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From The Vacuum Lab

By Phil Danielson

Nitpicking Your Vacuum System

Detailed system analysis is a painful process that can make all the difference between a successful design or a total failure. It's all a question of mindset.

It comes as no surprise to vacuum practitioners that vacuum technology is a difficult and unforgiving discipline. Although there are often hundreds of small decisions to make in designing a system, each and every one has to be either the right decision, or close to it, to achieve the best performance. In fact, anything less than the very best possible performance is often regarded as a failure. If a system doesn't pump down to the vacuum level required for a process specification, the process can't be run. It's a black and white world.

Daunting as this might sound, developing a particular mindset and the required skill to apply that mindset into a practical technique can minimize the pain of failure that is all too common. If the devil's in the details, then pursuing the details becomes an obvious need. Bluntly stated, this technique is called nitpicking.

Mindset

The mindset that's required to find the possible, or real, problems that will affect performance is an extension of "what's wrong with this picture?"-type analysis. Important as this kind of overview can be, it's necessary to dig through the system in layers of increasing detail. Consider a system that suddenly won't pump down as well as it previously had. There's a good chance that it's leaking air. A rough and cursory leak check might not show a leak to be present, but a more detailed, careful, and sensitive leak check might show several medium-sized leaks, or it might show a large number of really small leaks. In either case, the amount of leakage is additive to the point where the system's total leak rate is fairly large. Although this example would apply to trouble-shooting an existing system, variations will apply to either a new design or attempting to improve an existing system.

Taking a System Overview

It would be a waste of time and effort to attempt to make a detailed analysis of a system unless the overall design is acceptable to the point where it will totally meet the requirements of its intended process. This is usually accomplished by taking a macro-analytical look at the system and answering some basic questions. Is the pumping speed adequate, and are the roughing and pumping lines arranged to provide maximum conductance? Are the gauges arranged such that reliable pressure measurements can be accomplished?

An overall look at the system design at this point is relatively straightforward, but is necessary to, at least, partially establish a fixed design stage before proceeding to peel back the layers of a detailed analysis.

Analytical Criteria

If we consider the fundamental vacuum relationship Q (gas load) = S (pumping speed) x P (pressure), we can see that, once a pumping speed is defined, better pressure performance will result from ensuring that the gas load is as low as possible within the constraints of practicality. This stage is really where the onset of system nitpicking begins. Obviously, system atmospheric leaks have to be eliminated as a first step, but then it becomes necessary to consider other sources of partial gas loads.

Virtual leaks are one of the most common sources of unwanted gas loads. Virtual leaks are volumes of internally trapped gases that will slowly discharge the trapped gas into the chamber. They can range from milliliters of volume at the end of a blind-tapped-hole to adsorbed water vapor constrained between two planar surfaces in close contact with each other. Although it's virtually impossible to build a working system without, at least, some virtual leaks, it's necessary to avoid as many as possible. The most common technique is to provide some sort of pumpout space. For example, a blind-tapped-hole virtual leak can be relieved by providing a drilled-through hole along the screw's longitudinal axis. Once the major virtual leaks are dealt with, the small ones require the same attention. As with real leaks, a myriad of tiny virtual leaks will result in a additive gas load.

Surface area is another major source of gas load that is easily overlooked. Adsorbed water vapor will desorb from all internal surfaces, so it's a good plan to slowly work your way through the system in an attempt to reduce the surface area. A good example is that of flexible and insulated electrical conductors that are insulated with ceramic fish-spine beads. If it's possible, removal of the beads will greatly reduce the surface gas load. Additionally, using solid conductor instead of stranded wire will make a marked difference. Attention to this sort of detail will slowly chip away at the total gas load.

The materials exposed to the vacuum will be a major source of gas loads. Materials of construction is, in general, an important subject to start with when considering this criteria. A chamber, for example, that's made from wrought aluminum will have a much lower outgassing rate than will cast aluminum. Total surface area and porosity are prime considerations.Additionally, materials that are used within the chamber require a hard look. Brass is porous and contains zinc which can vaporize, especially if heated by the process. Cadmium or zincplated screws should also be avoided. Easy to machine metals such as 303 stainless steel which contains sulfur is another common malefactor. Although it is sometimes necessary to allow organic materials, such as plastic substrates, into a system, other plastics should be avoided or limited. The list of problem materials is too long to totally describe in detail, but the necessity of carefully considering any and all materials is essential. The stringency of materials limitations is, of course, dependent upon the degree of vacuum required by the process, but the thinking is still the same in maintaining the lowest possible gas loads.

A Vacuum Nitpicker's Checklist

Overview
- **Is pumping speed maximized?**
- **Is pump/chamber conductance maximized?**
- **Are pumps properly sized?**
- **Are gauge locations sited for accurate readings?**

Gas Loads
- **Virtual leaks?**
- **Is exposed surface area minimized?**
- **Are all materials check for minimum outgassing?**
  - **Bulk gas content?**
  - **Permeation?**
  - **Vapor pressure constituents?**
- **Vacuum seals**
  - **Minimum O-ring and/or vacuum baked**

The demountable vacuum seals themselves should come under consideration at this point. Elastomer O-rings, for example, can be a major source of gas loads; both outgassing and permeation. A survey of the sealing applications can find places to substitute metal gaskets for elastomers. Any seal that isn't disassembled often is a candidate for substitution. A single linear cm of an unbaked Viton O-ring will have the same outgassing rate as 100 cm^2 of a stainless steel or aluminum surface. If a metal gasket cannot be substituted, a linear cm of vacuum-baked Viton O-ring will only provide a gas load equivalent of 10 cm^2 of surface.

What Did I Do Wrong?

What did you do wrong, is the result you should expect to attain by a detailed, nitpicking system analysis. If you can't answer that question, it's probably time to reconsider the mindset question. There are just too many details involved with a vacuum system design to catch all of the problems initially. It can be done, but be careful. Those seemingly insignificant relaxations can easily add up to a major performance failure. In fact, once the details are cleaned up, it's often useful to take another hard look at the overall design of the system. Problems can easily be interactive to the point where changes in pumping speed might well be required to meet gas loads that cannot be reduced further. This is also the point where an analysis of the process will need to be reconsidered in light of additional problems that might be introduced. For example, many processes will generate heat sufficient to raise part of the system temperature to a level where materials that are adequate at room temperature might start to outgas heavily.

The Final Result

Once the detailed layers are peeled back and examined under a metaphorically harsh light, a much fuller understanding of the performance of a system is usually achieved. This condition is not only useful to an initial system design, but can be essential to obtaining better performance from an existing system.