Chapter 1 – Prerequisites

# 1.1 Sensors and actuators

Any complex system shall always use multiple number of sensors and actuators to receive inputs from the surrounding environment and then take necessary actions concerning the same. Following are a list of sensors and actuators (in that order) used in a fueling machine whose basic knowledge is prerequisite.

**Sensors**

1. **LVDT (Linear Variable Displacement Transducer):**

LVDTs are robust, absolute linear position/displacement transducers; inherently frictionless, they have a virtually infinite cycle life when properly used. As AC operated LVDTs do not contain any electronics, they can be designed to operate at cryogenic temperatures or up to 1200 °F (650 °C), in harsh environments, under high vibration and shock levels. LVDTs have been widely used in applications such as power turbines, hydraulics, automation, aircraft, satellites, nuclear reactors, and many others. These transducers have low hysteresis and excellent repeatability.

The LVDT converts a position or linear displacement from a mechanical reference (zero or null position) into a proportional electrical signal containing phase (for direction) and amplitude (for distance) information. The LVDT operation does not require an electrical contact between the moving part (probe or core assembly) and the coil assembly, but instead relies on electromagnetic coupling.

The linear variable differential transformer has three solenoidal coils placed end-to-end around a tube. The center coil is the primary, and the two outer coils at the top and bottom are secondary coils. A cylindrical ferromagnetic core, attached to the object whose position is to be measured, slides along the axis of the tube. An alternating current drives the primary and `causes a voltage to be induced in each secondary proportional to the length of the core linking to the secondary. The frequency is usually in the range 1 to 10 kHz.

As the core moves, the primary's linkage to the two secondary coils changes and causes the induced voltages to change. The coils are connected so that the output voltage is the difference (hence "differential") between the top secondary voltage and the bottom secondary voltage. When the core is in its central position, equidistant between the two secondary coils equal voltages are induced in the two secondary coils, but the two signals cancel, so the output voltage is theoretically zero. In practice minor variations in the way in which the primary is coupled to each secondary means that a small voltage is output when the core is central.

This small residual voltage is due to phase shift and is often called quadrature error. It is a nuisance in closed loop control systems as it can result in oscillation about the null point, and may be unacceptable in simple measurement applications too. It is a consequence of using synchronous demodulation, with direct subtraction of the secondary voltages at AC. Modern systems, particularly those involving safety, require fault detection of the LVDT, and the normal method is to demodulate each secondary separately, using precision half wave or full wave rectifiers, based on op-amps, and compute the difference by subtracting the DC signals. Because, for constant excitation voltage, the sum of the two secondary voltages is almost constant throughout the operating stroke of the LVDT, its value remains within a small window and can be monitored such that any internal failures of the LVDT will cause the sum voltage to deviate from its limits and be rapidly detected, causing a fault to be indicated. There is no quadrature error with this scheme, and the position-dependent difference voltage passes smoothly through zero at the null point.

Where digital processing in the form of a microprocessor or FPGA is available in the system, it is customary for the processing device to carry out the fault detection, and possibly ratiometric processing to improve accuracy, by dividing the difference in secondary voltages by the sum of the secondary voltages, to make the measurement independent of the exact amplitude of the excitation signal. If sufficient digital processing capacity is available, it is becoming commonplace to use this to generate the sinusoidal excitation via a DAC and possibly also perform the secondary demodulation via a multiplexed ADC.

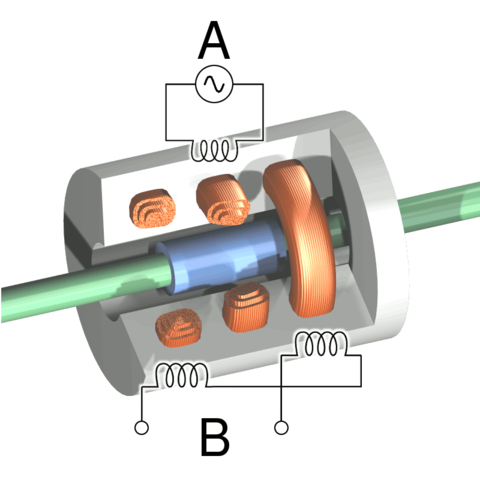
When the core is displaced toward the top, the voltage in the top secondary coil increases as the voltage in the bottom decreases. The resulting output voltage increases from zero. This voltage is in phase with the primary voltage. When the core moves in the other direction, the output voltage also increases from zero, but its phase is opposite to that of the primary. The phase of the output voltage determines the direction of the displacement (up or down) and amplitude indicates the amount of displacement. A synchronous detector can determine a signed output voltage that relates to the displacement.

The LVDT is designed with long slender coils to make the output voltage essentially linear over displacement up to several inches (several hundred millimeters) long.

The LVDT can be used as an absolute position sensor. Even if the power is switched off, on restarting it, the LVDT shows the same measurement, and no positional information is lost. Its biggest advantages are repeatability and reproducibility once it is properly configured. Also, apart from the uni-axial linear motion of the core, any other movements such as the rotation of the core around the axis will not affect its measurements.

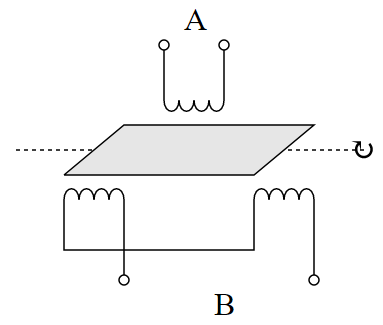
Because the sliding core does not touch the inside of the tube, it can move without friction, making the LVDT a highly reliable device. The absence of any sliding or rotating contacts allows the LVDT to be completely sealed against the environment.

LVDTs are commonly used for position feedback in servomechanisms, and for automated measurement in machine tools and many other industrial and scientific applications. Following is an illustration of the same.



**Figure 1.1.a – 1** Cutaway view of an LVDT

Following is another illustration of an RVDT, this time highlighting the coils in symbolic notations.



**Figure 1.1.a – 2** Principle of rotary variable differential transformer

1. **POT(Potentiometer):**

A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a variable resistor or rheostat. The measuring instrument called a potentiometer is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name. Potentiometers are commonly used to control electrical devices such as volume controls on audio equipment. Potentiometers operated by a mechanism can be used as position transducers, for example, in a joystick. Potentiometers are rarely used to directly control significant power (more than a watt), since the power dissipated in the potentiometer would be comparable to the power in the controlled load.

Potentiometers consist of a resistive element, a sliding contact (wiper) that moves along the element, making good electrical contact with one part of it, electrical terminals at each end of the element, a mechanism that moves the wiper from one end to the other, and a housing containing the element and wiper.

See drawing. Many inexpensive potentiometers are constructed with a resistive element (B) formed into an arc of a circle usually a little less than a full turn and a wiper (C) sliding on this element when rotated, making electrical contact. The resistive element can be flat or angled. Each end of the resistive element is connected to a terminal (E, G) on the case. The wiper is connected to a third terminal (F), usually between the other two. On panel potentiometers, the wiper is usually the center terminal of three. For single-turn potentiometers, this wiper typically travels just under one revolution around the contact. The only point of ingress for contamination is the narrow space between the shaft and the housing it rotates in.

Another type is the linear slider potentiometer, which has a wiper which slides along a linear element instead of rotating. Contamination can potentially enter anywhere along the slot the slider moves in, making effective sealing more difficult and compromising long-term reliability. An advantage of the slider potentiometer is that the slider position gives a visual indication of its setting. While the setting of a rotary potentiometer can be seen by the position of a marking on the knob, an array of sliders can give a visual impression of, for example, the effect of a multi-band equalizer (hence the term "graphic equalizer").

The resistive element of inexpensive potentiometers is often made of graphite. Other materials used include resistance wire, carbon particles in plastic, and a ceramic/metal mixture called cermet. Conductive track potentiometers use conductive polymer resistor pastes that contain hard-wearing resins and polymers, solvents, and lubricant, in addition to the carbon that provides the conductive properties.

Multiturn potentiometers are also operated by rotating a shaft, but by several turns rather than less than a full turn. Some multiturn potentiometers have a linear resistive element with a sliding contact moved by a lead screw; others have a helical resistive element and a wiper that turns through 10, 20, or more complete revolutions, moving along the helix as it rotates. Multiturn potentiometers, both user-accessible and preset, allow finer adjustments; rotation through the same angle changes the setting by typically a tenth as much as for a simple rotary potentiometer.

A string potentiometer is a multi-turn potentiometer operated by an attached reel of wire turning against a spring, enabling it to convert linear position to a variable resistance.

User-accessible rotary potentiometers can be fitted with a switch which operates usually at the anti-clockwise extreme of rotation. Before digital electronics became the norm such a component was used to allow radio and television receivers and other equipment to be switched on at minimum volume with an audible click, then the volume increased, by turning a knob. Multiple resistance elements can be ganged together with their sliding contacts on the same shaft, for example, in stereo audio amplifiers for volume control. In other applications, such as domestic light dimmers, the normal usage pattern is best satisfied if the potentiometer remains set at its current position, so the switch is operated by a push action, alternately on and off, by axial presses of the knob.

Others are enclosed within the equipment and are intended to be adjusted to calibrate equipment during manufacture or repair, and not otherwise touched. They are usually physically much smaller than user-accessible potentiometers, and may need to be operated by a screwdriver rather than having a knob. They are usually called "preset potentiometers" or "trimming pots". Some pre-sets are accessible by a small screwdriver poked through a hole in the case to allow servicing without dismantling.

Following is an illustration of a commonly used potentiometer in household appliances followed by its European electronic symbol



**Figure 1.1.b – 1** Potentiometer

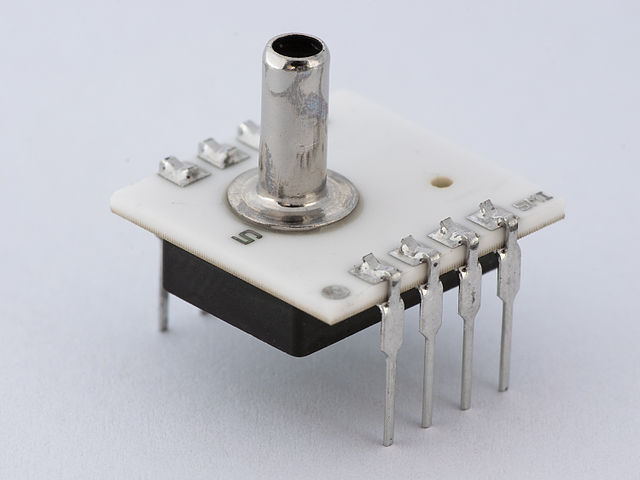
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**Figure 1.1.b - 2** Symbol for potentiometer (European)

1. **Pressure transducer/sensor/transmitter:**

A pressure transducer, often called a pressure transmitter, is a transducer that converts pressure into an analog electrical signal. Although there are various types of pressure transducers, one of the most common is the strain-gage base transducer. The conversion of pressure into an electrical signal is achieved by the physical deformation of strain gages which are bonded into the diaphragm of the pressure transducer and wired into a Wheatstone bridge configuration. Pressure applied to the pressure transducer produces a deflection of the diaphragm which introduces strain to the gages. The strain will produce an electrical resistance change proportional to the pressure.

Following is a digital pressure sensor chip



**Figure 1.1.c – 1** Digital air pressure sensor

**Differential pressure transmitter:**

There are already two answers. My humble opinion is that they miss the point.

Differential pressure Transmitter is used to measure flow of a liquid or a gas. To measure the difference between two pressures you require only two pressure gauges. Two measure flow in a pipe line where flow is happening you need to measure the pressure drop due to flow and hence a DP Transmitter is used.

They use the principle that there will be a pressure drop when a fluid passes through an orifice as when a restricted orifice is placed in a pipe line which is smaller than the pipe line the pressure upstream will be higher and immediately after the orifice downstream pressure will be lower due higher velocity. This is called differential pressure or called as Delta P. This is directly proportional to the flow rate. Thus the DP Transmitter will give a reading measuring the Delta P and a flow varies in a critical line from its set pressure an electrical signal is generated and set to a control valve to control the flow parameters to the Set Pressure and will adjust keeping process parameters.

This DP Transmitter enables constant control of flow or even reset the Set political from a remote location. This enables constant monitoring of a very critical parameter of a process.

Nowadays days we have corrialis meters which are even accurate that measure mass flow by using corrialis Principle very accurately capable measuring mass variation due to density variation or pressure variations. These are cen more precise and accurate leading to use in hazardous application in nuclear reactors, hazardous process requiring extreme precision and safety.

Following is an illustration of the same



**Figure 1.1.c – 2** A high performance differential pressure transmitter

1. **RTD (Resistance Temperature Detector):**

RTD stands for Resistance Temperature Detector. RTDs are sometimes referred to generally as resistance thermometers. The American Society for Testing and Materials (ASTM) has defined the term resistance thermometer as follows:

Resistance thermometer is a temperature-measuring device composed of a resistance thermometer element, internal connecting wires, a protective shell with or without means for mounting a connection head, or connecting wire or other fittings, or both.

An RTD is a temperature sensor which measures temperature using the principle that the resistance of a metal changes with temperature. In practice, an electrical current is transmitted through a piece of metal (the RTD element or resistor) located in proximity to the area where temperature is to be measured. The resistance value of the RTD element is then measured by an instrument. This resistance value is then correlated to temperature based upon the known resistance characteristics of the RTD element.

RTDs work on a basic correlation between metals and temperature. As the temperature of a metal increases, the metal's resistance to the flow of electricity increases. Similarly, as the temperature of the RTD resistance element increases, the electrical resistance, measured in ohms (Ω), increases. RTD elements are commonly specified according to their resistance in ohms at zero degrees Celsius. The most common RTD specification is 100 Ω, which means that at the RTD element should demonstrate 100 Ω of resistance.

Platinum is the most commonly used metal for RTD elements due to a number of factors, including its:

(1) Chemical inertness

(2) Nearly linear temperature versus resistance relationship,

(3) Temperature coefficient of resistance that is large enough to give readily measurable resistance changes with temperature and

(4) Stability (in that its temperature resistance does not drastically change with time).

Other metals that are less frequently used as the resistor elements in an RTD include nickel, copper and Balco.

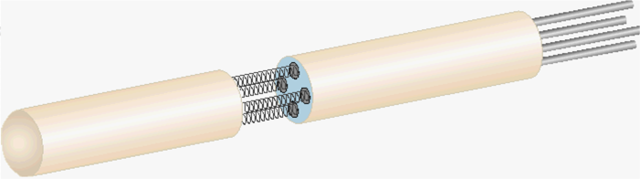
RTD elements are typically in one of three configurations:

(1) A platinum or metal glass slurry film deposited or screened onto a small flat ceramic substrate known as "thin film" RTD elements,

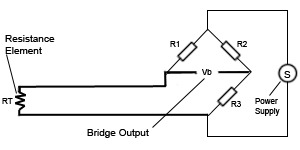
(2) Platinum or metal wire wound on a glass or ceramic bobbin and sealed with a coating of molten glass known as "wire wound" RTD elements.

(3) A partially supported wound element which is a small coil of wire inserted into a hole in a ceramic insulator and attached along one side of that hole. Of the three RTD elements, the thin film is most rugged and has become increasingly more accurate over time.

Following are the illustrations of a coil type RTD and a typical 2- wire configuration used in simple applications.



**Figure 1.1.d - 1** A coil element type PRT



**Figure 1.1.d – 2** An RTD constructed out of a 2 – wire configuration

1. **Ultra-sonic transducer:**

Ultrasonic transducers or ultrasonic sensors are a type of acoustic sensor divided into three broad categories: transmitters, receivers and transceivers. Transmitters convert electrical signals into ultrasound, receivers convert ultrasound into electrical signals, and transceivers can both transmit and receive ultrasound.

In a similar way to radar and sonar, ultrasonic transducers are used in systems which evaluate targets by interpreting the reflected signals. For example, by measuring the time between sending a signal and receiving an echo the distance of an object can be calculated. Passive ultrasonic sensors are basically microphones that detect ultrasonic noise that is present under certain conditions.

Ultrasonic probes and ultrasonic baths apply ultrasonic energy to agitate particles in a wide range of materials

Following is an illustration of a simple ultrasonic transducer



**Figure 1.1.e** Industry grade T30 ultrasonic transducer/sensor manufactured by Pyrotron India Inc.

**Actuators**

1. **Switches:**

In electrical engineering a limit switch is a switch operated by the motion of a machine part or presence of an object. They are used for controlling machinery as part of a control system, as a safety interlock system, or to count objects passing a point. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.

Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. They were first used to define the limit of travel of an object; hence the name "Limit Switch".

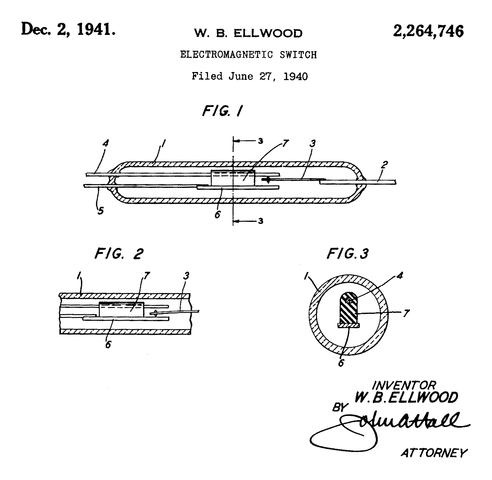
A limit switch with a roller-lever operator; this is installed on a gate on a canal lock, and indicates the position of a gate to a control system.

Standardized limit switches are industrial control components manufactured with a variety of operator types, including lever, roller plunger, and whisker type. Limit switches may be directly mechanically operated by the motion of the operating lever. A reed switch may be used to indicate proximity of a magnet mounted on some moving part. Proximity switches operate by the disturbance of an electromagnetic field, by capacitance, or by sensing a magnetic field.

Rarely, a final operating device such as a lamp or solenoid valve will be directly controlled by the contacts of an industrial limit switch, but more typically the limit switch will be wired through a control relay, a motor contactor control circuit, or as an input to a programmable logic controller.

Miniature snap-action switch may be used for example as components of such devices as photocopiers, computer printers, convertible tops or microwave ovens to ensure internal components are in the correct position for operation and to prevent operation when access doors are opened. A set of adjustable limit switches are installed on a garage door opener to shut off the motor when the door has reached the fully raised or fully lowered position. A numerical control machine such as a lathe will have limit switches to identify maximum limits for machine parts or to provide a known reference point.

Reed switch is a magnetic type switch which has been illustrated below



**Figure 1.1.f** Device shown in non-operated position Fig. 2 - device shown in operated position Fig. 3 - cross- section 1 - glass envelope 2 - terminal 3 - resilient magnetic member 4 - non-magnetic member 5 - conducting member 6 - magnetic member 7 - insulating p

1. **Commutator:**

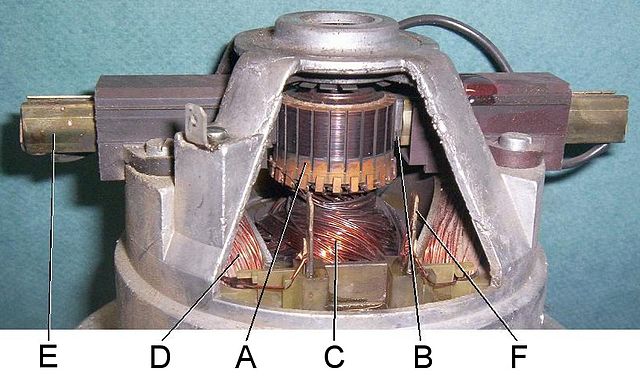
A commutator is a rotary electrical switch in certain types of electric motors and electrical generators that periodically reverses the current direction between the rotor and the external circuit. It consists of a cylinder composed of multiple metal contact segments on the rotating armature of the machine. Two or more electrical contacts called "brushes" made of a soft conductive material like carbon press against the commutator, making sliding contact with successive segments of the commutator as it rotates. The windings (coils of wire) on the armature are connected to the commutator segments.

Commutators are used in direct current (DC) machines: dynamos (DC generators) and many DC motors as well as universal motors. In a motor the commutator applies electric current to the windings. By reversing the current direction in the rotating windings each half turn, a steady rotating force (torque) is produced. In a generator the commutator picks off the current generated in the windings, reversing the direction of the current with each half turn, serving as a mechanical rectifier to convert the alternating current from the windings to unidirectional direct current in the external load circuit. The first direct current commutator-type machine, the dynamo, was built by Hippolyte Pixii in 1832, based on a suggestion by André-Marie Ampère.

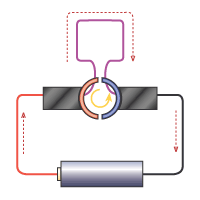
Commutators are relatively inefficient, and also require periodic maintenance such as brush replacement. Therefore, commutated machines are declining in use, being replaced by alternating current (AC) machines, and in recent years by brushless DC motors which use semiconductor switches.

A commutator consists of a set of contact bars fixed to the rotating shaft of a machine, and connected to the armature windings. As the shaft rotates, the commutator reverses the flow of current in a winding. For a single armature winding, when the shaft has made one-half complete turn, the winding is now connected so that current flows through it in the opposite of the initial direction. In a motor, the armature current causes the fixed magnetic field to exert a rotational force, or a torque, on the winding to make it turn. In a generator, the mechanical torque applied to the shaft maintains the motion of the armature winding through the stationary magnetic field, inducing a current in the winding. In both the motor and generator case, the commutator periodically reverses the direction of current flow through the winding so that current flow in the circuit external to the machine continues in only one direction.

Following is a cut away view of a universal commutator followed by a diagram illustrating the current flow in such a circuit



**Figure 1.1.g – 1** Commutator in a universal motor from a vacuum cleaner. Parts: (A) commutator, (B) brush, (C) rotor (armature) windings, (D) stator (F) (field) windings, (E) brush guides



**Figure 1.1.g – 2** Current flow in commutator ring

1. **MDV (Motorized Directional Valve)/Solenoid valve:**

A solenoid valve is an electromechanical device in which the solenoid uses an electric current to generate a magnetic field and thereby operate a mechanism which regulates the opening of fluid flow in a valve.

Solenoid valves differ in the characteristics of the electric current they use, the strength of the magnetic field they generate, the mechanism they use to regulate the fluid and the type and characteristics of fluid they control. The mechanism varies from linear action, plunger-type actuators to pivoted-armature actuators and rocker actuators. The valve can use a two-port design to regulate a flow or use a three or more port design to switch flows between ports. Multiple solenoid valves can be placed together on a manifold. Solenoid valves are the most frequently used control elements in fluidics. Their tasks are to shut off, release, dose, distribute or mix fluids. They are found in many application areas. Solenoids offer fast and safe switching, high reliability, long service life, good medium compatibility of the materials used, low control power and compact design. Here are many valve design variations. Ordinary valves can have many ports and fluid paths. A 2-way valve, for example, has 2 ports; if the valve is open, then the two ports are connected and fluid may flow between the ports; if the valve is closed, then ports are isolated. If the valve is open when the solenoid is not energized, then the valve is termed normally open (N.O.). Similarly, if the valve is closed when the solenoid is not energized, then the valve is termed normally closed. There is also 3-way and more complicated designs. A 3-way valve has 3 ports; it connects one port to either of the two other ports (typically a supply port and an exhaust port).

Solenoid valves are also characterized by how they operate. A small solenoid can generate a limited force. If that force is sufficient to open and close the valve, then a direct acting solenoid valve is possible. An approximate relationship between the required solenoid force Fs, the fluid pressure P, and the orifice area A for a direct acting solenoid valve is:

Where d is the orifice diameter. A typical solenoid force might be 15 N (3.4 lbf). An application might be a low pressure (e.g., 10 psi (69 kPa)) gas with a small orifice diameter (e.g., 3⁄8 in (9.5 mm) for an orifice area of 0.11 in2 (7.1×10−5 m2) and approximate force of 1.1 lbf (4.9 N)).

The solenoid valve (small black box at the top of the photo) with input airline (small green tube) used to actuate a larger rack and pinion actuator (gray box) which controls the water pipe valve.

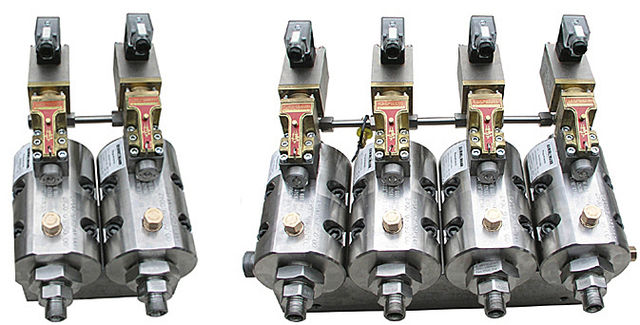
When high pressures and large orifices are encountered, then high forces are required. To generate those forces, an internally piloted solenoid valve design may be possible. In such a design, the line pressure is used to generate the high valve forces; a small solenoid controls how the line pressure is used. Internally piloted valves are used in dishwashers and irrigation systems where the fluid is water, the pressure might be 80 psi (550 kPa) and the orifice diameter might be 3⁄4 in (19 mm).

In some solenoid valves the solenoid acts directly on the main valve. Others use a small, complete solenoid valve, known as a pilot, to actuate a larger valve. While the second type is actually a solenoid valve combined with a pneumatically actuated valve, they are sold and packaged as a single unit referred to as a solenoid valve. Piloted valves require much less power to control, but they are noticeably slower. Piloted solenoids usually need full power at all times to open and stay open, where a direct acting solenoid may only need full power for a short period of time to open it, and only low power to hold it.

A direct acting solenoid valve typically operates in 5 to 10 milliseconds. The operation time of a piloted valve depends on its size; typical values are 15 to 150 milliseconds.

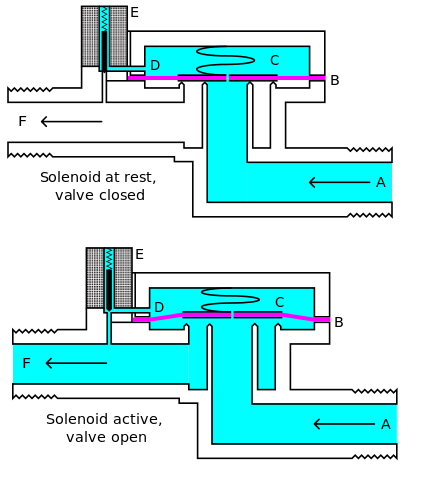
Power consumption and supply requirements of the solenoid vary with application, being primarily determined by fluid pressure and line diameter. For example, a popular 3/4" 150 psi sprinkler valve, intended for 24 VAC (50 - 60 Hz) residential systems, has a momentary inrush of 7.2 VA, and a holding power requirement of 4.6 VA. Comparatively, an industrial 1/2" 10000 psi valve, intended for 12, 24, or 120 VAC systems in high pressure fluid and cryogenic applications, has an inrush of 300 VA and a holding power of 22 VA. Neither valve lists a minimum pressure required to remain closed in the un-powered state.

Following is an illustration of a universal solenoid valve(s).



**Figure 1.1.h – 1** Solenoid valves

Following set of illustrations show typical SLV operation modes



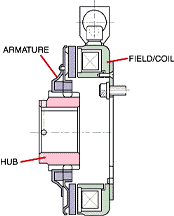
**Figure 1.1.h – 2** Two modes of operation of an SLV illustrating the necessary parts: A- Input Side B- Diaphragm C- Pressure Chamber D- Pressure relief passage E- Electro Mechanical Solenoid F- Output side

1. **EM BRAKE (Electromagnetic brake):**

Electromagnetic brakes (also called electro-mechanical brakes or EM brakes) slow or stop motion using electromagnetic force to apply mechanical resistance (friction). The original name was "electro-mechanical brakes" but over the years the name changed to "electromagnetic brakes", referring to their actuation method. Since becoming popular in the mid-20th century especially in trains and trams, the variety of applications and brake designs has increased dramatically, but the basic operation remains the same.

Both electromagnetic brakes and eddy current brakes use electromagnetic force but electromagnetic brakes ultimately depend on friction and eddy current brakes use magnetic force directly.

This is how a typical EM brake arrangement for a heavy RAM assembly looks like



**Figure 1.1.i** Electromagnetic brake (such assembly is used to constraint the vertical motion of the large RAM structure)