Hands-on Accelerator Experiments I, Vaccum system in accelerator

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I. THEORY

I.1. Introduction to Vacuum in Accelerators

In particle accelerators, vacuum systems are crucial for maintaining the stability and performance of particle beams. A vacuum, defined as a state where the pressure is lower than atmospheric pressure, is essential in reducing beam losses, minimizing ionization instability, and preventing background noise in detectors. Additionally, vacuum systems mitigate surface contamination, which can negatively affect accelerator components such as mirrors and beam pipes.

I.1.1. Importance of Vacuum

The role of vacuum in accelerators cannot be overstated. High-quality vacuum systems are required for:

- Reducing beam loss and increasing beam lifetime.
- Minimizing ionization instability caused by residual gases.
- Preventing background noise in detectors.
- Mitigating surface contamination that could affect sensitive equipment like mirrors and other optical components.

I.2. Types of Vacuum

Vacuum levels are categorized based on the pressure range. In accelerators, maintaining ultra-high vacuum (UHV) or extreme high vacuum (XHV) is often required. The standard measurement units for vacuum include Torr, mbar, and Pascal (Pa).

Vacuum Pressure Categories

Vacuum is typically classified into the following regions:

- Low Vacuum (10^3 Torr to 10^{-1} Torr)
- Medium Vacuum (10^{-1} Torr to 10^{-3} Torr)
- High Vacuum (10^{-3} Torr to 10^{-7} Torr)
- Ultra High Vacuum (UHV) (10^{-7} Torr to 10^{-10} Torr)
- Extreme High Vacuum (XHV) ($< 10^{-10}$ Torr)

I.3. Vacuum Systems and Their Design

Vacuum systems in accelerators are designed to control and maintain the desired pressure range. These systems consist of vacuum pumps, valves, and gauges that are strategically placed throughout the accelerator to achieve high-quality vacuum levels.

I.3.1. Vacuum Pumping

Vacuum pumps are essential components of a vacuum system. Various types of pumps are used, including:

- Rotary Vane Pumps for rough vacuum.
- Turbo Molecular Pumps (TMP) for achieving high vacuum.
- Cryo-Pumps for ultra-high vacuum.
- Non-Evaporable Getter (NEG) Pumps for maintaining low pressures in UHV.

These pumps work through various mechanisms such as momentum transfer, positive displacement, and diffusion to remove gases from the system.

I.3.2. Vacuum Pumping Mechanisms

Vacuum pumping relies on various mechanisms to remove gases:

- Positive Displacement: Molecules are physically compressed and displaced into a smaller volume, raising the pressure in the pump.
- Momentum Transfer: Molecules collide with fast-moving surfaces (e.g., in turbo molecular pumps), transferring momentum to the gas molecules, which are then expelled.
- Diffusion and Permeation: Molecules move across surfaces due to pressure gradients (diffusion), or they pass through porous materials (permeation).

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I.4. Vacuum Pumping Process and Time Constants

The efficiency of vacuum systems is often characterized by the time constant (τ), which indicates how long it takes for the pressure in the system to decrease to a fraction of its initial value. The equation governing the pressure change with time is:

$$\frac{d(PV)}{dt} = Q - PS_{\text{eff}}, \tag{1}$$

where Q is the gas load, P is the pressure, and S_{eff} is the effective pumping speed. If the gas load Q is negligible, the pressure decays exponentially:

$$P(t) = P_0 e^{-t/\tau}, \tag{2}$$

where $\tau = \frac{V}{S_{\text{eff}}}$ is the time constant, V is the volume of the vacuum chamber, and S_{eff} is the effective pumping speed.

I.5. Desorption and Diffusion Processes

Gases in vacuum chambers can be removed by processes like desorption, diffusion, and permeation. These processes are crucial in achieving and maintaining the desired vacuum levels.

I.5.1. Surface Desorption and Diffusion

Gases adhere to surfaces and are gradually released through desorption, depending on the energy of the surface and the temperature. Surface desorption follows the equation:

$$Q_s = Q_0 t^{-1},$$

where Q_s is the desorption rate, Q_0 is a constant, and t is time.

I.5.2. Diffusion-Limited and Recombination-Limited Models

In diffusion-limited processes, gas molecules move from areas of high concentration to low concentration. The rate of gas removal is described by a diffusion equation. In recombination-limited models, molecules on surfaces combine to form more stable compounds, reducing gas levels in the system.

I.6. Vacuum Measurement Techniques

Accurate measurement of the vacuum level is essential for proper accelerator operation. Several types of vacuum gauges are used:

- Ionization Gauges: Measures vacuum pressure by ionizing gas molecules.

- Thermocouple and Convectron Gauges: Measures pressure based on thermal conductivity or heat transfer.

- Mass Spectrometers (QMS): Analyzes the gas composition inside the vacuum chamber.

These gauges provide critical feedback for maintaining and monitoring the vacuum conditions within the accelerator.

II. EXPERIMENT

In this experiment, an experiment was conducted to make the clamp directly vacuumed. I will list the photos taken in the training class first and then provide additional explanations.

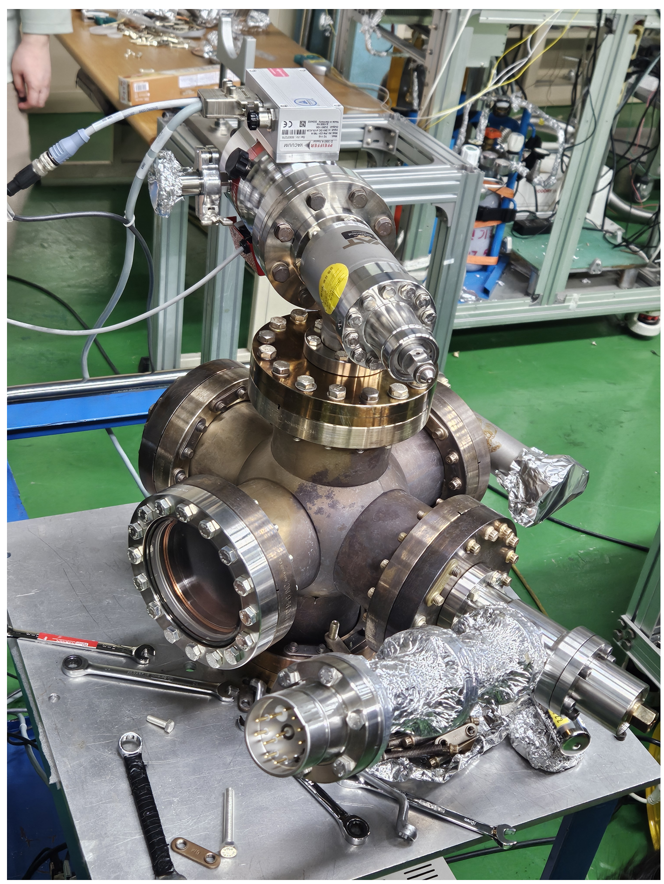

FIG. 1.

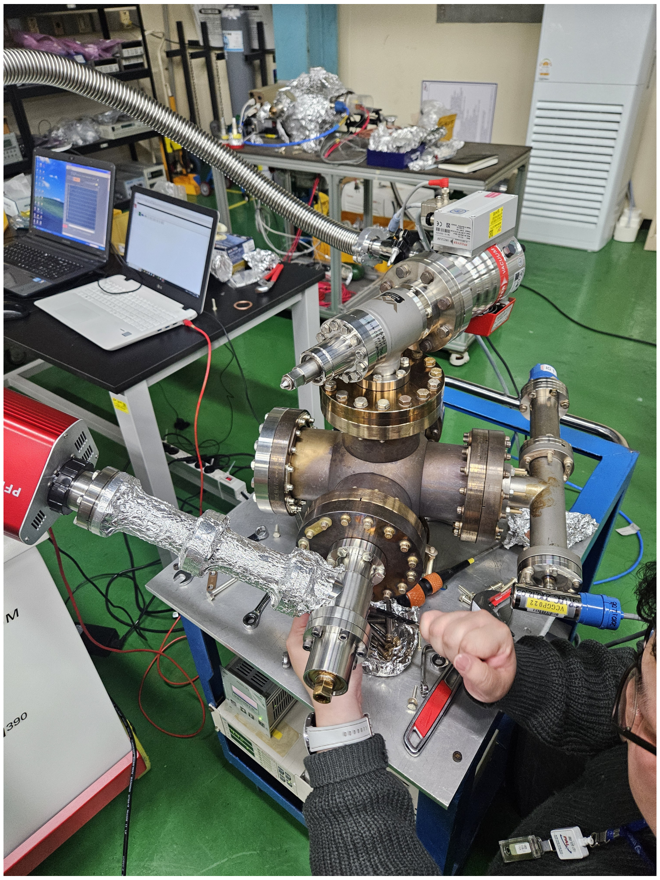

FIG. 2.

FIG. 4.

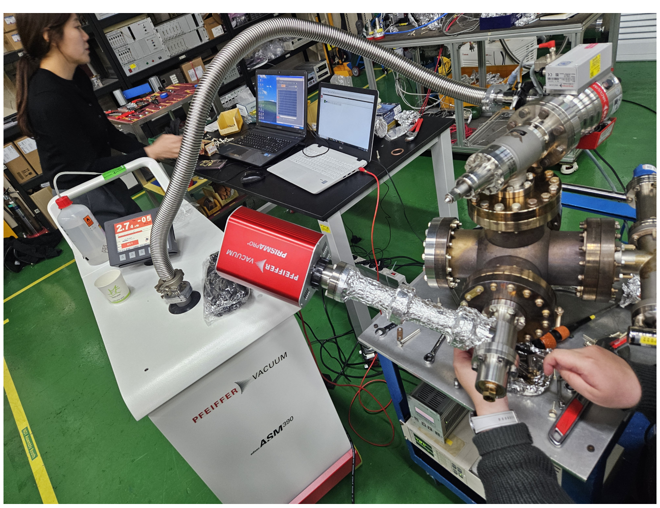

FIG. 3.

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 8.

FIG. 1. is a clamp to be used in this experiment. An experiment was conducted to make the inside vacuum.
FIG. 2. is a scene where you screw it to make it vacuum.
FIG. 3. does not create a vacuum at first, so check where the wind is leaking and check that part again to tighten it with screws.
FIG. 4. is an instrument that measures the pressure of the air. There is a very thin steel rod that is connected to it, and you put the rod to the clamp to see where the vacuum does not occur. The iron rod emits very minute helium gas. This value must be up to the -10th power of 10 to judge it as a useful vacuum. We remember that we completed it to about the -9th power.
The helium flowing through the steel rod in FIG. 4 is FIG. 5. I was worried because there was very little helium at the time, but fortunately, I was able to finish the experiment well.
FIG. 6. is an O-ring. A seal made of rubber or metal, used to maintain a vacuum. It serves to seal the vacuum system from leaking air or other materials. When connecting the two clamps, they were placed between them and tightened with screws.
FIG. 7. is a wiper that has the property of effectively removing dust or pollutants, so it is a kind of tissue used in precise work such as a vacuum or in places where a clean environment must be maintained.
FIG. 8. is a torque wrench. A torque wrench is a tool that

measures or sets and applies the correct force (torque) required to tighten a screw.
It also discussed why the low vacuum pump measures the degree of vacuum through helium. Most of the air is nitrogen or oxygen. But oxygen has a risk of corrosion. And basically, the reason why we don't use many elements in the air is because it's hard to check whether they are detected in the air or leaking from the place where we are measuring them. He also said that helium is the cheapest among them, so it is usually used. There are many methods of detecting such helium, such as a mass filter is good, but the easiest way is to detect it (F=ma) by ionizing the helium and applying voltage to it to the collector. Or, he said that he sees circular orbit by walking through a vertical magnetic field (because the size of the circle varies depending on the mass).

III. REFERENCE

[1] 하태균, "accelerator vaccum", *POSTECH*, 2025, pp. 1-79.