Technical Overview

How to Select a Vacuum Transducer

Introduction

There are many types of transducers to choose from to measure vacuum pressure, including mechanical, thermal and ionization gauges. Both the application and required pressure range will help determine what type of gauge to use, as different technologies are required for different pressure regimes. Gauges are broadly categorized as rough, high or ultrahigh vacuum gauges.

There is a trade-off between accuracy and price. Typically, the most accurate gauges are also the most expensive. However, for applications where accuracy is of the utmost importance, it is a necessary cost. System integration must also be considered.

Transducers for rough vacuum

Rough vacuum is the pressure range from atmosphere (ATM) to 10^{-3} Torr. This range is characterized by a large number of particles moving in viscous flow. Because there is viscous flow, mechanical gauges or thermal gauges are both good options for rough vacuum. Mechanical gauges are often used to directly measure physical force exerted by the gas molecules, while thermal gauges measure the heat loss from a filament to gas molecules through thermal transfer.

A great mechanical gauge option is the capacitance manometer gauge (also known as capacitance diaphragm gauge or CDG). These gauges can provide seven decades of accurate pressure measurement over a range from ATM to 10^{-4} Torr. Each 'version' of the gauge is effective over about 3.5 decades of pressure. Advantages of these gauges are that they are extremely accurate, gas independent and can be used for calibration. Disadvantages include that they are expensive, and several gauges are needed to cover the total measurement range.

There are three main thermal gauge options including the thermocouple gauge (TC), convection gauge and Pirani gauge. Thermocouples are the least expensive gauge for reading from approximately 2 Torr to 1 mTorr, but they have a slow response when large pressure changes occur. Also, a correction factor must be used when measuring pressure of gases other than air/nitrogen. The convection gauge measures current instead of temperature, which improves response time, and it has a wider dynamic range than the thermocouple (ATM to 1 mTorr). The Pirani gauge incorporates a Wheatstone Bridge Circuit for improved accuracy, range and response time, and can be mounted vertically or horizontally. See the table below for comparisons between the rough vacuum gauge options.

	Advantages	Disadvantages
Capacitance Manometer	• Very accurate • Used for calibration • Independent of gas type	• Expensive • Several gauges needed to cover total range
Thermocouple	• Low cost • Rugged • Easily calibrated	• Slow response • Limited accuracy, range • Dependent on gas type
Convection	• Medium response • Wider range than TC	• Position dependent • Limited accuracy • Dependent on gas type
Pirani	• Measure to mid-10^{-5} Torr range • Fast response • Position independent	• Dependent on gas type

Transducers for high vacuum

The high vacuum range spans from 10^{-3} Torr to 10^{-8} Torr. Ionization gauges are used in this range. The two types of these gauges are the Hot Filament Ionization Gauge (HFIG, Bayard Alpert or BA), and cold cathode/Inverted Magnetron Gauges (IMG).

Hot filament ionization gauges have a heated filament that emits high-energy photoelectrons. The grid accelerates electrons, promoting collisions with (neutral) gas molecules creating M+ ions. The collector attracts M+ ions with high negative potential, and the resulting current is proportional to gas density or pressure.

The cold cathode/IMG uses electric and magnetic fields to create plasma within a hollow stainless-steel cylinder. This accelerates electrons, which collide with neutral gas molecules creating M+ ions. The collector attracts M+ ions with high negative potential, and the resulting current is proportional to gas density and pressure. See the table below for direct comparisons between the two gauge types.

	Advantages	Disadvantages
Hot Filament Ion Gauge	• More accurate than cold cathode/IMG • Slightly wider range	• X-ray effect limits accuracy below 10^{-8} Torr range • Gas type dependent
Cold Cathode/ Inverted Magnetron	• More rugged than HFIG • Rebuildable	• Limited accuracy, range • Gas type dependent

Transducers for ultrahigh vacuum

The ultrahigh vacuum range spans from 10^{-8} to 10^{-11} Torr and presents challenges when measuring pressure. Modifications to the high vacuum gauges are made to address or mitigate factors which compromise their performance at very low pressures. For the HFIG, the glass envelope is eliminated, the sizes of the grid and standoffs are reduced, all metal seals are used instead of O-ring seals, and there is no elbow connection. For the IMG, an all-metal seal is used.

Residual gas analyzers and sputter ion pumps can also be used in ultrahigh vacuum. For the residual gas analyzer, residual gases at HV/UHV pressures can be ionized and separated using a quadrupole mass filter. Individual ions can be counted by a Faraday cup or electron multiplier. These partial pressures of gas species can be added to estimate total vacuum pressure in a chamber. For the sputter ion pump, ion pump current is proportional to pressure so it can be used as a vacuum gauge. See the table below for direct comparisons between different UHV gauges.

	Advantages	Disadvantages
Hot Filament Ion Gauge	• Wide pressure range • Better accuracy	• Hot filament produces photoelectrons • Additional wire required for collector
Inverted Magnetron Gauge	• Rugged and rebuildable • No hot filament	• Limited accuracy, range
Residual Gas Analyzer	• Identifies which gas species are present	• Limited accuracy when measuring total pressure
Ion Pump Current	• Free vacuum gauge	• Leakage current can compromise accuracy • Location of pressure measurement

Conclusion

Pressure range and application needs are key factors when deciding on a vacuum pressure transducer. There is frequently a tradeoff between cost and accuracy, with the more accurate gauges being more expensive. While this document does not cover every type of transducer on the market, it provides a framework to help you determine which transducer would be the best fit for your vacuum system.

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