Vacuum system in Accelerators

M. Jeong*, Pohang Institute of Science and Technology, Pohang, Korea

Abstract

In real accelerators, obtaining high vacuum condition is required due to beam-particle interactions which can be occured because of gas molecules inside the accelerators. Also, synchrotron radiation causes thermal load, gas load, and electron emission, which causes damage of beam pipe, reduction of beam lifetime, and electron cloud instability respectively. In this report, the measurement of the vacuum by gauge, the assembly of the vacuum chamber, and the achievement of the UHV was demonstrated.

INTRODUCTION

In real accelerators, beam-particle interactions such as gas ionization, Coulomb scattering, and bremsstrahlung can occur due to gas molecules inside the accelerators. Also, synchrotron radiation causes thermal load, gas load, and electron emission, which causes damage of beam pipe, reduction of beam lifetime, and electron cloud instability respectively. To prevent these effects, maintaining ultra-high vacuum(UHV) environment is required. Also. measuring the vacuum is an necessary procedure.

In this report, we demonstrated the measurement of the vacuum, the assembly of the vacuum chamber, and the achievement of the UHV condition.

THEORETICAL BACKGROUND

Vacuum Exhaust Process

Generation of high vacuum environment is conducted by vacuum pump. The graph between pressure and time during vacuum exhaust process is shown in Fig. 1[1]. The differential equation of pressure during exhaustion process is (1).

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

Thus, if Q«1, pressure P decreases exponentially over time.

However, when the pressure is in the regime where P≈ $10^{-5}Torr$, surface desorption becomes dominant. For surface desorption, pressure is proportional to inverse of time.

In the UHV domain, the diffusion of gas molecules inside the bulk should be considered. In this regime, pressure is proportional to $\frac{1}{\sqrt{t}}$.

Lastly, when the pressure is as low as $\approx 10^{-13}Torr$, permeation of hydrogen molecules becomes dominant. Due to permeation of hydrogen, reaching the pressure lower than $\approx 10^{-13}Torr$ is impossible.

Vacuum Pump

To create vacuum environment inside the chamber, vacuum pump must be employed. To create low vacuum or middle vacuum, rotary vane pump and cryosorption pump can be used. However, to reach higher vacuum, pumps such as diffusion pump, sputter ion pump, turbo pump should be used.

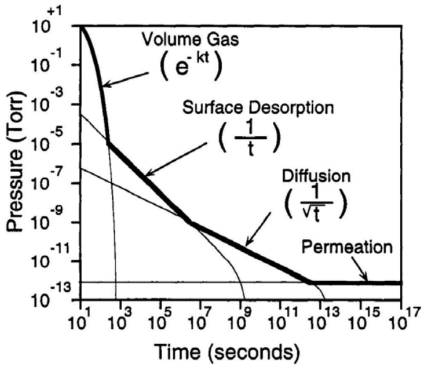

Figure 1: Characteristic behavior of pressure versus time during the pump of vacuum chamber.

In diffusion pump, oil is heated and evaporated by the heater below and gushes out through the nozzles downwards. Gas molecules collide with oil particles, are forced to move downward, and are emitted to the air side. Today, diffusion pumps are hardly used because of contamination issue, since they use oil for pumping.

Turbo pump shifts gas molecule by multiple disks attached to the motor with tilted blades. When gas flows inside the disk rotating in tens of thousands rpm, molecule is deflected by collision with tilted disk and moves to the next disk. Repetition of this process several times results in gas being emitted through the vent. Since disks rotate in high velocity, turbo pump requires precise processing and equilibrium.

Sputter ion pump removes gas molecule by desorption. Electron cloud is generated by electrical discharge at the cathode, and ionizes the gas molecule by collision. These ions are accelerated to create an impact on the titanium plate. Due to this impact, titanium molecule is sputtered from the plate, and chemically combines with gas molecules. Since the principle of the ion pump is based on chemical combination, it performs low pumping speed for noble gases(e.g. helium, nitrogen).

Measurement of Vacuum

For low vacuum($> 10^{-3}Torr$), thermocouple gauge or convection gauge is used to measure pressure. In a thermocouple gauge, an electric current is applied to the gauge filament, so that the filament is to be heated. Then, heat is dissipated by solid conduction, gas conduction, or radiation. The pressure can be measured by measuring the temperature of the filament, since heat dissipated by gas conduction depends on the gas pressure. The range of pressure measurable by thermocouple gauge is determined by radiation and

* msjeong@postech.ac.kr

gas conduction. If gas conduction becomes dominant, the sensitivity of gauge decreases.

The convection gauge(See Fig. 2) measures pressure by convection inside the gauge with tungsten wires. When the vacuum is low, the output voltage is high because heat dissipation due to convection is high. On the other hand, the output voltage decreases as the vacuum increases. The convection gauge is used more frequently than the thermocouple gauge, since the convection gauge can measure lower pressure.

Figure 2: Picture of convection gauge

For higher vacuum, ion gauge is used to measure vacuum. Ion gauge ionizes the gas and measures ion current. There are two types of ion gauge: hot cathode ion gauge and cold cathode ion gauge. Hot cathode ion gauge(see Fig. 3) ionizes gas molecule by thermionic electron emitted from the filament. To prevent the emission of X-ray, the collector which measures ion current is located inside the gauge. Tungsten is used for the material of filament, and thorium or iridium can be used to coat the tungsten filament to lower the work function.

Quadrupole mass spectrometer(QMS) is a mass spectrometer that consists of four parallel metal cylinders. The voltage applied to quadrupoles affects the trajectory of ions, thereby filtering the ions except the ones which satisfy certain m/z value.

EXPERIMENT

In this section, we assemled a vacuum chamber, detected a leakage of the chamber, and obtained the UHV environment by turbo pump.

In the vacuum chamber assembly process, the existing vacuum chamber was disassembled and reassembled, with QMS and ion gauge attached. Figure 4 is the picture of assembled vacuum chamber.

To detect the leakage of the vacuum chamber, helium gas was injected to the chamber. As the helium gas diffuses inside the chamber through the leakage, a portion of the gas flows in the detector. After ionization of helium gas in the detector, gas particles except helium are filtered by magnetic field and a slit, and detected by detector.

After the assembly of the vacuum chamber, high vacuum($10^{-10} mbar$) was obtained via turbo pump. After the process, the components of remaining gas inside the chamber were measured by quadrupole mass spectrometer. Figure. 5 shows the measurement result of QMS. According

Figure 3: Picture of hot filament ion gauge

Figure 4: Picture of vacuum chamber

to the graph, gas molecules with molecular mass 4, 18, and 28 were mostly measured. This implies that the majority of the residual gas consists of helium, water, and nitrogen molecule.

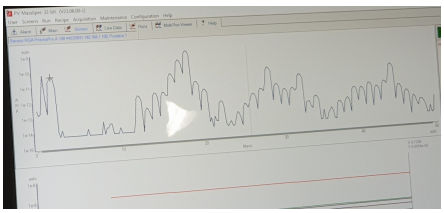

Figure 5: Measurement result of QMS

CONCLUSION

Obtaining, maintaining and measuring high vacuum is required in the accelerator system. In this report, the measurement of the vacuum by gauge and QMS, the assembly of the vacuum chamber, and the achievement of the UHV condition was conducted.

REFERENCES

[1] *Specimen Handling, Preparation, and Treatments in Surface Characterization*, Springer New York, New York, NY, USA, Apr. 2013, pp. 1–28.