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From THE VACUUM LAB

By Phil Danielson

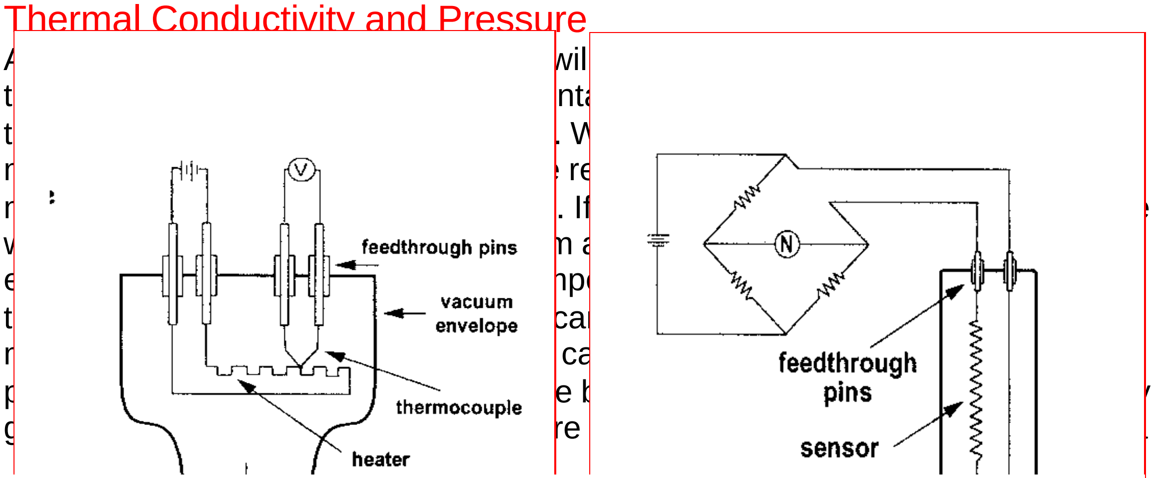
Thermal Conductivity Gauges

Thermal conductivity pressure gauges are extremely common in vacuum technology, but an understanding of their principles of measurement and operation can help in their proper application.

Measuring pressure is a necessity for virtually all vacuum processes and vacuum practitioners, but there are so many variations in pressure ranges and the degree of required accuracy and precision that there is no possibility of identifying a single type of gauge that will be of use to all. Applications might vary from simply monitoring all or part of a pumpdown cycle, carefully measuring a stringent ultimate pressure, or measuring and controlling a critical process gas. There are, however, two types of gauges that are arguably the most commonly used out of the many gauge types available: ionization gauges and thermal conductivity gauges.

A high vacuum process will need to be provided with gauging that follows the pumpdown cycle from atmospheric pressure through the volume zone and into the drydown zone. A thermal conductivity gauge can follow the pressure all the way through the volume zone, but when the system goes into the drydown zone below about 10^{-3} torr where water vapor becomes the predominant residual gas, an ionization gauge is required. In general, with the exception of some extended range gauge modifications, these two gauges together can be used to cover the full pumpdown cycle. This is why so many electronic gauge controllers combine both types of gauges in the same unit.

Thermal Conductivity and Pressure



(Left) The heated wire sensing element is one leg of a wheatstone bridge, and as the wire changes temperature in response to pressure changes, the bridge goes out of balance to provide an analog of pressure readout. Thermocouple Gauge Schematic View: (Right) Pirani Gauge Schematic View. The heated wire sensing element changes temperature in response

pressure range of about 10^{-3} – 1 torr. Below this range, heat transfer is mostly by radiation from the wire's surface and mostly by thermal convection above it. Thermal conductivity gauges covering this range have been in use for many years that fall into two main groups: thermocouple gauges and Pirani gauges.

Thermocouple Gauges

Thermocouple gauges, as the name suggests, use a thermocouple attached to the hot wire to measure its temperature. If, for example, a thermocouple gauge is used to monitor a pumpdown cycle, the wire will become hotter and hotter as the pressure drops and fewer and fewer molecules are available to transfer heat away from the wire.

Heat is also transferred by flow through both the thermocouple wire and the support/feedthrough pins for the hot wire.

This means that the entire sensing array must be constructed of conducting metal leads that are of as small a diameter as possible to avoid excess heat loss. This problem becomes more acute at the gauge's lowest pressures when the wire is at it hottest. Since the heated wire, in most thermocuple gauges, needs to operate at maximum temperatures between 200-300° C, it's made from a noble metal such as platinum to avoid oxidation problems.

At the lowest pressures, the hot wire is often exposed to oil vapors if oil-sealed mechanical pumps are used. The oil vapors can either crack to leave carbon deposits or polymerize to leave a layer of thermal insulation on the wire. Since the backstreaming rate of pump's oil is greatest at low pressures, this can be a significant problem since it will change the gauge's calibration. Although it is sometimes possible to clean the gauges by rinsing with solvents, success is by no means assured. The solvents might not totally remove coatings and the electrode arrays need to be delicate enough that sloshing liquids can easily cause mechanical damage. The necessary delicacy also means that they will not withstand mishandling shocks such as a free drop onto a concrete floor.

Thermocouple gauges are calibrated such that the wire's temperature is displayed as a pressure reading. This allows such problems as variations in heat flow through the supporting electrodes to be taken into account. One problem that can't be calibrated for is based on the fact that the wire must change temperature with pressure changes. Even though the heat capacity and thermal flow characteristics of the sensing array is kept to a minimum, there is some lag time associated with temperature changes in response to pressure changes. In most applications, this is not a problem, but rapid pressure changes such as might be found in rapid pumpdowns or backfilling operations can show significant delays in response time.

Pirani Gauges

Pirani gauges also take advantage of the change in temperature of a heated wire, but unlike thermocouple gauges, they don't measure the wire temperature directly. Instead they make use of the fact that the resistance of a metal wire changes with the wire's temperature. If the heated wire is made to be one leg of a wheatstone bridge with a balancing leg exposed to ambient temperature as a compensator, and both of these are set against two fixed resistors, a balanced circuit will go out of balance as the sensor wire changes resistance with pressure changes that change the wire's temperature. Pirani gauges, in general, operate with a heated wire that is much cooler (120-200^0 C) than a thermocouple gauge, and this makes them less likely to become contaminated by mechanical pump oil.

Pirani gauges that are heated with constant current will usually have a faster response time than thermocouple gauges due to such differences as smaller electrodes. Many modern gauges now operate in a constant temperature mode. A separate circuit constantly changes power input to maintain a constant sensor resistance. This produces full-scale response times in milliseconds.

Gas Specie Sensitivity

Both thermocouple and Pirani gauges share a potential application problem in that they both have widely varying sensitivities to the particular gas species being measured. This is due to the wide variations in thermal conductivity that differing gases display. Since these gauges are most often used to monitor a pumpdown from atmospheric pressure, this is seldom a problem, but it can be a problem if careful pressure measurements of a particular gas are required. When the gas to be measured is known, most commercial units will be provided with calibration tables, curves, or factors that allow the readout of pressure to be converted. If extremely accurate pressure readings, such as would be required for a process gas, it might be better to consider a capacitance manometer which responds to all gases equally.

Convection Enhancement

Although early thermal conductivity gauges were limited to a high pressure range below about 1 torr because heat transfer shifted from thermal conductivity to convection at higher pressures, newer gauges have solved this problem. Many gauges are now available that have extended their range to atmospheric pressure. Various techniques have been applied to account for changes in wire temperature due to convective gas motion. This list includes compensation electrodes and spacing that is small enough to preclude convective motion. In many cases, enhancement techniques require that the tubes be mounted in a specific attitude to account for gas motion in the higher range.

Extending the range has also introduced an additional specific gas sensitivity problem. If a gauge is being used to backfill a chamber to atmospheric pressure with a heavy gas like argon, a readout that is calibrated for nitrogen will read so low that the chamber will become over-pressured long before an atmosphere is displayed and an obvious safety problem results.

Applications

Like all vacuum devices, thermal conductivity gauges are application sensitive. In general, these devices are at their best when used to monitor a pumpdown cycle. They are inexpensive and reliable, but they do not generally have the accuracy required for stringent measuring of process gases. Their varying response to different gas species makes them into good practical leak detectors since a probe gas other than air, such as helium, will produce a sudden and large reading difference. Proper application can make them very useful devices

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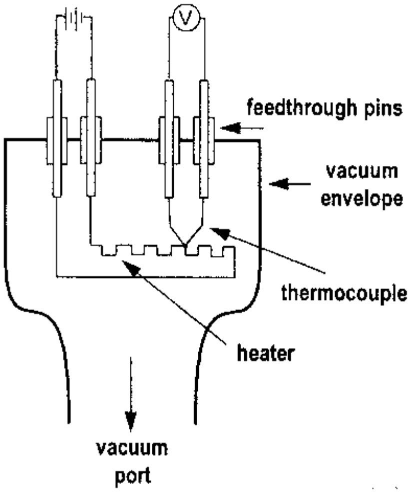

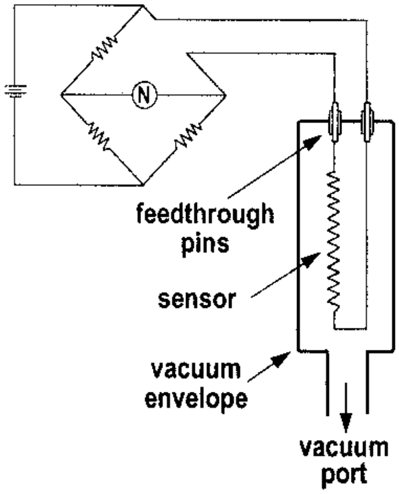
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