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Technical Note

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to: J. Alessi, M. Grau, M. Mapes, E. Beebe, A. Pikin, J. Tuozzolo

from: Steven Bellavia

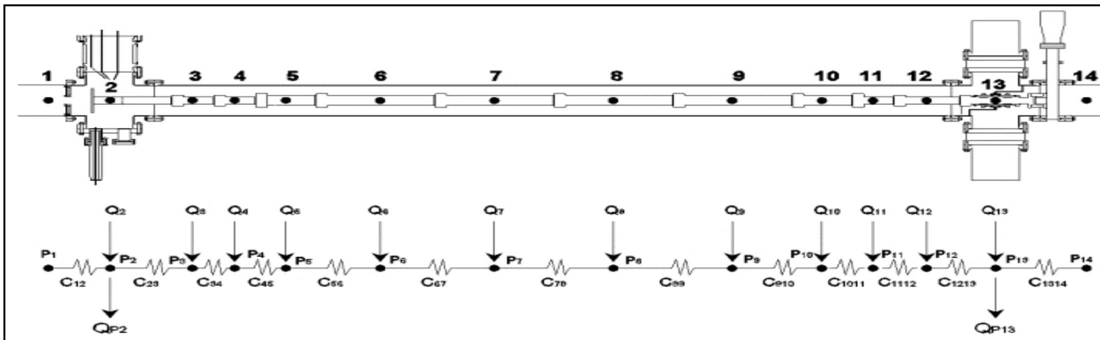
subject: EBIS Drift Tube Design

Discussion:

A meeting was held to discuss the design of the EBIS Central Drift Tubes. The major focus of this meeting was the vacuum requirements and how they would be met within the design.

Vacuum Model:

An analytical model was developed (in Microsoft Excel ®) which performs a finite-difference calculation to try to predict the vacuum level within the drift tube region. See figure 1. Below.



P1 =	1.00E-11	Torr
P14 =	1.00E-11	Torr
Residual Gas Load/Area =	1.00E-11	Torr-liter/sec/cm²

Note: Must iterate the following values to match pump speeds

Pump Throughput, Qp_2 =	1.53E-08	torr-liter/sec	
Pump Throughput, Qp_{13} =	1.51E-08	torr-liter/sec	
Getter Throughput, Qp_3 =	1.10E-09	torr-liter/sec	3
Getter Throughput, Qp_4 =	1.30E-08	torr-liter/sec	4
Getter Throughput, Qp_5 =	1.80E-08	torr-liter/sec	5
Getter Throughput, Qp_6 =	3.00E-08	torr-liter/sec	6
Getter Throughput, Qp_7 =	2.95E-08	torr-liter/sec	7
Getter Throughput, Qp_8 =	3.00E-08	torr-liter/sec	8
Getter Throughput, Qp_9 =	2.40E-08	torr-liter/sec	9
Getter Throughput, Qp_{10} =	1.50E-08	torr-liter/sec	10
Getter Throughput, Qp_{11} =	1.20E-08	torr-liter/sec	11
Getter Throughput, Qp_{12} =	3.10E-09	torr-liter/sec	12

Pump Speed, Sp_2 =	500.0	liter/sec
Pump Speed, Sp_{13} =	500.0	liter/sec
Getter Pump Speed, Spi =	270.0	liter/sec

The following data is extracted from the "Geometry-Conductance Calcs" Sheet

Location	Surf Area	Q_i		
Node 2	2720	2.72 E-08	Q_2	Torr-liter/sec
Node 3	967	9.67 E-09	Q_3	Torr-liter/sec
Node 4	1112	1.11 E-08	Q_4	Torr-liter/sec
Node 5	2057	2.06 E-08	Q_5	Torr-liter/sec
Node 6	2894	2.89 E-08	Q_6	Torr-liter/sec
Node 7	2969	2.97 E-08	Q_7	Torr-liter/sec
Node 8	2969	2.97 E-08	Q_8	Torr-liter/sec
Node 9	2524	2.52 E-08	Q_9	Torr-liter/sec
Node 10	1401	1.40 E-08	Q_{10}	Torr-liter/sec
Node 11	1163	1.16 E-08	Q_{11}	Torr-liter/sec
Node 12	1464	1.46 E-08	Q_{12}	Torr-liter/sec
Node 13	2008	2.01 E-08	Q_{13}	Torr-liter/sec
	24247	2.42 E-07	Q_{total}	Torr-liter/sec

Conductance	C		
from 1 to 2	987.0	C_{12}	liter/sec
from 2 to 3	838.1	C_{23}	liter/sec
from 3 to 4	1190.1	C_{34}	liter/sec
from 4 to 5	1087.5	C_{45}	liter/sec
from 5 to 6	772.5	C_{56}	liter/sec
from 6 to 7	684.7	C_{67}	liter/sec
from 7 to 8	665.4	C_{78}	liter/sec
from 8 to 9	665.4	C_{89}	liter/sec
from 9 to 10	798.8	C_{910}	liter/sec
from 10 to 11	1087.5	C_{1011}	liter/sec
from 11 to 12	1060.0	C_{1112}	liter/sec
from 12 to 13	968.3	C_{1213}	liter/sec
from 13 to 14	792.7	C_{1314}	liter/sec

Figure 1. Finite Difference Vacuum Model

Vacuum Model (cont):

The model uses the Clausing Factor (Ref 1., and Figure 2.) combined with the actual geometry to calculate conductance throughout the chamber. Certain assumptions were applied, as follows:

•Finite-difference approach can be used for a quasi-steady-state system:

$$Q = C\ DP$$

Where Q = throughput (Torr-liter/sec)
C = Conductance (liter/sec)
DP = Pressure Differential (Torr)

•Gas Load a function of:
- Material
- Surface preparation (Electro-polish, baking, etc) (see figure 3 below)
- Total Surface Area
- Energetic Particle-Induced Desorption

Inclusion of the Clausing Factor

Collisions with the walls of the hole can be neglected if the hole is very short compared to its radius. In other cases, collisions with the wall may effect both the distribution of velocities and the probability of particles to escape the vessel. This would in turn invalidate calculated pressure. To correct the deviation from the ideal 2 dimensional hole, the pressure is modified with a factor that is determined from the ratio of hole length to hole radius by a hyperbola-like curve. This factor, known as the Clausing factor is given by

$$K = (.98441 + .00466(L/R)) / (1 + .46034(L/R))$$

To correct the pressure value, the original pressure Pobs is divided by K and the "true" value results.

Using Equation:

L/R	K
0	0.98441
1	0.677287
2	0.517384
4	0.353018
8	0.218183
12	0.15946
16	0.126589
30	0.075908

Clausing Factor Curve

For Nitrogen (or Air) at 298K, R = 1 cm:
Orifice Conductance, F_0 = 37.19067

where $F_0 = 11.4R^2(T/M)^{1/2}$

L/R	F	$P = F/F_0$	1/P
0	36.66	0.985731	1.014475
1	24.64	0.662532	1.509361
2	18.83	0.50631	1.975075
4	13.16	0.353852	2.826039
8	8.492	0.228337	4.379494
12	6.302	0.169451	5.901407
16	5.013	0.134792	7.418844
30	2.922	0.078568	12.72781

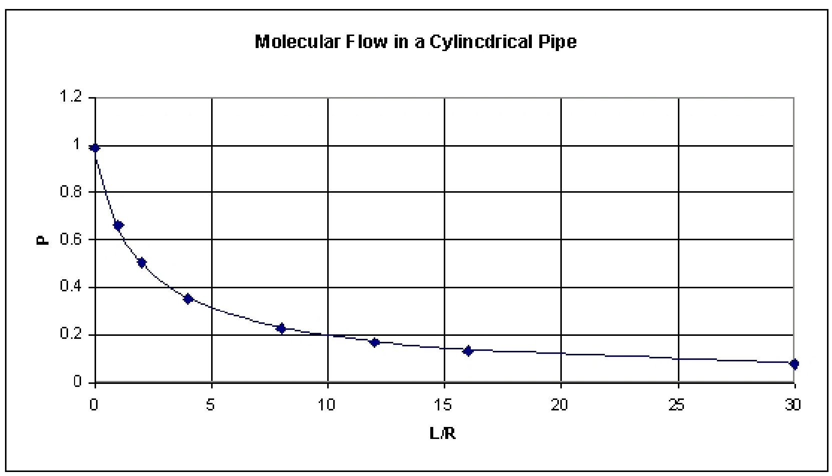


Figure 2: Clausing Factor used in Conductance Calculations

Outgassing rates in Torr l/s cm2

BAKING TEMP	BAKING TIME 20 hrs	40 hrs	100 hrs	200hrs
150C	6.3E-11	5.3E-11	2.8E-11	2.0E-11
250C	6.3E-12	5.3E-12	2.8E-12	2.0E-12
400C	4.0E-13	1.7E-13	1.0E-13	1.0E-13
500C	8.0E-15	8.0E-16	4.0E-17	8.0E-19

Figure 3. Out-gassing of Stainless Steel as a function of bake temperature and time.

Vacuum Model (cont):

Based on this information and other properties of the system, the following additional assumptions were used:

Total Gas Load (Outgas + Desorption from energetic particles striking surfaces):

Gas Load = 1.0E-11 Torr-liter/sec-cm^2

Pumping Speeds:

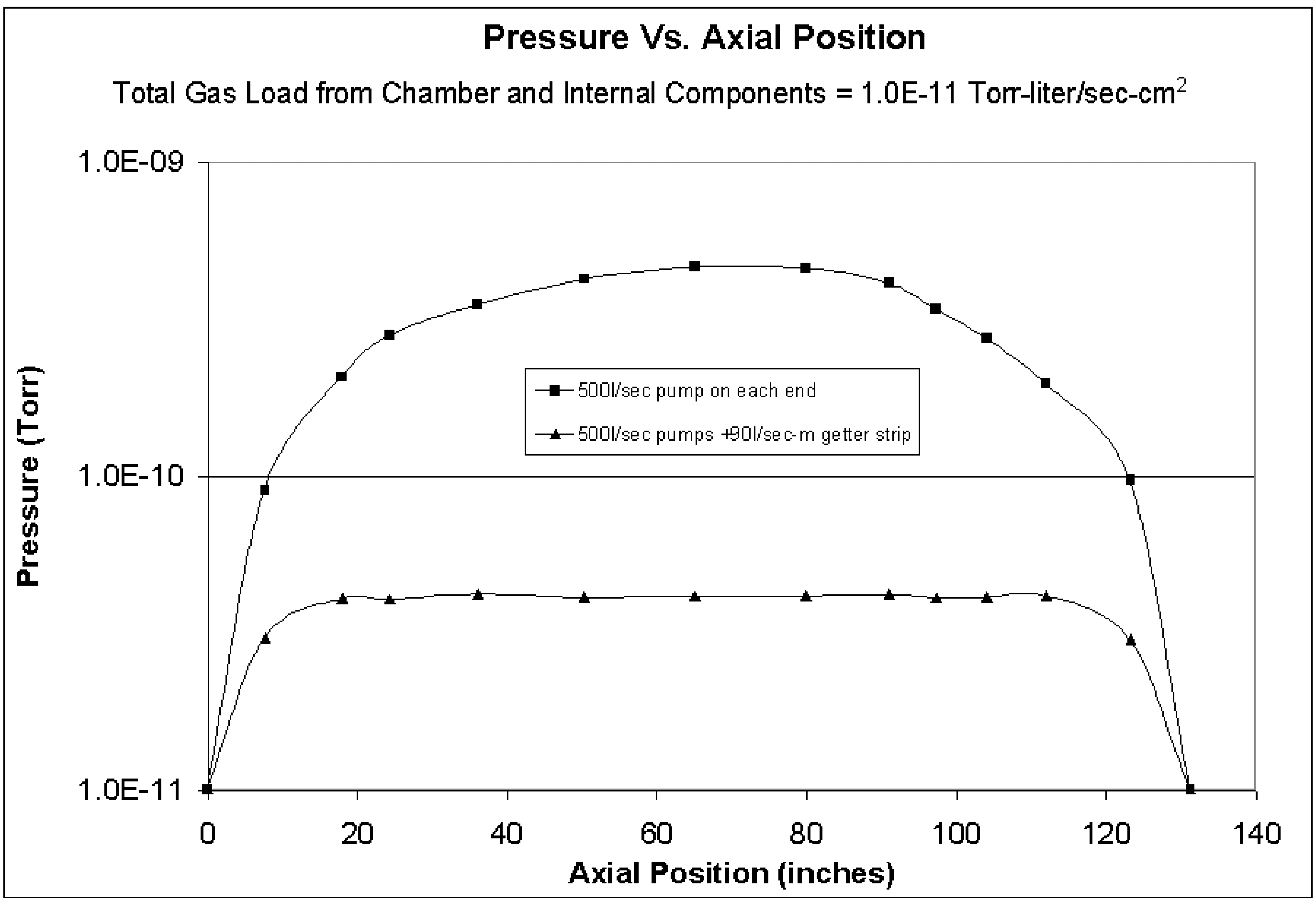
Cryo-pump Pumping Speed = 500 liter/sec (ends of Drift Tube Region)

Non-Evaporable Getter Strips (NEG) = 90 l/sec-m per strip (270 l/sec total) (Ref 2).

The 12 simultaneous equations used and solved are shown in Appendix 1.

Vacuum Model Results:

The model was run two ways: With and without the getter strip. The results are shown in Figure 4.



S. Bellavia 05/15/06

Figure 4. Results of Finite-Difference Vacuum Model

Individual Drift Tube Pumping and Bake-out Scenario:

There was discussion regarding additional pumping within specified drift tubes. This is accomplished by NEG strips in an annular region between the ID and OD of these tubes. The Inner tube is perforated to allow pumping of the central area. See figure 5. The vacuum model currently does not distinguish between the vacuum level inside the tube itself versus the vacuum chamber.

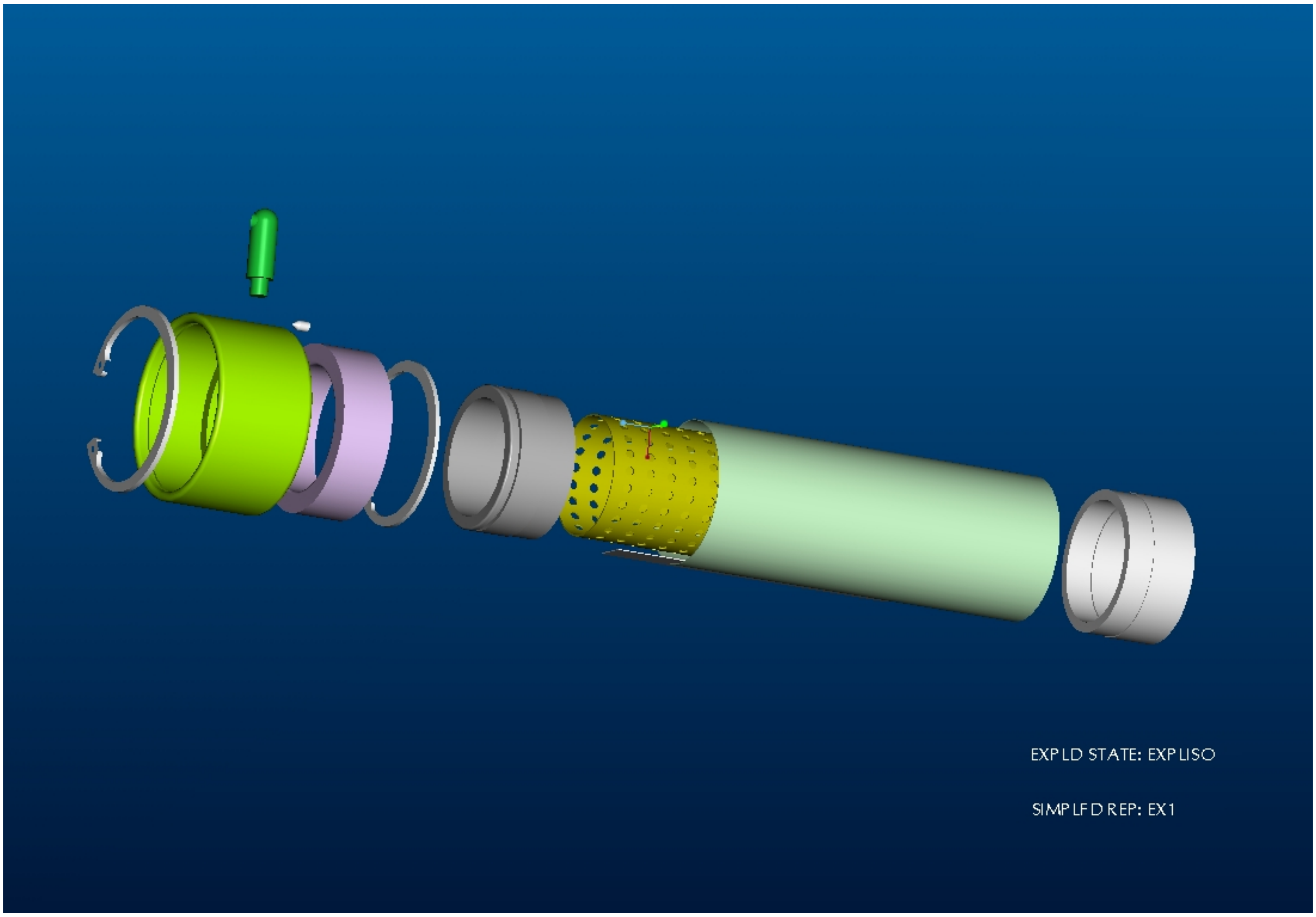


Figure 5. NEG-pumped Drift Tube

There was some discussion on coating versus NEG strips, which require activation. A graph of the performance of these different schemes is shown in Figure 6. However, it was concluded that coating would not suffice, as the mechanism for vacuum degradation is Magnetron Glow Discharge, which degrades the vacuum from the outside to the inside of the drift tubes. Coatings do not help this effect.

The bake-out scenario was also discussed. A requirement for the ability to withstand 400 ^{o}C was proposed. However, the ability to achieve and control this is a concern. Also, the activation of the individual tube NEG strips remains an issue, as there is little means to control the rise and cool-down time. It was suggested to bake at 250 deg C for longer periods, as is done throughout the AGS-RHIC complex. The length of time to reach 400 deg C is also a concern.

The baking of the central chamber can be accomplished using Cal-Rods ("Firebar") and an external water jacket for keeping the bore of the Cryogenic solenoid magnet cool. This is the current configuration on the EBIS Test Stand.

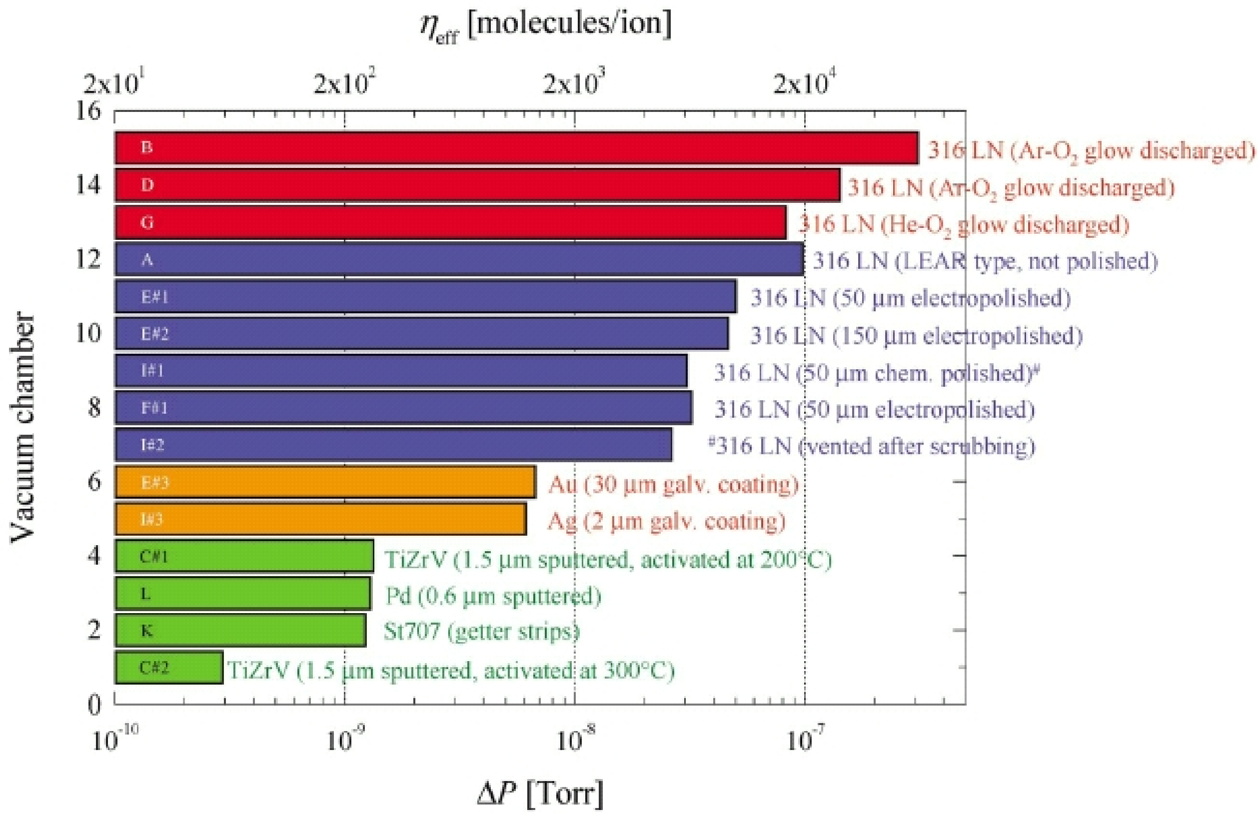


FIG. 6. (Color) Summary of pressure rise measurements for 15 different surfaces (10 different vacuum chambers) continuously bombarded with $\sim 1.5 \times 10^9$ Pb^{53+} ions under $\theta = 89.2°$ grazing incidence. The pressure increase ΔP is measured at the beginning of each scrubbing run. The plot summarizes the LINAC 3 results obtained between November 2000 and October 2002.

Transient Analysis:

A transient analysis was also performed using the same model and the following assumptions:

$(Pa)_{i+1} = (Pa)_i + [Qa * (dt/Va)]$

Where Pa = Pressure at nodal point "a"

Q = Total Throughput at nodal point "a" (+ = in, - = out)

Va = Volume at nodal point "a"

The goal was to determine the effect on vacuum when a small amount of Helium is injected into the central portion of the drift tubes. However, the model has some numerical stability issues (time constant very small), and is not working at this time.

The current design assumes a small vessel filled with helium at a pressure of approximately 1 x 10^{-5} Torr and the use of a piezo-electric valve that can inject Helium for 10 milliseconds once every second (maximum).

Summary and Action Items:

Several issues need to be resolved before the final design of the EBIS Central Drift Tubes. Below is a list of issues and associated action items:

1. Investigate activation temperature and heating and cooling ramp rates for various NEG materials to be used in the individually-pumped drift tubes. (Mapes, Bellavia)
2. Perform calculations (steady-state) for vacuum inside individual drift tubes as well as the chamber. (Bellavia, Pikin)
3. Continue transient analysis to determine effect on overall vacuum and requirements for helium injection system. (Bellavia, Pikin)
4. Investigate other options for perforated metal or wire mesh to improve throughput if NEG strips are indeed used for individually pumping the central drift tubes. (Bellavia, Grau)
5. Use the EBIS test stand to better correlate the vacuum levels with Magnetron Glow Discharge and other effects that degrade the vacuum during operation. (Pikin, Beebe).

References:

1. Clausing, P., “The flowing of very dilute gases through tubes of any length”, Annalen der Physik (Berlin, Germany) (1932), 12, 961-89 CODEN: ANPYA2; ISSN: 0003-3804
2. H.C. Hseuh and C. Lanni , “Evaluation of Zr-V-Fe getter pump for UHV system”, 20 September, 1982.

Appendix 1. Vacuum Model Simultaneous Equations:

Assume at each node, at some quasi-steady-state condition, throughput in = throughput out:

Node Number	
2	$C_{12}(P1-P2) - C23(P2-P3) + Q_2 - Q_{p2} = 0$
3	$C_{23}(P2-P3) - C_{34}(P3-P4) + Q_3 = 0$
4	$C_{34}(P3-P4) - C_{45}(P4-P5) + Q_4 = 0$
5	$C_{45}(P4-P5) - C_{56}(P5-P6) + Q_5 = 0$
6	$C_{56}(P5-P6) - C_{67}(P6-P7) + Q_6 = 0$
7	$C_{67}(P6-P7) - C_{78}(P7-P8) + Q_7 = 0$
8	$C_{78}(P7-P8) - C_{89}(P8-P9) + Q_8 = 0$
9	$C_{89}(P8-P9) - C_{910}(P9-P10) + Q_9 = 0$
10	$C_{910}(P9-P10) - C_{1011}(P10-P11) + Q_{10} = 0$
11	$C_{1011}(P10-P11) - C_{1112}(P11-P12) + Q_{11} = 0$
12	$C_{1112}(P11-P12) - C_{1213}(P12-P13) + Q_{12} = 0$
13	$C_{1213}(P12-P13) - C_{1314}(P13-P14) + Q_{13} - Qp_{13} = 0$

Thus, have 12 simultaneous equations of the form: **A X = B**, where X is the Pressure Vector being sought

Eqn #	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	B
2	-1825.1	838.1	0	0	0	0	0	0	0	0	0	0	-2.18E-08
3	838.1	-2028.2	1190.1	0	0	0	0	0	0	0	0	0	-8.57E-09
4	0	1190.1	-2277.5	1087.5	0	0	0	0	0	0	0	0	1.88E-09
5	0	0	1087.5	-1859.9	772.5	0	0	0	0	0	0	0	-2.57E-09
6	0	0	0	772.5	-1457.1	684.7	0	0	0	0	0	0	1.06E-09
7	0	0	0	0	684.7	-1350.0	665.4	0	0	0	0	0	-1.90E-10
8	0	0	0	0	0	665.4	-1330.7	665.4	0	0	0	0	3.10E-10
9	0	0	0	0	0	0	665.4	-1464.2	798.8	0	0	0	-1.24E-09
10	0	0	0	0	0	0	0	798.8	-1886.3	1087.5	0	0	9.94E-10
11	0	0	0	0	0	0	0	0	1087.5	-2147.5	1060.0	0	3.67E-10
12	0	0	0	0	0	0	0	0	0	1060.0	-2028.3	968.3	-1.15E-08
13	0	0	0	0	0	0	0	0	0	0	968.3	-1761.0	-1.29E-08

	A^{-1}												B	X		Pump Speed:	
2	-0.00095	-0.00087	-0.00081	-0.00075	-0.00066	-0.00056	-0.00046268	-0.00036207	-0.000278	-0.000217	-0.000154	-8.44E-05	-2.18E-08	3.06E-11	**P2**	**500**	**liter/sec**
3	-0.00087	-0.00188	-0.00176	-0.00163	-0.00144	-0.00123	-0.00100751	-0.00078844	-0.000606	-0.000472	-0.000334	-0.000184	-8.57E-09	4.07E-11	**P3**	**27**	liter/sec
4	-0.00081	-0.00176	-0.00243	-0.00225	-0.00199	-0.00169	-0.00139123	-0.00108872	-0.000837	-0.000652	-0.000462	-0.000254	1.88E-09	4.06E-11	**P4**	**27**	liter/sec
5	-0.00075	-0.00163	-0.00225	-0.00293	-0.00259	-0.0022	-0.00181114	-0.00141733	-0.001089	-0.000848	-0.000601	-0.000331	-2.57E-09	4.22E-11	**P5**	**26**	liter/sec
6	-0.00066	-0.00144	-0.00199	-0.00259	-0.00343	-0.00292	-0.00240231	-0.00187995	-0.001445	-0.001125	-0.000797	-0.000438	1.06E-09	4.11E-11	**P6**	**27**	liter/sec
7	-0.00056	-0.00123	-0.00169	-0.0022	-0.00292	-0.00374	-0.00306928	-0.0024019	-0.001846	-0.001438	-0.001019	-0.00056	-1.90E-10	4.15E-11	**P7**	**26**	liter/sec
8	0.000	-0.001	-0.001	-0.0018	-0.0024	-0.0031	-0.0038	-0.0029	-0.0023	-0.0018	-0.0012	-0.0007	3.10E-10	4.16E-11	**P8**	**26**	liter/sec
9	0.000	-0.001	-0.001	-0.0014	-0.0019	-0.0024	-0.0029	-0.0035	-0.0027	-0.0021	-0.0015	-0.0008	-1.24E-09	4.21E-11	**P9**	**26**	liter/sec
10	0.000	-0.001	-0.001	-0.0011	-0.0014	-0.0018	-0.0023	-0.0027	-0.0030	-0.0023	-0.0017	-0.0009	9.94E-10	4.11E-11	**P10**	**27**	liter/sec
11	0.000	0.000	-0.001	-0.0008	-0.0011	-0.0014	-0.0018	-0.0021	-0.0023	-0.0025	-0.0018	-0.0010	3.67E-10	4.12E-11	**P11**	**27**	liter/sec
12	0.000	0.000	0.000	-0.0006	-0.0008	-0.0010	-0.0012	-0.0015	-0.0017	-0.0018	-0.0019	-0.0011	-1.15E-08	4.16E-11	**P12**	**26**	liter/sec
13	0.000	0.000	0.000	-0.0003	-0.0004	-0.0006	-0.0007	-0.0008	-0.0009	-0.0010	-0.0011	-0.0012	-1.29E-08	3.02E-11	**P13**	**500**	**liter/sec**

Check:	**A**												**X**	**B**
2	-1825.11	838.1485	0	0	0	0	0	0	0	0	0	0	3.06E-11	-2.18E-08
3	838.1485	-2028.21	1190.065	0	0	0	0	0	0	0	0	0	4.07E-11	-8.57E-09
4	0	1190.065	-2277.54	1087.471	0	0	0	0	0	0	0	0	4.06E-11	1.88E-09
5	0	0	1087.471	-1859.93	772.4591	0	0	0	0	0	0	0	4.22E-11	-2.57E-09
6	0	0	0	772.4591	-1457.11	684.6524	0	0	0	0	0	0	4.11E-11	1.06E-09
7	0	0	0	0	684.6524	-1350.02	665.366135	0	0	0	0	0	4.15E-11	-1.90E-10
8	0.000	0.000	0.000	0.000	0.00	665.37	-1330.73227	665.3661347	0	0	0	0	4.16E-11	3.10E-10
9	0.000	0.000	0.000	0.000	0.00	0.00	665.366135	-1464.19646	798.8303	0	0	0	4.21E-11	-1.24E-09
10	0.000	0.000	0.000	0.000	0.00	0.00	0	798.8303297	-1886.301	1087.4711	0	0	4.11E-11	9.94E-10
11	0.000	0.000	0.000	0.000	0.00	0.00	0	0	1087.471	-2147.509	1060.038	0	4.12E-11	3.67E-10
12	0.000	0.000	0.000	0.000	0.00	0.00	0	0	0	1060.0379	-2028.347	968.3091	4.16E-11	-1.15E-08
13	0.000	0.000	0.000	0.000	0.00	0.00	0	0	0	0	968.3091	-1761.024	3.02E-11	-1.29E-08