CHAPTER 5

VACUUM SCIENCE

5.1 INTRODUCTION

A vacuum is a volume of space that is empty of matter, including air, so that gaseous pressure is much less than standard atmospheric pressure. The root of the word vacuum is the Latin word 'vacuus' which means 'empty', but space can never be perfectly empty. A perfect vacuum with a gaseous pressure of absolute zero is philosophical concept with no physical reality.

The quality of a vacuum is indicated by the amount of matter remaining in the system. For industrial purposes, vacuum is primarily measured by its absolute pressure, but a complete characterisation requires further parameters, such as temperature and chemical composition. One of the most important parameter is the mean free path (MFP) of residual gases, which indicates the average distance that molecules will travel between collisions with each other. As the gas density decreases, the MFP increases and when the MFP is longer than the chamber, pump or other objects present, the continuum assumptions of fluid mechanics do not apply. This vacuum state is called high vacuum. The MFP of air at atmospheric pressure is very short, 7×10^{-8} m, but at 0.1 hpa the MFP of room temperature air is roughly 10 cm, which is on the order of everyday objects such as vacuum tubes.

Vacuum quality is sub-divided into ranges according to the technology required to achieve it or measure it. These ranges do not have universally agreed definitions but a typical distribution is as follows:

TABLE 5.1. Pressure, Molecules Mean Free Path for Different Vacuum Ranges

Vacuum range	Pressure (h Pa)	Molecules (1/cm^3)	Mean free path
Low range	300 to 1	10^{19} to 10^{16}	0.1 to 100 μm
Medium vacuum	1 to 10^{-3}	10^{16} to 10^{13}	0.1 to 100 mm
High vacuum	10^{-3} to 10^{-7}	10^{13} to 10^{19}	10 cm to 1 km
Very high pressure	10^{-7} to 10^{-12}	10^{9} to 10^{4}	1 km to 10^{5} km
Extremely high vacuum	$< 10^{-12}$	$< 10^{4}$	$> 10^{5}$ km

Therefore, vacuum science is defined as a branch of physics which deals with the production and measurement of high vacuum using pumps and guages respectively. The concept of perfect vacuum is hypothetical state of zero pressure. In high vacuum technology, the pressure is measured in terms of mm of mercury. A pressure of mercury is called 1 torr.

5.2 IMPORTANCE OF VACUUM

Vacuum is useful in a variety of purposes and devices. The importance of vacuum in industries as follows:

- Discovery of electrons and *X*-rays
- Its used in incandescent high bulbs to protect the tungsten filament from chemical degradation.
- Vacuum cleaners
- Its chemical inertness is useful for vacuum welding, for chemical vapour deposition and dry etching in semiconductor fabrication and optical coating fabrication, and for ultra-clean inert storage and measurements.
- The reduction of convection improves the chemical insulation of thermos bottles and double-paned windoes.
- To remove humidity in food and pharmaceutical products.
- The electrical properties of vacuum make electron microscopes and vacuum tubes possible, including cathode ray tubes. Effect of vacuum on the oscillation properties of an oscillator used in various scanning probe techniques will be analysed.

Moreover, the following are the important applications of the high vacuum technology in the different fields:

(i) Radio and electronics

Quite a number of novel types of electron devices have been developed owing to vacuum techniques. With them, communications and navigation aids have gained a good deal in range, reliability, and durability. A wide range of vacuum plant is used in thin-film technology, solid-state circuit-component manufacture, integrated circuits, liquid-crystal devices, solar batteries, quartz-crystal resonator units, etc.

(ii) Electrical industry

Vacuum is used in driers and impregnators that process transformers, capacitors, cables, and electric motors.

(iii) Metal making

The physico-chemical properties of metals can be markedly improved through the use of vacuum in steel degassing, induction furnaces, electric-air and electron-beam refining units.

The manufacture of titanium, niobium, tantalum, zirconium, beryllium and their alloys needs a vacuum, either.

(iv) Chemicals

Vacuum driers have drastically stepped up the production of many valuable materials, such as synthetic fibre, polynamides, amino plastics, polyethylene, and organic solvents. Man-made ruby, diamond, and sapphire crystals used in lasers are also made with the aid to vacuum.

(v) Medical instruments and drugs

Vacuum is widely used in precision-casting plant of make medical instruments, and also in sterilizers, sublimation driers, in the preparation of antibiotics synthetic hormones, vitamins, serums, and a host of other valuable products.

(vi) Foods

Vacuum plays an important role in the production of sugar, in quick-freeze vacuum canning and meat packing plants. When vacuum-treated, foods retian all of their nutritional qualities.

(vii) Consumers industries

Metal evaporation in a vacuum is one of the ways to make metal-clad plastics, paper, and fabrics used as trimmings in furniture, ornamental applications etc.

(viii) Aircraft

Vacuum has proved its worth in precision-casting plant that handles titanium and high-grade alloys, electron-beam vacuum welding of parts for jet engines, and many similar uses.

(ix) Optics, Glass

Thin-film vacuum technology is used to make high quality lenses, optical and household mirrors.

(x) Scientific research

High and very high vacuum has given a big impetus to advances in nuclear physics and, later, to the practical uses of nuclear energy, and led to a deeper insight into the structure of matter. With ultra-high vacuum, space simulation chambers can be built, and the space environment can be simulated and investigated on the Earth.

It will be no exaggeration to say that further advances in vacuum technology will play a vital role in the study of new phenomena of nature, the development of novel instruments, and the creation of materials to customers specifications.

5.3 SCHEMATIC DIAGRAM OF A VACUUM SYSTEM

The Schematic diagram of a vacuum system is shown in Fig. 5.1

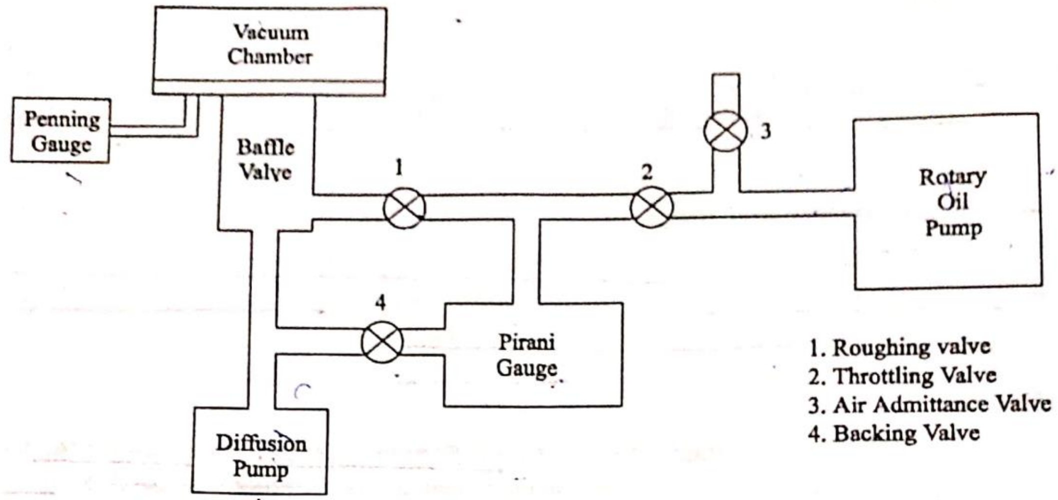


Fig. 5.1 Schematic Diagram of a Vacuum System

It consists of a vacuum chamber to which vacuum pumps are connected ie rotary pump and diffusion pump to create vacuum. Two gauges are connected (ie pirani gauge and penning gauge) to measure the pressure inside the vacuum chamber. All these pumps and gauges are connected with the help of valves namely baffle valve, roughing valve, backing valve, throttling valve, air admittance valve etc.

- Initially the air admittance valve is closed so that the pressure inside the chamber will be maintained.
- Rotary oil pump is switched ON and a vacuum is created up to 10^{-3} mm of mercury.
- This pressure is measured by using pirani gauge.
- The rotary oil pump is allowed to run continuously.
- The diffusion pump is switched ON.
- Now the rotary oil pump and diffusion pump is allowed to run continuously. Thus a very high vacuum is created inside the chamber.
- This high vacuum is measured by using the penning gauge.

5.4 PUMPING SPEED AND THROUGHPUT

To produce vacuum quickly inside the chamber, based on the speed at which the gas is removed from the chamber. This speed is called pumping speed and the amount of gas removed is called throughput.

Pumping speed

It is defined as the removal of the gas, whose volume of the chamber in one second.

Throughput

It is defined as the amount of gas removed from the vessel during the creation of vacuum.

Explanation

Let us consider the volume of a chamber V, from which the pressure of gas 'P' has to be removed. Let 'dt' be the time taken for the change in pressure p to dp.

$\therefore$ According to the definition of the pumping speed.

$$\left[\begin{array}{l}\text{The change in the amount of gas in the chamber}\\ \text{(or) the volume of the chamber in one sec}\end{array}\right] = \left[\begin{array}{l}\text{The amount of gas removed from the}\\ \text{vessel at anytime dt ie throughput}\end{array}\right]$$

$$-Vdp = SPdt \qquad \text{... (1)}$$

The negative sign indicates the decrease in volume, due to the removal of gas

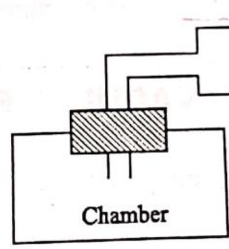


Fig. 5.2 Chamber Connected to Vacuum Pump

Rearrange equation (1)

$$\therefore \frac{dP}{P} = -\frac{S}{V}dt \qquad \text{... (2)}$$

If 't' is the time taken for the pressure to change from P_0 to P, then integrate equation (2)

$$\therefore \int_{P_0}^{P} \frac{dP}{P} = -\frac{S}{V}\int_{0}^{t} dt$$

(or) $$\log_e \frac{P}{P_0} = -\frac{S}{V}t$$

or $$S = -\frac{V}{t}\log_e \frac{P}{P_0}$$

$$S = \frac{V}{t} \log_e \frac{P_0}{P} \quad \cdots (3)$$

The above equation 3 represents the pumping speed of the gas from a chamber.

5.5 VACUUM PUMPS AND THEIR BASIC PRINCIPLE

Vacuum in a chamber in produced by means or a pump known as vacuum pump. To produce vacuum in the chamber the gas pressure in the chamber should be reduced. To reduce the pressure the total momentum of the gas in the evacuated space should be reduced. This may be achieved by

(i) by physically removing the molecules from the chamber.

(ii) providing sufficient momentum transfer to the gas at some point in the system through some kind of no return path.

(iii) by reducing the momentum of the gas to zero by sorption or condensation.

On the basis of these principles many vacuum pumps have been designed. These pumps are classified as fore pumps, high vacuum pumps and ultra high vacuum pumps depending upon the ultimate pressure attainable. Fore pumps are used to reduce the pressure from atmospheric pressure to a value 10^{-3} torr at which high vacuum pumps begin to operate.

5.6 CHARACTERISTIC OF VACUUM PUMPS

The characteristics of a good vacuum pump are

(i) the exhaust pressure

(ii) the degree of attainable vacuum

(iii) speed of the pump

and (iv) pumping speed.

(i) Exhaust pressure

In any vacuum pump there is an inlet connected to the chamber to be evacuated. The other side of the pump is called outer or exhaust side. The air or gas drawn from the chamber is expelled out at the exhaust side (Fig. 5.3)

The exhaust pressure is the pressure at the exhaust side with which gas or air is expelled out. This pressure may be equal to the atmospheric pressure or lower than it varying from pump to pump. In general to achieve high vacuum in the chamber the exhaust pressure for a pump should be small. So to produce high vacuum two pumps namely high vacuum pump and backing pump are connected in series with the chamber.

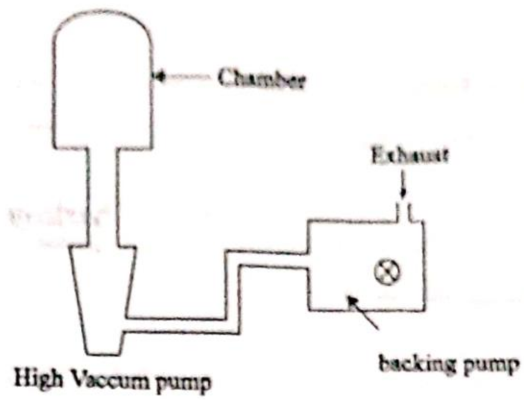


Fig. 5.3 Exhaust Pressure

The backing pump (Rotary pump) reduces pressure from atmospheric pressure to 10^{-3} torr called backing pressure. The backing pressure is further reduced from 10^{-3} torr to 10^{-7} torr by high vacuum pump or diffusion pump.

5.7 TYPES OF PUMPS

In the production of high vacuum, pressure is first reduced to 1 mm mercury by means of backing pump such as rotary oil pump and then the pressure is further reduced to a very low value from 10^{-4} to 10^{-7} mm of mercury by means of diffusion pumps. Nowadays, it is possible to reduce the pressure lower than 10^{-3} torr by using modern techniques.

Generally, there are many methods are used for the production of high vacuum. But exhaust pumps are mostly used to produce high vacuum and they are classified as follows:

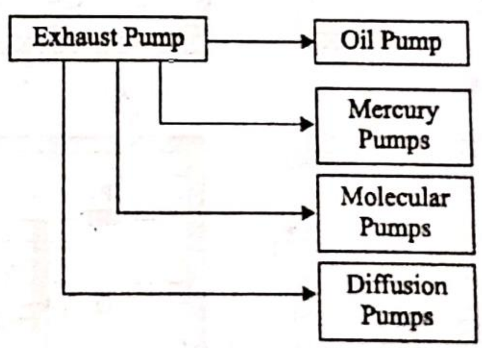


Fig. 5.4 Types of Pumps

Among the different types of pumps, we will concentrate on working principle, construction, pressure range, limitations and characteristics of rotary pump, diffusion pump and turbo molecular pump.

5.7.1. Rotary Pump

The rotary oil pump is further classified into two types, namely,

- Gaede's rotary oil pump and
- cenco rotary oil pump

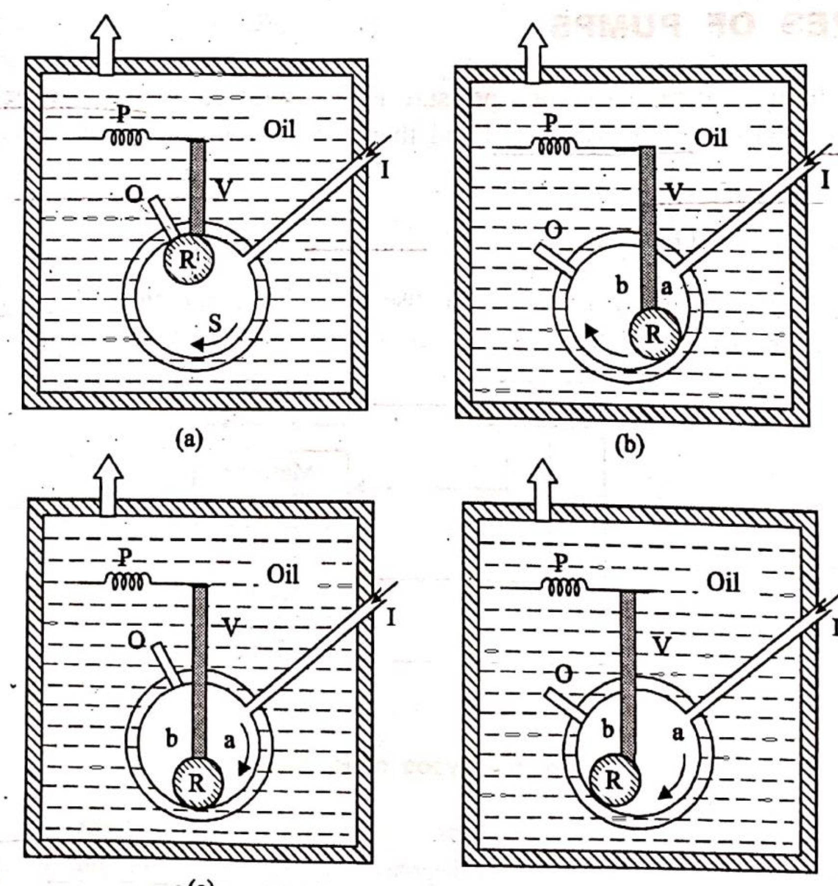
A common type of rotary pump is known as cenco ~~hyvac~~ rotary pump. This is widely used in laboratories and in vacuum coating units.

(i) Principle

The gas or air inside the vessel is compressed and forced out by continuously rotating the rotor, until a high vacuum is produced in the vessel, which is connected to the pump.

(ii) Construction

It consist of a solid cylinder '*R*' called rotor. The rotor rotates eccentrically inside a stout outer cylinder '*S*' called stator. The stator has an inlet tube '*I*' which is connected to the vessel to be exhausted and an outlet tube '*O*' through which the exhausted air/gas can be sent out as shown in Fig. 5.5.



The outlet is always opened outwards. An electric motor is used to rotate the rotor. The space inside the stator is divided into two straight compartments by means of a vane *V* between the inlet and outlet. The inlet and outlet are always tightly pressed against the rotor by means of a spring '*P*'. The whole arrangement is kept immersed in a special type of oil, which serves as a three fold purpose,

- It provides automatic lubrication,
- It prevents leakage of gas/air and
- It also acts as an efficient coolant, during its operation.

(iii) Working

To start with the rotor is kept initially at the position as shown in Fig. 5.5(a). Let the rotor be rotated in the clockwise direction. Four successive positions of the rotor *R* as shown in Fig. 5.5. The vessel to be evacuated is connected to the inlet tube 'I' and the gas from the vessel is allowed to enter into the space between the stator and the rotor '*R*'. In the first position the space inside the rotor is full communication with the vessel that is to be exhausted through inlet I.

The rotor is made to rotate, eccentrically with the help of motor. As it rotates, the space inside the stator is divided into two parts as in the Fig. 5.5(b). The rotor is further rotated and the air gets compressed as shown in Fig. 5.5(c). Also more air enters from the vessel to be evacuated.

As the rotor rotates further the outlet side part decreases in volume and hence the air inside it is compressed till it opens the outlet value '*O*' and then escapes out as shown in Fig. 5.4(d). The gas is expelled or sent out, by increased pressure at the exhaust valve for one complete rotation.

Meanwhile the inlet part space increases in volume and hence air is drawn from the vessel to be evacuated. Thus during each revolution of the pump, the air is drawn from the vessel and is removed from the vessel continuously. Within few minutes this pump can produce a low pressure of 10^{-3} in the vessel to be evacuated.

(iv) Advantages

- It can directly work from the atmospheric pressure.
- It can be used as a fore pump for high vacuum pumps like diffusion pump to attain still lower press uses.

(v) Disadvantages

- When gases and vapours dissolve in oil, it will be contaminated.
- It cannot be used for the production of high vacuum i.e., more than 10^{-3} mm of mercury.

5.7.2. Diffusion Pump

Mercury diffusion pump called as warren's diffusion pump it works on the principle of diffusion.

(i) Principle

The working of this pump is based on the principle of diffusion. It states that in a mixture of gases, a gas diffuses from a region where the partial pressure is higher to a region where the partial pressure is lower, irrespective of the total pressure in the two regions.

(ii) Construction

It consists of a conical shaped glass vessel 'A' containing some mercury with a nozzle 'N' at its top. This nozzle 'N' enters into a wider tube 'C' with a side tube 'I' near its top and to which the vessel to be exhausted is connected. The other end of 'C' has two side tubes 'O', which is connected to a backing pump or fore pump and 'D', which is connected to the lower end of conical shaped vessel 'A' as shown in Fig. 5.6. The wider tube is surrounded by a water jacket through which cold water is circulated.

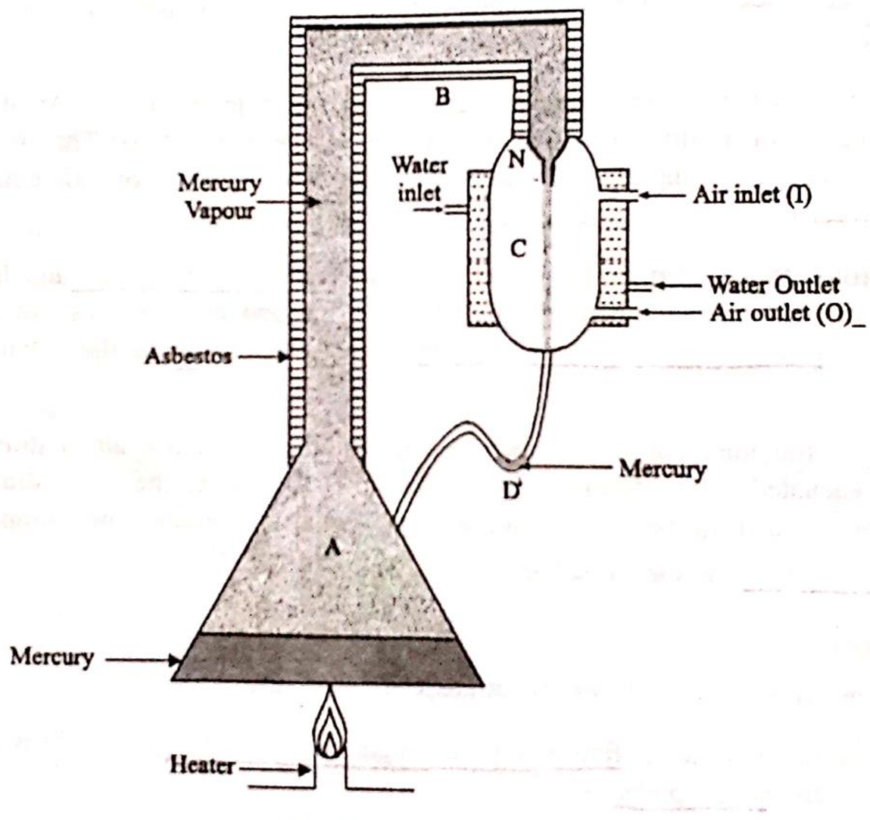


Fig. 5.6 Diffusion Pump

(iii) Working

The fore pump is worked before heating the vessel 'A' so that the pressure inside the vessel to be evacuated is reduced to as low a valve as possible. Now, the mercury is boiled in the conical vessel 'A' and is vaporised. The mercury vapours rise up and flow out of the nozzle 'N' towards D driving the air in C.

By Bernoullis principle, the pressure of air in C near N is lesser than that in the vessel to be exhausted and hence it diffuses into 'C' where it is carried away by the stream of mercury vapours. This continuous till the partial pressure of air in 'C' becomes greater than or equal to the pressure of air in the vessel to be evacuated.

The mixture of mercury vapours and air is drawn towards 'D'. However, the mercury vapours before reaching 'D' are condensed by the circulation of cold water in the water jacket and the condensed mercury flows back to the vessel 'A' for reboiling. The exhausted air is drawn out by the backing pump.

This process is repeated until a high vacuum is created in the order of 10^{-5} mm of mercury is created in the vessel connected to the inlet 'I'.

(iv) Advantages

- It can be used to produce vacuum of the orderof 10^{-5} to 10^{-7} mm of mercury.
- I that wide range usage such as X-ray tubes, photo-electric cells, electric bulbs etc.

(v) Disadvantages

- The action of the pump is slow.
- It require a rotary pump for reducing the pressure in the initial stage.
- It requires for vacuum to begin its operation.

5.8.1. Types of Gauges

According to principle of operation, vacuum gauges may be classified as follows,

1. Barometric types

The liquid may be mercury or oil. Without instrumental aid, the minimum difference of level which can be detected is of the order of 10^{-1} mm, so mercury types have a lower useful limit of about 1 mbar if 10% accuracy is required, the sensitivity of oil types being about 15 times greater. In some situations, the considerable improvement of sensitivity afforded by instrumentation (optical or electronic) may be justified.

2. Mechanical types

The most usual type is a capsule gauge in which the pressure causes mechanical movement of a septum forming on wall of an evacuated enclosure. The principle is similar to that of the aneroid barometer. Models are available in various ranges, e.g. 0-25, 0-50, 0-125 and 0-1000 mbar. The sensitivity of gauges of this type may be considerably increased by suitable instrumentation.

3. Gauges of the McLeod type

The basic principles is to take a sample of the gas, decrease its volume by a known factor and measure the resultant pressure. The manometric liquid is usually mercury. It assumes Boyle's Law, i.e. PV is constant at constant T.

4. Thermal conductivity gauges ↓

These depend on the decrease of thermal conductivity at low pressures resulting in an increase of the thermal insulation of a heated body as the pressure is reduced.

5. Hot-cathode ionisation gauges

In these the number density is deduced from the amount of ionisation produced by the passage of a known current of electrons of fixed initial energy through a fixed geometrical structure.

6. Cold-cathode ionisation gauges

In these, the pressure is deduced from the current in a cold-cathode discharge tube under controlled conditions of applied voltage. Details of the Penning gauge, which utilises this principle.

7. Gauges depending on other physical properties ↓V ↓T.

These include gauges utilising the decrease of velocity at low pressures (analogous to the decrease of thermal conductivity utilised in the thermal conductivity gauges), and the Knudsen gauge, which depends on the recoil force on a warm surface when a molecule rebounds from it.

5.10 PIRANI GAUGE

(i) Principle

When the pressure is lowered upto say 10^{-2} mm of Hg then the free path of the gas molecules increases and the thermal conductivity is directly proportional to the pressure '*P*'. That means the amount of heat loss '*Q*' per second due to thermal conduction is directly proportional to the pressure '*P*'.

i.e., $Q \propto P$

$$Q = \alpha P,$$

where α is a constant.

(ii) Construction

The Pirani gauge of a platinum or tungsten filament FF, which is a wire of diameter about 0.06 mm enclosed in a glass bulb and maintained at a temperature higher than that of the surrounding as shown in Fig. 5.10. The filament is connected to the arm *DC* of the wheatstone bridge network, which consists of fixed resistances R_1 and R_2 and a variable resistance '*R*', made of alloy like manganin. The lower end of the bulb is open and connected to the vessel in which the pressure is to be measured. A poor conductor of heat like a glass rod is used as a support for the filament and it is taken round glass beads with its longer portions equidistant from the walls of the bulb on the either side. The resistance R_1, R_2 and *R*, made up of manganin, have an almost zero temperature coefficient of resistance.

A high current sensitive galvanometer is connected across *BD*. The potential difference across the points *A* and *C* can be measured with the help a voltmeter '*V*'. The potential difference can be varied by means of a potential divider i.e., through the rheostat included in the battery circuit.

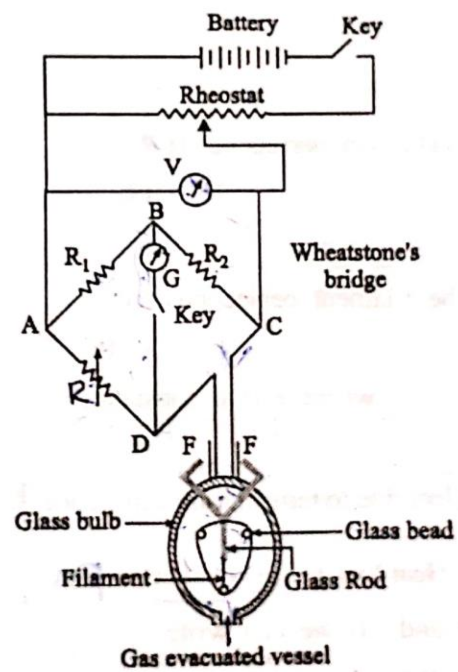


Fig. 5.10 Pirani gauge

(iii) Working

Initially, with the help of a rheostat the potential difference is adjusted. So that the filament gets heated to about 100°C and a constant temperature is maintained in the glass bulb. Now the wheatstone bridge is balanced by using variable resistance '*R*'.

Next the vessel containing the gas at low pressure *P* is to be determined is connected to the lower end of the pirani gauge bulb.

The pressure of the gas in the glass bulb decreases as a result, the heat conduction from the filament of the gauge decreases and the resistance increases. Therefore the bridge balance is upset and hence an out of balance the current flows through the galvanometer. This current is proportional to the pressure in the bulb. Sincethe galvanometer scale divisions are calibrated interms of pressure using McLeod gauge.

The variable resistance 'R' is adjusted to have null deflection in the galvanometer.

Now for various of low pressure P, the voltage V across the bridge is adjusted by using resistance 'R' so that the galvanometer deflection is restored to zero.

Let V_0 be the voltage across the bridge for zero pressure ie perfect vacuum. If θ is the temperature difference between the filament and the surroundings. Then the heat lost along the leads is directly proportional to θ.

(or) Heat lost along the leads due to temperature per second $\alpha\, \theta$

$$= \beta\, \theta \quad \ldots (1)$$

where β is a constant.

Also we know that,

Heat lost due to the conduction persecond $\alpha\, P$

$$= \alpha\, P$$

where α- is a constant. ... (2)

The heat produced in the filament persecond αV^2

$$= \gamma V^2$$

where γ is a constant ... (3)

Therefore,

$$\text{Heat produced} = \begin{bmatrix} \text{Heat lost due to temperature difference} \\ + \\ \text{Heat lost due to conduction} \end{bmatrix}$$

Substituting eqn (1) (2) and (3) we can write.

$$\gamma V^2 = \alpha\, P + \beta\, \theta \quad \ldots (4)$$

When $P = 0$ is at low pressure,

∴ We can write

$$V = V_0$$

(4) becomes

$$\gamma V_0^2 = \beta\, \theta \quad \ldots (5)$$

Subtracting (5) from eqn (4)

vacuum

$$\gamma (V^2 - V_0^2) = \alpha P \quad \ldots (6)$$

Dividing eqn (6) by eqn (5) we get

$$\frac{\gamma (V^2 - V_0^2)}{\gamma V_0^2} = \frac{\alpha P}{\beta \theta}$$

$$\frac{V^2 - V_0^2}{V_0^2} = KP$$

where $K = \frac{\alpha}{\beta \theta}$ is a constant, which depends on the nature of the gas.

Thus the unknown pressure can be determined by knowing the value of V. Which can be found from the balance point in the wheatstone bridge circuit.

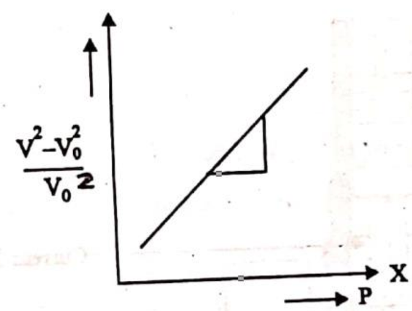


Fig. 5.11

If a graph is drawn $\frac{V^2 - V_0^2}{V_0^2}$ by taking pressure 'P' along 'X'-axis and $\frac{V^2 - V_0^2}{V_0^2}$ along Y axis. It is found to be a straight line. The slope of which is found to be a constant 'K'.

Advantages

(i) It is used to measure the pressure between 10^{-2} mm of mercury to 10^{-4} mm of mercury.

(ii) It is very much useful for the measurement of pressure even under pressure fluctuations.

Disadvantages

(i) It is not an absolute gauge, because it is calibrated against a McLeod gauge.

(ii) As the filament may be damaged by organic vapour. It is not suitable to measure the pressure for organic gases.

5.11 PENNING GAUGE

(i) Principle

It is a type of cold-cathode ionisation vacuum gauge. It works under the principle of cold discharge.

(ii) Construction

It consists of two unheated electrodes, an anode of ring type and cathode of plate type. The centre of the anode is fitted with an ignition pin for ignition as shown in Fig 5.12. The cold discharge can be initiated by supplying d.c voltage, so that the discharge may be continued at very low pressures. The ionisation current is passed through a current Lead through valve, which is separated from the anode by means of a ceramic washer. The entire arrangement is kept inside rigid case enclosing machinery so called housing. Behind the housing heavy magnets are kept.

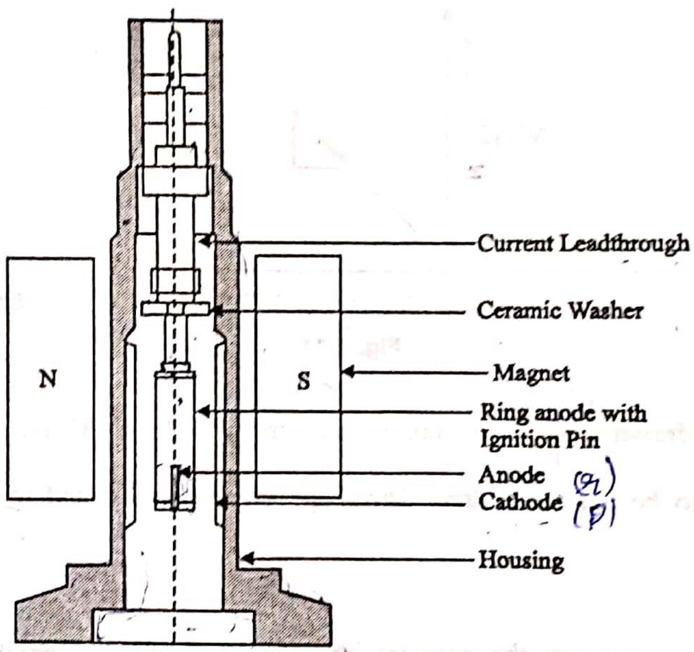


Fig. 5.12 Penning Gauge

(iii) Working

The pressure of the gas to be measured is connected inside the housing. A small discharge is initiated by means of a d.c voltage of around 3 kV. The path of the discharged electrons are made long enough with the help of strong magneticfield, kept behind the housing. The magnetic-field is applied in such a way that the magnetic lines of force crosses the electric field lines. In this way the electrons are confined to a spiral path. This increases the rate of collision of discharged electrons with the gas molecules. Thus producing a more number of positive and negative charge carriers.

Now, the positive and negative charge carriers produced by collision will move to the corresponding electrodes. Thus result in pressure dependent charge current which can be read through a meter.

Hence the pressure can be measured directly from the meter.

Advantages

1. It is very low cost compared to other high vacuum measuring instruments.
2. It is easy to operate.
3. The measuring system is insensitive to vibration and sudden admission of gas.
4. It can measure low pressure in the range of 10^{-7} mm of Hg.

Disadvantages

(i) The heavy magnets are used and will not be suitable to fit inside the housing.

(ii) The discharge power does not have linear relationship to pressure.

1. Define vacuum.

It is defined as the volume of space that is empty of matter including air, so that gaseous pressure is much less than standard atmospheric pressure.

2. What is pumping speed?

The removal of the gas, whose volume is equal to the volume of the chamber in are second is called pumping speed.

3. What is throughput?

The amount of gas removed from the vessel during the creation of vacuum is called throughput.

4. What are the different types of exhaust pumps?

1. oil pumps
2. mercury pumps
3. molecular pumps
4. diffusion pumps

5. Discuss the applications of vacuum technology.

1. Its used in incandacent light bulbs to protect the tungsten filament from chemical degradation.
2. High vacuum technology is used in discover of electrons and *X* rays.
3. Thin film vacuum technology is used to make high quality lenses, optical and household mirrors.
4. It is used to removed humidity in food and pharmaceutical products.

6. Write the principle employed in rotary pump?

The gas (or) air inside the vessel is compressed and forced out by continuously rotating the rotor, until a high vacuum is produced in the vessel, which is connected to the pump.

7. Give the principle of diffusion pump.

It is based on the principle of diffusion. It states that in a mixture of gases, a gas diffuses from a region where its partial pressure is higher to a region where its partial pressure is lower.

8. Mention the advantages and disadvantages of rotary pump.

Advantages

(i) It can directly work from the atmospheric pressure.

(ii) It can be used as a fore pump for high vacuum pumps like diffusion pump.

Disadvantages

(i) When gases and vapours dissolve in oil, it will be contaminated.

(ii) It cannot be used for the production of high vacuum ie more than 10^{-3} mm of mercury.

9. Mention the advantages and disadvantages of mercury diffusion pump.

Advantages

1. It can be used to produce vacuum in the order of 10^{-7} mm of mercury.
2. It has wide range usage such as *X*-ray tube, photoelectric cells, electric bulbs etc.

Disadvantages

1. The action of the pump is slow
2. It require a rotary pump for reducing the pressure in the initial stage.

10. Write the principle of McLeod gauge.

It is based on the principle of Boyle's law. Initially a known volume (V_1) of the gas of pressure (P_1) was considered. The gas then compressed to a small volume (V_2) at which the pressure (P_2) is measured. By using Boyles law the initial pressure (P_1) can be determined.

$$P_1 V_1 = P_2 V_2$$

$$\therefore \quad P_1 = \frac{P_2 V_2}{V_1}$$

11. Give the principle of pirani gauge.

When the pressure is lowered upto say 10^{-2} mm of Hg then the mean free-path of the gas molecules increases and the thermal conductivity is directly proportional to the pressure P. That means the amount of heat lost Q per second due to thermal conduction is directly proportional to the pressure.

ie $$Q \alpha P$$

$$= \alpha P$$

Where α is a constant.

12. What are the advantages and disadvantages of Pirani gauge.

Advantages

(i) It is used to measure the pressure between 10^{-2} mm of Hg to 10^{-4} mm of Hg.

(ii) It is very much useful for the measurement of pressure even under pressure fluctuation.

Disadvantages

(i) It is not an absolute gauge, because it is calibrated against a McLeod gauge.

(ii) It is not suitable to measure the pressure for organic gases, because the filament may be damaged by organic vapour.

13. Mention the advantages and disadvantages of Penning Gauge.

Advantages

1. It is very low cost compared to other high vacuum measuring instruments.
2. It can measure the pressure in the range of 10^{-7} mm of mercury.
3. It is easy to operate.