6

# Vacuum Materials and Hardware

When you have completed this chapter, you will be able to:

1. Describe the basic materials used in vacuum work.
2. Understand the common joining techniques used in the construction of vacuum systems.
3. Describe the hardware components usually found in typical vacuum systems.

# Introduction

Modern industrial vacuum equipment enables the manufacture of many different products. It enables processes such as vacuum skin packaging and vacuum drying. It also makes it possible to do many kinds of chemical processes, analytical work, and thin-film coating. These are only a few examples of the work done in vacuum systems. Of course, we must have the pumping mechanisms to produce high-purity vacuum environments. Let's now look at another key factor in vacuum equipment: the hardware components and materials used in vacuum systems.

## Vacuum Purity Levels

It will help to have another look at what we are doing when we want to use a vacuum system. Here's a summary of some information about vacuum for you.

| Pressure | | Gas Density | Mean Free Path | |
|---|---|---|---|---|
| Torr | Pa | Molecules/cc | Meters | English |
| 760 | $10^5$ | $3 \times 10^{19}$ | $6 \times 10^{-8}$ | $2.5 \times 10^{-6}$ in. |
| 0.76 | $10^2$ | $3 \times 10^{16}$ | $6 \times 10^{-5}$ | $2.5 \times 10^{-3}$ in. |
| $7.6 \times 10^{-3}$ | 1 | $3 \times 10^{14}$ | $6 \times 10^{-3}$ | $2.5 \times 10^{-1}$ in. |
| $7.6 \times 10^{-6}$ | $10^{-3}$ | $3 \times 10^{11}$ | $6 \times 10^{0}$ | 21 ft |
| $7.6 \times 10^{-8}$ | $10^{-5}$ | $3 \times 10^{9}$ | $6 \times 10^{2}$ | 2100 ft |
| $7.6 \times 10^{-10}$ | $10^{-7}$ | $3 \times 10^{7}$ | $6 \times 10^{4}$ | 40 mi |

Let's add two more numbers to compare to this table: About *$10^{15}$ molecules* can cover *one square centimeter* ($cm^2$) of surface area only one layer (a *monolayer*) thick, when the molecules are at room temperature. At a pressure of $10^{-6}$ torr, it takes about 1 second to deposit one monolayer of molecules on the surface.

$10^{15}$ molecules/$cm^2$ 1 sec at $10^{-6}$ tor

Now, we can look at these facts and make some use of them. Let's suppose we want to put down a few layers of our own choosing on a surface. What pressure would we need to use in order to put down what we wanted– not just whatever was flying around in the chamber? Every second there will be another layer coating our surface at $10^{-6}$ torr. We better work fast. If we take a long time to lay down our layers, we will need to work at very low pressure.

For example, MBE (molecular beam epitaxy) processes are carried out at ultrahigh vacuum levels ($10^{-9}$ torr) in order to allow us to put on a pure coating. At $10^{-9}$ torr, it takes about $10^3$ sec to lay down a monolayer! Now, we can work more slowly and still make sure that the layers that we want to put on our surface are indeed placed there.

We can look at these facts another way: Let's compare the purity of our vacuum to the purity of something that you perhaps know a little about. Let's use ultrapure helium, sometimes called "five nines" helium (meaning 99.999% pure), as our example.

Most people think of this as being very pure. To get an equivalent level of purity in our vacuum chamber would require that we remove all but ten parts of every one million parts that were originally present. Looking at our table, we see that one millionth of atmospheric pressure is about $760/10^6$, or about $7.6 \times 10^{-4}$ torr — barely into the high vacuum range! It's about 1 mtorr!

Even at 1 mtorr, our vacuum chamber has too many molecules (too much "dirt") to carry out some of the processes that we perform in a chamber. In fact, at a typical high vacuum working level ($10^{-6}$ torr), we are in the parts-per-billion purity level. Ultra-high vacuum gets us into the equivalent of parts-per-trillion purity level (one part per $10^{12}$).

You can see that we can indeed get a very clean working environment by using a vacuum system. This may also help you to see some of the problems that go along with using a vacuum system. Let's go on now to look more in detail at some of those problems.

## How Gases Are Pumped

One obvious problem is to get rid of all those gas molecules in our vacuum chamber. Let's look at what happens as we pump down.

Our roughing pump removes more than 99.99% of the air or gaseous contaminants from the chamber. We know that this is adequate to perform some vacuum processes but not those requiring high purity.

As we begin pumping at atmospheric pressure, we are pumping out the air. This air is sometimes called the volume gas. As we continue to pump, we begin pumping the molecules which have been fastened loosely to the walls. After these are gone, the remaining gas load is mostly water vapor. In fact, 75% to 95% of it is water vapor.

When the chamber is vented, the water vapor clings to all surfaces and to its own layers. Water can build up layers about 100 molecules thick on surfaces! After the volume gas is removed, the water begins to come off the surfaces, and makes up most of the remaining gas load.

As we continue to pump down to lower pressures, the character of the gas load changes. Other gases begin to make up the major portion of the gas load, as you can see in this table:

**RESIDUAL GAS LOADS**

| Pressure (Torr) | Major Gas Load |
|---|---|
| Atm | Wet air |
| $10^{-3}$ | Water vapor (75%-95%) |
| $10^{-6}$ | $H_2O$, CO |
| $10^{-9}$ | CO, $N_2$, $H_2$ |
| $10^{-10}$ | CO, $H_2$ |
| $10^{-11}$ | $H_2$ |

As we continue to pump, the mean free path of the gas molecules beomes longer and longer. We have gone from the viscous flow range into the molecular flow range. Remember that in molecular flow, pumping occurs only when the molecules randomly move into the pumps of their own accord. We now need high vacuum pumps.

*base pressure*

The vacuum system can be pumped to lower and lower pressure as long as the throughput of our pump is greater than the gas load. When the throughput equals the gas load, the pressure stabilizes. We have reached the *base pressure* for our system. Reaching base pressure means that in the high vacuum range, the following happens: the system pressure goes down only as long as the gases make it into the pumps faster than they come off the walls and other surfaces; then, when the gases come off the surfaces as fast as they make it into the pumps, the pressure for that particular system will go no lower.

*outgassing*

*virtual leak*

*real leak*

When you find that you cannot "pump down" to the typical pressure for your system, you may be seeing the effect of an increased gas load. We call this *outgassing*, or a *virtual leak*, or perhaps just a leak. Why the increase in the gas load? A dirty system—more molecules on the walls to be pumped off. (It may also be because of a *real leak*—a crack or hole in the system.)

We have briefly reviewed the purity levels that we achieve in a vacuum system and the way that gases are pumped. Let's now go on to consider how these are affected by the materials that we use in a vacuum system. So, in this next part of our discussion, we will touch on a few important properties of the materials that go into a vacuum system.

# Materials

Materials used in vacuum work often need to withstand wide changes in temperature. This is because the equipment is often baked to drive gases off the chamber surfaces and into the pumps. In other cases, chilling to very low temperatures helps to produce a good vacuum. Some equipment is exposed to both high and low temperatures.

*thermal expansion coefficient*

Materials change in size when their temperatures change. This size-to-temperature relationship is called the *thermal expansion coefficient.* These changes in size are different for different materials.

Materials with different expansion rates are often joined to each other in vacuum equipment. During bakeout, the materials change in size at different rates. This causes strains at the points where they are joined.

The strain distorts the joints and can result in—you guessed it—leaks! Unless, of course, something is done ahead of time to prevent them. We'll continue this part of our discussion later.

Another major problem in vacuum performance is the outgassing rate of the materials in the system. A rough surface has a larger surface area for gases to stick to than a smooth surface does.

The problem is that this kind of sticking is only temporary. The partially trapped gas slowly comes off the walls after roughing is complete, making it difficult to achieve good vacuum performance. Also, some materials just naturally outgas more than others.

So, we want the materials used in our vacuum system to have several characteristics:

- Wide temperature tolerance
- Similar thermal expansion rates
- Low outgassing rate

There are other characteristics that may be of importance to us. We may need an electrical conductor or insulator, high strength, a thermal conductor or insulator, a non-magnetic quality, elasticity, low volatility, low chemical reactivity, radiation resistance, and probably others as well. With these characteristics in mind, let's look at some of the materials used in vacuum systems.

## Stainless Steel

Stainless steel (or SST), 304 SST in particular, is widely used. It is a high-strength material that stands up to the wide temperature changes experienced in vacuum work. We need the high strength to withstand the air pressure trying to collapse our vacuum container.

Also, SST doesn't oxidize easily, so its surface remains smooth. This means that it doesn't produce large surfaces for gases to stick to. Therefore, it doesn't outgas much. It may be joined by welding or brazing.

A large work chamber made of "easily" machined 304 SST will usually have many ports welded to it. It may have pieces attached by brazing as well. Some stainless steels are non-magnetic, which is important in some applications.

## Copper

Our chamber may have OFHC™ copper used as gasket seals or as plumbing to carry materials in and out of the chamber. (OFHC means oxygen-free, high conductivity.) Because of its careful refining process, OFHC copper contains very little oxygen. Therefore, it doesn't outgas much.

OFHC copper can also take wide changes in temperature. This is important because copper is often baked at very high temperatures, then chilled to very low temperatures. It is a very good electrical and heat conductor.

Brazing and welding are common methods of joining copper to copper and copper to other materials. OFHC copper is an ideal gasket material because it is relatively soft. Also, it contains very few microscopic leak paths (micropipes), which would prevent production of high and ultrahigh vacuum levels.

The ability of copper to conduct heat makes it an excellent choice for cryogenic applications. Copper is used in liquid nitrogen traps and cryogenic pumps. It is not as inert (non-reactive) a material as we might like. As a result, we usually nickel-plate copper to improve its chemical resistance. We use copper to handle large heat loads, as in cooling a sputtering gun or evaporative source.

Of course, copper is widely used because of its electrical conductivity. We use it to get any amount of electrical energy into our vacuum system.

## Ceramics

We use ceramic materials (alumina, in particular) to contain electricity. Ceramics have excellent insulating properties, both for electricity and heat. We routinely braze the ceramics to the other materials in the system.

Ceramics are fragile but have great compressive strength. Their thermal expansion rate (also called coefficient of expansion) is very low.

## Kovar

We use an intermediate material, such as Kovar™, to join glass to metal and ceramic to metal. Kovar has a coefficient of expansion which is between that of ceramics and stainless steel. By brazing the Kovar to the ceramic, then the Kovar to the metal, we get a vacuum-tight seal that remains leak-free even when exposed to extremes in temperature. Kovar is the trade name for an alloy composed of 54% iron, 29% nickel and 17% cobalt. It is magnetic.

## Elastomers

Elastomers are materials that are flexible but not compressible. As such, they are very good to use for gasket seals. Because they are soft, they fill the gaps between mating surfaces and make leak-free joints. Their elasticity, or the ability to spring back to their original shapes, makes them reusable in most cases.

The permeability of elastomers can be a problem in some systems, particularly UHV systems. In these systems, the additional gas load caused by permeation causes problems. Elastomers in general are quite permeable to helium. Leak checking with helium can give slow indications of small real leaks when the source of helium is actually helium that is slowly diffusing through the seal into the system.

Buna-N™ is a common elastomer that is used because of its resistance to helium permeation and because it is inexpensive. It works very well in seals that are not going to be heated above 80°C. It is essentially a synthetic rubber material.

Viton™ is an excellent elastomer which is widely used for O-rings, valve seals, bonnet gaskets and chamber L-gaskets. It outgasses very little, so it can be used for both high and ultrahigh vacuum work. Viton will withstand temperatures up to about 150°C.

Polyimide™ is substituted for Viton where higher temperature tolerance is required. Polyimide will remain elastic up to about 200°C. It is a stiffer material than most elastomers. Therefore, it requires higher sealing pressure to assure leak-free operation. It is also more resistant to radiation than most elastomers. But it has the disadvantage of absorbing water.

Silicone compounds also withstand high temperatures, have poor outgassing rates and are quite permeable to helium and water. They are used in vacuum furnace work because of their temperature tolerance.

Teflon™ is also a good elastomer. However, it is also a plastic-like material, meaning that when it is deformed it tends to remain deformed. We call this "cold flow." When we try to use Teflon as an O-ring, it flows slowly out of the seal, even at room temperature. This, of course, results in a leak at the seal. Teflon is widely used to seal pipe thread joints and ferrules in flexible couplings. The threads help hold the Teflon in place and therefore stay leak-free. Teflon is quite permeable to helium. It can withstand temperatures to about 150°C.

Viton, Polyimide and Teflon are all fluoropolymers. They should not be overheated or burned due to the possibility of toxic gas production.

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We have seen quite a collection of materials here. These are, of course, not all the materials that are used in vacuum systems. Special processes may require materials that must meet quite different or special requirements.

Our requirements for vacuum systems in general expose some materials to very low temperatures, others to very high temperatures, and some materials to both. We must allow for the changes in the size of materials when their temperature changes.

We must also be concerned about the surface texture and how it will affect the outgassing rate into the system. Remember that the gases stored or adsorbed on the walls become our major problem under molecular flow conditions.

We may be quite concerned about the vapor pressure of solids under the conditions present in our vacuum system. Recall the graph of vapor pressure of the elements from chapter 1; the graph suggests that there are elements such as lead, zinc and cadmium which may have a vapor pressure which is too high for vacuum system use. This means that brass parts and cadmium-plated screws are not to be used in a high vacuum system. Their vapor pressure will be high enough to prevent us from reaching operating pressure, particularly if we will be using high temperatures in the process.

The same consideration should be used in determining what organic materials should be (or not be) used inside the vacuum system. Materials with high vapor pressure will cause higher gas loads. This typically means that the system will be unable to reach the desired pressure.

# Joining Techniques

We have already mentioned several joining techniques in talking about materials. Welding and brazing are very commonly used in construction of vacuum systems.

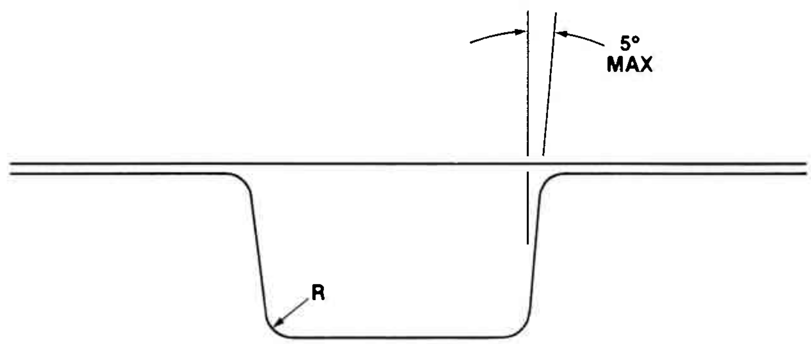
When we need to be able to take part of our system apart and put it back together leak-tight, we use flanges or couplings to join the system components. Let's take a look at the various types of flanges that can be used.

# Flanges

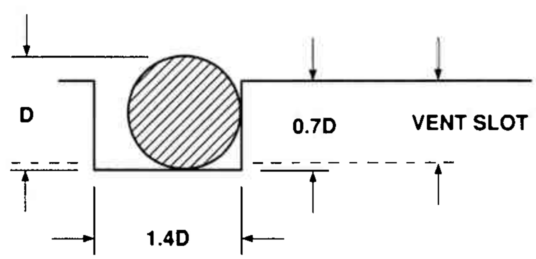
Flanges enable us to connect (join) the system parts in a reasonable and convenient manner. They also make it possible to quickly connect feedthroughs for purposes of controlling and monitoring system operation, and to maintain the system when trouble occurs.

## Elastomer-Sealed Flanges

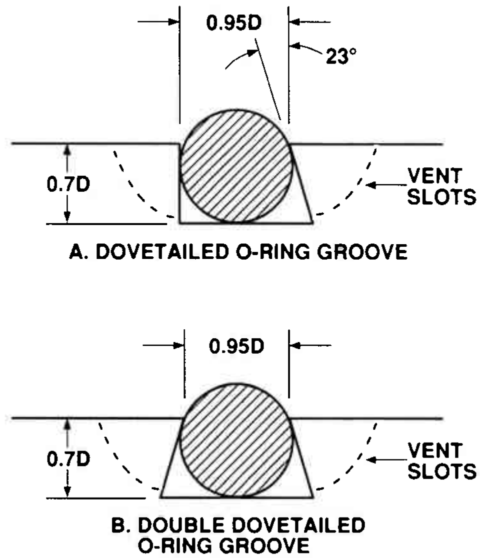
Elastomer-sealed flanges are used where there is little objection to the use of an elastomer, mostly based on temperature considerations and, perhaps, outgassing.




The groove in the flange for the O-ring should have sides that slope outward to a maximum of 5°. The groove should also have a radius on the inner corners equal to about two-tenths of the O-ring diameter. The surface finish of the seal area should be at least 32 microinches. The outer edges should be smooth, to avoid scratching the O-ring when making the seal.



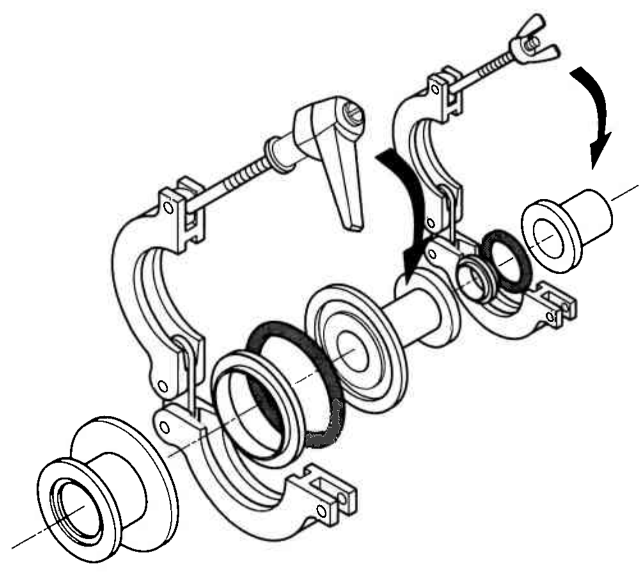

The depth of the groove provides for deformation of the O-ring to about 70% of its unsqueezed diameter. This gives enough elastomer material to make the seal without overstressing the O-ring, but not so much as to force it out of the groove where it might be pinched or cause excessive outgassing. A vent slot is usually machined across the face of the groove to eliminate trapped volumes and for leak detection.




**DOVETAILING OF O-RING GROOVES**

The O-ring groove can be dovetailed to help retain the O-ring. You may also see fully dovetailed O-ring grooves in cases where a gas flow process might otherwise blow the O-ring out of the groove. Dovetailing, or keystoning, is also useful for retaining the O-ring against the force of gravity. The O-ring groove must be relieved to prevent pockets of partially trapped gas from becoming sources of virtual leaks.

Another popular type of elastomer flange is the KF™ flange. As marketed by Varian, it is known as the KLAMP-FLANGE™.



**KF FLANGE ASSEMBLIES**

The flange is of standard ISO 2861/1 design, consisting of two symmetrical flanges, a center ring to support and position an

O-ring, and a clamp that allows assembly without any tools. KF flanges are quite convenient to use in rough and high vacuum systems.

Here are some suggestions you will find useful when working with O-rings:

1. When preparing to make a flange connection, be sure to clean and dry the groove and the flat mating surfaces. Check the sealing surfaces for scratches that cross the seal area.

2. Lightly lubricate the O-ring with a vacuum grease such as Apiezon-L™. Then, wipe off most of the grease with lint-free paper before making the connection. Keep in mind that the O-ring makes the seal, not the grease. The grease makes the O-ring slip and helps it to conform to its groove.

3. Don't apply a lot of helium to an O-ring when leak checking. You will get a small, slowly increasing signal as the helium permeates the O-ring and goes into the vacuum chamber.

4. If you reuse an O-ring, visually inspect it to make sure it has no small cross-wise cracks or nicks that might leak. If it has swollen because it has been exposed to solvents or excess heat, do not reuse it. It is best practice to replace used O-rings with new ones.

5. Leak checking O-ring sealed flanges with solvents affects the O-rings (acetone is an example). The solvent slowly works into the O-ring and on into the system, causing an outgassing problem. The O-ring may even tend to dissolve in the solvent and become gummy and sticky.

6. O-rings will absorb water and will cause outgassing of water vapor. Baking the O-rings will minimize this problem.

Let's go on now to discuss another variety of flanges, the metal-sealed variety.

### Metal-Sealed Flanges

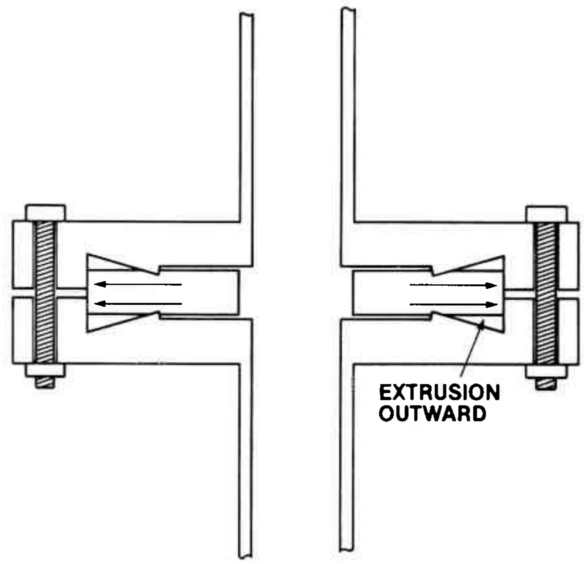
Metal-sealed flanges accomplish the same task that elastomer-sealed flanges do. They do have certain advantages over elastomer seals, however. They may be used at much higher temperatures—up to 500°C. They have low outgassing rates. They are more expensive to install than elastomer-sealed flanges.

The Varian ConFlat™ flange has become the vacuum industry's standard flange. Let's take a more-detailed look at this flange and the features that have made it a reliable and dependable flange.

The process starts with the selection of the 304 stainless steel. Either cross-forged or electroslag remelted (ESR) steel is used.

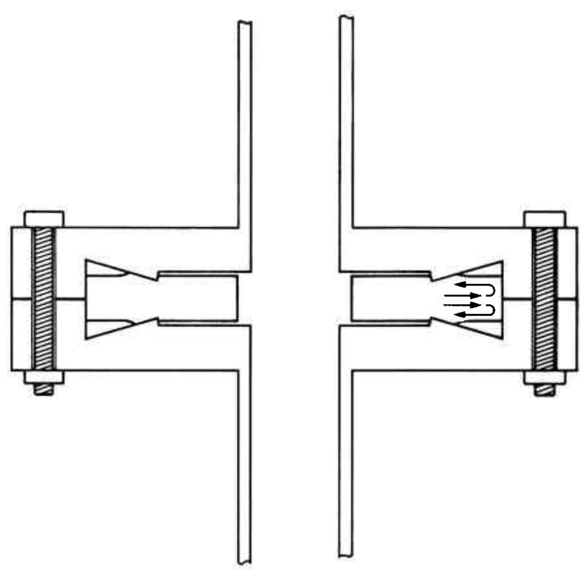
Care is used in selecting the material to eliminate leak paths caused by inclusions or micropipes in the material.

The design has built-in, long-term reliability because it captures the gasket. This prevents the gasket from flowing away from the seal area, even under the most extreme temperature changes. Let's look at the design of the flange, particularly the knife edge.




PARTIAL SEAL

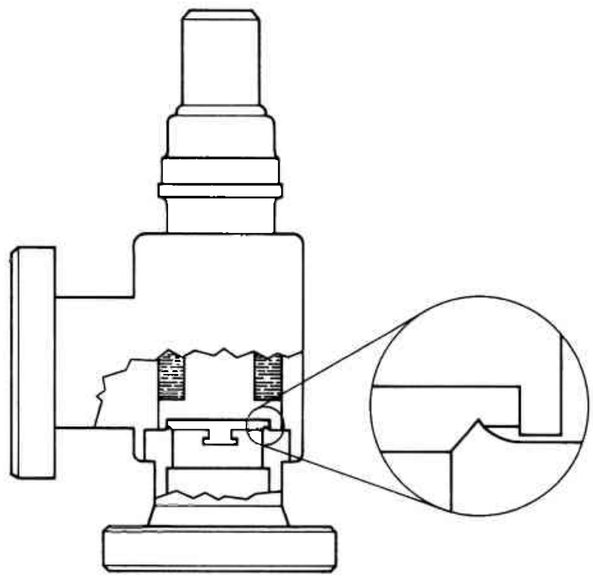
As the flange knife edge begins to bite into the copper gasket, the gasket material flows outward until it butts up against the flange supporting surfaces. At that point, additional outward movement is no longer possible. This keeps the material from flowing away from the sealing surfaces.



COMPLETED SEAL

As the flanges are bolted face-to-face, the gasket material is actually forced inward. This situation develops a tremendous pressure at the sealing edges. In fact, this gasket-capturing geometry develops close to 200,000 lb/in.[2] where the knife edges and gasket come together.

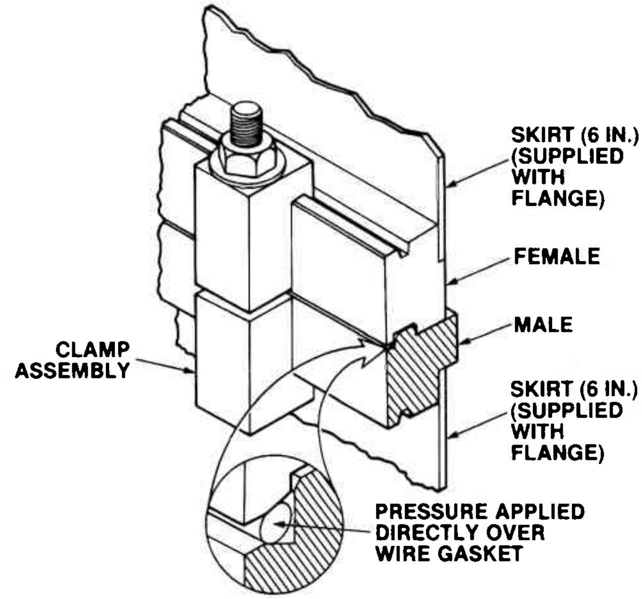
The ConFlat flange seal-capturing geometry is so reliable that it is used in many metal-sealed devices, such as valves and compression ports.



**ALL-METAL VALVE**

The figure shows an all-metal valve, made entirely of stainless steel and copper. The sealing surface inside the valve has a knife edge which cuts into the copper button to seal the valve closed. A valve of this sort can be baked to 450°C if necessary.

Another variation of the all-metal flange is the Wheeler™ flange, which is shown at the top of the next page.



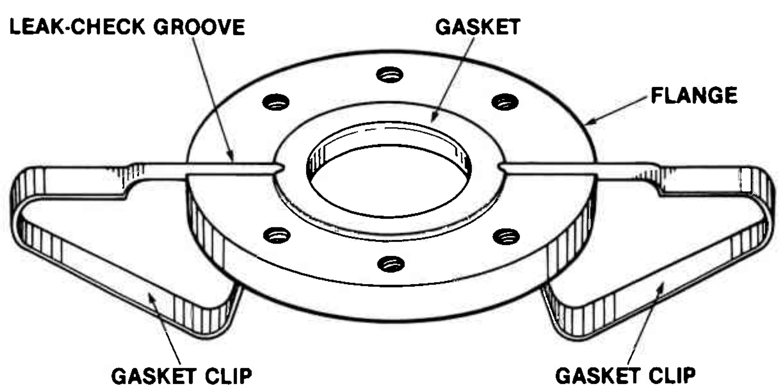

WHEELER FLANGE

This flange is used for larger diameter seals. It seals by forcing a copper wire into a compressed area under pressure, much like the ConFlat flange. The force is applied with large C-clamps. Wheeler flanges may be used reliably up to 450°C.

Here are a few suggestions to think about when using all-metal flanges:

1. The knife edges of fixed flanges are protected because they are set back behind the flange faces. The knife edges are exposed on the rotatable flanges and can be damaged if they are not handled properly. Protect the knife edges by covering them with plastic caps. Never place them on a bench or surface where they may be scratched.

2. The grooves milled across the flange mating faces are helpful. They can serve two functions: (1) for a quick leak check of the flange joint, just spray a little helium into the slot when leak checking; and (2) they will also allow the use of gasket clips to hold the gasket in place while you bolt the flanges together.



3. The bolts used on the ConFlat flanges have a twelve-point head on them. This is not done to frustrate you. It indicates that a high-strength steel has been used for that bolt. A good hardware supplier has the 1/4 in. or 5/16 in. twelve-point wrenches you need to hold these bolts while you tighten them. Lubricate these bolts to prevent them from seizing up (galling). We recommend a high-temperature lubricant such as Fel-Pro, C-100 or C-5A.

4. Don't reuse the copper gaskets. The time spent replacing a leaky used gasket that you just installed is much more expensive than the price of a new gasket.

5. Examine the knife edge of the flange, especially on rotatable flanges, to see if there are any nicks or scratches across the knife edge. The general rule is that if you can feel the scratch with a fingernail, it will leak. The flange should not be used. Some scratches may be burnished out.

6. Tighten the flanges metal-to-metal to insure a good seal and that any mismatched forces are carried through the flange faces, not the gasket.

Let's go on now to look at other joining techniques.

## Cold Welding

Cold welding, or pinch-off, is a common method of sealing OFHC copper tubes such as those on ion pumps and vacuum tubes. After the components are baked and pumped out, the connecting tubes are pinched off. This crushes the tube walls together so tightly that a leak-tight seal is made. This keeps the devices under vacuum.

When you open a pinched-off seal, use a tube cutter. Don't use a hacksaw or some other cutting tool that generates particles. The particles will be drawn into the sealed-off device as the seal is opened. Remember that the copper particles are good conductors, and may land so that they will short out the device (of course, at the worst possible time).

## Brazing

Brazing makes good vacuum joints. Brazing is a high-temperature soldering technique that is done in a hydrogen-filled furnace. The hydrogen atmosphere prevents oxidation at the joints, needs no flux, and allows for careful temperature control. You may have brazed something using a torch for heat. This is also a common process. But unless it is very carefully done, it results in strains which will develop into leaks. It may also leave flux residue which will outgas excessively.

Components that will be brazed are prepared by assembling them in a jig or holder with the brazing material placed between the parts. The brazing material is in the form of wires or gaskets.

They are then placed in the hydrogen furnace under very closely controlled temperature conditions. This is done so that no local heating and stresses occur where the parts are joined. This helps to keep the joints leak-free.

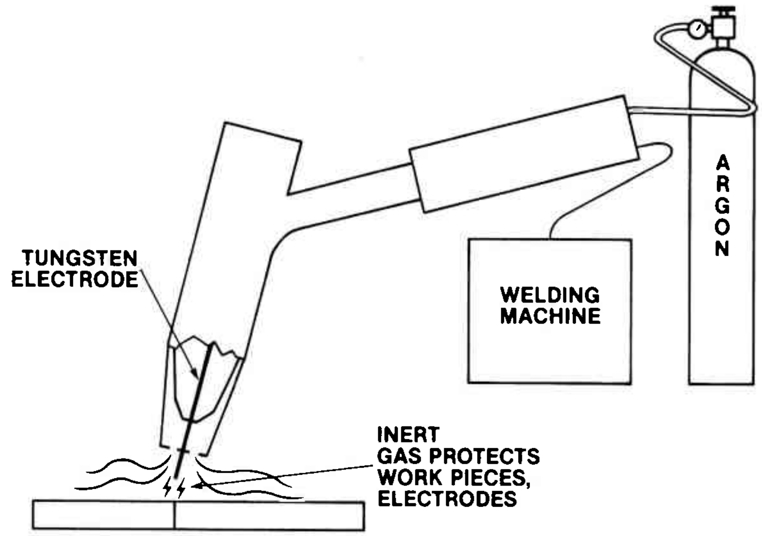
Gold or copper-based alloys are generally used as braze materials. It is possible to do multiple-step brazing by using alloys of varying composition and therefore different melting points.

Brazed joints may be quite strong. However, the material itself may have problems. We commonly use brazing to join ceramics to Kovar™ to stainless steel. The ceramic material is quite sensitive to shocks and tends to crack easily. Treat your brazed joints with care; you will have fewer leaks as a result.

## TIG Welding

Tungsten-inert gas (TIG) welding is a widely used joining technique. It is a form of arc welding that joins parts by fusing them together without the use of filler materials or flux.

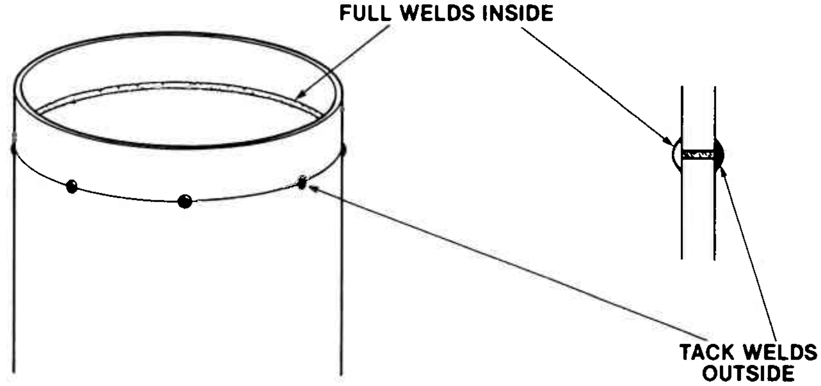
A TIG welding torch concentrates extremely high power at the joints. This makes it easy to weld stainless steel, which melts between 1,450°C to 1,550°C. TIG is also good for joining molybdenum, which melts at 2,620°C.



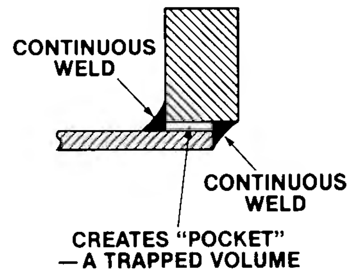

TIG (TUNGSTEN INERT GAS)
OXIDATION-FREE WELDING

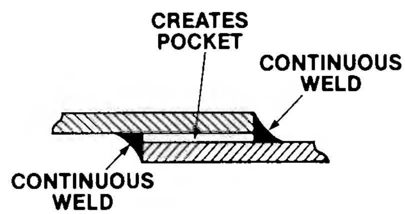
During the welding process, an inert or non-reactive gas, such as argon, floods the welding torch and the joints. The gas protects both the material and the joints from oxidation. This protection allows the welding of materials, such as aluminum, which tend to oxidize very easily if not protected from the oxygen in the air.

When welding parts together for vacuum usage, the weld should be made from the vacuum side of the joint whenever possible. Through welds, welds that penetrate through the material, are quite desirable, but not always possible.



When the full weld is made from the inside but an outside weld is desired for structural strength, the outside weld should be a tack weld, not a complete weld. This makes leaks easy to find and fix. It also prevents virtual leaks that occur because of a trapped volume between the two weld joints.




We'll talk more about leak detection in situations like this when we discuss vacuum systems.

## Glue-Like Materials

There is another joining technique that we should discuss briefly— that is the use of glue-like materials, specifically Torr Seal™. Torr Seal is a low vapor pressure resin which was originally designed to fasten things inside of a vacuum system. It is usable over the temperature range from –45°C to 150°C. The low vapor pressure is due to the fact that it contains no solvent. It does not outgas into your system as it dries. It also has found wide use as a leak sealant.

There may be other joining methods used in the vacuum industry; we don't claim to have covered all of them. However, brazing, welding, and flanges cover most of the techniques. Let's go on now to discuss some of the common components that are used in vacuum systems.

# Components

We have already discussed several components such as pumps and gauges. Let's look now at some of the other components that are commonly found in a typical vacuum system. Valves and feedthroughs will be our major focus.

Feedthroughs are used to get something from the outside world into the vacuum system. Typical examples are electrical, optical, water, instrumentation, high voltage, fluid, and motion feed-throughs, just to mention a few.

Although we will concentrate our discussion on these compo-nents, they do not cover all possibilities, just the more common varieties.

## Valves

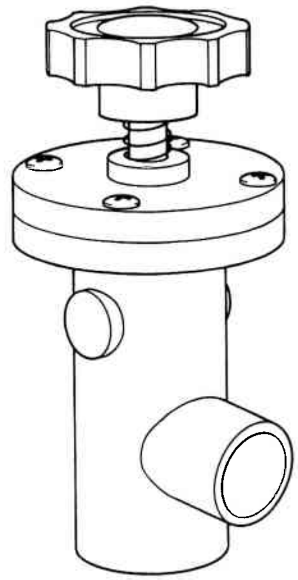
A variety of valves are manufactured for various vacuum require-ments. Each of these takes into consideration factors such as operating vacuum levels, degree of cleanliness needed, need for bakeout, and materials construction.

We will separate valves into several types based first on whether they are elastomer-sealed or all-metal; then, whether they are small or large valves.

Valves also come in hand-operated, pneumatically-operated, and solenoid-operated varieties. Small valves will be defined as valves with inside diameters less than 2 inches. Large valves will be defined as valves with more than 2 inches inside diameter. Valves can also be classified as right-angle, tee, straight-through, back-to-air, variable-leak, gate and slide valves.

Let's look first at elastomer-sealed small valves.

## Elastomer-Sealed Small Valves



These valves use various elastomers to make a reliable, leak-tight interface between the valve seal and the seat. Elastomers are also sometimes used to seal the actuating shaft from the outside environment.

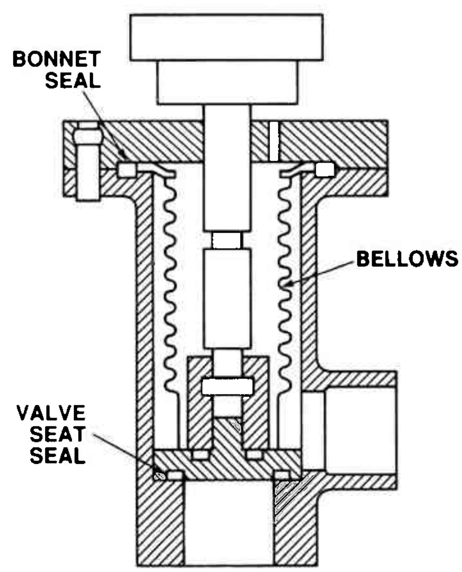
*dynamic seal*

*bonnet*

One variety of valve used for some rough vacuum applications is the O-ring-sealed variety. The seal on the shaft of the valve is a *dynamic seal*, that is, it moves. Therefore, it is subject to a lot of wear and leakage during operation. The portion of the valve above the opening is called the *bonnet*. This type of valve requires much maintenance and attention because of the shaft seal.

*bellows-sealed valve*

This dynamic seal problem can be avoided through the use of a *bellows-sealed valve*.



*static seals*

The valve shown at the bottom of the previous page is an elastomer-sealed bellows valve. All O-ring seals are *static seals*, meaning that they do not move. These valves are much more reliable than the O-ring shaft-sealed valve.

This type of valve has bellows made of brass, aluminum or stainless steel. The price, of course, varies accordingly. The choice of material depends upon the use of the valve.

The stainless steel bellows is generally used in high and ultrahigh vacuum systems. An example where a stainless steel bellows is not chosen is on valves used with sorption pumps. The hot steam that is produced during regeneration corrodes the stainless steel bellows rather quickly. Inconel bellows are therefore recommended rather than the stainless steel bellows.

Viton is generally the elastomer of choice in valves, although other elastomers are also used. Polyimide finds use in special applications requiring higher temperatures or better chemical resistance.

Valve maintenance is not needed often, but valves can cause problems if not properly cared for. Here are some suggestions to help you with your elastomer-sealed valve maintenance:

1. Look at the seals whenever you do maintenance on a valve. Inspect the seals to see if they have been warped, or are nicked or scratched.

2. The pistons on pneumatically-actuated valves need to be lubricated yearly. Most pneumatically-actuated valves are of the air-open, spring-closed variety. Be careful when disassembling the valve so that it doesn't come apart during disassembly.

3. Lubricate the piston on your pneumatic valves with a lubricant recommended for use with compressed-air lines. Please remember that this is not exposed to the vacuum system. This lubricant, which works fine for compressed-air pistons, will cause big problems if used inside your vacuum system.

4. Inspect the bellows for dents or cracks. The brass variety is easy to dent. The dent will cause the bellows to work-harden and crack at that location. You should replace it while you have it apart on the bench.

5. Lubricate the O-rings with a vacuum grease such as Apiezon-L™ or other lubricant as required by your process. Remember that only a very thin film is needed.

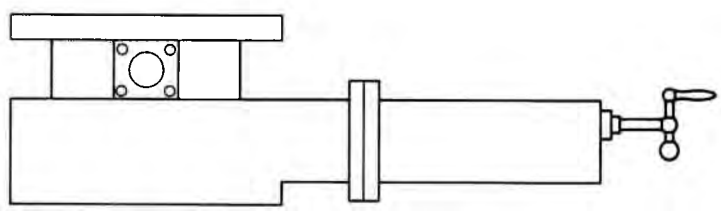
6. The valve should be leak-checked on a helium mass spectrometer leak detector. Don't forget to check the bellows as well as the valve seal and bonnet seal. Leak checking before reinstallation on the system can save a lot of disassembly/reassembly time should a leak be present.

## Elastomer-Sealed Large Valves

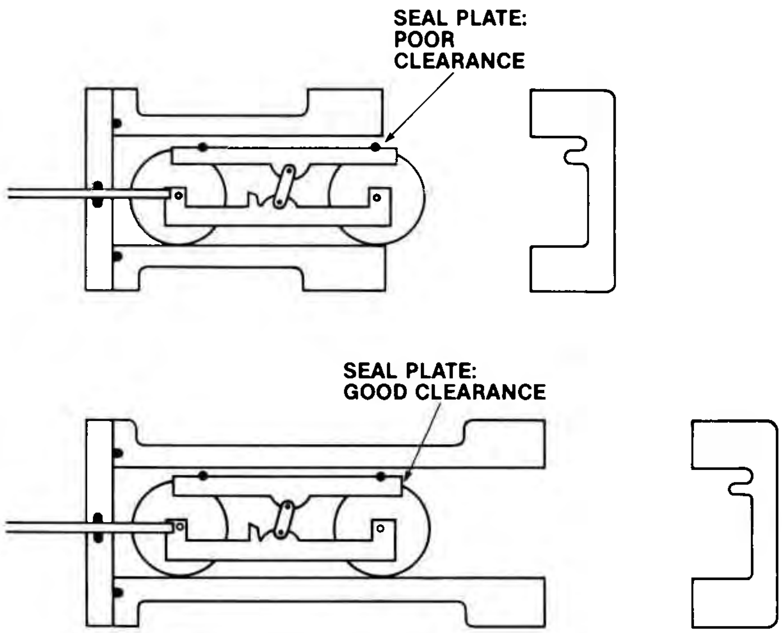
Most industrial applications require isolation of the work chamber from the system pumps. Many processes require that the chamber be alternately cycled from vacuum to atmosphere. Without a valve between the chamber and pump, the cycle time might be too long, or even physical damage to the pump or system components might result.

Valves for these uses are usually of the sliding gate or swing gate design. Typical port diameters of this type are 4, 6, or 8 inches, although much larger valves are available for specialized pumps and applications.

Since the seals in these valves are usually made of Viton O-rings, heat ranges and operating pressures are about the same as those for small elastomer-sealed valves. The valve bodies are usually made of cast aluminum or stainless steel.



The seal plate opens and closes in a gate fashion. That is, the seal plate drops and retracts from the port. In some designs, the plate does not fully clear the port and, therefore, doesn't give maximum conductance. Also, debris can fall on the seal and cause leaks.

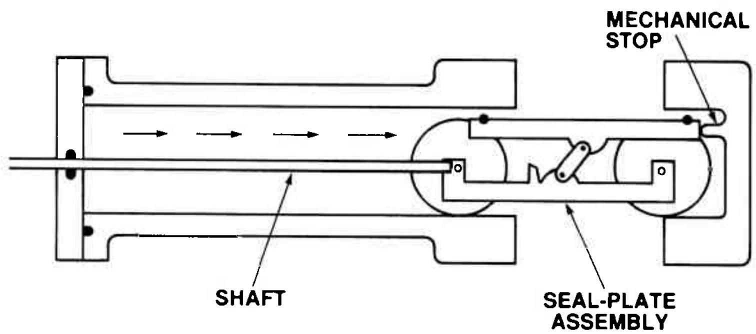



A PREFERRED DESIGN

A preferred design completely clears the ports.

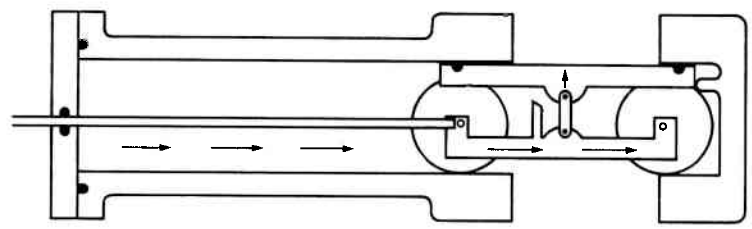
***How the Valves Work***

The valve closes when the shaft drives the seal-plate assembly into the gate until a mechanical stop prevents further forward motion.

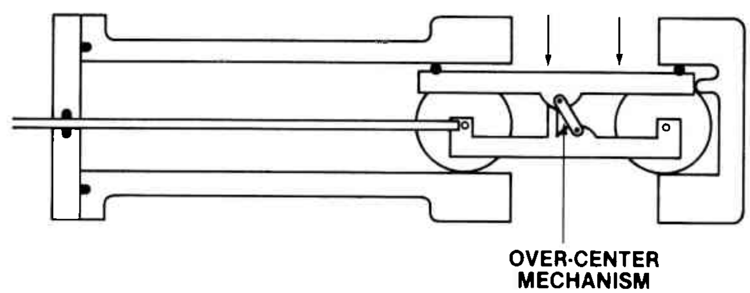



During the forward motion, grease and other debris get into the vacuum environment. And, the longer the stroke, the greater the contamination.

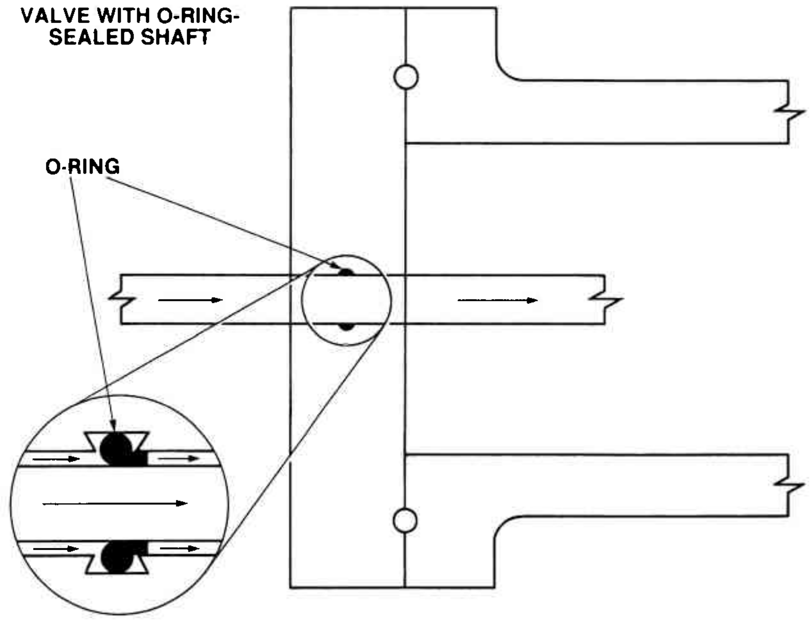
After forward motion stops, further driving motion moves the seal plate up into the sealed position.



The over-center mechanism and second mechanical stop insure that the seal plate is positively locked in the sealed position.

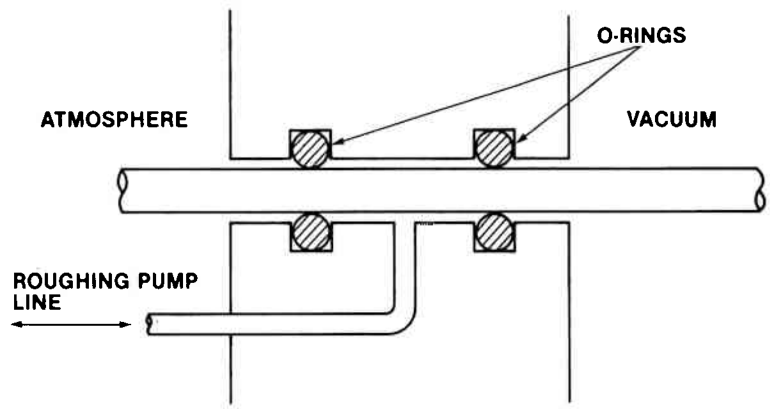



The valves are often air-operated and close with considerable speed and force. It is important to remember to disconnect both air and electricity when working on them.




### *Seals*

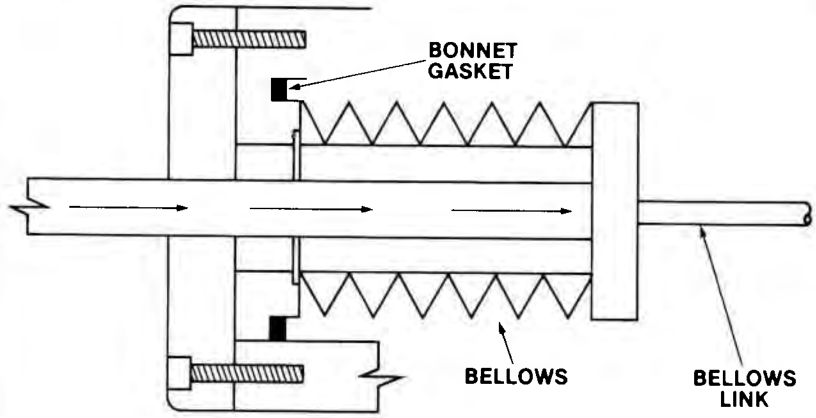
In a valve having an O-ring-sealed shaft, the seal is usually rolled and scuffed. This seriously reduces its life.




VALVE WITH DOUBLE O-RING SEAL

The shaft in the type of valve shown above is often equipped with a double O-ring seal. This double seal provides better separation between the vacuum chamber and atmosphere. This also creates a trapped volume which may result in a virtual leak. The volume between the two O-rings may also be connected to a roughing pump. This is to improve vacuum separation of the work chamber even further. When leak checking a double shaft seal such as this, the line to the rough pump is disconnected. Then both the outer and inner seal can be checked by inserting helium into the space between the O-rings.

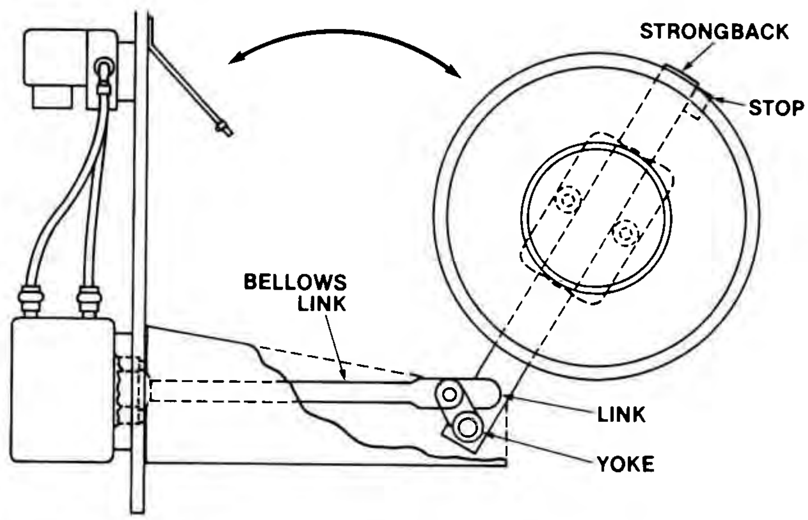
To eliminate contamination problems of the sliding gate valve design, bellows made of brass or stainless steel are often used.




**BELLOWS ACTUATOR ELIMINATES O-RING ROLLING, SCUFFING**

Bellows-sealed actuators eliminate O-ring rolling, scuffing, and wear problems. An O-ring bonnet gasket seals the bellows, but it's a static seal. Therefore, it isn't rolled, scuffed, or worn. The bellows flexes to transmit the valve-actuating motion.

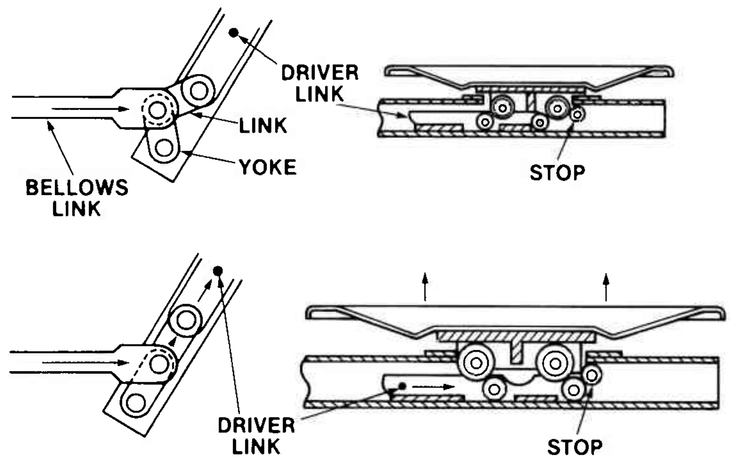
The extension of the actuator piston exposed to vacuum may be welded directly to the bellows. It is called the bellows link. The bellows is limited to the distance it can extend. Because of this, large valves that use this component are designed to "swing" the sealing plate into and out of position.




**HIGH VACUUM VALVE**

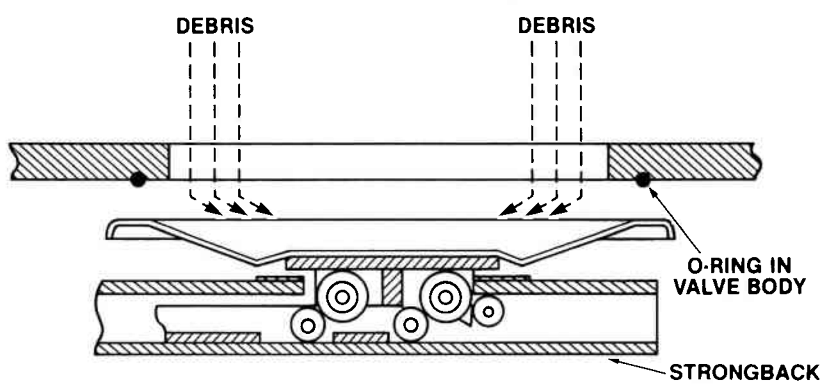
***An Example of an Elastomer-Sealed Large Valve***

A modern large valve design uses a short-stroke, bellows-sealed actuator. The short stroke is made possible by a swinging gate-type mechanism. The short stroke gets the maximum life out of the bellows because it doesn't get flexed very much. And yet, the port is completely cleared, giving maximum conductance. The valve body is stainless steel rather than cast aluminum. All internal bearing surfaces are dry-lubricated. This gives them a very low outgassing rate and contributes to leak-tight operation. They can be baked to 150°C in the open position and 125°C closed. Higher temperatures in the closed position can degrade the O-ring seal, causing leaks.




SEALING ACTION

In operation, the bellows link drives the mechanism to a mechanical stop. Notice the relationship of the bellows link to the link yoke. Also notice the driver link and rollers with respect to the seal-plate rollers. Once the first mechanical stop is made, further actuation spreads the link and yoke. This drives the driver link forward, into the strongback. This in turn drives the seal plate upward, into the sealed and locked position.




The conical shape of the seal plate causes process debris to fall *away* from the seal area. Also, the seal is located in the valve *body* instead of in the seal plate. This location further minimizes the possibility of seal leaks.

### *Maintenance*

The valve should be in the open position for maintenance and cleaning. The air and electrical lines should then be removed.