White Paper

Troubleshooting a Vacuum System

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Introduction

Monday morning you arrive at the plant and start up the vacuum system and it will not behave. The chamber hangs up at 5 millitorr or 0.8 millitorr and there you are. Your ability to diagnose the problem and restore the system to its normal behavior will depend on how well you have been prepared for this crisis.

This paper is intended to assist operating personnel in making routine analysis of vacuum problems. The key points of this paper concern the orderly recording of normal operation for purposes of comparison to existing conditions, and secondly, the isolation of various sections of the pumping system to narrow down the probable causes of performance deterioration.

The key to the solution of the problem is the word normal. If you are to proceed on a logical course of action to solve the problem, a careful definition of "normal" performance is essential. Figure 1 shows a typical high vacuum system. The records refer to time-pressure records of typical pumpdown cycles.

C	Chamber
IG	Ionization gauge
TC	Thermocouple gauge
AR	Air release valve
HVV	High vacuum valve
RV	Roughing valve
FV	Foreline valve
MB	Mechanical booster
RP	Roughing pump
CP	Control panel
FD	Fixture drive
PF	Power feedthrough
DP	Diffusion pump
HP	Holding pump

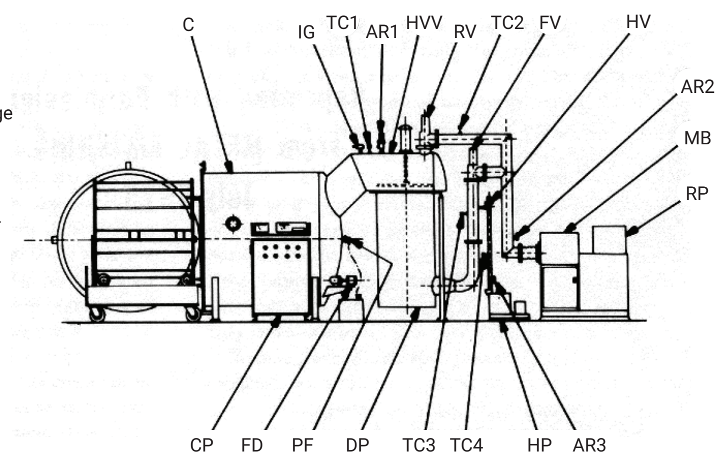

Figure 1. Vacuum system diagram.

Typically, thermocouple vacuum readings will be available at the chamber TC1, foreline TC3, and hopefully at the roughing pump TC2 and at the holding pump TC4. The ionization gauge at position 1G will read high vacuum at the chamber. The time to reach vacuum levels could be recorded for pumpdown cycles, for example, at the following points: 1 torr, 500 millitorr, 200 millitorr, 100 millitorr (open high vacuum valve), 1 millitorr, 5×10^{-4} torr, 2×10^{-4} torr, etc.

If your process pressure is lower, significant vacuum levels to the process pressure should be recorded. The roughing line and forepump pressures should be recorded on a daily basis with all valves closed.

Assuming you have recorded the data periodically, you are now in a position to proceed with a routine check of the system, comparing its performance with the normal information.

Roughing line and forepump

Assume that you are unable to pump the system below 0.5 torr with only the roughing valve (RV) open. A quick check of vacuum instrumentation error is available by reading gauges 1 and 3. If they read approximately the same, conclude that the instrumentation is adequate. If one is substantially lower, replace the gauge tube that reads higher.

Close the RV, and note the pressure at TC2. If the pressure remains high compared to normal, there are two possibilities to be explored: the roughing pump is not operating properly, or there is a relatively large leak in the roughing line.

The most common cause of poor vacuum in the roughing line is contaminated mechanical pump oil. This is usually evident from the milky appearance of the oil in the sight glass. Drain, purge, and clean the oil reservoir, and refill it with clean oil. If there is no oil flow, check the solenoid valve on the mechanical pump for proper operation. Replace it if defective; if not, remove and clean the oil lines. Tighten all connections on the oil line. If all else fails, follow the manufacturer's instructions. If the pump does not respond by lowering the pressure after these checks, it would indicate more serious problems with the pump, or a leak. The next step would be to disconnect the manifold and place a steel plate with a gauge on the pump inlet flange. If the pump pressure is reduced to below 25 microns, assume that the problem is a leak in the roughing manifold. Leak detection is discussed later in this paper. If the pressure approaches the previous reading, further work on the mechanical pump is indicated. Check the shaft seals for leakage, check the exhaust valve for proper operation, and check the gas ballast valve.

Checking the diffusion pump

Reassemble the manifold to continue troubleshooting. Assuming that the roughing line is now at a respectable pressure, you can continue the process.

Next, with the foreline valve (FV) closed and the holding line valve (HV) closed, check the holding line pressure at TC4. If it is below 25 millitorr, all is well. If it is substantially above 50 millitorr, repeat the mechanical pump checks process.

Open the HV and pump out the diffusion pump up to the high vacuum valve with the diffusion pump cold. Check thermocouples TC3 and TC4. They should read approximately the same, and the pressure in the foreline should be reduced to approximately 50 millitorr. At this point, open the FV and evacuate the diffusion pump up the high vacuum valve with the RV closed. Thermocouple gauges TC2, TC3, and TC4 should read approximately the same. If a gauge reads substantially higher than the other, replace the gauge tube. Compare the pressure reached with the previously recorded normal pressure in this condition. Assuming that the pressure can be reduced to below 100 millitorr, the system is operable. If the pressure is below 50 microns, there are no problems worth pursuing further.

If the pressure in the cold diffusion pump section exceeds 100 millitorr, in-leakage is probable, but it may also be caused by condensed water in the cold pump or manifolds, or by the presence of high vapor pressure contaminants.

A few drops of liquid water represents a substantial amount of gas when it is evaporated. Water at room temperature has a vapor pressure of approximately 20 torr. If the system pumps to 20 torr and stalls, suspect water in the system. As liquid water will be evaporating at a high rate with an accompanying drop in temperature, it can usually be detected by condensation or frost on the external surfaces.

Assuming the problems noted above are assessed and corrected with the exception of leaks, which will be discussed later, we can now concern ourselves with the performance of the system at lower pressures. The diffusion pump power is on and the system is operating in high vacuum mode. Assume the problem is long pumpdown cycles to the operating pressure.

The diffusion pump is basically a relatively trouble-free device as it has no moving parts and requires only proper water flow, proper power input to the heaters, and the correct charge of clean pumping fluid. Extensive damage to the internal jets or incorrect assembly of the parts can have an effect on pumping speed and back-streaming. A routine check should be made whenever a problem is encountered to ensure that the heaters are drawing the rated amps. The outlet water temperature should be kept at 100 to 130 °F. Water flow should be adjusted to maintain outlet water temperature in this range. If you are using a pump fluid that is durable, a check of the oil level is sufficient at this point. If, however, you are using one of the lower cost fluids, it may have been decomposed and require cleaning the pump and a fresh change of fluid. The life of the fluid is dependent on the exposure when hot to relatively high pressures. Excessive loss of pump fluid suggests misoperation of the valves that are opening either the FV or the high vacuum valve (HVV) at pressures in excess of the tolerable pressures specified by the pump manufacturer.

A slow pumpdown is normally associated with high gas loads. This is evident by high foreline pressures if the diffusion pump is operating correctly. The diffusion pump will be moving a relatively large mass of gas when pumping at 100 millitorr down to below 1 millitorr. It is normal for the foreline pressure (TC3) to rise to 200 or 250 millitorr during this part of the pumpdown, and the pressure will decrease rapidly as the chamber pressure is reduced to below 5×10^{-4} torr. As noted before, your records should indicate "normal" operation and the foreline pressure is a key to diagnosis. If the foreline pressure is below normal, the condition of the diffusion pump is suspect; if the foreline pressure is higher than normal, high gas loads in the chamber or leaks in any part of the system are suspected.

High gas loads

High gas loads in the system can come from two sources, leakage and outgassing. Outgassing is any gas that is absorbed in the chamber, work fixtures, substrate, or component surfaces. The gas evolved is usually predominantly water vapor but may also be volatile materials coming out of plastics, lacquers, or lubricants. As both leaks and outgassing have the same effect on pumpdown or on the minimum pressure achieved, check to determine the nature of the problem. Make checks both with an empty chamber and with fixtures and your product inserted.

To make a meaningful diagnosis, a record of normal operation is required. Assuming the problem is that the system pumps to the processure pressure in a longer time than usual, the system can be checked by the following procedure:

1. Pump the system from atmosphere 2 or 3×10^{-4} torr, recording the time it takes to pump from 100 millitorr to 2 or 3×10^{-4} torr.
2. Close the HVV, and allow the pressure to rise to 100 millitorr.
3. Open the HVV and record the time to reach 2 or 3×10^{-4} torr. If the two times are approximately the same, the bulk of the gas load is from in-leakage. If the time is shortened substantially, say by a factor of 2 to 5 or more, the bulk of the gas load is from outgassing. You must have a record of normal performance as the outgassing condition may be related to a normal gas load from your product. A gradual increase in this outgassing rate is expected as coatings accumulate in the chamber. At some point, this gas load becomes intolerable and a general cleanup is indicated. The most traumatic occurrence of this type of gas load comes in the spring when the heat is turned off in the plant. The relative humidity shoots up from an arid 10 to 20% to 50% or higher, and the accumulated spongy coatings absorb large amounts of water vapor. The result is a long, slow pumpdown. If your problem is outgassing, the only cure is a thorough cleaning of the chamber and fixtures.

Testing in-leakage

We have now covered the basic problems with the exception of in-leakage. Leaks of any magnitude should not be tolerated as they are costing you valuable process time and product quality. Having made checks of the system and compared the data with the normal data, you may have determined that a portion of your problem is in-leakage.

The procedure for detecting leaks varies substantially with the size of the leak. If you cannot reduce the pressure below 1 torr, you should be able to hear the leak hissing. If the pressure is below 1 torr, cigarette smoke can sometimes be used to find the point at which it is being sucked into the system.

If the system can be pumped below 100 microns, the points of suspected leakage may be checked by squirting them with acetone or Freon and watching the thermocouple gauge. Do one point at a time, and watch response. The gauge response may be needle deflection in either direction. The acetone may temporarily plug the leak, causing a drop in indicated reading, or it may go through and cause an increase in indicated reading as it will lower the temperature of the thermocouple. This is a makeshift method, and results are unpredictable.

The device used by vacuum equipment manufacturers to find leaks is the mass spectrometer leak detector. This device is basically an ionization gauge tuned for reading the partial pressure of helium. As the normal background of helium in the air is very low, traces of the gas introduced into a vacuum system can be detected readily.

The standard commercial leak detector is more complex than a portable unit. It has a diffusion pump, liquid nitrogen trap, a series of valves to permit pumpdown of the helium sensing tube to 10^{-5} torr, and throttling valves to allow the introduction of the gas sample into a helium sensing tube.

The portable unit has a remarkable innovation in the method of introducing the gas for analysis. The portable system has all the sensitivity you would need for system leak checking, as it is only slightly less than the more complex instrument. It only requires 115 V power input and a container of helium. Liquid nitrogen is eliminated and it can be started up with a known leak.

By applying helium to the part, the point of leakage is found and can be sealed temporarily using electrician's putty or silicone putty until a permanent repair can be made. Do not use varnishes or glyptal as they ultimately dry, crack, and make further leak testing or repairs more difficult.

In leak-testing a system:

1. Isolate the various sections of the manifold to locate the portion of the system that has the leak.
2. Connect the leak detector to the system at AR-2 and proceed with the helium check.
3. Probe the sections with helium in the order of probability of leakage:
    1. All sliding seals such as valve shaft seals.
    2. Rotating seals such as fixture drive seals.
    3. Compression seals and threaded joints on vacuum gauges, plugs, etc.
    4. Bellows shaft seals on valves.
    5. Flexible connectors in piping.
    6. Gasket and O-ring seals on valve discs, chamber doors, and removable flanges.
    7. Static gasket seals on sight ports, feed throughs, and manifolds.
    8. Welds and braze joints.

The leak detector can also be used with a probe to find leaks if your part can be pressurized. The part is filled with helium, and using the probe which is itself a carefully calibrated leak, the part can be checked with the probe and the point of leakage determined.

The above suggestions represent a method for checking a system that is in use and has been performing satisfactorily. The rate of rise indicated by TC1 was not rioted as it varies substantially with the volume of the system, the type of product, the room humidity, etc. A normal rate of rise, if recorded, should be qualified for temperature, relative humidity, type of product, and with and without fixtures. The rate of rise is significant only when compared to a well qualified norm.

With a good set of records and a few checks, you can establish an orderly program to restore the vacuum system to normal operation. You may even establish new normal reduced cycle times or improved product.

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