

## Valves in Vacuum Service

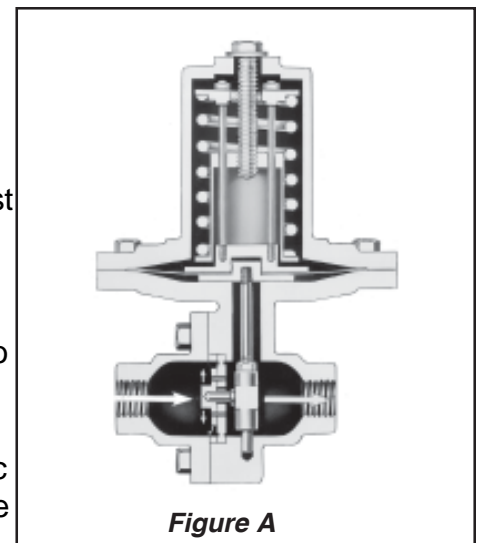
by Lyle Hamilton, Engineer, Richards Industries

Vacuum service presents special challenges for those who must specify valves for processes that require pressures less than the standard atmospheric pressure of 14.696 psi absolute. Creating and controlling a vacuum for your process will require valves with specialized design features to cope with the low absolute pressures that will be encountered, and special sizing considerations must be made to insure that the valve will have enough capacity to meet the flow demands of a vacuum system.

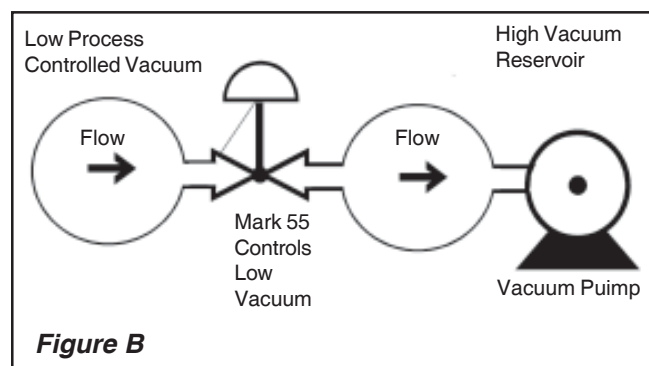
### Special Construction –

Creating and regulating a process vacuum requires valves of special construction, particularly where self-operated regulators are to be used. Standard pressure regulators have a range spring that pushes down on the diaphragm to act as a force balance to the pressure being regulated, whether it is downstream pressure as with the common pressure regulating valve (PRV) or upstream as with a back pressure regulating valve (BPRV). In the usual PRV, the spring opposes the force created by positive pressure (i.e. greater than atmospheric) downstream of the seats in order to push them open as pressure falls below the set point. Likewise, with the BPRV, the spring pushes the seats down and closed in order to maintain the desired upstream pressure. These types of regulators with springs that push downward are useless for creating or regulating a vacuum.

Since a vacuum is a “negative” pressure (i.e. less than atmospheric), a regulator controlling negative pressures must have a spring that *pulls up!* Figure A shows the top works of a regulator designed to sense and control pressures lower than atmospheric. Note that a special linkage is included so the foot of the spring is suspended by the adjusting screw so that the spring can push upward on a plate which pulls the diaphragm upwards via two connecting rods. Since the reference pressure on the top of the diaphragm, atmospheric pressure, is greater than the process pressure, the reference pressure pushes the diaphragm downward as the vacuum below the diaphragm grows stronger (decreasing absolute pressure). The spring that pulls up provides the force balance necessary to operate the seats, just as the spring pushing downward does in a standard regulator.

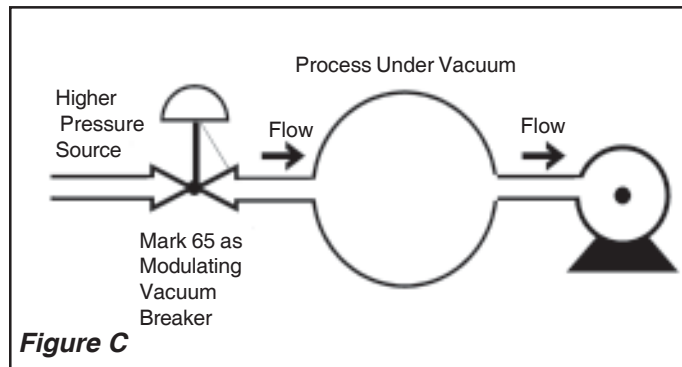


Now that we have the regulator, we can use it in an actual process (see Figure B) to create a controlled vacuum. We start with the chamber on the left of the schematic and using a Vacuum Regulator, create a vacuum in the process chamber by acting as a gateway between that chamber and the high



vacuum reservoir and vacuum pump on the right. The regulator creates the process vacuum as follows: The spring has pulled the seats up and open. Air flows out of the process chamber, through the valve, and into the high vacuum reservoir that was created by the pump. This continues until the process chamber reaches the preset vacuum level as determined by adjusting the spring. As the vacuum in the process chamber increases, the atmospheric pressure on top of the diaphragm overcomes the upward force of the spring pushing the seats down and toward closed. This limits flow out of the chamber preventing the vacuum from getting stronger than desired. If the vacuum weakens, the spring overcomes the force of the atmospheric pressure on top of the diaphragm thus pulling the seats toward open, allowing more flow out of the chamber to restore the lost vacuum.

Another common layout for a simplified process vacuum system is shown in Figure C. The vacuum pump acts directly on the process under vacuum by causing air to flow out of the process chamber. In order to keep the vacuum from getting too strong, we need a vacuum breaking valve. As the process vacuum continues to grow, the atmospheric



pressure on top of the diaphragm in our vacuum breaking regulator overcomes the force of the spring and pushes the seats downward and open, allowing replacement air to flow into the chamber thus preventing the vacuum from growing ever stronger due to the action of the pump. Note that action of our vacuum breaking regulator is the opposite of our vacuum making regulator in the previous example; where the seats closed as the vacuum got stronger.

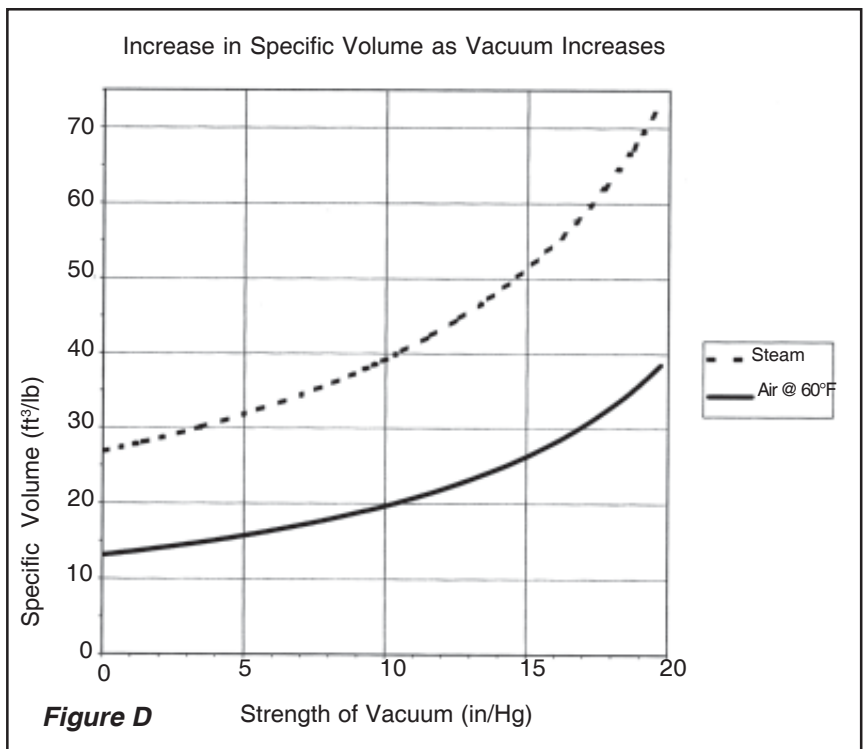
Another special consideration for vacuum service is the use of elastomer diaphragms for regulators. An elastomer diaphragm usually has a fabric re-enforcement layer behind the elastomer sheet. For vacuum service, the fabric side of the diaphragm must be sealed (usually with another layer of the same elastomer) to prevent blowout since the “pressure side” is on top facing the atmosphere instead of on the process side as with a standard regulator.

While regulators are specially built for vacuum service, most control valves can be easily adapted. The commonly used chevron “V-ring” packing used for stem sealing can be inverted so that the open end of the “V” is facing the higher outside pressure. Most standard gasket and o-ring seals are suitable as is.

### Sizing Considerations –

As mentioned in the opening paragraph, special sizing considerations must be made to insure that the valve will have enough capacity to meet the flow demands of a vacuum system. This issue is often overlooked because it is assumed that since normal atmospheric pressure is 14.696 psi absolute and most process vacuums don’t go below about 5-7 psi absolute that choked flow will not occur since the pressure drop across the valve is about 10 psi. This assumption is wrong because it fails to take into account the increase in specific volume that occurs with gasses and steam when the pressure falls below atmospheric. The chart in Figure D shows the dramatic increase in specific volume as the vacuum gets stronger. On the left side

of the chart we see that at atmospheric pressure the specific volume of air is about 13 ft<sup>3</sup>/lb, but at 15 inHg vacuum (approximately 7½ psi absolute) its specific volume is nearly double! The specific volume of steam shows a similar increase going from approximately 27 ft<sup>3</sup>/lb at atmospheric pressure to about 54 ft<sup>3</sup>/lb in a 16 inHg vacuum (about 7 psi absolute). The implication of this is that since velocity is equal to the volume flow rate divided by the cross-sectional flow area, as the volume increases the velocity increases, which means larger seats are required. The same holds true for steam sizing since



the flow in pounds per hour is usually converted to a volume flow rate according to its specific volume, the same effect means bigger seats too. Let us look at two examples: Sizing Report number 1 shows a Cv of 2.51 is required to produce a 20 SCFM flow of air through our 1" valve. Also note that the normal velocity is about 52 ft/sec. Sizing Report number 2 shows that with the same 5 psi pressure drop, we need 4.71 Cv to produce a 20 SCFM flow, and that the normal velocity is 200 ft/sec. Where did the difference come from, and why did the velocity quadruple? The first report shows inlet and outlet pressure in standard gage pressure mode, meaning the inlet pressure is 10 psi over atmosphere and outlet pressure is 5 psi over atmosphere. In the second report, the sizing program is in absolute pressure mode, meaning there is a light vacuum at the valve inlet, and a stronger vacuum at the valve outlet, and the differential pressure is 5 psi. The difference in Cv and flow velocity is caused by the difference in the specific volume of the air, approximately 9.8 ft<sup>3</sup>/lb in the first example, and approximately 39 ft<sup>3</sup>/lb in the second. Going back to the graph, the steam curve is even steeper, so even more dramatic results should be expected when sizing for steam. Keep in mind that most sizing programs assume the inlet and outlet pressures will be gage pressures, you must reset the program options to accept the input as absolute pressures, or size manually according to the ISA Valve Sizing standards.

When creating and controlling vacuums, remember that the same principles that apply to a regular system with all positive pressures also apply to vacuum systems, but those principles manifest themselves in very different ways. The real difference between a "vacuum making" regulator and a back pressure regulator is the direction in which the spring and pressure forces try to move the diaphragm up and down, they both control the pressure on the inlet side. Likewise a vacuum breaker and the common pressure regulator both control pressure on the outlet side, but the way the pressure and spring forces control the seats is reversed. A standard control valve can usually be converted for vacuum service simply by inverting the packing set. When sizing for vacuum service for either regulators or control valves, remember the specific volume increases dramatically in a vacuum, and that if not accounted for, an undersized valve will be the result.



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# Sizing Report #2

Date: 11/21/2003

## Design Parameters

### Valve Type: Globe

Calculated for: <b>Cv</b>	Valve Size: <b>1 in.</b>
Inlet Pressure: <b>10 psig</b>	PRF: <b>0.9</b>
Outlet Pressure: <b>5 psig</b>	Normal Flow: <b>25 SCFM</b>
Upstream Diameter: <b>1 in.</b>	
Downstream Diameter: <b>1 in.</b>	
Pipe Schedule: <b>Sched 40</b>	

## Fluid Parameters

### Fluid: Air @ Ambient Temp (40 - 100 deg F)

Fluid State: <b>Gas</b>	Specific Gravity: <b>1</b>
Specific Heat: <b>1.4</b>	Compressibility: <b>1</b>
Viscosity: <b>0.018</b>	

## Results

		Ft/sec	Meters/sec
Actual Cv: <b>2.51</b>	Norm Velocity	<b>52</b>	<b>16</b>

## Warnings

## Memo

The Cv Calculated is the actual Cv required. When sizing for the following valve types, the figure should be divided by:

PRV	(Pressure Regulator)	.7
BPRV	(Back Pressure Regulator)	.5
PPRV/PBPRV	(Piloted PRV/BPRV)	.9
TCV	(Temperature Regulator)	.9
DCV/MOV	(Diap/Motor Operated Valve)	.9



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## Results

		Ft/sec	Meters/sec
Actual Cv: <b>4.71</b>	Norm Velocity	<b>200</b>	<b>62</b>

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