EVALUATION OF DRY, ROUGH VACUUM PUMPS

PART V

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EDITOR'S NOTE:

This is the fifth in a series of articles based on an evaluation of dry roughing pumps performed by ASRC Aerospace Corporation for NASA. Thirteen pumps from various manufacturers were evaluated. The series will be roughly broken up into topics such as long term tests, pumps speed tests, voltage variance and vibration tests, static leak tests, exhaust restriction tests, and other performance tests; followed by a product summary. The test results found in this report, while unbiased, do not reflect the opinion of VT&C.

STATIC LEAK TEST

When a vacuum pump is turned off, gas will leak back through the pump and into the vacuum system at a certain rate. The purpose of this test is to quantify the rate at which this flow occurs. This backwards gas flow can contaminate the vacuum system with particulate and/or oil in the pump or exhaust system. The amount of oil and particulate entrained in the gas stream is related to the velocity of gas traveling back through the pump. However, results are traditionally presented in units of mass flow rate, not volumetric flow rate or velocity. Although mass flow rate is constant through the pump while choked (vacuum system is at approximately 350 torr or less), the velocity changes with the cross sectional areas encountered as the gas travels back through the pump, with the highest velocity occurring at the smallest cross-sectional area (the choke point). The cross sectional areas and the resultant velocities in sections of the pump must be considered when interpreting results for the mitigation of contamination.

Reasons other than contamination are important when considering static leak rate of pumps. Some systems assume the pump is leak tight, such as a vacuum chamber being vented with a gas. Consider a chamber being evacuated with a vacuum pump to remove oxygen and then filled with a flammable gas at sub-ambient pressure. If the pump is assumed to be leak tight, no flammable condition could occur. However, air leaking back through the pump provides oxygen and could possibly create a flammable condition over time. Turbo molecular pumps also require a small gas load to spin down properly. In systems without a vent valve, this job can fall to the backing pump, although this can cause other issues. Too high of a leak rate can damage the turbo pump by "crashing" it or contaminating the system with particles, and too small of a gas load will not allow the turbo to spin down in a reasonable period of time.

Leak tightness of pumps was determined by pumping down a pressure vessel equipped with a Granville-Philips 275 Mini-Convectron gauge. With this gauge, the vessel had no detectable leak (<0.1 torr) over a 1 hour period (< 0.02 sccm). Pumps were allowed to reach their ultimate pressure for several minutes and then were turned off. Pressure values were recorded at 15 seconds, 30 seconds, 1 minute, 5 minutes, 10 minutes, 15 minutes, and 30 minutes. Graphs of the data quickly became linear for all pumps. The slope of the linear portion of the line represents the leak rate in torr/min. When multiplied by the vessel volume, the slope is the leak rate in torr-L/min. All leak rates are shown for air. If a pump has been pumping helium into an exhaust plenum or manifold, the helium remaining in the manifold will travel backwards through the pump at a rate far exceeding the value for air.

Table 8 shows the leak rate in air for various pumps. The leak rate exhibited by the pump is influenced by several factors. The number of effective pumping stages, especially for diaphragm pumps, is one indicator of how leak tight a pump will be. Valve size also affects the leak rate. The larger the valves in a diaphragm pump, the higher the leak rate will be because of the greater area for leakage to occur. For scroll pumps, the leak rate varies widely, even within manufacturers. The primary source for leakage likely occurs at small gaps between the orbiting and fixed scrolls, where there is no sealing material to prevent it. Roots pumps exhibit poor leak-tightness for this very reason. There are no contacting parts, which means there are gaps between the individual stages where gas can leak back through.

The Iwata ISP 250 has a surprising trend which appears approximately 10 minutes after the pump is shut off. The indicated pressure inside the vessel actually decreased with time. This test was repeated a second time, and data was consistent with the previous run. One possible explanation for this is thermal adsorption coupled with a very low leak rate. As the pump body cools, water vapor, which makes up a significant gas load, adsorbs to the surface which reduces pressure. If this occurs at a rate higher than air leaking back through the pump, the pressure trend will be negative. Further investigation would be necessary to test this hypothesis, such as running the test for a longer period of time.

The Varian SH 100 is equipped with a solenoid inlet valve that seals the chamber from the pump when power is lost. This is responsible for the very low leak rate observed, although this can increase turbo spin downtimes. The TriScroll 300 seals poorly. It is unclear if this is because the pump has poor clearances, tip seal leakage, or if it is an inherent result of its design.

The ME 16 arrived with inlet flange damage it received during shipping. Although the pump did reach specified ultimate pressure, it was felt that this damage could contribute to an artificially high leak rate, and this test was not performed.

EXHAUST RESTRICTION TEST

Tubing and fittings used to route the exhaust of the pump away from personnel and equipment can have a significant resistance to flow. Often, this exhaust plumbing can be quite long. The maximum permissible exhaust pressure for a vacuum pump is typically only slightly above atmospheric pressure. With high

Table 8. Leak Tightness of Various Pumps in Air

Pump	Type	Use	Leak Rate (Torr-L/Min)	Leak Rate (SCCm)
Adixen ACP 28	Roots	Transport	2.23	2.93
Vacuubrand ME 16	Diaphragm	Transport	—	—
Iwata ISP 250	Scroll	Transport, Sample	-0.12	-0.16
Edwards XDS10	Scroll	Transport, Sample	0.11	0.15
Varian Triscroll 300	Scroll	Transport, Sample	2850	3750
Vacuubrand MD 4 Vario	Diaphragm	Sample	0.34	0.45
Vacuubrand MZ 2D	Diaphragm	Sample, Backing	0.46	0.61
Iwata ISP 90	Scroll	Sample, Backing	1.77	2.33
Edwards XDS 5	Scroll	Sample, Backing	0.18	0.24
Varian SH 100	Scroll	Sample, Backing	0.07	0.09
Edwards XDD1	Diaphragm	Backing	0.13	0.17
KNF Neuberger 84.4	Diaphragm	Backing	0.29	0.38
Vacuubrand MD 1 Vario	Diaphragm	Backing	0.17	0.22

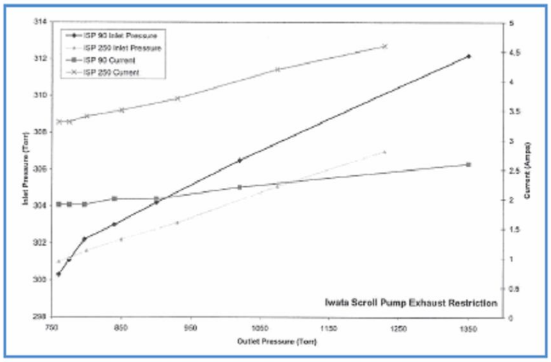

Figure 34. Typical Exhaust Restriction Curves

flow rates and long tubing and fittings on the exhaust it is easy to exceed the maximum exhaust pressure specification. For example, 40 sLpm of nitrogen through a ½" line, 130 feet long, and exhausting to atmosphere requires 2000 torr of pressure, more than twice the exhaust pressure specification for most vacuum pumps. This test attempts to quantify the effect exhaust pressure (exhaust restriction) has on the pump. A throttling valve was installed on the exhaust of pumps operating in air at 300 torr. By partially closing this throttling valve, the exhaust pressure could be increased and the inlet pressure and current demand recorded. A graph of inlet pressure vs. outlet pressure was developed, and all graphs were linear. **Figures 34** shows a typical graph. The slope of this line (dP_{in}/dP_{out}) is the sensitivity to exhaust restriction. A pump with a sensitivity of 0.300, for example, will have an inlet pressure rise of 0.300 torr for every torr the outlet pressure increases above atmospheric pressure.

All graphs presented are for air. Pumps showing a high sensitivity to air will likely have a much higher sensitivity to helium. This is important to remember when designing exhaust plumbing for systems operating in helium. One advantage to helium, however, is that it requires less pressure differential for a given flow rate than air or nitrogen does. This makes exhaust pressure less at a given flow rate compared to air or nitrogen, even though sensitivity will increase. Pumps had exhaust restriction tests performed on them while operating in air at 300 torr. **Table 9** shows the sensitivity to exhaust restriction, the type, and candidate uses for various pumps.

The number of effective stages has a strong effect on the sensitivity to exhaust restriction. Single stage diaphragm pumps, such as the ME 16, were most susceptible to exhaust restriction. The KNF 84.4 four stage diaphragm pump showed the least amount of sensitivity. Scroll pumps have a large number of effective stages due to their concentric design, and are not very sensitive. Although the ACP 28 has five stages, it is quite sensitive to exhaust restriction due to the clearance between the pumping lobes. In addition, the current demand of the pump became very unstable above an outlet pressure of 850 torr. This could indicate imminent pump failure, although exhaust pressures as high as 1150 torr were reached without damage to the unit.

Pumps typically require higher current as the exhaust pressure increases. This is because the pump must compress the gas at the inlet side to higher pressures, requiring more work to be done on the gas. There are exceptions, however. The Vacuubrand ME 16 has significant drop in current demand from atmosphere to 850 torr. Above 850 torr, the current rises until it surpasses the current demand at atmospheric pressure at approximately 1000 torr. A similar curve was observed with the XDS 5.

Table 9. Sensitivity to Exhaust Restriction in Air for Various Pumps.

Pump	Type	Use	Sensitivity at 300 torr: dP_{in}/dP_{out}
Adixen ACP 28	Roots	Transport	0.270
Vacuubrand ME 16	Diaphragm	Transport	0.300
Iwata ISP 250	Scroll	Transport, Sample	0.013
Edwards XDS 10	Scroll	Transport, Sample	0.062
Varian Triscroll 300	Scroll	Transport, Sample	0.062
Vacuubrand MD 4 Vario	Diaphragm	Sample	ANOMALY
Vacuubrand MZ 2D	Diaphragm	Sample, Backing	ANOMALY
Iwata ISP 90	Scroll	Sample, Backing	0.019
Edwards XDS 5	Scroll	Sample, Backing	0.025
Varian SH 100	Scroll	Sample, Backing	0.049
Edwards XDD1	Diaphragm	Backing	N/A
KNF Neuberger 84.4	Diaphragm	Backing	0.004
Vacuubrand MD 1 Vario	Diaphragm	Backing	N/A

No attempt was made to reproduce these results. The Edwards XDD1 and Vacuubrand MD 1 Vario were not tested for exhaust restriction due to the ⅜"-19 BSP exhaust fitting, which had no replacement available. However, their three stage diaphragm design and low flow rate indicate that smaller diameter exhaust lines should be sufficient for backing duty.

The Vacuubrand MZ 2D and MD 4 Vario showed anomalous behavior during the test. Other pumps quickly reached a steady state as the exhaust throttling valve was closed, but the exhaust pressure of the MZ 2D and MD 4 Vario pumps oscillated with time in a sinusoidal manner. The inlet pressure also varied proportional to the exhaust pressure during these oscillations. The period and amplitude of these oscillations were constant with time. The cause of these oscillations remains unknown. It must be noted that the sensitivity alone does not fully describe how the operation of the pump will be affected by specific exhaust plumbing. The exhaust pressure that will occur depends on the conductance of the exhaust plumbing and the flowrate at which the pump operates. Both flow rate and sensitivity indicate the degree of caution that must be taken when designing exhaust plumbing. For example, both the Vacuubrand ME 16 and Adixen ACP 28 have a high sensitivity exhaust restriction as well as large flow at which they will be operated. This indicates that large diameter exhaust lines are necessary to ensure the proper operation of these pumps.

Table 10 shows some flow vs. pressure data for both ½" and ½" line. This information is represented graphically in **Figure 35**, along with curve fits of the data. Fittings other than tubing, as well as bends and valves, will raise exhaust pressures

Table 10. Pressure/Flow Relationships for Various Tubing

Line: ½" OD, 0.170" ID Dekaron Plastic Tubing, 134 Feet			
Nitrogen		Helium	
Δ Pressure (Torr)	Flow (SLPM)	Δ Pressure (Torr)	Flow (SLPM)
0	0	0	0
35	4	20	4
94	8	72	8
272	13	135	13
525	19	264	22
960	29	804	72
1344	39	1458	72
Line: ½" OD, ⅜" ID Tygon Tubing, 91 Feet			
Nitrogen		Helium	
Δ Pressure (Torr)	Flow (SLPM)	Δ Pressure (Torr)	Flow (SLPM)
0	0	0	0
1	5	1	3
4	8	3	10
11	19	5	18
30	31	15	39
62	52	27	65
111	83	55	95
186	119	120	134
189	123	220	194

beyond those figures given in **Table 10** and **Figure 35**. Using a combination of the pump speed curve, flow curve, and exhaust restriction curves is an appropriate way to design exhaust plumbing. First, the user should determine the maximum operational pressure of the vacuum pump. The resulting speed can then be read from the pump speed curve, and converted into mass flow rate rather than volumetric flow rate. Next, determine the exhaust pressure required at this mass flow rate. **Table 8** and **Figure 35** can be used for ½" and ½" lines near 134 and 91 feet in length, respectively. Once the exhaust pressure is found, the exhaust restriction curve will yield the actual inlet pressure and current demand. An iterative process may be required for high exhaust pressures and sensitivities. The user should be cautioned that exhaust restriction curves are provided only around 300 torr, appropriate transport pressures. Sample and backing pumps generally have flow rates that low, and often ½" line is assumed to be all that is necessary.

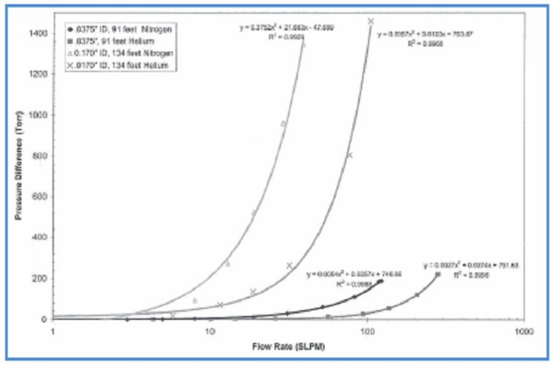

Figure 35. Pressure/Flow Relationships for Various Tubing and Gases.