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Selection of Appropriate Control Valves for Vacuum Systems

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Abstract- It is believed that a vacuum system designed for precise vacuum control will be much better from ample technical point of views with the convenience of better performance. Vacuum control valves are used for this purpose. These valves are mechanical devices employed to start, stop, fine control, adjust and maintain the required vacuum levels as well as for desired accurate flow rates of the process fluid in the vacuum system. As systems of various vacuum ranges are the requirement of different processes and research works, therefore the selection of such valves for diverse vacuum ranges is the matter of prime importance. Moreover, selection of the proper vacuum valve also involves a thorough knowledge of the process and processing fluid for which it will be used, the material of which it is made, in what geometry the valve is to fit and the size it must has to perform its designated task accordingly. Further more, the possible adverse occurrences that can take place in the system should also be observed for appropriate valve operation. In this paper effort is made to briefly deliberate these facts along with some guide lines regarding the selection of suitable vacuum valves for different vacuum systems.

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Selection of Appropriate Control Valves for Vacuum Systems

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I. Introduction

Vacuum valves are basically mechanical devices constructed by different materials. These are installed in the vacuum system for multiple purposes like isolation, air-admittance, throttling, adjust & maintain the required vacuum levels as well as for accurate flow rates of the process fluid in the vacuum system. As for as the construction of a conventional valve is concerned, it comprises the housing or body that encloses the valves' mechanism vacuum leak tight as well as contains inlet and outlet ports, the bonnet, through which the motion from the external atmospheric side is transmitted, and the stem which transfers this motion to the valve disc that opens or closes the flow passage depending on its position [1]. There is diversity of vacuum valves available. Some commonly used valves in the vacuum systems are shown in figure-1. Since the valves are important part of the vacuum system, consequently care should be taken to ensure that the precise valve is selected for a specific vacuum range to ease the required process. In case of

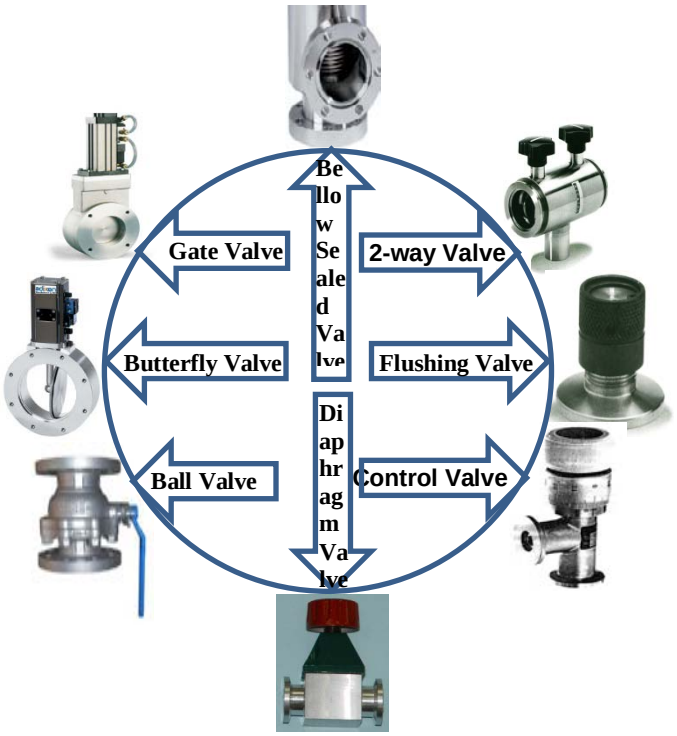

Figure 1 : Some valves commonly used in vacuum systems

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improper selection, valves can cause operational problems, including poor control, cavitation consequence, reduced conductance, and hydraulic transients that result the effects like poor performance, accelerated wear, repair, and replacement of the valve [2].The vacuum valves are classified on the basis of operating system. Classification of the systems forming a valve is shown in figure-2[3].

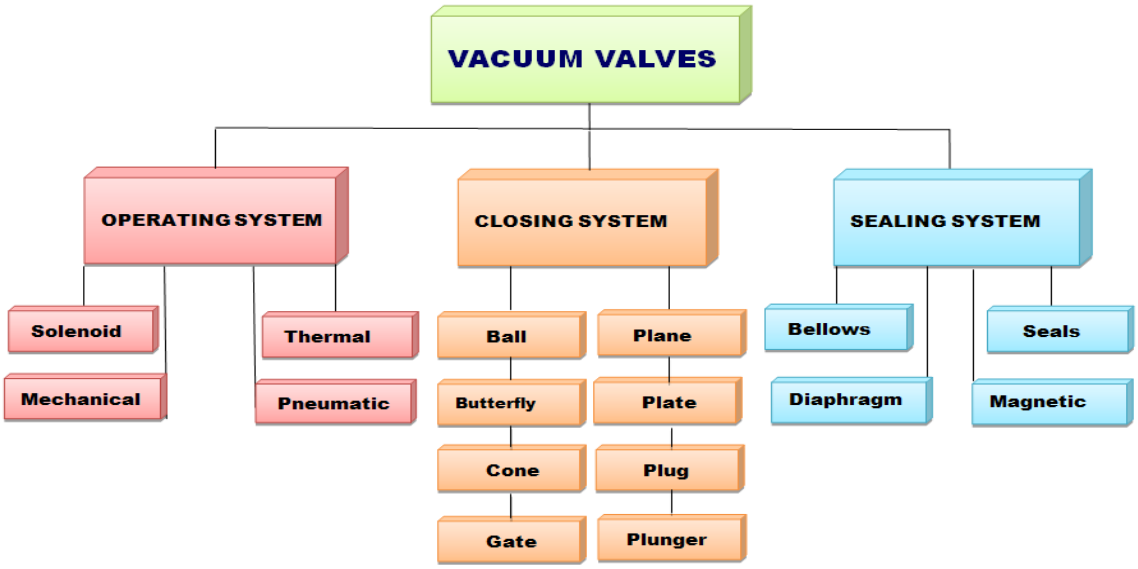

Figure 2 : Classification of the systems forming a valve

II. Valve Selection

There are diverse contemplations regarding the appropriate valve selection. Firstly, the valve should be selected according to the vacuum range in which the specific process has to take place. Secondly, which type of valve and its material is the most suitable for smooth process handling of the fluid in the vacuum setup, along with its long time suitability, compatibility and durability? Thirdly, the parameters like the size, geometry, flow capacity and conditions, shutoff response to leakage, virtual leak, temperature limits, cost, actuation, operational speed and time, port configuration, conductance, life cycles, maintenance ease, etc. Therefore, these considerations will briefly be discussed stepwise on the basis of various parameters in the following manner.

a) Valve Selection on Vacuum Range Basis

Vacuum has many ranges categorized on the basis of molecular density in the vacuum environment. These ranges along with molecular density are given in the table-1 [4]. Different vacuum valves are selected according to these vacuum ranges for their first-rate performance

Table 1 : Vacuum ranges along with molecular density

Range	Pressure (mbar)	Particle density (n/cm^3)
Atmospheric pressure	1×10^{3}	2.5×10^{19}
Low Vacuum	1×10^{3} - 1×10^{0}	2.5×10^{19} - 3.5×10^{16}
Medium Vacuum	1×10^{0} - 1×10^{-3}	3.5×10^{16} - 3.5×10^{13}
High Vacuum	1×10^{-3} - 1×10^{-6}	3.5×10^{13} - 3.5×10^{10}
Very high Vacuum	1×10^{-6} - 1×10^{-9}	3.5×10^{10} - 3.5×10^{7}
Ultra High Vacuum	1×10^{-9} - 1×10^{-12}	3.5×10^{7} - 3.5×10^{4}
Extreme High Vacuum	1×10^{-12} - 1×10^{-15}	3.5×10^{4} - 3.5×10^{1}

i. *Low and Medium Vacuum Valves*

Good quality commercial valves intended for pressure service are almost practically satisfactory for low vacuum range applications. Caste valves are acceptable for use in these ranges because out gassing and other sources of virtual leaks do not contribute significantly to the observed leakage rate. Moreover permeation is not a consideration in these vacuum ranges [5]. Therefore, the normal valves like ball valves, diaphragm valves, butterfly valves, gate valves, bellow sealed valves etc. can be used for these ranges.

Ball valves have many designs. One style of these valves has a spherical plug with a cylindrical hole drilled through to form the flow passage. For full-ported designs, the flow passage is the same diameter as the inside pipe diameter. These valves being low-cost and rugged are used in fore lines of the vacuum systems with low vacuum applications.

Diaphragm valves have good shut-off characteristics and there are no cavities that affect the flow of the fluid when open. These valves are constructed from either plastic or metal. Because the material of the membrane can chemically degrade, so the diaphragm valves are used for low vacuum range. It is suitable for the pharmaceutical and food industry.

Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation. The disk and seating is of varying designs. These valves are available in a range of sizes large enough to isolate diffusion pumps as well as small enough for many fore line applications. These are good for situations with straight flow. They are generally desirable due to their small size, which makes them a low cost control valve.

Gate valves are devices that are used for the flow of process fluid through a structure or aperture by opening, closing or obstructing a port or passage way. Gate valve applications include isolation between vacuum volume and pump, isolation between chamber and load lock during sample introduction, access between chamber and load lock during sample transfer, and isolation between synchrotron beam lines and experimental stations. Its actuation is available in manual as well as electropneumatic configurations. In open position these valves provide maximum clearance and conductance.

Bellow Sealed valves have metallic body and stainless steel bellow with seals made of different materials. These valves are of different sizes, geometry either straight through or right angled and can be operated manually or electropneumatically.

ii. *High and Very High Vacuum Valves*

Normally conventional valves are not acceptable for high and very high vacuum applications. Fine quality valves are used for these vacuum ranges, Interior surfaces of valves for such ranges must be properly machined and polished to minimize out gassing. Also the use of metal bellows to seal the shaft stem is standard, and the metal gaskets are used for the bonnet-to-body sealing. For high and very high vacuum ranges, fine quality high performance butterfly valves, gate valves, bellow sealed valves with some added features are used. They are installed in the vacuum system with metallic seals as elastomeric seals are avoided for such vacuum ranges due to their high out gassing rate.

iii. *Ultra High and Extreme High Valves*

For Ultra High Vacuum (UHV) and Extreme High Vacuum (XHV) ranges, specially made all metal valves are used. These valves are usually fabricated systematically from fine quality Stainless Steel or other suitable material having low out gassing rate. The internal surfaces of these valves are finished to the best quality and polished. Furthermore, these are with Conflate Flange (CF) and installed in the vacuum system with Oxygen Free High Conductivity (OFHC) Copper gasket using proper sealing torque, which is great enough to deform the Copper gasket on the valve CF knife-edge conical seat to make this joint leak tight [6]. The main reason that these valves are used in UHV and XHV with OFCS is to minimize the out gassing rate from these components which is the essential requirement for such uppermost quality vacuum ranges. Due to all metal assembly, these valves can be baked to high temperature for further reducing out gassing rate. These valves have different port geometry like straight through ports, right angled, 45 degree ports for simple system designing with maximum conductance. Excellent material gate valves are also used in this vacuum range as per requirement of the system.

iv. *Valve Selection on Control Basis*

Fine control valves are fitted in the vacuum systems of diverse vacuum ranges as given in table-1 to control precise flow rate for the desired vacuum level by fully or partially opening or closing as per requirement. They are mostly used to admit gas into a vacuum chamber or system at a controlled leak rate and less frequently to backfill a vacuum chamber to low pressure. These valves provide the essential control using a variable restriction created by a rotating plug or disk, a sliding sleeve or using a flexible membrane. Even when fully open, a control valve's low conductance means it should not be installed between a pump and vacuum volume. Other choice is needle valve used for precise flow control. In this valve a tapered stem fits into a conical sleeve. Moving the stem (needle) in/out changes the valve's conductance and consequently the gas flow rate through it. The needle's shaft is typically sealed by a dynamic O-ring or PTFE block. Another type of valve is air-vacuum or flushing valve generally used to admit air slowly at low pressure for the safety of the installed various equipment in the vacuum system.

b) Valve Selection on Material Basis

There is a variety of vacuum valves available. But it is generally not sufficient to simply select the type of valve suited to certain process parameters. Material with which the valve is made is also very important. Selection of valve fabricated with materials compatible with the process fluid helps ensure its lifespan and operation as well as the protection of the system. Valve construction materials include stainless steel, aluminum, brass and other suitable material. The choice of the valve material depends on the required bake out temperature, pressure range, and the construction material of the remaining vacuum system. Selecting the most appropriate materials of construction for valves is guided primarily by the service of the valve, then secondarily by cost; the least expensive material that is compatible with the service will be chosen to be used. Proper material selection promotes safety by avoiding the reaction of valve material with the process fluid. The standard materials need to be selected carefully as the parts made by these materials come into contact with the process fluid. These generally include the ball (for ball valves), the disk (for butterfly valves), the bellow (for bellow sealed valves) and the plug (for plug valves). This also includes the seats, which is the area where the valve disk "sits" when closed to provide the actual shut off. The material of seals and the valve body is also requires the same consideration during the material selection. [7]. All valves, small or large, should be constructed from materials whose out gassing load is low enough so that it does not contaminate the process at the operating vacuum.

c) Valve Selection on Design & Size Basis

After the selection of a specific valve type for a process, the next step is to figure out the size of the valve need to be installed in the vacuum system. Design and size of vacuum valves is determined by the size of the system for specific application. The valve may be small or large. Small valves are defined as valves with inside diameter less than 2 inches while the valves with inside diameter more than 2 inches are called large valves [8]. Valve should have maximum conductance for gas flow and long operating life [9]. The parameters to consider in valve sizing are the size and geometry of the system ports. The valve connecting ports should be of the same size and type as that of the vacuum system. The geometry of the valve should be well matching with that of the vacuum system. Vacuum valves are either straight through (ports at 180 degree) or corner (ports at 90 degree) or semi-corner (ports at 45 degree) valves. The selection of the right geometry valve ensures the appropriate conductance , rapid evacuation and proper flow rate The fluid flow characteristics are also important to make sure an appropriate size of the desired valve. Further typical criteria and requirements regarding the vacuum valve selection are listed in table-2 [1].

Table 2 : Typical criteria and requirements on vacuum valves

CRITERIA	REQUIREMENTS
Tightness of housings Leak rate ≤ 10^{-9} mbar l s^{-1} (10^{-7} Pa l s^{-1}) and valve seats	
Differential pressure at valve disc	At least 1 bar (10^5 Pa)
Conductance	Should be high. Resistance of flow should not impede gas flow noticeably
Differential pressure when opened	Should be as high as possible, e.g., 1 bar
Description	Appropriate materials and components necessary
Bake-ability	Maximum temperatures, e.g., 200 °C when open, 150 °C when shut
Service life	As high as possible
Safety criteria	Self-shutting in the event of power failure

From the above discussion it is quite obvious that there are various types of vacuum valves available for putting into practice in the vacuum systems.But an ideal valve should be selected. An ideal valve should meet specific requirements that have been briefly listed in table-2[3].

Table 3 : Requirements of an Ideal Vacuum Valve

AN IDEAL VALVE SHOULD MEET THE BRIEFLY LISTED SPECIFIC REQUIREMENTS:
It should consist of minimum parts, with smallest surface area to reduce outgassing rate.
It should have maximum conductance in open position without increasing system volume.
It should have minimum possible leak rate through the closing system when it is closed.
It should be mechanically strong, simple to construct, dismantle and reassemble.
It should operate according to predetermined pressure or time or sequence.
It should have leak tight seals between the body, the bonnet and the stem.
It should have positive action not influenced by pressure difference.
It should have body and bonnet made from non-porous materials.
It should have very small virtual leaks due to its internal fittings.
It should have the shape corresponding to its location on plant.
It should have the minimum possible leak rate from outside.
It should not contain materials with high vapor pressure.
It should be able to operate at large ranges of pressures.
It should have not double welds or other trapped areas.
It should be easy to operate remotely or by interlock.
It should be bankable to the required temperature.
It should be chemically resistant to the process fluid.
It should operate rapidly for the required action.
It should be capable of a number of cycles.
It should be easy to clean thoroughly.
It should be easy to install.

Unfortunately no valve can meet all these requirements. Consequently, in selecting a valve for a specific application a compromise should be made, insisting on the most significant requirements for the desired particular purpose.

III. Conclusion

Vacuum control valves are the vital part of the vacuum systems. There is a variety of such valves available that can be put into practice in the vacuum system to carry out multiple functions. But the selection

knowledge of the vacuum valve parameters like size, geometry, material, surface finish, vacuum range, flow capacity and conditions, shutoff response to leakage, temperature limits, cost, actuation, operational speed, port configuration, conductance, suitability, reliability, durability, life span, resistance to reaction, remote or interlock facility, installation, cleaning, dismantling and reassembling, leak rate, virtual leak, vapor pressure, out gassing, etc., are very essential. All these parameter have briefly been deliberated in this paper.

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