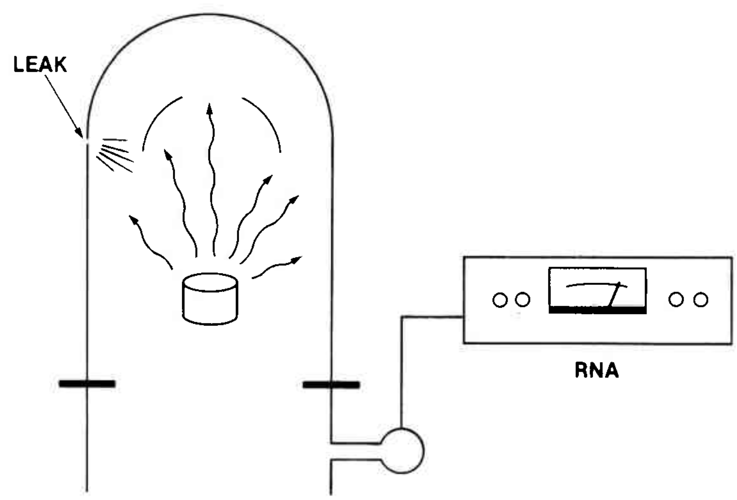
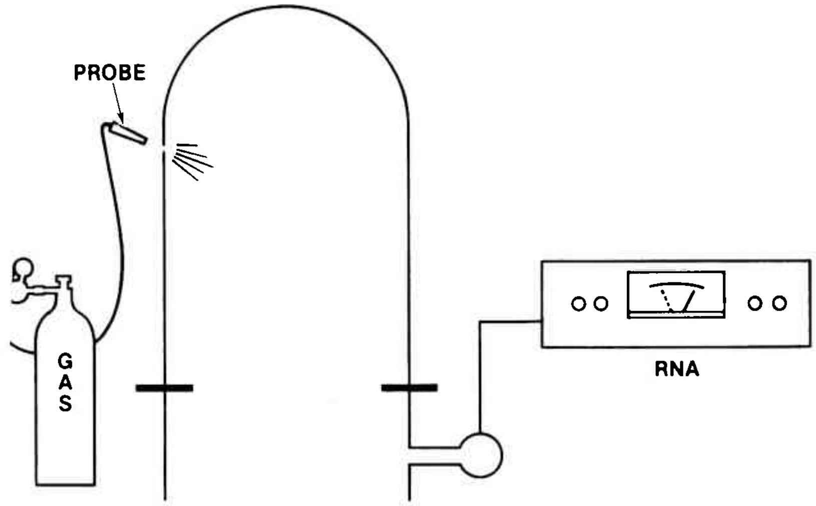
The RNA is a cold cathode gauge that also includes a window, an optical filter, and photomultiplier tube. Ionization produces light. This light has various colors, depending on the gases producing it. The filter passes nitrogen light and blocks the light from other ionized gases. Thus, the gauge reads only the nitrogen pressure. In the "normal" mode, this cold cathode gauge also reads the total pressure. We can use this to help us in determining the condition of our vacuum system.

Gases are pumped at different rates. Nitrogen is relatively easy to pump, so its percentage in a pumped-out system is lower than it is at atmosphere. A leak, on the other hand, admits an abundance of nitrogen. The RNA, which is tuned to nitrogen, senses this abnormality, and identifies an air leak.

For example, the percentage of nitrogen remaining in a normal evacuated leak-free system at 5×10^{-6} torr may be about 10%. An air leak can change this percentage to about 80%. A low nitrogen reading upsets the normal balance in the other direction, and is a good indication of outgassing or an internal leak in the system. The gauge is a simple way to diagnose a system problem. It answers a very important diagnostic question— does the system have a real leak or a virtual leak?



For example, coating material builds up with time, outgasses and raises the pressure. The RNA can tell the difference between outgassing, which may be still within acceptable limits, and an air leak, which is not.



The RNA also can be used to pinpoint the location of a leak. When a gas probe using any gas except nitrogen passes over the leak, the percentage of nitrogen is again changed. This change can be used to establish the location of the leak.

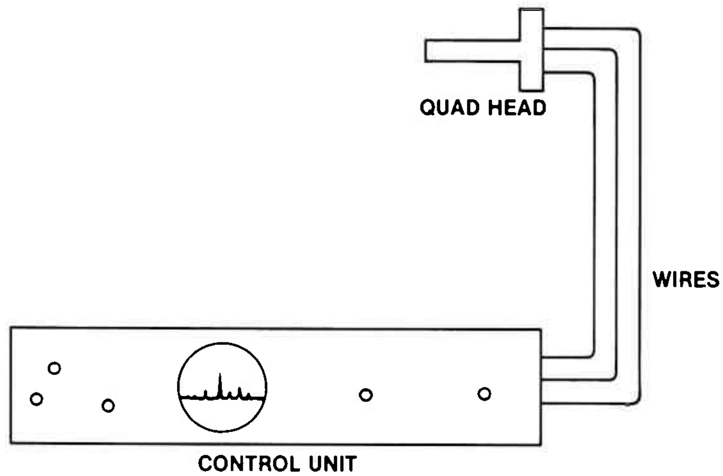
Maintenance

The RNA, being essentially a cold cathode gauge, requires the same maintenance. In addition, the window, filter and photo tube assembly may need attention periodically.

Residual Gas Analyzer

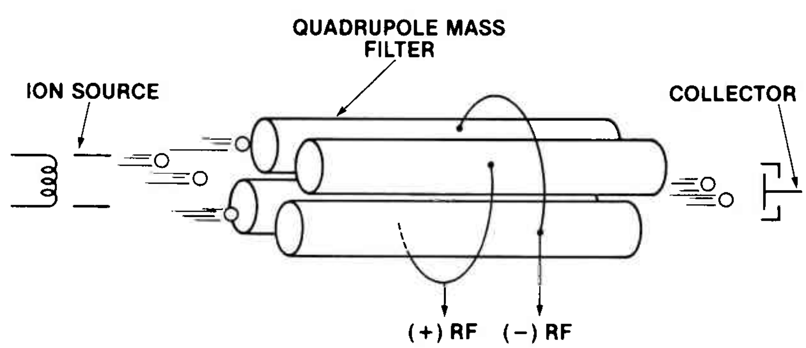
partial pressure

Another gauge that measures *partial pressure* is the RGA, or the residual gas analyzer. This instrument measures the partial pressure of each gas present in the vacuum system as well as the total pressure. It operates in the high and ultrahigh vacuum ranges. It is sometimes used to sample gases at higher pressure (above 10^{-4} torr), but the gauge head must operate at high vacuum.



One type of residual gas analyzer includes a quadrupole sensing head and control unit. The control unit has a computer-controlled screen that displays the ion current signals of the gases remaining in the chamber. Some of the older units use an oscilloscope to display the signals.

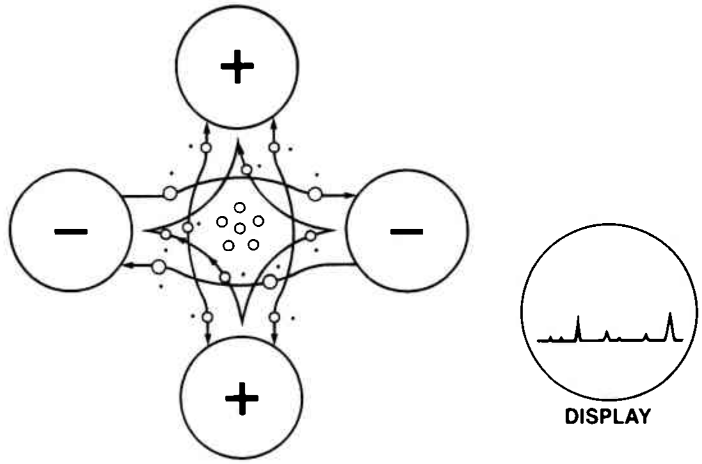
How the RGA Works



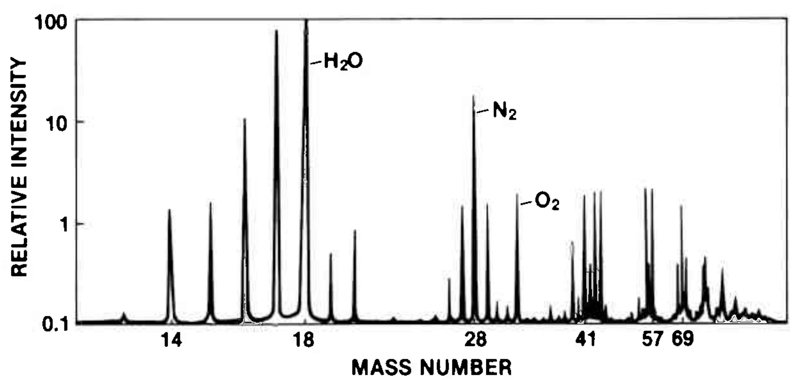
The residual gas analyzer separates, identifies and measures the partial pressures of residual, or remaining, gases in an evacuated chamber. The gases produce peaks in the display. The position of the peaks identifies the gases producing them. The partial pressures of the gases are measured by the heights of the peaks. Total pressure can also be measured.

A quadrupole RGA has a sensing head that includes an ion source, quadrupole mass filter, and a Faraday cup collector. Ionized gas molecules are injected into the mass filter. The ions that have the correct mass-to-charge ratio pass through the filter to the Faraday cup collector. These ions produce signals that are in proportion to the number of ions that get through the filter.

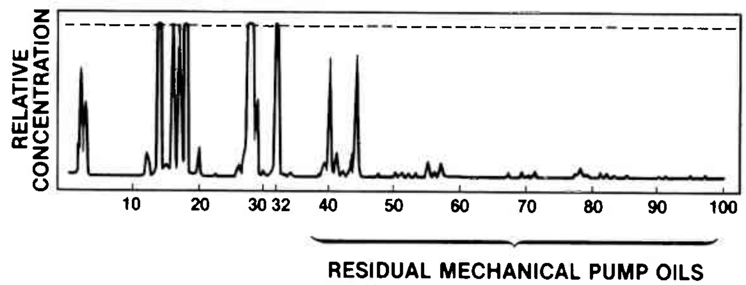
QUADRUPOLE MASS FILTER



The quadrupole mass filter is an array of two pairs of metal rods having equal and opposite rf and dc voltages. For a given set of voltages, only ions of a given atomic weight, or mass, pass through the filter. Ions above and below this mass are grounded on the rods. Then, by progressively changing the voltages on the rods, other ions are allowed through the filter in order. Thus, the various gases are separated and identified. Because this is an electrical process, it can occur quite fast, so that the instrument can display a wide range of masses. Typically, this display capability is 1–100, 200, or 300 mass units.



In this illustration, we can see that the vacuum system has an air leak by the large amount of nitrogen, oxygen and water vapor shown in the display. The instrument can then be used to find the leak by switching to detect helium only, and the system is probed with helium. When the probe is placed near the leak, helium enters the system and is quickly displayed. This pinpoints the location of the leak. Other gases may be used to probe for leaks if the RGA is properly tuned to that gas.



The residual gas analyzer is also useful for determining other types of contamination, such as water leaks or excessive outgassing from dirty components. (Vapors from backstreaming pump oils can also be identified with this instrument.)

Maintenance

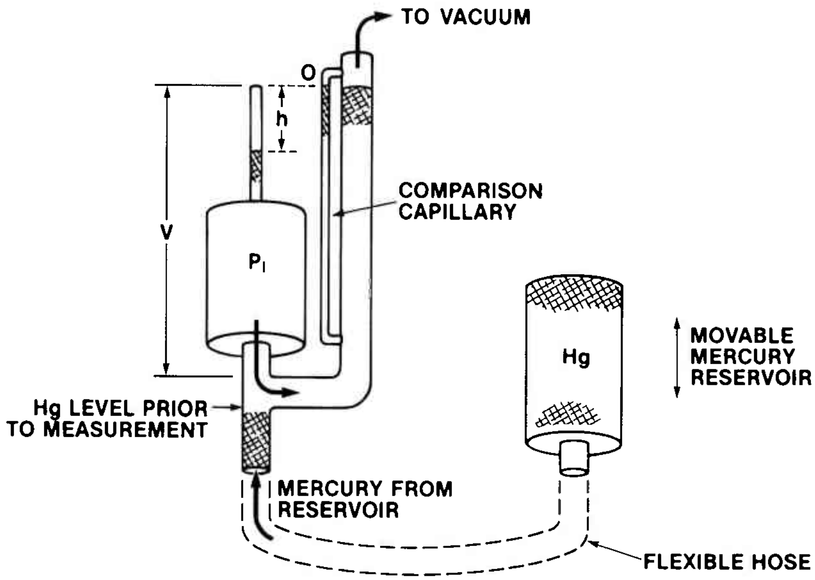
The RGA is a fairly complex and expensive instrument. Please consult your operation manual to determine the required maintenance.

Gauges Used for Calibration

In order to know what the pressure is in your vacuum system, you must measure it. But how do you know that your gauge is correct? Most of us take the manufacturer's word until we are forced to consider that it might be the gauge that is the problem.

To check the accuracy of a gauge, we need a known pressure. We must use an independent gauge to measure the pressure. This independent gauge is usually called a calibration gauge. A calibration gauge may range from one that you keep clean and use as your comparison gauge to a gauge that can be traced to the National Institute of Standards and Technology. Let's look at a few gauges that are used for calibration purposes. We will talk about the McLeod gauge and the spinning rotor gauge.

McLeod Gauge



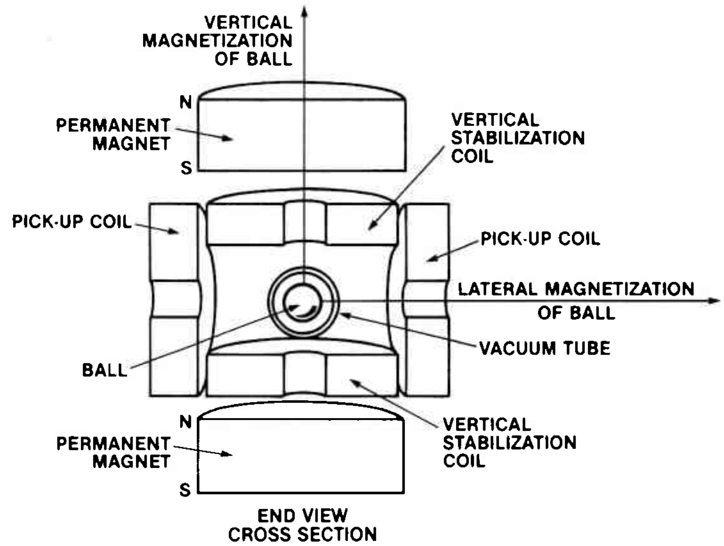
A McLeod gauge depends upon Boyle's Law for perfect gases. We use a large glass bulb and a small capillary tube with mercury to compress the gas at low pressure into a small volume at a higher pressure. A scale is attached so that we do not have to calculate the pressure from Boyle's Law each time. Because the gauge is made of glass and must use liquid mercury, it is rather fragile. If you had one on your production floor, it's broken by now! They are generally kept on a shelf in the "calibration lab" and used only there. The gauge suffers from several problems:

- It is fragile and is filled with mercury.
- It takes several minutes to get one reading.
- If the vacuum system contains a condensable gas (water vapor, for instance), the gas will condense during compression. The gauge reads incorrectly as a result. Therefore, drying filters must be used, and kept clean in order to get "correct" pressure readings for noncondensable gases.
- The mercury vapor is potentially toxic.
- It cannot measure rapidly changing pressures.

For many years, it has been the best "standard" gauge available, even with its problems.

To use the gauge, you connect it to your system and pump the gauge down. Be careful not to place the mercury bulb so that mercury can go into the vacuum system! When you think the gauge is pumped down (a problem), raise the mercury bulb slowly until it rises to the mark in the sidearm. Read the pressure on the scale. Lower the mercury to expose the gauge to the system pressure and try again.

Spinning Rotor Gauge



SPINNING ROTOR GAUGE

A newer gauge is now in the process of being accepted by the National Institute of Standards and Technology as a transfer standard gauge which they may certify. This is possible because the principle on which the gauge works can be related through calculation to basic laws of physics. Its name says exactly what it is— a spinning rotor.

You may recall from some experience that one of the problems with cars is the friction due to air. It's this property of air that is used in the gauge. A ball is magnetically suspended in a small chamber to eliminate all sources of friction except air friction. It is made to spin or rotate while suspended. If there are gases present in the chamber, the ball will slow down due to the impacts from molecules in the chamber. The rate at which it slows down is directly proportional to the gas pressure (number of impacts). All we need do then is to very accurately measure the rate at which the ball slows down, and calculate the pressure as a result. This calculation is, of course, done in the gauge control unit.

The manufacturer of this gauge states an accuracy of "1% of the reading plus or minus 3×10^{-8} torr from 10^{-2} to 5×10^{-7} torr." While you will not be using this gauge as a routine pressure gauge, your gauges may be calibrated using this gauge.

Other Calibration Gauges

The capacitance manometer may be used as a calibration gauge, generally in the rough vacuum range. It, in turn, could be calibrated using the spinning rotor gauge. You may keep one or more gauges in your tool box, just to replace a gauge on the system to see if they are about the same reading.

Summary

We have discussed various types of gauges used to measure pressure from the rough to ultrahigh vacuum ranges. You have learned what these gauges do, how they work, and how they are maintained.

Now that we've covered two major components of vacuum systems, pumps and gauges, let's move on to look at the hardware components and materials used in vacuum systems.

Notes

6 Vacuum Materials and Hardware

When you have completed this chapter, you will be able to:

1. Describe the basic materials used in vacuum work.
2. Understand the common joining techniques used in the construction of vacuum systems.
3. Describe the hardware components usually found in typical vacuum systems.

Introduction

Modern industrial vacuum equipment enables the manufacture of many different products. It enables processes such as vacuum skin packaging and vacuum drying. It also makes it possible to do many kinds of chemical processes, analytical work, and thin-film coating. These are only a few examples of the work done in vacuum systems. Of course, we must have the pumping mechanisms to produce high-purity vacuum environments. Let's now look at another key factor in vacuum equipment: the hardware components and materials used in vacuum systems.

Vacuum Purity Levels

It will help to have another look at what we are doing when we want to use a vacuum system. Here's a summary of some information about vacuum for you.

Pressure		**Gas Density**	**Mean Free Path**	
Torr	**Pa**	**Molecules/cc**	**Meters**	**English**
760	10^5	3×10^{19}	6×10^{-8}	2.5×10^{-6} in.
0.76	10^2	3×10^{16}	6×10^{-5}	2.5×10^{-3} in.
7.6×10^{-3}	1	3×10^{14}	6×10^{-3}	2.5×10^{-1} in.
7.6×10^{-6}	10^{-3}	3×10^{11}	6×10^{0}	21 ft
7.6×10^{-8}	10^{-5}	3×10^{9}	6×10^{2}	2100 ft
7.6×10^{-10}	10^{-7}	3×10^{7}	6×10^{4}	40 mi

Let's add two more numbers to compare to this table: About *10^{15} molecules* can cover *one square centimeter* (cm^2) of surface area only one layer (a *monolayer*) thick, when the molecules are at room temperature. At a pressure of 10^{-6} torr, it takes about 1 second to deposit one monolayer of molecules on the surface.

10^{15} molecules/cm^2 1 sec at 10^{-6} tor

Now, we can look at these facts and make some use of them. Let's suppose we want to put down a few layers of our own choosing on a surface. What pressure would we need to use in order to put down what we wanted— not just whatever was flying around in the chamber? Every second there will be another layer coating our surface at 10^{-6} torr. We better work fast. If we take a long time to lay down our layers, we will need to work at very low pressure.