PG105 vs. Thermocouple Gauges

The two most common thermal conductivity gauge technologies used in modern vacuum applications are Pirani gauges and thermocouple gauges.

This application note is designed to help vacuum users choose between the two competing gauge technologies and decide when a pressure measurement setup based on TC gauges should be upgraded to PG105 convection gauges.

In This Application Note

Introduction

Pressure measurement in a thermal conductivity gauge is based on the transfer of heat from a hot wire, located inside the sensor, to the surrounding gases. Since gauge output depends on the thermal conductivity of the gases as well as their pressure, all thermal conductivity gauges provide indirect, gas-dependent, pressure readings.

The two most common thermal conductivity gauge technologies used in modern vacuum applications are:

Pirani Gauges

In the Pirani gauge (PG) the voltage required to maintain the hot wire at a constant temperature is *used as a non-linear, gas-dependent, function of pressure*. Traditional Pirani gauges provide useful pressure readings between 10^{-3} and 10 Torr. In convection-enhanced Pirani gauges, the upper range is extended upward to 1000 Torr by taking advantage of thermal convection currents created at the higher pressures.

Thermocouple Gauges

In the thermocouple gauge (TC) the pressure is indicated by measuring the small voltage of a thermocouple spot welded directly onto the hot wire. The wire is fed with a constant current and its temperature depends on the thermal conductivity and pressure of the gases present. TC gauges display useful pressures between 10^{-3} and 1 Torr.

TC gauges have long been regarded a cost-effective means to (1) monitor the foreline pressures of pumping stations and (2) as crossover gauges for vacuum systems in general. However, they are being systematically replaced in all modern vacuum systems by more accurate and reliable Pirani gauges, such as the PG105 convection-enhanced Pirani gauge manufactured by Stanford Research Systems.

This appendix is designed to (1) help vacuum users choose between the two competing gauge technologies and (2) decide when a pressure measurement setup based on TC gauges should be upgraded to PG105 convection gauges.

For additional information on this subject consult the following references:

1. J. M. Lafferty, "Foundations of Vacuum Science and Technology", section 6.8. "Thermal Conductivity Gauges", p. 403-414, Wiley-Interscience, 1998. A great book with lots of great information on almost every imaginable vacuum subject.

2. J. H. Leck, "Total and Partial Pressure Measurement in Vacuum Systems", Chapter 2., "Thermal Conductivity Gauges", p. 39, Blackie and Sons, Glasgow, 1989.

3. Stephen P. Hansen , "Pressure measurement and control in loadlocks", Solid State Technology, Oct. 1997, p. 151.

4. Simplify Rough Pumping with a Wide-Range Gauge", R&D Magazine, May 1999, p. 57.

5. J. Zettler and R. Sud, "Extension of thermocouple gauge sensitivity to atmospheric pressure", J. Vac. Sci. Technol. A6(3) (1988) 1153. Note: this is what it takes to make a TC tube extend into atmospheric pressures!

6. Vic Comello, "Using Thermal Conductivity Gauges", Back to Basics, R&D Magazine, Vol 39, Number 8, July 1997, p. 57 .

7. Vic Comello, "When to Choose a Thermocouple Gauge", Back to Basics, R&D Magazine, May 2000, p. 75.

Pressure Range Considerations

TC gauges deliver useful pressure readings between 10^{-3} and 10 Torr. Pressure readings above the upper limit are virtually useless, making it impossible, for example, to tell the difference between an overpressure condition caused by (1) a malfunctioning pump or (2) an accidental venting to ambient air by improper use of the foreline valves. While pumping down a system, a TC gauge cannot indicate if the pumps are working until pressures in the 1-10 Torr range are achieved and valid readings start to be displayed. This forces the operator to wait in front of the vacuum system until a reading of vacuum is obtained before being able to move on to something new!

PG105 convection gauges deliver useful pressure readings between 10^{-3} and 10^{3} Torr. This extended pressure range makes the PG105 convection gauge ideal for monitoring the pumpdown of vacuum systems from atmosphere to the base pressure of most mechanical pumps, without any blind pressure spots. Convection gauges are found in virtually every modern semiconductor and thin film process system, for monitoring pumping system performance. The vacuum operator gets an immediate indication of pumping action as soon as the pumpdown begins! Atmospheric pressure response is what makes convection gauges one of the most popular sensors found in loadlock systems. Most loadlocks must be open to atmosphere under a positive internal pressure of dry nitrogen or air to ensure a gentle flow of gas out of the chamber once the door is open. A convection gauge is often used to decide whether it is safe to open the gate and expose the loadlock chamber to air! Many users even combine their convection gauges with differential pressure devices called atmospheric pressure switches for added reliability. *Thermocouple gauges should definitely not be used to monitor the backfilling of loadlocks!*

WARNING!
Claims of TC Gauge readings extending to atmospheric pressures must be treated with extreme caution!

Modern oil-free high vacuum systems increasingly rely on hybrid turbo pumps backed by oil-free mechanical pumps. As the compression ratios of turbo pumps continue to increase so do the foreline pressures those systems require. Convection gauges are better suited to monitor pressures in modern turbo pumped systems. It is not uncommon to cold start a turbo pumped station from atmosphere and use a convection gauge to follow the pressure in the foreline from atmosphere to the base pressure of a diaphragm or scroll pump. The ultimate pressure of the mechanical (diaphragm) pump is one of the numbers that can be used to define if the system is properly pumped down.

With proper precautions, the PG105 lower range can also be extended further down into the 10^{-4} Torr decade, providing an amazing seven orders of magnitude of dynamic range from one gauge!

Response Times

Operation at constant wire temperature provides the PG105 convection gauge the advantage of a faster response to pressure transients. The response time is very fast (milliseconds in most cases) because components do not have to change temperature as pressure changes. Response time to a pressure step-function is pressure dependent, but it is roughly about an order of magnitude faster than in TC gauges.

Fast response time makes the PG105 convection gauge ideally suited for protective functions, as in determining when ionization gauge emission current should be deactivated or turned off. They are also well suited to control valves, heaters, bakeout ovens and safety interlocks.

Ion Gauge Auto Start

The IGC100 has a built in IG Auto-Start mode that makes it possible to automatically link the emission status of an ionization gauge to the pressure readings of a PG105 gauge exposed to the same vacuum environment. The ion gauge emission is immediately turned off as soon as the pressure goes above a user specified threshold value. This protects the filament from accidental burnouts. The emission is automatically reestablished as soon as the PG105 pressure readings goes below the threshold value, making it possible to automate pressure measurements from atmosphere down to UHV during pumpdown.

Remote Sensing

Compatibility with long cabling and immunity to electrical noise are important specifications for thermal conductivity gauges used in vacuum setups where the sensor must be placed far away from the controller.

The bridge circuit used to set the wire temperature is built right into the PG105 head, and the voltages are read using a Kelvin probe (4 wire) arrangement making them independent of cable length. Up to 150 m long cables can be used with PG105 gauges.

The output of the PG105 convection gauge is between 0.3 and 6 V as opposed to the much smaller, and noise sensitive, 1 – 15 mV levels that are delivered by thermocouple gauges.

Controller/Gauge Interchangeability

Thermocouple gauge tubes are made in about seven types that cannot be used interchangeably. A TC gauge controller must be matched to the gauge tubes for which it was built to assure accurate pressure measurements. Many manufacturers make tubes with compatible specifications.

TC Gauges are often differentiated by the filament current they require for their operation, and it is not unusual to need to fine tune the current delivered by the controller to the gauge to obtain accurate readings. Some TC tubes include a label with the recommended heater current required to obtain accurate pressure readings. Re-zeroing of the controller is recommended every time a new TC gauge tube is connected.

Following factory assembly, each PG105 gauge tube is individually calibrated for nitrogen, and temperature compensated between 10 and 40°C. After calibration each gauge tube is then individually tested to determine if selected pressure readouts fall within narrow limits before the unit is ready for shipment. Individual factory calibration of the gauge response provides true 'plug-and-play' convenience and eliminates the need to rezero the controller each time a new gauge tube is connected. PG105 gauges and IGC100 controllers are completely interchangeable without any need for instrument adjustments! In order to assure that calibration does not change with use, all gauge tubes are baked at high temperature for an extended period of time before final calibration takes place.

Contamination Resistance

Some widely used TC gauges utilize sensor wire temperatures of 250°C or higher at vacuum. Such high temperatures can cause pump oil to crack and leave carbon residues on the sensor which can then cause calibration shifts.

The temperature of the wire inside the PG105 gauge tube is approximately 120°C during operation. This temperature delivers optimal gauge response while, at the same time, remains low enough to minimize contamination by surface induced decomposition of foreign materials, such as pump-oil vapors. Contamination resistance provides enhanced accuracy, repeatability and long term stability compared to TC gauges.

UHV Compatibility

TC gauges are not compatible with UHV environments. Most of them include plastic feedthru headers and cannot be baked out.

The standard PG105 convection gauge uses a high-quality Viton® O-ring to seal the feedthru flange end of the tube, allowing maximum bakeout temperatures of 110°C (with the plastic connector detached). Metal gasket sealed gauge heads are also available, option PG105-UHV, that can be baked up to 250°C for more complete UHV compatibility. The metal gaskets used in all UHV enhanced gauge versions, are made out of OFHC Cu and belong to the Helicoflex Delta® family of high-performance compression metal seals, widely used for ultrahigh vacuum and ultrahigh purity applications. (Note: Helicoflex Delta® Seal is a registered trademark of Garlock Helicoflex, Columbia, SC)

Metal sealed gauge tubes, option PG105-UHV, are recommended for all ultrahigh vacuum and ultrahigh purity applications incompatible with the standard compression O-ring seal.

The all-metal interior construction of the PG105-UHV gauge makes it the best choice for applications requiring ultrahigh vacuum and/or ultrahigh purity compatibility. PG105-UHV gauges are often connected directly to high and ultrahigh vacuum chambers and used as cross-over gauges to protect the filaments of much more expensive ionization gauges.

Price/Performance Ratio

In relative terms, convection gauges are more expensive than most thermocouple gauges (about twice the price). However, in absolute numbers, the difference amounts to a very small extra cost that is usually insignificant relative to other recurring costs associated to the design and operation of a standard vacuum system.

Cost only plays a role in heavily contaminated systems, which require constant gauge replacements and do not rely on high accuracy pressure reports. A TC gauge might be the way to go in those applications. TC gauges are often preferred for dirty or corrosive processes because they are inexpensive enough to be thrown away when they become contaminated.

Freeze-Drying Processes

TCs are the gauge of choice in freeze drying operations because of the high water contents present during the drying processes. Pirani gauges do not fare as well in high humidity environments.

Leak Testing

Gas dependence makes the PG105 useful as an inexpensive leak detector. By using a tracer gas whose thermal conductivity is very different from the gases in the vacuum system, leaks as small as 10^{-4} atm cc/sec can be sensed and located. Typical gases used for leak testing include hydrogen, helium, argon and freon. This can eliminate the need for a very expensive leak detector. Several applications of Pirani gauges to leak detection have been reported in the vacuum literature.