VACUUM SYSTEM DESIGN CONSIDERATIONS OF THE LOS ALAMOS ACCELERATOR TEST STAND (ATS)*

N. G. Wilson, AT-2, MS H818
Los Alamos National Laboratory, Los Alamos, NM 87545

Summary

The accelerator test stand (ATS), in operation at the Los Alamos National Laboratory, includes a hydrogen ion source, low- and high-energy beam-transport sections, and a 425-MHz radio-frequency quadrupole (RFQ) linear accelerator. A 425-MHz drift-tube linac (DTL) and a powered "buncher" matching section have been constructed and will be installed on the ATS.

The vacuum systems required for the various sections of the ATS are designed to provide (1) high gas-load capability, as required in the ion source, and (2) high-vacuum capability in the high-power, radio-frequency accelerator sections (where fast vacuum-system response time is of importance) through the use of distributed, differential pumping as a principal vacuum-system feature. This paper describes properties of accelerator materials, vacuum-systems engineering and analysis, vacuum equipment used, and ATS vacuum-system performance.

Introduction

Radio-frequency-driven particle accelerators are of increasing interest in many areas of particle physics. This paper briefly discusses the vacuum system of an existing 425-MHz linear accelerator, that is, the ion source/injector, an RFQ linac with buncher, and a DTL.

Each major section was analyzed during design to ensure that the required vacuum conditions would be achieved in operation. The analysis provided residual gas pressures expected in the various zones of each section, for no-beam and with-beam conditions. Response times (i/ϵ) for the RFQ and DTL were also calculated from the effective pump speeds and volumes.

The low-energy beam-transport region is not specifically analyzed because it is integral to the ion-source section. The high-energy beam-transport region is not analyzed because it is frequently changed, according to experimental/diagnostic arrangements, and is provided with its own stand-alone vacuum system.

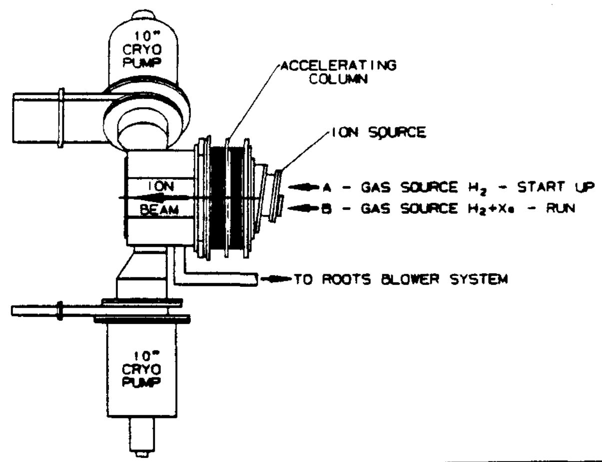
Material Characteristics

The accelerator components exposed to the vacuum environment are clean (degreased) polished OFHC copper, plated copper (UBAC[1]), stainless steel, and VITON[2] elastomer O-rings. Dynamic outgassing rates were measured for typical samples of OFHC and plated copper; characteristic unbaked outgassing rates after 24 hours under vacuum were 4 X 10^{-10} torr ℓ/s/cm^2. Similar measurements for unbaked stainless steel were 5 X 10^{-11} torr/ℓ/s/cm^2.

Ion Source

The ion-source operation involves three functional phases: (1) start-up/conditioning, (2) run (pulsed) operation, (3) standby. (Figure 1 schematically shows the ion source system arrangement and vacuum-system parameters.)

During start-up, gas flows of ≥1 torr ℓ/s are used with source pressures of 1 to 5 X 10^{-1} torr.



ION SOURCE CHARACTERISTICS

Pump Speeds	Condensable	Hydrogen
Roots blower	140 ℓ/s	140 ℓ/s
Ten-inch cryopumps	9000 ℓ/s	3000 ℓ/s
Effective Pump Speeds (calculated)		
Ion source (start up)	10 ℓ/s	37 ℓ/s
Ion source high vaccum	2600 ℓ/s	4700 ℓ/s

Gas Sources	
Start-up (H_2)	≥ 1 torr/ℓs
Run	6.5 x 10^{-2} torr/ℓs
Standby	3 x 10^{-4} torr/ℓs

Pressures	Calculated	Observed
Start-up (Roots blower)	-0.1 torr	0.1 - 0.2 torr
Run (high vacuum)	-1.4 x 10^{-5} torr	7 - 8 x 10^{-6} torr[a]
Standby	-1.2 x 10^{-7} torr	2 x 10^{-7} torr

[a]Hot-cathode ion gauge indication, corrected for hydrogen sensitivity. Gauge uncertainty > ±50%.

Fig. 1. Ion source section.

In the ATS, the evacuation of the start-up gas is performed by a Roots blower vacuum system providing ~50 ℓ/s pump speed (hydrogen) at the ion source. During 5-Hz, 10-ms pulse-length pulsed operation, the average gas source is reduced to 6.5 X 10^{-2} torr ℓ/s. The pumping speed necessary to produce the required operating condition of less than 5 X 10^{-5} torr is produced by two 10-in.-diam cryogenic pumps of 9 000 ℓ/s (condensable) speed operated in parallel, connected to the source through the injector accelerating column. The effective hydrogen speed at the accelerating column entrance is 1.1 X 10^4 ℓ/s. A pressure of about 6 X 10^{-6} torr is predicted; operation at 10-Hz pulse rate has been initiated with a pressure of about 1.2 X 10^{-5} torr predicted.

Standby conditions in the ion source are provided by either of the two pumping systems, that is, the Roots blower start-up system or the dual 10-in.-diam cryogenic high-vacuum pump system. The Roots blower system provides a thermoelectrically cooled baffled pressure of less than 1 X 10^{-3} torr; whereas, the

*Work performed under the auspices of the U.S. Dept. of Energy and supported by the U.S. Army Strategic Defense Command.

cryogenic pumps produce a standby pressure of less than 1 X 10^{-7} torr. Selection of these pump systems, either of which has been shown to be satisfactory for retention of operating characteristics, depends principally on the operational schedule and/or the degree of hydrogen "loading" of the cryogenic pumps. Instability of the cryogenic pumps as they become saturated with hydrogen has resulted in the necessity for regeneration after approximately 30 hours of source operation (or 12 standard liters of H_2).

ATS RFQ

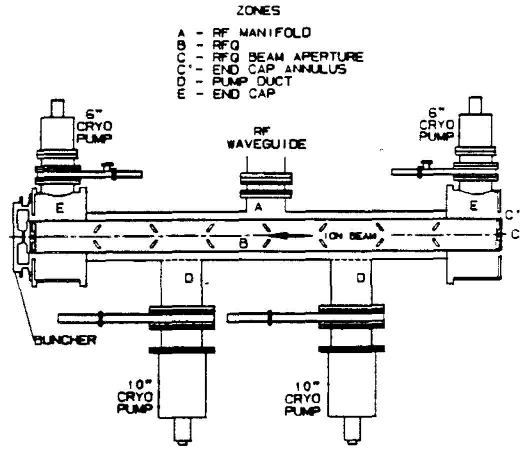
The RFQ operated on the ATS requires a vacuum environment in the accelerating cavity to (1) allow beam transport through the structure without degradation from residual gases, (2) provide a gas density that will not produce electrical breakdown with rf excitation of twice the Kilpatrick[3] criterion and, (3) provide a residual gas density low enough to prevent recontamination of the accelerator structures after rf conditioning; a pressure of less than 2 X 10^{-6} torr is expected to provide these conditions. The RFQ pumping systems should also provide adequate speed for rapid-volume cleanup response time to allow recovery from gas bursts resulting from intermittent rf discharges and sparks. Figure 2 schematically shows the RFQ system and a summary of the vacuum-system parameters.

The pumping systems of the RFQ, based on the use of two 10-in.-diam cryogenic vacuum pumps, produce a calculated effective speed in the accelerating cavity of 930 ℓ/s (condensable) and 2240 ℓ/s (hydrogen). The calculated pressures in the cavity are (1) without an ion beam, about 3.0 X 10^{-8} torr, and (2) with an ion beam, 8.0 X 10^{-8} torr. The availability of two pumps, either of which has the performance required to operate the RFQ, permits regeneration of either pump while continuing operation.

The RFQ manifold end caps, equipped with 6-in.-diam cryogenic pumps, are used to provide an evacuated zone where eight water-cooling circuits and four rf pick-up cables are connected to vacuum feedthroughs without adversely affecting the RFQ accelerating cavity. The low-energy end cap also provides a guard vacuum zone at the RFQ entrance to minimize effects of streaming hydrogen gas on the RFQ accelerating-cavity entrance. The high-energy end cap also provides pumping for the beam-matching rf buncher cavity, which will be installed between the RFQ and the DTL.

Drift-Tube Linac

The DTL requires an operating vacuum condition of less than 2 X 10^{-6} torr, which is similar to that of the RFQ. The vacuum system planned for the DTL will use a pumping system similar to that of the RFQ to provide commonality of equipment, controls, and operating parameters. Figure 3 schematically describes this system as well as the typical calculated operating conditions. In this system, two 10-in.-diam cryogenic pumps of 9000 ℓ/s speed (condensable) will be ducted to the DTL tank as was done in the RFQ. A pumping speed of 6000 ℓ/s in the tank and an operating pressure of about 4.5 X 10^{-9} torr was calculated for this system. The cleanup response time calculated for this pump arrangement is 0.07 s. Because either pump can produce the required operating conditions, regeneration of alternate pumps can be accomplished without shutdown of the DTL.



RFQ CHARACTERISTICS

DESIGN PARAMETERS

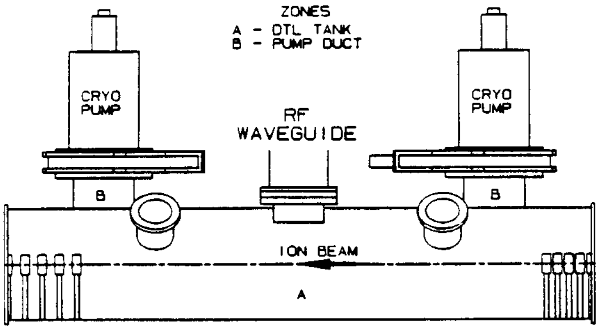
Pump Speed	Condensable	Hydrogen
Ten-inch cryopump	9000 ℓ/s	3000 ℓ/s
Six-inch cryopump	3000 ℓ/s	1000 ℓ/s
Calculated Effective Pump Speeds		
Zone A	1610 ℓ/s	3130 ℓ/s
Zone B	930 ℓ/s	2240 ℓ/s
Zone D	2345 ℓ/s	2390 ℓ/s
Zone E	570 ℓ/s	606 ℓ/s
Calculated Gas Loads		
Zone A	4.2 x 10^{-5} torr ℓ/s	1.5 x 10^{-4} torr ℓ/s
Zone B	2.8 x 10^{-5} torr ℓ/s	1.5 x 10^{-4} torr ℓ/s
Zone C	1.2 x 10^{-6} torr ℓ/s	1.5 x 10^{-4} torr ℓ/s
Zone C	3.8 x 10^{-5} torr ℓ/s	8.3 x 10^{-3} torr ℓ/s
Zone D	6.0 x 10^{-5} torr ℓ/s	7.5 x 10^{-5} torr ℓ/s
Zone E	4.1 x 10^{-5} torr ℓ/s	8.3 x 10^{-3} torr ℓ/s
Calculated Response Time (i/ε)		
Zone A	0.11 s (Cond)/0.06 s (H_2)	
Zone B	0.07 s (Cond)/0.03 s (H_2)	

SYSTEM PRESSURES

	Calculated	Observed
Zone A	w/o H_2 - 2.6 x 10^{-8} torr w/H_2 - 7.6 x 10^{-8} torr	
Zone B	w/o H_2 - 3.0 x 10^{-8} torr w/H_2 - 8.0 x 10^{-8} torr	
Zone D	w/o H_2 - 2.6 x 10^{-8} torr w/H_2 - 4.9 x 10^{-8} torr	1-3 x 10^{-8} torr [a] 7.7 x 10^{-8} torr [a, b]
Zone E	w/o H_2 - 7.1 x 10^{-8} torr w/H_2 - 1.1 x 10^{-6} torr	8.0 x 10^{-8} torr [a] 1.9 x 10^{-6} torr [a, b]

[a]As indicated on ion gauge — N_2 calibration. Calibration uncertainty > ±50%.
[b]H_2 sensitivity ≈ 0.5 N_2.

Fig. 2. RFQ section.



DTL CHARACTERISTICS

Pump Speed	Condensable	Hydrogen
Ten-inch cryopump	9000 ℓ/s	3000 ℓ/s
Calculated Effective Pump Speeds		
Zone A	3100 ℓ/s	
Zone B	1750 ℓ/s	
Calculated Gas Load		
Zone A	2.7 x 10^{-5} torr ℓ/s	
Calculated Pressure		
Zone A	1.5 x 10^{-8} torr	
Zone B	4.4 x 10^{-9} torr	
Calculated Response Time (i/ε)		
	0.25 s	

Fig. 3. DTL Section.

Conclusion

The vacuum systems provided for the accelerator test stand have been used on the RFQ and on the ion source in its present configuration since 1983. The operating conditions in both zones have closely approached those calculated for the arrangements used. Of particular utility has been the ability to regenerate one cryogenic pump while its mate is used to continue operation. The reliability of the pumps has been gratifying, with only minor maintenance requirements in nearly 30 000 hours of operation for two of the 10-in.-diam pumps and 9 000 hours operation for the other two 10-in.-diam and two 6-in.-diam pumps. The fast response time of the RFQ pumping system has been a significant advantage during rf conditioning and recovery from rf discharges/sparks in operation; it is expected that the DTL will benefit similarly.

Acknowledgments

The author wishes to recognize the contribution of the AT-2 operating staff with particular recognition of Martin Milder (accelerator operations), Stuart Orbesen (ion-source operation), Wayne Lemons (vacuum-system technologist), Harry Dilello (accelerator-systems technologist), and Fred Humphry (accelerator-systems coordinator).

References

1. Udylite Bright Acid Copper, trade name of Udylite Oxy Metal Industries Corporation.

2. Trade name of E. I. duPont deNemours Co., Inc.

3. W. D. Kilpatrick, "A Criterion for Vacuum Sparking designed to include both RF and DC." University of California Radiation Laboratory report UCRL 2321 (1953).