

Technical Considerations in Selecting and Configuring Welded Vacuum Chambers

You'll ask a lot of your vacuum chamber. Let's make sure it's up to the task.

Introduction

From housing sophisticated process prototypes to simple degassing of epoxies, welded vacuum chambers are fully capable of performing a wide range of processes.

Configuring the right vacuum chamber for a need is an important task. An under-specified chamber may be difficult to work with, or worse, unable to perform at the required levels. An over-specified chamber can be unnecessarily costly. The purpose of this paper is to assist the prospective end-user or buyer of a chamber by identifying and discussing important factors that go into specifying the design of a welded vacuum chamber.

Chamber Geometry

Chambers can be constructed in various shapes to match the needs of a process. There are a handful of popular shapes with basic advantages and disadvantages that are described below:

Spherical chambers are commonly used in focal point applications such as laser deposition or surface sciences, where ports are all needed to point to the same location. Spherical chambers can prove difficult to work with and access internally, and typically are only used when the application absolutely requires it. **Cylindrical** chambers can often be constructed with off the shelf tube and flanges. They are generally inexpensive and easy to assemble, but like spherical chambers, can be challenging to mount and internally fixture. **Cube-Shape** (or "Box" chambers) provide high volume for their size (Figure 1). They are simple to mount,

typically offer large door access, and can easily be fitted for holding removable trays. This makes them a simple, popular choice for general purpose uses.



Figure 1: Cube-shaped stainless steel vacuum chambers are cost-effective alternatives to volumetrically similar spherical chambers.

D-Shape chambers can offer the focal point features of a cylindrical chamber with the convenience of a rectangular door for tray access. They are often used with a spinning substrate tray for PVD (Plasma Vapor Deposition) processes. Both D-Shape and Cube-Shape chambers are generally easy to work inside, with large door access capabilities.

Chamber Material

Stainless steel is a readily available material, often selected for constructing welded vacuum chambers because it is chemically inert, compatible with standard stainless steel vacuum flanges, and easy to weld. Ideal Vacuum's standard line of stainless chambers uses 304L SS, but these chambers can also be made from 316L SS for improved corrosion resistance.

While aluminum alloys are inexpensive and have excellent low outgassing properties,

aluminum chambers require specialized bi-metallic conflat flanges for UHV applications and are reactive to many common process gasses. Aluminum can be more challenging than stainless steel to weld due to its vulnerability to weld contamination and tendency to develop porous weld beads. Aluminum is most commonly used in chambers for rough vacuum.

Interior Wall Surface Treatment

Surface finish and treatment becomes important when considering outgassing of water vapor during system operation. Water vapor molecules adhere to interior surfaces of a vacuum system while it is open, in standard atmospheric conditions. The smoothness of interior surfaces affects not only how much vapor clings to those surfaces, but also how easily that vapor can be pumped off those

A few common vacuum chamber surface finishes are machined, bead blasted, mechanically brushed, sanded, or polished. Standard Ideal Vacuum aluminum chambers have a sanded finish, and stainless steel chambers come with a sanded finish and electropolish. Additional coatings or treatments such as electropolish, nickel plating, copper plating, or anodize can be added or substituted to meet special system requirements. Figure 2 shows the difference between electropolish, mill finish, bead blasted and aluminum oxide surfaces under a microscope. This helps in visualizing the advantage to electropolishing when trying to eliminate chamber wall outgassing.

Temperature Control

Some processes involve controlling temperature during system operation. As covered in other areas of this paper, the appropriate considerations should be made regarding the suitability of a chamber for the temperatures it will see.

For heating chambers above room temperature, electrical **resistive heaters** can be fitted to chamber walls with a PID controller to set heat levels. Heaters can be installed during chamber fabrication or retrofitted onto existing systems if needed.

For applications that require cooling, chambers can be configured to circulate a coolant through machined passages or tube that is welded or brazed to chamber walls. Many chiller systems can cool or heat to set temperatures, making them a versatile choice for both positive and negative temperature control. A **circulating system** is generally more costly than heating pads.

For thermal chambers, materials with high thermal conductivity (such as aluminum) are a popular choice, due to fast response to temperature changes. If corrosion is a factor (such as an environmental salt-spray chamber),

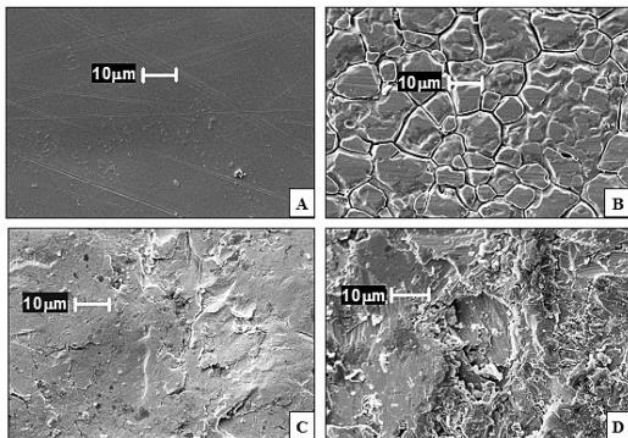


Figure 2: Scanning electron microscopy (SEM) images of clean stainless-steel surfaces at 2260x magnification: (a) electropolished finish; (b) mill finish; (c) bead blasted finish; and (d) aluminum oxide (anodized) treated finish.⁴

surfaces and out of the system.¹ Relatively speaking, rough surfaces will have more issues with outgassing than smooth surfaces and will not perform as well. In chambers that are repeatedly accessed without high temperature bakeouts or purged with dry gasses, this effect will negatively affect pump down speed.

a stainless steel like 316L may be a better choice. In some situations, direct **internal heating** or cooling is more appropriate than external control of an entire chamber. This can be accomplished with in-vacuum heating elements or cooling plates with feedthroughs to supply power or coolant.

Vacuum Chamber Seals

Vacuum chamber systems are generally assembled with either metal or elastomer seals. While variations of each type exist, the general benefits to an elastomer seal are low cost, reusability, and ease of use. Meanwhile, metal seals have superior permeability characteristics, corrosion resistance, operating temperature range, and lower outgassing rates.

Elastomer Choices

Elastomer	Minimum Temperature °C (°F)	Maximum Temperature °C (°F)	H ₂ O (N ₂) Permeability K
NBR (Buna-N)	-34 (-30)	100 (212)	100 (0.024)
FKM (Viton™)	-26 (-15)	200 (400)	5.2 (0.03-0.07)
Silicone	-54 (-65)	200 (400)	400-1000 (10-16)
FFKM (Kalrez™ / Chemraz™)	-30 (-22)	320 (600)	- (0.3-0.88)

Table 1: Common elastomer seals used for vacuum systems and their properties. Units (K) stdCC/sec./cm²/torr x 10^{-10,5,6}

While dozens of materials exist for making elastomer seals, they are usually made from one of four types of rubber; NBR (Buna-N), FKM (Viton™), Silicone, or FFKM (Kalrez™/Chemraz™). Major factors in selecting the proper rubber for an elastomer seal include temperature, chemical resistivity, permeability, and cost. Cost and chemical resistivity are highly dependant on application; consult seal manufacturers' datasheets for chemical compatibility between user specific chemicals and elastomer choices.

Permeability of a seal, or the rate at which gasses "leak" through the seal, can be calculated as a function of the permeability constant, *K*, listed in the chart above, pressure differential across the seal, ΔP , area of seal exposed, *A*, and o-ring cross section, *d*. With these variables, the permeation of a gas into a chamber, *Q*, can be calculated using $Q=K*\Delta P*(A/d)$. For applications that do not require High Vacuum (HV), the permeation loss through elastomer seals is typically acceptable and will not significantly affect system performance.

Temperature plays a large role in any vacuum system, but more so in a system with elastomer seals. As temperature increases, compression set rate increases as well, causing the O-ring to permanently lose its original shape. This effect begins to occur with Viton above 150°C, limiting its max temperature if the oring needs to be reusable to any significant number of cycles. While elastomer seals will generally work once or twice near their temperature limits, they may become hard quickly and need to be replaced. When extreme temperatures are needed, metal seals are the better option.

Metal Choices

Material	Maximum Temperature °C (°F)	Cost
Copper	450 (842)	Low
Silver Plated Copper	450 (842)	Medium
Nickel	450 (842)	Very High
Aluminum	200 (400)	Medium

Table 2: Cost and temperature ratings for typical metal seals used in vacuum systems.

Metal seals, while expensive, can offer the best sealing characteristics possible for a vacuum system. While many materials and standards exist for metal seals, a standard ConFlat™ (CF) style flange generally uses copper, silver plated copper, nickel, or

aluminum. Temperature and cost considerations for these types of seals are available above.

While most metal seals share the benefits of low permeability and low outgassing rates, all metals are not created equal. Copper is the standard for metal seals, due in part to its relatively low cost and ductile properties, but it may not be suitable for all circumstances. Silver plated copper is more appropriate for processes which may require frequent bakeouts or higher sustained temperatures. Nickel will perform better in applications requiring high chemical resistivity. Aluminum is generally used with aluminum flanges that are too ductile to use with nickel and copper seals.

Extra care must be taken while handling delicate knife-edge flanges, as even small defects can compromise their seal. Metal gaskets only seal at peak performance on first use and should be replaced upon disassembly of a flange connection.

In addition to temperature and permeation benefits, specifying CF style flanges sealed with copper gaskets in lieu of elastomeric O-rings in KF or ISO flanges effectively eliminates the flange as a source of outgassing. Mounting semi-permanent fixtures like sensors, gauges, valves, and feedthroughs to CF flanges is an easy way to “set and forget” seals that aren’t subject to frequent change-overs.

Chamber Pressure

The desired ultimate pressure of your vacuum system should factor into decisions made on chamber selection and configuration.

A chamber that must operate at UHV, levels of 10^{-8} torr or lower, will need careful attention to be given to its configuration. The chamber should be constructed with low-outgassing materials and very smooth walls. Metal seals such as CF type are recommended. If elastomer seals are absolutely necessary in any location, differential pumping can be used to limit permeation losses.

Internal surfaces and components should be cleaned thoroughly, and in some cases, bakeout of individual components or the complete system may be necessary to achieve full UHV.

Running a system to HV (10^{-3} - 10^{-7} torr) allows more flexibility in system design. In some cases, the use of high outgassing materials may be acceptable. Elastomer seals may be used freely on connections and door interfaces. Good cleaning and assembly practices are still important, but HV is significantly easier to attain than UHV.

For chambers requiring rough vacuum (Atmosphere to 10^{-3} torr), there are few challenges. In general, a chamber system that does not leak and has adequate pumping will be able to easily achieve the needed vacuum level.

Vacuum chambers are designed and manufactured to withstand large pressure loads under vacuum. For example, a 20 inch square vacuum chamber wall can experience a distributed load of nearly 6000 lbf (2720 kg) during use (Figure 3).

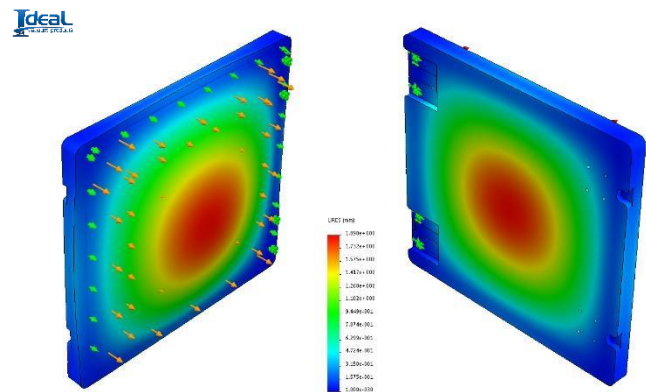


Figure 3: A 20 inch square acrylic door is shown to deflect nearly 0.080 inch under vacuum. If an application requires minimal deflection of internal components, consider structurally isolating them from chamber walls.

Some vacuum chambers may be used to contain positive pressures up to 1 atm with modifications. Note that above 1 atm, positive pressure chambers must be designed and manufactured in accordance with strict codes.

Chambers which will see positive pressure require careful engineering as the consequences of a poor design may be serious.

Vacuum Chamber Doors

Beyond its use as the main opening into a vacuum chamber, the door itself can serve several important functions whose configuration should be carefully considered. For example, clear acrylic doors are an attractive, inexpensive option that can conveniently eliminate the guesswork in knowing what's inside a vacuum chamber. Clear doors also allow direct, visual

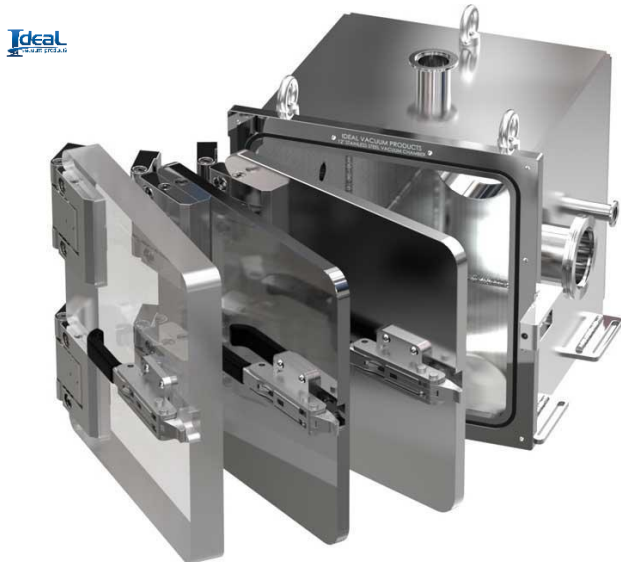


Figure 4: A stainless steel chamber shown with acrylic, aluminum, or stainless steel door options.

observation of a process or performance of some component under vacuum. However, these doors are relatively delicate and are unsuited for a variety of applications that require high temperatures or produce high splatter. Acrylic is also a high outgassing material that negatively impacts pump-down speed and ultimate pressure. However, metal doors can be easily modified with an integrated viewport or standard flange interface for viewport mounting.

Other features worth considering when choosing a door is the ability to mount internal components directly to the inside surface (or for that matter, directly to the outside). Where internal components must be swapped out frequently, as in a production run, door-mounting your component holder turns the vacuum chamber door into an extremely convenient swiveling holder. Stainless steel and aluminum doors must be rigid and resist pressure induced deformation that may compromise the seal.

Chamber Mounting

If the vacuum chamber is to be mounted in a fixed location, we recommend making certain that mounting points are sturdy, electrically conductive, and easy to adjust. Floor standing mounts should be stout and tip resistant. Ideal Vacuum welded chambers are designed for easy tabletop mounting if desired, but it is important to



Figure 5: A fully integrated mobile vacuum chamber system complete with dry rotary pump, turbo pump, and control unit that can be quickly and easily moved to different parts of a facility. The ROI on such equipment can be quickly realized.

bolt or anchor a chamber, even when resting on a work surface. Unsecured chambers which are stable while closed can tip and fall on a user

when a heavy front door is opened. Mounting points on top of the chamber can be useful for stacking multiple chambers. Top-mounted lifting points provide a convenient way to relocate heavy chambers using lifting equipment.

If mobility is needed, consider a heavy-duty rolling cart assembly that can support a chamber, along with the added weight of pumps and accessories. Carts such as the iCart (Figure 5) are designed for easy system transport and setup of a chamber and all its peripherals. Efficiently moving and running a chamber system is possible with integrated power, leveling feet, and adjustable and expandable equipment mounts.

Flange Configurations

Selecting the flanges and connection ports to use on a vacuum chamber is an important decision. Try to consider all the possible chamber connections that will be needed in order to operate your system. What will be needed to run the chamber? What might be needed in the future?

The standard port types Ideal Vacuum offers in a chamber include: KF (NW), ISO, CF, NPT (National Pipe Thread), and Thru-Hole. Matching the right connection types and sizes to chamber peripherals can reduce how many adapters and reducers may be needed in the future. It can be useful to make a list of gauges, feedthroughs, pumps, and other accessories that will be used with the chamber. For example, many chambers will need the following:

- Pumping Ports
- Vacuum Gauges
- Feedthroughs
- Load Lock Ports
- System Vents
- Viewports

It's a good idea to have a few spare ports open on a chamber to handle unforeseen changes on

a system. Extra ports can easily be capped off when not in use.

Selecting Your Chamber

Once you have considered the critical factors and determined which characteristics are appropriate for your application, it is time to consider available options. Selecting or configuring a vacuum chamber can be a daunting process. Ideal Vacuum offers solutions and tools to simplify the task.

In many cases, a **pre-configured chamber** may fill your needs. Pre-configured chambers have already been designed with versatile configurations in many sizes are available off the shelf. These chambers have the advantage of short lead times and relatively low cost, compared with custom solutions. Pre-configured chambers are available with various door options for flexibility.

Assess the placement, type, and size of pre-configured chamber flanges, carefully evaluating if they will work with your process.

If off the shelf options are not adequate and your application requires a **custom chamber**, you may benefit from discussing your system with a vacuum engineer. Custom chambers can be more costly and require more time to design and manufacture, but they can be tailored to fit your exact needs. You may need ports aimed at a specific point or need feedthroughs for sample manipulation. Perhaps your chamber is but one in a series of in-line chambers that have isolated a particular step of a complex process. The Ideal Vacuum engineering team is ready to assist you in creating the right solution for your needs.

In an environment where chamber requirements may change or quick reconfiguration is useful, you may wish to consider a **modular chamber** rather than a welded chamber. Modular vacuum chambers such as the patented Vacuum Cube system allow quick and inexpensive reconfiguration of

chamber walls with off the shelf plates and accessories. This can lend a significant advantage when comparing against the time and cost of recutting and rewelding a fabricated chamber when modifications are required.

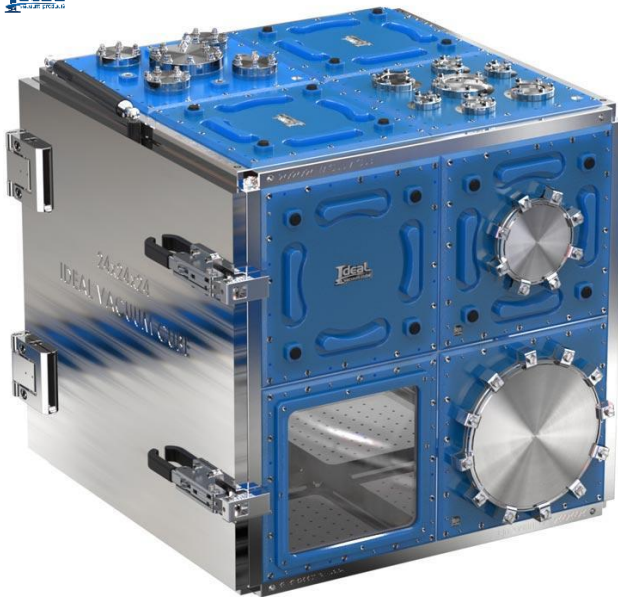


Figure 6: A 24in. X 24in. Modular Vacuum Chamber that includes 20 different, changeable 12in X 12in plates. Changing the plates and completely re-configuring this vacuum chamber requires nothing more than an allen wrench.

Conclusion

Determining the appropriate vacuum chamber for your application requires considering the factors outlined above. Some requirements may be readily apparent, such as size, pressure, and port configuration, due to the purpose of the vacuum chamber. You know that you need to fit an object into the chamber of a certain volume, that needs to be pumped down to a particular pressure and needs to have compatible flanges to connect to your pumps and accessories. In some cases, process requirements will influence other decisions, such as selecting appropriate seals for a UHV or a corrosive environment. Finally, other considerations such as mounting and surface finish may strongly influence how you use your chamber. With this in mind, you

can weigh these requirements against the timeline and budget of your project to determine which chamber is most appropriate for you.

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