DOWNLOAD PDF AN INTRODUCTION TO THE FUNDAMENTALS OF VACUUM TECHNOLOGY

Chapter 1 : Textbooks on Vacuum Science and Technology

1 Preface Oerlikon Leybold Vacuum, a member of the globally active industrial Oerlikon Group of companies has developed into the world market leader in the area of vacuum technology.

We will review the most common types of vacuum pumps, their principles of operation and where in the system they are used. In the coming months we will focus on each of these pumps in more detail. Pump Categories by Operating Pressure Vacuum pumps are categorized by their operating pressure range and as such are classified as: Within each pressure range are several different pump types, each employing a different technology, and each with some unique advantages in regard to pressure capacity, flow rate, cost and maintenance requirements. Regardless of their design, the basic principle of operation is the same. The vacuum pump functions by removing the molecules of air and other gases from the vacuum chamber or from the outlet side of a higher vacuum pump if connected in series. While the pressure in the chamber is reduced, removing additional molecules becomes exponentially harder to remove. As a result, an industrial vacuum system Fig. In research and scientific applications this is extended to Torr or lower. In order to accomplish this, several different styles of pumps are used in a typical system, each covering a portion of the pressure range, and operating in series at times. Vacuum systems are placed into the following broad-based grouping of pressure ranges: Rough and low vacuum pressure ranges. Secondary High Vacuum Pumps: High, very high and ultra-high vacuum pressure ranges. Figure 1 â€" Typical industrial vacuum system Illustration Courtesy of Edwards Terminology The two technologies used by vacuum pumps are gas transfer and gas capture Fig. Transfer pumps operate by transferring the gas molecules by either momentum exchange kinetic action or positive displacement. The same number of gas molecules are discharged from the pump as enter it and the gas is slightly above atmospheric pressure when expelled. The ratio of the exhaust pressure outlet to the lowest pressure obtained inlet is referred to as the compression ratio. Kinetic transfer pumps work on the principle of momentum transfer, directing gas towards the pump outlet to provide increased probability of a molecule moving towards the outlet using high speed blades or introduced vapor. Kinetic pumps do not typically have sealed volumes but can achieve high compression ratios at low pressures. Positive displacement transfer pumps work by mechanically trapping a volume of gas and moving it through the pump. They are often designed in multiple stages on a common drive shaft. The isolated volume is compressed to a smaller volume at a higher pressure, and finally the compressed gas is expelled to atmosphere or to the next pump. It is common for two transfer pumps to be used in series to provide a higher vacuum and flow rate. For example, a turbomolecular Kinetic pump can be purchased in series with a scroll Positive displacement pump as a packaged system. Figure 2 â€" Types of vacuum pumps Illustration Courtesy of Edwards Capture pumps operate by capturing the gas molecules on surfaces within the vacuum system. Capture pumps operate at lower flow rates than transfer pumps but can provide ultra-high vacuum, down to Torr, and generate an oil-free vacuum. Capture pumps operate using cryogenic condensation, ionic reaction, or chemical reaction and have no moving parts. Types of Pumps â€" An Overview The different pump technologies are considered either wet or dry type pumps, depending on whether or not the gas is exposed to oil or water during the pumping process. Dry pumps have no fluid in the swept volume and rely on tight clearances between the rotating and static parts of the pump, dry polymer PTFE seals, or a diaphragm to separate the pumping mechanism from the swept gas. Although dry pumps may use oil or grease in the pump gears and bearings, it is sealed from the swept gas. Dry pumps reduce the risk of system contamination and oil disposal compared to wet pumps. Vacuum systems are not easily converted from wet to dry by simply changing pump from a wet to a dry style. The chamber and piping can be contaminated by the wet pump and must be thoroughly cleaned or replaced, otherwise they will contaminate the gas during future operation. Following is an introduction to the most commonly used vacuum pump types by function. The valve is spring loaded and allows the gas to discharge when atmospheric pressure is exceeded. Oil is used to seal and cool the vanes. The pressure achievable with a rotary pump is determined by the number of stages used and their tolerances. It has a pumping speed of 0. Liquid is fed into the pump and, by centrifugal acceleration, forms a moving cylindrical ring against the inside of the casing. This liquid ring creates a series of seals in the space between the impeller vanes, which form compression chambers. This pump has a simple, robust design as the shaft and impeller are the only moving parts. It is very tolerant of process upsets and features a large capacity range. It is compact, and low maintenance. The lifetime of the diaphragms and valves is typically over 10, operating hours. The diaphragm pump Fig. A typical ultimate pressure of 5 x mbar can be achieved when using the diaphragm pump to back a compound turbo-molecular pump. It has a pumping speed range of 0. A spiral polymer PTFE tip seal provides axial sealing between the two scrolls without the use of a lubricant in the swept gas stream. A typical ultimate pressure of 1 x mbar can be achieved. It has a pumping speed range of 5. Two lobes mesh without touching and counter-rotate to continuously transfer the gas in one direction through the pump. Roots pumps can have two or more lobes. It is frequently used in combination with a Roots pump, that is a Roots-claw primary pump combination in which there are a series of Roots and claw stages on a common shaft. It is designed for harsh industrial environments and provides a high flow rate. The rotation transfers the gas from one end to the other. The screws are designed so the space between them becomes reduced as the gas passes along, and it becomes compressed, causing a reduced pressure at the entrance end. This pump features a high throughput capacity, good liquid handling, and tolerates dust and harsh environments. A typical ultimate pressure of approximately 1 x Torr can be achieved. By transferring momentum from the rotating blades to the gas, they provide a greater probability of molecules moving towards the outlet. They provide low pressures and have low transfer rates. A typical ultimate pressure of less than 7. These pumps feature an older technology, largely superseded by dry turbomolecular pumps. They have no moving parts and provide high reliability at a low cost. These pumps are very effective but have limited gas storage capacity. Cryopumps require a refrigeration compressor to cool the surfaces. These pumps can achieve a pressure of 7. A high magnetic field combined with a high voltage 4 to 7kV , creates a cloud of electrons-positive ions plasma which are deposited onto a titanium cathode and sometimes a secondary additional cathode composed of tantalum. The cathode captures the gases, resulting in a getter film. This phenomenon is referred to as sputtering. The cathode must be periodically replaced. These pumps have no moving parts, are low maintenance, and can achieve a pressure as low as 7. Figure â€” Cross section of a typical ion pump In Summaryâ€¦ The various types of vacuum pumps have been briefly described here but a more detailed discussion of each is needed to fully understand the advantages and limitations of each technology. Vacuum pumps are one of, if not the most important set of components supplied on vacuum furnaces. The processes we run and the quality we achieve is a function of how these systems perform.

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Chapter 2 : Pearson - Introduction to Vacuum Technology - David M. Hata

*An introduction to the fundamentals of vacuum technology (American Vacuum Society monograph series) [Harland G Tompkins] on calendrierdelascience.com *FREE* shipping on qualifying offers.*

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Chapter 3 : The Fundamentals of Vacuum Theory

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In this series of articles, we will review the first principles of vacuum technology and explain them using real-world illustrations. Most industrial vacuum systems can, in broad-based terms, be categorized in terms of low i. These ranges are very useful in describing the various pressure, flow, and other phenomenon encountered, which leads to a better understanding of vacuum pump selection and operation, and system operational requirements at the different vacuum levels. Table 1 â€” Typical pressure ranges of industrial vacuum systems Table 2 Density of gas molecules per cm3 for various pressure ranges As shown by the difference in pressure from low to ultra-high vacuum, industrial vacuum systems must operate under an extremely wide range of pressure. In fact, the range is so large it is hard to actually comprehend. Consider a volume of gas at a pressure of mbar atmospheric pressure in a 1 meter by 1 meter by 1 meter container sealed so that no molecules can escape or enter. If, for example, the container volume is doubled to 2 cubic meters, the pressure will decrease by half, to mbar. When this relationship is expanded to the scale of industrial vacuum systems, the result is striking. If we take this same 1 cubic meter volume of gas and increase its volume sufficiently for the pressure to be reduced to mbar ultra-high vacuum , the container will be a staggering 99 km long x 99 km wide x 99 km high, or times the volume of the grand canyon! Figure 1 The Grand Canyon National Park1 Another way to understand the operating pressure range of industrial vacuum systems is to consider gas density or the number of gas molecules that reside in a given volume. There are roughly 2. Under lower and lower pressure, the molecules spread out further and further, until, at ultra-high vacuum mbar , there are only 2. At this density, there is only one molecule roughly every 0. Since the diameter of each gas molecule is much less than this 4 x cm for air, for example , there is a great deal of space between molecules. To put it into proportion, if gas molecules were grains of sand, at ultra-high vacuum they would be 1, meters apart. At these extremely low pressures, the collisions between molecules, which normally dictate the properties of gases, become very infrequent and a different theoretical model is required to explain their properties the so-called Kinetic Theory of Gases. The Continuum Theory and The Kinetic Theory of Gases At or near atmospheric pressure, and in non-vacuum systems, the so-called continuum theory accurately describes the properties of gases. In simple terms, it tells us that collisions between gas molecules dictate the properties of a gas. In a perfect or ideal gas the change in density is directly related to the change of both temperature and pressure Boyles Law: In a mixture of non-reacting gases, the total pressure exerted is equal to the sum of the partial pressures of the individual gases After vacuum pump technology developed to the extent that fewer and fewer gas molecules were possible in a given volume, the governing principles affecting the properties of these gases changed, and molecular considerations became primary. Namely, the gas molecules become so spread out that intermolecular collisions between gas molecules no longer dominated, but rather collisions with the chamber walls were the determining factor affecting the gas properties. This led to the Kinetic Theory of Gases, which applies not only at low pressures high vacuum but is also accurate over the entire range of pressures seen in industrial vacuum systems. Molecular Density and Mean Free Path The primary concept of the kinetic theory is that a gas consists of a great number of individual particles molecules each moving individually and randomly and that the collisions between them, as well as their collisions with the vessel walls, determine the pressure created by the gas. The molecular density, or the number of gas molecules per unit volume Table 2 , varies in proportion to pressure. Further, the mean free path or the average distance a molecule must travel before colliding with another molecule increases greatly as the pressure decreases Fig. Most importantly, the increased mean free path at reduced pressure dictates that molecular collisions with the vessel walls govern the gas properties at reduced pressure. This means that collisions between gas molecules are so infrequent that each molecule has to travel an average of , meters before a chance collision with another molecule. Since the sides of the vessel are much closer than this, collisions with the vessel wall are much more frequent than with other molecules. For this reason, at high and ultra-high vacuum molecular collisions with the walls of the vessel Fig. Figure 3 Collisions between gas molecules and the walls of a vessel generate the pressure in the vessel2 This understanding leads to the formulation of gas pressure as a function of gas density, mean square velocity, and mean free path of the individual gas molecules. With this foundation, referred to as the Kinetic Theory of Gases, calculations of pressure, flow, and conductance over the entire vacuum operating range are derived. The kinetic gas theory is based on the following five assumptions. Gases are comprised of a large number of particles that behave as inelastic, spherical objects in a state of constant, random motion. The particles move in a linear manner until colliding with another particle or the walls of their container. The size of the particles is negligible in relation to the space between them and therefore most of the gas volume consists of empty space. There is no force of attraction or repulsion between gas particles or between the particles and the walls of their container and thus their total energy is simply equal to their kinetic energies. None of the energy of a gas particle is lost when it collides with another particle or with the walls of the container. Considering the above assumptions, we can derive a formula Equation 1 to describe the pressure of a gas under the kinetic gas theory. Gravesande found that a ball with twice the speed of another would leave an indentation four times as deep, from which he concluded that the force generated by a body in motion is proportional to the square of its velocity. This same principle applies to the kinetic gas theory where the force of the molecules impacting the walls of the vessel is what generates the gas pressure, in proportion to the square of their speed. As an example, it is useful to consider nitrogen, since air is mostly made up of nitrogen. Each individual nitrogen molecule in a closed container is rapidly moving in a straight line, until bouncing off another nitrogen molecule or off the container wall, essentially like a bunch of billiard balls. Although each molecule is tiny, the cumulative impact force generated from all the molecules striking our skin each second roughly 3 x per square meter is the pressure of ordinary air on our bodies. In actuality, the gas molecules in a system move at a wide range of velocities, but the average mean velocity is used for the purposes of calculating pressure and other effects. In other words, molecules of the same gas exhibit a distribution of speeds Fig. Some move faster, and others slower. Figure 4 Distribution of Molecular Speeds for Various Gases3 There is an interesting consequence of the distribution of molecular speeds in a gas. Due to the bell-shaped curve of the speed distribution, there are significant numbers of molecules with a speed much faster about 6 times faster than the average. The escape velocity from earth for any moving object including gas molecules is So the fastest hydrogen atoms, those in the tail of the distribution, are energetic enough to overcome the grip of gravity. Hydrogen will, therefore, escape into space, as will helium. In the article above, we talked about the Kinetic Theory of Gases and how it can be used to calculate gas properties. Now we turn our attention to a discussion about temperature and kinetic energy, pressure and kinetic energy, and types of flow in vacuum systems. Again, we will focus on the basics, using fundamental comparisons to explain the concepts significant to industrial vacuum systems. The relevance of Temperature to the Kinetic Theory of Gases Based on an atomic understanding of the world we live in, the Kinetic Theory reveals that gas properties are highly dependent on the speed of their molecules, which determines their kinetic energy, and therefore the gas pressure. When considering the effects of the Kinetic Theory, it is also important to understand the influence of temperature. Specifically, the speed of the molecules in a gas is dependent on its temperature the higher the temperature the faster the gas molecules move. Another way to think of it is that the temperature of a gas is a measure of the average kinetic energy of that gas. According to Kinetic Theory, a gas consists of a large number of tiny molecules, all in constant random motion, elastically colliding with each other and the vessel that contains them. Pressure is the net result of the impact force of those collisions against the vessel wall. The speed of the molecules during this motion is not random at all, but follows a bell curve, with a predictable distribution about the average. The molecular speed is dependent on the weight of the molecules and their temperature, or inherent heat energy. So for a given gas, the heat energy contained in its molecules determines their energy level and therefore their speed. In order to fully appreciate the influence of temperature on a gas, it is useful to understand degrees Kelvin more correctly defined simply as Kelvin , which is an absolute temperature scale degrees above so-called absolute zero where all motion stops. This is a true measurement of kinetic energy. This is borne out when the volume of a gas at several different temperatures is measured and plotted Fig. When the graph is then extended to 0 K, the volume goes to zero. Keep in mind the gas molecules do not individually have zero volume, but the space between molecules approaches zero. Although absolute zero has never been attained, temperatures as low as a billionth of a kelvin have been achieved on small samples. With an understanding of absolute temperature, we can discuss the effects of temperature on gas volume and pressure. Figure 1 Volume vs. Take nitrogen for example Fig. Figure 2 Molecular velocity distribution of nitrogen as a function of temperature5 Also note on figure 2 that at lower temperatures, the curves are narrower and taller. At higher temperatures, there is a wider distribution of energy levels and corresponding molecular velocities among the population of molecules. At lower temperatures, there is less variability between the velocities of different molecules and so the curve is narrower at its base. When the absolute temperature of a gas is understood to be a measure of its kinetic energy, the implications of the Kinetic Theory of Gases in regard to temperature become clear. Recall that under the Kinetic Theory of Gases, the pressure exerted by a gas is the sum total of the force exerted by all the physical impacts between the gas molecules and the vessel or vacuum chamber, or vacuum piping, etc. Since the velocity of the molecules is directly related to the square of temperature, the pressure of the gas is therefore also directly related to temperature, by the square root of its absolute temperature. The effect of temperature on pressure as described by kinetic theory can be illustrated by a simple experiment using a party balloon and liquid nitrogen Fig. As a result of the decrease in molecular speed, two things happen; a the collisions between molecules become less frequent, allowing the space between them to decrease, and b the force with which the molecules collide with their container the balloon decreases, reducing the pressure the air exerts on the balloon. This causes the balloon to shrink. The reduced volume of the air is proportional to its absolute temperature. Figure 3 Pressure in a balloon decreases when submerged in liquid nitrogen5 Types of Flow in Vacuum Systems; Continuum, Molecular and Knudsen The manner in which a gas flows in a vacuum system is dependent on the gas pressure. At rough vacuum pressures above approximately 1 mbar. At these pressures, the molecules are relatively close together, and their collisions more frequent. Therefore flow is governed by interaction between molecules. As a result, the entire volume of gas, or group of molecules can be made to move in an ordered motion, that is flow Fig. This ordered motion is superimposed, or added to, the normal random motion of the individual molecules. The gas at these pressures can be thought of as having a viscosity, or stickiness, that permits their ordered motion due to the internal friction between molecules. Therefore the preferred speed and direction of molecule flow will be the same as for the macroscopic gas flow. Figure 4 Continuum flow of gas molecules through a pipe Molecular flow, on the other hand, is seen at pressures below. At these pressures, intermolecular collisions are much less frequent due to the fact that there is so much space between gas molecules Fig. Molecules move freely without any mutual interference, and therefore there is no ordered group flow possible. The molecules individually move in a straight line without colliding, until they strike the wall of the vessel or pipe containing them. Molecular flow is present where the mean free path length average distance a molecule must travel before colliding with another molecule is much larger than the diameter of the pipe the gas is flowing through and therefore the molecules are free to travel until they collide with the pipe walls. As a consequence, a gas particle can move in any arbitrary direction in a high vacuum and macroscopic, continuum flow is no longer possible. Figure 5 Molecular flow of gas molecules through a pipe In the transitional range between continuum flow and molecular flow, Knudsen flow prevails. In this range both wall collisions and intermolecular collisions are influential in determining flow characteristics. Pump Technology In The Continuum and Molecular Flow Range Vacuum pumps that operate in the continuum viscous flow range such as roots blowers, screw pumps, claw pumps and rotary vane pumps function by moving the molecules as a group.

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