TECHNICAL BULLETIN #101

Magnetic Sector vs Quadrupole Mass Spectrometer / RGA …

The VTI AERO VAC Odyssey Mass Spectrometer / Residual Gas Analyzer (RGA) utilizes the ‘original’ principle of using a magnetic field to separate components of an ion beam on a mass/charge basis. As such, it is unique in that other instruments offered for RGA generally use a quadrupole and all use electric fields to provide mass separation.

There are differences in the ways the two instruments operate and so care must be taken when comparing the two both for a specific application and from a purely specification point of view. Both instruments have a role to play but, after careful consideration of factors discussed below, it may be surprising to find how universally applicable the Magnetic Sector instrument can be due to it’s inherent simplicity, durability and practicality.

Although not used in the same way as a quadrupole for some RGA applications, the sector instrument has been the backbone of both leak detection systems and higher end (larger molecule, higher precision) systems from it’s development to today. Check out the analyzer, tuned to Helium usually, in any dedicated / portable vacuum leak checker – you will find it is a sector device.

Some twenty years or so ago, the quadrupole became popular as it offered then unrealized speed (compared to a sector instrument) and a uniquely linear mass scale which could be digitized by then available computers. With a resolution proportional to mass, (see discussion below), it presented easy to interpret (constant width and separation) peaks for both the computer and the operator. This became a ‘perceived advantage’ over the sector despite the significant compromises this actually gave over resolution, sensitivity and stability.

Today, with digital electronics and computers, long ago capable of ‘linearizing’ any mass scale, the AERO VAC can scan extremely quickly and visually present itself in the same way as any quadrupole. With a pedigree approaching forty years, *(check out one of the first AERO VAC instruments on the VTI web-site – built in 1965!)*, and all the inherent advantages of stability, ruggedness and simplicity, the AERO VAC requires consideration for all RGA applications. This technical bulletin is designed to discuss the relative merits of magnetic sector and quadrupole technology.

One word of note, as with any set of specifications, they remain meaningless unless the conditions under which those specifications are achieved are also made clear. Let us look at some of the key issues facing the prospective purchaser:

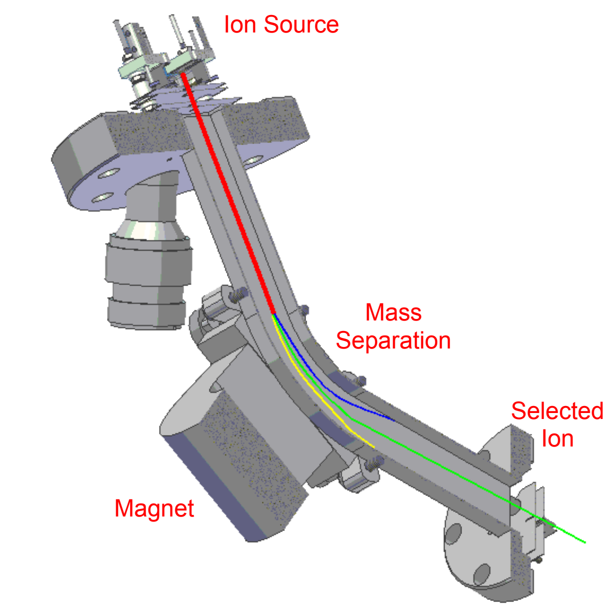
1) **Separating Field**
2) **Resolution**
3) **Sensitivity**
4) **Instrument Stability**
5) **Contamination Resistance**

TECHNICAL BULLETIN #101

1) Separating Field

Magnetic Sector: The AERO VAC RGA utilizes a 2" radius of curvature, 60° deflection beam tube with a 92° permanent magnet sector. Separation occurs based on the fact that a charged particle moving in a magnetic field follows a curved trajectory. For a given ion velocity (energy), lighter ions curve more sharply than the heavier mass ions. A spectrum is produced by varying the ion accelerating voltage from 10 to 2500volts sweeping the separated ions past the analyzer exit slit and onto the detector.

The AERO VAC has the unique advantage of placing the ion source and the detector 'off-axis' meaning they cannot 'see' each other. For any ion to get from one end to the other it has to be 'selected' by the mass filter.



AERO VAC ODYSSEY ANALYZER

Quadrupoles, on the other hand, are 'in-line' devices. As they tend towards lower masses, the filter effect reduces towards zero allowing all ions through the filter. This is fundamental to all quadrupoles and is known as the "Zero-Blast" effect. Without going to extraordinary lengths to raise the RF frequency and make the unit 'non-standard' it is not possible to avoid this without compromising the performance in some other way. The result is a major rise in baseline making it difficult to measure Hydrogen.

Clearly, this is not an issue for the magnetic sector device allowing hydrogen to be easily monitored and for unequalled precision and stability in leak checking operations with helium at mass four.

One possible disadvantage of the magnetic sector instrument is that the somewhat longer flight path, as compared to smaller end quadrupoles, could yield a greater probability for ion/neutral molecule interactions in-flight. This effect is reduced by the considerably higher ion beam energy of up to 2500 volts compared to the 10 volts or so of the quadrupole. In practice, the ion spends less time in the magnetic filter than it will do in a smaller quadrupole.

Quadrupoles separate ions using a combination of Radio Frequency (RF) and DC fields on four rods. The ions pass between the four rods. The electric fields are generated such that only ions of a certain mass to charge ratio will pass completely through the rods from the ion source to the detector, all other ions follow unstable trajectories which hit the rods. The discussions on STABILITY and CONTAMINATION RESISTANCE below refer to the effect ions colliding with the rods have on long term system performance.

The analyzer is dependent upon complex electronics requiring matching (although there are some 'self-tuning' systems around) of the RF unit to operate the quadrupole. Even with self-tuning, no system can match the simplicity of selecting the mass by controlling one single voltage! Clearly, susceptibility to electronic drift is greatly reduced and therefore stability much higher for the AERO VAC.

2) Resolution

Resolution, expressed as M/delta M, is a constant for the magnetic sector instrument. Typically this will be 50 at 10% peak height with a .010" slit width. (The slit size can be changed). Most importantly, this is constant over the mass range resulting in narrow peaks (which are very well separated) at the lower mass region and broader peaks in the higher mass region.

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TECHNICAL BULLETIN #101

Quadrupoles typically claim unity resolution, (1 amu wide @ 10% valley), that is, M/delta M always equals one. This means the low mass peaks are less well separated when compared to the sector and that high mass peaks are better separated. There are many issues to consider here:

a) The superior low mass resolution of the AERO VAC makes it ideal for use in the typical RGA range of say 1 to 70 amu with better separation, reduced cross–talk (contribution from the base of one mass peak to an adjacent mass peak) and, of course better stability. This also makes the instrument ideal for use as a leak detector and routinely capable of measuring hydrogen.

b) Resolution is fixed both by geometry and physical component dimensions on the AERO VAC, therefore, no changes can occur due to electronic drifts. Peak shape is similarly defined and stable. On the Quadrupole, resolution is set by adjusting the ratio between the RF and DC voltages. Both of these are subject to electronic drift.

c) Unity resolution on the quadrupole means that the instrument has a resolution of 28 at mass 28 and a resolution of 50 at mass 50. In this way you obtain a linear output with say mass 30 being exactly in between masses 25 and 35. The cost of achieving this is found if you look at a sensitivity curve and realize that Sensitivity is INVERSELY PROPORTIONAL to Resolution. So as you increase the mass position of a quadrupole you decrease the sensitivity every step of the way.

Great care should be taken when reading quadrupole specifications since often, the sensitivity and resolution are quoted as maximum values. In practice, these may not be achievable at the same time.

3) Sensitivity

Most Quadrupole RGA's offer a sensitivity of $1x10^{-4}$ Amps per Torr but, with contamination, will not retain this initial sensitivity. The AERO VAC also offers $1x10^{-4}$ Amps per Torr of sensitivity and we specify this at 1mA of emission current and at mass 28.

What is not offered by other units is the up to 5mA emission capability of the AERO VAC which means that when conditions allow, the unit can run at up to a sensitivity of $1x10^{-3}$ Amps per Torr. The superior design of the AERO VAC ion source greatly reduces 'space charging' effects which plague other instruments at high emission currents. When system pressure are low, (less than $1x10^{-7}$ Torr) it is possible to increase this current to gain from this extra sensitivity right when it is needed the most, as signal levels decrease. This greatly enhances the UHV capability of the AERO VAC instrument and provides the user with a unique advantage.

4) Instrument Stability

There are two key factors contributing to overall instrument stability, namely Peak Height and Peak Position stability.

The AERO VAC ion source with the close attention to space charge and electrostatic lens design insures optimum ion extraction and excellent source peak height stability. When combined with the fixed geometry of the mass separation hardware, the analyzer produces well defined peak shapes which allows for more accurate measurement of the peak height for excellent overall peak height stability performance.

Peak position is determined by magnetic strength, tube geometry and ion source voltage, and is very stable and repeatable. Neither the magnetic field nor the tube geometry changes with time so that the ion source voltage for the ion is constant, and hence so is the peak position. One point to consider with the magnetic sector is that baking the tube to 150°C may shift the peak position slightly due to the thermal expansion of the beam tube. VTI has software to automatically mass tune the instrument to correct for this and any other type of mass position drift so this is not normally a concern. This is also a problem for the quadrupole where accurately aligned rods supported in ceramic rings may also move out of position when thermally cycled.

TECHNICAL BULLETIN #101

With a quadrupole, peak position is electronically determined and generally must be set by adjusting low mass and high mass potentiometers. The peak position, because it is electronically determined, can drift with time.

5) Contamination Resistance / Durability

As discussed above under Separating Field, the AERO VAC uses a constant magnetic field to separate the ion beam in to it's component masses. In fact, there are no changing fields in the flight tube of the analyzer and the flight tube sits at ground potential.

The situation is radically different within the quadrupole unit where complex alternating phase opposed radio frequency fields are mixed with DC potentials, which are themselves being scanned, to provide the 'filtering effect' of the quadrupole assembly. It is vital to get these to operate 'cleanly' on the ion beam to optimize the filtering effect. Anything causing distortion of these fields is to be avoided.

Unfortunately for the quadrupole, contamination impacts performance greatly by generating a capacitive layer on the surface of the rods. This has the effect of distorting these critical fields causing loss in sensitivity, degradation of resolution and drift effects that become very noticeable. On the other hand, the Magnetic Sector mass filter is unaffected in this way.

Quadrupole manufacturers have had to develop techniques to minimize these issues such as adding smaller filters before, and sometimes after, the main filter to 'capture' the contamination. At best this is a problem reduction and not elimination technique and adds to the cost and complexity of the assembly in actually making it more difficult and expensive to clean.

Be wary of applications running at higher pressures, dirty environments or requiring the analyzer to be repeatedly vacuum cycled such as for regular pump out procedures on the vessel to be sampled. Examples of such processes where the AERO VAC excels would be leak checking and coating although any application dealing with a difficult sample would benefit from a high level of contamination resistance.

In Summary

Simplicity is the key to the new AERO VAC Odyssey. Digital electronics ensure the power supplies that are provided are as stable as possible. That these need to be very straight-forward in nature – no RF and DC generation – reduces the susceptibility of the instrument to temperature change and electronic drift.

Add to this the excellent resolution performance over the typical RGA mass range and the inherent contamination resistance of the analyzer and you have very compelling reasons to consider the magnetic sector mass spectrometer. The Odyssey should be considered not just as an equal to a quadrupole, but as a superior choice for many applications today.

vti VACUUM TECHNOLOGY INCORPORATED

1003 Alvin Weinberg Drive
Oak Ridge, TN 37830 U.S.A.

Tel **+1 865 481 3342**
Fax **+1 865 481 3788**

E-mail sales@vacuumtechnology.com
www.vacuumtechnology.com

Contact:

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