MECHATRONICS -

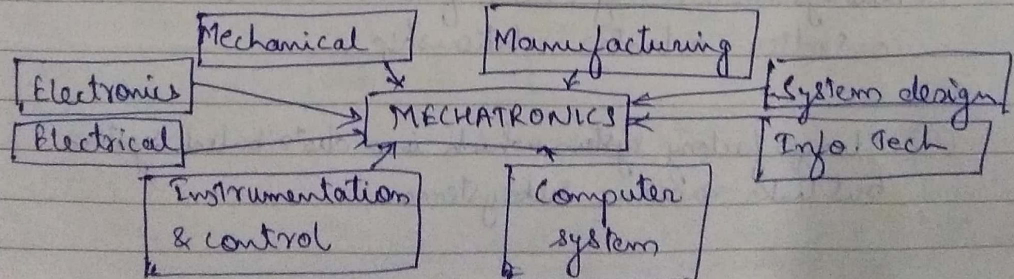
It is a multidisciplinary field of engineering that includes a combination of systems engineering, mechanical engineering, electrical engineering, telecommunication engineering, control engineering and computer engineering.

Elements of mechatronics system -

- Consists of mechanical, electrical and information technology system.

- Concept of mechatronics is to bring together the areas of technology involving sensors and measurement systems, drives and actuation systems and analyse the behaviour of system, I/p system and control system.

- Servo motor is an example of mechatronics system. It consists of servo motor (rotor & stator) and a feedback system which facilitates obtaining very complex & precise motions.



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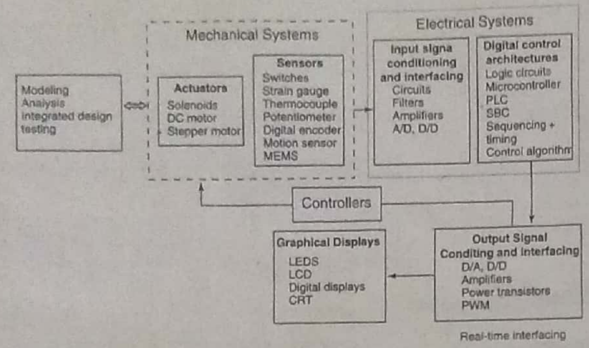


Figure 1.3 | Key elements of a typical mechatronics system.

[Liquid crystal display]
Light emitting diods.

Key elements of a Mechatronics system are-

1. Information systems
2. Mechanical systems
3. Electrical systems
4. Computer systems
5. Sensors & actuators
6. Real time interfacing

Levels of Mechatronics System-

1. Stand alone system; eg- washing machine, camera
2. ~~Sens~~ Systems with high level of distributed sensor-micro controller-actuator relationship
3. A large factory system which is a distributed system but links various subsystems.
4. A system incorporating Artificial Intelligence.

MECHATRONICS DESIGN PROCESS

Any mechatronics system consists of many types of interconnected subsystems and components.

A traditional approach is to design electrical and mechanical systems seperately and then interconnect them together. This may result in-

1. Change in original characteristics and operating conditions due to actual loading & dynamic interaction.
2. Perfect matching of the two independently designed systems will be almost impossible.

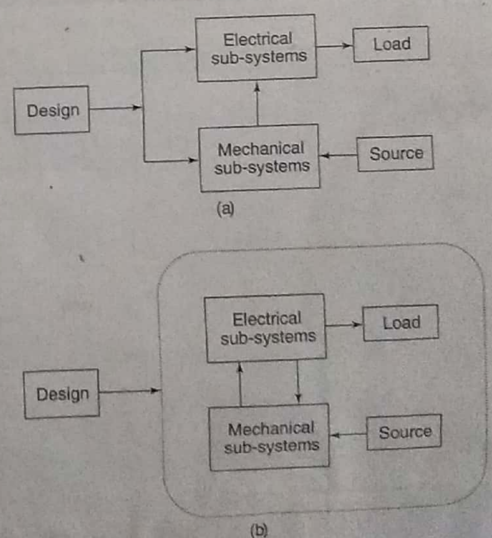


Figure 1.4 | Design concept: (a) conventional procedure and (b) mechatronics system design.

Therefore, the philosophy is to use an integrated approach

The mechatronics design process essentially consists of three aspects as follows -

① Modelling and Simulation

a) Physical systems are represented by a suitable model for describing the behaviour characteristics such as block diagrams.

b) Numerical or computer simulation methods are used for solving models.

c) Models can be analysed with computer simulations for obtaining useful information that will guide the design process.

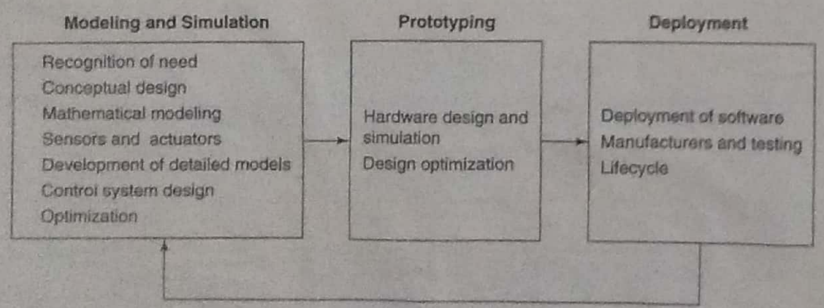


Figure 1.5 | Phases of mechatronics design process.

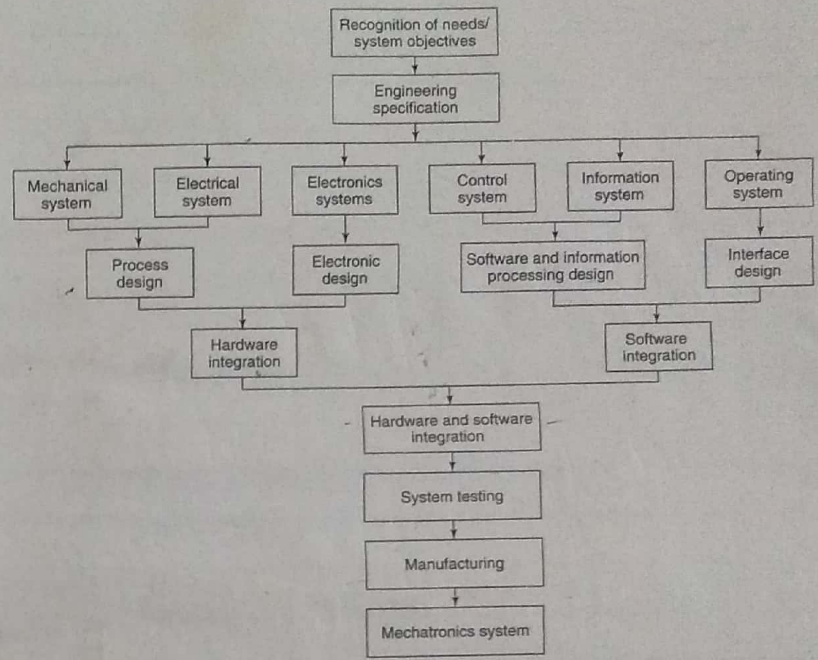


Figure 1.6 | Integrated design approach.

② Prototyping-

ⓐ Process of replacing non computer subsystems with actual hardware.

ⓑ Sensors and actuators are interfaced with input and output signals & connected with models, resulting in partial mathematical & real models.

ⓒ Of the two parts, the mathematical part provides simulated time based response and the real part provides real time analysis.

ⓓ Both parts are synchronised to understand and validate the design.

③ Deployment

This is associated with the final product, embedded software deployment and lifecycle.

MEASUREMENT SYSTEM

① Fundamental part of any mechatronics system

② Comprises of 4 basic parts as given below

I/P (Qty being measured) → Transducer or Sensor → Signal Conditioning → Intelligence → Display → O/P

③ Transducer or sensor is used to convert a physical input into an output, usually a voltage

④ Signal processor filters or amplifies or modifies the signal

⑤ Intelligence - Ability to communicate with other sensors and subsystems (feedback)

⑥ Display - for online monitoring and subsequent processing of data

Functional elements of a measurement system consist of -:

a) Primary sensing element
b) Variable conversion element
c) Variable manipulation element
d) Data transmission element
e) Data processing element
f) Data presentation element

a) Primary sensing element - receives energy from the ~~measurand~~ measured medium and produces output. Output is then converted into electrical signal by a transducer.

b) Variable conversion element - converts the output electrical signal of the primary sensing element into suitable required form without changing the information content. May or may not be required.

c) Variable manipulation element - amplifies the signal to required magnification.

d) Data transmission element - transmits data from one element to other eg- shaft and gear assembly.

e) Data processing element - it is used to

① Convert data into useful form
② Seperate signal & noise
③ To provide corrections for errors, if any.

④ Data presentation element - used to display information to human observer for monitoring, control and analysis.

CONTROL SYSTEMS

- Interconnection between the constituent components.
- May be electric, mechanical, hydraulic, pneumatic, thermal or chemical in nature

- Basic functions are
① To minimize the error between the actual and desired output
② To minimize the time response to load changes in the system.
eg - Water level control system in tank

Requirements of a Control System

The three important requirements of a control system are -
① Stability - for any change in the input signal, the output of the system reads or makes its response at a reasonable value.

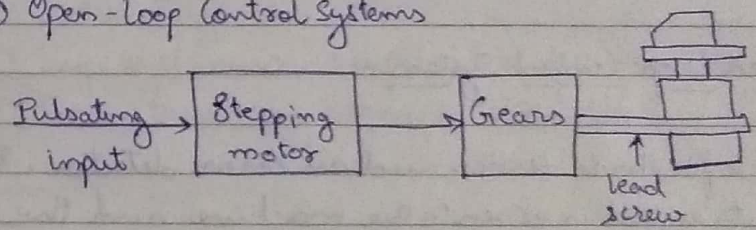
② Accuracy - The closeness of the measured value to the true value is the accuracy.

③ Response - The quickness with which an instrument responds to a change in the output signal is its response.

An ideal system has perfect stability, 100% accuracy and immediate response

- Types of Control Systems -

ⓐ Open-Loop Control Systems



The input signal or command signal is given to the machine tool to perform the required machining operation. The tool moves with respect to a command signal given by the operator. There is no return signal to verify if the tool has moved to the correct position or not. Thus any error is not found and hence not corrected. Hence it is called as open loop system.

Advantages of open loop system are -

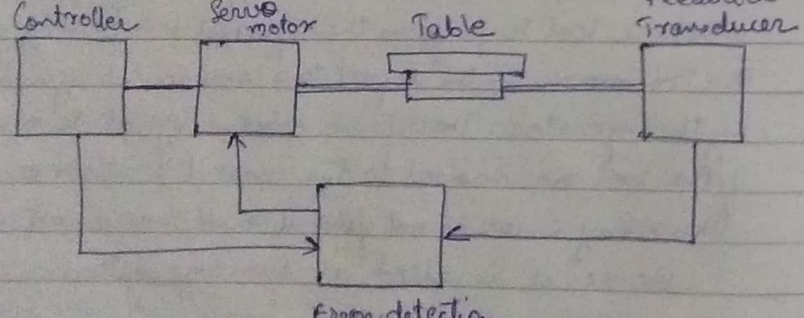
1. More suitable where accurate positioning of the tool is not required.
2. It is very simple
3. It has better reliability and stability.
4. It is ~~less~~ less costly.

Disadvantages of open loop system are -

1. It is not suitable for accurate works
2. The error cannot be corrected
3. The control action depends upon input command
4. The presence of nonlinearities can result in malfunctioning.

Closed loop Control System -

Has a feedback device and an error detector. The input signal is given to the machine and the table moves.



Closed loop System

~~The input signal is given to the machine & the table moves.~~

- Feedback device is connected to table which senses the movement & position
- Transducer which senses the movement of the table
- After sensing the transducer Converts it (mechanical movement) into electrical signal
- This electrical Signal is then fed to error dectector device
- Compares with the set value or referance value called an error
- Gives feedback to controller to rectify error by operating servo motor
- Process continues till the error becomes zero.

Advantages -

1. Position is more accurately controlled
2. Useful in all automation processes
3. Change in system is automatically taken care of.
4. Control action is dependent on feedback.

Disadvantages -

1. The system is complicated & expensive
2. The system may become unstable.

Elements of a feedback system -

1. Forward path - consists of
   a. Error detection device - receives the output signal and compares it with a standard value. Also gives command output signal at every instan
   b. Amplifier - Amplifies output signal to required scale.

(c) Compensating network - improves the overall performance of the systems

(2) Feedback system - The path that sends the information about the output signal at each instant to error detecting device.

Classification of feedback Control System -

(1) Regulatory system - This feedback control system is used when the input signal is constant, for example refrigerator, iron box

(2) Follow up systems - This is used when the input signal changes at every instant and where the output follows the input signal closely, for example, cam & follower

(3) Servo mechanism systems - This is used where the mechanical quantity output with time derivatives is used.

(4) Continuous data feedback control system - This is a system where the input signal has functions of the continuous time variable, example potentiometer.

(5) Sampled or discrete data control systems - is used in input signals that have pulses or have numerical codes, for example, A/D converter & D/A converter.

Advantages of mechatronics systems -

1. High level of integration
2. Increased functionality & better design
3. More use of electronics & software than mech^n functions.
4. Assumes responsibility with little operator interference.
5. Uses AI & intelligent process control
6. Multisensory & programmable environment
7. High reliability & ~~saft~~ safety
8. Improved & less expensive controls.

Disadvantages of Mechatronics system -

1. Initial cost is very high
2. Complicated design & system
3. Repair & maintenance is complex.
4. Replacement is difficult, difficult to change old system with new system.

EXAMPLES OF MECHATRONICS SYSTEMS

Examples of Automatic Control Systems

Furnace Pressure Control System

The pressure inside the furnace is automatically controlled by an actuator. This control system consists of a pressure gauge, actuator and damper. Figure 1.20 shows the arrangement of a pressure control system. If the pressure inside the furnace decreases from the desired pressure, first the pressure sensor senses this change and sends the corresponding signal to an error detector. The error detector compares the measured value with the set value or reference pressure to find the error signal. Then, this error signal is applied to a controller for making corrections in the furnace pressure. The controller gives corresponding controlling action to the actuator for actuating the damper in such a way so as to decrease the furnace pressure. Similarly, the damper is actuated in such a way so as to increase the furnace pressure when the measured furnace pressure decreases from the set pressure or reference pressure.

Temperature Control in a Metal-melting Furnace

After melting the metal in the furnace, the molten model is tapped out using ladles for producing castings in the foundry shop (Figure 1.21). The temperature of the molten metal should be the same until the entire molten metal is tapped out. However, the entire molten metal cannot be tapped out at a stretch. The temperature of the molten metal decreases with time. If the temperature decreases further, some solidification of the molten metal will start before tapping out the molten metal fully from the furnace. The uniform temperature of the molten metal should be maintained throughout the mixture during the tapping process.

The temperature sensor senses the temperature of molten metal inside the furnace. Then this temperature is applied on the error detector for finding an error by comparing the measured temperature with the reference temperature. After finding this, the error signal goes to the controller. The controller gives its control action to the actuator according to the error signal. The actuator actuates the supplementary heating circuit with respect

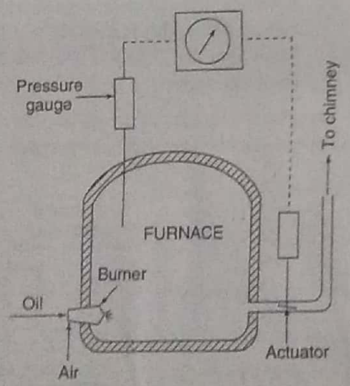


Figure 1.20 | Furnace pressure control system.

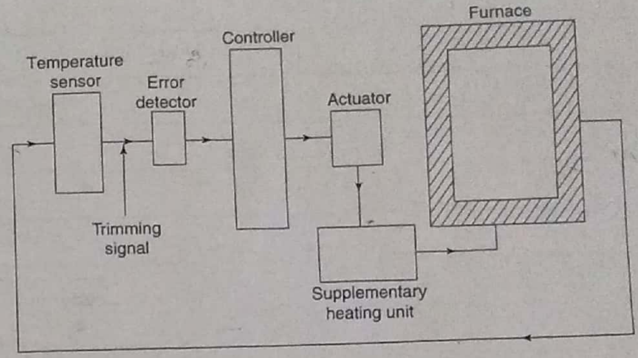


Figure 1.21 | Temperature control in a metal-melting furnace.

to the error signal. If the temperature is less than the reference temperature, the actuator acts to turn ON the supplementary heating circuit. The supplementary heating circuit is turned OFF when the temperature of the molten metal reaches the reference temperature.

Water-level Control System in a Water Tank

Figure 1.22 shows an automatic control system for maintaining the level of water. When the fluid level decreases from the set level or reference level, the object floating on the water senses this situation due to a change in resistance. Then this measured level is compared with the set level or reference level to find an error signal. This error signal is applied to the controller. The controller gives the corresponding controlling action to the pneumatic valve to turn ON, allowing water inside the water tank to flow through a flow valve by actuating an electrical motor. Similarly, when the water-level increases to the reference level the corresponding error signal is applied to the controller to turn OFF the inflow valve by switching OFF the electrical motor.

Temperature Control on Refrigeration System

Another example is the temperature control system shown in Figure 1.23. The temperature coming out of an evaporator is sensed by the temperature sensor. Then this temperature is fed to the error detector to find an error

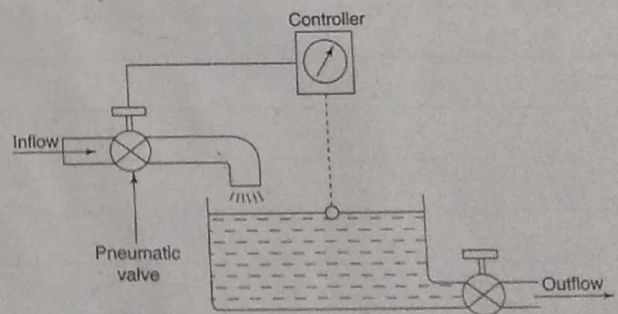


Figure 1.22 | Water-level control system.

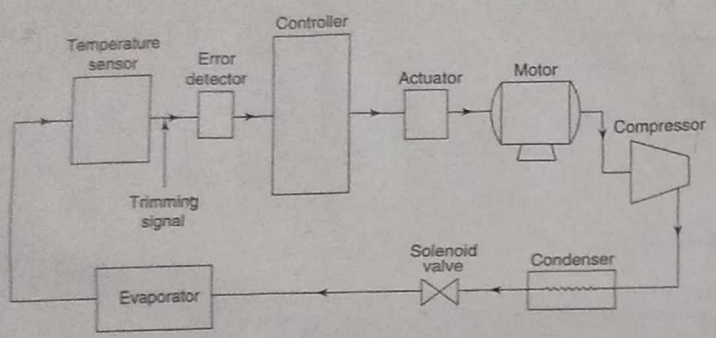


Figure 1.23 | Temperature control on refrigeration system.

signal, which is equal to the difference between the measured temperature and the reference temperature. This error signal is called a trimming signal that is applied to the controller for adjusting the temperature inside the evaporator. According to the error signal, the controller sends its control action to the actuator. The actuator is either switched ON or switched OFF for the motor to run the compressor. If the measured temperature exceeds the reference temperature, the motor is tripped ON to run the compressor for providing a cooling effect in the evaporator. If the measured temperature reaches the reference temperature, the motor is tripped OFF to stop the compressor and to maintain the uniform cooling effect. The condenser allows the high temperature refrigerant coming from the compressor to reduce the temperature and change the phase to liquid at the same pressure. Note that the solenoid operated valve allows the expansion of refrigerant to reduce the pressure.

Thrust and Flight Control

The pilot gives the input signal, called a *set value* or *reference value*, to the controller. The actual input is given to the controller through a gyroscope. This input is used to change the direction of the flight. Then, the controller compares the set value with the actual value and produces an error signal. According to the error signal, the flight is turned in the required direction (Figure 1.24). The required velocity of the flight is set on the controller by the pilot. The velocity sensor senses the velocity of flight. Then, the controller compares the flight velocity with the set velocity to produce an error signal. This error signal is used to control air thrust. Thus, the speed of the flight is controlled to the required value.

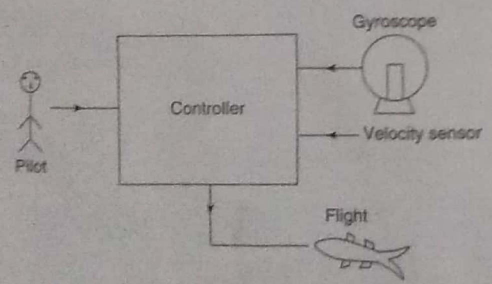


Figure 1.24 | Thrust and flight control.

Sequential Control

A system operating with sequential control is one where a number of prescribed operations are performed in sequence. The control may be implemented as event based, where the next action cannot be performed until the previous action is completed. Another mode of sequential control is termed "time-based", where the operations are sequenced with respect to time. Among these two modes, event-based control is intrinsically more reliable than time-based control.

An example of time-based sequential control system is shown in Figure 1.27. The pump is switched ON for a particular time to discharge enough water into the tank to fill it to approximately the correct level. Following this, the pump is switched OFF and the heater is switched ON. Heating is similarly allowed to continue for a preset time, after which the liquid temperature would have approximately reached the desired value. Here, the control function is inexact and there are no fail-safe features. Even though the pump fails to rotate, the heater will still be switched ON at the prescribed time, irrespective of whether there is liquid in the tank or not.

An example of an event-based sequential control system is a washing machine. In this system, a number of operations or events have to be carried out in the correct sequence. The various events of the washing machine are given in the Figure 1.28.

Each event of the washing machine may consist of a number of sub-events or steps. For example, a pre-wash cycle involves various steps such as opening an inlet valve to fill water into the drum to the required level, closing the valve, switching ON the motor to rotate the drum to a number of revolutions or a particular time and operating the pump to empty the water from the drum.

Figure 1.29 depicts the block diagram of a basic washing machine and its operation.

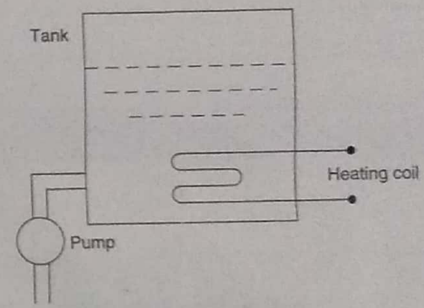


Figure 1.27 | Water heating system.

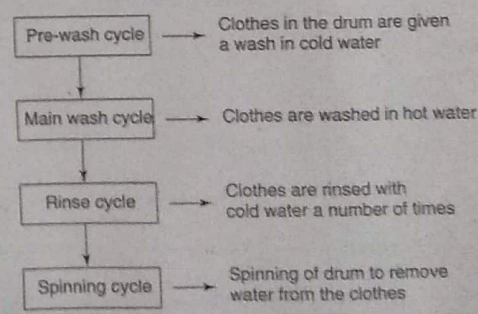


Figure 1.28 | Various events of a washing machine.

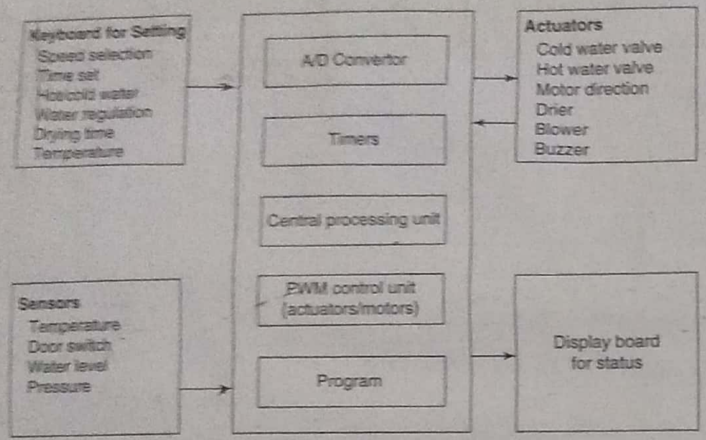


Figure 1.29 | Washing machine system.

Modern washing machine design uses a microcontroller. All the control functionalities of the system are built around this. Single-phase motors or brushless DC motors are used in the design of washing machines. Controlling the motor is a very crucial part of the design. The pulse width modulation (PWM) feature of the microcontroller controls the motor speed. PWM output is fed to the driver circuit and then to the motor. To rotate the motor in two different directions, "forward" and "reverse" direction control blocks are used. A motor speed sensor is interfaced to a microcontroller. The microcontroller reads the speed of the motor and appropriately controls the speed of the motor in different phases of washing using PWM output. Door sensor, pressure sensor, keypad are also interfaced to the microcontroller

The various sequences of operation of the microprocessor-controlled washing machine system are explained next. During a pre-wash operation, the inlet valve is opened when the machine is switched ON and the valve is closed when the required level of water is filled in the drum. A water-level indicator sensor is used to give the feedback to the microprocessor unit regarding the water level in the drum. After completing this operation, the microprocessor operates the motor to rotate the drum. The outlet valve is opened and a pump is operated to drain the water from the drum after completing the pre-wash operation.

The main wash cycle is then started by the microprocessor by operating the inlet valve to allow the water into the drum. The water-level sensor senses the water level in the drum and it closes the inlet valve after reaching a certain level. Now, the microprocessor switches ON the heating coil in the drum to heat the water. The temperature sensor sends the feedback of temperature of water in the drum and switches OFF the heating coil when the water temperature reaches the preset value. Then the microprocessor operates the motor to rotate the drum. The motor rotates for a preset time or a number of revolutions and the microprocessor switches OFF the motor. The microprocessor then operates the pump to drain the water from the drum.

The rinse cycle is started now, which has similar operations as explained above. This cycle is repeated two to three times. The spinning cycle follows the rinse cycle. In this cycle, the microprocessor switches ON just the motor, which rotates at a higher speed than the other cycles to drain the water from the clothes.

Requisite important design features of a washing machine include the following:

1. **Fully automatic mode:** Here user intervention should be zero. Once the system is started in this mode it should perform its work independently, and after the completion of work it should notify the user that the work is finished.
2. **Semi-automatic mode:** Here also user intervention should be nil. But the user has to choose any one of the semi-automatic modes in which washing conditions are pre-defined.
3. **Manual mode:** Here continuous intervention of the user is required. The user has to specify which operation is to be performed and has to provide related information to the control system.
4. When the lid is open the system should not work. If the door is accidentally opened in between the wash operations, the system should stop working in minimum possible time.
5. The system should provide all basic features of a washing machine such as washing, rinsing, spinning, drying, cold wash, hot wash, etc.
6. The system should have a feature of protecting itself from power supply voltage variations.
7. In the event of power failure, the washing machine should automatically start its cycle from the point of interruption when power is resumed.

15.3 Case Examples

Boat Autopilot

The objective of an autopilot system is to automate the movement of the boat once the direction and destination are fixed. The autopilot takes over and goes on correcting the course of drive continuously so that the direction does not change substantially. Though the autopilot cannot make substantial changes in the direction of the boat all of a sudden, it definitely corrects the course on a continuous basis and keeps the variation within a margin. This eliminates the probability of running on a wrong course for a longer time and increases the fuel consumption.

The boat autopilot is a very good example of an integrated mechatronics system. Figure 15.2 shows a general arrangement and the schematic. The user has to set up the boat using the landmark or boat's mariner's compass and then push the autobutton ON. Changes and trimming adjustments on direction of the course (route) can be made from the control unit. The direction of the course is measured by a compass linked to a single microprocessor microcontroller. The output of the computer through a power IC board is to a DC motor. The mechanical drive is taken through a double reduction toothed belt drive on to a screw which propels the hollow ram (used to turn the rudder angle) using a low friction ball nut. Ram movement is calculated by integrating motor emf and feedback is from the headings of the boat itself.

Mechanical design should meet the requirements of the tiller force generated at specific angles and rate of rotation, taking into account the hydrodynamic forces due to particular envelops of rudder configuration and forward speed. Based on this the size of the components, required power levels of the driver and associated power electronics are outlined. This product is a very good example of an integrated mechatronics design application.

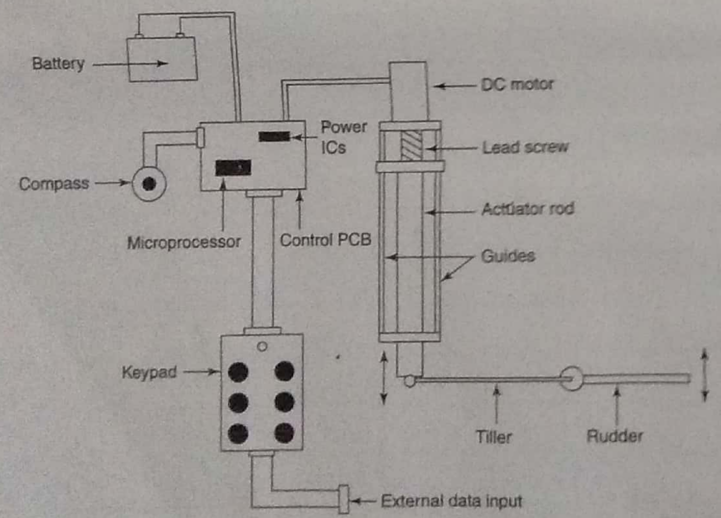


Figure 15.2 | Schematic arrangement of boat autopilot.

High-Speed Tilting Trains

When a train is negotiating a corner the passengers experience a lateral force that is proportional to v^2/r, where v is the velocity of the train and r the radius of the curve. This causes severe discomfort when it exceeds a limit. This also causes radial forces on the track and the track wears out. The track wear-out issue can be overcome by adding this parameter into the design aspect but the discomfort due to the radial force remains. Conventional solution to this problem has been to make the track inclined so that forces are normal to the floor of the carriage body. However, if the speed of the train is greater or lower than the speed for which the track inclination is designed, then again this phenomenon causes discomfort and lays extra stress on the track in the reverse direction. Some tracks are custom made for certain trains such as the bullet train and the tracks are very specifically designed for the designed speed of the train so that such effects are minimized. The problem of constraint on the speeds that can be attained is prominent when the train has to be run on the existing tracks and the track inclinations that exist already.

Figure 15.3 shows an alternative to this problem, known as tilting trains. Here the carriage floor is tilted when negotiating a bend so that the forces are normal to floor of the carriage, and causes least discomfort to the passengers. The degree of tilt is controlled to match the speed of the train. This train uses active suspension controlled by an onboard computer. Lateral actuators act in conjunction to provide the tilting force in accordance with the speed. Controlled variable rate springs and dampers act to provide additional control over the motion. Operation of the tilting mechanism is controlled by sensor information which is in the form of a pendulum constrained to swing in a plane of the carriage cross section as shown in Figure 15.4.

The sensor system consists of sensors and pendulum. As the train takes the bend, the pendulum gets displaced outward toward the circumference of the bend and the tilt angle of the carriage would be adjusted to bring back the displacement of the pendulum relative to the carriage vertical within defined limits. Information on speed and lateral acceleration is used in association with the predefined program to control lateral actuators (hydraulic cylinders) and variable rate springs and dampers.

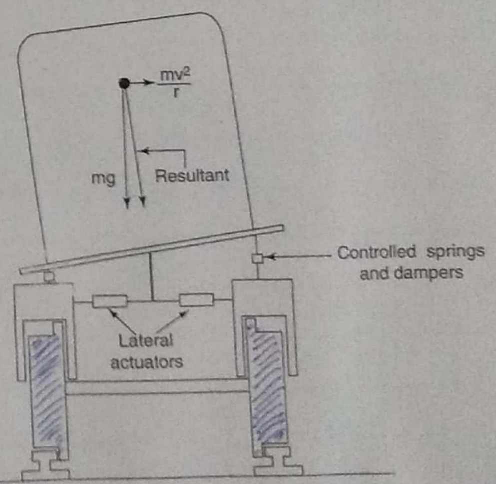


Figure 15.3 | Centrifugal and resultant forces in a tilting train.

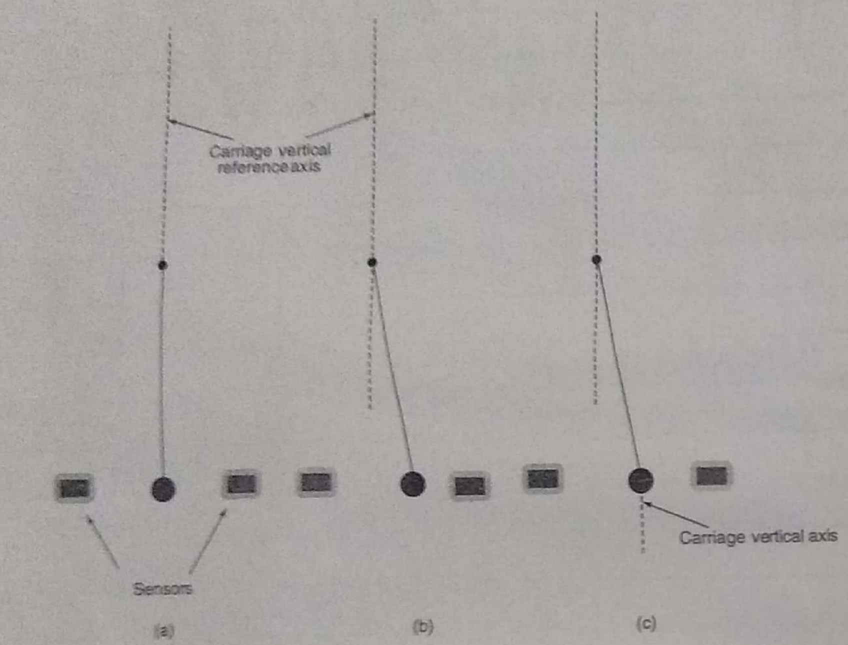


Figure 15.4 | Tilt control using a pendulum. (a) Pendulum in the plane of the cross section when the train is going on a straight track. (b) Pendulum as the carriage entered the bend. (c) Carriage is tilted to adjust pendulum within limits relative to the carriage vertical.

Figure 15.5 depicts the control of the tilting train. Tilting trains have been installed in UK, Italy and Sweden.

Automatic Car Park System

Consider an automatic car park system with barriers operated by electrical pushbutton. The system uses a PLC for its operation. There are two barriers used, namely in-barrier and out-barrier. In-barrier opens when the pushbutton is pressed while out-barrier opens when a car is detected in front of it. Figure 15.6 shows a schematic arrangement of an automatic car park barrier. It consists of a barrier which is pivoted at one end, two solenoid valves *A* and *B* and a pneumatically controlled piston cylinder arrangement. Solenoid operated valves are used to control the movement of the piston. Solenoid valve *A* is used to move the piston upward in turn barrier whereas solenoid *B* is used to move the piston downward. Limit switches are used to detect the foremost position of the barrier. When pushbutton *A* is pressed, current flows through solenoid *A*, and the piston in the cylinder moves upward causing the barrier to rotate about its pivot. The barrier now opens to allow a car through.

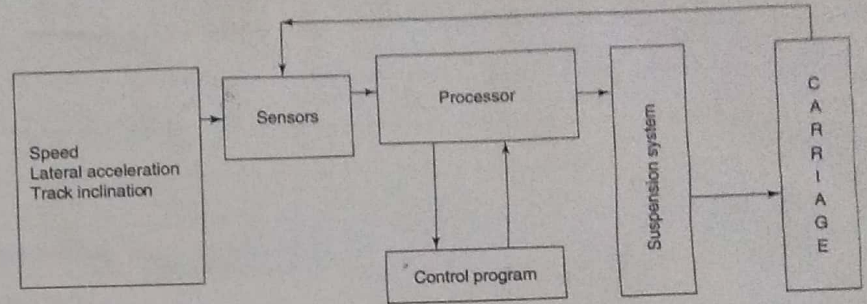


Figure 15.5 | Control schematic of the tilting train.

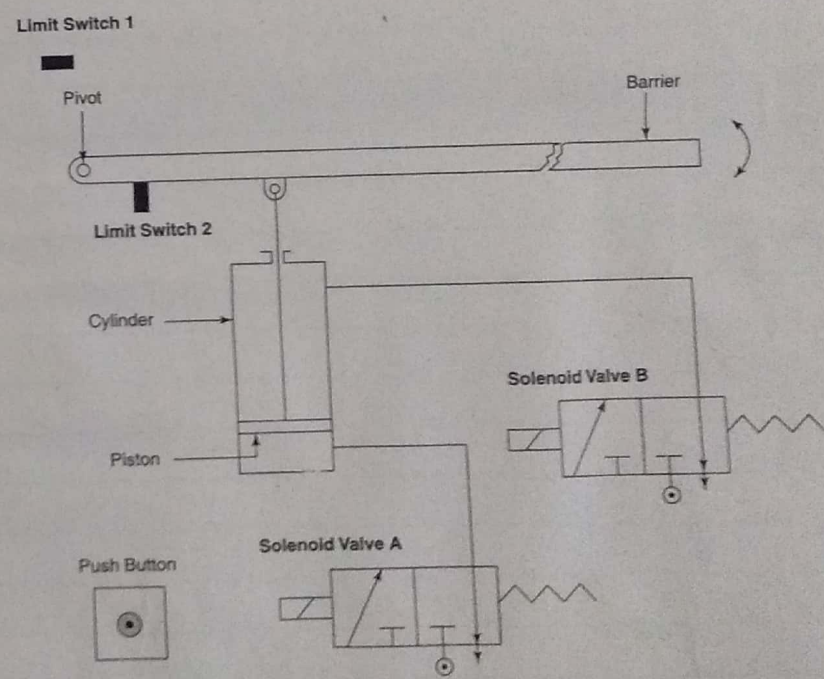


Figure 15.6 | Automatic car park barrier system.

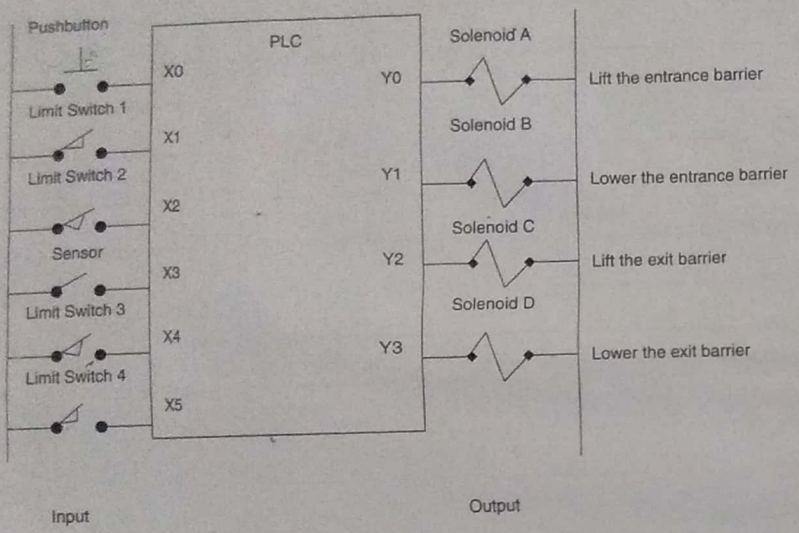


Figure 15.7 | PLC arrangement for operating barrier.

When the barrier hits the limit switch 1, it will turns on the timer to give a required time delay. After that time delay, the solenoid *B* is activated which brings the barrier downward by retracting piston in the cylinder. Same principle is adopted for exit barrier, but a sensor is used to detect a car and allow exiting. Note that limit switches 3 and 4 and solenoid valves *C* and *D* are designated for the exit barrier.

Figure 15.7 shows a PLC arrangement to operate the barrier. Figure 15.8 shows the ladder program for that PLC system of entry and exit.

Coin Counter

This case study is to enlighten on the integration of mechanical and electronic engineering principles. It is intended that out of a handful of coins we have to recognize coin denominations and add the value and send it to a visual display. The coins have different diameters, weights and different patterns on their faces and any of these can be used to recognize the coin denominations. Consider the three Indian coins of Rs 5, Rs 2 and Re 1. The diameters of these are 23, 26 and 25 mm, respectively. There is a reasonable difference between 23 and 26 mm, and a small difference between Rs 2 and Re 1 coins. Let us see the possibility of using diameter as the distinguishing feature for coin recognition. Weight can also be used as a distinguishing parameter. A mechanical device should be developed which may use an electric motor AC/DC/stepper to entrain the handful of mixed Indian rupee coins in a serial order to identify the coin denomination by a sensor array capable of acquiring the required discriminating data. The total value of each denomination is to be displayed on a single display in a multiplexed fashion. The display should also show the grand total as well along with the total number of coins in each denomination.

One of the designs for a coin counter is shown in the Figure 15.9. This contains a chamber to accept a handful of coins and to select coins individually and present them to a sensor array that can read the

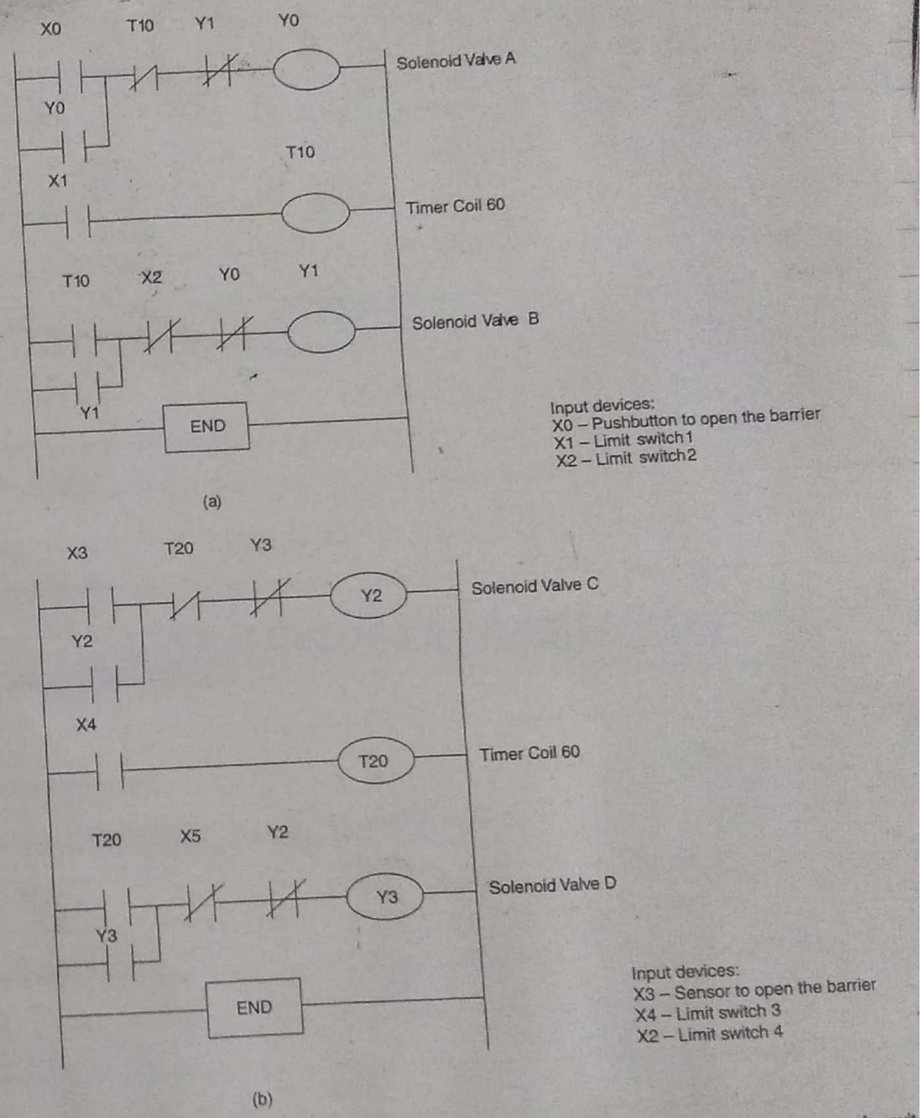


Figure 15.8 | Ladder diagram for PLC system. (a) Ladder diagram for entry. (b) Ladder diagram for exit.

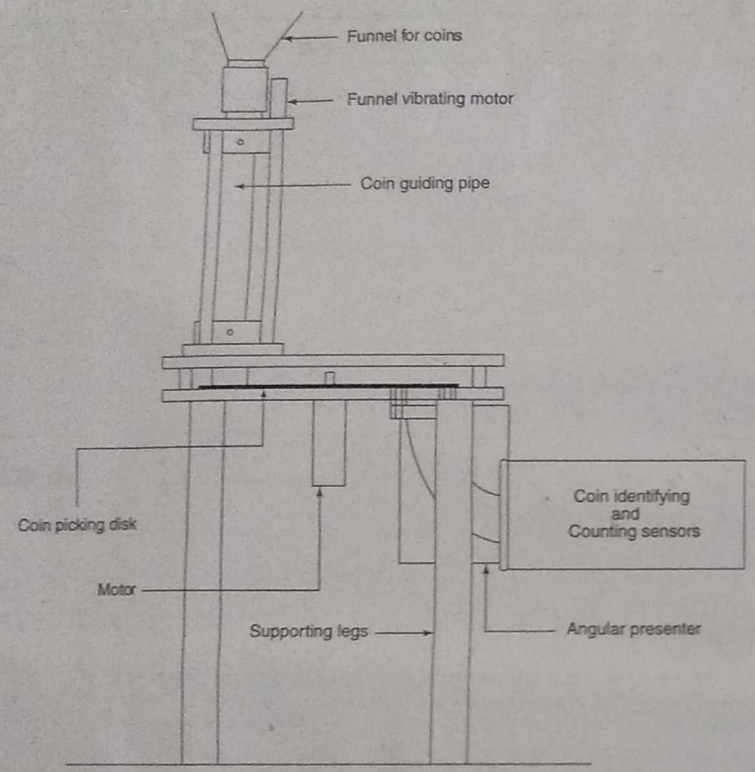


Figure 15.9 | Coin counter.

attributes. The horizontal slotted disk type has a disk with circular holes cut in it to accept the coins, rotated by a motor. As the disk rotates it takes a coin along and sends it down a rectangular chute where the sensor array is installed.

Detecting the Denomination

1. A suggestion is to use diameter as the distinguishing parameter and accordingly we have proceeded. When the diameters are very different the positioning of the optical sensor array becomes very easy whereas when the diameters are very close the positioning becomes equally different. Here the diameters are 23, 25 and 26 and as such positioning the sensors may pose difficulties.
2. Sensor logic is as follows. We may have three sensors: one sensor would be sensing only the largest diameter coins (Rs 2 coin) and other sensor would be sensing Rs 5 and Re 1 coins and the third would be sensing all the coin types.
3. We observe that as diameters are different, the pulses start at different points in time and pulse width would also be different. This subtlety requires careful sequential logic design so that correct coin denomination is identified.
4. Let A be the sensor which outputs a signal to any coin, B be the sensor that outputs a signal for Rs 5 and Re 1 coins and C be the sensor that outputs which outputs a signal only for Rs 2 coin.
5. If the sensor signals from TTL logic are synchronized then the Boolean expression for different denominations could be written as

$$X = ABC$$
$$Y = AB\,(\text{NOT}C)$$
$$Z = A\,(\text{NOT}B)\,(\text{NOT}C)$$

where X, Y and Z correspond to Rs 2, Re 1 and Rs 5 coins, respectively.

Combinational and sequential logic as shown in the Figure 15.10 has to be used to identify the coin denominations because of the differing starting time of the pulse and differing pulse widths.

Combinational and sequential logic determines the denominations and increments the displayed output by a value corresponding to the denomination. This can be achieved by using digital ICs and the results sent to a display driver to display.

Engine Management System

For years, many auto majors are developing eco-friendly clean engine systems featuring port injection, direct injection and diesel applicability. Furthermore, through the development of high-efficiency torque transmission the companies are offering overall enhancement in fuel efficiency and more comfortable drivability. To protect our environment from air pollution and global warming, increasingly stringent automotive regulations have been issued year after year, such as reductions in gas emissions and improvements in fuel efficiency.

An electronic engine management system is made up of sensors, actuators and *microprocessor or microcomputer.* Electronic management systems monitor and gather data from a number of sensors in the engine and continuously adjust the fuel supply and injection timing. This minimizes emissions and maximizes fuel efficiency and engine output at any given load. Engine electronics also feature self-diagnostic functions and provide enhanced engine protection.

Components of Engine Management System

The electronic engine management generally consists of the following basic components: an electronic control unit (ECU), a fuel delivery system (typically fuel injection), an ignition system and a number of sensors. The sensors provide feedback to the ECU to indicate how the engine is running so that the ECU can make the necessary adjustments to the operation of the fuel delivery and/or ignition system. The ECU should determine, based on sensor information, that the engine is having a problem or is in need of maintenance or repair. The ECU can store diagnostic codes or actuate displays or warning lights. Figure 15.11 shows an engine management system schematic.

1. **Electronics control unit (ECU):** The ECU takes input from various sensors and then uses that data to continually optimize engine operation and performance. It is programmed right outputs based on the sensor information. For example, if the engine knock sensor indicates there is premature detonation, the ECU instantly adjusts spark timing to eliminate the problem. In industrial applications, this can greatly increase the service life of the engine.

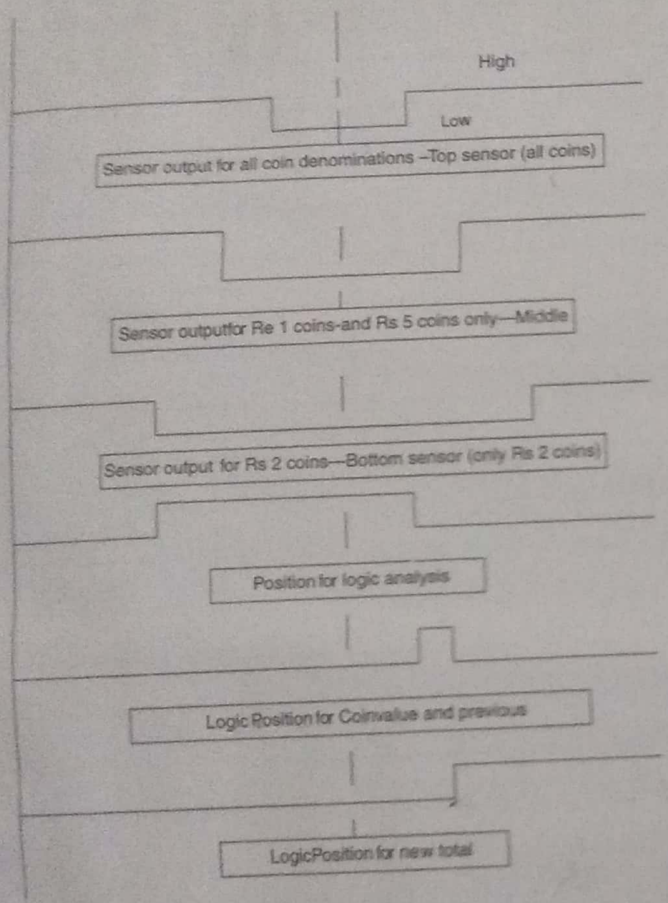


Figure 15.10 | Combinational and sequential logic.

2. **Fuel delivery system:** This starts off at the high pressure fuel pump (pictured) that is mounted in or near the tank. The fuel line from the pump passes through a filter before it runs forward to the engine bay. The fuel line connects to a fuel rail that feeds each of the injectors. At the end of the rail is a fuel pressure regulator, with surplus fuel heading back to the tank in the return line.

Various Sensors used in Engine Management System

Engine sensors fall into five broad categories: throttle-position sensors, exhaust gas oxygen (EGO) sensors, manifold absolute pressure (MAP) sensors, temperature sensors and speed/timing sensors.

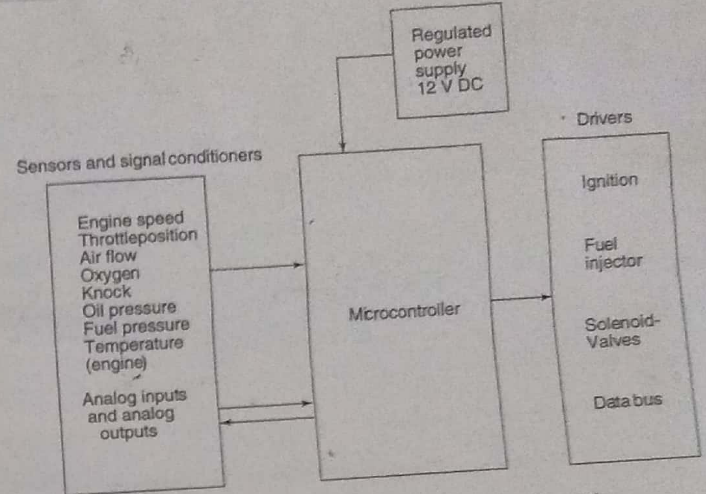


Figure 15.11 | Engine management system schematic.

1. **Throttle-position sensors:** Throttle-position sensors let the ECU know how far open the throttle is and how hard the user is "pushing the gas pedal". The ECU will use its knowledge of the throttle position to control fuel delivery and spark timing. For example, under a heavy throttle, the spark timing will usually be advanced further than under a light throttle. Two common throttle-position technologies are potentiometric and Hall effect.
2. **EGO sensors:** They are placed within the engine's exhaust system. The amount of oxygen in the exhaust gas indicates whether or not the ECU has directed the fuel delivery system to provide the proper air-to-fuel ratio. If the relative amount of air is too high or too low, engine power, smoothness, fuel efficiency and emissions will all suffer. The most common type of EGO sensor is the "thimble type". This type of sensor generates a voltage which is proportional to the difference in the oxygen concentration between the exhaust gas and the ambient air. The amount of oxygen in the exhaust gas can therefore be determined using this analog voltage.
3. **MAP sensors:** MAP sensors measure the degree of vacuum in the engine's intake manifold. The amount of vacuum depends on speed and throttle opening. In general, the vacuum is greater at idle, and the ECU can use this information to provide the optimum fuel delivery and spark timing for a smooth idle. The vacuum decreases as the throttle is opened and the engine is placed under a load. Again, the ECU can use this information to tailor fuel delivery and spark timing for this completely different set of operating conditions. The most common MAP sensor technology uses micro-machined piezo-resistive sensors. Another common MAP sensor technology uses a variable capacitor approach.
4. **Temperature sensors:** Temperature sensors can be used for a variety of applications in electronic engine management systems. They can be used to report engine temperature to the driver/operator via dash panel-mounted temperature gauge, report engine temperatures to the ECU to activate/de-activate cooling fans in water-cooled engines, to richen fuel mixtures for easier starting in cold weather

and to lean-out mixtures for maximum fuel economy once the engine is up to operating temperature. Two common temperature-sensing technologies are based on thermistors or thermodiodes.

5. **Speed/timing sensors:** They provide information to the ECU regarding how fast the engine is turning and exactly where the crankshaft is in its rotation (its "timing"). This fundamental information is used by the ECU to control fuel and ignition, as well as to make sure that engine speed does not exceed safe operating limits. Timing information is used by the ECU to determine exactly when fuel injectors should be actuated and when spark plugs should be fired. Speed/timing sensors typically use a target wheel with a missing or odd-shaped gear tooth to provide a reference position. These targets are attached to the crankshaft of the engine so whenever the engine is turning, the target is turning. The two most common speed/timing sensor technologies available are variable reluctance and Hall effect.
6. **EGR diagnostic switch:** On some vehicles with port fuel injection system that control exhaust gas recirculation (EGR) operation, an EGR diagnostic switch is used to tell the ECU if the EGR is actually being applied when it is commanded to be applied.
7. **EGR valve position sensor:** The signal from EGR valve position sensor is used to adjust the air fuel mixture. A variety of sensors or switches are used to determine when the EGR valve is open. The exhaust gases introduced by the EGR valve into the intake manifold reduce the available oxygen and thus less fuel is needed in order to maintain low hydrocarbon level in the exhaust. Figure 15.12 represents the engine management system with sensors and actuators.

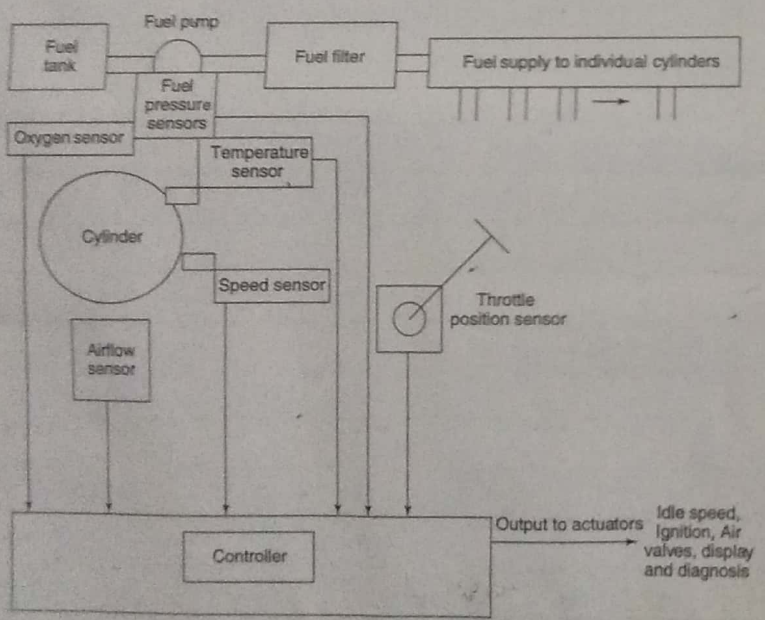


Figure 15.12 | Sensors and actuators in an EMS.

8. **Coolant temperature sensor:** This sensor tells the ECU how hot or cold the engine is. It is positioned on the thermostat housing on most cars. The sensor has different resistances to electricity at different temperatures. It is fed by a regulated voltage by the ECU, and looks at the changing voltage across the thermister. This sensor is located on the cylinder head or intake manifold. The output signal from the sensor is used to regulate the following engine functions:
   - activating and deactivating the early fuel evaporation system;
   - start-up fuel enrichment on fuel injected engines;
   - spark advance and retard (spark advance is often limited until the engine reaches normal operating temperature);
   - canister purge, which does not occur until the engine is warm;
   - transmission torque converter clutch lockup;
   - EGR flow, which is blocked while the engine is cold to improve drivability.
9. **Intake air temperature sensor:** The temperature of the intake air is also measured. The sensor can be located on the air box or on an intake runner. Just like the coolant temperature sensor, the intake air temperature sensor is a variable resistor. This particular sensor has a resistance of 3555 Ω at 20°C and just 475 Ω at 70 °C. Therefore, this sensor regulates the intake air temperature between 20 °C and 70 °C.
10. **Mass airflow (MAF) sensor:** The ECU must know what the engine load is if it is to squirt in the right amount of petrol and fire the spark at just the right moment. Some cars use an airflow sensor to measure engine load. The amount of power being developed depends on how much air the engine is breathing. If the engine is drawing in a lot of air (because the throttle is fully open at 5000 rpm up a hill, for example), then lots of fuel will need to be injected to keep the air/fuel ratio correct. The following are the different types of airflow sensor available: (a) hot wire airflow sensor; (b) vane airflow meter.
11. **Crankshaft position sensors:** The ECU needs to know how fast the engine is spinning and where the crankshaft is in its rotation. This lets the ECU fire the spark and injectors at the right time. The different types of crankshaft position sensors are: (a) optical crankshaft position sensor; (b) Hall effect crankshaft position sensor.
12. **Vehicle speed sensor:** The sensor can be mounted on the gearbox or in the speedometer. Speed sensing is used by the ECU in some cars to limit top speed and also to improve fuel economy and drivability.
13. **Knock sensor:** The knock sensor is like a microphone listening for the sounds of knocking (detonation). It is screwed into the block and is designed to separate out the special noise which means that knocking is occurring. Many electronic fuel injection (EFI) engines run ignition timing very close to knocking. Therefore, this sensor is vital if engine damage is not to occur on a bad batch of fuel or on a very hot day. Some cars (especially those with V engines) run two knock sensors.
14. **Brakes ON or OFF sensor:** This input signals the microprocessor to disengage the torque converter clutch. It can also lower the idle speed.

Antilock Brake System (ABS) Control

An ABS is a system on motor vehicles which prevents the wheels from locking while braking. Stopping safely is one of the most important functions a motor vehicle can perform. Failure of the brake system will almost invariably result in property damage, personal injury or even death. An ABS allows the driver to maintain steering control under heavy braking by preventing a skid and allowing the wheel to continue to roll forward and create lateral control, as directed by driver steering inputs. The ABS designer is faced with requirement to ensure that the system functions properly under strict operating conditions and that each one of the failures is detected and handled properly. Further, they are also expected to traction control, brake assist and electronic stability control. Figure 15.15 shows a wheel fitted with ABS system.

A typical ABS is composed of a central electronic unit, four speed sensors (one for each wheel) and two or more hydraulic valves on the brake circuit. The electronic unit constantly monitors the rotation speed of

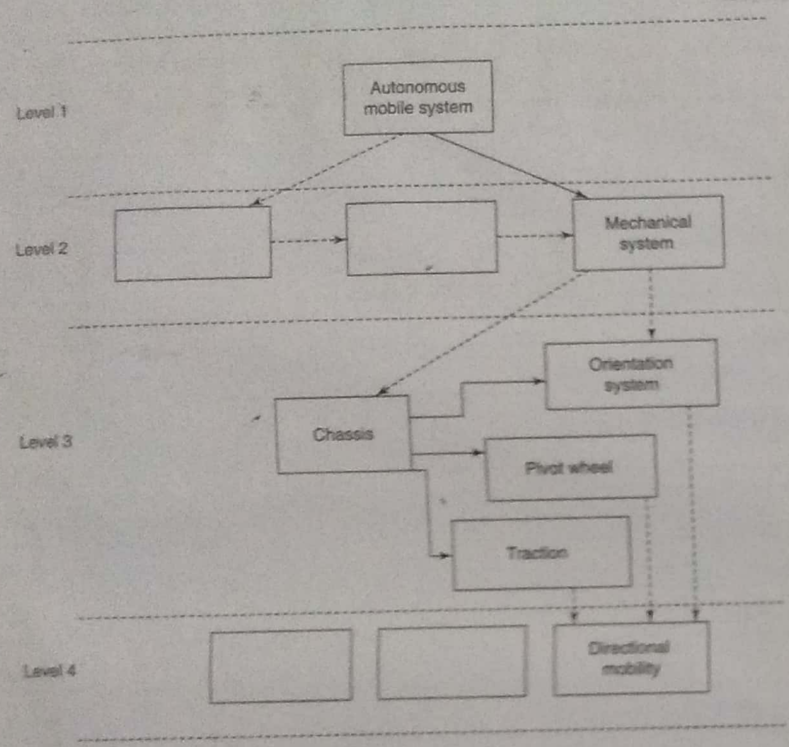


Figure 15.14 | Hierarchical decomposition.

Figure 15.15 | A wheel fitted with ABS system.

each wheel. The pulsed output from the wheel speed sensors goes to an electronic controller, which monitors each wheel's speed relative to the speed of the other wheels. As long as the brakes are not being applied and all of the monitored wheels are rotating at roughly the same speed, the system takes no action. If, however, the brakes are being applied and one or more of the monitored wheels suddenly begins to reduce speed at a higher rate than the others – indicating a loss of traction with the road and an imminent wheel lockup and skid – the controller then activates the antilock system.

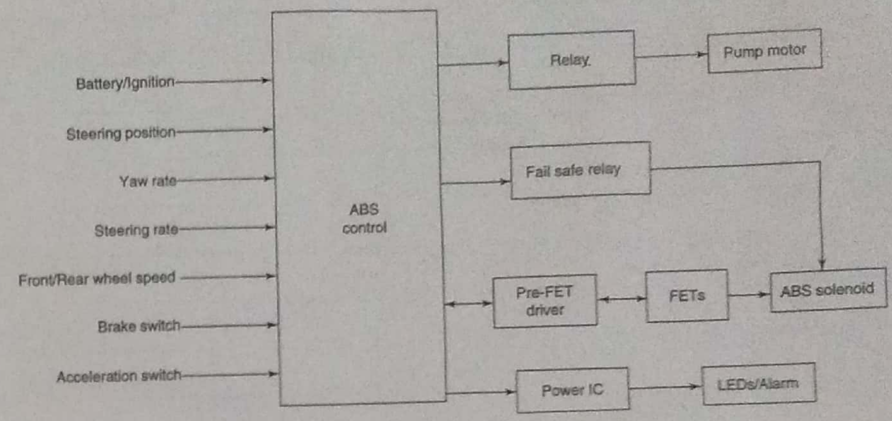


Figure 15.16 | ABS control block diagram.

When it senses that any one of wheels is rotating considerably slower than the others, it moves the valves to decrease the pressure on the braking circuit, effectively reducing the braking force on that wheel. The wheels then turn faster and when they turn too fast, the force is reapplied.

The ABS equipment may also be used to implement traction control on acceleration of the vehicle. If, when accelerating, the tire loses traction with the ground, the ABS controller can detect the situation and take suitable action so that traction is regained.

Design

The entire ABS system is considered to be a hard real-time system, while the subsystem that controls the self-diagnosis is considered soft real-time system. The general working of the ABS system consists of an electronic unit, also known as ECU, which collects data from the sensors and drives the hydraulic control unit (HCU) mainly consisting of the valves that regulate the braking pressure for the wheels.

An ABS control block diagram is shown in Figure 15.16. The typical inputs for ABS control system includes front and rear wheel speeds, steering rate and position and an acceleration switch. The pump motor is responsible for providing the fluid pressure for the brakes. LEDs/lamps are used in the warning light to indicate proper function of the ABS system. Power control devices provide fault protection and isolation to drive the discrete FETs for flexible control of loads. These power ICs are low-side pre-FET drivers that provide serial and parallel interfaces. Hence, the e-system designer can have flexibility of selecting the power output stage that best fits the system load requirements. ABS solenoids enable or disable by means of a fail safe relay switch. Power control devices are based on PWM.

The communication with the valves of the HCU is usually done such that response time is not very critical. The ECU and the HCU are generally very close together. Therefore, the control data will be transferred via serial interface to ECU. This closes the loop between the retriever and the ECU. The valves, usually solenoid valves, are controlled directly by the ECU. To drive the valves based on signals from the ECU, some circuitry and amplifiers are needed. The communication between the ECU and the sensors must happen quickly and at real time.

The central control unit generally consists of two microcontrollers, both active simultaneously, to add some redundancy to the system. The software that runs in the ECU has a number of functions. Most notably, the algorithms drive the HCU as a function of the inputs or control the brakes depending on the recorded wheel spin. Apart from this, the software is also needed to process the incoming information, for example the signals from the sensors. The control algorithms and the signal processing software certainly fall in this category and get a higher priority than the diagnosis and the testing software.

9.1 Data Acquisition Systems (DAQS)

DAQ is the first step in any automated system. By data we mean signals obtained by transducers. DAQS basically consists of sensors to measure different physical parameters from a process, hardware to convert this into digital form so that processing is possible in a microprocessor. DAQS also includes the methodology for data storage and display, and it addresses transmission of data if the transducers are distributed widely in a physical area. In a single channel DAQS only one variable is sensed, conditioned and transmitted to a digital system for storage, display and/or further processing. In multichannel DAQS we have separate sensors and conditioners for each physical parameter which we call a channel and then through a multiplexer and sample and hold circuits each signal is sent to a common analog to digital converter. The multiplexed digital data are available at the input port of the microprocessor, where they are collected and stored for further processing or display. "Data loggers" is another terminology used for this system of instrumentation that receives multiple data from various transducers distributed across plant-wide processes and records relevant parameters. For example a wind monitoring system or wind monitoring data logger collects wind speed and direction of wind continuously at different wind monitoring sites and transmits and stores the data for display and presentation and further processing like integrating with the characteristics of a wind turbine to arrive at power and generation of electricity or aggregated generation of electricity from wind turbines at a remote computer.

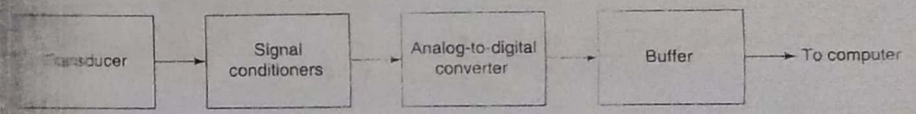


Figure 9.1 | Single channel data acquisition system or single channel data logger.

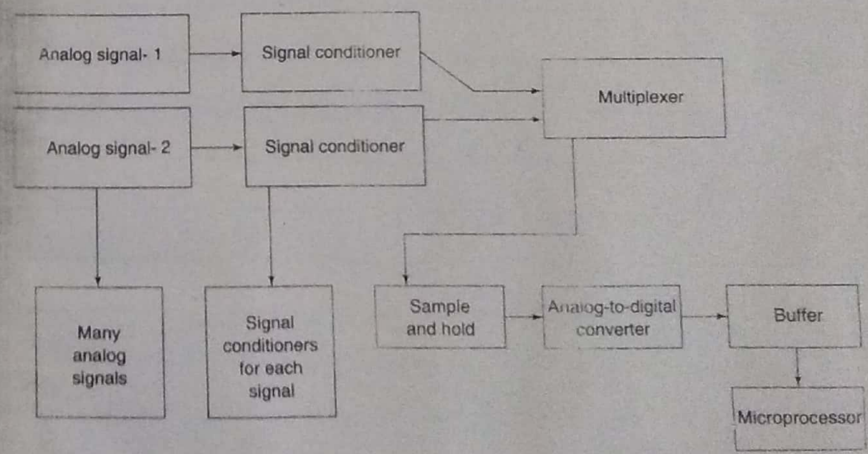


Figure 9.2 | Multichannel data acquisition system or multichannel data logger.

Figure 9.1 indicates the block diagram of a single-channel data acquisition system. Here each physical parameter measured has its own signal conditioner and A/D converter and a buffer before linked onto the computer.

Figure 9.2 indicates a multichannel data acquisition system. Multichannel data acquisition systems have individual transducers, signal conditioners and a multiplexer followed by common sample A/D converter and buffer. Individual elements of the block diagram like multiplexer, sample and hold are explained later in this chapter.

Data Loggers

Data loggers are again either single channel or multichannel, and as such the block diagrams of the loggers are same as the block diagrams in Figures 9.1 and 9.2. Data loggers basically consist of standard conditioned data input channels (the numbers vary depending on the make). Generally in most of the transducers available, the output is in standard current and voltage outputs (like 4–20 mA is the standard current output range). The input scanner selects each input channel for a particular duration of time. Typical scanning capacity of data loggers is 128–150 channels per second. Generally dual slope, voltage-to-frequency or integrating type A/D converters are used. The digital output from A/D converters and digital outputs from rotary encoders are interfaced with microprocessors as explained in this chapter later. The microprocessors process the data. Processing involves any combination of averaging, linearization, annunciation settings, totalization, setting of set points, amplifier gain control, control actions to control elements, formatting the output signal, conversion of units, interface control, etc.

Supervisory Control and Data Acquisition (SCADA)

SCADA generally refers to an industrial control system which is meant to function across a wide area with an autonomous remote terminal unit (RTU). SCADA system is expected to have open-loop controls (human operator watches near real-time data and issues commands). By comparison, a distributed control system (DCS) is expected to have closed-loop controls (real-time loop data is applied directly to an industrial controller without human intervention). These differences are more in the nature of academics than real. Industrial processes include those of manufacturing, production, power generation, fabrication and refining and may run in continuous, batch, repetitive or discrete modes. SCADA systems include I/O signal hardware, controllers, human-machine interfacing (HMI), networks, communications, databases and software. The term SCADA usually refers to centralized systems which monitor and control entire sites or complexes of systems spread out over large areas (on the scale of kilometers or miles). Most site control is performed automatically by RTUs or by programmable logic controllers (PLCs). Host control functions are usually restricted to basic site overriding or *supervisory* level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set points for the flow and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop.

Data acquisition begins at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data are then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a Database Management System to allow trending and other analytical auditing.

Complete SCADA systems or DCS may be acquired from a single supplier, but they are more often assembled from hardware and software components available from ABB, Allen-Bradley, DirectLOGIC, GE Fanuc, Omron, Schneider Electric, Schweitzer Engineering Laboratories and Siemens PLCs, along with related HMI packages from Adroit, Citect, Control Microsystems, Emerson, GE Fanuc, Honeywell, ICONICS, Inductive Automation, Kongsberg Maritime, OSIsoft, Rockwell Automation, Schneider Electric, Siemens, Elipse Sistemas, SUPCON, Telvent, COPS C-DAC open process Solution [C-DAC] and Wonderware.

An HMI is the apparatus which presents processed data to a human operator and through which the human operator controls the process. The HMI industry was essentially born out of a need for a standardized way to monitor and to control multiple remote controllers, PLCs and other control devices. While PLCs do provide automated, pre-programmed control over a process, they are usually distributed across a plant, making it difficult to gather data from them manually. Historically PLCs had no standardized way to present information to an operator. The SCADA system gathers information from the PLCs and other controllers via some form of network, and combines and formats the information.

The three components of an SCADA system are multiple remote terminal units (also known as RTUs or outstations), master station and HMI computer(s) and communication infrastructure. The RTU connects to physical equipment and reads status data such as the open/closed status from a switch or a valve as well as reads measurements such as pressure, flow, voltage or current. By sending signals to equipment, the RTU can control equipment, such as opening or closing a switch or a valve or setting the speed of a pump.

An important part of most SCADA implementations is alarms. An alarm is a digital status point that has either the value NORMAL or ALARM. Alarms can be created in such a way that when their requirements are met, they are activated. An example of an alarm is the "fuel tank empty" light in a car. The SCADA operator's attention is drawn to the part of the system requiring attention by the alarm. E-mails and text messages are often sent along with an alarm activation alerting managers along with the SCADA operator.

Communication Methods

SCADA systems have traditionally used combinations of radio and direct serial or modem connections to meet communication requirements, although Ethernet and IP over SONET are also frequently used at large sites such as railways and power stations. The remote management or monitoring function of a SCADA system is often referred to as telemetry.

Typical SCADA protocols include Modbus, RP 570 and Conitel. These communication protocols are all SCADA-vendor specific. Standard protocols are IEC 60870–5–101 or 104, IEC 61850, Profibus and DNP3. These communication protocols are standardized and recognized by all major SCADA vendors. Many of these protocols now contain extensions to operate over TCP/IP. It is good security practice to avoid connecting SCADA systems to the Internet so the attack surface is reduced.

RTUs and other automatic controller devices were being developed before the advent of industry-wide standards for interoperability. The result is that developers and their management created a multitude of control protocols. Among the larger vendors, there was also the incentive to create their own protocol to "lock in" their customer base.

The move from proprietary technologies to more standardized and open solutions together with the increased number of connections between SCADA systems and office networks and the Internet has made them more vulnerable to attacks. Consequently, the security of SCADA-based systems has come into question as they are increasingly seen as extremely vulnerable to cyber attacks.

9.2 I/O Hardware and Software at the Microprocessor Level and Communication

An input routine in a program is a program segment that inputs words from the external world and the output routine does the reverse. A computer without these routines and hardware to carry out these would be useless. In this section, we will discuss how the I/O operations are implemented in hardware and software using simple ports available in the microcontrollers. Other concepts introduced are the use of buffers, synchronization and simplified timer interrupt mechanisms available in microcomputers. Further discussions include polling and interrupt mechanisms, A/D and D/A conversions and use of several communication philosophies.

I/O Operations

I/O instructions use the same data and address bus. In many microcomputers different instructions are used for memory read or write and for I/O operations. Block diagram of a microcomputer is shown in Figure 9.3.

Certain 8-bit or 16-bit memory locations are chosen to be output ports, which have output lines connected to an output device. Similarly, certain 8-bit and 16-bit memory locations are used as input ports, with input lines coming from input devices. The term "peripheral" is also used for these devices. Each line in the address data or control bus has a signal (logical) "1" if the voltage is above threshold level and a logical "0" if the voltage is below that level. The voltages corresponding to "1" and "0" are also termed high signal and low signal, respectively. Figure 9.4 is the schematic of the memory and its connection to the microprocessor unit.

Clock signal is alternatively low and high in a square wave as shown in the Figure 9.5.

$$\text{Clock rate or clock frequency} = 1/\text{cycle rate}$$

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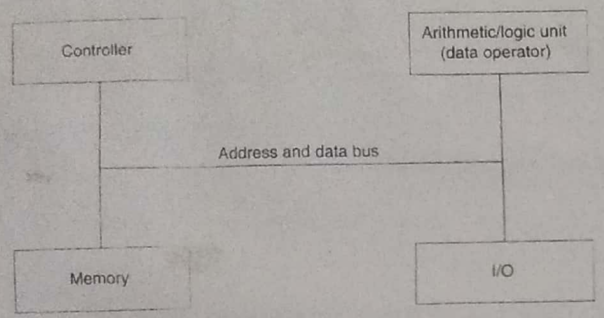


Figure 9.3 | Diagram of a microcomputer.

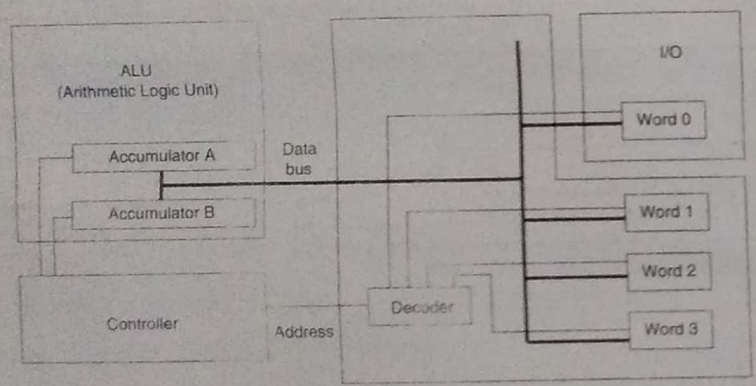


Figure 9.4 | Memory and its connection to the microprocessor unit.

A read/write signal commands memory to read or write. In each clock cycle, the microcomputer can read a word from an input port, by putting the address of the word to be read on the address bus and by putting the read/write line to high throughout the clock cycle. At the end of the clock cycle, the device puts data present on the input lines onto the data bus and the processor copies the word on the data bus into some internal register. In a similar way, microcontroller can write a word into an output port. The written data will become available on the devices' output lines (output lines meant to instruct some action to the device or actuator) until changed by another output instruction sent to it.

In a sense, whenever the microcomputer reads from an input port (output from an input device) or writes onto an output port (input to an output device), for the microcomputer it is just like reading from a memory location and writing onto a memory location. This is called memory mapping.

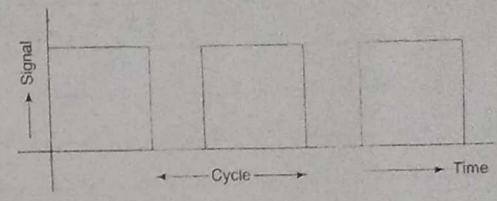


Figure 9.5 | Clock signal.

Data Width

One most common assumption is that I/O ports are always 8-bit wide and this assumption is not necessarily true. There are a number of 16-bit I/O ports on I/O chips designed for 16-bit microcontrollers. Neither 8- nor 16-bit is a fundamental width. If the port is 8-bit wide LDAB instruction can be used in "C" by accessing a variable of type "char". If the port is 16-bit, they can be read by LDD instructions or as an "int" variable in C or C++. Many ports read and write ASCII data that are 7-bit wide and not 8-bit wide. If we are reading a 10-bit A to D data, we shall be reading a 10-bit port.

I/O Instructions

With assembly language (Motorola MC6800), the instruction "STA and output port address" sends data to an output port and the instruction "LDA with an output address" loads data from an input port. With C language we would just write statements to put the value in the output port address or statements to read the input port address, having first defined the port address, for example the definition of the port address might be by the header file or by # define port B (*(char*) 0 × 1004). This states that the variable is char type and its address is 0 × 1004.

For input and output we write the following:

```
PortB = 0 × 34h; /*writes34htoPortB*/
x = PortB; /*readsPortB*/
```

Alternatives to memory mapping (which is explained so far) are isolated I/O in which memory and address are separately decoded.

Memory mapped systems are most common. Microprocessors use parallel ports to input or output bytes of data. Many peripherals may require more than one port as the data word of the peripherals may be longer than that of the CPU. CPU has to transfer data in segments. For example, if we require 16-bit output with an 8-bit CPU, the procedure is as follows. The CPU sends the eight most significant bits (MSBs) of data to the first port and then eight least significant bits (LSBs) to the second port. After a delay 16-bit data are available to the peripheral.

Interfacing Requirements

1. **Electrical buffering/isolation:** The peripheral may operate at different voltage/current level. When a microprocessor needs to be isolated by the peripheral power systems then a buffer is used.

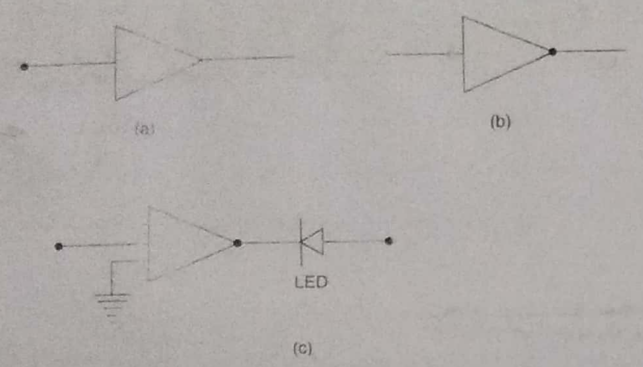


Figure 9.6 | Buffer (a) where the logic remains same but signal gets amplified and (b) which amplifies and also inverts the input. (c) A buffer application to light up an LED when the input from the microprocessor is high. (When the input is high from the microprocessor, buffer gives low output and provides low resistance path to earth so that LED comes ON.)

2. **Handshaking/timing control:** When the peripheral and microprocessor have different data transfer rates, special lines are used to control the timings of data transfer. This process is called handshaking and the lines are called handshaking lines. The peripheral sends a "data ready" signal to the I/O section of the CPU, and the CPU recognizes it and reads the data and sends an acknowledgment to the peripheral. Similar things happen when data are sent to a peripheral. Similarly, the codes used by peripherals and microprocessor may differ in calling for a code conversion. The line width of peripheral and microprocessor may differ. Sometimes, it may not be possible to transfer data in parallel mode and may call for a parallel to series conversion. Similarly, it may be necessary to convert serial data into parallel data for the microprocessor.
3. **ADC and DAC conversion:** Output from sensors is generally analog in nature and needs to be converted to digital form for the microprocessor. Similarly, digital outputs may have to be converted to analog signals to operate an actuator.

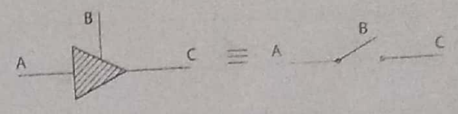
Buffers

Buffers are used to interface for amplification of current, voltage and power levels between the inputs and the outputs. Symbol of an amplifier is used for buffers too.

Figure 9.6(a) shows a buffer which amplifies without altering the logic. Note the fact that symbol used is that of an amplifier and we may appreciate the fact that the function of a buffer is that of changing a voltage, current or power level. Figure 9.6(b) shows a buffer that amplifies and inverts the input. Figure 9.6(c) shows an application of buffer which lights up an LED when the input from the microprocessor is high.

Three-State Buffers

When many peripheral devices are expected to share the data lines, the process is called multiplexing. This is achieved by using three-state buffers. The output from the buffer can be low, high or floating. The floating state is a very high impedance state so that the lines seem to be open-circuited to anything connected to them.



Input		Output
A	B	C
0	0	Z
0	1	0
1	0	Z
1	1	1

Figure 9.7 | Tri-state buffer and truth table.

In digital electronics **three-state, tri-state** or **3-state** logic allows output ports to have a value of 0, 1 or Z. A Z output stands for the output port being disconnected from the rest of the circuit, putting the output in a high impedance state. The intent of this state is to allow multiple circuits to share the same output line or bus without affecting each other. *Tri-state* is a registered trademark of National Semiconductor but is often used to describe devices made by any manufacturer.

Three-state outputs are implemented in various families of digital integrated circuits such as the 7400 series of TTL gates, and often in the data and address bus lines of microprocessors. Three-state outputs may be found on individual logic gates, or in multiples in one integrated circuit package as a buffer for connection to a bus.

As shown in Figure 9.7, a tri-state buffer can be thought of as a switch. If *B* is ON, the switch is closed. If B is OFF, the switch is open.

Uses of Three-State Buffers

Three-state buffers can be used to implement efficient multiplexers, especially those with large numbers of inputs. Three-state logic devices are used to accommodate multiple bus drivers. If the outputs of several tri-state logic devices are electrically connected together, only one three-state logic device may be active. The other three-state logic devices must be in the high impedance mode and thus will not affect the output of the active three state logic device. Otherwise a short circuit will occur when one device is driving the bus to logical one (supply voltage) and other(s) to logical zero (ground). This conflict leads at least to severe malfunction and possibly damages to the devices. If three-state logic is used for control signals, such as write enable, they are not allowed to "float" at any time. Floating means that all devices are in high-impedance state. During inactive period the signal is driven to non-active state, usually with a pull-up or pull-down resistor, depending on the polarity of the signal.

For example, a microcomputer system may have a read-only memory and also read–write memory connected to the processor; the data bus of the two forms of memory will be connected in common to all three devices, but only the active device will set the logic level on the memory bus. The devices not currently enabled will go to their three-state high-impedance state, preventing conflict of logic levels. Three-state logic can reduce the number of wires needed to drive a set of LEDs (tri-state multiplexing).

Usage of three-state logic is not recommended for on-chip connections but rather for inter-chip connections. Basic multiplexers can be used on chip because the number of components and wires is not limited to the extent as in PCB (printed circuit board).

Figure 9.8 shows how such a buffer can be used. Such buffers are available as integrated circuits. For example, we have Motorola 74125 with four non-inverting active low buffers and 74126 with four non-inverting active high buffers.

Networks and Network Topology

The term network is used for the interconnection of computers or microcontrollers for exchange of data between them. Logical form of links is known as the topology of the networks. Node is the point where one or more communication lines terminate or where a device is connected to the communication lines.

Commonly Used Topologies

Data bus is the term applied to a line of transmission and the devices are connected to them. This is the preferred method where the distance between nodes is not more than 100 m. **Star** is a configuration where a central computer (which acts as a hub) is linked by dedicated lines. All communication is passed through the hub. Major problem is that of reliability if the central hub fails. **Tree** is a system of linked buses and there is only one path between any two stations. This is also called hierarchy and is used where distance between nodes is less than 100 m. **Ring** is a popular method for local area networks and each station is connected to form a ring. **Mesh** is another method where multiple data paths are provided.

LAN (local area network) is used for local geographical area like buildings or one site area. WAN (wide area network) is used in networks at national and international level. Network access control is the term applied to methods used to ensure that only one user of the network is able to transmit at any particular time. Not elaborating we may mention here that "token passing" and "slot passing" are two techniques used in ring-based LANs and "carrier sense multiple access and collision detection" is used with bus and tree networks.

Broadband is the term used for transmission in networks where the information is modulated onto a radio frequency carrier and passed through mediums like coaxial cables or optic fiber cables, which allow many channels to be transmitted simultaneously on one cable. "Base band transmission" is the term used to mean a transmission network that can support only one channel at a time. RS 232 is the most popular serial interface standard. This was originally defined by the American Electronic Industries Association. This standard relates to data terminal equipment (example being a microcontroller) as well as data circuit termination equipment and data circuit terminating devices (example: a modem, an essential link between a microcontroller and conventional telephone facilitates communications). RS 422 and RS485 are similar to RS 232 and are used for higher transmission rates and longer distances. RS 232 has limitation of 15 m length for cables and transmission rates of 20k bits per second. With parallel communication, commonly used standards are the centronics parallel interface and the general purpose interface bus (IEEE-488). This was originally defined by Hewlett Packard.

Buses

Some of the buses or architecture used with personal computers are the XT bus used with IBM PC-XTs, AT bus used with ATs (also called ISA, industry standard architecture). EISA (extended ISA) used with 386 and 486 machines and MCA (micro channel architecture) has 16-/32-bit data transfer bus used with XT/AT boards. Nubus is 32-bit bus used in apple Macintosh II computers.

VME bus is the bus designed by Motorola for use with its 32-bit 68000 microcontrollers. VXI bus is an extension of this is meant for instrumentation applications such as automatic test equipment. This system involves the plugging in of VXI boards into mainframe computers.

Universal Asynchronous Receiver and Transmitter (UART)

This is an essential element of all serial communication systems. The function of UART is to convert parallel data to serial data and serial data into parallel data. A common programmable form of a UART is the asynchronous communications interface adapter (ACIA) from Motorola, the MC 6850. The data flow to the microprocessor is through eight bidirectional lines. The "direction of the data flow" is controlled through read/write input to the ACIA. The chip select lines are used for addressing a particular ACIA. The register select line is used to select a particular register in the ACIA. The status register contains information on the status of the serial data transfer as they occur and is used to read "data carrier detects" and "clear-to-send" lines. The control lines are used to reset the ACIA and later to define the serial data transfer rate and the data format.

Motorola microcontroller M68HC11 has in-built UARTs. M68HC11 has a serial peripheral interface (SPI), a synchronous interface and a serial communication interface (SCI). General-purpose microprocessors do not have UARTs and they have to use a UART (MC 6850) to enable serial communication. Sometimes even the M68HC11 may need more than one SCI and may need to be supplemented by a UART.

Peripheral Interface Device (PIA)

Interfaces can be designed for particular inputs and outputs. Motorola MC 6821 is a peripheral interface adopter which gives various I/O options that can be selected by means of software. The 6821 can be directly attached to MC 68000 and MC 68HC11 buses.

The PIA has two 8-bit ports A and B. Each port has a peripheral interface register, a data direction register, a control register and two control lines. Output port has to operate in a different way than an input port. The data has to be held for the peripheral which is stored in a register (peripheral inter-phase register). The data direction register is said to be latched when data are being sent and unlatched when used for input. The data direction register determines whether the I/O lines are inputs or outputs. The control register determines the active logical connections to the peripheral.

Example of Interfacing

Figure 9.9 shows how a microcontroller is used to drive a seven-segment display (interfacing for getting digital display). The seven LED elements are either ON or OFF and based on that the display has to show 10 digits from 0 to 9. This is done by 7447 decoder. Pins 7, 1, 2 and 6 are the BCD inputs and pins 13, 12, 11, 10, 9, 15 and 14 the outputs to the display. When we have to blank out the leading zeroes, when using more than

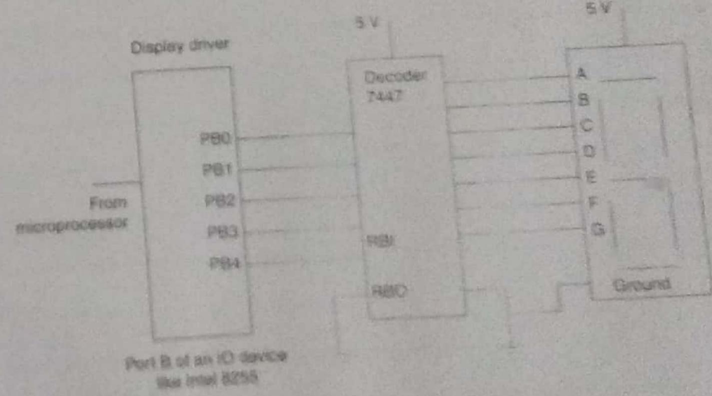


Figure 9.9 | Display driver

Schematic diagram:

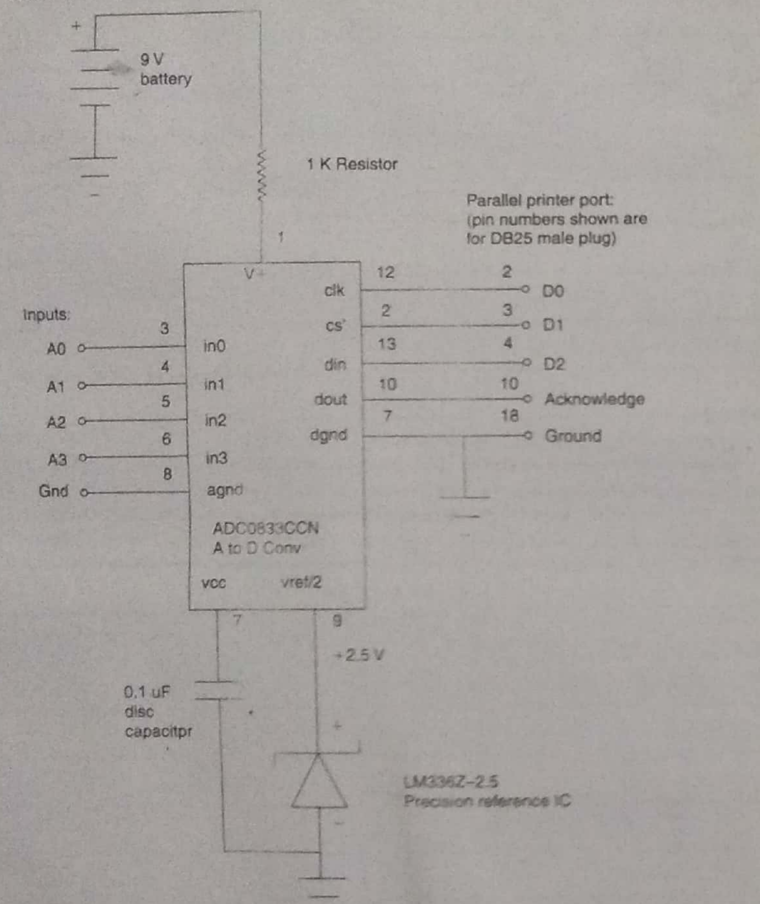


Figure 9.10 | Schematic diagram of a 4-channel ADC using IC ADC0833CCN.

Note: The pins of the LM336 can be identified as follows: The (+) terminal is the middle pin. Now, look at the lettering on the chip. While holding the chip with pins down and lettering facing you, the (−) terminal is on the right. First, V+ is the input to an internal Zener regulator, and power supplies ranging from +9 to +15 V can be used. This makes it convenient to mount the circuit inside an existing powered device, such as a light meter. The circuit can also be powered by eliminating the battery and resistor, and connecting a +5 V supply to the V_{cc} terminal.

Source: www.ic.ac.uk

one digit display, RBO of the first digit is connected to RBI of the second display and so on, thus allowing only final 0 to be displayed.

Analog Interfacing

Analog interfacing is required when output from a microprocessor or microcontroller is required in the analog form. Here we are discussing a 4-channel–8 bit A/D converter that can used on personal computers (PCs). The schematic diagram is shown in Figure 9.10.

This is an extremely simple ADC for the PC. It connects to the parallel printer port and runs from a 9 V battery. Input voltage range is 0–5 V. Driver software is in Turbo Pascal. The measured speed is roughly 1200 samples/s on an 8 MHz XT and 5700 samples/s on the same PC with a 10 MHz 80286/cache accelerator card. One can see that this circuit does not require a bidirectional 8-bit I/O port. It should work even on the most wild of clones.

Needless to say, this is not an extremely precision device, but should suffice for many medium-speed applications, such as temperature logging and alarms. An LM34 temperature sensor (10 mV/F output) would allow 2° resolution.

9.3 Analog-to-Digital and Digital-to-Analog Conversions

Introduction

Typically, the status of a physical system is measured by parameters available in the analog form, meaning as continuous time functions. Additionally, control signals or control inputs to physical systems have to be provided in the analog form. At the same time, we also visualize the fact that the digital computation blocks (microprocessors, digital signal processors) have become an integral component of any modern control system. Digital data acquisition has gained enormous importance in the light of data logging requirements, continuous condition monitoring, performance evaluations, fault diagnosis, feedback and control and system stability requirements. Figure 9.11 indicates the system at work.

We observe that ADC and DAC are two important interface functions, in any interface board, interfacing external world analog and digital signals from analog and digital transducers, with the digital world of the

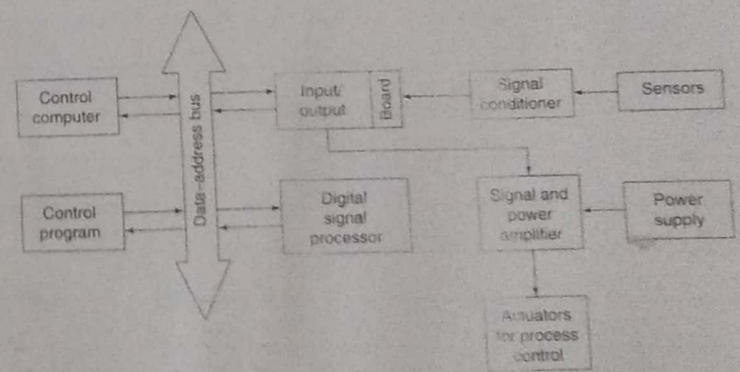


Figure 9.11 | Typical computer control.

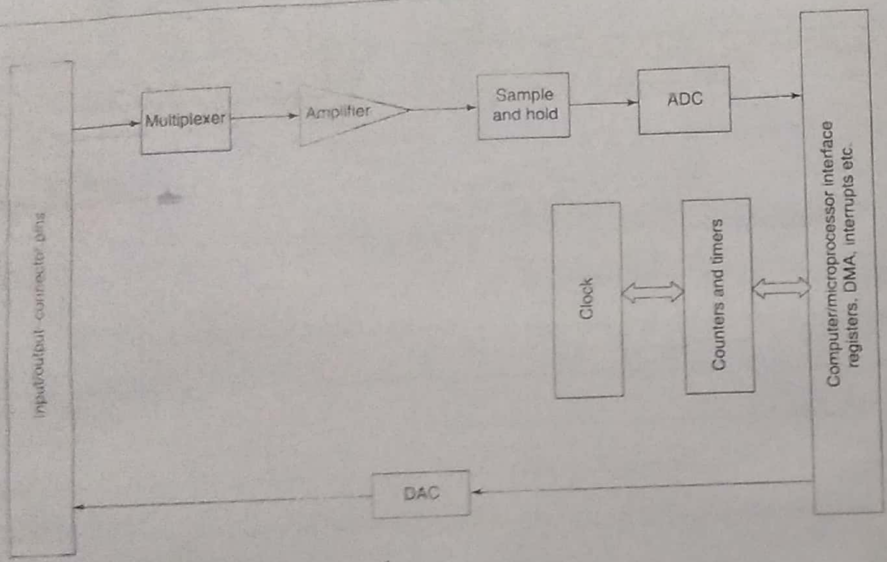


Figure 9.12 | I/O board organization.

computers and microprocessors. So, ADC elements are important components of any typical I/O board. Figure 9.12 is the schematic of the I/O board organization.

I/O boards are available from companies such as National Instruments, Precision Micro Dynamics, etc. These I/O boards can plug into a The I/O boards can also provide digital outputs and accept digital inputs. Specification of a typical I/O board slot of a personal computer and automatically get linked with the PC bus. Multiplexers (MUXs), sample and hold (S/H) circuits and A/D and D/A connections is given in Table 9.1. are available as peripheral chips to be used along with microprocessors.

There are I/O cards available with better capabilities like 8 channels of ADC and DAC and 16-bit word lengths.

Digital to Analog Conversion

Function of a DAC is to convert a sequence of digital words stored in a register (DAC register) in the binary form into an analog signal. These are basically of the following two types:

1. The weighted type (also called summer or adder type)
2. The ladder type

The latter is desirable though slightly costly.

Adder Type

The schematic is shown in Figure 9.13. Binary word is

$$W = (b_{n-1}, b_{n-2}, b_{n-3}, \ldots b_1 b_0)$$

Table 9.1 | Typical specifications of a PC plug in I/O board

1	Number of analog input channels	16 single ended; 8 differential
2	Analog input range	±5 V; 0–10 V; ±10 V; 0–20 V
3	Input gain ranges	1, 2, 5, 10, 20, 50, 100
4	Sampling rate for A/D	100 kHz
5	Word size of ADC	12 bits
6	Number of A/D outputs	4
7	Word size DAC	12 bits
8	Range of analog output	0–10 V; ±10 V
9	Digital input lines	12
10	Low voltage of input logic	0.8 V (max)
11	High voltage of input logic	2.0 V (min)
12	Digital output lines	12
13	Low voltage of output logic	0.45 V (max)
14	High voltage of output logic	2.4 V (min)
15	Number of counters/timers	3
16	Resolution of timer/counter	16 bits

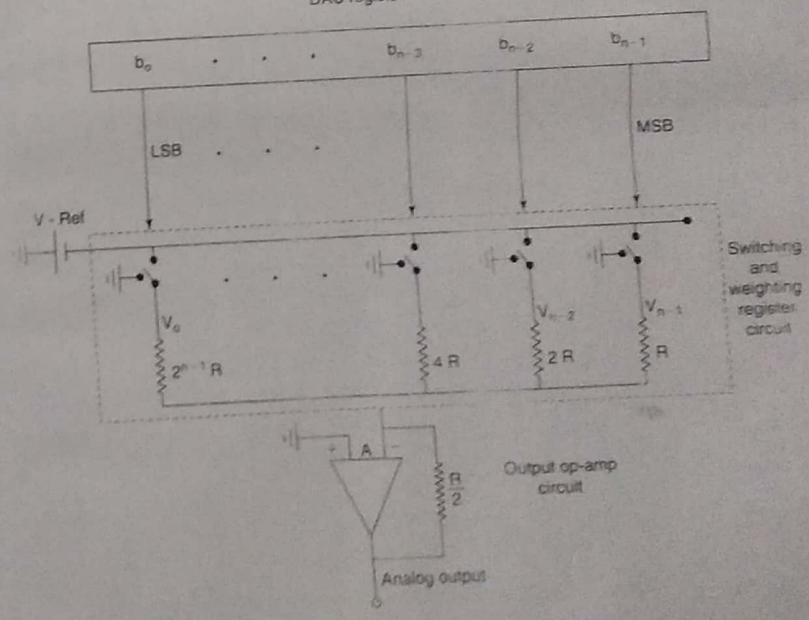


Figure 9.13 | Adder DAC schematic.

where b_i is the bit in the ith position. This takes the value 0 or 1 depending upon the value of the digital output. The decimal value of the binary number is

$$D = 2^{n-1} b_{n-1} + 2^{n-2} b_{n-2} + \cdots + 2^0 b_0$$

Here b_0 is the LSB and b_{n-1} is the MSB. A voltage proportional to D must be generated at the output. Microswitches shown in the schematic would be ON if any corresponding bit is high.

Current in node A would be given by

$$\frac{V_{n-1}}{R} + \frac{V_{n-2}}{R} + \cdots + \frac{V}{R/2} = 0$$

The assumptions made are that the voltage is same at all the input nodes and the current through each node is zero. We have $V_i = -b_i V_{Ref}$ where b_i is either 1 or 0 depending on the bit value. Therefore

$$V = \left[b_{n-1} + \frac{b_{n-2}}{2} + \cdots + \frac{b_0}{2^{n-1}}\right]\frac{V_{Ref}}{2}$$

Full scale value (FSV) occurs when all bits are "1". So FSV is equal to

$$\text{FSV} = \left[1 + \frac{1}{2} + \frac{1}{4} + \cdots + \frac{1}{2^{n-1}}\right]\frac{V_{Ref}}{2}$$

Using the formula for summation of a geometric series, where common ratio is <1, we have

$$\text{FSV} = \left[1 - \frac{1}{2^n}\right]V_{Ref}$$

Note that this value is less than V_{Ref}. Disadvantage with adder type DAC is that the range of resistance values required is wide. This presents an accuracy problem when the number of bits "n" of DAC is large.

Ladder DAC

Figure 9.14 shows a ladder DAC circuit. This circuit uses resisters of two types only having values R and $2R$. Also precision of the resisters is not as high as in the case of summer (adder) DAC. We mention here without proof that the analog output is given by the same equation as given for summer DAC.

DAC Error Sources

Errors are possible due to the following reasons:

1. **Code ambiguity:** In the straight binary code, incrementing a number by one LSB leads to change in two bits. If the switching of the bits is not simultaneous, then there is a possibility of error. This may be reduced by adopting Gray code and improved switching circuitry.
2. Associated circuitry time delays and oscillations may affect the analog output. The settling time should be less than half the data arrival time.
3. Switching at higher frequencies would cause associated noise. This is not significant at low conversion rates.
4. Aging and environmental changes will change the parametric values particularly in summing type of DAC.
5. Variation in reference voltage will be directly reflected as an error.
6. DAC output should change by its resolution for every LSB change in input. At least the analog output should not decrease when the value of digital output increases.

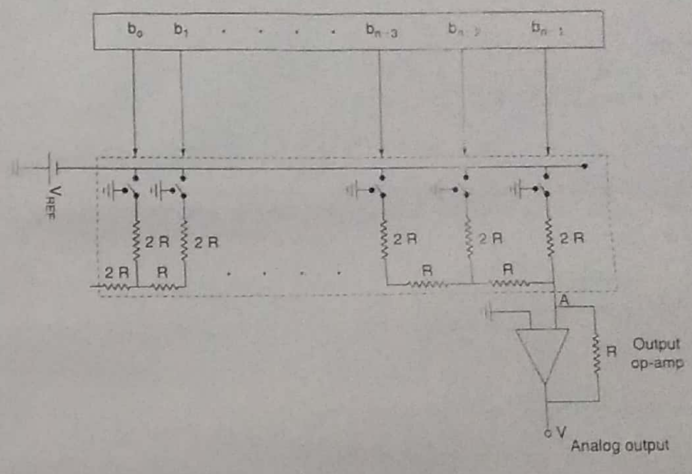


Figure 9.14 | Ladder DAC schematic.

7. When digital input changes from (000 ... 0) to (111 ... 1), the analog output should change in steps and best linear fit should be a stepped line with a slope of resolution/step. This step is known as the ideal scale factor. Non-linearity of a DAC is measured by the largest deviation of the DAC output from this line.

The main causes of such a non-linearity are bit transition errors and non-linearity in the circuit elements such as op-amps and resisters. The latter can be addressed by calibration.

Analog-to-Digital Conversion

Continuously time-varying analog signals are to be sampled at discrete time points and these sampled values are to be represented in the digital form. ADC process is more complex and time consuming than DAC. So the conversion rates are slow.

Successive Approximation ADC

Figure 9.15 shows the schematic of successive approximation ADC. Sampled analog circuit from an S/H circuit is applied to a comparator, typically an op-amp. Concurrently "start conversion control signal" (SC pulse) is sent into the control logic unit by the microcomputer. No new data would be accepted by the ADC unit (not sent by the computer) until conversion complete (CC) signal sent by the control unit is received by the computer. Initially registers are cleared so that they all contain zero bits. Now ADC is ready for conversion.

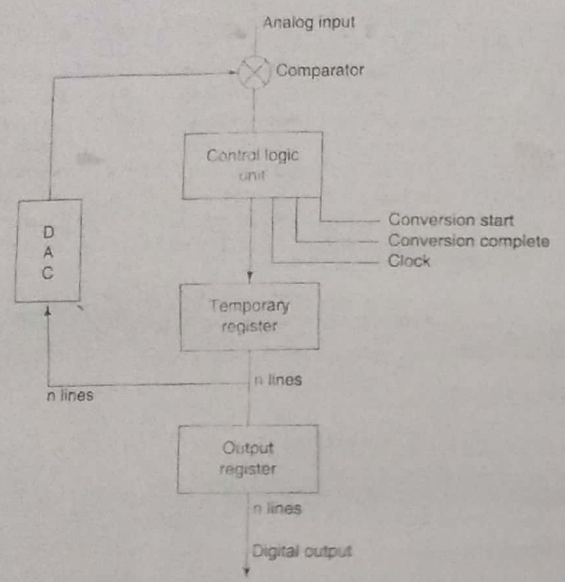


Figure 9.15 | Successive approximation ADC

First approximation begins with a clock pulse. Then the control logic unit will set the MSB of the temporary register to 1, all the other bits in that register being 0. This word in the temporary register is supplied to the DAC. The analog output from DAC is subtracted from the input signal at the comparator. If the result is positive, the MSB is retained (we may note here that presently the output of the DAC is half the FSV). If the result is negative the MSB is set to 0 before proceeding with the next approximation. The same process is repeated until all the bits from MSB to LSB are set. Then the contents of the temporary register are transferred to the output register along with a data valid signal to the interfacing device (computer) to read the contents of the output register. Next CC signal is sent out by the control logic unit and the temporary register is cleared. Now the ADC is ready to receive the next sample. Typically conversion time is "*n*" cycles ("*n*" is the number of bits) as 1-bit conversion takes one cycle.

We may note that the maximum value of the analog signal should be limited to FSV of DAC in the ADC. If it exceeds, it would contribute to the error in the digital output. So DAC unit should match the analog input.

In case the sign of the analog input has to be accommodated, the procedure is as follows. The sign is to be detected from the comparator initially when all the bits are 0, and if negative, then the same ADC is carried out after switching the polarity of the comparator. Finally, sign is represented correctly in the digital output.

Other A/D converters are dual slope ADC, counter ADC, etc. Since the analog input has infinitesimal resolution and the digital output has one LSB resolution, an error is introduced in the process of conversion. This is called quantization error.

9.5 Data Flow in DSPs, Block Diagrams and Typical Layouts

Figure 9.22 indicates a block diagram indicating the data flow representation in a DSP. Signal processing systems can be expressed as a network of transfer functions, data sources, data sinks and control functions. Such networks can, in turn, be represented clearly by diagrams, with icons or "blocks" (representing the functions) linked by lines (which depict communication between the functions). Each block represents a function, such as addition, subtraction, FFT, etc. The blocks are connected with lines or arrows, called directed arcs, which indicate how data moves between the blocks. Such diagrams are called data flow graphs, or more commonly, block diagrams, and they provide a convenient method of describing, documenting and analyzing a signal processing system. Figure 9.23 indicates a block diagram indicating the functional blocks of a typical DSP.

Figure 9.24 indicates the use of DSPs in a typical layout. DSP56001 has many I/O functions which simplifies the implementations. Motrola 56001 has 13.5 MIPS processing power with 24-bit word length. The implementation shown below has the following interfaces:

1. Host interface to the host computer.
2. Line level analog inputs and outputs.
3. Microphone preamplifier inputs and headphone output.
4. Special monitor loud speaker output.
5. Eight general-purpose high current outputs and four general-purpose inputs.
6. TTL level time multiplexer to interface more A/D and D/A converters.

Types of DSPs

Because different applications have varying ranges of frequencies, different DSPs are required. DSPs are classified by their dynamic range, the spread of numbers that must be processed in the course of an application. This number is a function of the processor's data width (the number of bits it manipulates) and the type of arithmetic it performs (fixed or floating point). For example, a 32-bit processor has a wider dynamic range than a 24-bit processor, which in turn has a wider range than 16-bit processor. Floating-point chips have wider ranges than fixed-point devices.

Each type of processor is suited for a particular range of applications. 16-bit fixed-point DSPs are used for voice grade systems such as phones, because they work with a relatively narrow range of sound frequencies. Hi-fidelity stereo sound has a wider range, calling for a 16-bit ADC and a 24-bit fixed-point DSP. Image processing, 3D graphics and scientific simulations have a much wider dynamic range and require a 32-bit floating-point processor.

How Fast are DSPs?

The primary reason for using a DSP instead of a traditional microprocessor is *speed*, the ability to move samples into the device, carry out the needed mathematical operations and output the processed data. This

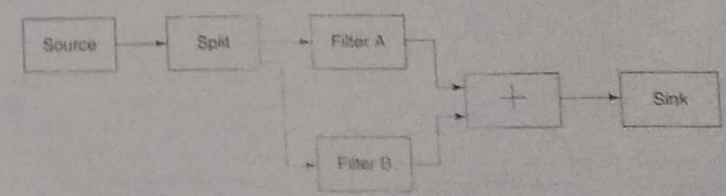


Figure 9.22 | Block diagram for data flow in DSP

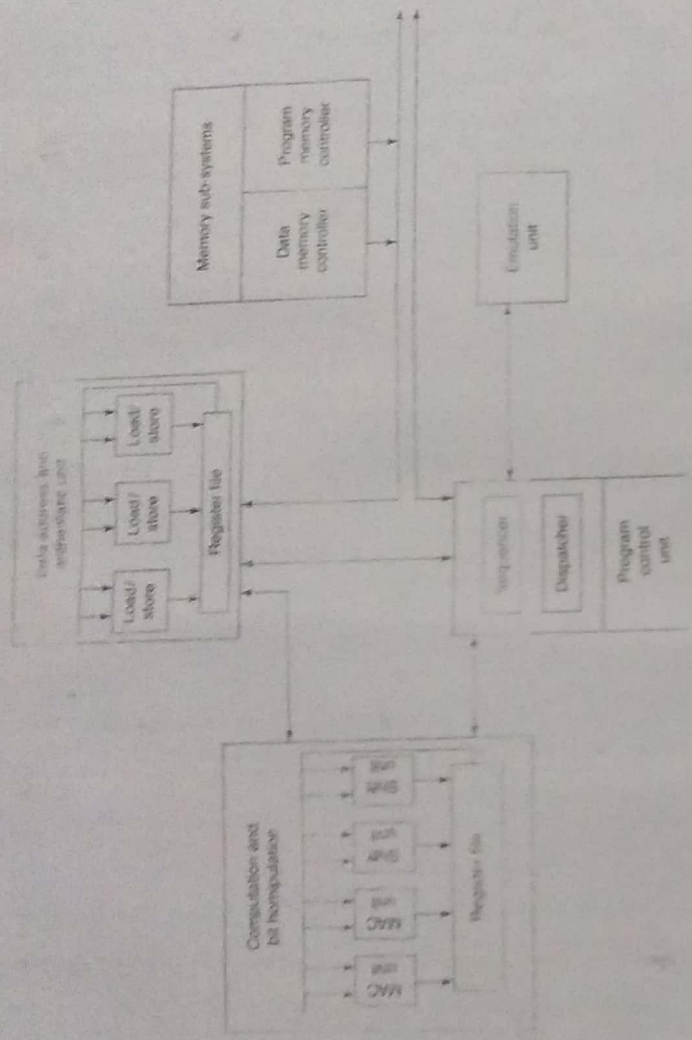


Figure 9.23 | Block diagram of internal functional units of DSP

brings up the question: How fast are DSPs? The usual way of answering this question is *benchmarks*, methods for expressing the speed of a microprocessor as a number. For instance, fixed-point systems are often quoted in million integer operations per second (MIPS). Likewise, floating-point devices can be specified in million floating-point operations per second (MFLOPS).

About 150 years ago, British Prime Minister Benjamin Disraeli declared that there are three types of lies: *lies, damn lies* and *statistics*. If Disraeli were alive today and working with microprocessors, he would add *benchmarks* as a fourth category. The idea behind benchmarks is to provide a head-to-head comparison to show which is the best device. Unfortunately, this often fails in practicality, because different microprocessors excel in different areas.

There is an old saying in electronics: *"A specification writer can get twice as much performance from a device as an engineer"*. These people are not being untruthful; they are just paid to have good imaginations. Benchmarks should be viewed as a *tool for* a complicated task. If you are inexperienced in using this tool, you may come to the wrong conclusion. A better approach is to look for specific information on the execution speed of the algorithms you plan to carry out. For instance, if your application calls for an FIR filter, look for the exact number of clock cycles it takes for the device to execute this particular task.

When it comes to understanding the execution time, we may mention here that many DSPs can carry out a multiply accumulate operation in a single clock cycle. Since most FIR filters use 25–400 coefficients, 25–400 clock cycles are required, respectively, for each sample being processed. As previously described, there is a small amount of overhead needed to achieve this loop efficiency (priming the first loop and completing the last loop), but it is negligible when the number of loops is large. To obtain the throughput of the filter, we can divide the clock rate (say 40 MHz) by the number of clock cycles required per sample. This gives us a

Uses

DSP chips are used in each and every application in the communication and computing industry like sound cards, fax machines, modems, cellular phones, high-capacity hard disks and digital TVs. DSPs are used as the engine in 75% of the world's digital cellular phones, and with the increase in wireless applications, this number will only increase. DSP is used in many fields where the amount of data to be collected are immense for any meaningful calculation, processing and meaningful outputs. These fields include biomedicine, sonar, radar, seismology, speech and music processing, imaging and communications.

9.6 Component Interconnection and Impedance Matching

Component interconnection is an important topic in any field of engineering application, particularly mechatronics. As an example when we have to couple a motor onto a load, we will have to match

...speed characteristics. These may be achieved by electrical means, mechanical means or with a combination of electrical and mechanical hardware and computer software.

Impedance Characteristics

To realise the rated performance of components, it is necessary to match impedances at each interface points. The adverse effect of improper impedance matching is the loading effect. In any measurement process, the measuring instrument distorts the signal being measured.

An ammeter would affect the current being measured. An accelerometer may introduce an additional ... load. Mechanical loading errors can result in an input device due to inertia, friction and other ... forces generated by an interconnected output component.

Another effect of improper impedance matching is inadequate output signal, which can affect functions such as signal processing and transmission, component driving and actuation of the final control element. Many transducers have high output impedances in the order of a thousand Mega-ohms. These devices need impedance-matching amplifiers with high input impedance and low output impedance. An example is the voltage follower operational amplifier.

Cascade Connection of Devices

Consider a standard two-port network as shown in Figure 9.25(a). Ratio of open circuit voltage at the output port to the short circuit current at the output port is called output impedance (Z_o). The input impedance is the ratio of the input voltage to the corresponding current through the input terminals when the output port is open circuited. Figure 9.25(b) shows the cascade connection of two two-port networks as well as Z_o and

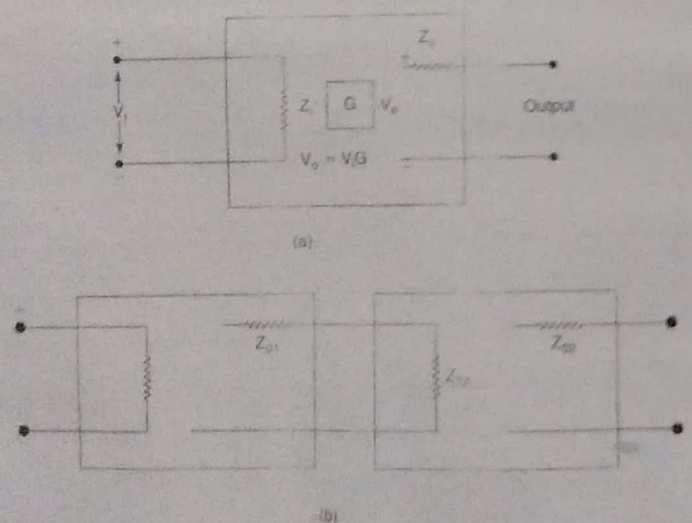


Figure 9.25 | (a) Two port network; (b) cascade connection.

Z_i for each of the two-port networks. Without elaborating on the proof, we may mention here the condition for minimal distortion of frequency response characteristics of two devices as follows.

The condition for the deviation of the frequency response characteristic to become insignificant is

$$\frac{Z_{o1}}{Z_{i2}} \ll 1$$

When two electrical components are interconnected, the requirements are as follows:

1. Electrical loading of the signal sources should be reduced.
2. Adequate current and power are required for the operation of drivers, signal communication and signal conditioning.

The above two conditions are satisfied by impedance-matching amplifiers or impedance-matching transformers. When dealing with very low signal levels, it might be necessary to use several stages of amplification. The first stage is a voltage follower op-amp with very low output impedance and very high input impedance. The last stage is a high gain amplifier stage to step up the signal power level. In many data acquisition systems, the output impedance of the output amplifier is made equal to the transmission line impedance. For maximum power amplification, the input impedance and output impedance of the matching amplifier are made equal to the complex conjugates of the source impedance and the load impedance, respectively.

Problem 9.3

A load is supplied by a source with an impedance of 5 Ω and represented in the complex form as (3 + 4j). What should be the load impedance for maximum power transfer?

Solution

The impedance should be the complex conjugate of the source impedance. This means that in complex form it should be (3 – 4j), that is if the source impedance is inductive then the load impedance must be capacitive with reactive and resistive components same in magnitude.

Impedance Matching in Mechanical Systems

The process of impedance matching can be extended to mechanical systems as well. Take the example of a motor driving a mechanical load. Sometimes it is not possible to drive the load due to differing speed load characteristics of the driven and drive equipments. By suitable choice of a gear transmission between motor and load, it is possible to modify the speed–torque characteristics of the drive system as felt by the load. This is impedance matching.

➢ Example: Purely inertial load.

Figure 9.26 shows a purely inertial load with and without gear transmission. We conclude without giving proof that given

J_l = load moment of inertia

J_m = motor moment of inertia

$\ddot{\theta}$ = load acceleration without gear transmission

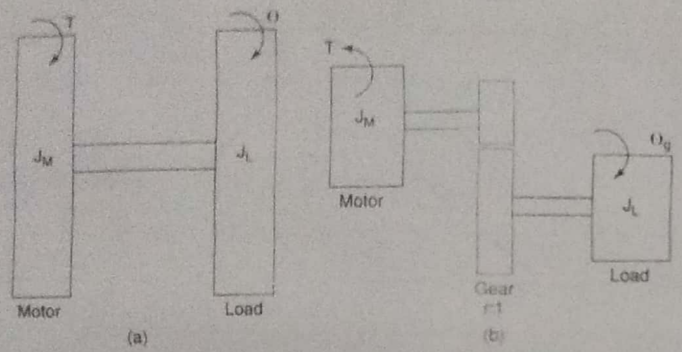


Figure 9.26 | An inertial load (a) without gear transmission; (b) with gear transmission.

$\ddot{\theta}_g$ = load acceleration with gear transmission and defining a and p as

$$a = \frac{\ddot{\theta}_g}{\ddot{\theta}} \text{ and } p = \frac{J_l}{J_m}$$

"r" being the gear ratio, we have the relation

$$a = \frac{r(1+p)}{(r^2+p)}$$

Peak value of "a" is given by

$$a_p = \frac{1+p}{2\sqrt{p}}$$

a_p = peak value of a

This we get by differentiating the relation $a = r(1+p)/(r^2+p)$ with respect to r (gear ratio) and finding the condition for "a" to be maximum.

We can state that for a purely inertial load for maximum load acceleration "a", the choice of the gear ratio is as follows:

1. When moment of inertia of load and motor are same use direct drive ($r = 1$).
2. When moment of inertia of load is less than that of motor use speed up gear with r as the square root of the ratio of J of load to J of motor.
3. When moment of inertia of load is greater than that of motor use speed down gear with r as the square root of the ratio of J of load to J of motor.

➤ Example: Other type of loads

If the load has a very specific speed-torque characteristic because of the driven equipment characteristics such as a pump, a compressor, etc., then matching of speed-load characteristic would become of utmost importance. Figure 9.27 indicates the matching that is required.

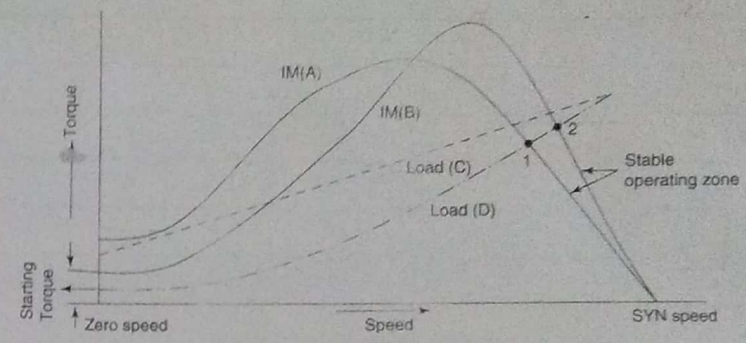


Figure 9.27 | Matching of load and induction motor characteristics [I.M.(A) – induction motor characteristic; I.M.(B) – induction motor characteristic; C – load characteristic; D – load characteristic].

Curves A and B indicate the torque–speed characteristics of induction Motors "A" and "B" respectively. Motor B characteristic does not match load C characteristic. This load would never start as the starting torque of motor is lower than the torque required by load "C". Load C can work on motor A. We may also observe that when load D operates on Point 1 on Motor A it will have larger speed variation per unit change in torque than when operating on Point 2 on Motor B. If we want different speed regulations, we may use the differing slopes available with different motors on the stable operating zone of the motors and choose the motors accordingly.

Interfacing Microcontroller Outputs with Actuators

The simplest device is a solenoid. When a microcontroller or PC interface is used to drive a solenoid, the output of the microcontroller had to be amplified in order to control the solenoid. The block diagram in Figure 9.28 shows the process. The output from the interfacing board is supplied to a driver IC like ULN 2003A which is a Darlington pair driver. The relay is 12 V relay single pole double throw. Such an arrangement can drive a 10 W, 6 V DC continuous solenoid. When choosing the driver IC and the relay for the solenoid we should know the current and voltage of operation of the solenoid, so that proper choice is made.

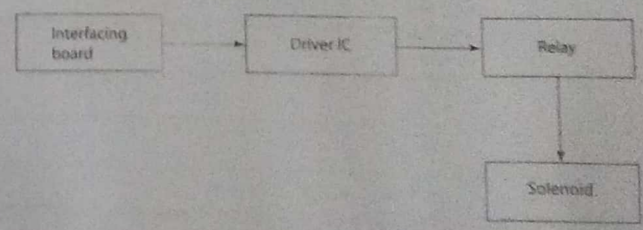


Figure 9.28 | Block diagram showing the process.

9.7 Interfacing Motor Drives

Interface Boards for Motor Drives

I/O Card or Data Acquisition Card is a hardware module with associated driver software. This can be connected to the computer Bus. A typical I/O card can provide analog input to as many as eight motors. DAC capability is inbuilt into the card (16-bit DAC including a sign bit and +10 V range). 8-channels ADC is also inbuilt into the card. Figure 9.29 indicates a schematic of a motor speed control system using an interface board. I/O board does the task of interfacing the motor side with the computer side.

Drive Units: DC Drives

These are of two types of drive units for DC motor drives: linear amplifiers and pulse-width modulated (PWM) amplifiers.

Motor Drivers

Drivers are required to generate necessary currents to energize the windings of the motors. Angular position and speed of the motor can be controlled by getting a feedback from a speed sensor. Drive units primarily contain a drive amplifier and a DC power supply. Drive is controlled by a control input from a computer. The computer receives feedback signals of the motor motion and generates control signals. Driver parameters such as amplifier gains are software programmable. Sophisticated control schemes can be implemented in addition to typical servo control schemes such as PID. Figure 9.30 is the schematic representation of PWM driver system.

Linear amplifiers have the basic disadvantage of power loss as the output voltages are proportioned in a dissipative way using resistive circuits. Power consumption remains same irrespective of the power consumed by the motor. Efficiency can be made close to unity by using PWM amplifiers. There are two feedbacks. One of speed and another of current. When the load on the motor increases then immediate reaction is an increase in current drawn and a fall in the voltage. Both have to be attended by the PWM amplifier. Here the speed control is much finer than having only one feedback. There are applications where torque is itself the primary output as in the case of metal forming operation, machining, grasping, etc. In digital control more sophisticated combinations of torque and speed can be achieved.

Basic PWM amplifier has inputs from the current sensing and speed sensing devices. Output is the pulse width modulated power supply to run the motor.

Typically, PWM driver consists of speed reference, speed feedback, a differential amplifier and a second stage amplification based on the current feedback from the motor to fine tune the torque performance of

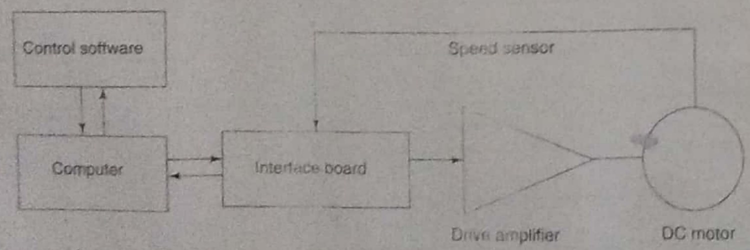


Figure 9.29 | Schematic for motor speed control using I/O Board

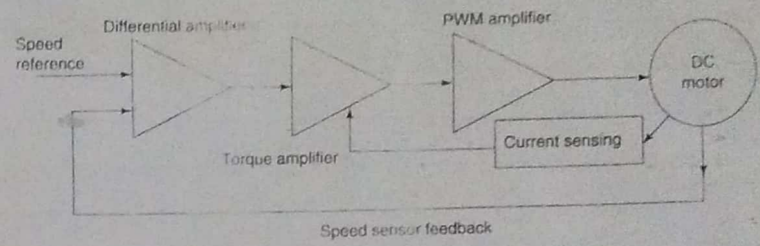


Figure 9.30 | PWM driver system.

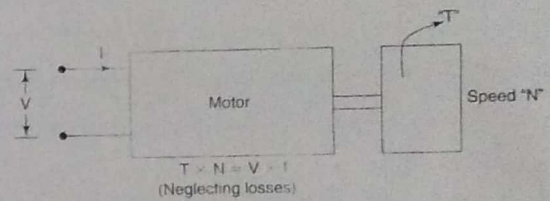


Figure 9.31 | Speed torque relation in a motor (AC or DC).

the motor. PWM driver output is fed to the windings of the motor. PWM is accomplished by varying the duty cycle of the generated pulse signal through switching control as explained next. Final control of the DC motor is achieved either by varying the supply voltage or the field current. Controlling the speed by armature current gives a wider range, whereas field weakening can only change the speed from the nominal operating speed in a small band.

In a typical situation, when the voltage remains constant , and the torque on the motor increases, the speed decreases and current increases. Figure 9.31 indicates this relation.

These reduction in speed and increase in current together see that power output (mechanical) given by the product of torque and speed is balanced with the power input which is the product of voltage and current (in DC or AC with constant power factor). But the current has to be brought down by increasing the supply voltage as the scope for changing the current is limited by the I^2R losses in the motor. In fact the I^2R losses and the iron losses that can be dissipated safely decide the power rating of the motor. At any point of time the power input to the motor is equal to the product of T and N.

When T increases N falls and I increases. How much N falls and how much I increases depend upon the motor characteristic.

Figure 9.32 shows a typical DC drive. We may observe that digital firing circuit is controlled by current and speed feedbacks.

Variable Frequency Drive (VFD)

VFDs brought the use of AC motors into prominence and reduced the predominance of DC motors in variable speed applications. VFD is the electronic controller designed to change the frequency of supply to the motor. As the frequency supplied to the motor is increased the motor speed increases. In the early

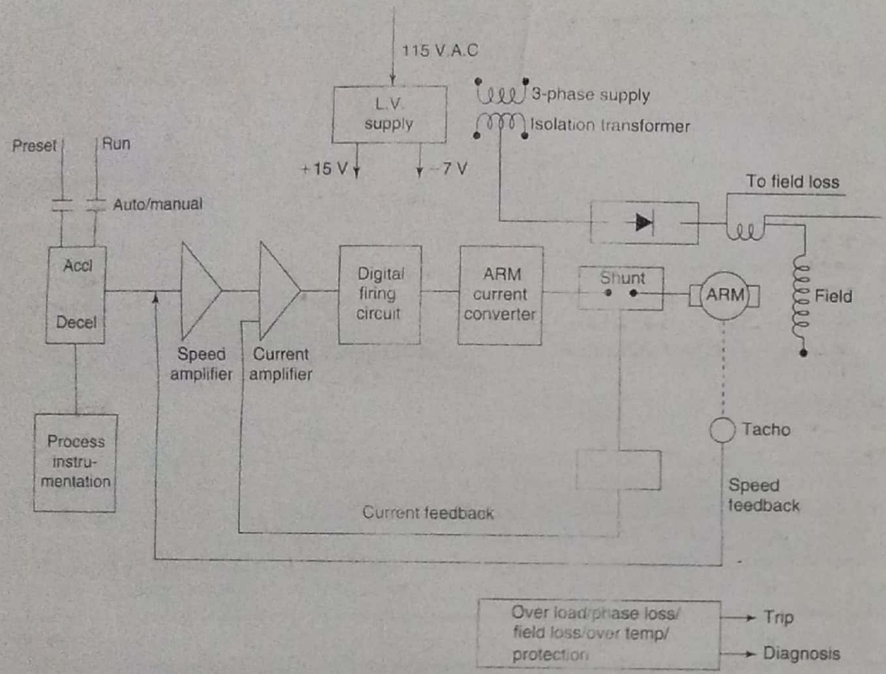


Figure 9.32 | Block diagram of a DC drive

1960s the VFD was used to control small motors, but in 1980s the drive was extended to cover very large motors as larger transistors became available. Advent of microprocessor control has enabled the VFD to have, in addition to speed control, protection against over-current during ramp up and ramp down conditions.

In large motors the reduction in starting current and associated demand reduction itself reduces the utility bills substantially. Also in applications where the motor has to operate at part loads, for long periods, the savings in energy is very high. One example is primary air fans in utility boilers.

These drivers are available in smaller sizes and are lot effective, efficient and occupy less space. Schematic of a VFD is shown in Figure 9.33. The VFDs has following three main sections:

1. AC-DC converter (rectifier);
2. DC-intermediate section (filter);
3. DC-AC inverter (switching).

Components used are regular transistors, darlington pair transistors, or IGBTs (insulated gate bipolar transistors).

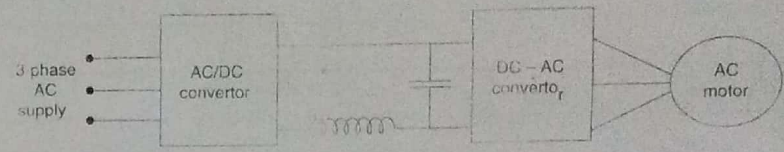


Figure 9.33 | Schematic of a VFD

Typical VFD

Figure 9.34 shows a typical VFD schematic. In the block diagram, R, S, T terminals are three-phase inputs and UVW are the VFD output to the three-phase motor. These voltages can be 240–400 at low voltage levels and can be 1.1–3.3 kV in power station applications.

Next section would be the filtering of rectified AC before supplying to the inverter.

The inverter stage consists of three pairs of IGBTs which are turned ON and OFF for approximately 12 times in each half cycle by a PWM control circuit. The amplitude will be adjusted so that overall shape of the output wave looks like a sine wave. The frequency can be adjusted between 0 and 120 Hz typically and in some cases between 0 and 400 Hz. The voltage and current of the output would be adjusted to generate the required torque to the motor. The drive maintains a volt to frequency (V/F) ratio so that motor has sufficient power to provide the torque requirements. This ratio can be adjusted slightly to take care of typical load requirements of larger loads at lower speeds.

Terminals indicated are self-explanatory. Stop and start pushbutton switches start the start frequency. Start sequence will provide a slowly increasing ramp of voltage and frequency to start the motor slowly.

Drive enable contacts can be controlled by an external control relay. A jog pushbutton will run the motor at a jog speed written into the program. External switches SW1, SW2 and SW3 provide fixed speeds as entered into the program. A specific application may require the motor to operate at three fixed speeds for three specific operations. These can be selected by the operator. An external potentiometer 0–10 kΩ can be used along with 0–10 V input or 4–20 mA input to generate any speed from 0% to 100%.

The serial ports for communication and for operator interface are provided. Serial communication can be used for reloading the parameters from a portable computer.

One advantage of VFD is its ability to run in the reverse direction without using expensive reversing motor starters. This is accomplished by changing the input phase sequence obtained by changing the timing logic. Provision is also provided for braking the motor. VFD is basically an open loop controller, with motor supplied at different frequency levels for larger speed variations and torque and speed ranges dictated in a small band by the induction motor characteristic.

Scalar and Vector Drives

Some manufacturers provide additional circuits inside the drive to bring in the closed loop feedback signals from encoders or resolvers. These circuits decode the signals from the sensors and scale them to the required level. This makes the drive operate like a package. This helps the designer to immediately put a system together where the components match. Such drives are called vector drives by "Allen Bradley". Scalar drives of "Allen Bradley" can be operated either on open loop or on closed loop.

Stepper Motor Driver and Controller

A stepper motor is basically an open loop actuator. Stepwise rotation of the motor is synchronized with the command pulse train. Because of this, this is also called digital synchronous motor. Basic schematic is as shown in Figure 9.35.

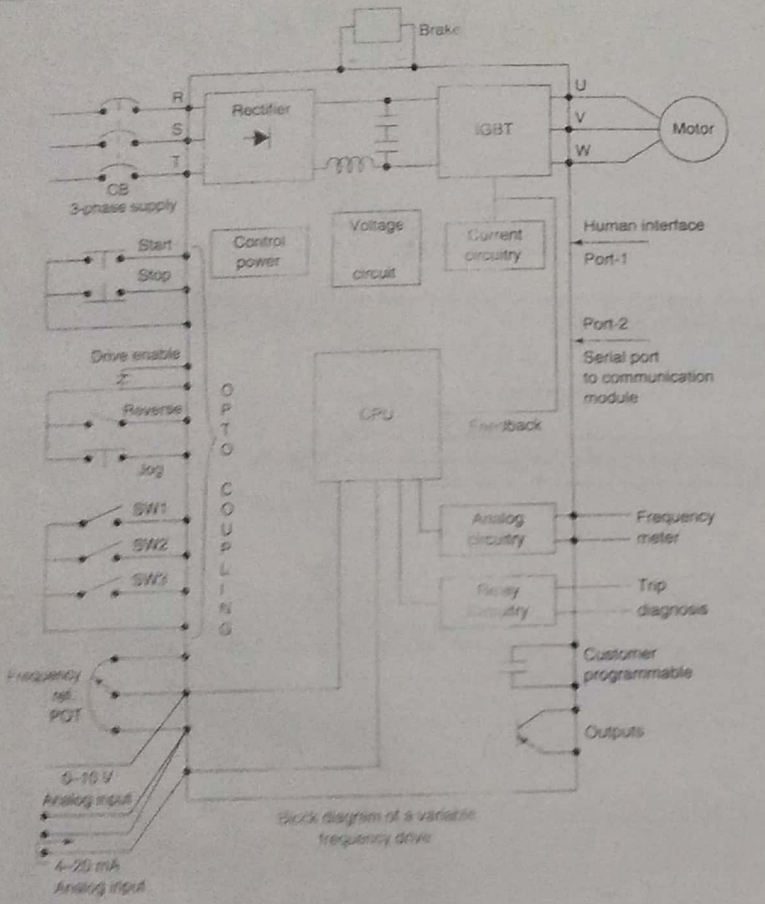


Figure 9.34 | Block diagram of a VFD

The basic components are identified in the diagram. Main basic component is a translator to interpret the command pulses and switch the analog circuits to generate the high currents required by the windings of the stepper motor.

The command pulses are generated either by a control computer, microprocessor or a variable frequency oscillator (hardware approach). For bidirectional motion two pulse trains are required: the position pulse train and direction pulse train. For steady-state operation, the stepping rate can be set manually, adjusting the potentiometer connected to the translator to get simple motion (e.g. starting from rest and stopping after

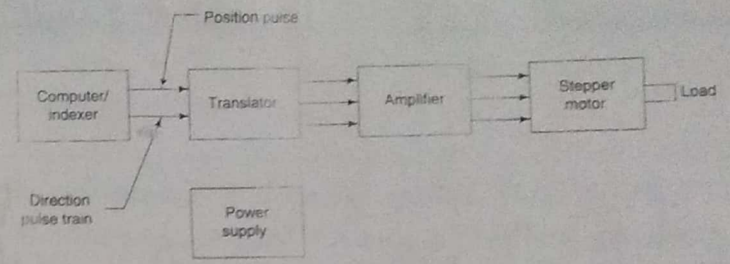


Figure 9.35 | Basic components of a stepper motor driver.

a predetermined angular position). Under more complex projections, computer based generation of pulse commands would be required.

Drive Unit

The driver hardware consists of the following components:

1. The drivers for stepper motors contain the digital hardware to interpret the information carried by the stepping pulse signal and the direction pulse signal, and provide appropriate signals to the switches that actuate the phase windings of the motor.
2. Drive circuits for phase windings with switching transistors to actuate the phases.
3. Power supply to the phase winding.

These components are commercially available as single packages to operate corresponding class of stepper motors. An integrated heat sink is also provided to dissipate the heat generated in the hardware. Figure 9.36 indicates a unipolar drive (no current reversal in a phase winding). So the windings have two coil segments for each phase. Consequently, the motor has five input points. The translator generates the proper logic to

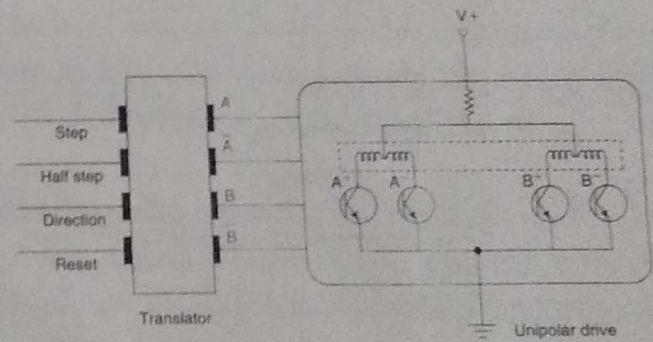
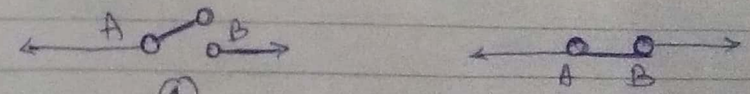


Figure 9.36 | Drive hardware for bifilar wound stepper motor.

A&B when switch is in off position. and



(1)

UNIT NO - 3

Actuating systems-

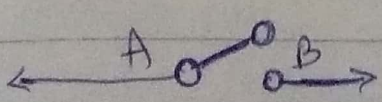
An actuator is a type of motor that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion.

Switching -

(1) Any switching device consists of one or more pairs of contacts. These contacts can be mechanically actuated to close or open electrical circuits. Principals of various electrical switching are as follows-

(A) Normally open contact - The circuit is open between A & B, when the switch is in Off position. The circuit is created between points A & B as the switch is moved to ON position.

(B) Normally ~~open~~ closed contact - The circuit is closed between A & B when switch is in off position. and



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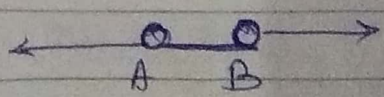
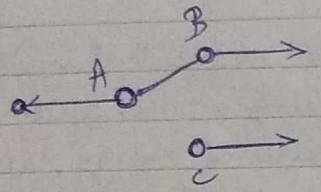
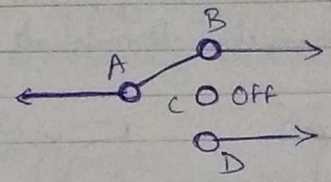


② Single Pole Double throw - It is used when we require ON & Off operation as the circuit is actuated



④ Off SPDT switch - The Off SPDT is a three position switch, with off position at the centre.

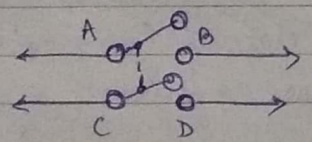


③ Double Pole, single throw & double pole, double throw -

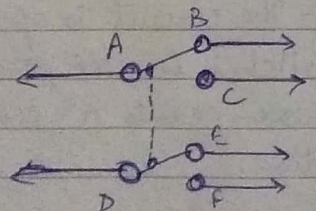
Ⓐ (DPST) is used when we need to turn two seperate circuits ON and Off simultaneously with a single switch.

Ⓑ DPDT switches are used when a switch is turned ON & Off between B & C with double pole switches.

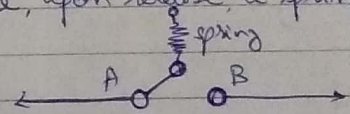
Ⓐ



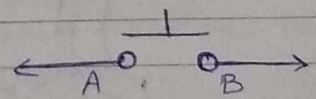
Ⓑ



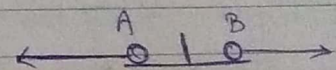
⑤ Spring return SPST - When the switch is actuated, the contacts A and B are closed as shown in figure, upon release, it springs back to open position



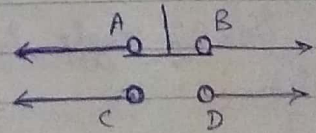
⑥ Push buttons - They are all spring return switches, as given.



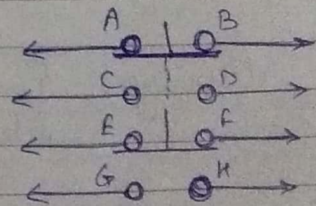
① Normally open



② Normally closed



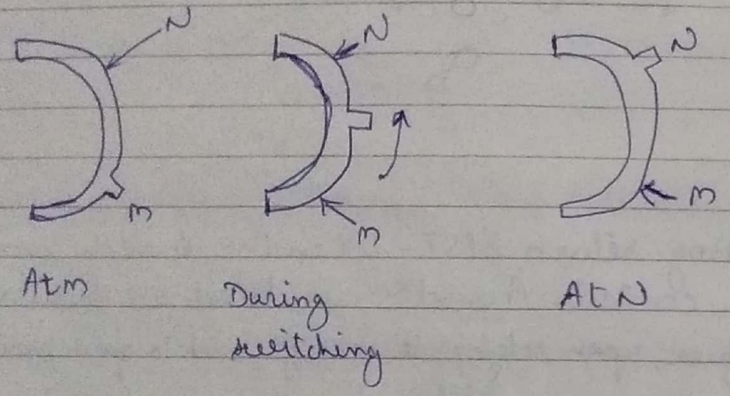
③ Single pole, double throw



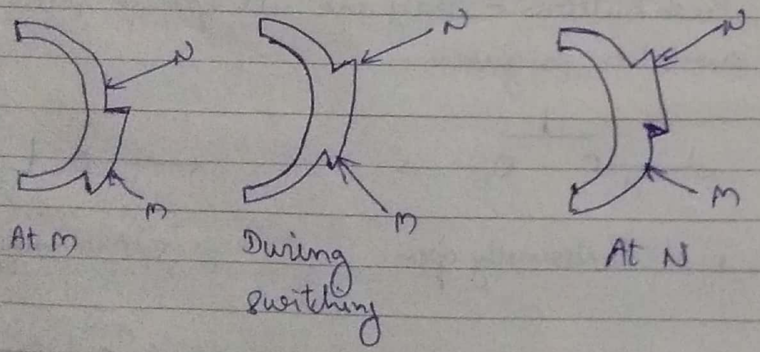
④ Double pole, Double throw

(8) Multiple switching arrangement

(a) Break before make - In going from M to N, the circuit is broken in intermediate position



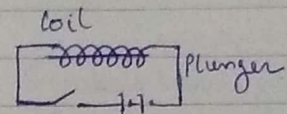
(b) Make before break - The circuit is connected to both M&N in intermediate position

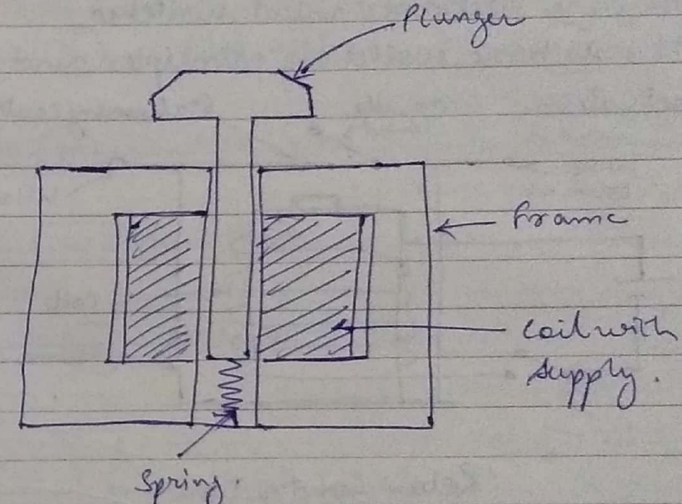


Other types - Pushbutton, On&Off toggle, & Selector switch.

Solenoids -

A solenoid is used for translating ON/OFF electrical signals to ON/OFF mechanical movements and are normally used as a linear actuator.





(1) The solenoid is made up of a coil with movable iron core

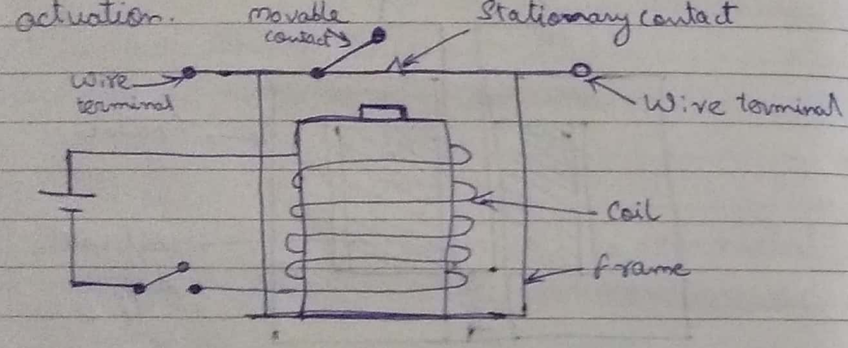
(2) The coil will have some voltage or current rating

(3) When the coil is energised, the core is pulled inside the coil.

(4) The amount of force by which the core is pulled depends upon the number of coils & the amount of current flowing through coil.

The choice of solenoid depends on-
1. Size of mechanical load
2. The movement distance of plunger
3. the type of voltage & current

Electrical Relays-
→ They are electromechanical switches
→ It uses basic switching principles and solenoid actuation.

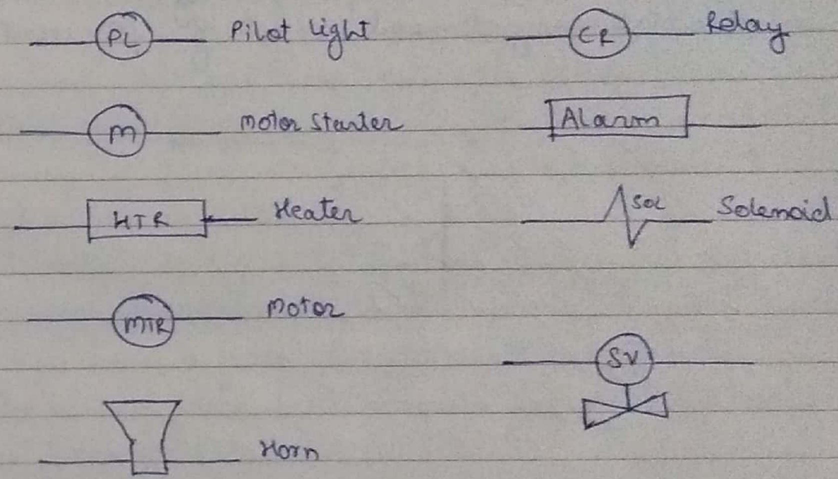


Relay Construction

→ It contains a coil of wire wound around an iron core
→ The relay has a set of 2 contacts, one is movable and one is fixed.
→ When the relay is energized, a magnetic field is created around the coil; this attracts the movable contact towards the stationary contact, thus completing the ~~...~~ circuit.
→ When the current is stopped the coil is de-energized and the contact is broken.

Applications - in devices such as motors, heaters and valves

Symbols used for output devices-



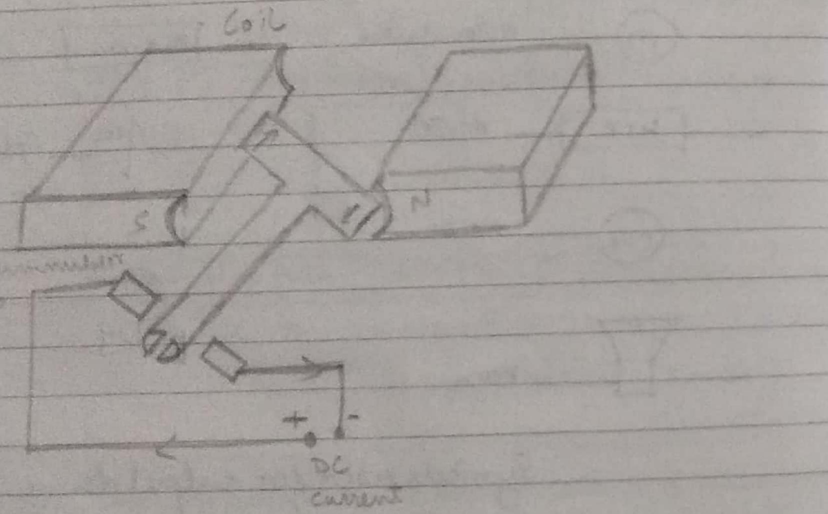
Symbols used for output devices.

Electrical Motors.—:

① D.C. servomotors

→ D.C motors are used when torque varies over a wide speed range and also in situations where a constant speed is required.

Construction- In its simplest form of a DC motor, the stationary element consists of a permanent



magnet to produce a static magnetic field across two pole pieces.

→ The rotating element consists of a series of coils placed on the periphery of a rotating body called the armature which is connected to the source of a DC current through a switch mounted on the shaft (a commutator).

→ The current in the coil will produce a magnetic field and a north south orientation causing the repulsion of the Permanent magnet in south (N) pole and coil in south (N) pole resulting a torque that will rotate the coil.

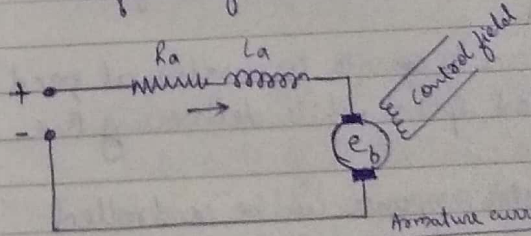
Principle of Operation-

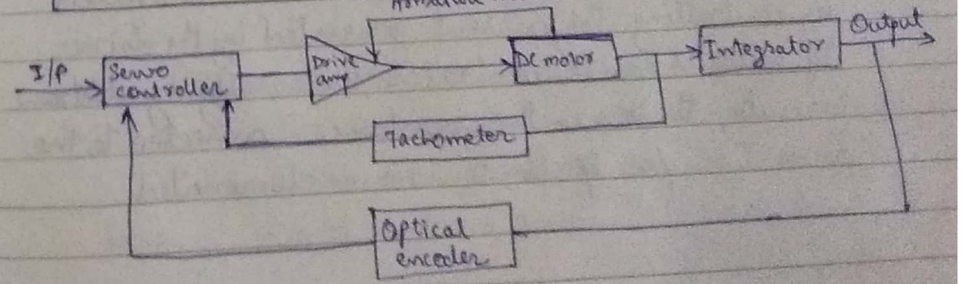
→ The operation of a motor depends on the interaction between two magnetic fields.

→ One of the magnetic fields is provided by a current carrying conductor which is free to rotate. The other one is stationary.

→ According to the law of magnetism, when a current carrying conductor is placed in a magnetic field, it will experience a force at right angle to the field.

→ The lines of force due to magnetic ~~force~~ field, produces a force of rotation





Speed control of DC motors -

For proper performance of DC motor, both speed and torque of a motor needs to be controlled -

① Field Control or Flux Reduction method -

-> One of the effective methods

-> Done by weakening the field flux by controlling the speed.

-> A variable resistor, called field regulator, can be incorporated in series with the field winding to reduce the flux, particularly for shunt and compound motors.

② Armature Control -

-> In armature control the field current (stator) is kept constant and the armature voltage to the rotor is regulated.

-> Normally preferred to operate the motor at speed lower than its rated speed while delivering the same torque.

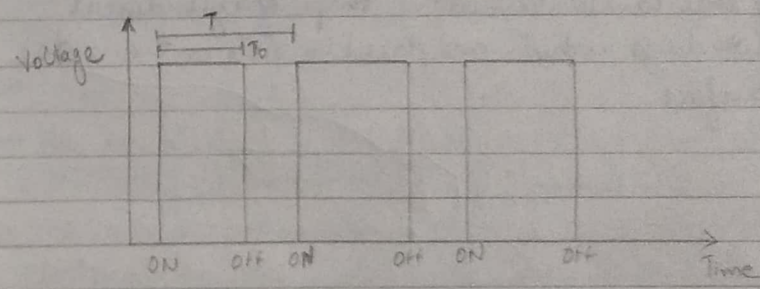
-> In general, the motor response can be controlled by controlling the current generated by the driver. If current can be controlled externally by electronic circuits, the loss in the resistance connected to the armature for speed control is eliminated.

③ Pulse Width Modulation (PWM) & PWM DC Converter -

One of the methods of controlling the motor driver is to vary the frequency of supply which can inturn be used to vary the speed of motor.

The voltage control using the inverter is known as pulse width modulation (PWM). Here, the pulse width of a signal is adjusted as a function of time.

The process attempts to approximate a low frequency waveform by adjusting the duty cycle of a square wave.



Duty cycle is the ratio of the ON pulse to the time of one cycle. ie $-\left(\frac{T_0}{T}\right) \times 100\%$;

where,

T is the pulse period and

To is the ON period.

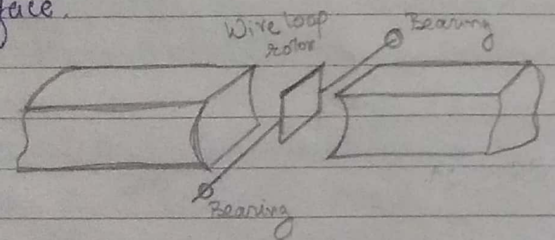
Here, $1/T$ is held constant and To is varied.

AC Motors -

AC motors are better than DC motors due to their robustness, lower cost, simplicity of construction, easier maintenance and heavy duty application.

An induction motor replaces the PM with a heavy wired coil, into which is induced a current from the changing field of the AC excited field coils.

Any AC motor has two components - Stator and rotor.
The stator consists of electromagnets secured to the frame, spaced at equal distances. The rotor is made of steel lamination in the shape of cylindrical windings which are placed in slots on the rotor surface.



Single Phase Induction Motor -

The stator consists of a combination of high grade sheet steel and the rotor consists of laminated ferromagnetic material. This is energised by a single phase alternating current and operation of the motor depends upon the creation of a rotating magnetic field.

→ When an a/c current is flowing through the stator, a flux is established which induces an emf into the rotor winding and a current flows in the rotor.

→ The current will develop rotor flux which develops a revolving magnetic field. The value of rotor flux increases with increasing speed.

→ The motor is not self starting and a mean is to be provided for turning the rotor to create a revolving field.

Three Phase Induction Motor -

→ Has the simplest construction of any type of motor.

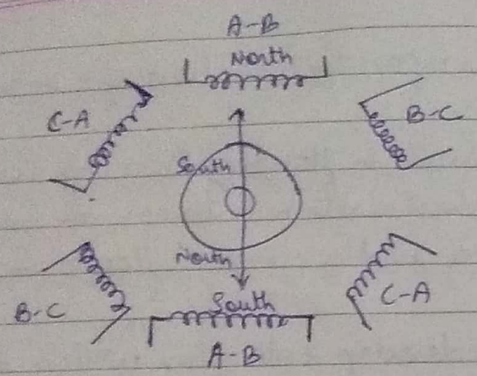
→ Has no starting windings and it runs at an essentially constant speed.

→ The coils are wound in slots in the ~~rotor~~ stator & electrical power is fed into these stator coils.

→ Copper or aluminium bars are put into the rotor slots

→ When an input AC voltage is applied to the stator windings, the current is 120 degree apart and continuously alternating in value and changing direction

→ This produces a rotating field. Therefore, the different phase angle of the three alternating voltages cr[illegible] the rotation.



Advantages of AC motors -

- They are more rugged, simple, have high degree of reliability and require less maintenance.

Disadvantage -

- Speed control is very complex and difficult

Stepper Motor -

A stepper motor is a rotating machine which converts a DC voltage pulse into a series of discrete rotational steps.

→ Each step position is an equilibrium position without further excitation, hence they are ideally suitable for use with a digital control.

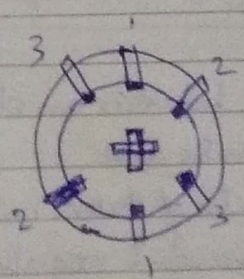
→ The torque produced is very small and it can be used to give accurate positioning as in case of printers, robots, machine tools, etc.

For a stepper motor - $\text{step angle} = \dfrac{360}{\text{No. of steps/rev}^n}$

Mainly 3 types -

① Variable reluctance type
② Permanent magnetic
③ Hybrid type.

① Variable reluctance type -

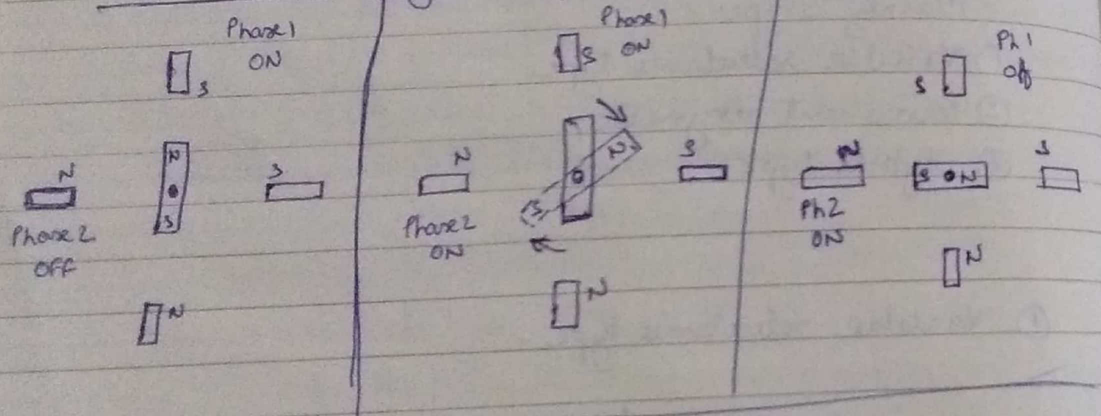


→ The rotor has a number of soft iron teeth which is less than the number of poles on the stator.

→ The stator has pairs of poles being activated by a series of coils.

→ When one pair of poles (pair 1-1) is activated, a magnetic field is produced and the rotor will align itself with the energized coil to give the least magnetic reluctance. To move the rotor, the new pair is switched (2-2) and the rotor lines up with those poles. Thus, by sequentially switching the current from one pair of poles to the next, the rotor can be made to rotate in steps.

Permanent Magnet Stepper Motor



→ Operates on interaction between an electromagnetic field and permanent magnetic rotor.

→ The stepper motor has 2 sets of stator windings, placed at 90° and a two pole permanent magnetic rotor.

→ The clockwise or counter clockwise movement of rotor can be produced by switching the currents in the two phases in an appropriate sequence.

→ The working is as shown in figure.

→ The rotor rotates as per excitation of the phase 1 & 2 stator winding.

→ When both the phases are ON, the rotor turns through a single step of 45°

Application and advantages of Stepper Motor -

→ Are essentially digital in nature and compatable for designing computers and computer peripherals equipments

→ Stepper motor is used where precise positioning is required, in combination with a μp controller.

→ Feedback is not essential for stepper motor & it is compatible with both analog or digital feedback.

→ Error is minimum and non-cumulative.

→ Can accelerate its load easily as max^m torque occurs at low pulse rate

→ Eliminates the use of gear reduction as low velo[...] can be obtained with stepper motor.

Hydraulic and Pneumatic Actuating Systems

Fluid Power System-
It is nothing but utilization of liquids such as oil, water and gas as a media for transmission of energy.

The fluid power systems may be used for the following

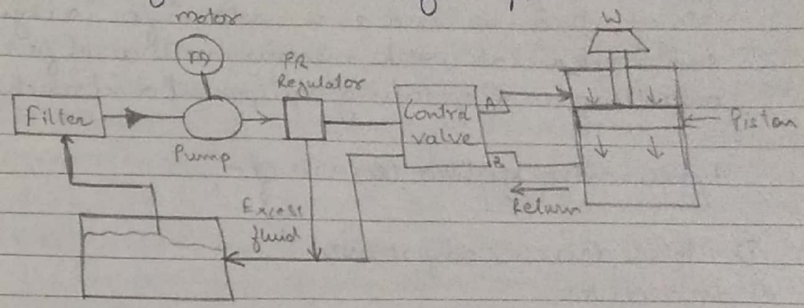
1. Carrying out mechanical work - using linear swivel and rotary ~~motion~~ motion for plant equipments & machinery

2. Controlling application- Controlling of plant, process and equipment. They are also used to sense operational status of process and feed this information to the controller element to take necessary corrective action.

3. Measurement of process parameter - these process measurements are then used to act on necessary output.

Components of a Hydraulic System-

The basic Hydraulic system essentially consists of a pump and a cylinder. Figure shows a simple hydraulic system, where a hydraulic piston is lifted by a hydraulic pump driven by an electric motor. The system consists of a closed loop piping network, with fluid transferred from a storage tank to one side of the piston and returned from other side of the piston to the tank.



Hydraulic System

The pump converts a mechanical force to hydraulic power and the fluid is drawn from the tank by a pump which produces pressure at the required amt. A pressure regulation/relief valve protects the system from high pressure and is essential to spill excess fluid back to the tank, due to a dead end load, in order to prevent failure of a pipe or pump where fluid pressure rises.

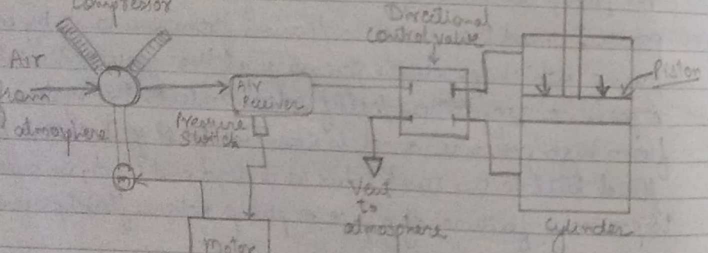
Hydraulic fluids needs to be very clean, hence a filter is needed to remove dust particles before the fluid passes from the tank to the pump.

Pneumatic System -

Systems using gas for power transmission are called pneumatic systems. When air is compressed and stored, it can be used as a medium for carrying out mechanical work, measurement and for controlling and operating equipment and machines.

A pneumatic system consists of -

① Motor driven compressor
② Air receiver
③ Directional control valve
④ Pneumatic cylinder



Pneumatic system

A pneumatic system uses compressed air, and air is usually stored in a pressure vessel called an air receiver.

Air is delivered to the air receiver by a motor driven compressor. The compressor is controlled by a pressure switch in order to start/stop the compressor depending upon the demand.

The cylinder movement is controlled by a DCV which directs the air into various pressure ports and releases the air from the cylinder to the atmosphere.

Pneumatic system requires clean, dry air to remove dust and dirt. A primary air treatment consists of a cooler and a seperator. The cooler is used to reduce the temperature of air after compression, whereas a seperator removes water vapour in the air. The secondary air treatment provides oil mist to lubricate the ~~g~~ system and also incorporates further filteration of water particles.

Advantages of Hydraulic and Pneumatic Systems -

① Availability - air is available everywhere in unlimited quantities.
② Transport - Air and hydraulic fluid can be easily transported over a large distance
③ Storage - Compressed air can be stored in a reservior and removed as required. Hydraulic
④ Temperature - Compressed air is relatively sensitive to temperature fluctuations, whereas hydraulic fluids are relatively insensitive.
⑤ Explosion proof - Compressed air offers min^m risk of fire.

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⑥ Cleanliness - Any unlubricated air which escapes through leaking pipes or components does not cause contamination.

⑦ Components - The operating components of pneumatic system are simple in construction and they are relatively cheaper.

⑧ Speed - Compressed air and hydraulic fluids are very fast working mediums

⑨ Adjustable - With compressed air and hydraulic components, speed and force are infinite variables.

Comparison of various systems-

	Hydraulic	Pneumatic
1) Energy source	Electrical/Diesel	Electrical/Diesel
2) Running	Needs cooling	Runs cool
3) Space	Compact	Very compact
4) Transport	Limited, local	Plant wide & easy
5) Energy cost	Medium	Highest
6) Availability	Limited	Unlimited
7) Force of application	V. High force	Medium force
8) Cleanliness	Very clean	Messy leaks.
9) Speed of operation of actuators	Low speed	Accurate & high speed
10) Safety	Fire hazard	Explosion proof
11) Noise level	Less noisy	Noisy
12) Temperature	Insensitive	Sensitive.

The disadvantages of using such systems are as follows-

① Require good amount of prior preperation

② Compressible - Not possible to achieve uniform and constant piston speeds with pneumatic systems

③ Compressed air is only economical when the working pressure of 6-7 bar is maintained.

④ Noise level - The exhaust air is noisy

⑤ Costs - Compressed air and hydraulic fluid are relatively expensive means of conveying power.

CONTROL VALVES

The primary function of a control valve is to direct and regulate the flow of fluid from an energy source to the various loading devices.

They are used for the purpose of sensing, processing and controlling.

Control valve cover following functions-

① Allowing the passage of air/fluid and directing it to a loading line.

② Cancel the signal by blocking its passage

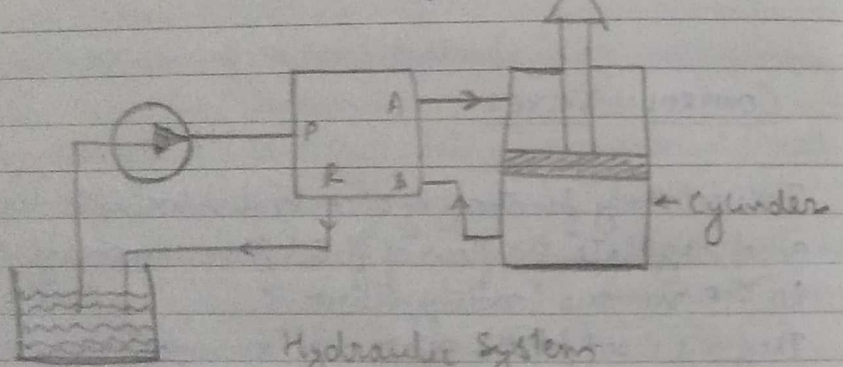
③ Alter or generate the signal

④ Release the air atmosphere or return the fluid to the tank.

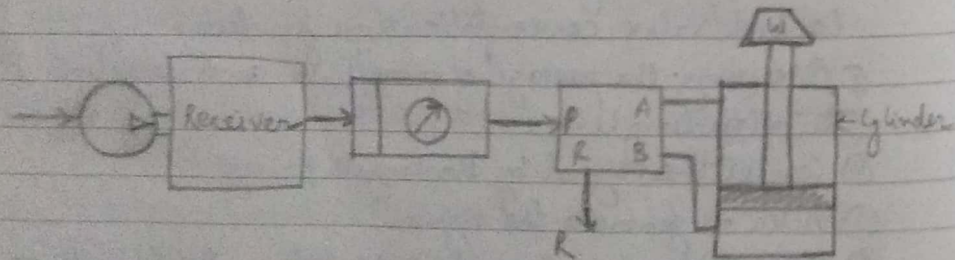
DIRECTIONAL CONTROL VALVES

The Directional Control valves are used for controlling the passage of a fluid signal. This is done by generating, cancelling or redirecting signals. DCV's are essentially categorized into three groups

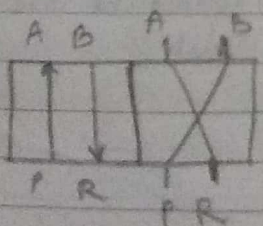
1) Signaling element
2) Processing element
3) Power elements or final control elements.



Hydraulic System



Pneumatic system



→ Figure shows operation of DCV.
→ There are four ports.
→ Ports A and B are the signal output ports as load is connected to these ports
→ The pressure port is labelled as P and the pressure (hydraulic or pneumatic) is supplied through this port.
→ The release port is labelled as R which ensures that the fluids are returned to tanks in hydraulic system whereas in case of pneumatic system, it is vented back to atmosphere.
→ In order to extend the piston forward P is connected to A
→ In order to retract the piston, P is connected to B.
→ The valve has 4 ports and two control positions and hence are called as 4 port and 2 piston valve (4/2 valve.)

Construction of Control Valves -

There are essentially three types of control valves

① Poppet valves - Ball seat type
- Disk seat type

② Slide valves or spool valves - longitudinal slide valve
- plate slide valve

③ Rotary valves.

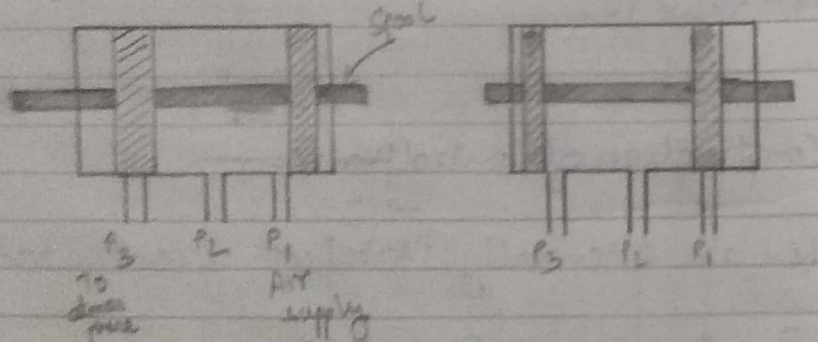
Directional Control Valves -

→ Both Pneumatic and Hydraulic systems use directional control valves to direct the flow of fluid through the system.

→ They are not intended to vary the rate of flow of fluid through a system but are either completely open or completely closed ie - on/off devices.

→ They are widely used to develop sequenced control systems

① Spool valve -



→ Most common type of directional control valve

→ A spool moves horizontally within the body to control the flow

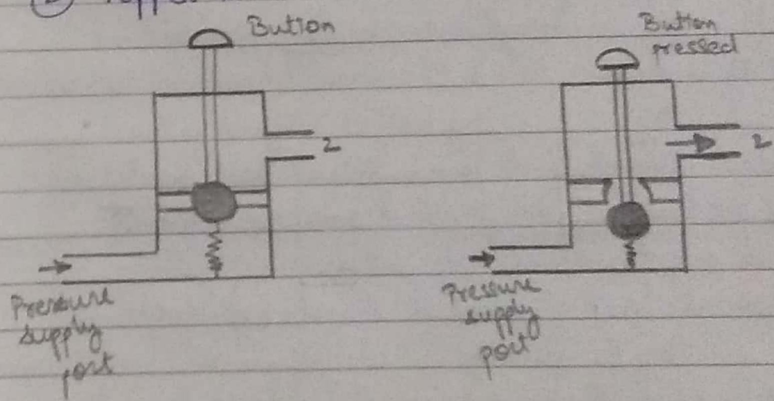
→ In position one, the air supply connected to port 1 is ON and port three is closed. So, the device connected to port 2 can be pressurised.

→ When the spool is moved to the left, the air supply is cut off and ports 2 & 3 are open. Port 3 is a vent to atmosphere and so the air pressure in the system attached to port 2 is vented.

→ Thus the movement of the spool allows the air firstly to flow into the system and then be reversed and flow out of the system.

→ Rotary spool valves have a rotating spool which, when it rotates, opens and closes ports in same way.

② Poppet valve -



→ Figure shows poppet valve.

→ The valve is normally in closed condition, there

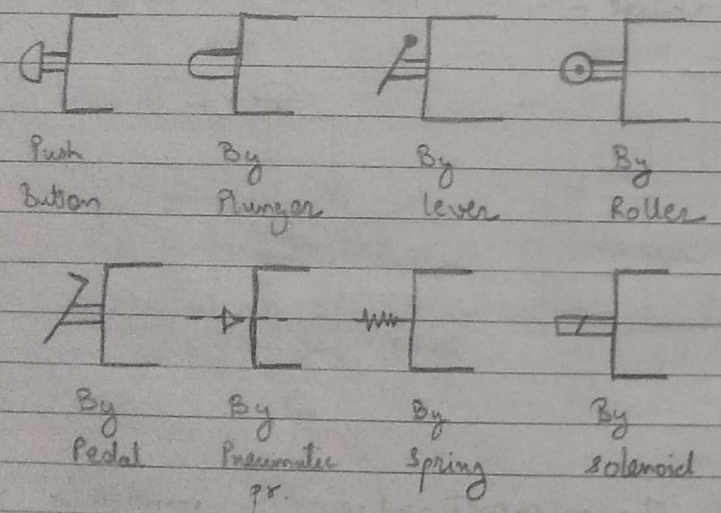
• being no connection between port 1 to which the pressure supply is connected and port 2 to which the system is connected.

→ In poppet valves, balls, discs or cones are used in conjunction with valve seats to control the flow.

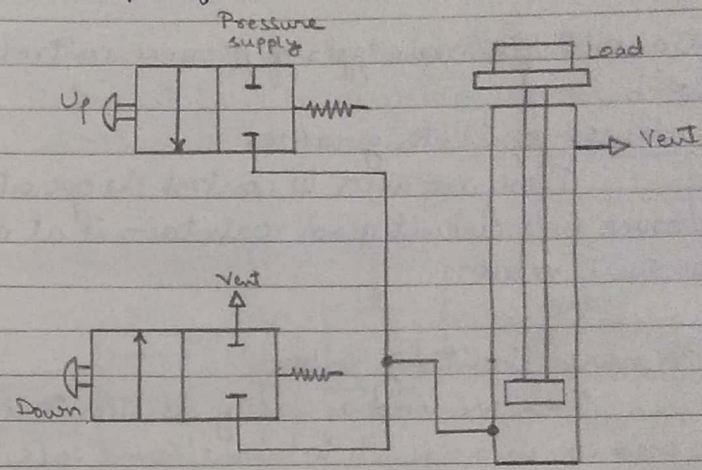
→ In figure, when the push button is pressed, the ball is pushed down and the flow occurs as a result of ports 1 & 2 being connected.

→ When the button is released, the spring forces the ball back up against its seat and so the flow is closed.

Valve Actuation Symbols.

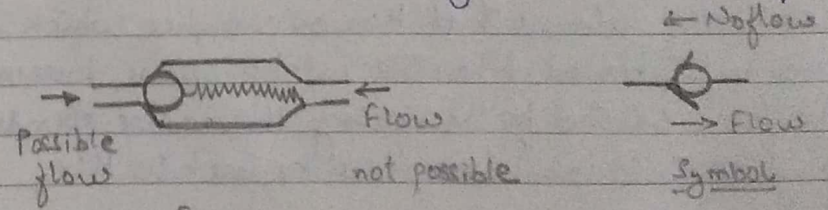


Example of an application of valves



- Figure shows a pneumatic lift system. Two push button 2/2 valves are used.
- When the button on the "UP" valve is pressed, the load is ~~shifted~~ lifted.
- When the button on the "DOWN" valve is pressed, the load is lowered.
- With pneumatic systems, an open arrow is used to indicate a vent to the atmosphere.

Directional valve - Figure shows a simple directional valve. Free flow can occure in only one direction through the valve.



Figure

PRESSURE CONTROL VALVES

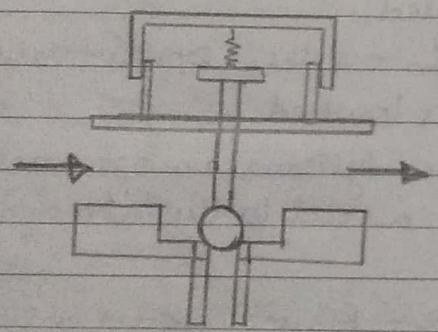
There are three main types of pressure control valves -

① Pressure - regulating valves

These are used to control the operating pressure in a circuit and maintain it at a constant value.

② Pressure limiting valves

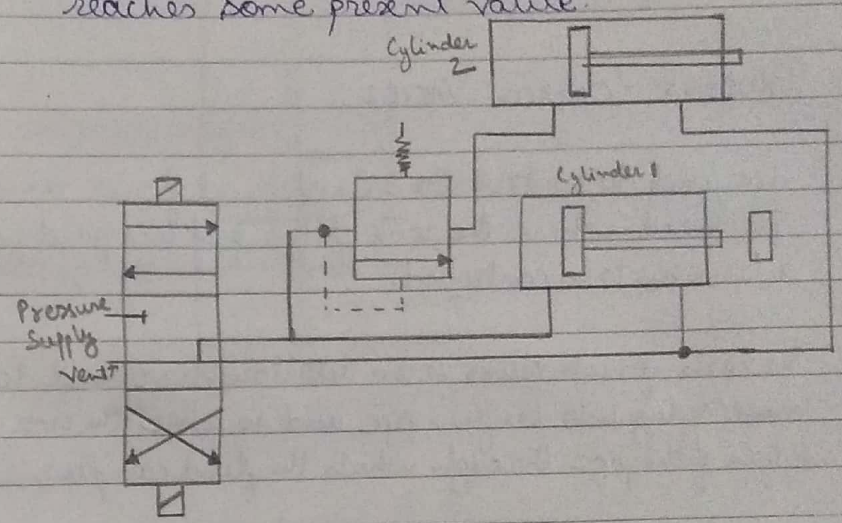
These are used as safety devices to limit the pressure in a circuit to below some safe value. The valve opens and vents to the atmosphere, or back to the sump, if the pressure rises above the set safe value. Figure shows a pressure limiting



or a relief valve which has one orifice which is normally closed. When the inlet pressure overcomes the force exerted by the spring, the valve opens and vents to the atmosphere, or back to the sump.

③ Pressure sequence valves -

- These are used to sense the pressure of an external line and give a signal when it reaches some present value.



- With the pressure limiting valve, the limiting pressure is set by the pressure at the inlet to the valve. Such type of valve can be used to give sequence.

- Figure shows a system where, when the 4/3 valve first operates, the pressure is applied to to cylinder 1 and its ram moves to the right. While this is happening the pressure is too low to operate the sequence valve and so no pressure is applied to cylinder 2.

- When the ram of cylinder 1 reaches the end stop, then the ~~system~~ pressure in the system rises and, at an appropriate level, triggers the sequence valve to open and so apply pressure to cylinder 2 to start its ram in motion.

PROCESS CONTROL VALVES

Are used to control the rate of fluid flow and are used where the rate of flow of a liquid into a tank has to be controlled.

The basis of such valves is an actuator being used to move a plug into the flow pipe and so alter the cross-section of the pipe through which the fluid can flow.

A common form of pneumatic actuator used with process control valves is the diaphragm actuator.

It consists of a diaphragm with the input pressure signal from the controller on one side and atmospheric pressure on the other, this pressure difference is termed as gauge pressure

The diaphragm is made of rubber which is sandwiched in its centre between two circular steel discs.

The effect of change in the input pressure is thus to move the central part of the diaphragm

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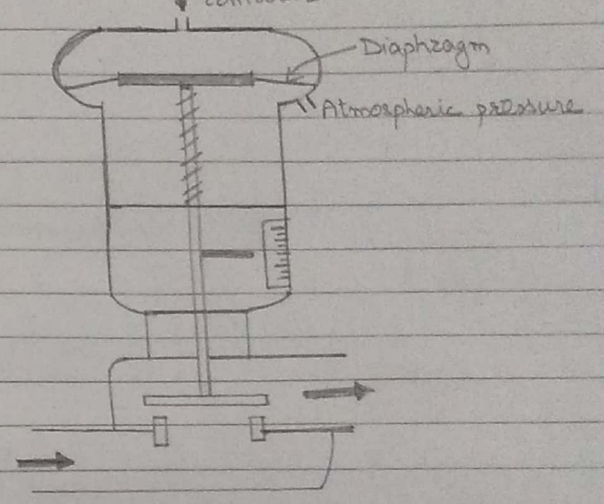
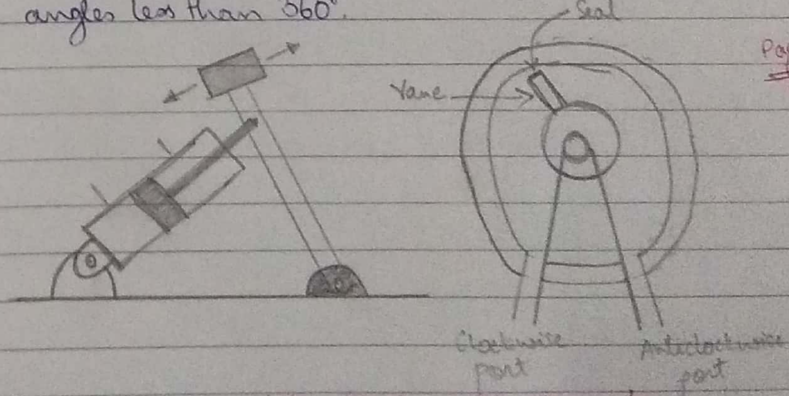


Rotary actuators -

A linear cylinder can, with suitable mechanical linkages, be used to produce rotary movement through angles less than 360°.



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Identification of Graphical symbols - Pg 253/ Ramchandran