EVALUATION OF DRY, ROUGH VACUUM PUMPS

PART IV

The following was obtained via public disclosure from a NASA document.

EDITOR'S NOTE:

This is the forth 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.

Part 4. VOLTAGE VARIANCE TEST

The purpose of the voltage variance test is to quantify the effects input voltage variation has on the pump during nominal operating condistions. In a brown-out condition, pumps could increase current demand to the point where breakers are tripped or shutdown occurs. Excessively high voltage could damage the pump motor or electronics. This test attempts to quantify the results of voltage variance.

Pumps were operated at 300 torr or ultimate pressure, and voltage was varied with a transformer or adjustable DC power supply to voltages both above and below the nominal operating voltage of the pump. Current and pressure was measured at each voltage. In addition, the minimum voltage required to sustain operation was determined.

Pumps were tested to determine current and pressure variations as input voltage was varied. In addition, the minimum input voltage required to sustain operation is listed in **Table 5**. This voltage is not the minimum input voltage required to start the pump, rather to maintain operation. Curves presented in **Figures 57-62** shows the variation of inlet pressure and current with voltage. Edwards scroll pumps require the highest voltage to sustain operation, while Varian scroll pumps require the least voltage to sustain their operation. The Edwards XDD1 required the least amount of voltage of diaphragm pumps tested.

Part 5. VIBRATION TESTING

Vibration is the motion of a body about an equilibrium position. The motion can be the result of motors or rotating equipment inside of the machine that is vibrating, or induced on a body by an outside force. Both emissions from operation and susceptibility to induced vibration are investigated. All motion can be described in one of six ways: X, Y, and Z directions, as well as 3 possible spherical rotations between these axes. For purposes of this test, only motion in the Cartesian X, Y, and Z directions are considered. The X-axis is defined as the axis of rotation of the pump motor; Y is defined as the axis perpendicular to the pump motor axis and parallel to the mounting

Table 5.

Minimum Voltage Requried for Sustained Operation		
Pump	**Function**	**Minimum Voltage Required for Sustained Operation**
Adixen ACP 28	Transport	83 VAC
Vacuubrand ME 16	Transport	95 VAC
Iwata ISP 250	Transport, Sample	78 VAC
Edwards XDS 10	Transport, Sample	100 VAC
Varian Triscroll 300	Transport, Sample	58 VAC
Vacuubrand MD 4 Vario	Sample	72 VAC
Vacuubrand MZ 2D	Sample, Backing	72 VAC
Iwata ISP 90	Sample, Backing	64 VAC
Edwards XDS 5	Sample, Backing	90 VAC
Varian SH 100	Sample, Backing	57 VAC
Edwards XDD 1	Backing	47 VAC
KNF Neuberger 84.4	Backing	14.5 VAC*
Vacuubrand MD 1 Vario	Backing	14.8 VAC*

*Tested at Ultimate Pressue.

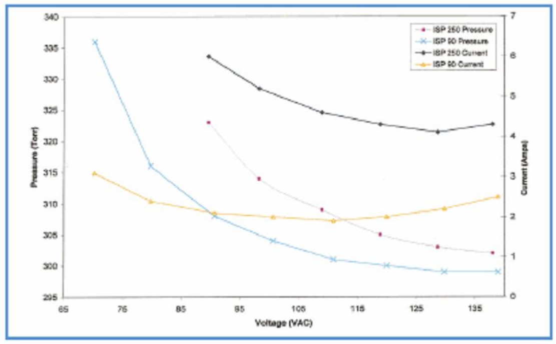

Figure 57. Voltage Variance Curves for Iwata Scroll Pumps.

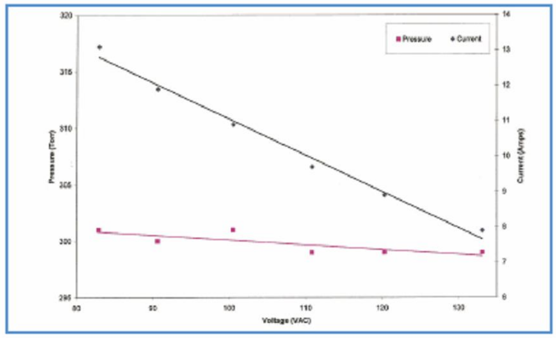

Figure 58. Voltage Variance Curves for Adixen ACP 28.

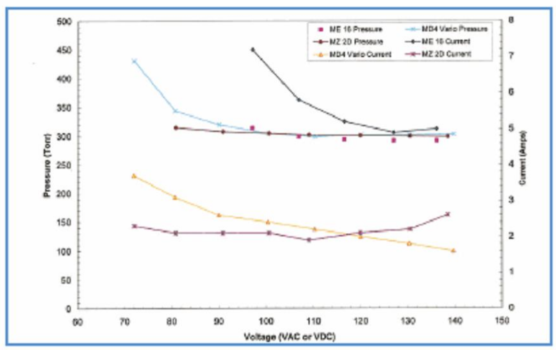

Figure 59. Voltage Variance Curves for Vacuubrand Pumps.

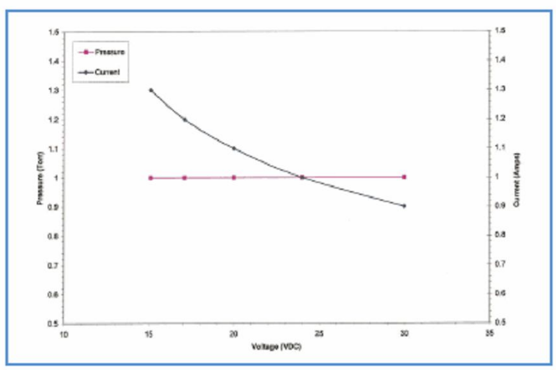

Figure 60. Voltage Variance Curves for Vacuubrand MD 1 Vario.

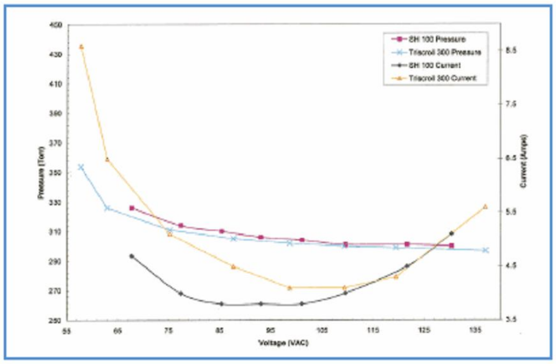

Figure 61. Voltage Variance Curves for Varian Scroll Pumps.

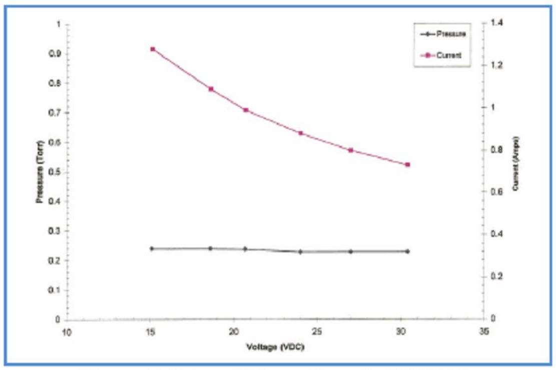

Figure 62. Voltage Variance Curve for KNF 84.4.

surface, and the Z axis orthogonal to both the pump motor axis and mounting surface.

Vibration emissions can affect the precision instrumentation associated with gas analysis systems, as well as accelerate wear on turbo molecular pumps rotating at high speed. Emissions are measured using accelerometers, which measure the acceleration a pump undergoes as it vibrates in all 3 directions. This vibration was measured both on the pump itself and on a tabletop the pump was resting on. By doing this, it is possible to determine the vibration that can travel along hoses and electrical connectors, as well as the vibration transmitted to the mounting surface. For this test, no extra vibration isolation was added.

The results of vibration emissions testing are usually presented in root mean square acceleration, abbreviated G_{rms}. By taking the root mean square of the acceleration, negative accelerations become positive and contribute to the overall acceleration experienced by the body. Otherwise, the average acceleration would be zero because the body is vibrating around an equilibrium position. As the abbreviation implies, G_{rms} is related to the acceleration due to gravity on the earth, but is different because it accounts for the oscillatory nature of vibrations, while the acceleration due to gravity occurs only in one direction.

Vibration emissions data are presented in **Figures 31, 32, 33.** Pumps not only generate vibration while in operation, they can be susceptible to vibration induced by outside factors. Pumps were shaken to launch vibration spectra. Pumps were bolted to a _" aluminum plate in a half-size 24" rack using mounting points already existing on the pump. Turbo backing pumps were run at ultimate pressure while shaken, transport and sample pumps were run at approximately 300 torr. Pass/fail criteria was based on whether or not the pump continued to function after being shaken. Note that rubber feet were sometimes removed to provide mounting points.

VIBRATION EMISSIONS

The vibration of pumps depends on the inlet pressure they are operated at. To facilitate easier testing by the vibration lab, pumps were tested at both ambient pressure and ultimate pres-

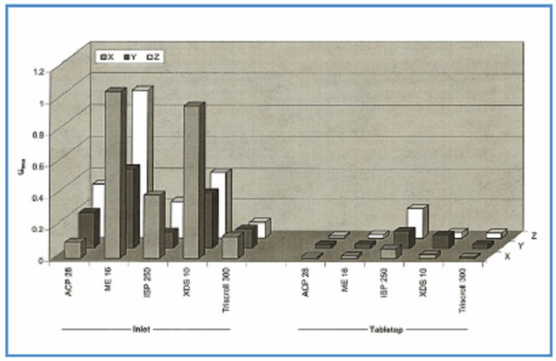

Figure 31. Vibration at Pump Inlet and Tabletop for Transport Pumps.

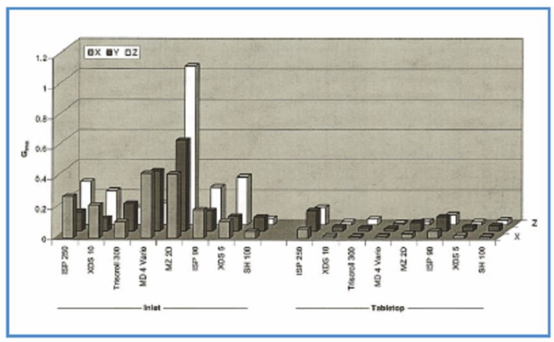

Figure 32. Vibration at Pump Inlet and Tabletop for Sample Pumps.

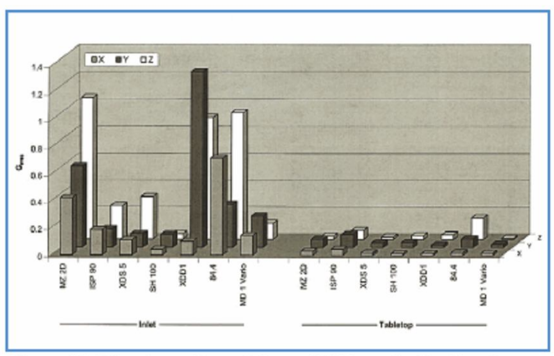

Figure 33. Vibration at Pump Inlet and Tabletop for Backing Pumps

sure. Transport pump vibration data is presented from data collected at ambient pressure. Sample pump and backing pump vibration data is presented from data collected at ultimate pressure. Each graph shows the root mean square acceleration at both the inlet and tabletop. Relative comparisons can be made between vibration at pump inlets and between the vibrations transferred to the tabletop. Low vibration is desirable, although some vibration is tolerable. Pumps having high relative vibrations will require third party vibration isolation systems if used.

TRANSPORT PUMP EMISSIONS DISCUSSION

Transport pumps are often large, heavy, and have high flow rates. Because of the amount of power involved with these pumps, they can have substantial vibration associated with their operation. At the pump inlet, the Varian TriScroll 300 produces the least amount of vibration overall, with accelerations well under 0.2 G_{rms} in all axes. The Adixen ACP 28 and Iwata ISP 250 also have comparatively low vibrations. The Vacuubrand ME 16 and Edwards XDS 10 produce the most amount of vibration at the pump inlet, with the ME 16 having the most vibration associated with it. The ME 16 reaches over 1 G_{rms} in the X axis and nearly 1 G_{rms} in the Z axis.

The amount of vibration a transport pump transfers to a mounting surface, or in this case a tabletop it was resting on, is highly dependent on the way the two surfaces are mated. The acceleration of the tabletop quantifies the amount of vibration transferred. Vibration absorbing rubber feet drastically reduce the transfer, as the ME 16 shows. Although it had the highest vibration at the pump inlet, it causes very low acceleration at the tabletop. Conversely, the ISP 250 had comparatively mild vibration at the pump inlet, but transfers the more vibration to the tabletop than any other transport pump. This is because the ISP 250 has a large metal base with no rubber feet. The TriScroll 300 had the lowest vibration at the pump inlet, but because of its large metal base does not have the lowest acceleration at the tabletop. The ACP 28 has both low vibration and rubber feet, and therefore transfers the least amount of vibration of any pump. Although the XDS 10 has rubber feet, they are of a configuration that absorbs a smaller percentage of the vibration than feet on other pumps. This, coupled with the significant vibration of the XDS 10 at the inlet, leads to significant acceleration at the tabletop. A more complete description and results of the vibration emissions test may be provided upon request.

SAMPLE PUMP EMISSIONS DISCUSSION

Sample pumps are often the same pumps as transport pumps, but run at much lower pressure. This can cause significant changes in pump acceleration. Some pumps experience higher vibration while operating at low pressures, and other pumps experience lower vibration while operating at low pressures. The XDS 10 shows a lowering behavior; although pump acceleration with an open inlet was near 1 G_{rms} in the X axis, with a closed inlet it dropped to approximately 0.2 G_{rms}. Conversely, the TriScroll 300 acceleration rose slightly when the inlet was closed, especially in the Y axis. The acceleration of the ISP 250 stayed essentially the same.

Other scroll pumps that were not candidates for transport duty were candidates for sample duty. These include the Iwata ISP 90, Edwards XDS 5, and Varian SH 100. All three of these pumps had mild vibration, with the Varian SH 100 having the lowest vibration at the pump inlet of any pump tested at 0.1 G_{rms} in the Y axis and less than half of that in the X and Z axis. Two diaphragm pumps were tested as candidates for sample duty. The Vacuubrand MD 4 Vario had moderate vibration, with acceleration in the X and Y axes approaching 0.4 G_{rms}. The Vacuubrand MZ 2D had the highest vibration of any pump tested, with acceleration in the Z axis over 1 G_{rms}. Acceleration of the MZ 2D in other axes are also substantial. Both the MZ 2D and MD 4 Vario share the same pumping heads and are similar in many ways, although the MD 4 had lower vibration.

The variable speed technology of the MD 4 Vario slows down as ultimate pressure is reached, which helps reduce vibration. In addition, the MD 4 Vario has 4 pumping heads, while the MZ 2D has only two. This helps balance the MD 4 Vario more effectively.

The amount of vibration the sample pumps transferred to the mounting surface is highly dependent on the way the two surfaces are mated. The acceleration of the tabletop quantifies the amount of vibration transferred. Vibration absorbing rubber feet drastically reduce the transfer. While diaphragm pumps produce far more vibration at their inlets than scroll pumps do, they transfer a similar amount or less vibration to the tabletop than scroll pumps. This is because diaphragm pumps are generally equipped with rubber feet and scroll pumps are not. The Iwata ISP 250 and ISP 90 transfer the most vibration to the tabletop because of their large metal bases. All other pumps transfer similar amounts of vibration to the tabletop, although the MZ 2D transfers slightly more in the Y axis than average.

BACKING PUMP EMISSIONS DISCUSSION

Like sample pumps, backing pumps were run at ultimate pressure while their vibration emissions were taken. As expected, diaphragm backing pumps had the highest acceleration at the pump inlet.

The Edwards XDD1 had the highest acceleration in any single axis, over 1.2 G_{rms} in the Y axis. The Vacuubrand MZ 2D and KNF 84.4 also had large vibration. The Vacuubrand MD1 Vario, however, showed similar acceleration to scroll pumps. This is because the Vario technology slows the pump down near ultimate pressure, reducing the vibration.

At the pump inlet, all scroll pumps had vibration less than 0.3 G_{rms} in all axes. The Varian SH 100 had the least amount of vibration of any pump tested. The Iwata ISP 90 and Edwards XDS 5 had similar vibration output in all axes.

The amount of vibration the backing pumps transferred to the mounting surface is highly dependent on the way the two surfaces are mated. The acceleration of the tabletop quantifies the amount of vibration transferred. Vibration absorbing rubber feet drastically reduce the amount of vibration transferred. The KNF

Table 6.

Power Spectral Density for Vibration Susceptibility Testing: X and Y axes	
Frequentcy (Hz)	Power Spectral Densly (G^2Hz)
10	0.01×10^{-3}
20 - 30	2.75×10^{-3}
45 - 400	3.5×10^{-3}
800	1.5×10^{-3}
850 - 1200	2.5×10^{-3}
1400	0.01×10^{-3}
Composite: 1.28 G_{rms}	

Table 7.

Power Spectral Density for Vibration Susceptibility Testing: Z axes	
Frequentcy (Hz)	Power Spectral Densly (G^2Hz)
3	0.01×10^{-3}
5.5 - 10	32×10^{-3}
20	27×10^{-3}
45 - 400	0.1×10^{-3}
800	3.5×10^{-3}
850 - 1200	2.5×10^{-3}
1400	0.01×10^{-3}
Composite: 1.37G_{rms}	

84.4 accelerates the tabletop most strongly in the Z axis, with almost 0.2 G_{rms}. This is because it has high acceleration at the pump inlet, and no rubber feet to isolate this vibration from the mounting surface. Scroll pumps can transfer more vibration to the tabletop than diaphragm pumps because they often lack of rubber feet. The Iwata ISP 90 produces the most vibration in the X and Y axes because of its large metal base, which transfers vibration easily.

VIBRATION SUSCEPTIBILITY TESTING

The purpose of the vibration susceptibility test is to determine if pumps are able to withstand the vibrations experienced during certain NASA applications. All pumps must withstand essentially the same vibration, regardless of their funtction. Pumps were shaken for 30 seconds to the vibration spectrum, shown in **Tables 6** and **7**.

Pumps were bolted to a ½" aluminum plate in a half-size 24" rack using mounting points already existing on the pump. Turbo backing pumps were run at ultimate pressure while shaken. Transport and sample pumps were run at approximately 300 torr. Pass/fail criteria was based on whether or not the pump continued to function after being shaken.

No pump failures were noted during vibration testing. Therefore all pumps tested passed the vibration susceptibility test in the X, Y, and Z axes. However, two minor pump anomalies were observed. The BSP-threaded inlet fitting of the Edwards XDD1 became loose, and an M6 thread on a metal foot of the Vacuubrand ME 16 was stripped. It is unclear if the thread became stripped due to vibration or simply from excessive use, as the metal feet of the ME 16 are rather soft, and the M6 thread has only a 1 mm pitch. It should be noted that these threads are designed only to hold the rubber feet of the ME 16, not necessarily to provide mounting points. A coarser, larger thread would provide more resistance to stripping. A steel nut and bolt through the mounting plate would provide more resistance to stripping as well as strength. The loosened inlet fitting of the XDD1 could potentially be solved with thread sealant, although some chemical compatibility and contamination issues may exist with using this product in vacuum systems.

Because of the very small clearances between the pumping lobes, the Adixen ACP 28 was thought to be likely to fail the susceptibility test. However, the pump body is apparently mounted on a suspension within the pump case. During the test, high speed cameras showed large amounts of displacement on the pump inlet and exhaust relative to the case. This suspension is likely responsible for the durability of this pump during high vibrations. The Varian TriScroll 300, Varian SH 100, and Vacuubrand MZ 2D were not tested here, but have passed under actual use in NASA applications. The MZ 2D, however, had third party vibration isolation in place.