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LLL 100-MeV ELECTRON LINAC: DESIGN CONSIDERATIONS AND PERFORMANCE OF THE BEAM-TRANSPORT VACUUM SYSTEM*

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Summary

This paper describes the vacuum system for the beam-transport lines used with the Lawrence Livermore Laboratory 100-MeV electron-positron linear accelerator. It is operated in the high (10^{-4} to 10^{-5} Pa) range using standard ion pumps with turbomolecular pumps for roughdown. This paper also reviews the important factors considered during the initial design phases; these factors have contributed to the very reliable performance of the vacuum system since its startup five years ago. The cleaning and handling procedures used on the beam-transport lines, magnet vacuum chambers, and other vacuum components are discussed.

Vacuum System Description

Particle accelerator systems have wide use in nuclear physics experiments. The typical system is composed of an accelerator, a particle beam-transport system of pipes, bending magnets, and target areas where experiments are conducted. In a well-developed facility there is usually an extensive and complicated beam-transport line or lines that must be evacuated to high or ultra-high vacuum.

The vacuum system for the beam-transport line of the LLL 100-MeV electron-positron linear accelerator (Linac)[1] is located 8 m below ground level. It starts from the exit of the fifth accelerator waveguide section of the Linac. A complex bending, focusing, and steering magnet arrangement splits the beam transport line into four lines that terminate in four experimental caves. Figure 1 is a general layout of the vacuum system, showing the vacuum equipment on the beam-transport lines and the experimental caves.

The vacuum system was designed to maintain the beam-transport lines in the high vacuum range of 10^{-4} to 10^{-5} Pa. Getter-ion pumps are used for the high vacuum requirements and turbomolecular pumps for roughdown. We chose ion pumps because diffusion pumps are subject to oil contamination accidents and liquid nitrogen trap problems. Ion pumps require more sophisticated system design, but our ion pump vacuum system has been very satisfactory in fulfilling design objectives. We chose turbomolecular pumps because of their non-contaminating and hydrocarbon-free characteristics and their ability to pump noble gases. This combination of pumps provided a clean, compact, simple, and efficient vacuum system compatible with the Linac vacuum system.

The vacuum system has been in operation since Autumn, 1969.

Beam Transport Lines

The beam transport lines contain the largest potential outgassing load in the entire vacuum system, a major consideration in the vacuum system design. They have a total internal surface area of 4.7×10^5 cm^2. The total combined length of the initial beam transport lines is 140 m. The lines consist of 102-, 152-, and 204-mm-diam tubing rectangular beam lines, 16 magnet vacuum chambers, and 72 bellows, all made of stainless steel 304. There are 240 mechanical joints in the beam transport lines, vacuum-sealed with shear pinch-type stainless steel flanges with copper gaskets. Targets and other components added to the beam transport lines will contribute to the outgassing load.

Roughing and High Vacuum Pumps

The beam transport lines are roughed down to 10^{-3} Pa or better by two turbomolecular pumps. Each pump has a pumping speed of 260 ℓ/s and handles approximately half the total gas load from the internal volume of the beam transport lines. The turbomolecular pumps are connected directly to the 102-mm-diam beam transport lines at two locations in the system.

The optimized high vacuum system design called for six 600-ℓ/s and one 200-ℓ/s ion pumps. The pumps are directly connected to the beam transport lines with 6- to 9-m spacings between each pump station. The size of the ion pumps are determined by the total outgassing load of the internal surface area and the conductance limitations in the overall beam transport lines. Conductance limitations were calculated from the various beam transport line restrictions, collimator openings, magnet vacuum chamber apertures, and pumpout valve ports. Outgassing rates of stainless steel exposed to air from 1 to 10 h are in the range of 10^{-5} to 10^{-7} Pa (Refs. 2-4).

Engineering Design Considerations

Design Criteria

At the preliminary design stage, the engineering requirements considered essential to the design of the vacuum system were defined:

1. Vacuum operating pressure must be at the high 10^{-4} to 10^{-5} Pa range.

2. System must have maximum reliability and minimum downtime.

3. System design must be economically optimum.

4. System design must consider the intense radiation environment and its effects on the equipment.

5. Vacuum system must be compatible with the Linac 8×10^{-5} Pa vacuum system.

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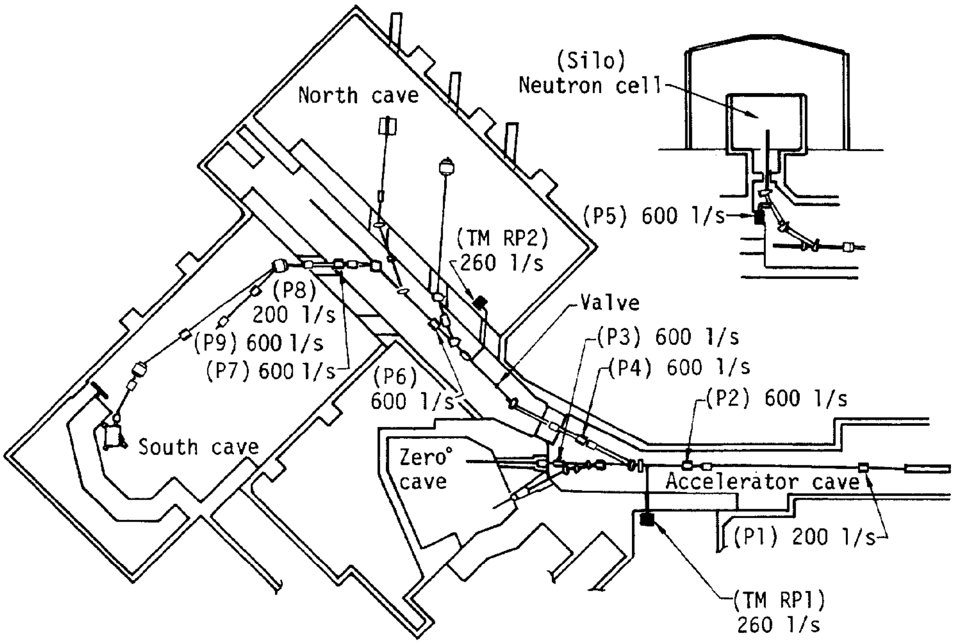

Fig. 1. General layout of vacuum system. Ion pumps are labeled P1 through P9. Only P1 through P7 are presently in use.

6. Materials and components must be selected to maintain the integrity of the vacuum system.

7. Handling, assembly, disassembly, and operating methods of the vacuum system and its components must be established.

Component Design

Using getter-ion pumps for the vacuum system meant reevaluating the design requirements for all vacuum components. The following design factors were used:

1. Materials must have very low outgassing characteristics.

2. The vacuum operating range must be in the high 10^{-4} to 10^{-5} Pa range to extend the working life of the ion pumps.

3. All mechanical joints must be flanges with metallic gaskets for resistance to radiation damage and increased vacuum seal reliability.

4. Organic materials must be used on a very limited and selective basis. The outgassing rates of such materials must be reduced whenever possible.

5. Vacuum brazing must be used for all metal bonding when materials are not weldable.

6. Parts used must be designed to eliminate any possibility of trapped gases.

7. All components must be degreased to remove all oil and grease or chemically cleaned to dislodge all unstable oxide from the surface.

The need for very clean vacuum components is particularly significant with getter-ion pumps. Several techniques for cleaning materials to reduce outgassing exist.[5-9] We used the Stanford Linear Accelerator Center (SLAC) chemical cleaning procedure "V" without bakeout for the stainless steel 304 in the beam transport lines. Table 1, provided by E. Hoyt[10], show the necessary steps. The magnet vacuum chambers were cleaned with the Diversey process.[6,9]

Pumpdown Tests

We tested the beam transport lines cleaned by SLAC procedure "V" to determine the response time from atmosphere to the 10^{-4} to 10^{-5} Pa range. We used 15.5 m of 102-mm-diam strainless steel 304 beam transport lines. The first tests were made with a turbomolecular pump on one end; ensuing tests used an ion pump located at the midpoint of the system.

Table 1. SLAC chemical cleaning procedure "V".[a]

1.	Vapor degrease
2.	Alkaline clean
3.	Hot tap water rinse
4.	Acid clean with 20 to 25% HNO_3, 2 to 3% HF for 10 min at 50 to 60°C
5.	Cold tap water rinse
6.	Hydrowash (551 kPa air + water mix)
7.	Cold tap water rinse
8.	Deionized water rinse at 80°C
9.	Deionized water rinse at 95°C
10.	Clean air blow-off

[a]From Ref. 10.

Figure 2 shows the actual pumpdown times to reach the 10^{-2} to 10^{-3} Pa range with the turbomolecular pump and the 10^{-4} to 10^{-5} Pa range with the ion pump. Figure 3 shows that the overall beam transport line pumpdown time from air to 10^{-3} Pa using the turbomolecular pumps was 3.5 h. At 10^{-3} Pa the ion pumps were turned on. The overall vacuum system of the beam transport line was in the high 10^{-5} Pa range after a continuous pumpdown of 35 h.

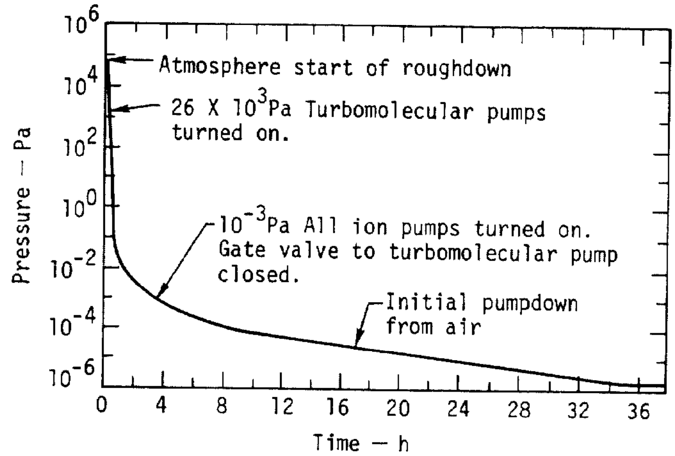

Fig. 3. Actual pumpdown curve for beam transport line. Test date November 13 to 15, 1969.

Vacuum System Performance

The overall performance of the vacuum system through five years of operation has been very reliable. Of the seven original ion pumps installed in 1969, five are still in operation and two have failed after 4.5 years of service. The operating pressures of the seven ion pumps between Autumn, 1969 and Autumn, 1974 are given in Table 2.

To avoid interrupting experiments and increasing costs, it is necessary to keep downtime to a minimum. Table 3 shows the total downtime record of the beam transport line vacuum system. Our maximum downtime has been 64 h; it stemmed from a failure in the vacuum system caused by leaks in the flanges of two magnet vacuum chambers. Our minimum downtime has been 11 h. Comparing Linac downtime resulting from beam-transport vacuum system failure to Linac downtime from other major component failures, we find that the latter is responsible for 5 to 15 times more.

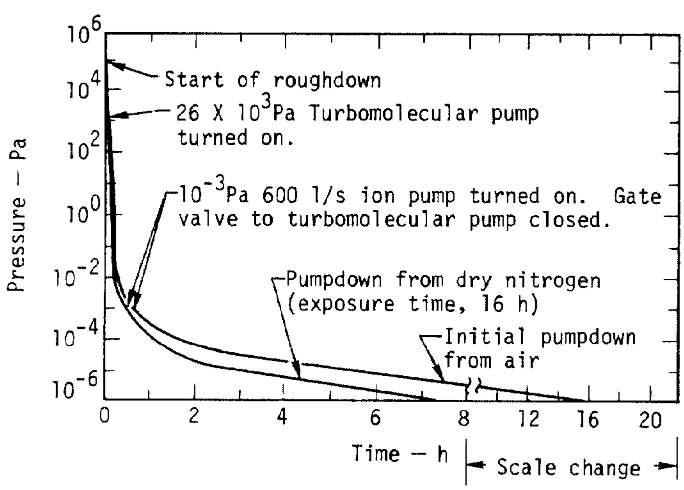

Fig. 2. Actual pumpdown curve for 15.5 m of 102-mm-diam beam transport line. Ambient temperature was 30°C. Test date July 24 to 28, 1968.

Our experience with the vacuum system for the beam-transport lines emphasizes its reliable performance. It indicates that the design requirements for the vacuum system, the use of turbomolecular and getter-ion pumps, and the special cleaning and handling techniques imposed are economically justified and that the design objectives were fulfilled.

Acknowledgment

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Table 2. Recorded operating vacuum pressure of ion pumps.

Pump No.	Pumping speed ℓ/s	Vacuum pressure readings (Pa) Autumn 1969	Summer 1972	Spring 1974	Autumn 1974
P1	200	5×10^{-6}	6×10^{-6}	6×10^{-6}	9×10^{-6}
P2	600	6×10^{-6}	9×10^{-6}	3×10^{-5}	8×10^{-5}
P3	600	3×10^{-5}	9×10^{-5}	1×10^{-4} (failed)	3×10^{-5} (new)
P4	600	5×10^{-6}	9×10^{-6}	3×10^{-5}	8×10^{-5}
P5	600	6×10^{-6}	3×10^{-5}	8×10^{-4}	8×10^{-4}
P6	600	6×10^{-6}	9×10^{-6}	1×10^{-3} (failed)	3×10^{-5} (new)
P7	600	8×10^{-6}	3×10^{-5}	8×10^{-5}	8×10^{-4}
P8	200	–	–	–	New, not in use yet
P9	600	–	–	–	New, not in use yet

Table 3. Yearly downtime: for beam-transport line vacuum system.

Fiscal year	Downtime (h)	Downtime (%)	Total Linac time available (h)
1970 (9 mo)	13	0.44	2908
1971	64	1.4	4487
1972	11	0.34	7784
1973	22	0.39	5581
1974	23.75	0.44	5362
1975 (6 mo)	7.75	0.26	3000
Averages	28.3	0.48	5824

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