DESIGN AND DEVELOPMENT OF THE VACUUM SYSTEMS FOR THE APT PROJECT ED&D CRYOMODULE *

G. Hansen, K. Kishiyama, S. Shen, P. V. Shoaff#, LLNL, Livermore, CA

Abstract

The mechanical design for both the insulating vacuum system and the cavity vacuum system of the APT ED&D Cryomodule is summarized. The pre-cooldown pressure limits for the insulating vacuum and the cavity vacuum are 10^{-5} Torr and 10^{-6} Torr, respectively. In addition, the cold cavity operating pressure limits are 10^{-6} Torr for the insulating system and 10^{-8} Torr for the cavity system. The designs of these systems utilize both turbomolecular pumps and the cold surfaces of the superconducting Nb cavities to arrive at and maintain their operating vacuum pressures. A synopsis of the analysis undertaken to predict the vacuum system performance is also presented.

1 INTRODUCTION

The Accelerator Production of Tritium (APT) Project Engineering Design and Development (ED&D) Cryomodule consists of a cryostat with all accelerator components and auxiliary systems installed. The vacuum system for the Cryomodule is composed of two distinct subsystems. The first subsystem, the insulating vacuum system, is responsible for evacuating the insulating chamber of the external cryostat. The other subsystem, the cavity vacuum system, evacuates the RF coupler, beam tube, and Nb cavity assemblies.

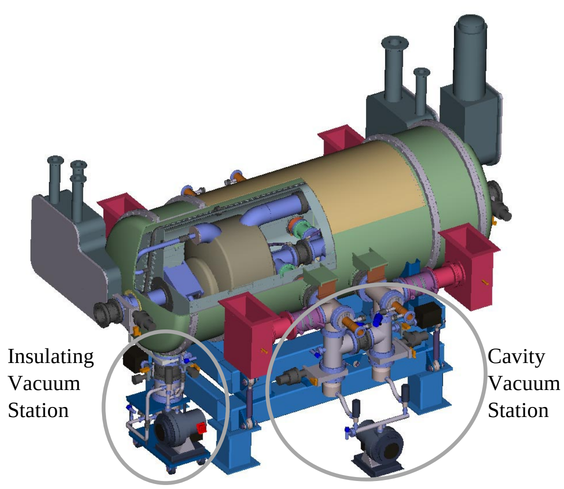

Figure 1: Final Design Layout for the Insulating and Cavity Vacuum Systems

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Email: shoaff1@llnl.gov

Figure 1 shows the layout for the final design of both the insulating vacuum system station and the cavity vacuum system stations. The insulating vacuum system is composed of a single portable turbo pump station attached to a cryostat endcap. The cavity vacuum system includes two pump stations on either side of the Cryomodule. Each station contains two turbo pumps, which are permanently attached to RF power coupler ports.

2 DESIGN CONCEPTS

2.1 System Requirements

The cryostat chamber pumped by the insulating vacuum system must be evacuated in order to minimize convective heat transfer to the He vessels surrounding the Nb beam cavities. The turbo pump of the insulating vacuum system is required to bring the chamber pressure level to 10^{-5} Torr prior to cryogen transfer. As the Nb cavities are cooled to 2 K, the He vessel surfaces will cryopump the insulating space and maintain it below the prescribed operating pressure of 1×10^{-6} Torr.

The two Nb cavity assemblies and their respective power couplers share a common ultra-clean vacuum system. The turbo pumps are required to initially evacuate the cavity and power coupler to 1×10^{-6} Torr. Upon cooldown the cavity surfaces, in conjunction with the continuosly running turbo pumps, should bring the pressure below the required 10^{-7} Torr at the RF windows and 10^{-8} Torr in the Nb cavities. All pumps for both systems are required to be oil-free [1].

2.2 Insulating Vacuum System Station

The insulating vacuum system station consists of a Varian Turbo V-700HT pump. The turbomolecular pump provides a pumping speed of 680 L/s for N_2. It is backed by a Varian DS610 Dry Scroll pump. The roughing pump provides a pumping speed of 585 L/min, for an ultimate total pressure of < 7.5×10^{-3} Torr, and operates hydrocarbon free.

As seen in Figure 2, the access port will be connected to the vacuum system through an 8” MDC C-Loc Gate Valve. The gauge ports on the access stem allow for mounting of both a convectron and a Granville-Phillips Stabil-Ion gauge. In addition, the roughing pump can be directly connected to one of these ports in order to bypass the turbo pump during system roughdown. This will minimize the risk of contaminants being sucked through the turbo pump during the viscous flow phase of the initial pump down.

The turbo pump will be connected to the gate valve through a stainless steel spool connected to a flexible bellows assembly with 10" stainless conflat flanges. A Residual Gas Analyzer can be attached to a 2.75" conflat on a 1.5" diameter access stem provided on the spool. Also, to accommodate gas analysis, a manual valve is provided in the foreline of the turbo pump to throttle down the pump speed. As called for by the program design requirements, the insulating vacuum system can be fully detached from the cryomodule at the gate valve and transported on the cart provided.

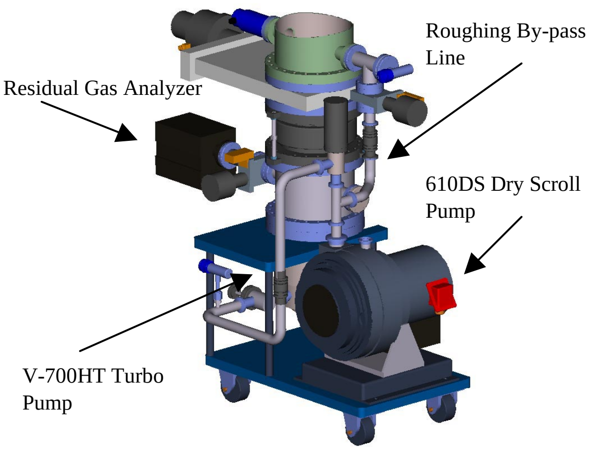

Figure 2: Details of the Insulating Vacuum System Station

2.3 Cavity Vacuum System Station

There will be two cavity vacuum stations and each will consist of two Varian Turbo V-300HT pumps backed by a single Varian 610DS Dry Scroll pump. Every turbo pump will provide a pumping speed of 280 L/s for N_2 to give a total system turbo speed of 1120 L/s. The roughing pumps are again hydrocarbon free and provide 585 L/min pumping speed per station and an ultimate total pressure of < 7.5×10^{-3} Torr.

As seen in Figure 3, the pump stations will be hard mounted to the 6" power coupler vacuum access ports with 8" conflat flanges and run continuously throughout Cryomodule operation in order to maintain the vacuum level at the RF windows and reduce the system gas load. Each of the vacuum access stems will host a 1.5" diameter gauge port ending in a 2.75" conflat flange. The roughing pumps will be floor mounted and attached to the hanging turbo pumps on each station via a 1.5" flexible stainless tube. Since the cavity system will be clean and free of contaminants, no bypass of the turbo pump will be necessary and the cavity system will be roughed directly through the foreline.

The goal post configuration mounts each turbo pump vertically through a 6" MDC C-Loc gate valve to a 6"stainless Tee attached to the power coupler vacuum access port. Each Tee hosts an additional 2 3/4" conflat gauge port. All connections are made with 8" conflat flanges. The Tees are then vacuum coupled across a 6" bellows with rotatable 8" conflat flanges. The addition of a vacuum coupling tube connecting the adjacent turbo pumps of a cavity vacuum station prevents the isolation of any RF window from a turbo pumping source in the event of a single pump shutdown. This helps to reduce the risk of a RF window failure.

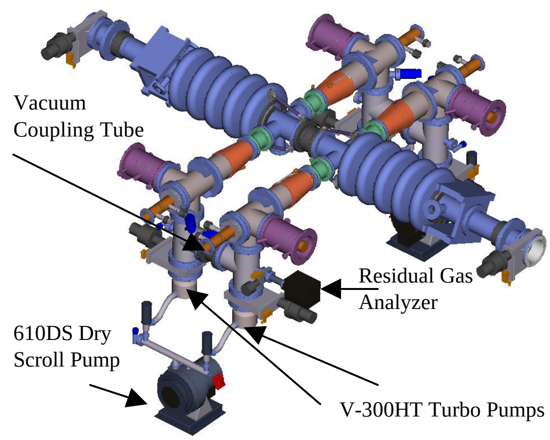

Figure 3: Detail of Cavity Vacuum Station with Cavity System Removed from the Cryostat

A Granville-Phillips Stabil-Ion gauge will be attached to each of the gauge ports on the power coupler vacuum access stem. Two convectron gauges will be placed at either side of the cryostat on the 6" Tee gauge ports opposite and diagonal from each other. The third Tee gauge port will accommodate an RGA and the fourth Tee gauge port will host the gas purge system. This purge system will provide clean filtered inert gas to pressurize the cavity volume.

For both the insulating and cavity vacuum system designs, all the high-vacuum valves are electro-pneumatic actuated and sealed using Viton O-Rings with a leak-rate at the body and valve seat of < 1×10^{-9} Torr-Liters/sec. Finally, all plumbing will consist of 304 stainless steel tubing, bellows, and off-the-shelf fittings, whenever possible. Additional design details are found in [2].

2.4 Cryomodule Vacuum Control Systems

As per design requirements, the design of the Cryomodule systems incorporates a control system that can either operate as a stand-alone system or interface with the supervisory control system, EPICS. The vacuum control system will have interlocks to close the high-vacuum valves in the event of a high-vacuum pump failure or other vacuum system problem. In the event of a vacuum system malfunction, interlocks will also be available to the cryogenic controls to shutdown the cryogenic refrigeration. In the event of a power failure, the vacuum system will shutdown, i.e. the high-vacuum pumps will stop and valves will close. When power is restored, the control system will restart, but the vacuum system will require a manual restart of the pumps and opening of any valves.

3 ANALYSIS

The APT ED&D Cryomodule Vacuum System performance has been analyzed numerically both during the initial pump down and nominal operation.

3.1 *Initial Pump Down*

The first analysis stage examines the initial pump down from 760 Torr of both the cavity and insulating vacuum systems. It is assumed that the RF power is off and the Nb cavities are at room temperature. Additionally, the pressure dependence of the mechanical pump speeds and the time dependence of the surface outgassing loads are taken into account.

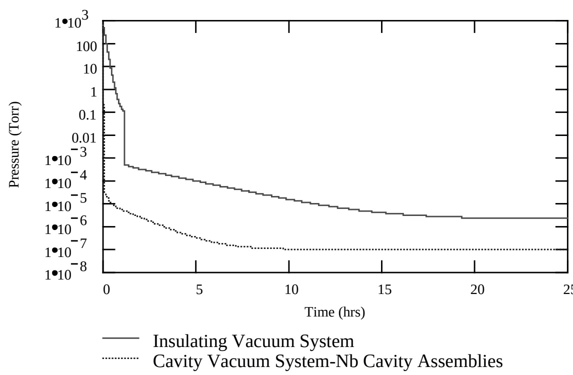

Figure 4: Initial Pump Down Curves for Both Cavity and Insulating System

Figure 4 illustrates the performance of both the cavity and insulating vacuum systems during the initial pump down stage. The analysis predicts that the insulating system will reach its warm cavity design requirement within 13 hours and the cavity system will reach its analogous requirement within 4 hours. Additionally, both of their base pressures are below the pressure limits required for RGA analysis.

3.2 *Cavity Specific Analysis during Nominal Operation*

The second analysis stage occurs during nominal operation when there is full RF power transfer and the Nb cavities are held at a constant 2 K. During this stage, the temperature profile of the cavity system is assumed constant, full cryopumping exists, and the gas loads are adjusted by temperature and RF power transfer effects. The RF power effects are approximated using empirical results obtained by LANL during testing of the APT RFQ windows [3].

Applying these conditions, the analysis shows that, within seconds, the minimum base pressures obtained in the Nb cavity assemblies are well below their operational requirements, however, the base pressures in the RF window volumes are estimated to be 1.07×10^{-7} Torr. Thus, the current design is at the operational limit. A plot of the pressure vs. time curve is seen in Figure 5.

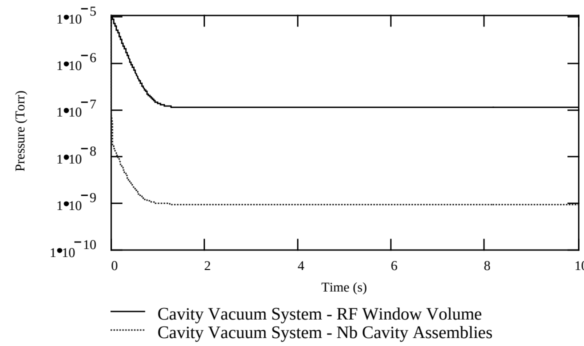

Figure 5: Pump Down Curves from 10^{-5} Torr for the RF Window Volumes and the Nb Cavity Assemblies under Nominal Operating Conditions

The final design analysis also included an examination of several sets of failure scenarios including turbo pump shutdowns and RF window failures. The analysis parameters and more detailed results of the Cryomodule vacuum system, including the various failure scenarios can be found in [2], [4].

4 CONCLUSION

The designed system presented in this paper is consistent with the requirements of the APT ED&D Cryomodule. It is a robust, reliable, and redundant system capable of providing the required vacuum level for the APT ED&D Cryomodule with comfortable margins. A review of the final design for the ED&D Cryomodule will be scheduled in the near future and held at Los Alamos National Laboratory.

5 REFERENCES

[1] B. Campbell, “Preliminary Design Requirements of the ED&D Cryomodule for the Accelerator Production of Tritium,” LANL, (1997)

[2] P. Shoaff, et al., “APT/ED&D Cryomodule Vacuum Pumping System, Final Design Report,” LLNL/APT 99002, (1999)

[3] P. Shoaff, et al., “RF Window Vacuum Quality Report,” LLNL-APT-98-006, (1998)

[4] P. Shoaff, et al., "Analysis of the Cavity Vacuum System Response to an RF Window Failure," LLNL-APT-98-007, (1998)