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Considerations for Primary Vacuum Pumping in Mass Spectrometry Systems

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Considerations for Primary Vacuum Pumping in Mass Spectrometry Systems

Mass spectrometry systems have specific vacuum requirements. New developments in oil-free, or dry, primary vacuum pumps have been introduced recently and are discussed in this article with respect to capacity, throughput, and specific pumping requirements for process gases.

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There are many drivers for vacuum configuration in mass spectrometry (MS) and other scientific instrumentation applications. These include: vacuum performance of the primary pump itself (speed, compression, power, and so forth); environmental impact, power, construction, service interval, and the requirements (if any) for oil; regulatory compliance; cleanliness of the vacuum produced; and compatibility with process and target gases–vapors.

MS systems have very specific vacuum (physics and engineering) requirements. The systems primarily considered here are liquid chromatography–MS (LC–MS), gas chromatography–MS (GC–MS) and inductively coupled plasma MS (ICP-MS). New developments in oil-free (dry) primary vacuum pumps have been introduced recently to the scientific instrument user markets and their impact is discussed below.

Specific Vacuum Requirements

There are several performance requirements for vacuum systems used with mass spectrometers.

Capacity. This refers to the nominal pumping speed of the pump or, more importantly and specifically, the throughput for process–target gases (carrier, collision, and shield) at a nominal process pressure. This might be to provide a sufficiently low backing pressure for a turbomolecular pump when the process gas line shares the backing line of a turbomolecular pump.

Alternatively, the pump might be required to create a stable inlet–process pressure, for example, at the source. Other specific pumping requirements include resistance to gas latency. An example of this is in the pumping of helium. The permeable nature of helium is such that a latent signal of helium, or drift in the inlet pressure, can occur in pumps of

Figure 1. XDS35i Scroll Pump.

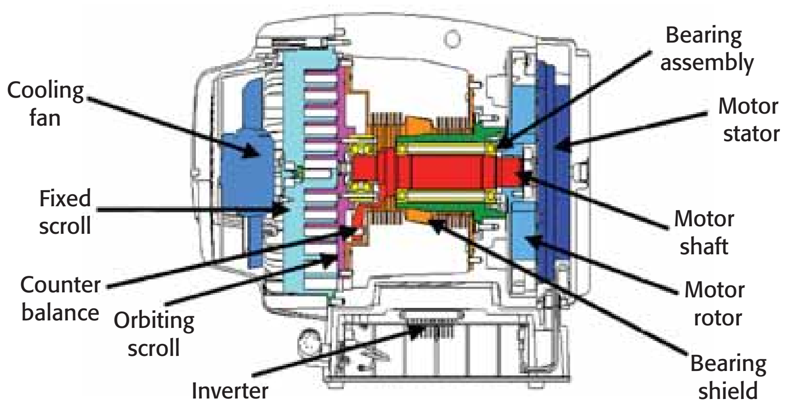

Figure 2. XDS35i general assembly.

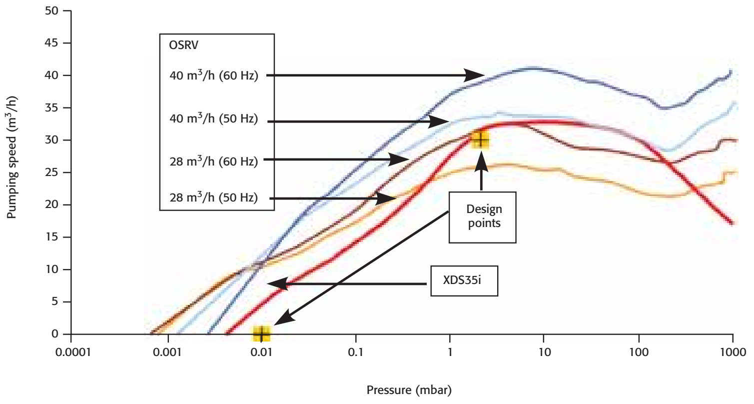

Figure 3. Performance curves for the XDS35i and oil-sealed rotary vane comparisons.

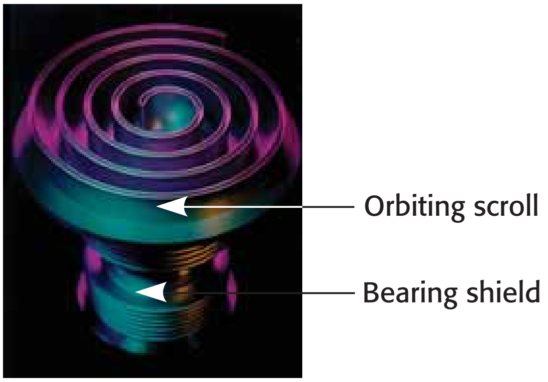

Figure 4. The Orbiting Scroll and Bearing Shield Assembly

certain configurations.

Correspondingly, the compression ratio of the pump itself to the range of target gases must stay constant within bounds so as not to cause drift of pressure and hence the potential loss of signal.

Constant performance worldwide. The global nature of the marketplace of end-users is such that the consistency of performance worldwide (that is, independent of voltage–frequency supply) is required. This minimizes the number of configurations that the OEM must consider.

End-user serviceability. The ever-increasing requirement for reliability and process uptime demands the simplification of the service elements and a maximization of the interval between services. An end-user routine serviceability allows the maximization of uptime and reduces service costs.

Cleanliness of vacuum and chemical compatibility. Pumps using oil require mitigation of the potential for back-migration of oil vapor to the process chambers. The move to dry primary pumps allows a completely dry running pressure. The dry pump in equal part provides system compatibility to process gases (for example, in sample preparation acetonitrile or ethanol solutions).

Reliability/uptime. As with end-user serviceability, there is a great driver for the pump to be "fit and forget." That is, the pump should require minimal intervention for maximized uptime. This is a crucial element in the design philosophy, manifesting itself, for example, in the minimization of the number of parts.

Backwards compatibility. An important element is the compatibility with current pumps used both as "upgrades," for example, from systems installed using oil-sealed rotary vane pumps and incorporation into new machines where power, footprint, and other parameters must be compatible. Here, a series of approvals to verify these compliance elements is undertaken by the OEM and often end-users.

Vacuum Specifications

For a typical mass spectrometry application, the pumping speed target is 32 m^3/h (19 cfm) or greater, at an inlet pressure approximately in the range of from 1 to 3 mbar. The target gases typically are nitrogen, argon, helium, and hydrogen, for example in LC–MS and ICP-MS. The target ultimate pressure (base pressure) is <0.1 mbar. The equivalent throughput is 30–70 mbar m^3/h (460–1073 sccm). The ultimate when using gas ballast is < 0.2 mbar.

As discussed earlier, a universal supply voltage is desirable to ensure consistency of operational characteristics across different voltage and frequencies. Hence a stipulation is taken for a universal supply for a "switchable" voltage 100–120 V and 200–230 V, both at 50/60 Hz. This ensures constant pumping speed, ultimate pressures, and throughput worldwide.

A stipulation was taken to completely remove any bearings from the vacuum space. This was with regard to the cleanliness of the vacuum and the compatibility of the pump with process gases (the bearings and the process gases being separated).

Mechanism

Figures 1 and 2 show a platform mechanism for a dry pumping solution. Performance curves of the mechanism are shown in Figure 3. Two crucial design–performance points are indicated by the crosses. The vacuum performance criteria are shown to be satisfied. For comparison, oil-sealed rotary pumps' curves for 28 and 40 m^3/h are shown.

The bearing shield configuration shown in Figure 4 provides isolation of the lubricated bearings from the vacuum space. This mechanism prevents any trace or fingerprint of the lubrication of the bearings from being seen in the vacuum space. This provides a completely dry vacuum; no oil or grease is in the vacuum environment, so there is no risk of back-migration of the oil. Additionally, the bearings are not exposed to process gases and water vapor, which can

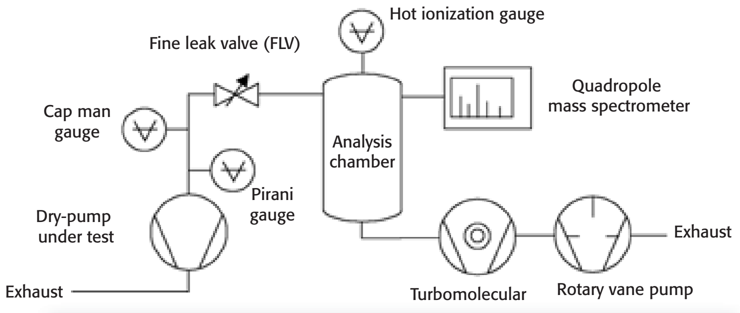

Figure 5. Schematic of equipment for evaluation of pump cleanliness (P R Davis, R A Abreu and A D Chew, "Dry vacuum pumps – a method for the evaluation of the degree of dry" (Invited) Journal of Vacuum Science and Technology A, 18, (2000)).

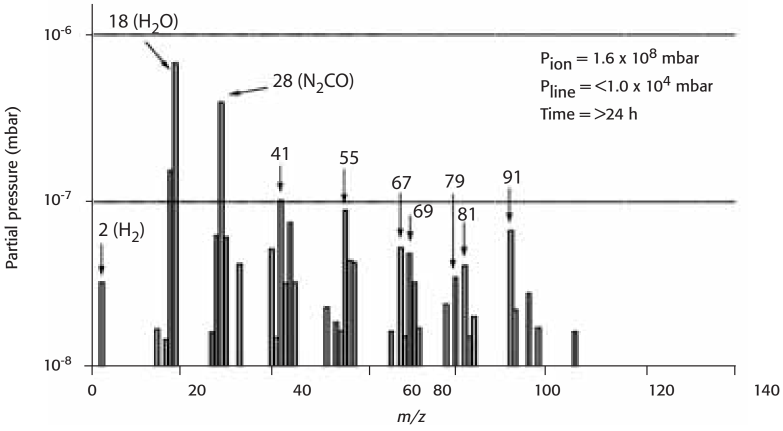

Figure 6. Oil-sealed rotary vane pump inlet trace.

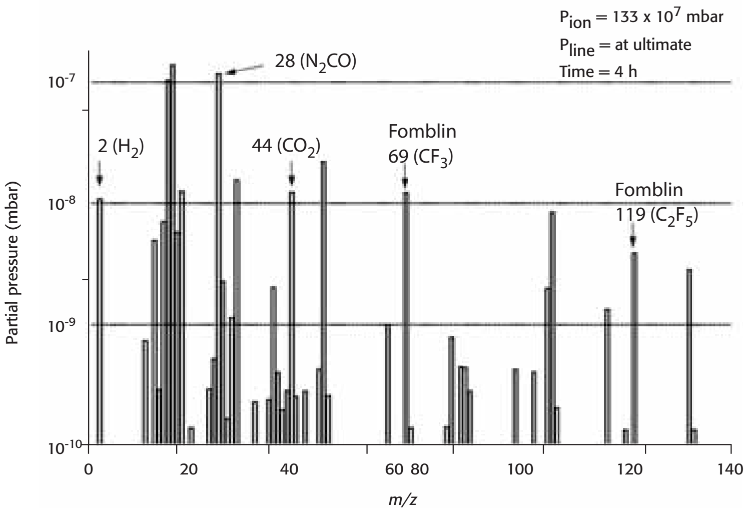

Figure 7. Conventional scroll pump trace.

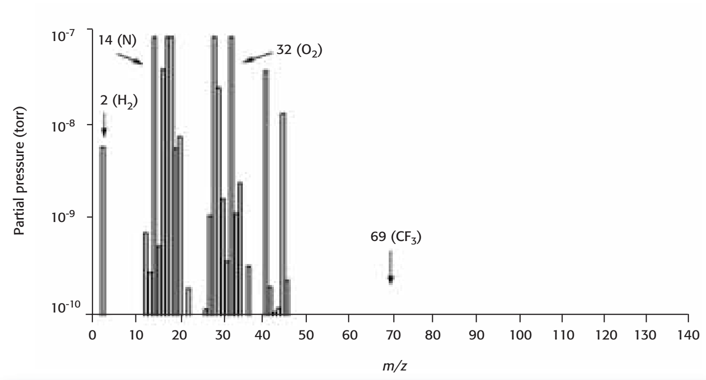

Figure 8. XDS35i pump trace.

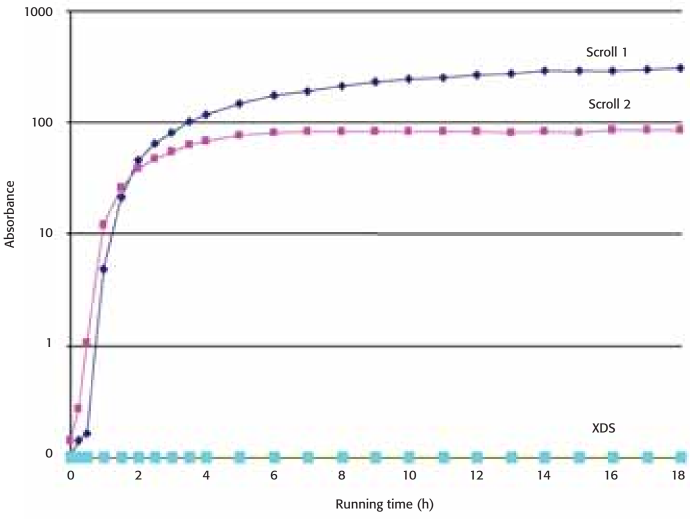

Figure 9. Development with time of contamination trace.

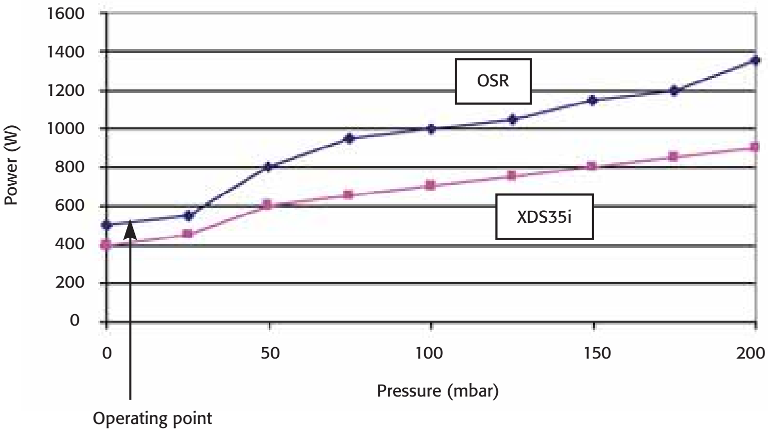

Figure 10. Power versus inlet pressure.

degrade the lifetime and performance of the bearings significantly. In short, the vacuum space is isolated from the bearings and the bearings are isolated from the elements of the vacuum space. There is no need for shaft or lip seals to be used, and the leak tightness of the system is low ($<<10^{-6}$ mbar L/s).

Cleanliness

Figure 5 shows a schematic of an experimental arrangement used to evaluate or measure the cleanliness of different types of pump. The technique is explained fully in the reference of the original work. Figure 6 shows a residual gas analysis spectrum of an oil-sealed vane pump.

The characteristics of the hydrocarbon oil (fingerprint) are shown by the groups of peaks separated by mass-to-charge ratios (*m/z*) of 14 (CH_2 separated groups). The residual gas trace from a conventional scroll pump (where the bearings are in the vacuum space) is shown in Figure 7. This shows the characteristic of perflouropolyether (PFPE) peaks at *m/z* 69 and 119. This is from the bearing lubricant exposed to the vacuum in a conventional scroll pump configuration.

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The trace from this type of pump is shown in Figure 8. No trace of hydrocarbon or PFPE lubrication is visible. Since the bearings are isolated from the vacuum, a hydrocarbon (superior) lubricant is used as opposed to PFPE. Figure 9 shows the development of contamination versus time from start of two traditional scroll pumps and in the case of the XDS, constant cleanliness.

Environmental Considerations

The design of such an instrument allows for the minimization of the number of parts. For example, there are two bearings (compared with seven) in a conventional scroll. The pump has an annual service interval which is inherently simple and done by the end-user. This reduces costs as well as negating the need for transportation (no travel by a service technician or of the pump to a service hub). Clearly the fully dry nature of the pump has a significant benefit because there is no oil to dispose of or replace. The pump has been designed with a reduced power mode; the pump can be set to idle mode (40 Hz) to run at one third of normal operating power. Additionally, the pump runs with reduced power versus an equivalent capacity oil-sealed rotary vane (OSRV) pump as shown in Figure 10.

A typical split-flow turbomolecular pump configuration is shown in Figure 11. The backing pump must not promote the migration of carrier gas to the ion optics or analyzer, etc., stages. This means that the compression ratio (backing pressure/chamber pressure) or latency of a given gas being pumped, should be large enough to prevent interference with other parts of the instrument.

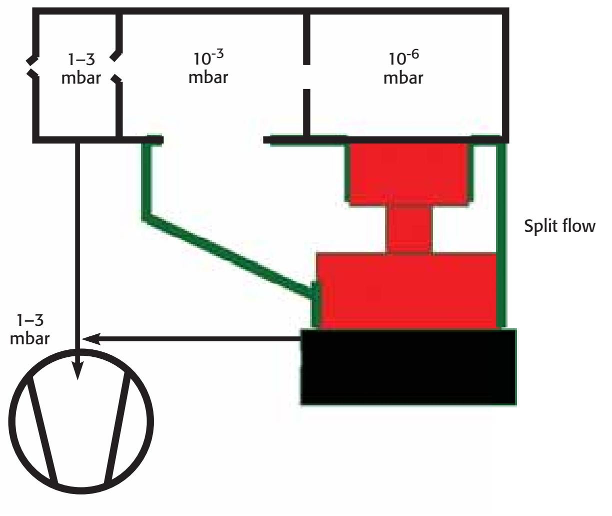

Figure 11. Typical split flow turbomolecular pump configuration.

Summary

There are significant demands, drivers and requirements in mass spectrometry and related applications for primary vacuum pumps. These have been discussed and reference made to a vacuum pump that complies with these performance drivers and environmental parameters. Such a dry pumping solution simplifies the pumping system and offers clean and stable vacuum performance. ■

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