APPLICATION NOTE

GAS SENSITIVITY OF VACUUM GAUGES

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Vacuum gauges have historically been developed in parallel with the development of vacuum pumps.

The measurement of pressure is important for many reasons ranging from characterising the state of a vacuum environment to integrating pump-down routines, interlock and process controls and even for safety.

The discipline of vacuum is almost unique in having a dynamic range of 15 or more orders in its application. As with pumps, there is not one gauge mechanism that can span this range.

There are **many** additional **aspects and variables to consider when choosing a gauge.**

These include technical parameters such as:

- Accuracy/uncertainty (the range of systematic error),
- Precision (the level of random error),
- Resolution,
- Measurement range,
- Linearity of output,
- Reproducibility,
- Robustness (process compatibility, radiation and magnetic field resistance)
- And response time.

Additionally **Size, Communication protocols and cost** all have a bearing on the choice.

Direct reading or Mechanical gauges are so called because they measure pressure 'directly' as the force per unit area (of a solid or liquid area). These are 'Total'[1] pressure gauges and include U-tube and Capacitance Diaphragm Manometers and Bourdon gauges.

Indirect gauges are often the most practical and employed gauges and measure a pressure dependent physical property of the gas, for example thermal conduction or viscosity, or a physical quantity which is proportional to number density.

1 Dalton's law: the total pressure of a mixture of gases = ∑ partial pressures of each gas

These Total Pressure gauges include Pirani, Bayard-Alpert Hot Cathode Ionization (BAG), Penning and Spinning Rotor Gauges.

Partial pressure gauges (Residual Gas Analysers) with reliance on ionization can be used to analyse the relative constituents of a vacuum.

Indirect gauges are most often calibrated for nitrogen.

From first-principles for a range of constituent gases where $r_i = P_i/P_{N_2}$ is the relative constituent of the ith gas. The relative sensitivity of the ith gas is s_i =Pmeasured(N_2)/P_{true}.

As an example consider a turbomolecular pumped stainless steel UHV system which has been baked and has a base pressure of 10^{-9} mbar. The rises to $5x10^{-5}$ mbar when a flow of a gas mixture of 10 percent Nitrogen (r_i = 1), 60 percent Helium (r_i = 6) and 30 percent Carbon dioxide (r_i= 3) is introduced. The system pressure is measured using a BAG.

The sensitivity factors for BAGs can vary widely in the literature; for example 0.14 to 0.25 for He (value of 0.2 is assumed here) and 1.3 to 1.45 for CO_2 (though a mean value of 1.35 is most often quoted). Using these values the above equation the 'true pressure' = (10/6.25) x 'indicated pressure' ~ $8x10^{-5}$ mbar.

A similar exercise could be performed to correct the base pressure ($1x10^{-9}$ mbar) of the UHV system where the main constituents would be expected to be H_2, CO, CO_2 and H_2O. Additionally the same process could be performed for a Pirani gauge measured backing line pressure, with for example a dry scroll pump. In this case the sensitivity factors will be determined by thermal conductivity of the different gases.

There are added complications to these calculations since gauge sensitivity factors can vary with pressure. Also there can be significant differential pumping speeds (and compression ratios) for different gases for both primary and secondary pumps.

This adds the complication that the percentage gas constituents r_i introduced into the chamber may not then be the same percent breakdown during process. In this case RGAs can be used to determine percentage composition but these have the same requirement to account for different gas sensitivities and correction factors.

In summary gas sensitivity factors can make a huge impact on the measured pressure:

For a BAG measured pressure for Xenon of $1x10^{-5}$ mbar then the true pressure can be ~1/2.7 x this value $=3.7x10^{-6}$ mbar. If there is a Pirani gauge measured pressure for Xenon of 0.1mbar then the true pressure would be ~0.35 mbar.

For a more in depth study see the 'Vakuum in Forschung und Praxis paper', 'Gas Correction Factors for Vacuum Pressure Gauges' on the Wiley Online Library at *https://onlinelibrary.wiley.com/doi/10.1002/vipr.201700640*

Edwards APG200 Pirani Gauge

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