Residual Gas Analyzer System For Sealed Ultra-High Vacuum Environments

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Background

Sealed ultra-high vacuum (UHV) environments are vital in scientific and industrial processes like manufacturing, medical imaging, and industrial inspection. Maintaining a pristine UHV environment, characterized by pressures below 10^-7 Torr, is crucial for precision operations and equipment integrity. Despite rigorous sealing mechanisms and advanced vacuum technologies, UHV environments remain susceptible to residual gas contamination from sources such as outgassing, permeation, leaks, and surface desorption.

- Vacuum quality monitoring (VQM) offers insights into residual gas composition, concentration, and distribution, enabling identification of contamination sources.
- Total pressure gauge (TPG) allows the real-time measurement of total pressure through the use of ionization vacuum technology.

Integrating a VQM and TPG into a ultra-high vacuum systems enhances transparency and facilitates targeted measures to analyze residual gas effects.

Problem Statement

The UHV system selected for investigation is an X-ray tube provided by Varex Imaging. The project address the crucial challenge of integrating the design of an positioning mechanism alongside a VQM-TPG systems. With a focus on maintaining pristine vacuum conditions, our aim is to design a solution that is capable of analyzing residual gases and monitoring internal pressure. The data collected from this sub-system will be processed to determine the cause and quantity of residual gases, enabling appropriate measures to prolong the system's lifespan.

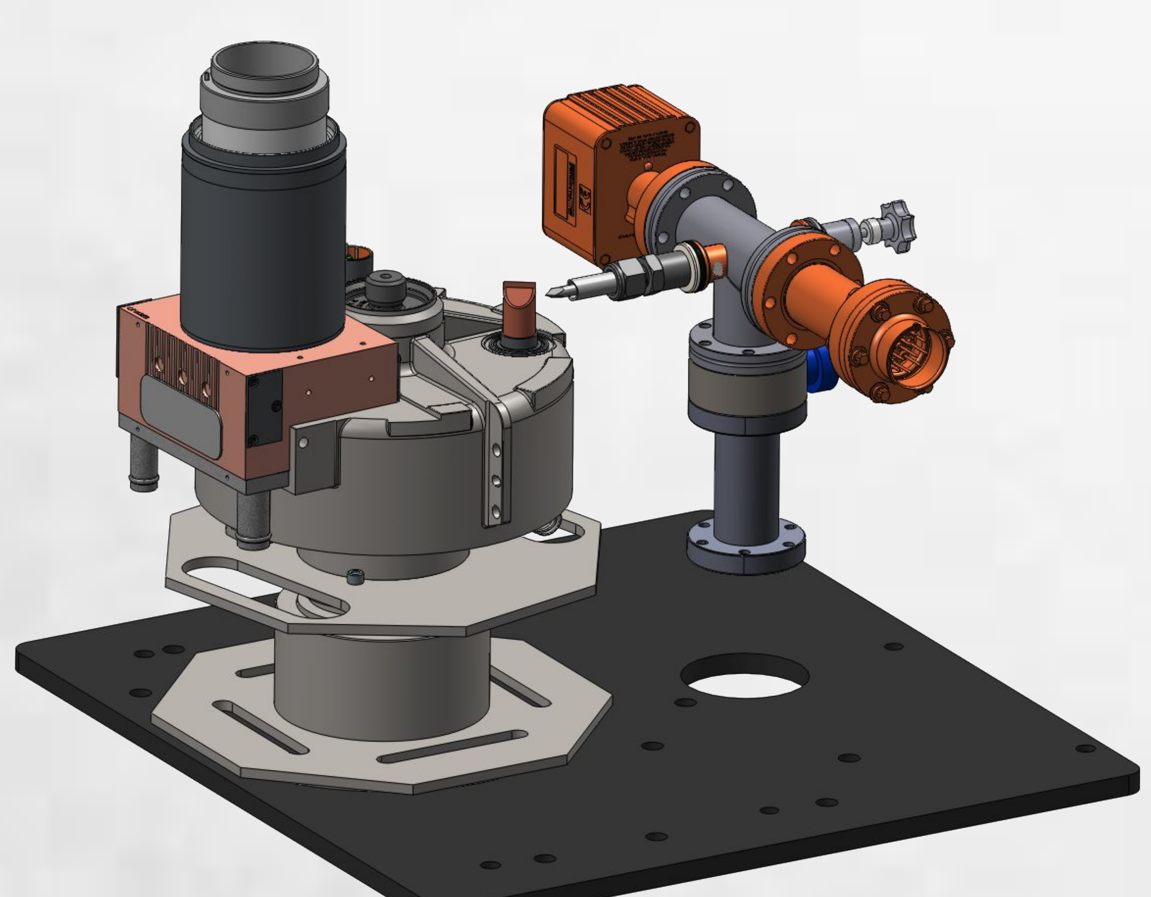


Fig 1. CAD overview of the entire environment. Consisting of X-ray tube, Drum Stool, VQM, TPG, T-toot, and the drill device

Sub-system

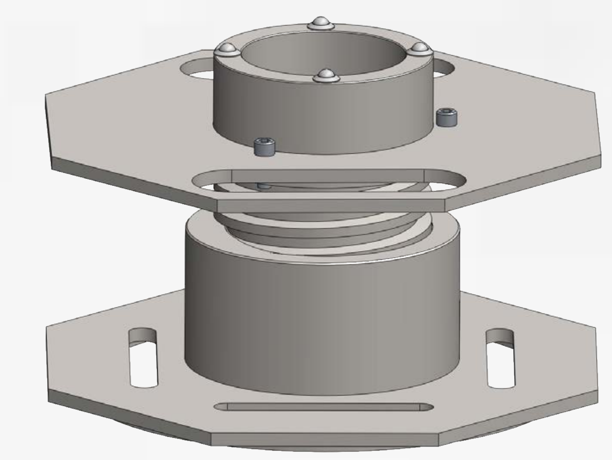
The sub-system consist of three sections:

- Vacuum Quality Monitor (left)
- Total Pressure Gauge (right)
- Drilling device (center)

The drilling device's purpose is for puncturing the X-ray tube. The bottom connects to a vacuum pump maintaining a pressure of 10^-7 Torr.

Positioning Mechanism

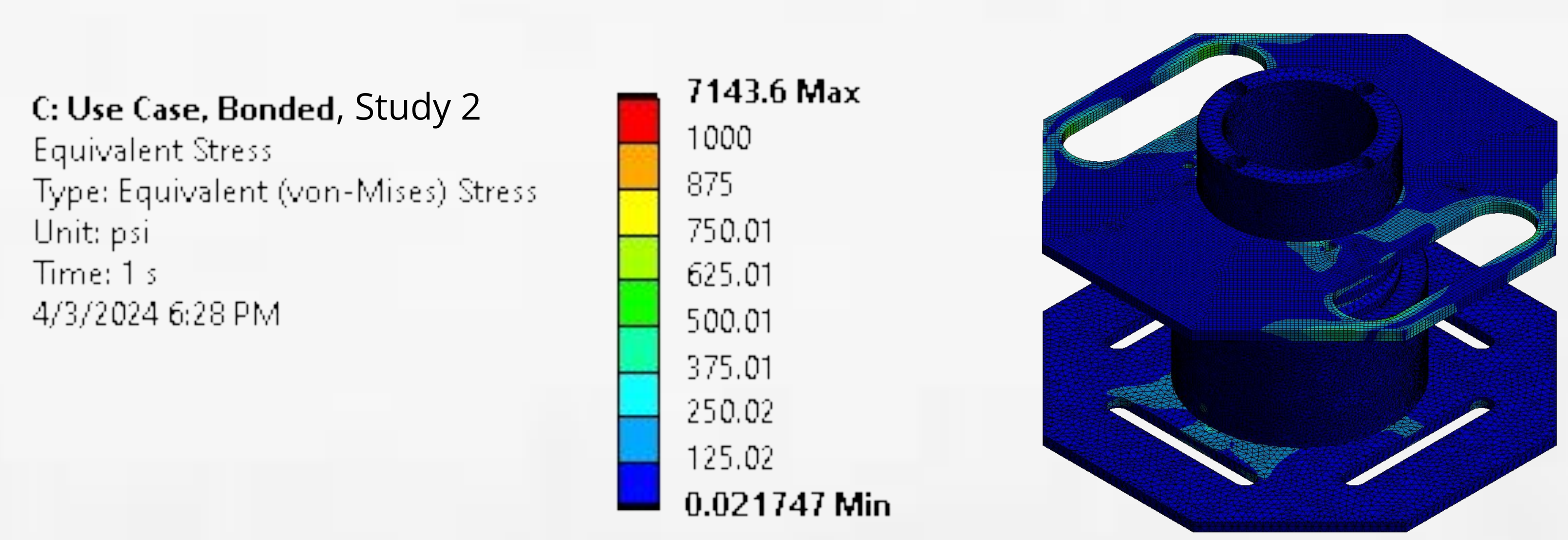
- Purpose: Supports and orients X-ray tube for single-user operation, ensuring desired contact with sub-system.
- Design: Engineered for safety, stability and ergonomic use. Material : 304 Stainless



Two FEA studies were conducted to validate design integrity.

- Study 1: Analyzed the impact of gravity on the Drum Stool while sustaining the weight of the X-ray tube. Main stress was found between the bottom cylinder and plate.
- Study 2: Simulated cross-threaded threads scenario, applying a torque of 25 lbf to the top plate. Highlighted stress concentration at the hardware mating point between the top plate and cylinder.

	Study 1	Pass/Fail	Study 2	Pass/Fail
Max Stress [Psi]	918.36	Pass	7143.6	Pass
Max Deformation [Inch]	3.12·10^-4	Pass	3.39·10^-4	Pass
F.O.S. @ Max Stress	33.97	Pass	4.38	Pass



A geometry test was conducted to validate clearances and tolerances. Required ranges were derived from calculating the minimum translation and rotation needed to achieve the desired contact due to copper tubulation shape.

	Required Range	Measured Range	Pass/Fail
X, Y & Z Translation [Inch]	X- [0, 4.08] Y- [0, 1.95] Z- [0, 1.50]	X- Platform Y- Platform Z- [0, 1.75]	Pass
Z Rotation [Deg]	[0, 90]	[0, 360]	Pass
Water Tube Clearance [Inch]	1.2>	[0, 1.4]	Pass

Experiment Results

- The data collected using the VQM and TPG reveals a significant presence of water vapor which dictated the trend of the total pressure. Carbon monoxide came in as the second highest presence.
- Significant increase in gas molecular mass of 15 and 31 during puncturing
- Total pressure peaked in the 6th decade, which similar to a previous analysis done on the X-ray tube, 2.1e-6.

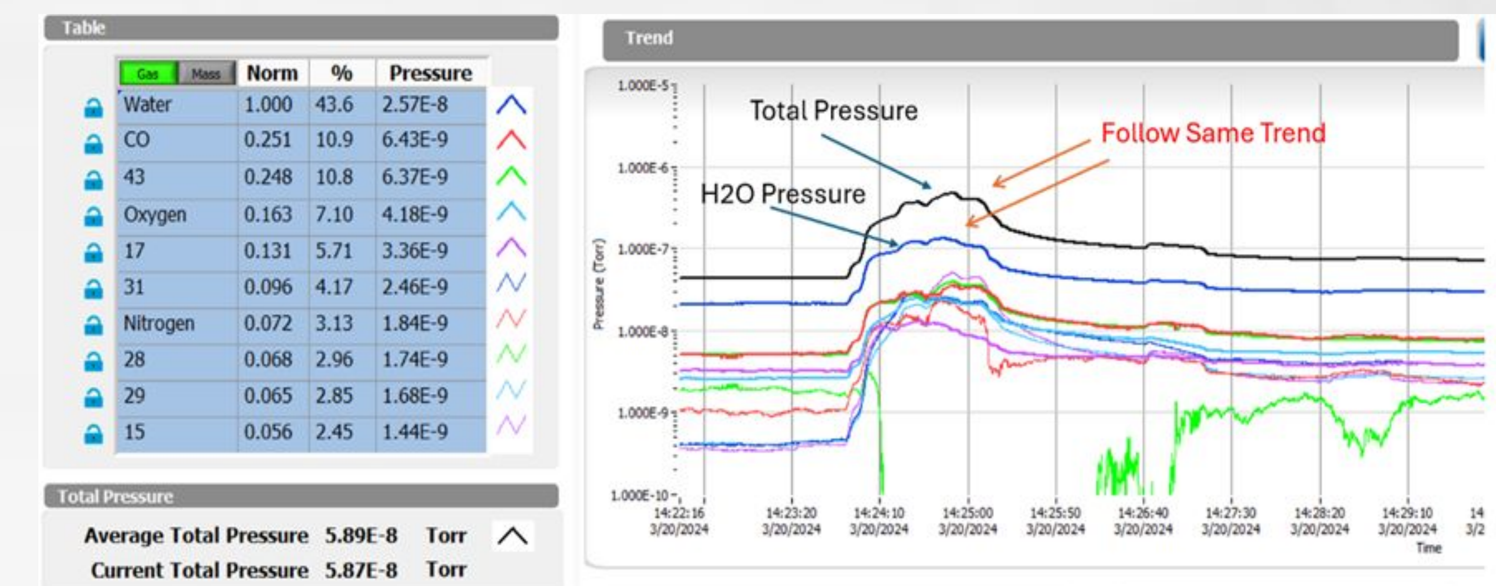


Fig 2. Results from VQM and TPG of before and after puncturing the X-ray tube. Graph shows H20 as dominant pressure.

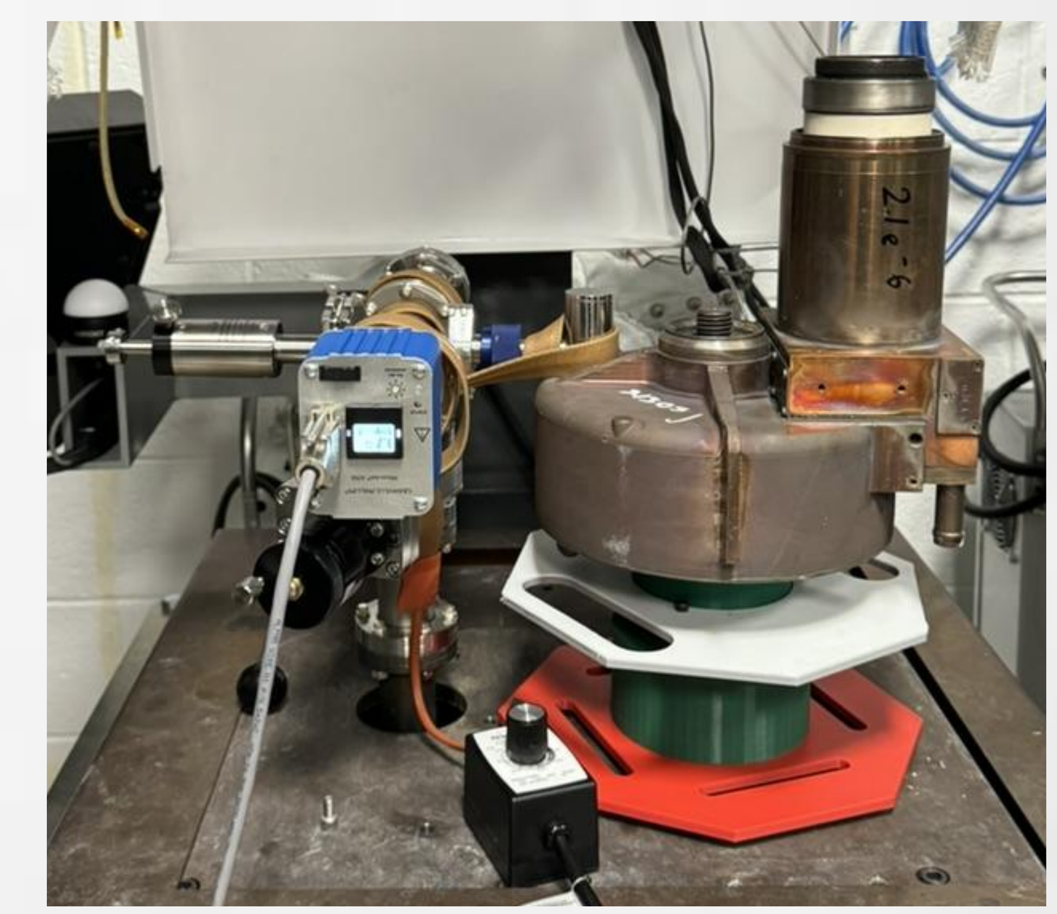


Fig 3. Image of experimental environment. Includes sub-system, X-ray tube, Drum Stool, and heat tape.

Conclusion

Our investigation of the UHV device has led to a critical discovery regarding the primary source of contamination and its detrimental impact on device longevity. Through our analysis, we have identified water vapor and carbon monoxide as the predominant contaminant gas. However, our research encountered limitations stemming from the open nature of the system. As an result, we faced challenges in performing comprehensive fragmentation analysis and identifying all residual gas components, although identifying major contaminant was successful. For future works, addressing this limitation will be paramount. Implementing strategies to close the system and enable thorough analysis of residual gas is critical for advancing our understanding of contamination mechanism.