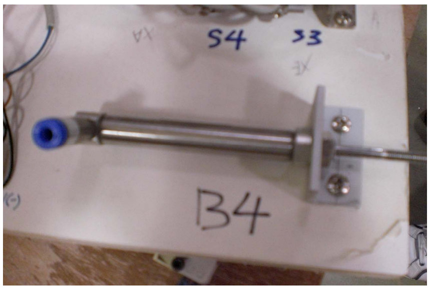


Figure 4.32 Pneumatic cylinder

c. Hydraulic

Robots, that use hydraulic, are generally performing heavy duty jobs. This power type is noisy, large and heavier than the other power drive sources. Hydraulic drives were used on a large number of early robots as it was more rigid and controllable than pneumatics. It could provide more power than the electric drives. The problems with hydraulics are that it tends to be fairly slow in operation, but the leaks, that due to the high-pressured oil, can be very messy.

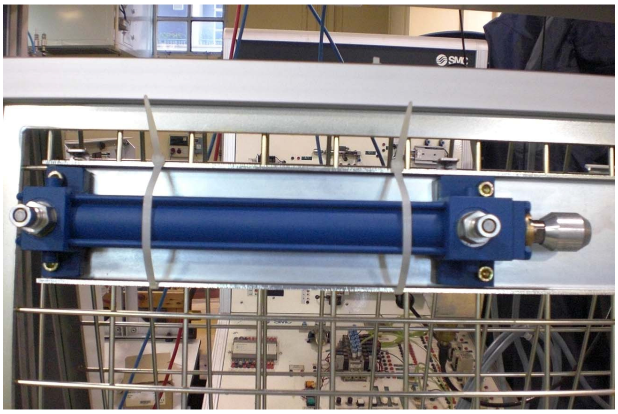


Figure 4.33 Hydraulic actuator

S T O P A N D T H I N K

1. Why solenoid actuator can only perform duty of light loading?
2. Why pneumatic drive system has difficulty of controlling with high accuracy?

(II) Types of robot control

a. Limited-sequence robot

It is the most elementary control type and can only be used for simple motion cycle, such as pick and place application. It is designed by arranging the limit switches or mechanical stops at each joints and sequencing the actuation of joints to accomplish the cycle. Simple pneumatic driven robot without an electronic controller is the type of limited sequenced robot.

b. Point to Point control

The controller has a memory for storing the sequence of motion and the location of each joint in a given work cycle. Feedback control is used to assure that an individual joint has achieved the desired location defined in the program. However, in this PTP control, only the final location of an individual joint is controlled. The path taken for the joint to move from the initial location to the final location is not of concern.

c. Continuous Path control

The movement of the arm and wrist is controlled during the motion. Servo control is used to maintain the continuous path control over the position and speed of the robotic arm. Its advantage is to provide a smooth continuous path for the robot.

d. Intelligent Robot

With the advancement in microprocessor and Artificial Intelligence (AI) technology, robots can be equipped with advanced sensory systems, such as vision sensors and face recognition technology, that process information and function like a human brain. AI allows a robot to perceive conditions and make decision based on the perceived condition. An intelligent robot can make decisions when things go wrong during the work cycle, communicate with human beings and make computation and correction during the motion cycle.

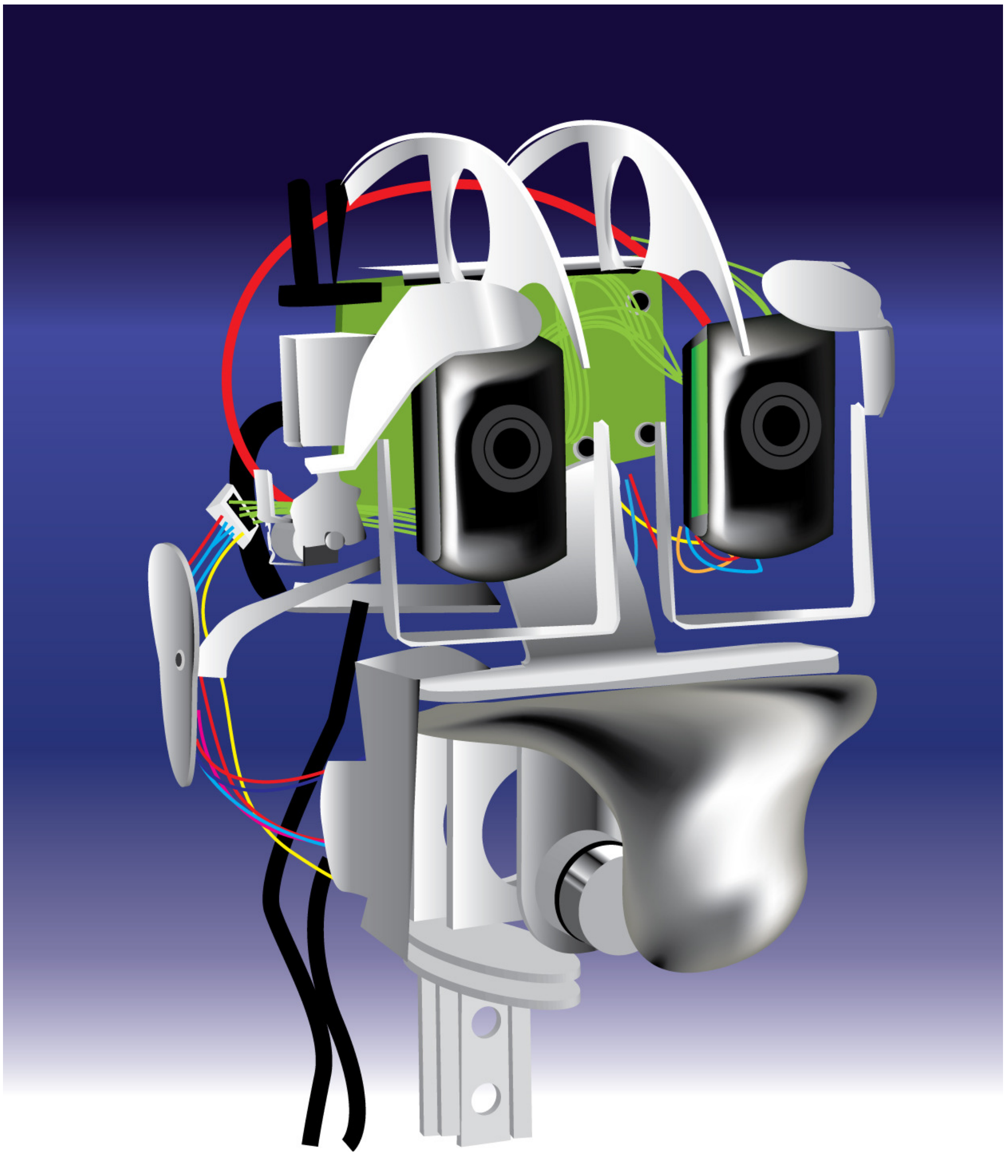


Figure 4.34 Intelligent robot with machine vision and face recognition technology

(III) Programming a robot

a. Teach Pendant Method

A teach pendant (handheld programmer) is used to control and program the robot. Operator can teach the robot by driving individual robotic joints independently. The operator can use either the world coordination system (WCS) which is located at the robot base or Tool coordinate system (TCS) which is originated at the robot wrist. This system is especially useful when the tool is near to the work piece.

This method of programming is very simple to use where simple movements are required. However, when teaching, the robot cannot be run in production, this reduces the machine utilization rate.

Figure 4.35 Teach pedant for teach method of robot programming

b. Leadthrough Programming

This programming method is mainly used by spray painting robots. The robot is programmed by being physically moved through the task by an operator. This is exceedingly difficult where large robots are being used. Therefore, a smaller version of robot is sometimes used for this purpose.

Any hesitations or inaccuracies that are introduced into the program cannot be edited easily without reprogramming the whole task. The robot controller simply records the joint positions at a fixed time interval during the leadthrough and then plays back the sequences.

c. Off-line Programming

It is used to program robots from the CAD models of the robots, fixtures and accessories. The program structure is built up in much the same way as for teaching programming but intelligent programming tools are available which allow the CAD data to be used to generate sequences of location and process information. The benefits of this form of programming are:-

- Reduced down time for programming.
- Programming tools make programming off-line, thus can reduce product lead time.
- Work cell design and allows process optimization.

However, because off-line programming is not accurate, it requires adjustment interactively on the factory floor until all positions and orientations are correct before the robot can run in the production.

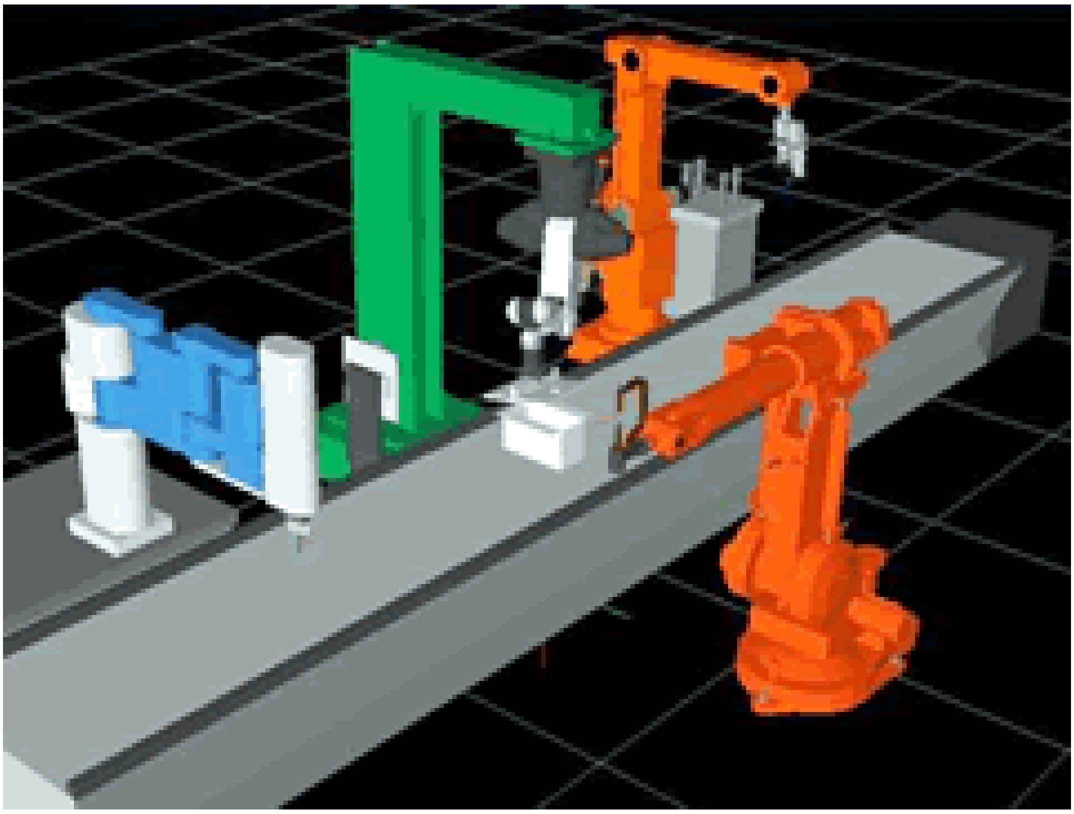


Figure 4.36 Teach pedant for teach method of robot programming

4.5 Applications of Robots

Robots offer some obvious advantages in terms of speed, accuracy and productivity as they can run 24/7 repeating jobs, which would be tedious to operators, and without human error.
Below are some common applications which can provide a robotic solution to increase productivity. It may also be possible to integrate more than one application of robots into a system to suit variety of needs.

(I) Medical Robots

Robots are used in medical fields because they are highly precision machines. By tooling the end-effector with surgical instruments, they used to perform delicate surgery.
These machines still require a human surgeon to operate and input instructions. Remote control though Internet and voice activation are going to be used to control these surgical robots.

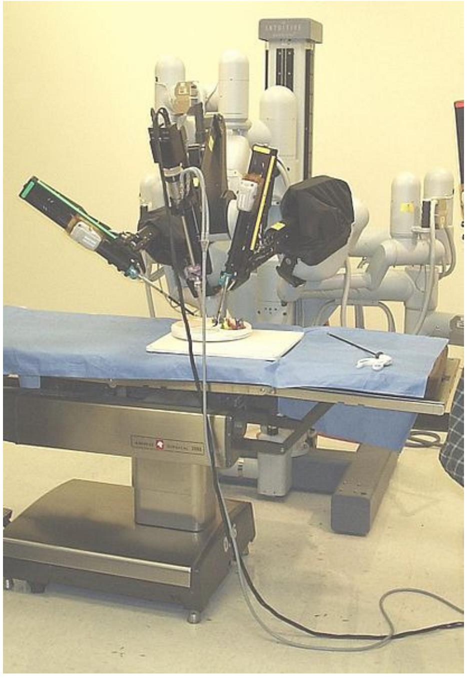


Figure 4.37 Surgery Robot

(II) Robots in Automobile Industries

In the automobile industry, robotic arms are used in diverse manufacturing processes including assembly, spot welding, arc welding, part transfer, laser processing, cutting, grinding, polishing, deburring, testing, and painting. Robots have been proved to help automakers to be more agile, flexible and to reduce production lead times.

Figure 4.38 Industrial robot in manufacturing plant

(III) Electronics/Semi-Conductor

Application of clean room Robots in semiconductor manufacturing results in the reduction of scraps from broken chips. The avoidance of contamination and the savings in scraps from dropped wafers in machine loading and unloading can be a major savings. Typically, clean Room robots are used in machine loading, unloading, and parts transfer in the semiconductor industry. Assembly, packaging, and testing processes are other application areas for clean room robots.

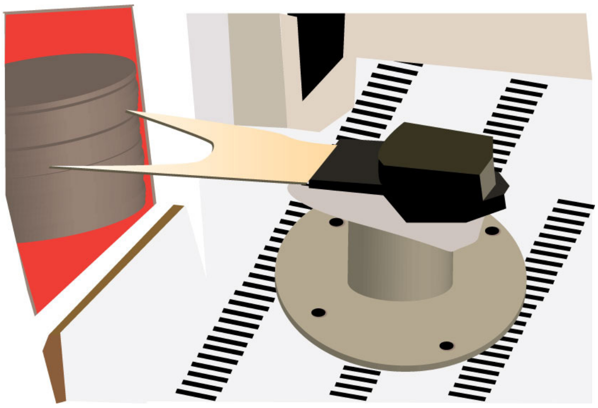


Figure 4.39 Industrial robot in manufacturing plant

(IV) Food & Beverage

Food and beverage applications represent a small fraction of industrial robotics application. However, it is widely recognized as one of the fastest growing segments, like automotive industry. The vast majority of robots in the Food & Beverage industry are found in the packaging area. High-speed material handling robotic arms and vision-guided systems are beginning to work in food factories.

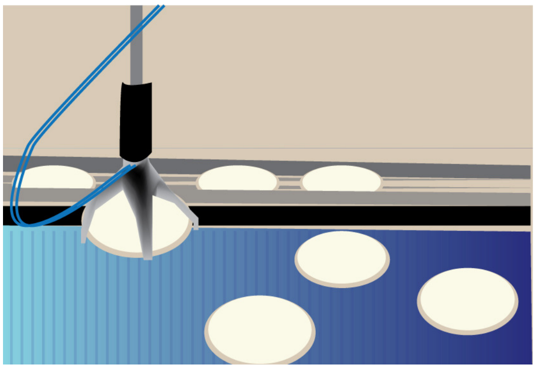


Figure 4.40 Industrial robot in manufacturing plant

(V) Construction

Construction robots aim to improve the efficiency of work at construction sites. Robots are used in the applications like inner pipe crawling, excavation, load transport, mining, bricklaying, earth work, foundation, prefabrication of reinforcement and pavement work.
Generally, construction robots will replace human workers in dangerous conditions or problem of limited accessibility.

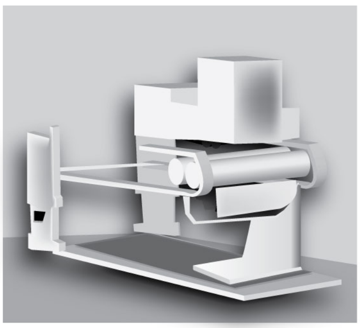


Figure 4.41 Construction Robot for pavement work

(VI) Space Robots

Space robotics is generally divided into two main areas: 1. serving the functions of robotic manipulators, such as the mechanical arm installed in US space shuttle for maintenance of space station or as a crane for material transfer or construction work. 2. Robotic explorer for inspection of hostile environment in planetary surfaces and collection of soil samples for analysis.

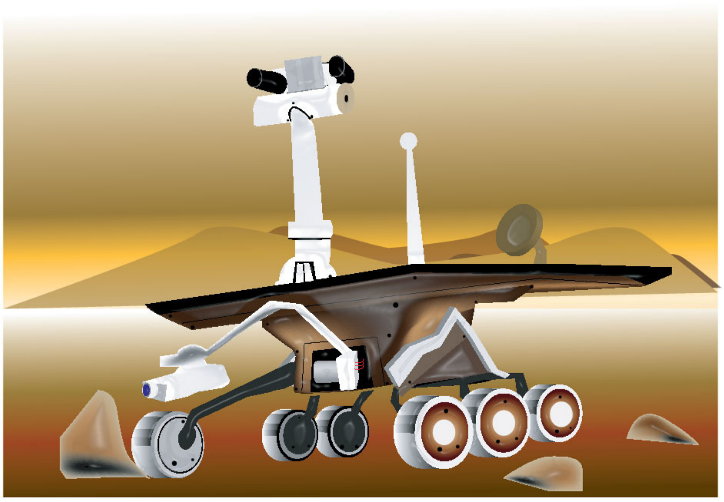


Figure 4.42 MARS lander for US MARS Exploration Program

(VII) Military/Security Robots

They are usually deployed as unmanned remote-control vehicles, typically of terrace-type. They are capable of taking surveillance photographs and serve as mine sweepers or bomb disposal to safeguard people from endangering into a hostile environment.

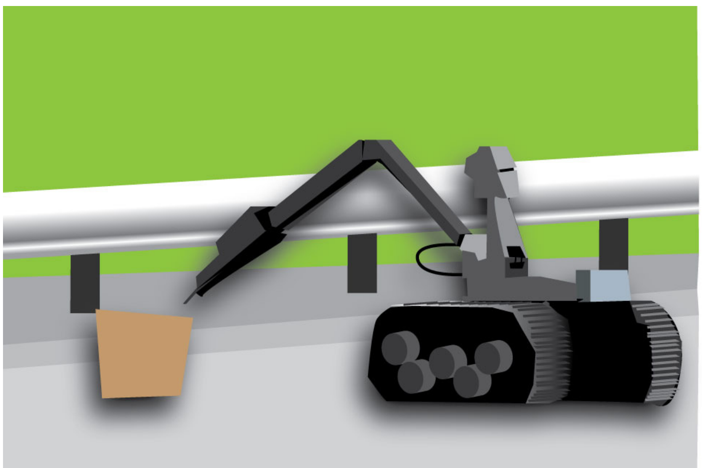
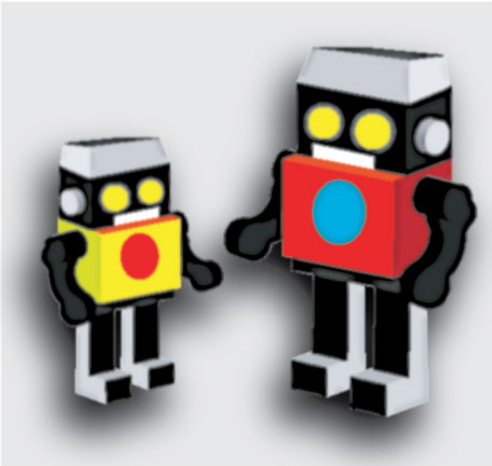


Figure 4.43 Bomb disposal robot checking suspicious

Quizzes (Chapter 4)

1. What is the limitation of Gantry Robot?
2. What are the differences of DOM and DOF?
3. List the five types of joints used in robots.
4. Suggest any specific applications of electric, pneumatics and hydraulic drive systems of robots? State your reasons.
5. What are regarded as Intelligent Robot?
6. What will the possible limitations of using surgery robot through Internet be?
7. Which of the followings are regarded as robots? State your reasons.


a

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THEME-BASED LEARNING TASK 1

Practical Design Appreciation - Case Study of Intelligent Fire Alarm System

Figure 1.1 High rise commercial building on fire

(I) Background

Most of the Hong Kong people may remember the tragedy of Grade 5 fire in Garley Commercial Building in 1996. The fire had caused a great causality and alerted people to the safety of public premises. After this tragedy, there is a law stating that all the commercial buildings, which were built before 1987, are enforced to install Intelligent Fire Alarm system to safeguard the people from severe causality by early warning and to extinguish the flame automatically and intelligently.

(II) What is Automatic Fire Alarm (AFA) or Intelligent Fire Alarm system (IFA)?

1. Conventional system

Figure 1.2 Sprinkler head (left); Alarm gong (mid); Break glass (right)

Traditionally, the fire alarm system is triggered by the "break glass" manually to alert people inside the building in the event of fire. The red alarm gong will be triggered to alert the residents inside the building and the pedestrians outside the building. The fire is extinguished by the sprinkler system that is triggered locally by the heat of fire. The pre-pressurized water inside the pipes of sprinkle system will be sprayed through the nozzle of each sprinkler head until the pressure head along the pipeline drops to zero.

2. Automatic Fire Alarm (AFA) or Intelligent Fire Alarm (IFA) system

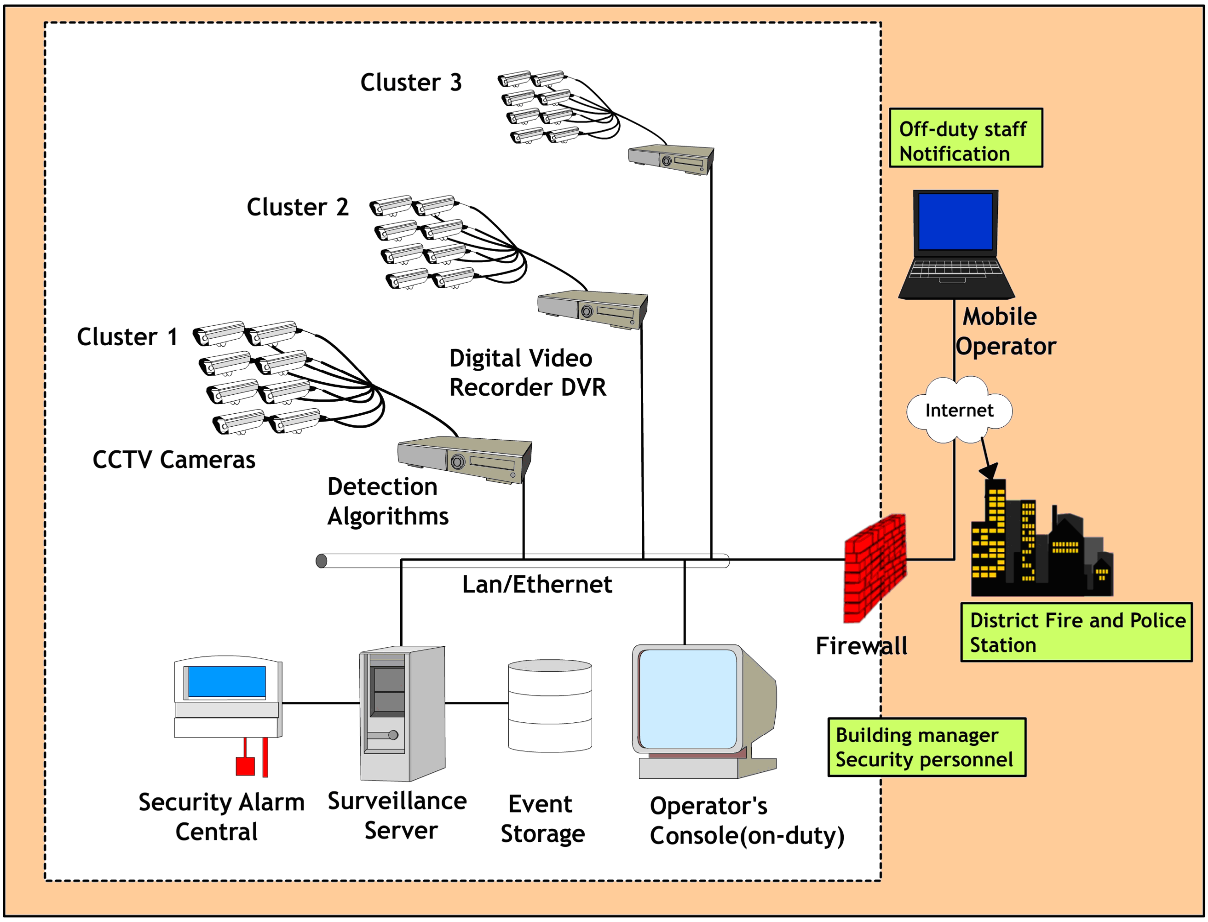


Figure 1.3 Block diagram of Intelligent Fire Alarm system

For the Intelligent Fire Alarm System, the fire is detected by intelligent sensors, which verify the flame by the heat and smoke of the location. The signal will be transmitted to the Control Panel that is usually housed in the security room and monitored by the on-duty operator. The control panel is basically comprised of a CPU and a number of interfacing cards and networking cards. Once the flame is "verified" by the intelligent system, the signal will be sent to the pump room to turn on the duty pumps to charge the sprinkle system. The fire alarm signal will also be relayed to the Regional Fire Office automatically through the dedicated signaling line. The fire engines will then be sent to the fire location through this AFA or IFA.

Figure 1.4 User Interface of Flame and Smoke detection system

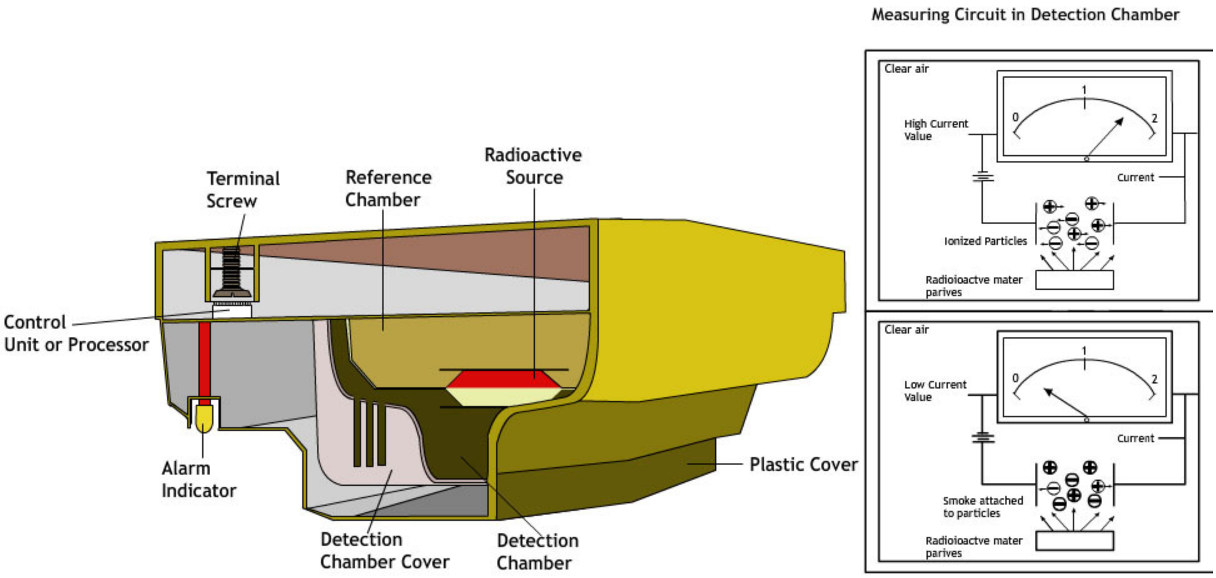


Figure 1.5 A cutaway diagram of intelligent smoke sensor

The owner or responsible personnel of this property will also be notified by the messaging function of the control panel through mobile phone. The user interface has imported the building floor plan in the initial configuration. The floor plan is divided into number of zones according to the arrangement of smoke and heat sensors. Once the fire happens, the zone concerned will be flashing and alerting sound on the screen to alert the responding personnel to take any pre-planned emergency procedure.

This intelligent fire alarm system will be integrated with the surveillance system to have a real time monitoring of the fire location as shown in Figure 1.4. Once the flame is notified in one a (zone), the surveillance system will alert the on-duty personnel and indicate the exact location of the building by the pre-loaded site drawing or the building floor plan.

All the intelligent sensors are connected by the twisted-pair cables and are communicated through an Ethernet network. Each sensor has its own IP address and their distribution over the building are stipulated by the fire regulation.

(III) Learning Tasks

1. Investigative Questions:

Students are expected to form groups, by conducting information search through Internet and small group discussion, to answer the following questions:

A. Explain why the Intelligent Fire Alarm system does not use the pre-pressurized sprinkle system but use the “dry” pipe.
B. Explain why each sensor has its own IP address.
C. Investigate how the intelligent sensors ‘confirm” the fire is happening.
D. Investigate what other fire extinguish methods are used besides the sprinkle system.

2. Follow-up Activities

A. Form groups and carry out a field study of fire safety measures taken in the school premises. Appraise the level of automation for this fire safety measure.
B. Also, other groups of students can take a look at the shopping mall nearby. Study what fire safety devices and systems are being adopted. A comparison can be made with those used in the school campus. Prepare a brief verbal report to state the differences and give appropriate reasons.
C. Suggest any improvement plan to upgrade the fire safety system for your school.

Hands-on Activity – Controlling an Automated Traffic Lights using Programmable Logic Controller (PLC)

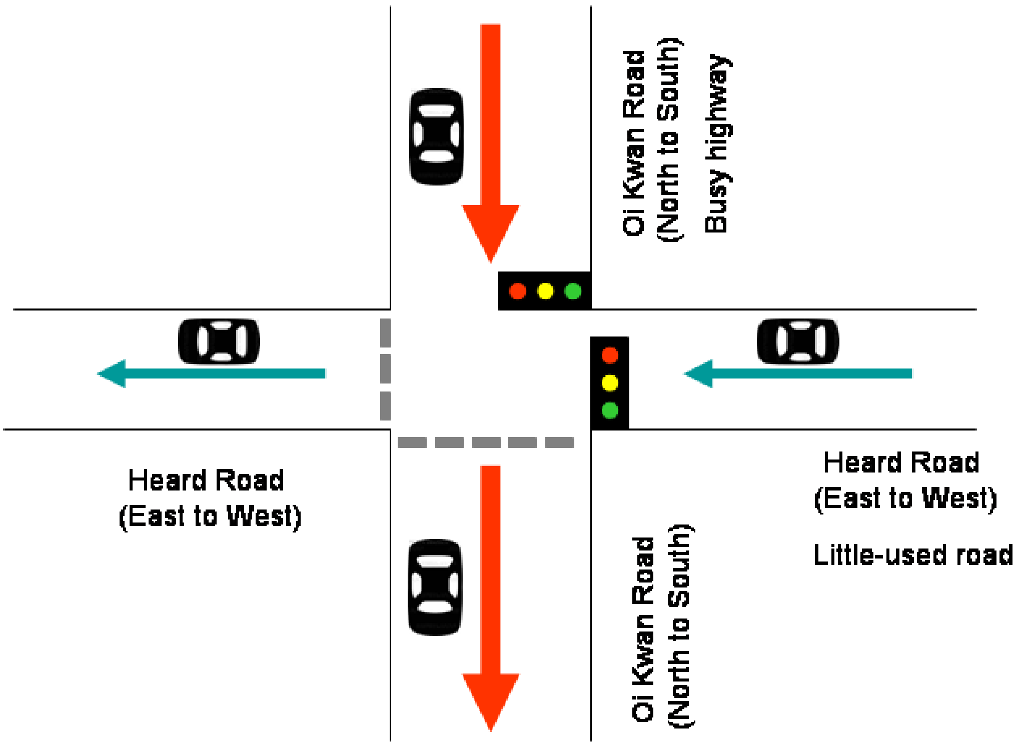


Figure 2.1 Traffic light control between Oi Kwan Road and Heard Road

(I) Background

A pair of traffic lights is set at the intersection of Oi Kwan Road and Heard Road. Oi Kwan Road is the busy highway, Heard Road is the little-used road. One traffic light is used for highway and the other is used for the little-used road.

Three timers are used for the traffic light control:

1. First timer is used to provide a short delay of 2 seconds, TS_2
2. Second timer is used to provide a medium delay of 5 seconds, TM_5
3. Third timer is used to provide a long delay of 10 seconds, TL_10

The state variables are as follows:

1. OG for Oi Kwan Road Green
2. OY for Oi Kwan Road Yellow
3. AR for both roads Red
4. HG for Heard Road Green
5. HY for Heard Road Yellow

Converting the traffic lights situations into a light sequence condition for analysis.

State	Oi Kwan Road Light	Heard Road Light
OG	Green	Red
OY	Yellow	Red
AR	Red	Red
HG	Red	Green
HY	Red	Yellow
AR	Red	Red

Table 2.1 Light and state conditions

The light sequence can be represented by the state diagram and timing chart for better understanding.

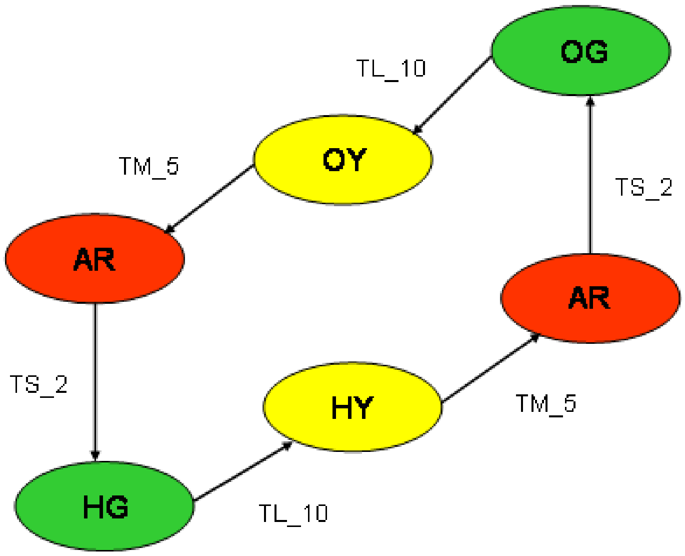


Figure 2.2 State diagram for the traffic lights intersection

(II) Learning tasks

Part A

1. Equipment

- A PLC with a handheld programmer or a computer
- LEDs (Red, Yellow and Green for 2 sets)
- x 1k resistors
- Connecting wires

2. Tasks

A. Construct the timing diagram
B. Construct the ladder diagram
C. Setup the PLC control and demonstrate to teacher

Part B

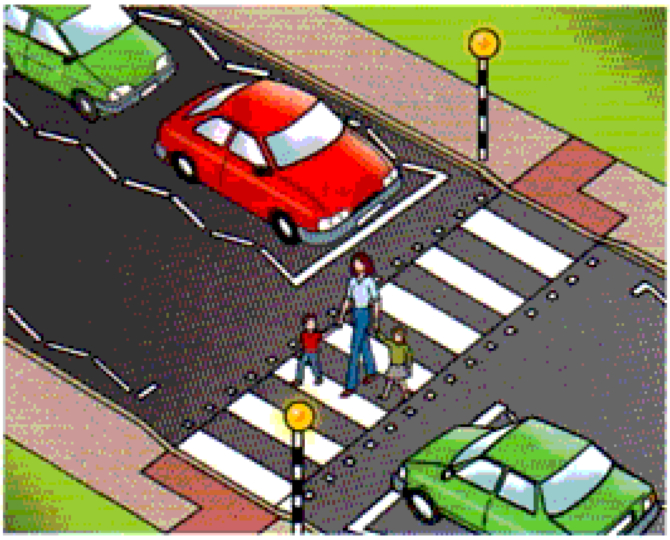


Figure 2.3 Traffic light on a motorway for pedestrian

Students can conduct a simple field study at the zebra crossing point and observe the traffic light operation in a real scenario. They can record the sequence of light cycle. The traffic light should have a button (interrupt) for the pedestrian to adjust the traffic light to cross the road.

1. Equipment

- A PLC with a handheld programmer or a computer
- LEDs (Red, Yellow and Green for 1 set)
- A push button
- x 1k resistors
- Connecting wires

2. Tasks

A. Construct the timing diagram
B. Construct the ladder diagram
C. Setup the PLC control and demonstrate to teacher
D. Give any suggestions to improve the road safety for this zebra crossing condition.

Design and Make Project – Pipe Cleaning/Inspection Robot

(I) Introduction

In Hong Kong, most of the drivers complain that the maintenance and construction work of underground pipe works are so frequent which are blamed for the major cause of traffic jams. The repair of underground pipes is mainly due to the leakage caused by prolonged clogging in the old metal pipe and accumulation of rubbish in PVC pipe.

These pipes cannot be cleaned by routine maintenance. Once the leakage happens, the only way is to replace them with new ones. Therefore, it is unavoidable to cause a lot of disturbances to the traffic condition. If these pipes can be cleaned regularly to reduce the clogging of dirt, they can "live" longer and, thus, reduce the tremendous maintenance works.

Figure 3.1 A typical pipe inspection robot

Students are required to apply their knowledge to design and make a Pipe Cleaning/Inspection Robot.

(II) Project Brief

(a) Consumables

No.	Descriptions	Qty.
01	Aluminum (of wide range of forms and size, such as angle, flat, rod, channel and tube, etc.)	numerous
02	Acrylics (of wide range of forms, size and color, such as triangle, flat, rod and tube, etc.)	numerous
03	Fasteners (i.e. machine screws, washers, nuts, rivets, pop rivets, lock clips, studs, self-locking nuts, strap fasteners and spanners, etc.)	numerous
04	Conventional workshop hand tools (marking-out tools, cutting tools and finishing tools) and machinery (such as drilling machine, sander and buffing machine, etc.)	Sufficient numbers

Table 3.1 Consumables needed for making the robots

(b) Test Rig

No.	Descriptions	Qty.
01	A 300mm internal diameter opaque PVC or transparent acrylic pipe with length of not less than 4 feet.	1 pc.
02	A tailor-made wooden container with nylon covering for collection of leakage water (placed under the test pipe)	1pc.
03	A pair of tailor made wooden stands to support the test pipe and with appropriate fasteners for security and safety.	1pc.

Table 3.2 Part list for the test rig

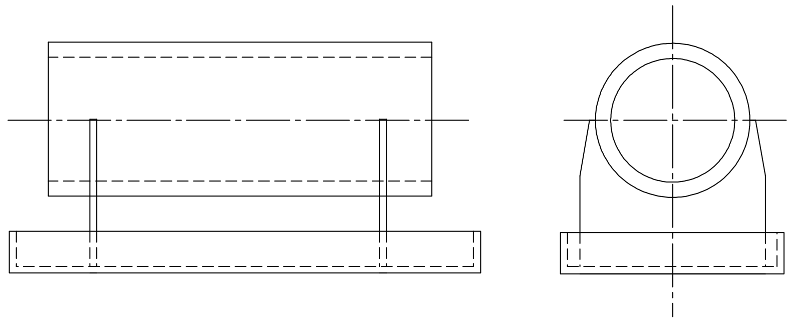


Figure 3.2 Schematic diagram of Test rig

(c) Tasks

- Students are required to design and make a pipe cleaning robot prototype that can demonstrate how to clean a pipe in the test rig.
- The robot can be autonomous with suitable sensory feedback, execution of preset program or real-time remote control.
- Students have to design an appropriate locomotion that can move effectively along the inner wall of the test pipe.
- An end-effector should be a pipe cleaning device.
- It may need to install a camera or appropriate sensors to collect image and information from the pipe being inspected.
- Robots can also be controlled by wireless through radio frequency or bys wired real-time remote control according to the competency of students.

Mars Exploration – Design an Innovative End-effector for Mars Lander

(I) Background

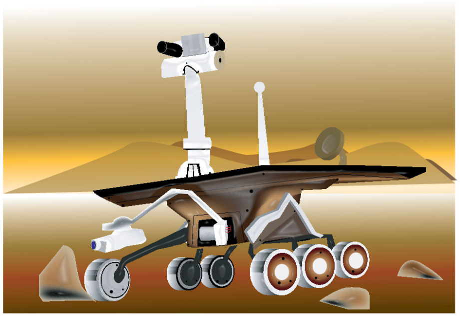


Figure 4.1 MARS Lander used in sample extraction on Mars surface

Though Mars exploration seems to be a far-reaching issue to a hassle and financial city like Hong Kong, the patented "Space Plier" that was designed and developed by a group of engineers and scientists from Hong Kong Polytechnics University had been used by Europe NASA in the Mars Exploration Program in 1995 and 2003 respectively. The "Space Plier" is used to pick up soil samples of MARS surface. It has a small drilling bit to dig a hole on the surface and has a little "pliers", like a chopstick, to collect the soil sample out of the drilled hole.

(II) Task

Students are provided with a remote-controlled locomotive, either wheel-driven or terrace-type (common mechanical toys can be considered). The locomotive is a platform on which students are expected to design and make a special end-effector to simulate the tasks in MARS. Teacher can provide a Mars-like field to promote the students' motivation.

The end-effector can be driven by whatever the means students can think of, maybe powered by water or air syringes, elastic bands, DC motors or any other means. The design of this end-effector is encouraged to be more innovative, not only to the use of 2 or 3-fingers mechanical gripper.

Figure 4.2 Toys chassis used as a locomotive platform

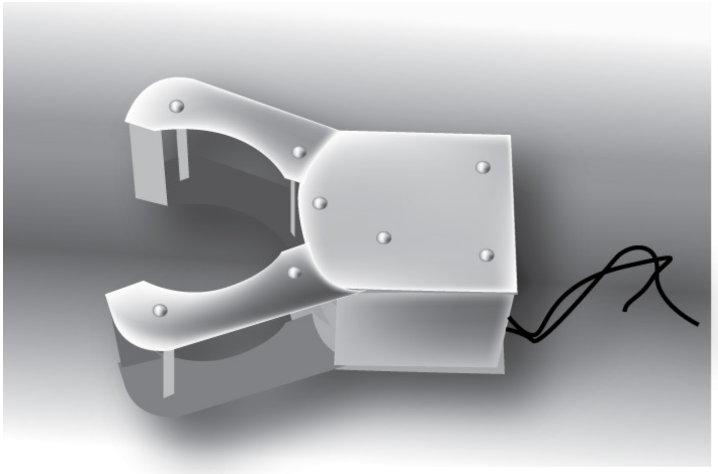


Figure 4.3 Typical 2-fingers gripper design based on linkage and driven by electric motor

(III) Follow-up Activities

A. Describe any trade-off when designing an "innovative" end-effector.

B. If the answer to the last question is "absolute", why do we still need to pursue innovation?

ASSESSMENT TASKS

QUESTION 1: (RELEVANT TOPIC: BASICS OF CONTROL SYSTEMS)

Students are required to study the sequential operations of a washing machine at home.

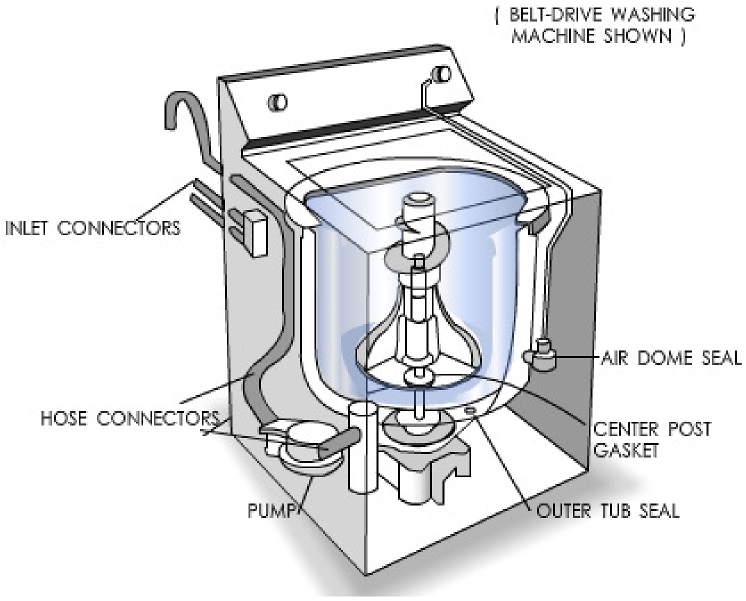


Figure A.1 A cutaway view of a washing machine

A. Complete the Record Form and study the sequential operations of the washing cycle.
B. Draw a flow chart/block diagram to present the sequence of the washing cycle.
C. Draw a timing diagram to represent the washing cycle.
D. List any state variables for the washing cycle.

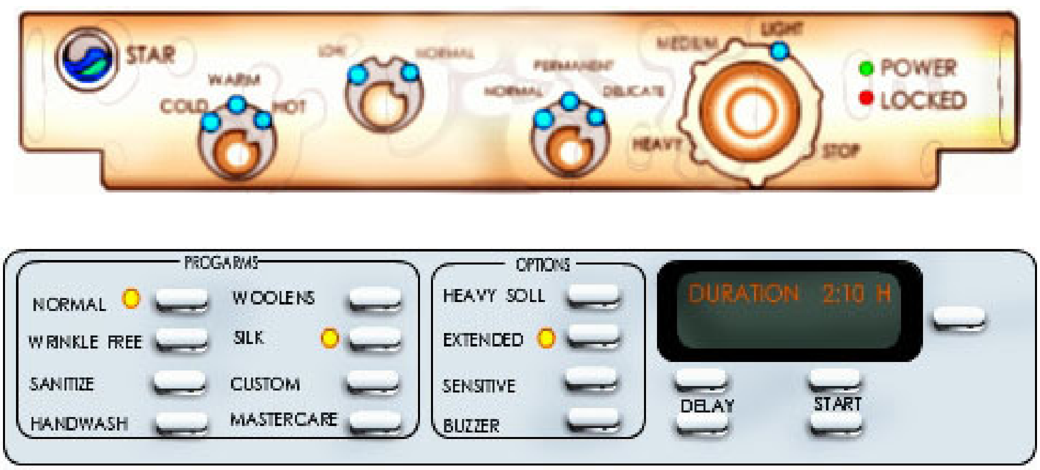


Figure A.2 Control panels of washing machines

Design and Applied Technology
Washing Machine Analysis and Record Form

Student Name:		**Class:**	
		Date:	
Machine Model:		**Brand:**	
Capacity: (if any)		**Country:**	
Tasks:			
Record the sequential actions of the washing cycle?			

Steps No	Descriptions	Periods
001	e.g. Close the door	N/A
002	e.g. Turn on the power	N/A
003	e.g. Turning the control dial to start position	N/A
004	e.g. Inlet of water automatically	3mins.
005	e.g. Water inlet stops.	N/A
006	e.g. Drum turn at low speed (CW)	1min.
007		
008		

QUESTION 2 (RELEVANT TOPIC: PNEUMATICS)

(I) Situation

Packs of cut foods are accumulating at the end of conveyor. These parts need to be transferred to other conveyor for quality inspection. An operator needs to activate a transfer device to remove these accumulated packs. This transfer device is powered by a pneumatic cylinder.

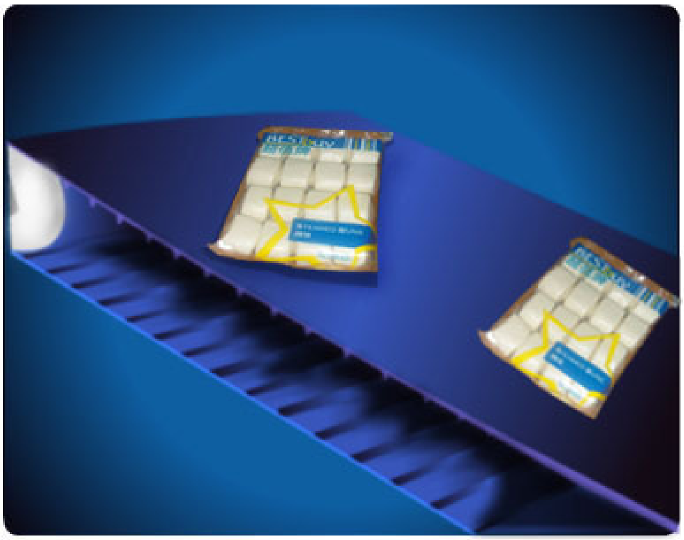


Figure A.3 A conveyor belt

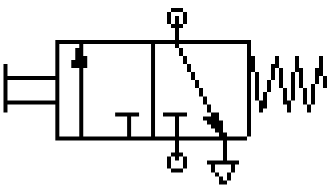
(II) Control Task

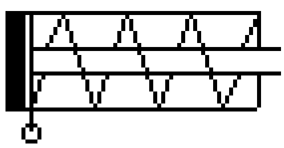
To design and assemble a circuit that can extend and retract a single acting, spring-return cylinder by an operator.

(III) Circuit Problem

Using the given components and layout, design a schematic circuit which will operate a spring return cylinder with a two-position, spring return, three-way valve.

1. Design and draw the schematic circuit diagram
2. Connect components according to the schematic diagram
3. Operate and explain to teacher.





(IV) Hints

- 3/2 Normally Close NC x 1
- single acting cylinder x 1

Note: If there is no pneumatic learning/training kit, magnetic symbols and white board can be used for demonstration.

QUESTION 3 (RELEVANT TOPIC: PNEUMATICS)

(I) Situation

A part needs to be clamped for a drilling operation. An operator needs to activate and deactivate a pneumatic clamp that holds the part in a fixture on a drilling table. The clamp must be activated before the drilling cycle begins and deactivated at the end of the drilling cycle.

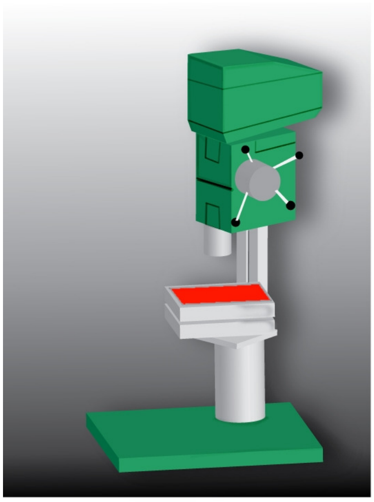


Figure A.4 A drilling machine

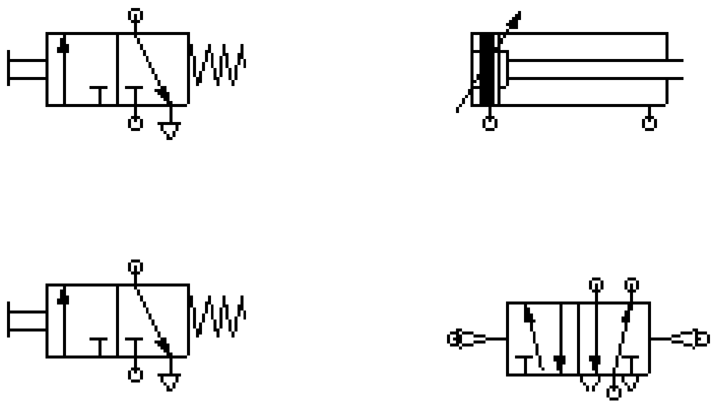
(II) Control Task

To design and assemble a circuit that extends and retracts a double acting cylinder.

(III) Circuit Problem

Using the given components and layout, design a schematic circuit which will operate a double acting cylinder with a two position five -way valve.

1. Design and draw the schematic circuit diagram
2. Connect components in according to the schematic diagram
3. Operate and explain to teacher



(IV) Hints

- 3/2 Normally Close NC x 2
- 5/2 directional valve, air pilot x 1
- double acting cylinder x 1

Note: If there is no pneumatic learning/training kit, magnetic symbols and white board can be used for demonstration.

QUESTION 4 (RELEVANT TOPIC: PNEUMATICS)

(I) Situation

A large stamping press must have the work piece in place, clamps engaged and safety guard in position before the "Start" button can activate. This interlock design is needed for minimizing potential risks.

Figure A.5 A Stamping machine

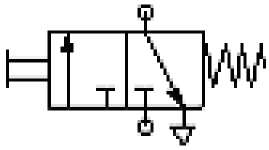
(II) Control Task

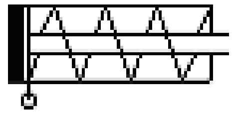
To design and assemble an "AND" logic circuit to control a single acting, spring-return cylinder.

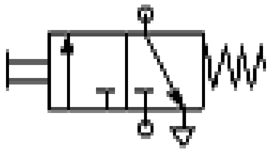
(III) Circuit Problem

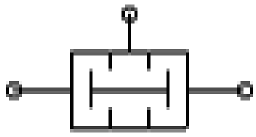
Using the given components and layout, design a schematic circuit which will only operate the cylinder when the three valves are all simultaneously operated, implying the safety precautions are all in effect.

1. Design and draw the schematic circuit diagram
2. Connect components in according to the schematic diagram
3. Operate and explain to teacher









(IV) Hints

- 3/2 Normally Close NC x 3
- AND valve, air pilot x 2
- Single acting cylinder x 1

Note: If there is no pneumatic learning/training kit, magnetic symbols and white board can be used for demonstration.

QUESTION 5 (RELEVANT TOPIC: PNEUMATICS)

(I) Situation

Semi-finished parts are accumulating on a conveyor belt and waiting to be released and transferred to the next stage for wrapping. Operators at different points can turn on the gate release mechanism to let the trays moving into the packaging unit.

Figure A.6 A conveyor for food industry

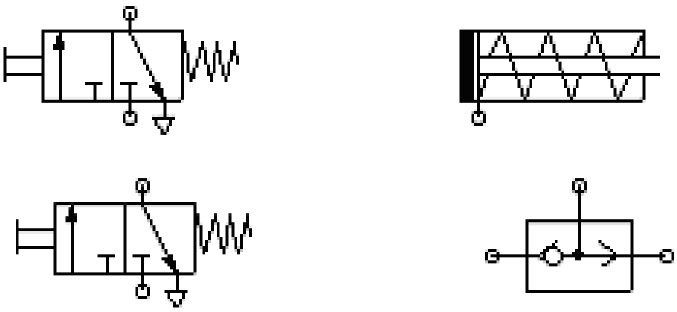
(II) Control Task

To design and assemble an "OR" logic circuit to actuate a single-acting, spring return cylinder.

(III) Circuit Problem

Using the given components and layout, design a schematic circuit which will operate a spring return cylinder from any one of three identical valves.

1. Design and draw the schematic circuit diagram
2. Connect components in according to the schematic diagram
3. Operate and explain to teacher



(IV) Hints

- 3/2 Normally Close NC x 3
- OR Shuttle valve, air pilot x 1
- single acting cylinder x 1

Note: If there is no pneumatic learning/training kit, magnetic symbols and white board can be used for demonstration.

QUESTION 6 (RELEVANT TOPIC: PNEUMATICS)

(I) Situation

A plastic thermo-forming machine is capable of heating and forming parts of various thicknesses. The parts must be held in their molded positions for curing to its final form. The length of time needed to cure the plastic will vary depending on its thickness. This requires a forming operation to have a variable time delay function so that the part can be held in place before the part is automatically released.

Figure A.7 A Forming Machine

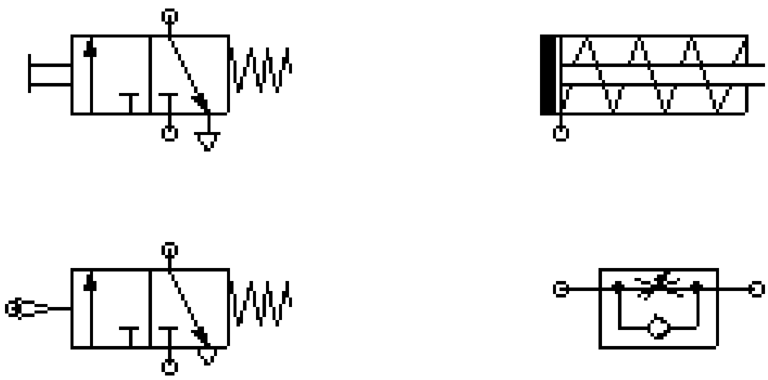
(II) Control Task

To design and assemble a "Time delay off" circuit to actuate a single acting spring return cylinder.

(III) Circuit Problem

Using the given components and layout, design a schematic circuit which will extend a cylinder for an adjustable period of time, then automatically retract the cylinder.

1. Design and draw the schematic circuit diagram
2. Connect components in according to the schematic diagram
3. Operate and explain to teacher



(IV) Hints

- 3/2 Normally closed NC, air-pilot x 1
- 3/2 Normally closed NC, manual x 1
- Flow speed control valve x 1
- Single-acting cylinder x 1

Note: If there is no pneumatic learning/training kit, magnetic symbols and white board can be used for demonstration.

QUESTION 7 (RELEVANT TOPIC: PNEUMATICS)

(I) Situation

A furnace outlet has a single conveyor that can transport iron bars to two different loading docks. In order to shift the out feed of the conveyor to the alternate loading dock, the operator must push a button. As a safety precaution, the conveyor will always be held in the last shifted position until the reception of next signal.

Figure A.8 Furnace and a conveyor belt

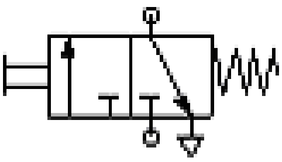
(II) Control Task

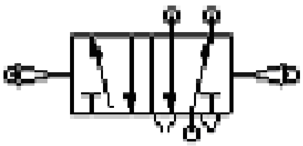
To be able to design and assemble a "Memory" circuit to actuate a double acting cylinder.

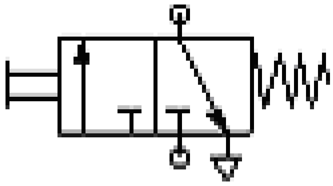
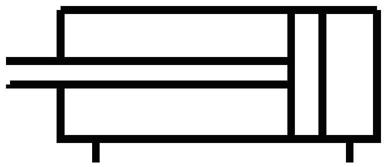
(III) Circuit Problem

Using the given components and layout, design a schematic circuit that requires the operator to push one of two buttons that in turn shifts a retented, two position, four-way valve. The valve is air-piloted in both directions to operate a double acting cylinder.

1. Design and draw schematic diagram.
2. Connect components in according to the schematic diagram.
3. Operate and explain to teacher.





(IV) Hints

- 3/2 Normally Close NC, manual x 2
- 5/2 directional valve, air pilot x 1
- Double acting cylinder x 1

Note: If there is no pneumatic learning/training kit, magnetic symbols and white board can be used for demonstration.

QUESTION 8 (RELEVANT TOPIC: ELECTRO-PNEUMATICS/PROGRAMMABLE LOGIC CONTROLLER)

When the push button is pressed, two motor M1 and M2 (outputs) must run. After 4 minutes Motor 1 stops. Motor 2 keeps running for another 2 minutes and stops. At this moment, a lamp is switched on. After a further 90 seconds, the lamp will go off and the cycle restarts. If the stop switch is pressed at any time, the motor will continue until the completion of this cycle, then stop.

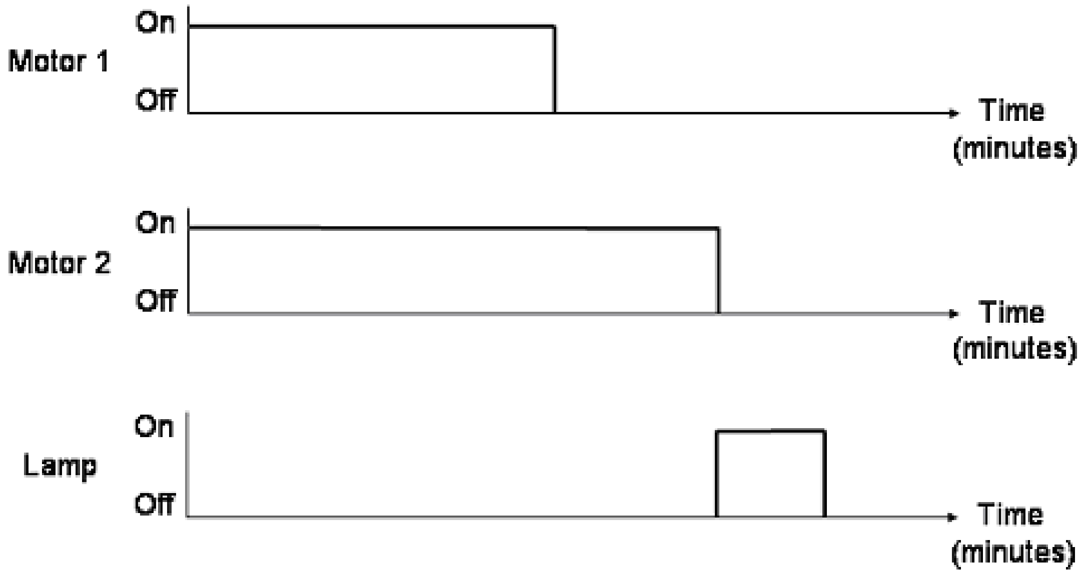


Figure A.9 Timing diagram for the operation sequence

1. Construct a ladder diagram and program it to PLC to make it work.
2. Draw an electro-pneumatic circuit diagram.

QUESTION 9 (RELEVANT TOPIC: PROGRAMMABLE LOGIC CONTROLLER)

Components pass along a pair of photo-sensors along the conveyor belt. When the components pass the sensors, the light beam is interrupted and the signal will go low (Off). After 6 components have been counted by the sensors, an eject operation will be actuated and used to remove the batch out of the conveyor. Then, the cycle starts again.

The ejecting device is pushed by a single-acting cylinder that is controlled by a solenoid valve.

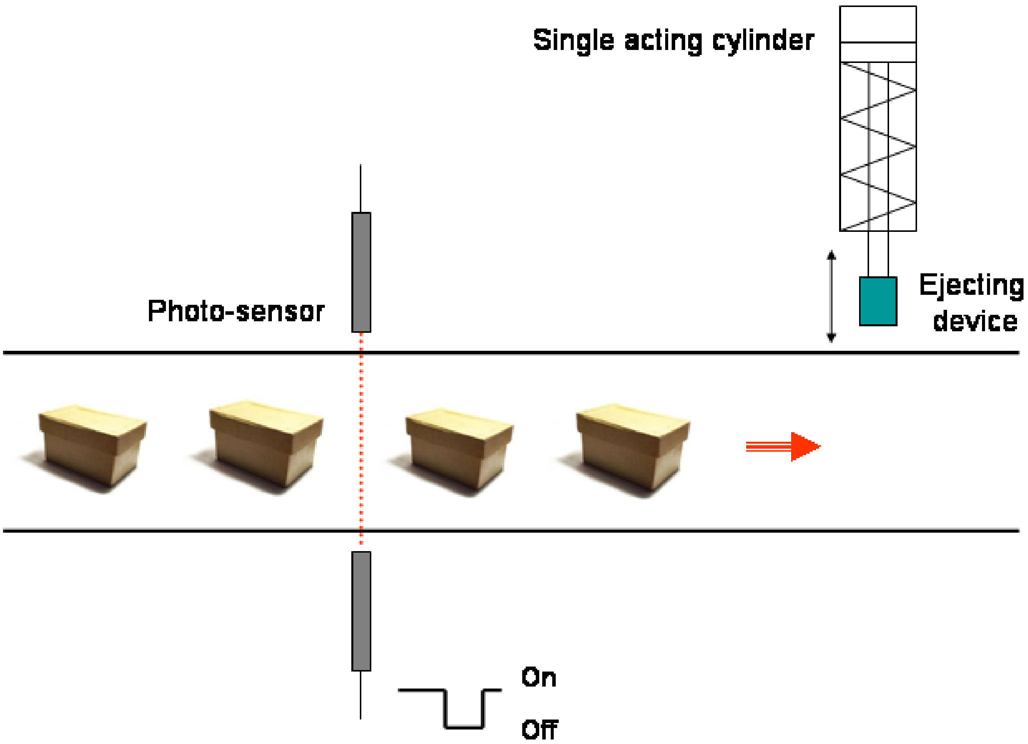


Figure A.10 Schematic diagram of the system

1. Construct a ladder diagram and program it to PLC to make it work.

QUESTION 10 (RELEVANT TOPIC: PROGRAMMABLE LOGIC CONTROLLER)

A machine is switched on by pressing either A or B push button. A safety guard D is in place with a limit switch D triggered in the closed position. In addition, there is a proximity switch C to detect if anyone is standing inside the dangerous zone. All the switches are normally open contacts and the machine will not start when they remain open.

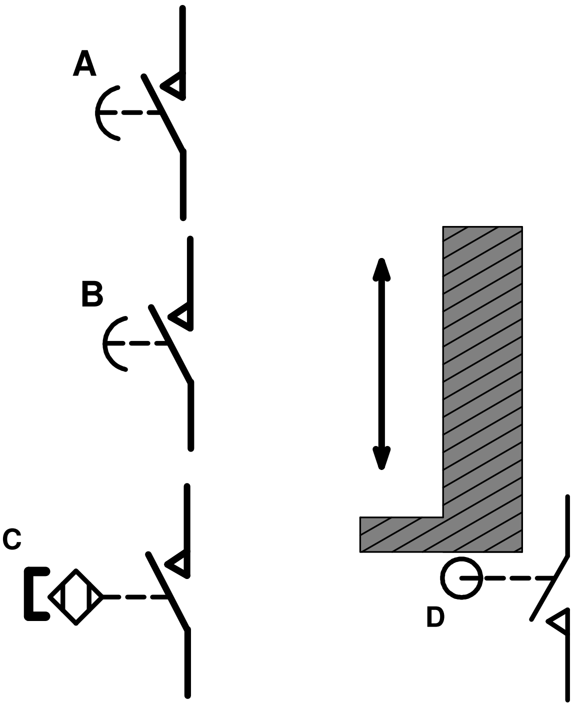


Figure A.11 Schematic diagram of the system

1. Draw a ladder diagram for the system
2. Write a Boolean expression for the system
3. Construct a truth table for all possibilities

USEFUL WEB SITES

TITLE	URL	Explanatory Note
Traffic light control circuit	http://home.cogeco.ca/~rpaisley4/20step.html#Traffic	20 sequential circuits
Information and Computer Science	http://www.ics.uci.edu/~mghodrat/ics151/hw5/prob8/final.html	Traffic light Lab Sheet
Sequential Circuit Design	http://www.cs.swarthmore.edu/~mstone/school/cs/cs24/web/lab3/	Dynamic Traffic Controller
Electrical Training Series	http://www.tpub.com/content/neets/14187/css/14187_92.htm	Open loop control
O'Reilly Network	http://www.oreillynet.com/pub/a/network/synd/2003/08/05/closed_loop.html	Closed-Loop control
Delphion Integrated View	http://www.delphion.com/details?pn10=US03264544	Washing machine patent article
LG Washing Machine User Manual	http://www.lgwasherdryer.com/pdf/3431_manual.pdf	LG Washing Machine User Manual
Festo Pneumatics Learning System	http://www.festo-didactic.com/int-en/learning-systems/equipment-sets/562/564/semi-rotary-drive,size-16,184.htm	
Fuzzynet Online Application Note	http://www.aptronix.com/fuzzynet/applnote/air.htm	Air Conditioning Temperature Control
Control Weekly Review	http://controlsweekly.com/pneumatics.htm#Tool	Pneumatics
KINEQUIP INC.	http://www.kinequip.com/basic_advantages.asp	Basic advantage of Pneumatics
Fluid Power Education Foundation	http://www.clippard.com/downloads/general/PDF_Documents/Intro_to_Pneumatics.pdf	Introduction to pneumatics and Pneumatics Circuit problem for FPEF trainer
101 Basic Series - Electrical	http://www.eatonelectrical.com/html/101basics/Modules/Module24.pdf	Module 24 Programmable Logic Controller
Introduction to PLC programming and implementation – from Relay logic to PLC logic.	http://www.idc-online.com/technical_references/pdfs/instrumentation/Intro_to_PLC_20Pro.pdf	
Pneumatic Application and Reference Handbook	http://www.allair.com/pdf/mead_pneumatic_handbook.pdf	
Loop Technology, UK	http://www.looptechnology.com/index.asp	Industrial Automation Technology, Machine Vision System

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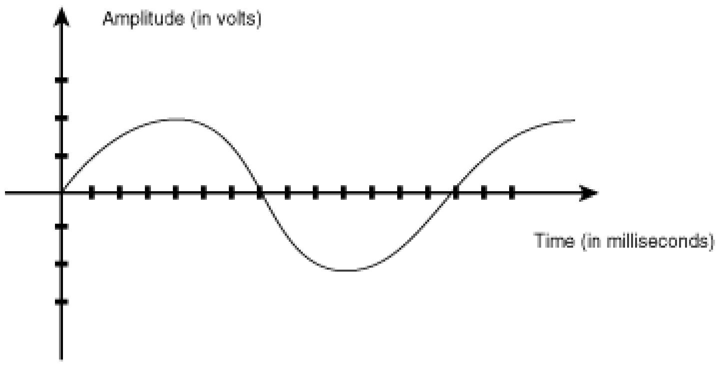
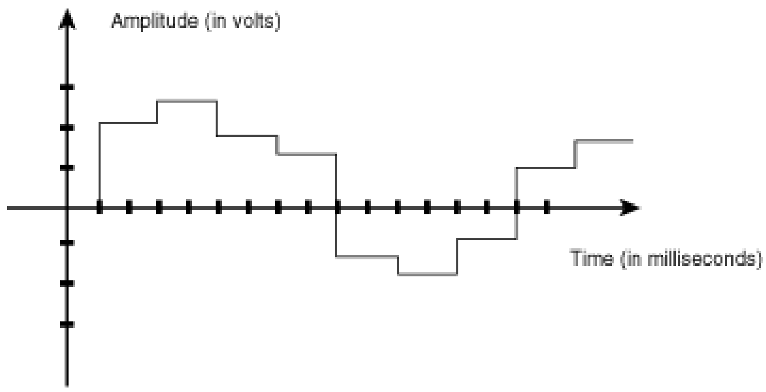
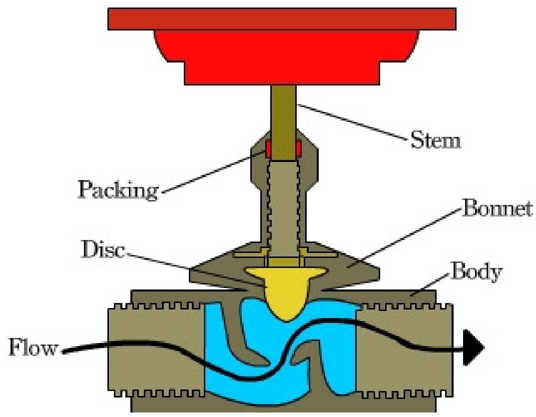
GLOSSARY OF TERMS

Term	Definition
Algorithms	an algorithm is a sequence of instructions, often used for calculation and data processing. It is formally a type of effective method in which a list of well-defined instructions for completing a task will, when given an initial state, proceed through a well-defined series of successive states, eventually terminating in an end-state. The transition from one state to the next is not necessarily deterministic; some algorithms, known as probabilistic algorithms, incorporate randomness.
Analog signal	Any type of input or output that has more than two states (on and off). An analog signal can vary in magnitude from "off" to a high-end value or between two non-zero values. An example of an analog device would be a level sensor that returns a voltage somewhere between 0 and 10 V that can vary over time. 
Bit	A single digit that only has two possible values either 0 or 1.
Boolean expression	A general term used to describe logic functions. It includes AND, OR, XOR, etc.
Central Processing Unit (CPU)	The main processor of information in a computer. This single chip performs all of the logic and math operations of the PLC.
Digital signal	Any type of input or output signal that has exactly two states, on and off. An example of a digital device would be a pushbutton, which can either be pressed (ON) or released (OFF).

Term	Definition
	
DSP (Digital Signal Processing)	is concerned with the representation of the signals by a sequence of numbers and the processing of these signals. DSP measures or filters continuous real-world analog signals, usually to convert the signal from an analog to a digital form
Globe Valve	is a type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a generally spherical body. 
I/O (Inputs and Outputs)	refers to the communication between an information processing system (such as a computer). Inputs are the signals or data received by the system, and outputs are the signals or data sent from it.
Ladder Diagram	The logic of ladder programming used to program and control a PLC. The fundamental theories of ladder diagram are consistent among all manufacturers but each PLC manufacturer generally has a proprietary ladder software package.

Term	Definition
Logic	A series of directives or boundaries created to allow a process to be controlled. Logic can be programmed via hard wiring (as is the case with relay logic) or via a PLC.
Multiple bits	can be combined to form bytes or words.
Network	Several devices connected together, through electrical means, for data acquisition and/or control.
Non-retentive	All values are resent to zero after powering down the unit.
Off-Delay Timer	Will turn an output OFF after X amount of seconds has passed.
On-Delay Timer	Will turn an output ON after X amount of seconds has passed.
Operator Interface (O/ I)	A device that allows the operator of a machine to monitor and control devices attached to a PLC.
Register	A storage area, within the PLC, for information.
Relays	An electromechanical switch that can control on/off of AC or DC loads.
Relay Circuits.	Devices often used in control. Can be opened and closed electronically to perform logic circuits.
Retentive	Will store data in memory so that it remains intact after powering down the unit.
Sensor	The basic element that usually changes some physical parameter to an electrical signal.
Solenoid	A type of output device and a specific type of coil. Both coils and solenoids utilize voltage to convert electrical energy to mechanical energy via magnetic fields.
Starter	A control device usually consisting of a contact and overload. It will also contain a communication module used for starting and stopping loads.
Transistors	A solid-state, electronic switch. It is fast, switches a small current, has a long lifetime, and works with DC only.
Triacs	Or Silicon Controlled Rectifiers (SRCs) act as a mediator

Term	Definition
	between the PLC and the AC output device. The triac or SCR functions as a switch that responds to the commands of the PLC logic.

ACKNOWLEDGEMENTS

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- Figure 4.2, 4.34, P.120

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