TECHNOCRATS ROBOTICS

VACATION TASKS

SET-4

Mosfet as a switch, Pneumatic solenoids

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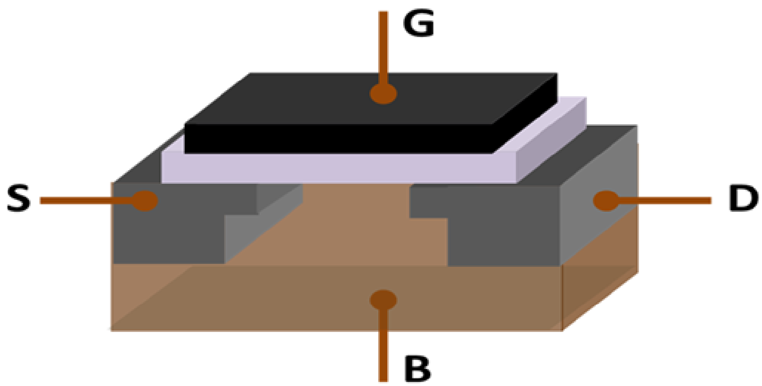
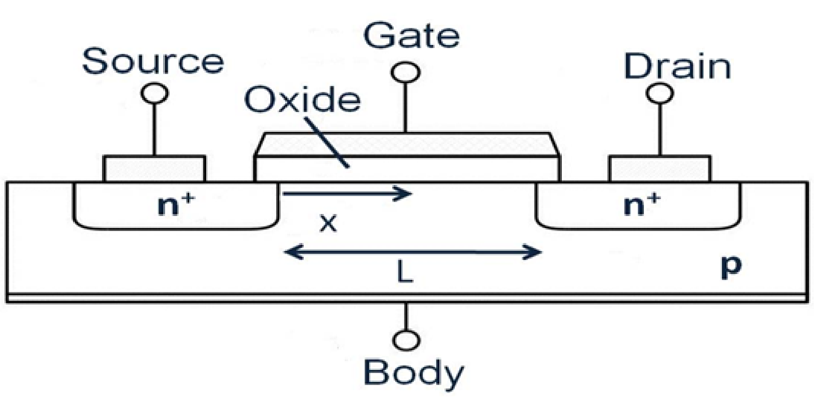
MOSFET

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and it can be designed and fabricated in a single chip because of these very small sizes. The MOSFET is a four terminal device with source(S), gate (G), drain (D) and body (B) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits.



The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity present in the device is the main part.



MOSFET as a Switch

MOSFETs exhibit three regions of operation viz., Cut-off, Linear or Ohmic and Saturation. Among these, when MOSFETs are to be used as amplifiers, they are required to be operated in their ohmic region wherein the current through the device increases with an increase in the applied voltage. On the other hand, when the MOSFETs are required to function as switches, they should be biased in such a way that they alter between cut-off and saturation states. This is because, in cut-off region, there is no current flow through the device while in saturation region there will be a constant amount of current flowing through the device, just mimicking the behaviour of an open and closed switch, respectively. This functionality of MOSFETs is exploited in many electronic circuits as they offer higher switching rates when compared to BJTs (bipolar junction transistors)

Figure 1 shows a simple circuit which uses an n-channel enhancement MOSFET as a switch. Here the drain terminal (D) of the MOSFET is connected to the supply voltage VS via the drain resistor RD while its source terminal (S) is grounded. Further, it has an input voltage Vi applied at its gate terminal (G) while the output Vo is drawn from its drain.

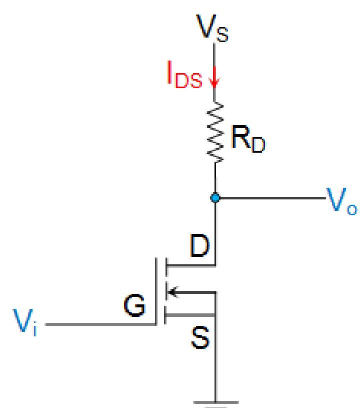
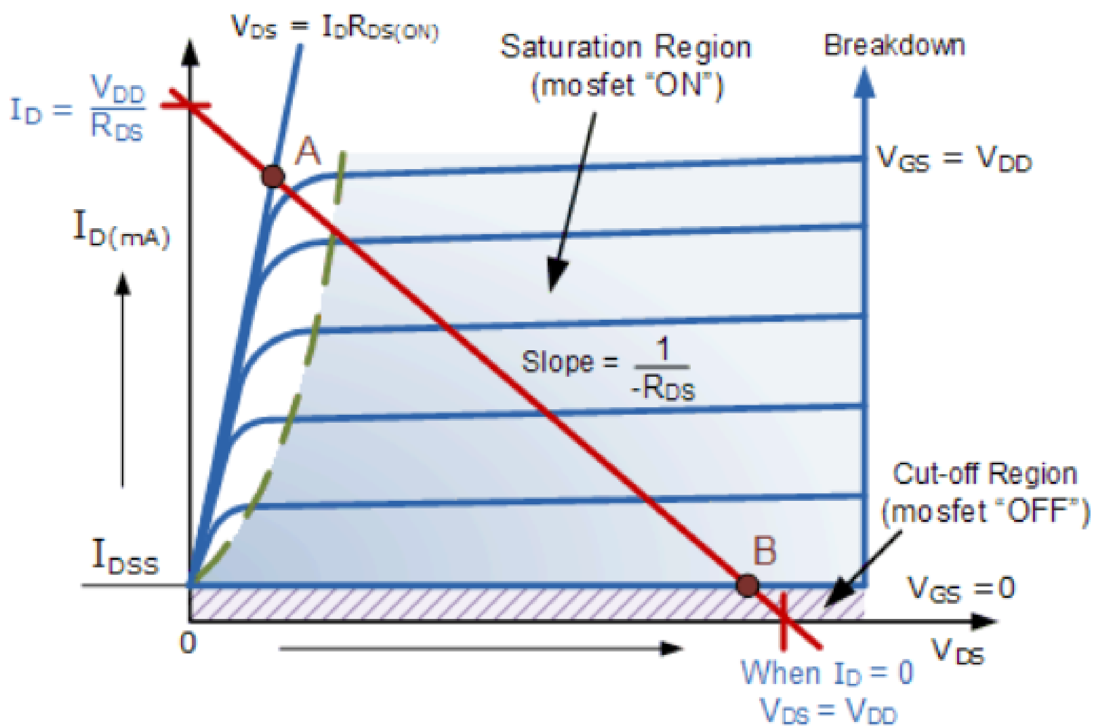


Figure 1 ***n*-Channel Enhancement-type MOSFET Functioning as a Switch**

Now consider the case where Vi applied is 0V, which means the gate terminal of the MOSFET is left unbiased. As a result, the MOSFET will be OFF and operates in its cutoff region wherein it offers a high impedance path to the flow of current which makes the IDS almost equivalent to zero. As a result, even the voltage drop across RD will become zero due to which the output voltage Vo will become almost equal to VS.
Next, consider the case where the input voltage Vi applied is greater than the threshold voltage VT of the device. Under this condition, the MOSFET will start to conduct and if the VS provided is greater than the pinch-off voltage VP of the device (usually it will be so), then the MOSFET starts to operate in its saturation region. This further means that the device will offer low resistance path for the flow of constant IDS, almost acting like a short circuit. As a result, the output voltage will be pulled towards low voltage level, which will be ideally zero.



From the discussion presented, it is evident that the output voltage alters between VS and zero depending on whether the input provided is less than or greater than VT, respectively. Thus, it can be concluded that MOSFETs can be made to function as electronic switches when made to operate between cut-off and saturation operating regions.

Similar to the case of n-channel enhancement type MOSFET, even n-channel depletion type MOSFETs can be used to perform switching action as shown by Figure 2. The behaviour of such a circuit is seen to be almost identical to that explained above except the fact that for cut-off, the gate voltage VG needs to be made negative and should be lesser than -VT.

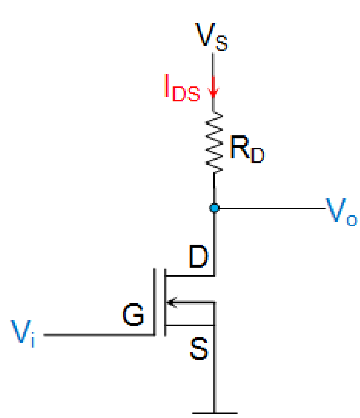


Figure 2 ***n*-Channel Depletion-type MOSFET Functioning as a Switch**

Next, Figure 3 shows the case wherein the p-channel enhancement MOSFET is used as a switch. Here it is seen that the supply voltage VS is applied at its source terminal (S) and the gate terminal is provided with the input voltage Vi while the drain terminal is grounded via the resistor RD. Further the output of the circuit Vo is obtained across RD, from the drain terminal of the MOSFET.
In the case of p-type devices the conduction current will be due to holes and will thus flow from source to drain ISD, and not from drain to source (IDS) as in the case of n-type devices. Now, let us assume that the input voltage which is nothing but the gate voltage VG of the MOSFET goes low. This causes the MOSFET to switch ON and to offer a low (almost negligible) resistance path to the current flow. As a result heavy current flows through the device which results in a large voltage drop across the resistor RD. This inturn results in the output which is almost equal to the supply voltage VS.

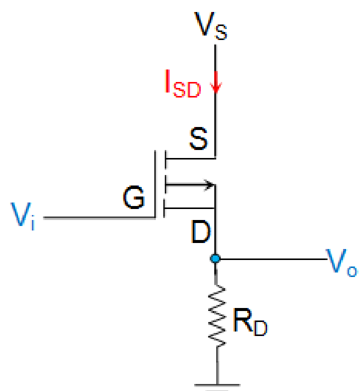


Figure 3 ***p*-Channel Enhancement-type MOSFET Functioning as a Switch**

Next, consider the case where Vi goes high i.e. when Vi will be greater than the threshold voltage of the device (VT will be negative for these devices). Under this condition, the MOSFET will be OFF and offers a high impedance path for the current flow. This results in almost zero current leading to almost zero voltage at the output terminal.

Similar to this, even p-channel depletion-type MOSFETs can be used to perform switching action as shown by Figure 4. The working of this circuit is almost similar to the one explained above except for the fact that here the cut-off region is experienced only if Vi = VG is made positive such that it exceeds the threshold voltage of the device.

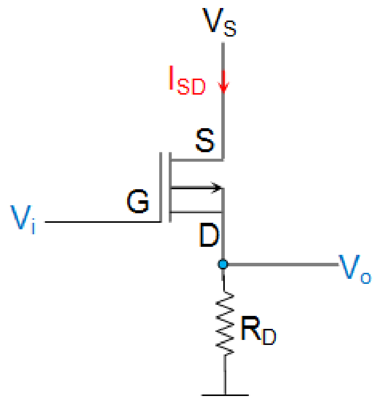


Figure 4 ***p*-Channel Depletion-type MOSFET Functioning as a Switch**

The table presented below summarizes the discussion presented above.

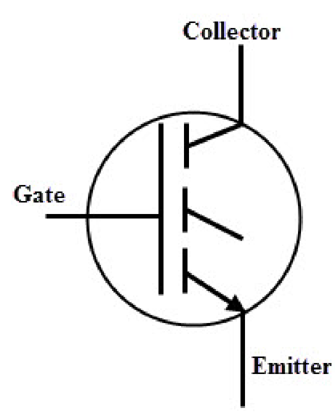
MOSFET type	State of the device	
	ON	OFF
n-Channel Enhancement-type	$V_i > V_T$	$V_i < V_T$
n-Channel Depletion-type	$V_i > -V_T$	$V_i < -V_T$
p-Channel Enhancement-type	$V_i < -V_T$	$V_i > -V_T$
p-Channel Depletion-type	$V_i < V_T$	$V_i > V_T$

Alternatives to MOSFET

IGBT

IGBT (Insulated Gate Bipolar Transistor) combines the several advantages of bipolar junction power transistor and power MOSFET. Like a MOSFET, it is a voltage controlled device and has lower ON state voltage drop (less than that of MOSFET and closer to power transistor).

It is a three terminal semiconductor high speed switching device. These terminals are emitter, collector and gate.

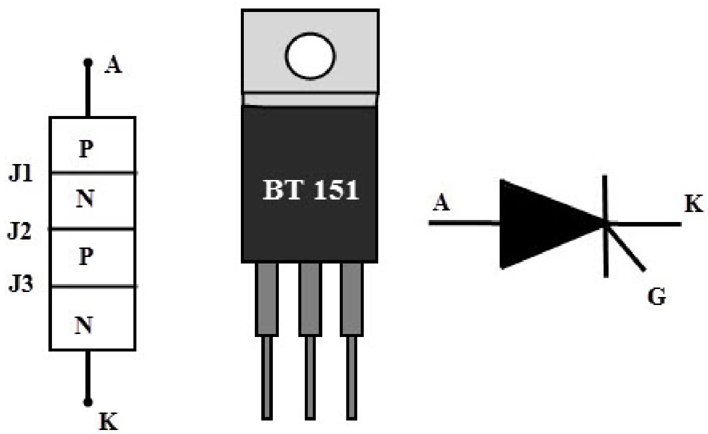


Similar to the MOSFET, IGBT can be turned ON by applying a positive voltage (greater than the threshold voltage) between the gate and emitter. IGBT can be turned by reducing the voltage across the gate-emitter to zero. In most of the case it needs negative voltage to reduce turn OFF losses and safely turn OFF the IGBT.

SCR

A Silicon Controlled Rectifier (SCR) most widely used high speed switching device for power control applications. It is a unidirectional device as a diode, consisting of three terminals, namely anode, cathode and gate.

An SCR is turned ON and OFF by controlling its gate input and biasing conditions of the anode and cathode terminals. SCR consists of four layers of alternate P and N layers such that boundaries of each layer forms junctions J1, J2 and J3.

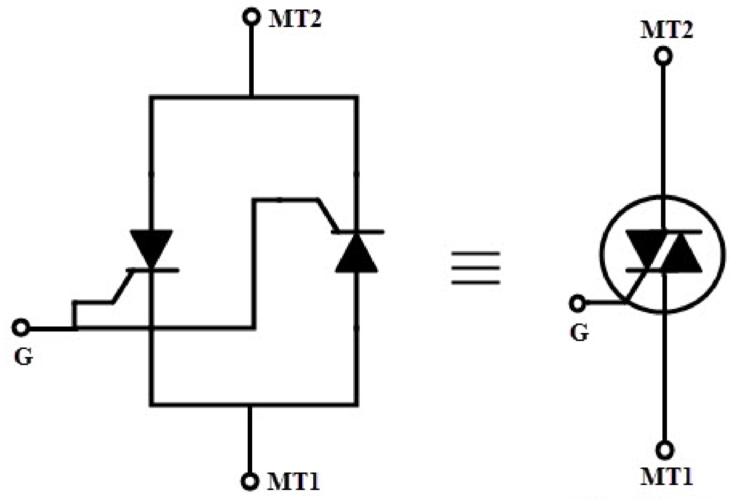


Silicon Controlled Rectifier (SCR)

TRIAC

Triac (or TRIode AC) switch is a bidirectional switching device which is an equivalent circuit of two back to back SCRs connection with one gate terminal.

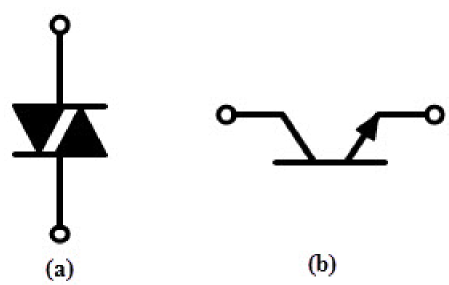
Its capability to control AC power in both positive and negative peaks of the voltage waveform often makes these devices to be used in motor speed controllers, light dimmers, pressure control systems, motor drives and other AC control equipment.



Two Thyristor Analogy Circuit Symbol

DIAC

A DIAC (or Diode AC switch) is bidirectional switching device and it consists of two terminals which are not named as anode and cathode. It means that a DIAC can be operated in either direction regardless of the terminal identification. This indicates that the DIAC can be used in either direction.



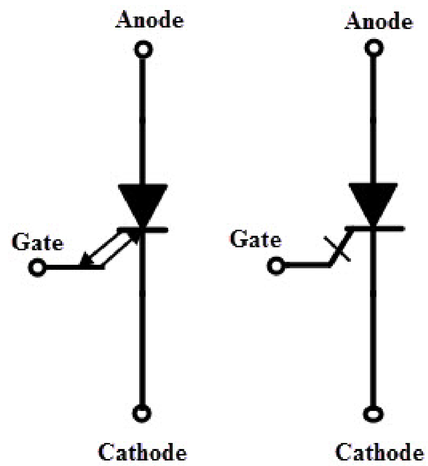
Symbols Used for DIAC

When a voltage is applied
across a DIAC, it either operates in forward blocking or reverse blocking mode unless the applied voltage is less than the breakover voltage. Once the voltage is increased more than breakover voltage, avalanche breakover occurs and device starts conducting.

Gate Turn-Off Thyristor

A GTO (Gate Turn off Thyristor) is a bipolar semiconductor switching device. It has three terminals as anode, cathode and gate. As the name implies, this switching device is capable to turn OFF through gate terminal.

A GTO is turned ON by applying a small positive gate current triggers the conduction mode and turned OFF by a negative pulse to the gate. GTO symbol consists of double arrows on the gate terminal which represents the bidirectional flow of current through gate terminal.



Gate Turn-Off Thyristor Symbols

Pneumatic Solenoids

The term solenoid usually refers to a coil used to create magnetic fields when wrapped around a magnetic object or core. In engineering terms, the solenoid describes transducer mechanisms used to convert energy into motion. Solenoid valves are controlled by the action of the solenoid and typically control the flow of water or air as a switch. If the solenoid is active (current is applied), it opens the valve. If the solenoid is inactive (current does not exist), the valve stays closed. The action of the pneumatic solenoid is controlled by the use of pneumatics. The opening or closing of a valve is referred to as “changing state.”

Working

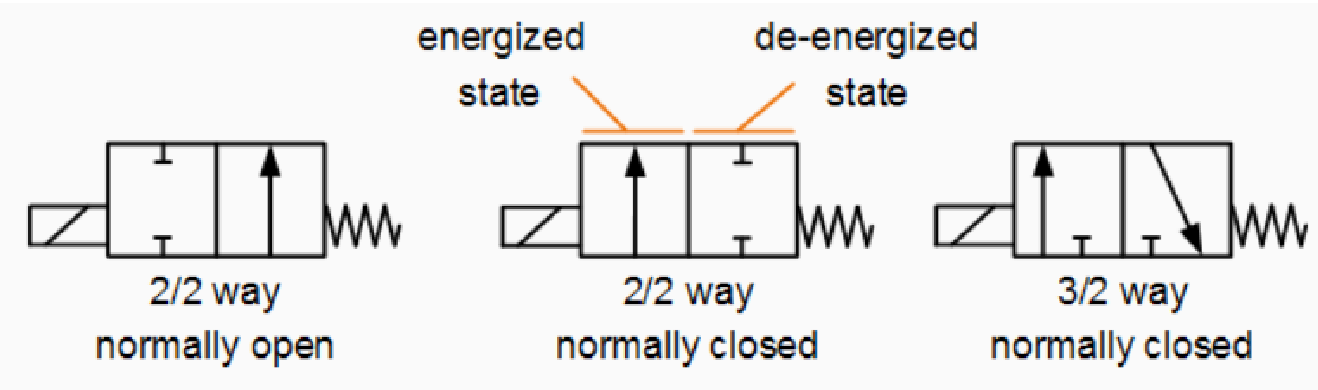
A solenoid valve is an electromechanical controlled valve. The valve features a solenoid, which is an electric coil with a movable ferromagnetic core in its centre. This core is called the plunger. In rest position, the plunger closes off a small orifice. An electric current through the coil creates a magnetic field. The magnetic field exerts a force on the plunger. As a result, the plunger is pulled toward the centre of the coil so that the orifice opens. This is the basic principle that is used to open and close solenoid valves.

Solenoid valves are amongst the most used components in gas and liquid circuits. The number of applications is almost endless. Some examples of the use of solenoid valves include heating systems, compressed air technology, industrial automation, swimming pools, sprinkler systems, washing machines, dental equipment, car wash systems and irrigation systems.

Circuit functions of solenoid valves

Solenoid valves are used to close, dose, distribute or mix the flow of gas or liquid in a pipe. The specific purpose of a solenoid valve is expressed by its circuit function. A 2/2 way valve has two ports (inlet and outlet) and two positions (open or closed). A 2/2 way valve can be 'normally closed' (closed in de-energized state) or 'normally open' (open in de-energized state). A 3/2 way valve has three ports and two positions and can therefore switch between two circuits. 3/2 way valves can have different functions such as normally closed, normally open, diverting or universal.

More ports or combinations of valves in a single construction are possible. The circuit function can be expressed in a symbol. Below are some examples of the most common circuit functions. The circuit function of a valve is symbolized in two rectangular boxes for the de-energized state (right side, visualized by) and energized state (left). The arrows in the box show the flow direction between the valve ports. The examples show a 2/2-way Normally Open (NO) valve, a 2/2-way Normally Closed (NC) valve and a 3/2-way Normally Closed valve.

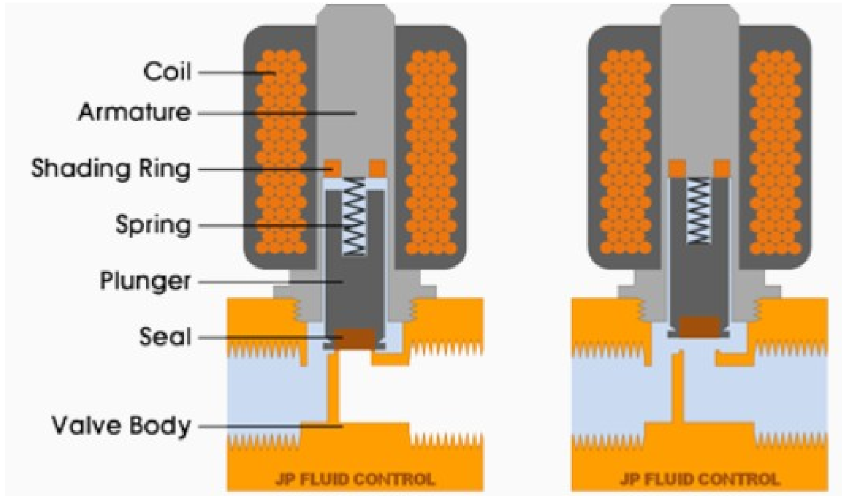


Type of operation

Solenoid valves can be categorized into different groups of operation.

Direct operated

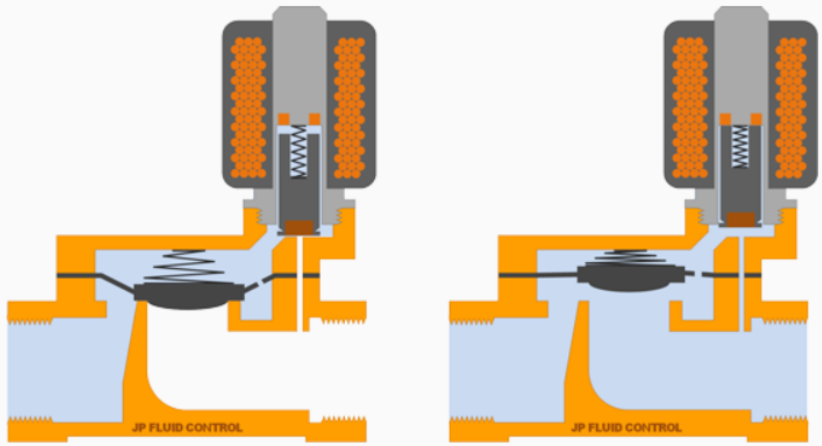
Direct operated (direct acting) solenoid valves have the most simple working principle. The medium flows through a small orifice which can be closed off by a plunger with a rubber gasket on the bottom. A small spring holds the plunger down to close the valve. The plunger is made of a ferromagnetic material. An electric coil is positioned around the plunger. As soon as the coil is electrical energized, a magnetic field is created which pulls the plunger up towards the centre of the coil. This opens the orifice so that the medium can flow through. This is called a Normally Closed (NC) valve. A Normally Open (NO) valve works the opposite way: it has a different construction so that the orifice is open when the solenoid is not powered. When the solenoid is actuated, the orifice will be closed. The maximum operating pressure and the flow rate are directly related to the orifice diameter and the magnetic force of the solenoid valve. This principle is therefore used for relatively small flow rates. Direct operated solenoid valves require no minimum operating pressure or pressure difference, so they can be used from 0 bar up to the maximum allowable pressure. The displayed solenoid valve is a direct operated, normally closed 2/2 way valve.



Schematical representation of a direct operated solenoid valve (2/2-way, normally closed).

Indirect operated (servo or pilot operated)

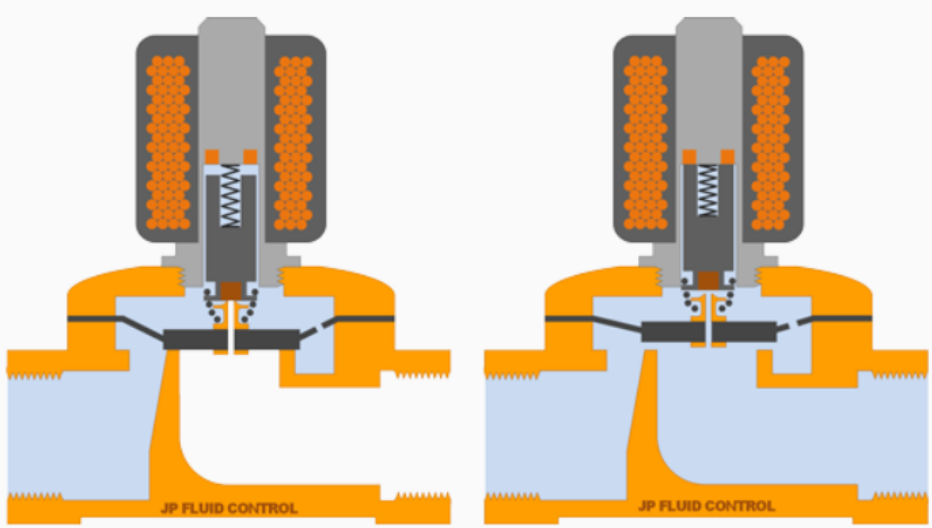
Indirect operated solenoid valves (also called servo operated, or pilot operated) use the differential pressure of the medium over the valve ports to open and close. Usually these valves need a minimum pressure differential of around 0.5 bar. The inlet and outlet are separated by a rubber membrane, also called diaphragm. The membrane has a small hole so that the medium can flow to the upper compartment. The pressure and supporting spring above the membrane will ensure that the valve remains closed. The chamber above the membrane is connected by a small channel to the low pressure port. This connection is blocked in the closed position by a solenoid. The diameter of this "pilot" orifice is larger than the diameter of the hole in the membrane. When the solenoid is energized, the pilot orifice is opened, which causes the pressure above the membrane to drop. Because of the pressure difference on both sides of the membrane, the membrane will be lifted and the medium can flow from inlet port to outlet port. The extra pressure chamber above the membrane acts like an amplifier, so with a small solenoid still a large flow rate can be controlled. Indirect solenoid valves can be used only for one flow direction. Indirect operated solenoid valves are used in applications with a sufficient pressure differential and a high desired flow rate, such as for example irrigation systems, showers or car wash systems. Indirect valves are also known as servo controlled valves.



Schematical representation of an indirect operated solenoid valve (2/2-way, normally closed).

Semi-direct operated

Semi-direct operated solenoid valves combine the properties of direct and indirect valves. This allows them to work from zero bar, but still they can handle a high flow rate. They look somewhat like indirect valves and also feature a movable membrane with a small orifice and pressure chambers on both sides. The difference is that the solenoid plunger is directly connected to the membrane. When the plunger is lifted, it directly lifts the membrane to open the valve. At the same time, a second orifice is opened by the plunger that has a slightly larger diameter than the first orifice in the membrane. This causes the pressure in the chamber above the membrane to drop. As a result, the membrane is lifted not only by the plunger, but also by the pressure difference. This combination results in a valve that operates from zero bar, and can control relatively large flow rates. Often, semi-direct operated valves have more powerful coils than indirect operated valves. Semi-direct operated valves are sometimes called assisted-lift solenoid valves.



Schematical representation of a semi-direct operated solenoid valve (2/2-way, normally closed).