

Ion pumps are long lived; the lower the pressure, the longer the life. Once they begin pumping, they quickly lower the pressure to the long-life region. As long as they are not pumping against a leak, they will last for years. Ideally, ion pumps should be started at pressures approaching 10^{-5} torr. At higher pressures, the plasma discharge that is generated minimizes pumping speed and reduces cathode life. A more common and practical approach is to sorption rough the pump to less than 10^{-2} torr before applying the ion pump power. At very low pressures, the time taken to begin the ionization process may be excessively long.

TYPICAL DIODE PUMP SERVICE LIFE

Pressure (Torr)	Life (Hours)
10^{-3}	20
10^{-4}	200
10^{-5}	2,000
10^{-7}	200,000 (over 20 years of constant operation)

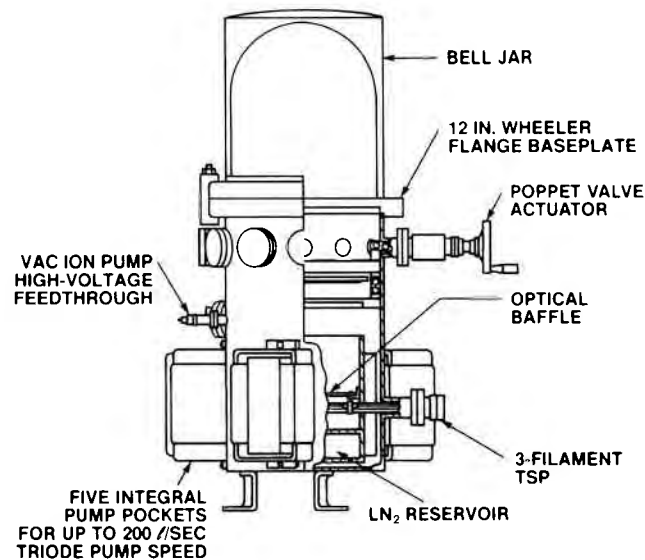
Life (Pumping N_2 at 10^{-6} Torr)

Triode	35,000 hours — approx. 4 years
Diode	50,000 hours — approx. 6 years
StarCell	80,000 hours — approx. 9 years

Vacuum System Use

Ion pumps are typically used in systems which demand ultra-clean, ultrahigh vacuum. This type of vacuum system is pumped to high vacuum or lower pressure and then kept in that condition

for long periods of time. A load-lock chamber is often built on the system to allow access to the chamber without bringing the chamber back to air. Typical uses are for electron microscopes, mass spectrometers, and surface analysis, to mention a few.



Maintenance

Very little maintenance can be performed on ion pumps other than an occasional bakeout. When pumping eventually deteriorates to the point where operating pressures can no longer be attained, pump replacement or sometimes anode/cathode assembly replacement is necessary.

Summary

We have discussed the pressure ranges of vacuum pumps and the major types of pumps in each range. By now, you should be familiar with the different types of vacuum pumps—what their major components are and how they work. You have also learned how they are placed in vacuum systems and some general maintenance information.

Let's go on now to gauges. These are major vacuum components that tell you what is going on inside your vacuum system.

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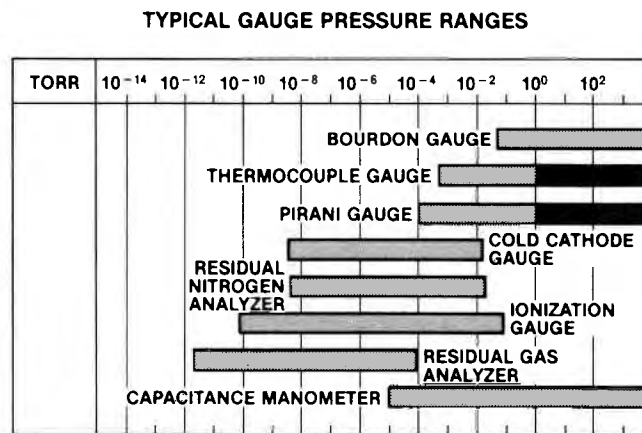
Gauges

In this chapter, you will learn to do the following:

1. List the commonly used vacuum gauges.
2. Give the pressure range in which each of these gauges operates.
3. Explain how these gauges work.
4. Describe how these gauges are maintained.

Introduction

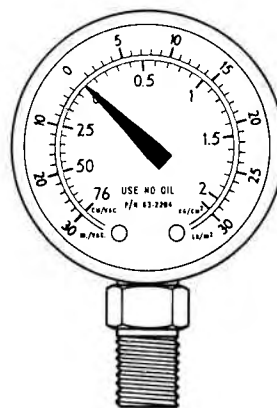
Gauges are an important part of your vacuum system. You rely on them to tell you what is happening inside the system. If you have worked with vacuum systems, you know that you must read several gauges— not just one. The pressure range is too great for any one gauge to read. The various gauges all have limited useful ranges. As a result, we must use several different types of gauges in order to read all the pressure ranges. Many gauges measure pressure. Only the commonly used ones are covered here. For example, the Bourdon, thermocouple, ionization, and cold cathode gauges, residual nitrogen analyzer, capacitance manometer, and residual gas analyzer. This chart shows typical pressure ranges of the gauges.



The gauges cover the entire operating range of all vacuum pumps covered in the previous chapters. We will start with rough vacuum gauges and work our way to the high vacuum gauges.

We would like our gauge to respond to total pressure— force per unit area— in order to be able to read the pressure in our vacuum system. We will see that for most vacuum gauges, the actual force per unit area is not what is measured. The gauge senses some other property. This reading is then converted to a pressure reading. Let's look at some rough vacuum gauges now.

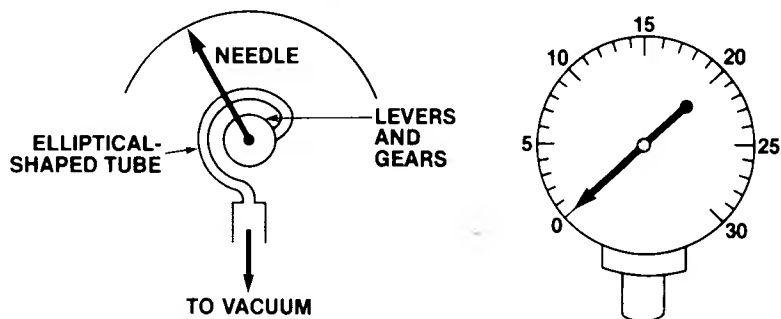
Bourdon Gauge



The Bourdon gauge is rugged and reliable. It can be used for measuring pressures above and below atmospheric pressure. Notice that it resembles a vacuum pressure gauge used in automotive tune-ups—same principle!

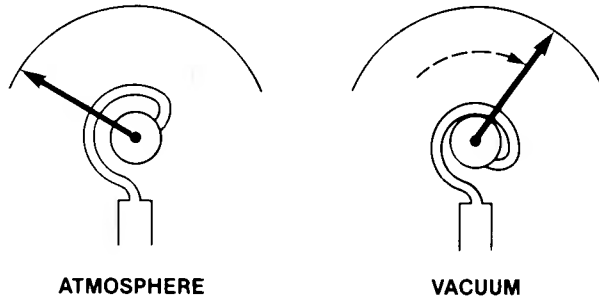
Generally, the accuracy of the Bourdon gauge is not high, but it is simple and reliable. At the lower end of its range, it really is not very sensitive. It stops reading around 1 to 0.1 torr.

How the Gauge Works



The Bourdon gauge measures relative pressure. Here's how it works. A tube in the Bourdon gauge is bent into an arc. One end is open to the vacuum chamber. Its other end is sealed and connected to an indicator needle. The meter scale is calibrated in inches of vacuum: zero is atmospheric pressure, and 30 inches corresponds to the low end of its range. This, of course, means that it is reading the relative pressure, or gauge pressure. It is comparing the pressure inside the tube to the pressure outside the tube. The gauge does respond to changes in pressure; but these

are the changes inside relative to the pressure outside. Since the pressure outside is always changing, by as much as $\pm 10\%$ from the average pressure, its accuracy is only moderately good.



The inside of the tube is open to the chamber, and the outside is at atmosphere. As the chamber is pumped out, the pressure difference between the inside of the tube and the outside of the tube causes the curvature of the tube to change. A system of levers and gears moves the needle according to the change in the bend of the tube.

Maintenance

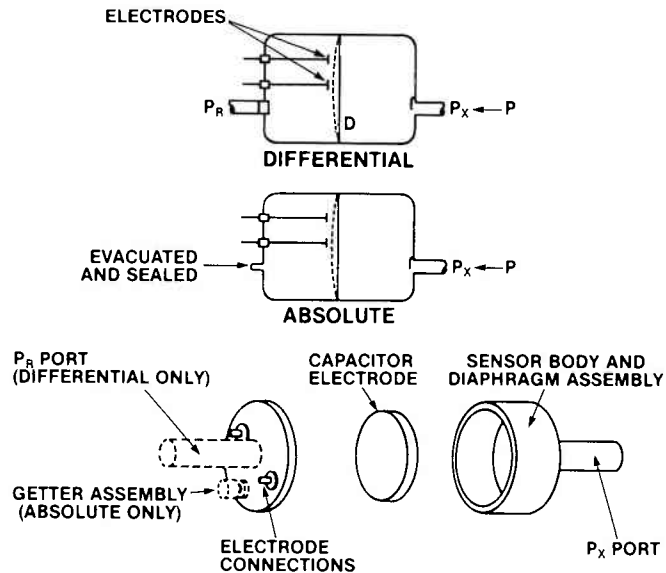
Bourdon gauges typically do not get any maintenance. The more expensive varieties may have mechanical adjustments that can be made. In general, the gauge is replaced rather than repaired.

Capacitance Manometer

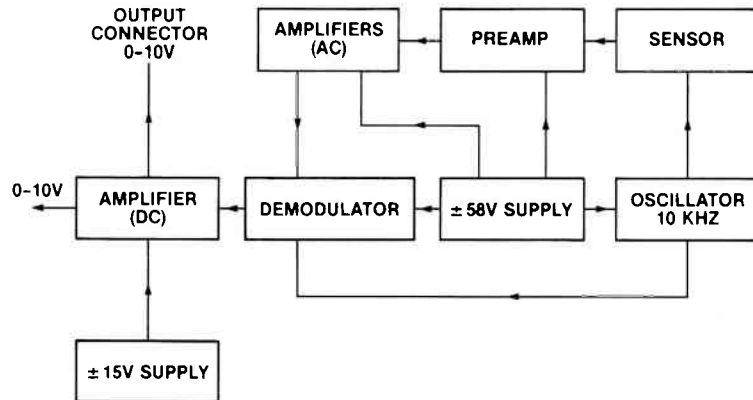
The capacitance manometer is another pressure gauge which can be used in the rough vacuum range. It is capable of measuring the absolute pressure or relative pressure, depending on the gauge model used. It does respond to the total pressure. It is not sensitive to changes in gas mixture as are many other gauges.

The sensing unit contains a tensioned metal diaphragm, one side of which is exposed to the gas whose pressure is to be measured. For absolute pressure measurement, the other (reference) side contains an electrode assembly placed in a sealed high vacuum reference cavity. Since the electrodes in the absolute pressure gauge are not exposed to the gases being measured, this gauge is not affected by oil or water vapors, or by corrosive or other chemically-active process gases.

How the Gauge Works



The diaphragm deflects with changing pressure—force per unit area— independent of the composition of the measured gas. This causes a capacitance change between the diaphragm and the adjacent electrode assembly. The capacitance change is sensed in an oscillator circuit and converted to a frequency change proportional to the diaphragm deflection.



This frequency change, in turn, is converted in the unit to be displayed as the pressure reading. The sensor unit may be constructed of materials such as inconel and stainless steel, allowing the gauge to be used with corrosive gases.

This gauge is sufficiently accurate (about 1% of reading) and precise that one can worry about the effects of temperature changes (Charles' Law) on the pressure readings. The sensor head may be placed in a constant temperature oven as a result.

This gauge is often used as a flow controller because of its fast response (milliseconds) to pressure changes. If you desire to use a capacitance manometer over a wide range, you may need several units. The gauge is constructed to read over three or four orders of magnitude. If you wish to read from atmosphere (7.6×10^2 torr) into the high vacuum range (1×10^{-5} torr), that is seven orders of magnitude. Therefore, you need several different gauge units. These gauges can be constructed so that pressures from 10,000 (10^5) torr to 10^{-5} torr may be sensed, but any particular gauge is limited to about four orders of magnitude of that range. Below 1 mtorr (10^{-3} torr), the accuracy falls dramatically.

Maintenance

The capacitance manometer may receive more maintenance than many gauges because of its ability to read accurate and precise pressure values. It may periodically be taken to the calibration lab for a check against some standard gauge. When it is used in dirty or corrosive gas systems, the sensing side of the gauge head may be flushed with an appropriate solvent.

Overpressuring the gauge (20% over full scale) may shift the reading or permanently damage it. An isolation valve is often used to prevent this.

Heat Transfer

Well, we are finished with “real” pressure gauges. The rest of the gauges we will be discussing sense some property of the gas present in our vacuum system and convert it to a pressure reading. One of these properties we will be using is the thermal conductivity of gases. Let’s take a minute to discuss the concept of heat transfer.

You have probably learned somewhere that heat can be transferred three ways: conduction, convection, and radiation. Let’s look at these three ways on a molecular scale.

conduction

To transfer heat, or energy, by *conduction*, molecules need to touch a surface or another molecule in order to transfer the heat. This principle is used in gauges between 2 torr and 10^{-3} torr.

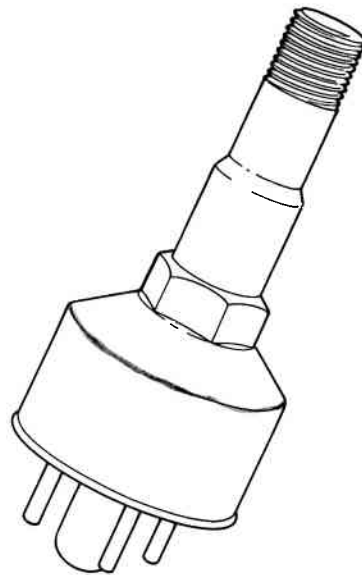
convection

To transfer heat by *convection*, we need massive numbers of molecules flowing. Your hot-air furnace heats by convection. Some gauges use this principle between 760 torr and 2 torr but are generally less accurate in this pressure range.

radiation

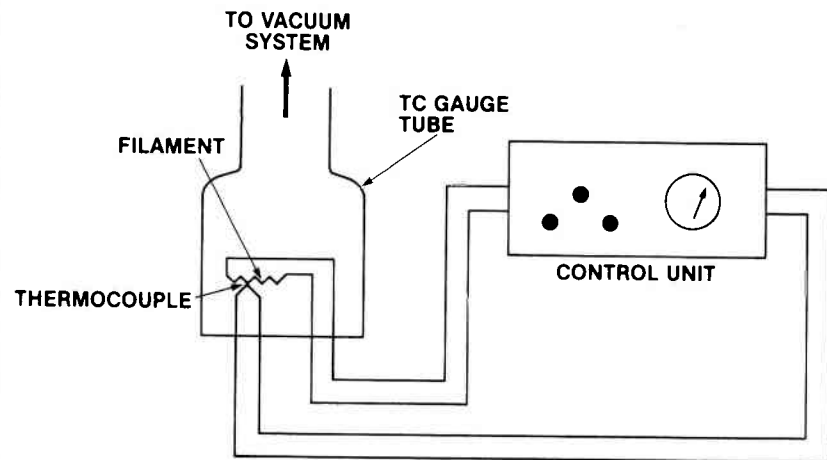
To transfer heat by *radiation*, we need light energy. Not the kind of light that you see, but typically infrared light. The heat you feel when standing in front of a fireplace is mostly the radiated heat. No gas molecules need be involved; that is, radiation is independent of the number of gas molecules present. Radiated heat is the only way to transfer heat inside of a vacuum system at high vacuum. There are insufficient molecules present to provide heat transfer by either conduction or convection. Now, let's go on to discuss gauges that depend on heat transfer to work.

Thermocouple Gauge



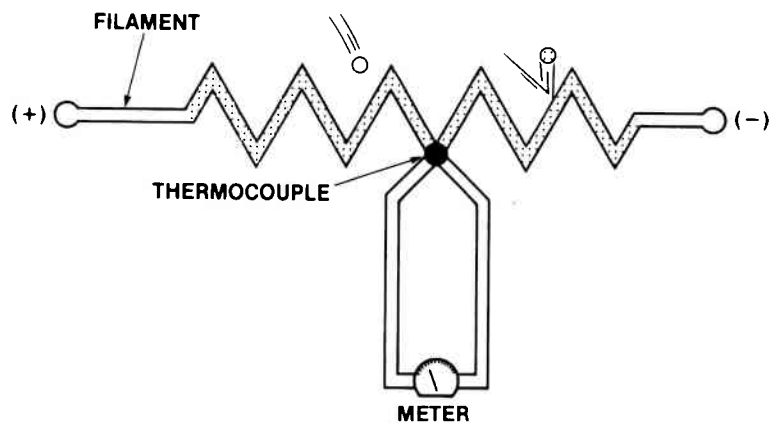
The thermocouple, or TC, gauge is another rugged, simple instrument. It is used to measure pressures in the rough vacuum range. It does its work well under less than ideal conditions. The TC gauge measures temperature and converts it to a pressure reading. Many modern thermocouple gauges have been modified to use convection as well as conduction principles. This effectively extends their useful range to atmosphere. It is typically considered as a very approximate device. Let's take a look at how it works.

How the Gauge Works



A thermocouple gauge consists of a gauge tube and control unit. Within the gauge tube is a heated filament. Spot welded to the filament is a thermocouple that measures the temperature of the hot wire. The meter is calibrated in pressure units, not in temperature.

THERMOCOUPLE GAUGE PRINCIPLE



At atmospheric pressure, there will be many molecular collisions with the heated filament. The gas molecules conduct heat away from the filament. The amount of heat removal can be related to the amount of gas in the chamber. At higher pressures, with lots of molecules, much heat will be conducted away from the wire. Therefore, the wire will be at a lower temperature (cooler). When we pump away the gas, there are fewer molecules to collide with the wire. The wire is therefore at a higher temperature (hotter).

There is not a linear relationship between wire temperature and pressure, so the pressure scale on your TC gauge is not linear. The gauge stops responding at about 1 mtorr (10^{-3} torr) because the heat loss through radiation is now the largest factor. The heat lost through radiation is also constant. Therefore, the gauge reads "zero." Compared to other gauges, the TC gauge has a slow response time. This is because the wire must have time to heat up or cool down as the pressure changes. Some newer gauges speed up the response time by operating the gauge at constant temperature and measuring the change in current required to hold the temperature constant.

Maintenance

If the sensing unit, or gauge head, gets dirty, it may be cleaned with an appropriate solvent. Most people will simply discard the TC gauge and install a new one in its place.

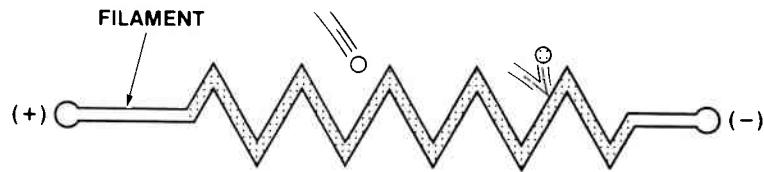
Whenever you clean or replace a TC gauge, it should be adjusted to read the proper values. To do this, you expose the gauge head to a pressure of 10^{-4} torr or less and adjust the control unit to read zero on the pressure gauge. If for some reason you cannot obtain a pressure below 10^{-4} torr, then install a "good" gauge and set the system gauge to read the same pressure.

Please check the operation manual for your particular unit for adjustment instructions, because they do vary in detail.

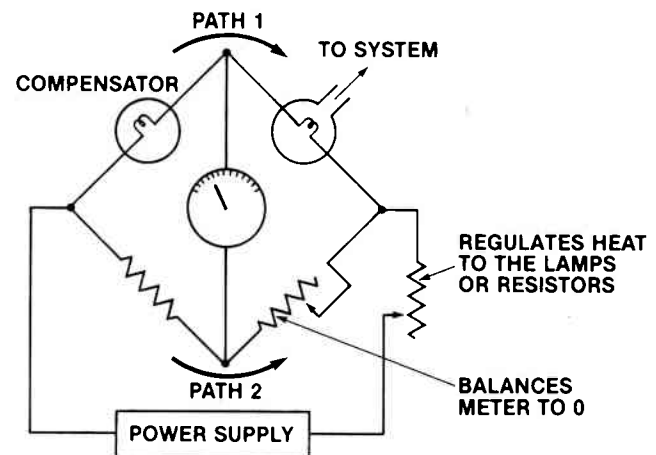
Pirani Gauge

The Pirani gauge operates similarly to the thermocouple gauge. It will read pressures best from about 2 torr to 0.001 torr. The appeal of this gauge is based mostly on its faster response time and range. Because of its more complex design, it is larger and more costly than the thermocouple gauge.

How the Gauge Works



In the Pirani gauge, gas molecules also conduct heat away from a hot filament. In this gauge, we depend on the change in resistance as the temperature changes. The temperature change causes a change in the filament resistance. The filament is part of a bridge circuit that drives the pressure meter. A simplified explanation of this circuit is given below.



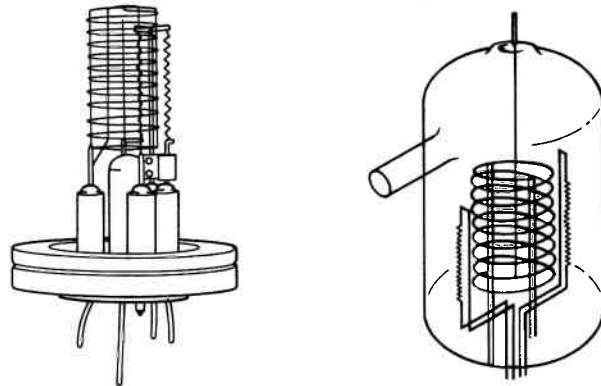
In a balanced bridge circuit, the current flow in Path Number One equals the current flow in Path Number Two. A meter, placed in the center as shown, indicates zero. When heat is conducted away from the filament, its resistance is changed, and this balance is upset. This unbalance develops a voltage difference at the meter connections, and current flows through it. Again, the meter is calibrated in pressure units. The hotter the filament, the more resistance it has. The compensator, which is a very similar filament, remains at a constant temperature and pressure. Therefore, its resistance is relatively constant. Ambient temperature changes do affect the gauge significantly below 10^{-3} torr.

Maintenance

Pirani gauge maintenance includes adjusting and cleaning. A Pirani gauge can be adjusted. Please consult your manual for the gauge to determine the proper procedure.

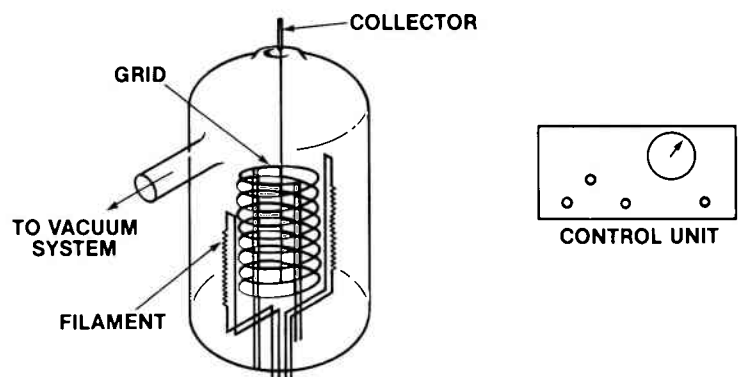
Ionization Gauge

The ionization gauge works on yet another property of molecules. They use the property that if you can energize an atom or molecule, it may lose an electron and become charged. These charged molecules (ions) can be attracted and "counted" as they pick up an electron to become neutral again. This is very similar to the way the ion pump works. Let's look at how this is accomplished as we discuss the gauge.



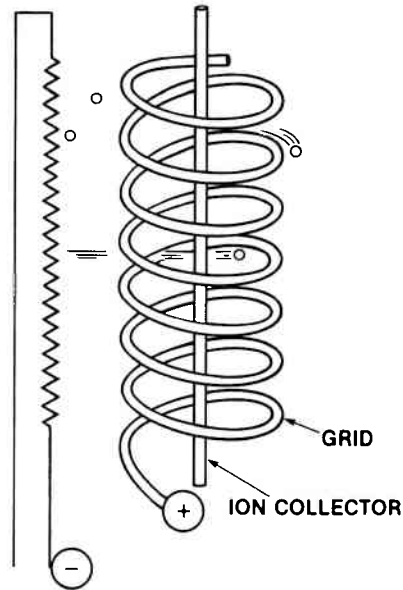
The ionization gauge is perhaps unique in that it can be used over a pressure range spanning eight orders of magnitude (10^{-3} to 10^{-11} torr). It is commonly used over seven orders of magnitude (10^{-3} to 10^{-10}) and expected to be within $\pm 20\%$ of the correct value over that range. This makes it the most widely used gauge for high vacuum work. Models include both glass and metal envelopes as well as "nude" gauges which mount directly in the chamber.

How the Gauge Works

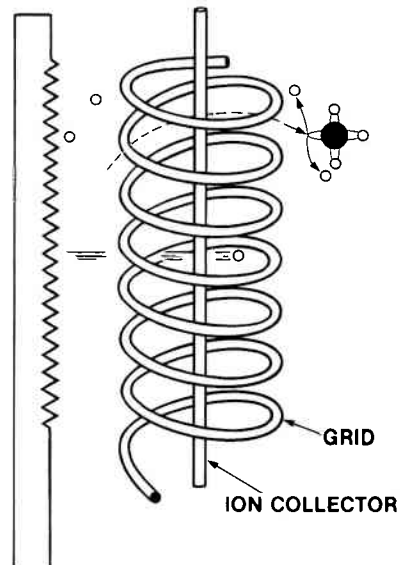


hot cathode ionization gauge

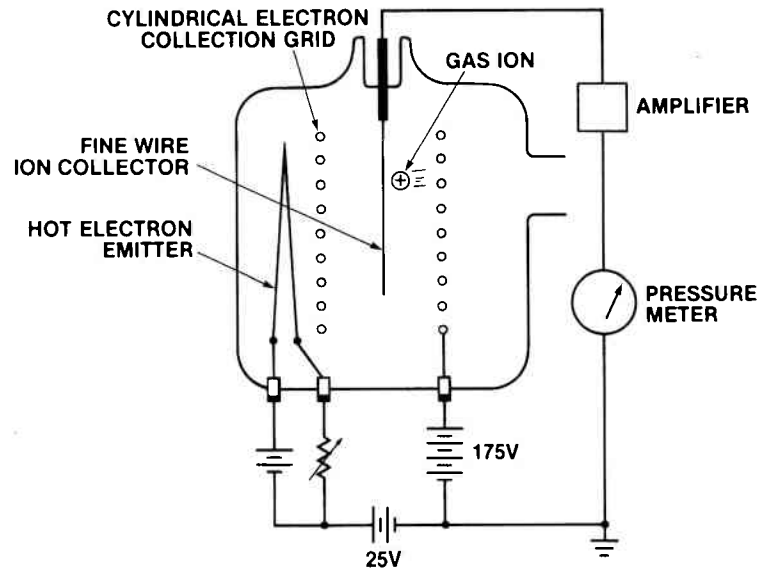
One *ionization gauge* has a hot filament, a grid and an ion collector. A control unit provides power, amplification, and metering. The hot filament supplies ionizing electrons. The grid attracts these electrons. The ion collector attracts the ions and gives up electrons as ions are neutralized. This process creates a small "ion current" which is then amplified.



Let's look at the process in more detail. Electrons emitted by the hot filament are attracted to the positive grid. However, many electrons miss the loosely wound grid and swing past it several times before finally striking it. Because of the large number of electrons emitted by the filament, a fairly constant "electron cloud" is present about the grid in the gauge tube.



On their long, round-about flight to the grid, electrons may collide with gas molecules, ionizing them and releasing more electrons. The longer the flight of these electrons, the greater the chance of collision. Therefore, a stronger, more usable signal is produced.



The positively ionized gas molecules are attracted to the collector. This produces an ion current proportional to the pressure in the chamber. To get meaningful pressure readings, the sensitivity of the gauge must be known, and the emission current must be well regulated. The "sensitivity" selector on the controller must be set the same as the rated sensitivity of the gauge tube. If this "matching" is not done, you will get inaccurate pressure readings.

The sensitivity of the ion gauge is obtained from the relationship

$$P = \frac{1}{S} \times \frac{i_p}{i_e}$$

where P is pressure,

S is gauge sensitivity,

i_p is the positive ion current,

i_e is the emission current.

As you can see from the ratio i_p/i_e , there are two variables, not one. If the emission current varies, it will cause a variation in the ionization current and therefore the pressure. Most manufacturers of ion gauges go to great pains to insure that i_e is constant. Varian uses a patented Ratiomatic™ circuit to directly measure the ratio of the ion current to the emission current. This allows small variations in the emission current to occur without affecting the gauge reading.

The ion gauge has limits like any of the other gauges. The x-ray limit determines the low end of the ion gauge range. Low-energy