Linac to Booster Transfer Line (LTB1) Vacuum System Technical Design

CLS DESIGN NOTE 2.2.33.1 Revision 3

(formerly 2.1.32)

Date: September 13, 2000

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Revision History

Revision	Date	Description	Author
A	November 26, 1999	Draft	Jason Fielden
B	December 03, 1999	Original Issue	Jason Fielden
C	December 22, 1999	Reviewed	Jason Fielden
0	February 14, 2000	Issued	Jason Fielden
1	March 31, 2000	Approved for detailed design	Jason Fielden
2	July 26, 2000	Revisions for detailed design	Jason Fielden
3	September 13, 2000	Approved	Jason Fielden

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1. Introduction

The linear accelerator (Linac) to booster ring transfer line, LTB1, transports electrons at an energy of 250 MeV from the Linac to the Canadian Light Source booster synchrotron ring. The electrons will be transported through a high vacuum system having an average pressure less than or equal to 1.0×10^{-7} Torr or 1.3×10^{-5} Pascal (Pa). Gas sources such as surface sublimation, desorption, gas diffusion, permeation and inleakage provide an ongoing gas load that can compromise the desired state of the vacuum. As a result, ion pumps will be placed periodically along the LTB1 line in order to maintain a pressure profile below 1.3×10^{-5} Pa. The placement of these pumps must not interfere with the positioning of vital system components such as bending magnets, steering magnets, quadrupoles and diagnostic equipment and will give consideration to the guidelines set in the previous CLS design note on the LTB1 vacuum system[1]. Lastly, the design must insure accessibility to the pumps as well as locate valves and roughing pump ports. This document will outline the process of developing the vacuum system for the new part of the LTB1 line located after the Switchyard or room 0003.

2. Theory

The material that composes the walls of the vacuum provides an incoming gas load due to several phenomena. The first is outgassing which is a generic term involving the natural evolution of adsorbed or absorbed species contributing to the gas load arising from one of the following conditions:

-Sublimation of the actual surface,
-Desorption from the walls of physically adsorbed molecules,
-Diffusion of gas out of the grain boundaries of the metal,
-Permeation of gases through the wall material or through O-rings.[2]

Another source of gas load is inleakage which is described as gas entering the system through holes in the vacuum wall, e.g., seals, porous welds, brazes, porous metal.[2] These gas loads are given on a surface area basis and can be converted to a total gas load if the surface area of the system is known.

The result of these gas loads is that the system must be continually pumped to maintain a constant pressure. Ion pumps are best suited for vacuum applications and must be placed periodically throughout the system to negate the gas load. The following relationship is used to determine the required pumping speed,

$$S = \frac{Q}{\overline{P}} \qquad (1),$$

where S is the required pumping speed in liters/second(L/s), Q is the gas load in Pa·L/s and $\overline{P}$ is the desired average system pressure in Pa.

The ion pumps are positioned to provide the required pumping speed for a given length. However, due to inherit resistances in the pump set-up and geometry, the actual pumping speed delivered to the system is somewhat less than the nominal speed quoted by the manufacturer. The delivered pumping speed as seen by the system can be determined by the following relationship,

$$\frac{1}{S_D} = \frac{1}{C_T} + \frac{1}{S_P} \qquad (2),$$

where S_D is the delivered pumping speed as seen by the system, C_T is the total conductance (inverse of resistance) from the vacuum system to the actual pumping chamber and S_P is the nominal or "book" value of the pumping speed. This delivered pumping speed must be greater than or equal to the speed required to pump out the section.

The LTB1 line itself has a conductance that is a limiting factor as to how easy it is to pump out the system. The conductance of a tube is defined by the following equation:

$$C_{Tube} = 12\frac{D^3}{L} \qquad (3)$$

where C_{Tube} is the conductance of the tube in L/s, D is the diameter of the tube in cm and *L* is the length of the tube in cm.

From equation (3), it is obvious that the molecules furthest away from a pump will have the lowest conductance and greater difficulty reaching the pump when compared to closer molecules. As a result, the pressure profile will be high far away from pumps and low close to pumps. The challenge is to determine the correct frequency for pump placement so as to keep the maximum line pressure of these "dead spots" below 1.0×10^{-7} Torr or 1.3×10^{-5} Pa.

The pressure profile of any given length of pipe can be determined using the following equation:

$$Q = C_{Tube} \cdot \Delta P \qquad (4),$$

where Q is the throughput in Pa·L/s, C_{Tube} is the conductance of the line in L/s and ΔP is the pressure difference between two points in Pa.

3. LTB1 Vacuum Pumping Layout

The LTB1 line was divided into sections separated by valves. These sections were examined using ANSYS 5.5 Finite Element Program. The analysis was done iteratively by sizing and inputting the sections, sizing and placing pumps and observing the resultant pressure profile. The pump positions and section sizes were varied until the pressure profiles were below 1.3×10^{-5} Pa. The final layout involved five sections separated by valves containing two ion pumps per section.

Two runs of each section were made with different gas loads. The first run assumed any inleakage effects to be negligible. This assumption is made because, in the observable range, inleakage results from a mistake and can usually be corrected. As a result, the outgassing rate governs the analysis in an ideal system. This run employed an outgassing rate of 3×10^{-13} Torr·L/s/cm^2 or 4×10^{-11} Pa·L/s/cm^2 for baked stainless steel[3] and pumping speeds of 30 L/s for Varian Vaclon Plus 40 StarCell pumps. The proposed final layout of sections is shown in Figure 1. The resulting pressure profiles for the five sections at an outgassing rate of 4×10^{-11} Pa·L/s/cm^2 and two ion pumps per section can be seen in Appendix A. Obviously, the proposed layout is satisfactory for this magnitude of gas load. The pump layout can be seen in drawings LTB1/ME/0034601, 0034602, 0034603, 0034604, 0034605.

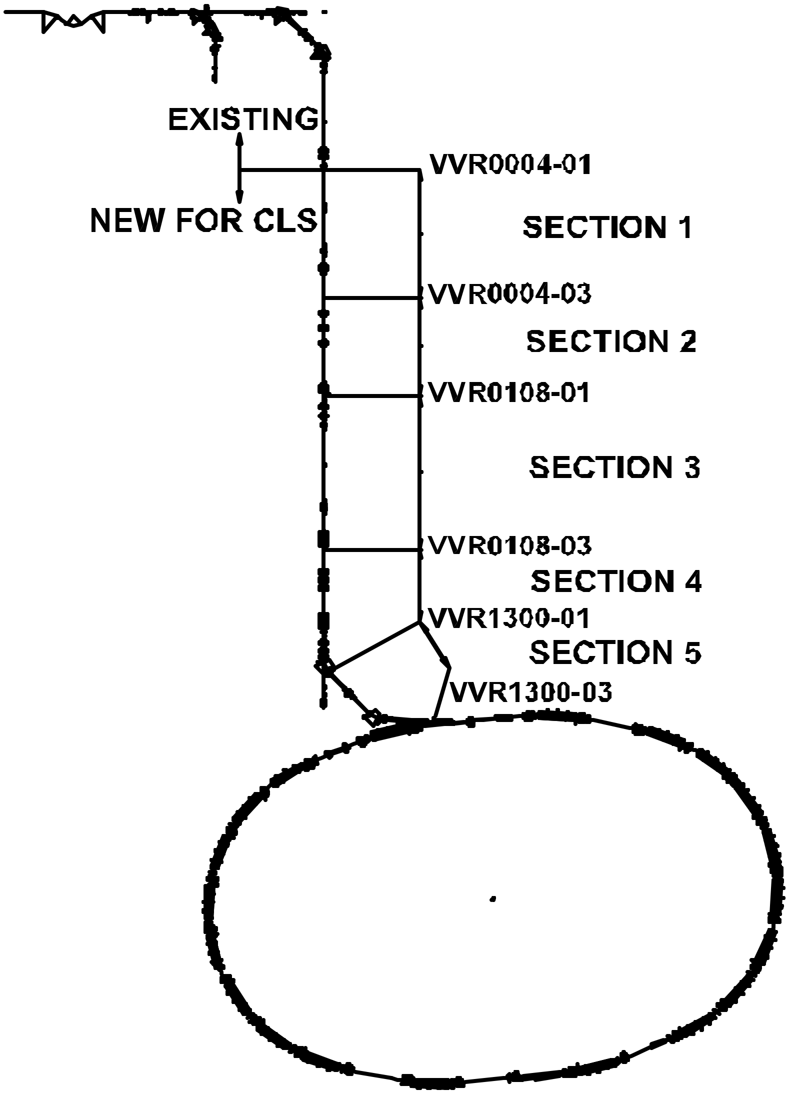


Figure 1: Layout of Vacuum Sections for LTB1

The second run of the proposed LTB1 transfer line layout was a conservative analysis. This analysis was done to acknowledge that the system may not act ideally and the surface outgassing may be greater than that indicated. The outgassing rate was increased to 1×10^{-10} Torr·L/s/cm^2 or 1.3×10^{-8} Pa·L/s/cm^2 while the pumping speeds remained at 30 L/s. The proposed layout maintains a pressure profile below the 1.3×10^{-5} Pa range as shown in Appendix A. The pressure profile for LTB1, as a whole, with its valves open is also shown in Appendix A.

From the two cases described above, the proposed layout will be successful in maintaining a system pressure less than or equal to 1.0×10^{-7} Torr or 1.3×10^{-5} Pa for the LTB1 line. All of the pump and valve locations are accessible and each section has two roughing ports. The ion pumps will be Varian Vaclon Plus 40 StarCell pumps capable of 30 L/s pumping speed each at the pressure range of interest. These pumps are present at the existing SAL facility and can be reused for LTB1. The ion pumps and roughing lines will be attached to the vacuum system using four or six way crosses. The valves which separate the vacuum sections will be in-line gate valves with metal sealed bonnets. All connections will use OFHC copper gaskets. Finally, BOC Edwards Active Inverted Magnetron pressure gauges and Gauge Displays or equivalent will be placed periodically throughout the system. A listing of the equipment required for the LTB1 vacuum system is shown in Table 1.

Table 1: Quantities of vacuum pumping components by section

Section	Ion Pumps*	Inline Valves	Roughing Ports	Pressure Gauge
1	3	3	2	1
2	2	1	2	0
3	3	2	3	1
4	3	2	3	1
5	2	1	2	1

* LTB1 will reuse SAL ion pumps (30 L/s Vaclon Plus 40)

4. Required Material and Equipment

Table 4.1 is a listing of the required material and equipment for the LTB1 transfer line. It shows the total number of each item needed for the line. Some items are existing at the facility and can be reused to fill some of the following requirements (see note 1).

Table 4.1: LTB1 Required Material and Equipment

Component	Amount	Description
Ion Pump*	13	30 l/s Varian Vaclon Plus 40 StarCell
Power Supplies*	11	for use with multiple StarCell Ion Pumps
6-way cross	9	2.5"OD tubing, 4.5"OD CF flanges
4-way cross	11	2.5"OD tubing, 4.5"OD CF flanges
4-way reducing cross	1	4.5"OD CF x 2.75"OD CF for IOP0004-02 and PT0004-01
Reducing Tee	1	6"OD CF flanges to 4.5" OD CF flanges at IOP0003-03
Reducing Tee	3	4.5"OD CF flanges to 2.75"OD CF flange for pressure gauge
Zero Length Reducers	13	Used for attaching 2.75"OD ion pump CF flanges to 4.5"OD CF flanges leading to LTB1 line
Zero Length Reducers	9	Used in switchyard, used for 6"OD CF pumps attached to 4.5"OD CF ports, used for dipole chambers
Zero Length Reducers	2	Used for attaching 8"OD CF ion pump flanges to 4.5"OD CF flanges leading to LTB1 line
Blank Flange	6	2.75"OD CF to blank dipole chamber ports
Blank Flange	3	6"OD CF to blank dipole chamber ports
Flange	1	6"OD CF, 2.5"ID to seal aluminum "window" leading to BST0003-02
Flange	4	4.5"OD CF, 2.5"ID to seal aluminum "window" leading to BST0004-01, BST0108-01, BST1300-01
OFHC Copper Gasket & Bolt Set	195	mates with 4.5"OD CF flange
OFHC Copper Gasket & Bolt Set	36	mates with 6"OD CF flange
OFHC Copper Gasket & Bolt Set	24	mates with 2.75"OD CF flanges for pressure transducers and ion pumps
OFHC Copper Gasket & Bolt Set	2	mates with 8" OD CF flanges
Window	3	Aluminum blank to mate with 4.5"flanges leading to beam dumps
Window	1	Aluminum blank to mate with 6"flanges leading to beam dumps
Bellows	18	4.5"OD CF flanges to mate with 2.5"OD tubing,6.25" free length,5.5"compressed length
Inline valve	10	Stainless Steel with metal seals, 4.5"OD CF flanges, pneumatic actuator, VAT Series 10 or equivalent
Right angle valve*	17	Stainless Steel with metal seals, 4.5"OD CF to 4.5"OD CF, hand wheel, VAT series 57 or equivalent
Hybrid Flange Adapter*	17	4.5"OD CF x NW50, for transition from right angle valve flange on roughing port to roughing pump tubing
Centering Ring Assembly*	17	Viton O-ring for seal of hybrid flange adapter on roughing port
NW50 Blank Flange*	17	To blank roughing pump port when not in use
Hinged Clamp & Bolt Set*	17	For clamping roughing port NW50 flange
Pressure gauge and Monitor	4	BOC Edwards Active Inverted Magnetron pressure gauges and Gauge Displays or equivalent

*Note 1: Some of these requirements will be filled by existing Pulse Stretcher Ring or PSR equipment. Table 4.2 is a listing of existing PSR equipment that has been claimed for the LTB1 line for this purpose.

Table 4.2: PSR reusables

Component	Amount	Description
Varian StarCell 30 l/s Ion Pumps	13	SAL pumps P401/402/403/404/405/407/408/409/410/411/413/414/415
StarCell Power Supplies	10	SAL power supplies
4.5"CF x NW50 Right Angle Valves	1	existing in swithyard; Huntington - does not require hybrid flange adapter
4.5"CF x 4.5"CF Right Angle Valves	4	
Hybrid Flange Adapter	4	4.5"CF x NW50
Centering Ring Assembly	5	for NW50
NW50 Blank Flange	5	
Hinged Clamp & Bolt Set	5	for NW50

5. In-Vacuum Diagnostic Equipment

Table 5.1 is a breakdown of the diagnostic equipment required for the LTB1 line. All requirements shown in the table are new units.

Table 5.1: LTB1 Diagnostic Equipment

	Stripline Monitor	View Screen	Fast Current Transformer	Integrating Current Transformer	Transition Radiation Monitor
Existing Line	1	0	1	1	6
Section 1	1	0	0	1	1
Section 2	0	0	0	0	0
Section 3	2	0	0	0	3
Section 4	1	1	0	0	1
Section 5	1	0	0	1	1
TOTALS	6	1	1	3	12

6. References

1. “CLS Design Note 2.1.27: LINAC to Booster Transfer Line (LTB1) Vacuum System”, D. Lowe, (Canadian Light Source, Saskatoon, Saskatchewan, 1999).

2. “An Introduction to the Fundamentals of Vacuum Technology”, H.G. Tompkins, (AVS Monograph, American Institute of Physics, New York, 1984).

3. “Vacuum System Design”, H.G. Patton, (Lawrence Livermore National Lab, Livermore, California.1995).

Appendix A: LTB1 Pressure Profiles

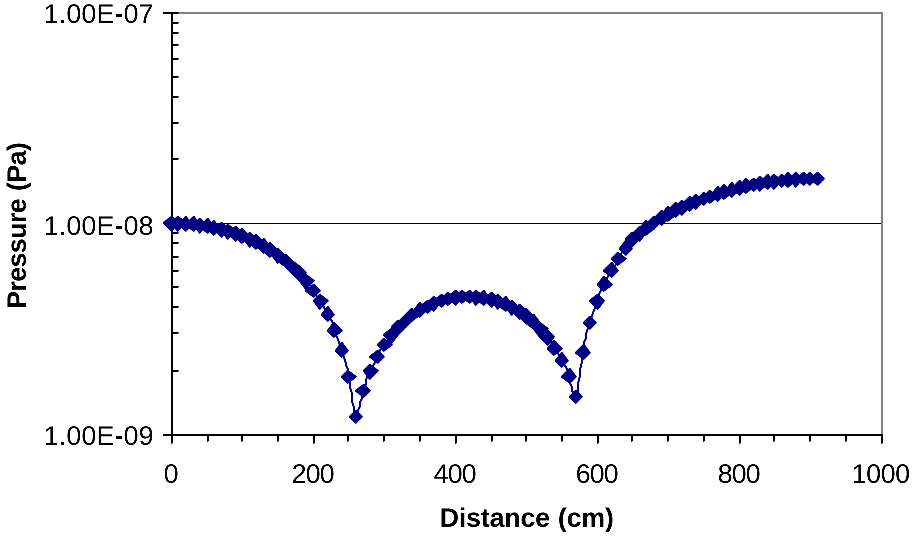


Figure 1: Pressure Profile for Section 1 at 4×10^{-11} Pa·L/s/cm^2 Gas Load

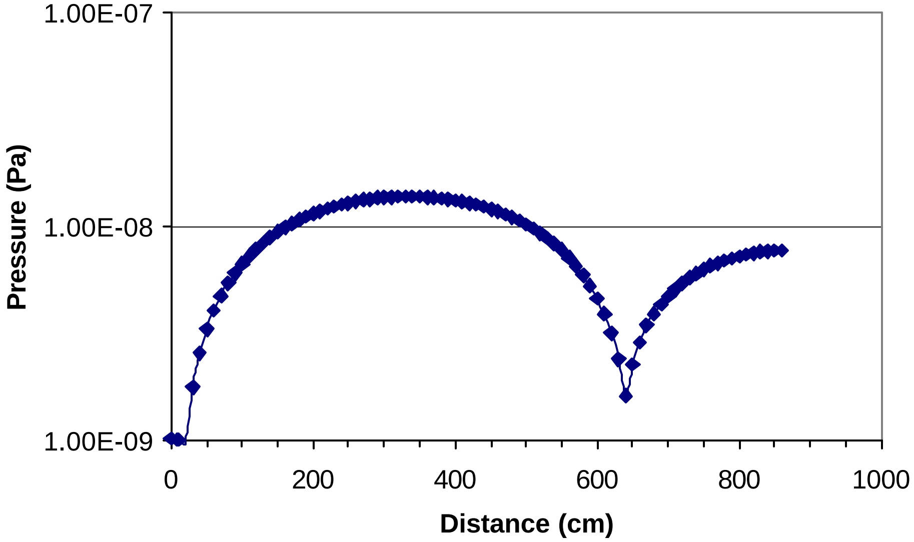


Figure 2: Pressure Profile for Section 2 at 4×10^{-11} Pa·L/s/cm^2 Gas Load

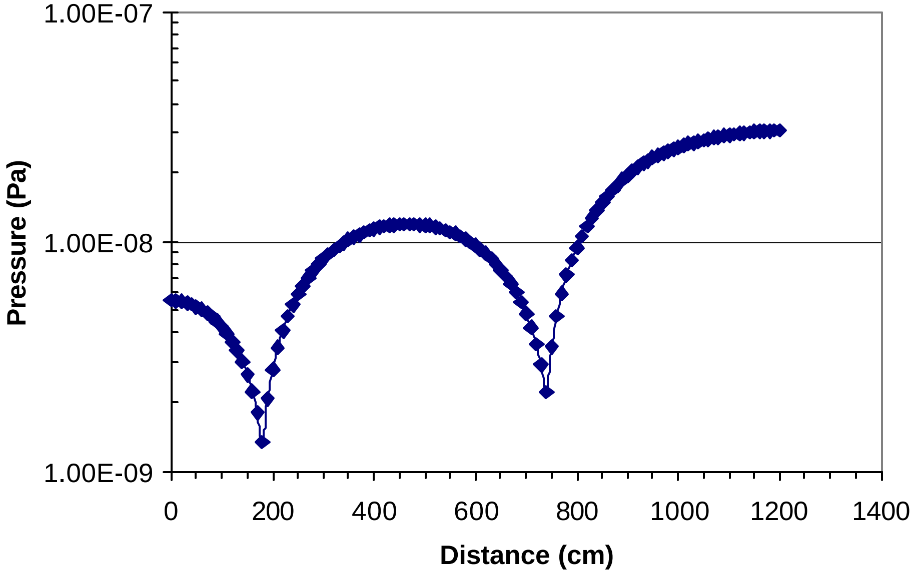


Figure 3: Pressure Profile for Section 3 at 4×10^{-11} Pa·L/s/cm^2 Gas Load

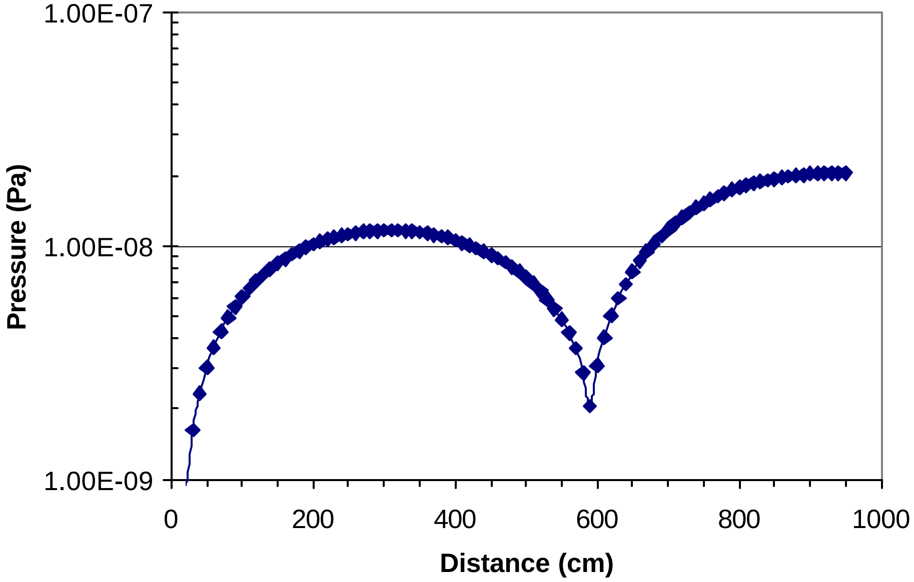


Figure 4: Pressure Profile for Section 4 at 4×10^{-11} Pa·L/s/cm^2 Gas Load

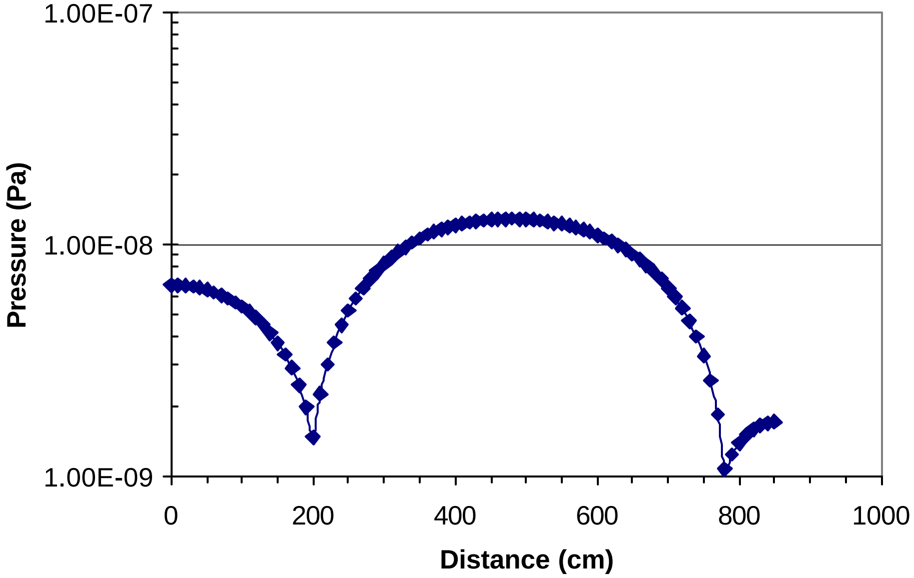


Figure 5: Pressure Profile for Section 5 at 4×10^{-11} Pa·L/s/cm^2 Gas Load

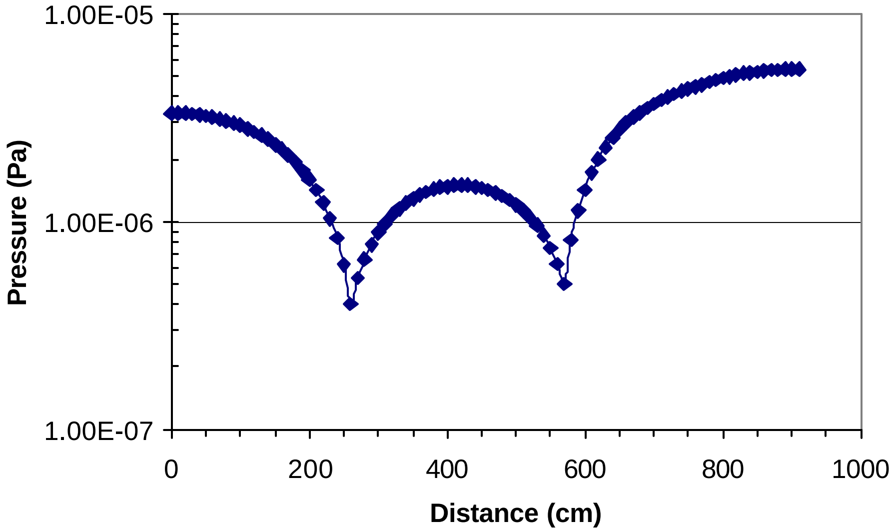


Figure 6: Pressure Profile for Section 1 at 1.3×10^{-8} Pa·L/s/cm^2 Gas Load

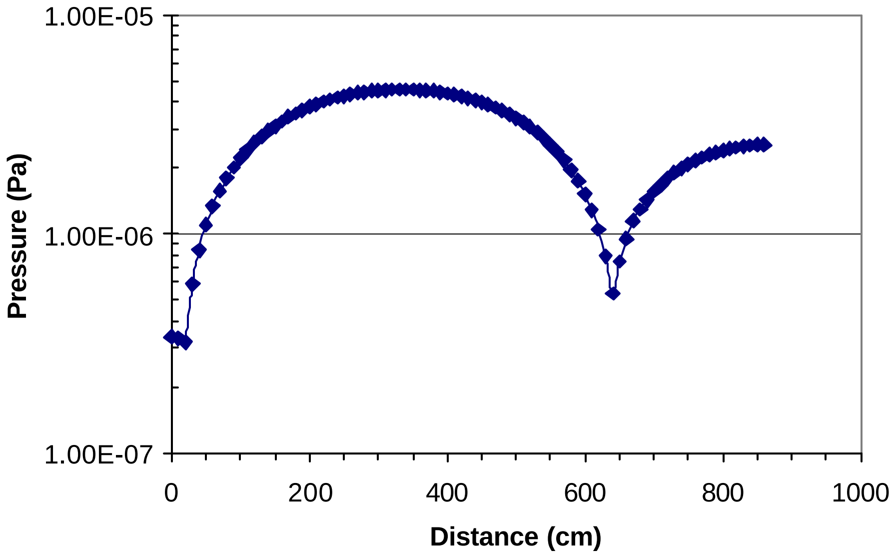


Figure 7: Pressure Profile for Section 2 at 1.3×10^{-8} Pa·L/s/cm^{2} Gas Load

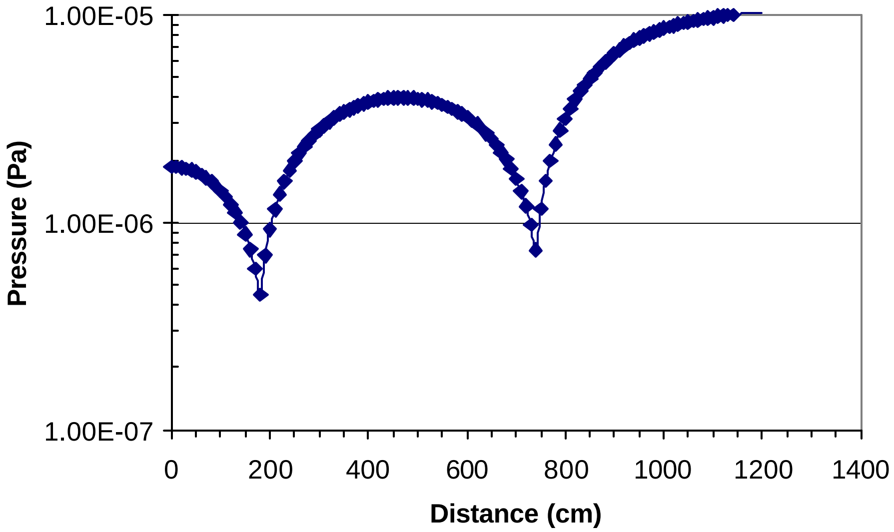


Figure 8: Pressure Profile for Section 3 at 1.3×10^{-8} Pa·L/s/cm^{2} Gas Load

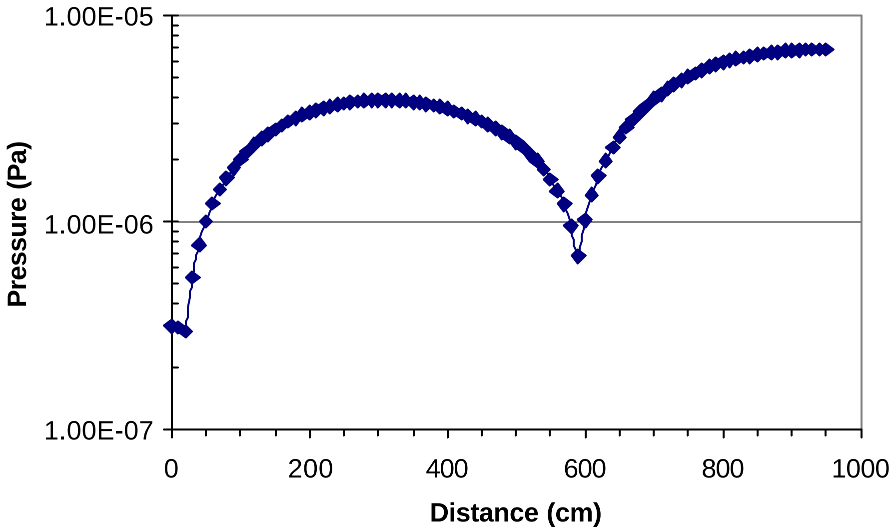


Figure 9: Pressure Profile for Section 4 at 1.3×10^{-8} Pa·L/s/cm^2 Gas Load

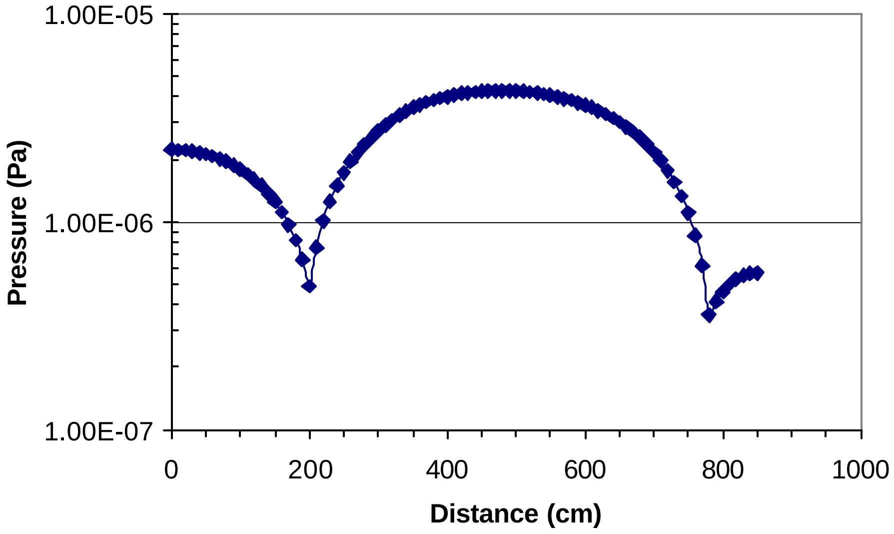


Figure 10: Pressure Profile for Section 5 at 1.3×10^{-8} Pa·L/s/cm^2 Gas Load

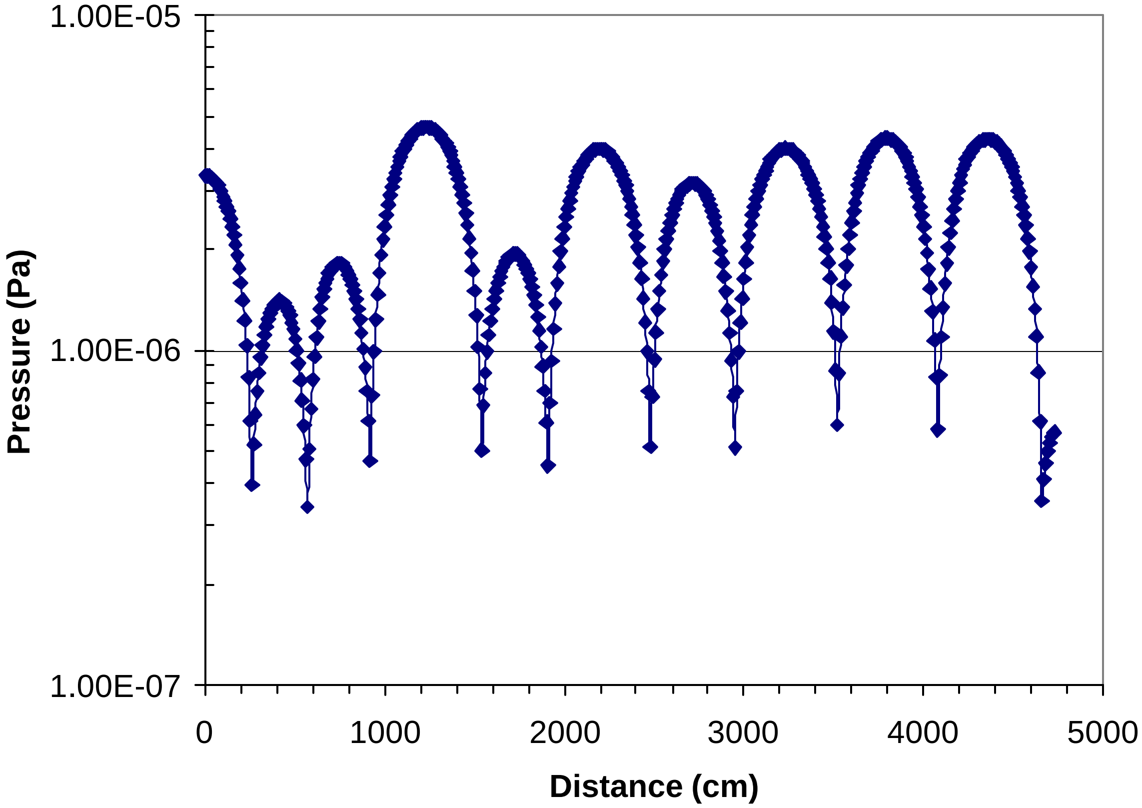


Figure 10: Pressure Profile for LTB1 (all sections) at 1.3×10^{-8} Pa·L/s/cm^2 Gas Load

Appendix B: Sample Calculations

Section 1:

$$\text{Gas load} \;=\; 1.333\times10^{-8}\,\frac{\mathrm{Pa\cdot L}}{\mathrm{s\cdot cm}^2}$$

$$\begin{aligned}\text{Area of Section 1} &= \text{Area of vacuum chambers + Area of Dipole Chamber}\\ &= 897cm\times p\,(6.35cm)+[2(75cm\cdot 5cm)+2(75cm\cdot 50cm)]\\ &= 26144.4cm^2\end{aligned}$$

$$Q \;=\; 1.333\times10^{-8}\,\frac{\mathrm{Pa\cdot L}}{\mathrm{s\cdot cm}^2}*26144.4\mathrm{cm}^2 = 3.486\times10^{-4}\,\frac{\mathrm{Pa\cdot L}}{\mathrm{s}}$$

$$S \;=\; \frac{Q}{\overline{P}} \;=\; \frac{3.486\times10^{-4}\ \mathrm{Pa\cdot L}/\mathrm{s}}{1.333\times10^{-5}\ \mathrm{Pa}} \;=\; 26.14\ \ \mathrm{L/s}$$

Two pumps are to be used in the section,

$$S_P = 2\times50\ \ \mathrm{L/s} = 100\ \mathrm{L/s\ total}$$

However, the delivered pumping speed must be determined. This pumping speed is dependant upon the conductance between the vacuum chamber and the pump chamber. This conductance can be determined by accounting for the conductance of the opening leading from the vacuum chamber, C_O, and the length of pipe leading to the chamber, C_L.

$$\frac{1}{C_T} = \frac{1}{C_O} + \frac{1}{C_L}$$

Where,

$$C_O = 11.6A = 11.6\cdot\left(\pi\cdot\left(\cdot\,(4.5\cdot 2.54)^2\big/4\right)\right) = 1190.3\ \ \mathrm{L/s}$$

$$C_L = 80\,D^3\!\big/L = 80\cdot\frac{4.5^3}{6.82} = 1068.9\ \ \mathrm{L/s}$$

Therefore,

$$C_T = 563.2\ \ \mathrm{L/s}$$

The delivered pumping speed, S_D, is determined as follows:

$$\frac{1}{S_D} = \frac{1}{C_T} + \frac{1}{S_P} = \frac{1}{563.2\mathrm{L/s}} + \frac{1}{50\mathrm{L/s}}$$

$S_D = 45.92 \quad \mathrm{L/s}$ (each pump)

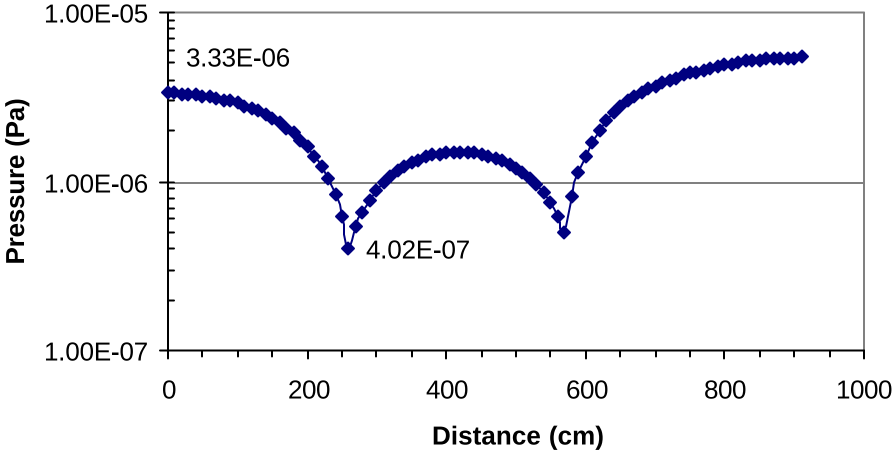
Therefore, with two pumps working for each section, the total delivered pumping speed is:
$S_D = 91.84$ L/s

The required pumping speed for the section was determined to be 26.14 L/s. Therefore, it is safe to say that the system will be below the desired pressure as long as the pumps are placed evenly to avoid severe "dead spots".

The pressure distribution is determined using the following equation:

$$Q = C_{\mathrm{Tube}} \cdot \Delta P \qquad (4),$$

where Q is the throughput in Pa·L/s, C_{Tube} is the conductance of the line in L/s and ΔP is the pressure difference between two points in Pascal (Pa).



The plot shown above is for section 1 at 1.3×10^{-8} Pa · L/sec/ cm^2 gas load. The process for determining pressure distribution can be illustrated as follows.

Point 1: 0cm & 3.330×10^{-6} Pa
Point 2: 260 cm & 4.020×10^{-7} Pa
Therefore ΔP is 2.928×10^{-6} Pa from ANSYS 5.6.

We can calculate ΔP as well.

$$C_{Tube} = 12\frac{6.35^3}{260} = 11.82 \quad L/s$$

$$Q_{Avg.} = 1.334 \times 10^{-8} \frac{Pa \cdot L}{s \cdot cm^2} \times \left(\pi \cdot 6.35 cm \cdot 260 cm / 2\right) = 3.46 \times 10^{-5} \frac{Pa \cdot L}{s}$$

$$Q = C_{Tube} \cdot \Delta P$$

$$3.46 \times 10^{-5} \frac{Pa \cdot L}{s} = 11.82 \quad L/s \cdot \Delta P$$

$\Delta P = 2.927 \times 10^{-6}$ Pa

The values agree.