Ultra-High Vacuum Practices for Accelerator Applications

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1 Abstract

This report consolidates experimental practices and theoretical insights into ultra-high vacuum (UHV) systems, focusing on vacuum chamber assembly and helium leak detection. Key topics include maintaining UHV conditions in accelerators, addressing synchrotron radiation effects, and executing leak testing procedures. This summary integrates theoretical principles with practical training outcomes.

2 Introduction

Particle accelerators require ultra-high vacuum (UHV) systems to minimize beam-gas interactions, which degrade beam lifetime and increase background noise. Achieving pressures below 10^{-9} mbar is critical. UHV maintenance involves addressing synchrotron radiation (SR) effects and implementing robust vacuum engineering practices.

3 Theoretical Background

Synchrotron Radiation and Photon-Stimulated Desorption (PSD): High-energy electrons in accelerators emit SR, inducing PSD when photons interact with chamber walls. This increases gas load and poses challenges to beam stability. The power density due to SR is quantified by:

$$\langle P_{\text{line}} \rangle = 88.4 \times 10^3 \frac{E_e^4 \cdot I_e}{\rho_C} \tag{1}$$

where E_e is electron energy, I_e is beam current, and ρ_C is the bending radius.

Evacuation Stages: The vacuum evacuation process includes:

1. *Volume Gas Removal:* Initial stage reducing pressure to 10^{-3}–10^{-4} Torr.
2. *Surface Desorption:* Adsorbed gas removal to achieve 10^{-6}–10^{-7} Torr.
3. *Diffusion:* Gas from materials reducing pressure to 10^{-8} Torr.
4. *Permeation:* Long-term process addressing gas ingress from external environments.

4 Experimental Procedures

Assembly of Vacuum Components: Single-port and multi-port chambers were assembled with copper gaskets ensuring vacuum seals. A crisscross bolt-tightening pattern was employed to distribute force evenly.

Figure 1: Assembling the Vacuum Chamber Components.

Helium Leak Testing: After assembly, chambers were connected to helium leak detectors. Helium was sprayed around potential leak points, and detectors identified leaks through ingress measurement.

Figure 2: Leak checking using a helium leak detector.

Key Observations: Single-port chambers showed no leakage, while a minor leak in the multi-port chamber required corrective measures.

5 Diagnostics and Monitoring

Thermal-conductivity gauges (e.g., Pirani) and ionization gauges ensure accurate pressure monitoring across UHV ranges. These diagnostics are critical for maintaining vacuum integrity and beamline stability.

6 Conclusion

Maintaining UHV conditions is crucial for accelerator performance. Training in component assembly and helium leak detection equips personnel with essential skills. Addressing synchrotron radiation effects and adhering to robust evacuation protocols ensure optimal system operation.

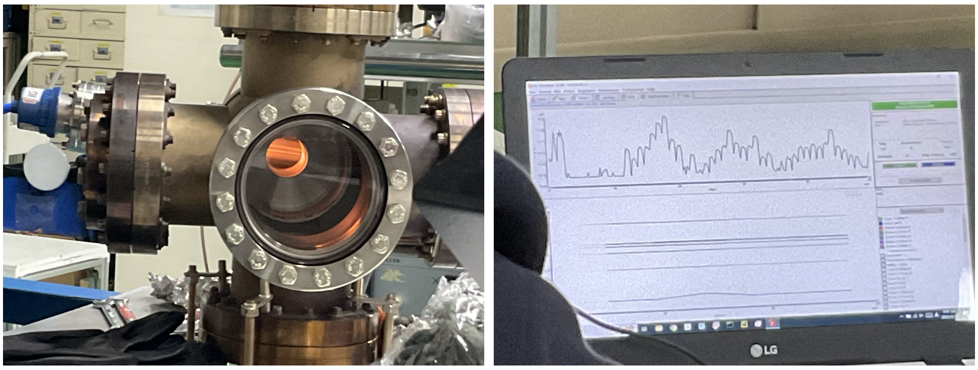

Figure 3: (a) View of vacuum chamber showing the interior through a window. (b) RGA measurement of residual gases inside the UHV chamber.

References

[1] T. Ha, Lecture note on accelerator vacuum environment, Division of Advanced Nuclear Engineering (DANE), POSTECH, Pohang, Korea, Mar. 2025.