VALVES FOR INDUSTRIAL APPLICATIONS

CONTENT

1. Introduction

Valves are integral components in piping systems they are the primary method of controlling the flow, pressure, and direction of the fluid. Valves may be required to operate continuously e.g. control valves, or they may be operated intermittently e.g. isolation valves, or they may be installed to operate rarely if ever e.g. safety valves. A valve can be an extremely simple, low cost item or it may be and extremely complicated, expensive item. In piping design, the valves probably require more engineering effort than any other piping component.

In this paper are considered only the valves used in the heavy industry, like oil &gas, mining, chemical, power, and similar industries. Valves for water distribution and for home uses and valves made of plastic materials are not considered.

2. Valves classification

2.1 Isolation and on-off valves

The isolation of the downstream system by use of an isolation valve is a critically important function. The prime requirements of this valve are tight shut off when closed and minimum restriction to flow when open.

Valves used for this function are ball, gate, globe, plug, butterfly, diaphragm, and pinch valves.
The most recommended type for this application is ball valves

2.2 Flow control

Many applications require the flow of the fluid be regulated (throttled) at some fixed or variable level between fully zero and maximum flow limits. This is achieved by introducing resistance to flow, or by bypassing flow or by changing the direction of the flow. An important feature for control valves is that the output variable (flow) is related to the input variable by the valve position. An ideal operating characteristic of a flow control valve is that the flow is directly proportional to the opening of the valve.

Valve types for this function include globe, needle, ball with segmented ball design, butterfly. Globe and needle valves are best suited for this duty, but ball valves are also easily adapted to give reliable flow control.

2.3 Back flow prevention – check valves

In some circumstances it is important to prevent reversed fluid flow. The type of valve for this duty is a non-return-valve (NRV) or check valve. The important criteria when selecting these valves are, tight shut off against reverse flow, low resistance to flow for forward flow, fast response. The valve can be operated to close by gravity, fluid flow or spring.
The main types for this function are swing, spring, ball, or swivel check valves.

2.4 Pressure regulation

In many applications, generally associated with gases, there is a need to reduce the supply pressure to a set fixed value. It is also necessary to maintain this reduced pressure over a range of fluid flow conditions. There are several conditions of the flow at these fluids, so that the valves are specifically engineered for each application. The valve is basically a globe valve biased open by an adjustable spring force with the feedback pressure tending to move the valve to a closed position such that at the set pressure the feedback pressure force just exceeds the spring force.

The pressure regulator valve operates using the downstream fluid pressure as feedback. This is mostly taken from within the valve (self-acting). For more accurate control a feedback connection can be taken from the downstream piping.

The pressure regulation at low near zero flows is difficult and it is often necessary to include internal or external relief valve functions to ensure that high pressures cannot reach the downstream system.

2.5 Pressure relief valves- Safety valves

A very important valve for safety is the pressure relief valve. This valve is used in applications where excessive pressure in the system can cause damage or failure or can introduce a safety risk. Uncontrolled excessive pressures can result in disastrous accidents e.g. when potentially explosive gases are being controlled. Relief valves are mainly spring loaded, but they can also be gravity operated and other more specialized designs are available.

The bursting / rupture disc must be included under the general heading of safety valves. This is simply a disc which ruptures when a set pressure is exceeded. The fluid then escapes through the ruptured disc. If the bursting disc operates the system has be closed down and vented and the bursting disc is then replaced

Relief valves when used for safety applications are engineered in line with safety regulations and require regular inspections to confirm the settings and the operation. An important part of the relief valve installation is the routing of the relieved fluid. This pipe route must be to a safe location and must be engineered such that it is always fully open.

2.6 Special valves

There are a wide variety of special valves developed for specific industries, an example are scrapper valves, which are modified ball valves to permit the access to the pipe of pigs through a door.

3. Fluid properties and operation conditions

The properties of the fluid to be controlled has a major impact on the design and materials of construction of the valve. The piping industry, over the years, has developed a wide range of valve designs and material to handle virtually all the fluids being handled. The selection of the valve should consider fluid flowrate, temperature, pressure, viscosity, density, and composition, e.g. content of solid material (if present), mixtures of gas/liquid, etc. The valve must be suitable to withstand resulting corrosion and erosion and if necessary, the valve may have to be design for no internal hold up of fluids.

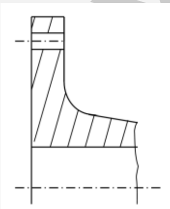
Important considerations include:

- Internal and external leak tightness specially when handling toxic or explosive fluids, and in general to prevent environmental effects of leakages to the ambient.
- Fire safety design to maintain its internal and external integrity when the valve is surrounded by flames from a fire.
- Stem anti blow out design that prevents that the stem cannot be expulsed from the valve body in case of internal overpressure.
- Antistatic design, with which it is assured that all components of the valve are electrically interconnected, so that no static electricity can produce a spark.

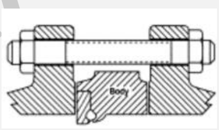
4. Connection to the pipeline

There are several methods of connecting valves into the piping systems:

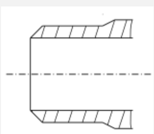
- Flanges: the valve ends have suitable rated flanges in different shapes.
- Wafer: the valve is provided with suitable sealing faces and is trapped between line flanges.
- Butt Weld: the valve ends are machined for butt welding into the piping system
- Socket Weld: the valve ends are machined to allow the installation in sockets on the pipe.
- Threaded: the valve ends with female or male screwed ends according to different standards.
- Compression Fittings (Clamp): valve ends can be provided with compression fittings, mainly used for sanitary connections



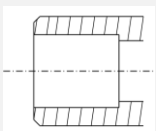
Flanges



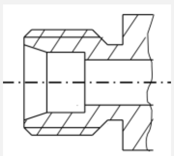
Wafer



Butt Weld (BW)



Socket Weld (SW)



Threaded

Tweezers

5. Hermeticity of the body

An important requirement in valve design is to minimize the leakage of fluids into the surrounding environment. This is very important in the nuclear industry and when transferring toxic or flammable fluids. The possible leakage points on valves are:

- The end connections with the piping.
- The operating stem gland seals - allowing axial and rotary motion.
- For top entry valves the sealed top closure joint
- For two or three piece side entry ball valves - the split joints
- Drain and vent connections

The best option for minimizing risk of leakage from the pipe connections is to use welded joints which can be verified by non-destructive-testing (NDT). This option obviously eliminates the valve types which must be removed for maintenance.

Stem package leakage can be minimized by using appropriate sealing elements. The risk can also be reduced by incorporating dual seals with a test point between. At pinch valves and diaphragm valves the fluid is not in contact with the stem and therefore there is no risk of gland leakage.
At valves which are used in hazardous areas, a double seal is imperative, at the stem packing and at the body joints, one of the seals must be of graphite which resist the temperatures during a fire.

6. Flow factors

It is clear, that different sized valves have different flow rate capacities and it is very important to be able to assess the flow through a valve for a fluid at certain conditions. The flow characteristics for an on-off valve are fixed and can be evaluated directly using the relevant flow factor. The flow through flow control valves, relief valves, pressure reducing valves and check valves depend on the operating condition for the valve and require a more detailed evaluation.

The most general method of identifying the flow capacity of a valve is the Cv or KV Factor.

The Cv factor is based on American Imperial units and is defined as follows:
Cv = The flow of water through a valve at 60°F in US gallon/minute at a pressure drop of 1 lb/in^2

The metric flow factor (KV) is used throughout outside of America and is defined as follows:
KV = the flow of water through a valve at 20°C in m3/hr with a pressure drop of 1 bar

The conversion between the two factors is KV = 0.865 Cv

The KV valve can also be defined with following units:
k v = the flow of water through a valve at 20°C in **liters/min** with a pressure drop of 1 bar
The conversion between KV and Cv using these units is KV = 14.42 Cv

6.1 Flow of liquids

To establish the flow (Q) in liters /min. at a differential pressure (Δp) in bar for a liquid with a specific gravity relative to water (γw).

$$Q = KV \times \sqrt{\frac{\Delta P}{\gamma_w}}$$

Note: This relationship only applies for liquids like water at reasonable flows (sub-sonic).

6.2 Flow of gas

For gases and supersonic flows more complicated formulas are required

The formula below must be used only for thumb estimates. The assumption that the critical ΔP is at $P_1/2$ does not hold for all valves. For accurate flow calculations the valve manufacturers data sheets must be used.

For gases flowing at sub-sonic velocities the following relationship holds.

$$\text{For } \Delta P < \frac{P_1}{2} \ \ldots \ Q_n = 457 \times KV \times P_1 \times \left(1 - \frac{2\,\Delta P}{3\,P_1}\right) \times \sqrt{\frac{\Delta P}{P1 \times \gamma a \times T_1}} \quad \text{in normalized liters/min}$$

Where

T1 = Inlet gas temperature in °K = °C + 273

γa =Gas specific gravity relative to air

Q_n = gas flow at normal conditions

P1 = Inlet Pressure (absolute)

For gases flowing at super-sonic velocities the following relationship holds

$$\text{For } \Delta P > \frac{P_1}{2} \ \ldots. \ Q_n = 215 \times KV \times \frac{P_1}{\sqrt{\gamma a \times T_1}} \quad \text{in normalized liters / min}$$

Gas reference conditions are:

Normal conditions: P=1013.25 mbar and T=273.15 K (0°C)

Standard conditions: P=1013.25 mbar and T=288.75K (15°C)

7. Calculation of the diameter of pipes

To estimate the optimal diameter of a pipe, and correspondingly the valve the following formula can be used to get an approximate value:

$$d = \sqrt{(4Q / \pi \times W)}$$

Where
Q: flow in m^3/sec.
D: diameter of the pipe in meter
W: flow speed in m/sec

As flow speed the following values can be used as reference:

For liquids	for natural gradient	
	viscous liquids	0,1 up to 0,5 m/sec
	Non viscous liquids	0,5 up to 1 m /sec
	For pressurized lines	
	Inlet of pumps	0,8 up to 2 m/sec
	Output of pumps	1,5 up to 3 m/sec
For gases	low pressure (fans)	4 up to 15 m/sec
	High pressure	15 up to 25 m/sec
For steam	Saturated steam	30 up to 50 m/sec
	Superheated steam	15 up to 75 m/sec (depending on the pressure)

8. Types of valves

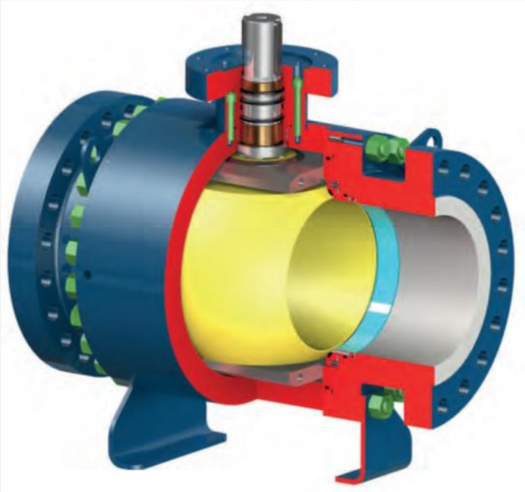
8.1 Ball valves

The ball valve is basically a plug valve with a spherical plug and a round hole. The materials of construction of the ball valve have been developed such that the ball valve is becoming the most popular valve for most process applications. The valve is a quarter turn valve.
There are two primary options for the ball valve design

- Floating Ball Design - This is low cost option for the lower duties
- Trunnion Ball Design - This is a more costly option for the higher duties

The ball valve can be provided in a full-bore version, in which the internal diameter of the valve is identical to the internal diameter of the pipe. In this design the pass of scrappers to clean the pipes is possible (pigable design). They can also be provided in a reduced bore design allowing a smaller body but still with relatively low head loss compared to most other valve options e.g. a 25 mm nominal bore valve has a 20 mm reduced bore. Ball valves can be manufactures with a multi-port design for flow diverting (three or four ways)

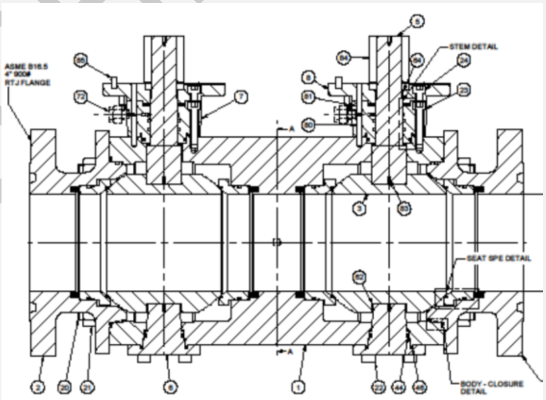
Ball valves can be designed as "top entry" when all the internals are accessible by removing the top flange and allows a replacement without dismounting the valve from the pipe. Another method is to use a three-piece body based on a central piece sandwiched between two pieces connecting the valve to the pipework.



Others design of ball valves are:

- Top entry, in which all the internal components are accessible by dismantling the top cover, without extracting the valve from the pipeline. Another version is to use a body of three pieces installed between the two pieces which make the connection to the pipe.
- Twin valve, in which two independent balls are installed in one body

Top entry



Doble (Twin ball)

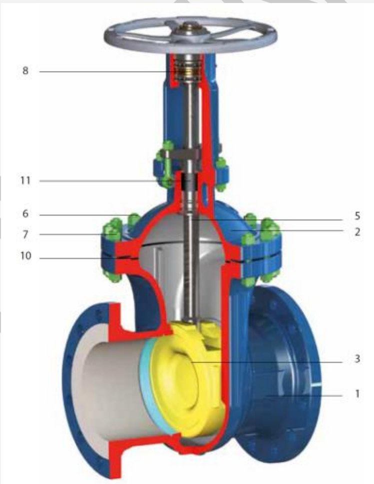
Ball valves are available in all materials in sizes from 5 mm to over 1400 mm (and larger in special cases).   The valves can be used at pressures up to 700 bar, higher pressures are possible. The sealing of the fluid can be achieved either by soft seat inserts, in which seats are elastomer inserts. Soft seated valves have restrictions in the temperature limits of the elastomer used as insert, in general the maximum temperature for soft seats is 250°C. The seats can also be designed for a metal / metal sealing, which has no restriction in relation of the temperature and is also suitable for abrasive media. Using metal / metal sealing, the ball and the seats must be coated with hard material to prevent scratching when the fluid has solids in suspension.

In general ball valves are used for on-off service, the characteristic is not lineal through the movement. There are special versions which can be used for control purposes,
One of these versions use a ball with segmented design, with which a linear characteristic can be achieved.
In another version an orifice plate is installed at the outlet, with orifices distributed in such a way that the requires characteristic is obtained.

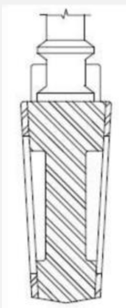
8.2 Gate valves

Gate valves are generally used in the process industry for on-off service. The valve is a multi-turn valve. The design is not suitable for throttling duty because the sealing surfaces can easily suffer from erosion when low flows are being maintained against high differential pressures and the design give very poor flow control characteristics.

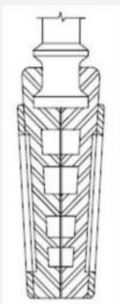
The gate valve can be manufactured in a wide range of sizes from 5mm to above 2000mm dia. The designs are proven and well tested.



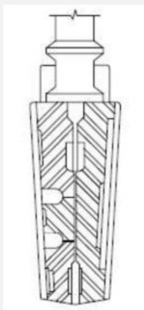
There is a great number of different gate valves for specific applications.



Solid wedge

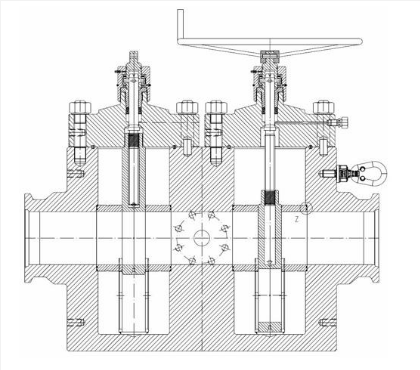


Flexible wedge



Split wedg

Gate valves are available in “twin” versions, in which two valves are installed in one body.



Gate valves are pigable in their full-bore version, which means that a pig can pass the valve without interruption.

8.3 Butterfly valves

The butterfly valve is used to interrupt or regulate the flow of a fluid in a pipe, increasing or reducing the passage section by means of a disc, called "butterfly", which rotates on an axis. By decreasing the passage area, the pressure loss in the valve increases, reducing the flow. The valve has a quarter turn operating system.

The main variations of this valve are the methods of sealing the disc in its closed position.
Those with a central axis have a body completely covered with an elastomer and have the advantage that it is protected against possible corrosion of the fluid transported, in addition to being bidirectional.
The other variations are based on offsetting the plane of the disc on the axis of rotation, allowing the disc to close against a circular face seal (Seat) so that fluid pressure increases the sealing effect. The modification of the axis of rotation is achieved with a single, double, or triple axis eccentricity. There is also the variant of using metal seals, which allows the valve to be used in a wide range of fluids at high temperatures.

The butterfly valve is suitable for many tasks as it provides an optimal solution for an on-off valve, watertight that could supplant the gate valve. The butterfly valve is designed in diameters from 25mm to extremely large sizes over 5000mm in diameter. Depending on the size of the valve, working pressures of up to 100 bar can be handled.

Butterfly valves are not suitable for the passage of scrapers, they cannot be used in pipes that must be cleaned or inspected with this system

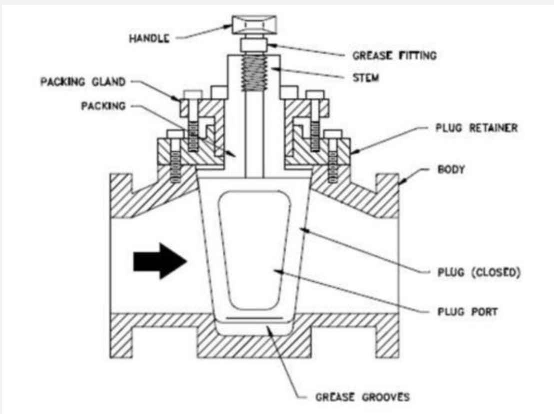
8.4 Plug valves

The plug valve is the oldest of the valves. Plug valves have been in use for over 2000 years. This valve has been in continuous development over recent years. The plug valve is basically, and on-off valve based on a plug with a rectangular hole through which the fluid flows. The plug is either tapered or cylindric is located in the valve body and can be rotated through a quarter turn to line the hole up with the pipe when open or across the pipe when closed.

The plug can be adapted for multi-port use allow the valve to be used for diverting flow. The valve can be engineered with a lubricated plug which uses the lubricant to enable convenient operation over a wide range of pressures. The lubrication film also provides a seal.

The unlubricated design includes seals in the plug and requires plastic bearing systems.   The valve can include a cage between the plug and the body which includes the bearing a sealing system and allow convenient maintenance. These valves have been specially developed for use in industries requiring high performance operation under arduous conditions and allowing remote maintenance e.g. the nuclear industry.

The valve is a full bore and has virtually no internal cavities but is not pigable in its standard version. Special versions which are pigable are available on the market, but this design increases drastically the size and weight of the valve.



8.5 Globe valves

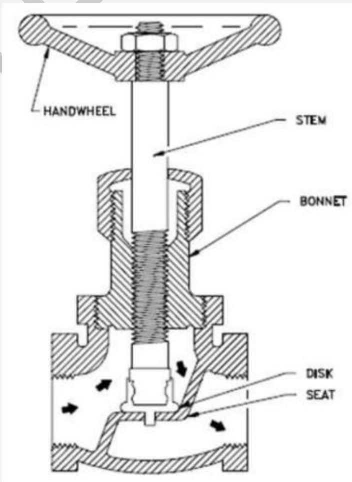
The globe valve includes an orifice set into the body through which the fluid flows. A disc located on the end of the spindle is engineered to move in and out along the axis of the orifice. When the disc is moved to sit in the orifice the flow path is shut-off. The flow path is progressively increased as the disc is moved away from the orifice.

The surface of the orifice (seat) is generally engineering as a replaceable item made from erosion resistant material with a polished surface finish. The disc can be fitted with a soft seat if a tight shut-off is required. For flow control duties the disc is supplied with an engineered shape (lineal, equal percentage, etc.).

For manually operated valves the spindle screwed so that rotation of the handle moves the disc in and out. For actuated control valves the spindle is moved in and out using a linear actuator which can be pneumatic, hydraulic, or electric.

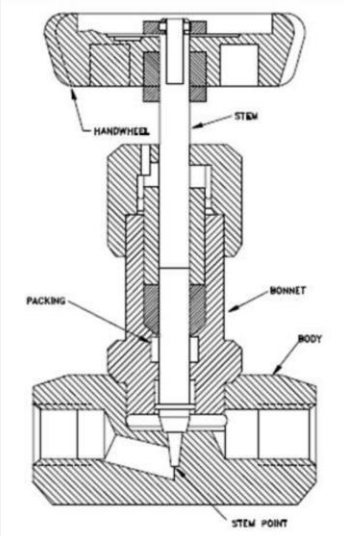
The fluid flow path through globe valves is such that there is normally a high fluid head loss through the valve. The inline body design has the highest head loss, the angle pattern body design has a lower head loss. There are certain designs of globe valves which have been engineered to have low head loss characteristics. Globe valves are supplied in sizes from 3 mm bore through 400 mm and can be used, size limiting at pressures up to 450 barg. Depending on the sealing systems the valves can be used at temperatures the 600°C.

Globe valves are not pigable and cannot be used in pipes which must be cleaned or inspected with pigs.



8.6 Needle valves

The needle valve is used specifically for accurately controlling the flow of fluids at low flows and/or micro flows. The valve is basically a globe valve with a obturator that remembers a needle. It is generally used provided in small sizes of up to 20 mm bore, but there are manufacturers that offer larger sizes.
Needle valves are not pigable and cannot be used in pipes which must be cleaned or inspected with pigs.



8.7 Diaphragm valves

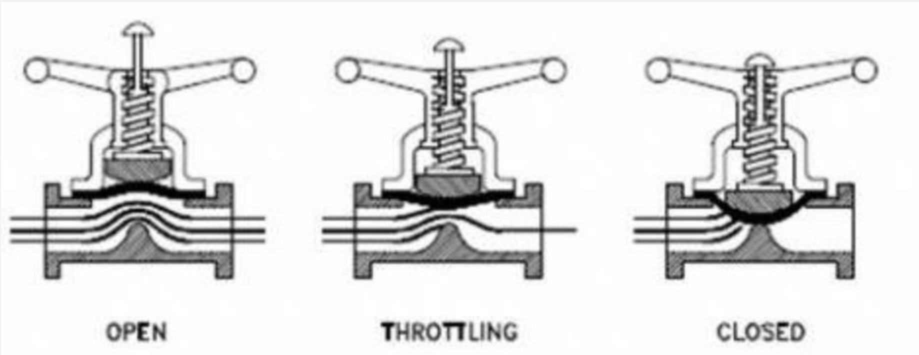
The diaphragm valve has no gland seal requirement. The fluid flows straight through the valve via a chamber over which is an elastomer diaphragm. This diaphragm is normally arranged to provide no resistance to the flow. The perimeter of the diaphragm is simply clamped to a seal face of the valve body as a static seal.
To close off the valve the diaphragm is simply forced down into the chamber to block off the flow. The chamber can include a weir across the flow path against which the diaphragm can be pressed to affect a more efficient seal with reduced diaphragm distortion.

The straight through variation is effectively a full-bore valve design with all the associated benefits. However, this option results in a much more arduous duty on the diaphragm which must be a softer material.

This type of valve is manufactured in sizes from 6mm to 400mm and is generally limited to relatively low fluid pressures (less than 7 bar). However, in the smaller sizes (up to 50mm) valves can be specially engineered for use at pressures up to 30 barg. The diaphragm must be chosen to be compatible with the fluid. Whatever the fluid the diaphragms must be replaced at regular intervals and it is advisable to operate the valves frequently.

These valves are often used for duties which require a high degree of cleanliness as they can be supplied lined, and polished and can be very conveniently cleaned and for transport of solids slurry. In this last application the advantage is the low cost of the valve, the disadvantage is that the diaphragm must be replaced very often.

Diaphragm valves can be supplied in pigable versions.



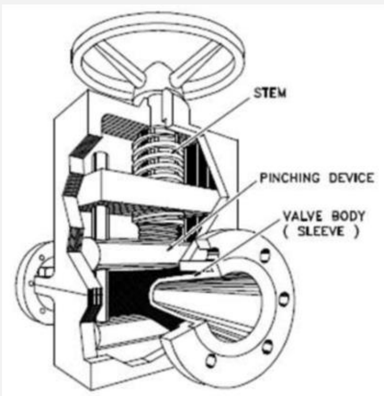
8.8 Pinch valves

The pinch valve is a theoretically ideal solution for fluid on-off duties. The valve is simple a length of pipe made from an elastomeric material with a mechanical system for squeezing the tube closed when a shut off is required. The valve is a true full-bore valve - there are no mechanical parts in contact with the fluid- The operation of the valve is ideally simple; the valve can be easily engineered as a tight-shut off valve.

The valve is often supplied with the pinch tube contained within an outer pipe between the end flanges.

The valve has similar limitations to the diaphragm valve. The diaphragm valve is really a variation on the pinch valve principles. Pinch valves are supplied is for diameters 25 mm - 1000 mm, temperatures -50 C - +160 C, and pressures 0 - 50 bar.

Pinch valves can be supplied in pigable versions



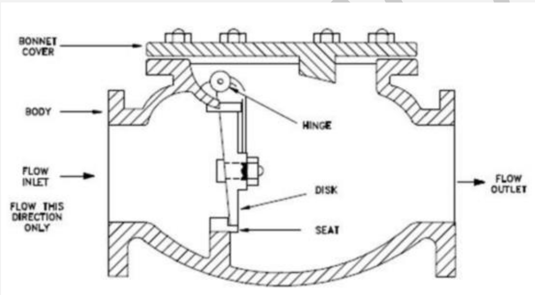
8.9 Check valves

Check valves are normally auto actuated and designed to prevent reversal of flow of the fluid in the pipe. The valves are maintained open by the flow of fluid in the forward direction and are closed by back pressure of the fluid or by the weight of the closing mechanism or by a spring force. Various designs are available as listed below.

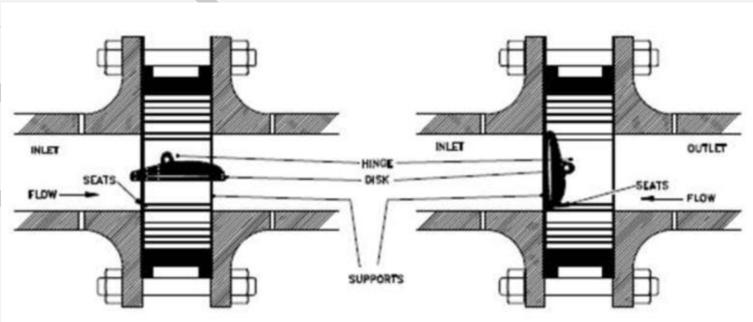
- Swing check
- Tilting disc
- Ball lift type
- Disc lift type
- Piston check
- Stop check

The range of check valve sizes range from 6mm to massive units of 3000 mm diameter and more.

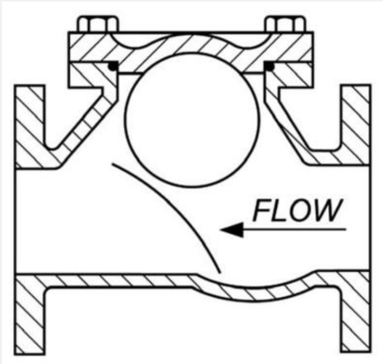
The **swing check** variation is a low pressure drop unit based on a hinged disc. This type of valve is suitable for low velocity applications with infrequent velocity reversals. The valve can be fitted with external weights to allow faster closure to reduce water hammer or shock pressure on flow reversal. External systems can also be included to force the valve closed in the event of a local fire.



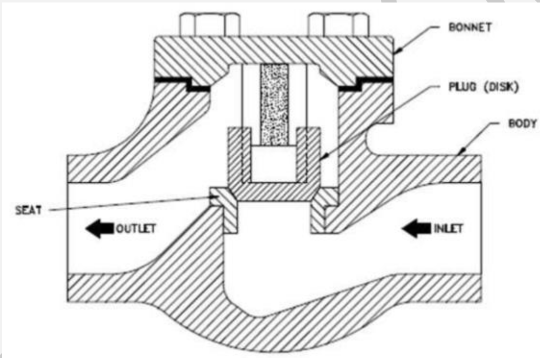
The **tilting disc** variation on the swing check valve provides improve speed of operation and pressure performance and is probably the most popular design of check valve used in the process industry.



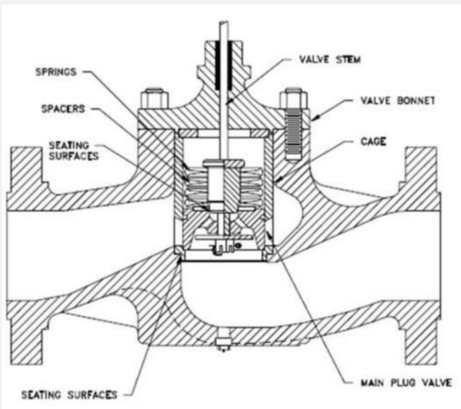
At the **ball check valve**, the function is like the piston type, in which a ball inside the body is used to control the flow. The ball can move freely, what results in a uniform erosion and cleaning of the areas between the ball and the seats. This makes this type of check valve ideal for viscous liquids.



The **lift check valve** has a seat design like a globe valve. The disc is generally in the shape of a piston or a ball.
Lift check valves are particularly suitable for high pressure service where the flow rate is high. On lift check valves the disc is precisely guided and fits snugly on the dash. The lift check valves are suitable for installation in horizontal or vertical pipes with up flow.

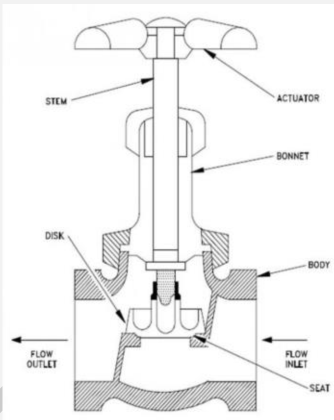


Piston check valves are used to avoid problems in the piping and pumping systems (cavitation) avoiding any reversal of the flow. They are opened by the passage of the fluid and use a spring to close them. They also keep the pipes full of fluid if the pumping equipment is stopped.



Stop check valve. In the stop verification configuration, the stem head floats on the balloon disk (i.e. it is not connected). Stop check valves have two main purposes: 1) as a globe valve, they isolate or regulate flow, and 2) modified as a check valve, they prevent reverse flow. In other words, they are generally used as a globe valve to start or stop media flow, but they also act as a check valve to automatically close in the event of pressure loss, thus preventing back flow that could cause damage. to equipment such as boilers or pumps.

Because of this, having a stop check valve is like having two valves in one. The inner disc, which is not attached to the stem, functions as a lift control that allows the freely move up and down when the stem is raised to adjust opening and closing. This controls the flow rate, but when a return flow occurs, the disconnected disc works like a piston control and closes quickly, thus preventing reverse flow into the boiler. If necessary, the stem can be lowered manually to stop flow or close completely.
These valves are mainly used in power plants, among others, in applications such as boiler circulation, generation of steam and boiler feed water, turbine cooling, starting water and safety systems.



If the passage of scrapers is required in the check valves, the corresponding version must be selected.