Vacuum Conductance Analysis of the CKM Vacuum Veto System

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Del Allspach
PPD/Mechanical/Process Systems

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Fermilab
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1.0 Introduction

The CKM Vacuum Veto System is a large vacuum volume containing detector systems for the experiment. Its total length is 34 meters. The upstream portion is 20 meters long with a diameter of 1.68 meters and the downstream portion is 14 meters long having a diameter of 1.91 meters. The vacuum pressure specification for the vessel is 1.0E-6 Torr.

This design note summarizes the test results and calculations performed in order to understand the vacuum characteristics of the Vacuum Veto System vacuum volume. These include:

(1) Outgassing rate of the vacuum system based on outgassing tests,
(2) Vacuum volume conductance based on the outgassing rate,
(3) Pumping system inlet conductances for various high vacuum pumps, and
(4) Conductance of the foreline piping leading from the Roughing Pumps.

2.0 Determination of the Vacuum Veto System Total Outgassing Rate

The Vacuum Veto System primary outgassing sources include the Vacuum Veto System (VVS) Detectors, the Beam Interaction Veto System (BIVS), the Downstream Magnetic Spectrometer (DMS) Straw Chambers, VVS Vessel walls and support components, virtual leaks, and beam windows. These outgassing sources are discussed below and the assumed rates for each is shown.

2.1 VVS Detector Outgassing

The outgassing rate of the detectors is based on VVS prototype vessel vacuum measurements [1]. This prototype vessel contains one-eighth of an upstream VVS detector ring. The current VVS design includes 20 upstream detector rings and 14 downstream detector rings. The downstream detector rings are larger than the upstream detector rings by a factor of 1.2. Thus, the total scaling factor from the prototype to the VVS is:

$$\text{Scaling Factor} = (8 \times 20 \text{ chambers}) + (1.2)\,(8 \times 14 \text{ chambers}) = 294.4$$

A characterization of the prototype vessel while empty has shown its outgassing rate to be 6.3E-6 Torr-L/sec. This was determined by performing rate-of-rise tests. The Photo Multiplier Tube (PMT) ports were blanked off for these tests. With the detectors and PMT's installed in the vessel, additional rate-of-rise tests were performed. After 2 weeks of pumping on the prototype, the total outgassing rate of the vessel, detectors, and PMT feed-throughs was found to be 1.8E-5 Torr-L/sec, for which the vessel background rate has been subtracted. Applying the above calculated scaling factor results in a VVS detector system outgassing rate of 5.3E-3 Torr-L/sec.

The scintillator used in assembling the prototype detectors was Bicron 404 [2], a poly-vinyl toluene material. The current design specifies that the scintillator to be used in the VVS detector system is a poly-styrene material fabricated by IHEP/Protvino. A comparison of the outgassing rates of the two materials was performed in an outgassing test chamber at Fermilab [1]. The rate-of-rise data was recorded after one week of pumping for each test. The comparison shows that the IHEP/Protvino material outgases at a rate which is 1.8 times greater than the Bicron 404 material. Assuming that the scintillator material dominates the outgassing rate of the VVS detectors, the VVS detector system outgassing rate is estimated at 1.0E-2 Torr-L/sec.

2.2 BIVS Outgassing

The mass of the BIVS detectors is currently designed at 11% of the VVS detector system. The outgassing rate of the BIVS is estimated by scaling by mass to the VVS detector system rate. The result is an assumed BIVS outgassing rate at 1.0E-3 Torr-L/sec.

2.3 DMS Straw Chamber Outgassing

The outgassing rate of the straw chambers has been estimated by the CKM DMS Group based on leak measurements made using nitrogen. The actual gas mixture to be used is not yet determined but, given the gas mixtures being considered, using nitrogen for the leak rate estimate is likely conservative. The gases under consideration include Argon, Ethane, Carbon Tetrafluoride, Isobutane, and Isopropyl Alcohol vapor. The total leak rate estimate is 1.0E-3 Torr-L/sec. This rate assumes five straw planes at DMS station 1 and eight straw planes at each of DMS stations 2, 3, and 4. Each plane includes 160 straws and has physical dimensions 80 cm by 80 cm. The straw outside diameter is 5 mm. Any modifications to this design will change the total leak rate and the required pumping speed in the DMS region.

2.4 Outgassing due to VVS Vessel Walls, Support Components, and Virtual Leaks

The VVS vessel walls will be fabricated from carbon steel. The interior wall surface will be cleaned, primed, and painted as was done for the K-TeV vacuum vessel walls. A NASA Technical Memorandum [3] documents the outgassing rate of a paint similar to that used in K-TeV and under consideration for use in the CKM VVS. Surfaces that are properly prepared and finished with a paint such as Aeroglaze Z-306 with Aeroglaze 9922 primer [4] as described in the NASA Memo provide a vacuum vessel with walls that have an extremely low outgassing rate. The painted surfaces are not of concern given the vacuum conditions required of the CKM VVS vessel.

What is of concern for the CKM vessel are those surfaces which cannot be coated with paint such as flange faces. O'Hanlon [5] documents the outgassing rate of mild steel as 5E-8 Torr-L/sec/cm^2. Assuming that 5% of the CKM vacuum vessel walls and support components are not painted, the following outgassing rate is determined.

$$Q_{surfaces} = (5\%)\ (2E+6\ cm^2)\ (5.0E\text{-}8\ Torr\text{-}L/sec/cm^2) = 5.0E\text{-}3\ Torr\text{-}L/sec.$$

Although efforts will be made to minimize the virtual leaks in the VVS vessel, it is difficult to completely eliminate them. The outgassing rate of the prototype vessel without the detectors installed was determined as 6.3E-6 Torr-L/sec. This is about 25% of the total outgassing rate. Scaling the total VVS detector outgassing rate, an allowance for virtual leaks is taken as 2.5E-3 Torr-L/sec. This rate may be considered conservative, however, given the uncertainty in other outgassing source rates, it is prudent to provide some contingency in the estimated total VVS outgassing rate.

2.5 Beam Window Leak Rate

The general beam window design for the downstream end of the VVS is the same as the K-TeV window design. From rate-of-rise data performed for the K-TeV window it was determined that the window leak rate would be very high for the CKM VVS system whose design pressure is 1.0E-6 Torr (note that the K-TeV design pressure was 1.0E-4 Torr). The CKM leak rate using a 1.0 meter diameter window has been scaled from the K-TeV window whose diameter was 1.8 meters. The percentage of the leak rate due to permeation was estimated at 71% based on data for aluminized mylar. The remaining 29% is a result of leaks through the seal. The estimated CKM 'single window' rate is 0.062 Torr-L/sec. In order to lower this rate, a double window design is planned. The volume between the windows will be pumped with the foreline pumping system with a pressure near 1.0E-2 Torr expected. This lowers the window leak rate by nearly five orders of magnitude to 8.2E-7 Torr-L/sec. This leak rate now becomes insignificant to the VVS vacuum system design. It is not clear that a double window design will be possible for the upstream window, however, work is in progress to design an upstream window which will have an insignificant load on the pumping system.

2.6 Total VVS Outgassing Rate Estimate

The outgassing rates considered above are summarized in Table 1.

OUTGASSING SOURCE	OUTGASSING RATE
VVS Detectors	1.0 E-2 Torr-L/sec
BIVS	1.0 E-3 Torr-L/sec
DMS Straw Chambers	1.0 E-3 Torr-L/sec
Vessel Surfaces	5.0 E-3 Torr-L/sec
Virtual Leaks	2.5 E-3 Torr-L/sec
TOTAL OUTGASSING RATE	**2.0 E-2 Torr-L/sec**

Table 1. VVS Outgassing Rate Summation

The VVS conductance calculations and pumping system design assume a total outgassing rate of 2.0E-2 Torr-L/sec.

3.0 Conductance through VVS Vessel

In an effort to understand the limiting factors of the VVS from a vacuum pumping speed point of view, the conductance through the VVS detector rings and around the BIVS are determined. The annular space between the vessel wall and the detector rings is not considered here as the calculations indicate that the area available through the center of the rings is great enough to provide a relatively high conductance as compared to the pump inlet conductances calculated later in this note. The actual pressure drop across the VVS areas considered will depend upon the quantity of pumps, their placement, and local outgassing rates. Given the following results, consideration of the pressure differential across these components is given in the overall vacuum system analysis on the order of 1.0E-7 to 2.0E-7 Torr.

3.1 VVS Upstream Conductance

The upstream portion of the VVS has the following geometrical design:

Vessel Length	100.0 cm
Vessel Inside Radius	84.2 cm
Detector Ring Outside Radius	70.0 cm
Detector Ring Inside Radius	30.0 cm
Detector Ring Length	50.0 cm

Detector Ring Inner Cross-sectional Area = 2827 cm^2
Detector Ring Outer (annular) Area = 1717 cm^2,
where 50% is filled with scintillator fibers = 859 cm^2

The conductance through several upstream detector rings is calculated in order to understand the effect of vacuum pump placement. The cross-sectional area of each component is required as is the transmission probability. The transmission probabilities for several geometries are provided by O'Hanlon [5]. The method used to find the total transmission probability for a series of components with differing diameters is shown below [5].

$$\frac{1}{A_1}\left(\frac{1-a_{1-n}}{a_{1-n}}\right)=\sum_{1}^{n}\frac{1}{A_i}\left(\frac{1-a_i}{a_i}\right)+\sum_{1}^{n-1}\left(\frac{1}{A_{i+1}}-\frac{1}{A_i}\right)\delta_{i,i+1} \qquad (1)$$

where,

A = area
a = transmission probability
$\delta_{i,i+1}$ = 1 for $A_{i+1}<A_i$, and $\delta_{i,i+1}$ = 0 for $A_{i+1}>A_i$
n = # of elements

The total transmission probability for 12 rings in series is calculated to be 0.04856. See Appendix A.1. The conductance can then be found.

$$C=\frac{nV}{4}a_{1-n}A_1 \qquad (2)$$

where,

C = Conductance
n = # of elements = 24

v = gas velocity = 445 m/s for air
a = transmission probability = 0.04856
A = area = 2827 cm^2

$$C = 36{,}650 \text{ L/sec}$$

Assuming a load of 0.5E-2 Torr-L/sec (one half of the VVS upstream load), the pressure differential can be calculated:

$$P_2 - P_1 = Q / C \qquad (3)$$

where,

Q = Throughput
P = Pressure

$$P_2 - P_1 = (0.5\text{E-2 Torr-L/sec}) / (36{,}650 \text{ L/sec})$$
$$P_2 - P_1 = 0.14 \text{ E-6 Torr}$$

3.2 VVS BIVS Conductance

The BIVS portion of the VVS has the following approximate geometrical design:

Vessel Inside Radius	84.2 cm
BIVS Outside Radius	54.2 cm
BIVS Length	500 cm
BIVS to VVS Detector distance	50.0 cm
VVS Detector Inside Radius	30.0 cm

The BIVS detectors are located adjacent to the VVS upstream beam window. The conductance is modeled with three elements in series: an annular space, a pipe length, and an aperture. The transmission probabilities for each of these elements is found from data provided by O'Hanlon [5]. The conductance for each is found from equation (2) for air and summarized in Table 2.

Element	Transmission Probability	Area, cm^2	Conductance, L/sec
Annular Space	0.21	19,445	45,428
Pipe Length	0.8	22,273	198,230
Aperture	1.0	2,827	31,450

Table 2. Element Conductance for BIVS Total Conductance Calculation

The total conductance of the three elements in series is given by,

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \qquad (4)$$

$$C_T = 16{,}991 \text{ L/sec}$$

From equation (3), the differential pressure resulting from the BIVS, at its outgassing rate of 1.0E-3 Torr-L/sec, is 0.6E-7 Torr.

$$P_2 - P_1 = (1.0\text{E-}3 \text{ Torr-L/sec}) / (16{,}991 \text{ L/sec})$$
$$P_2 - P_1 = 0.6 \text{ E-}7 \text{ Torr}$$

3.3 VVS Downstream Conductance

The downstream portion of the VVS (upstream of the DMS region) has the following geometrical design:

Vessel Length	100.0 cm
Vessel Inside Radius	95.5 cm
Detector Ring Outside Radius	80.0 cm
Detector Ring Inside Radius	40.0 cm
Detector Ring Length	50.0 cm

Detector Ring Inner Cross-sectional Area = 5026 cm^2
Detector Ring Outer (annular) Area = 1960 cm^2,
where 50% is filled with scintillator fibers = 980 cm^2

The conductance through the downstream detector rings in the area upstream of the DMS region is calculated as for the VVS upstream detector rings in paragraph 3.2 above. An overall transmission probability is calculated for 8 rings in series. See Appendix A.2. The conductance is then found using equation (2) above,

where,
n = # of elements = 16
v = gas velocity = 445 m/s for air
a = transmission probability = 0.08349
A = area = 5026 cm^2

$$C = 74{,}693 \text{ L/sec}$$

Assuming a load of 0.5E-2 Torr-L/sec (approximately one half of the VVS downstream load), the pressure differential can be calculated given equation (3):

$$P_2 - P_1 = (0.5\text{E-}2 \text{ Torr-L/sec}) / (74{,}693 \text{ L/sec})$$
$$P_2 - P_1 = 0.7 \text{ E-}7 \text{ Torr}$$

4.0 Vacuum Pump Inlet Conductance for Various Pump Sizes and Types

Given the experimental specifications for placement of the VVS detectors and PMT feed-throughs, the largest vacuum pump port size that can be placed on the vessel is 18 inches in diameter. It is understood that some special VVS vessel sections provide areas on which larger ports could be placed, however, the larger pumping speeds of the diffusion pumps cannot be well utilized in the DMS regions. The 18 inch port size is clearly the limiting factor for the overall pumping speed of a diffusion pump vacuum system as the following calculations indicate.

4.1 Diffusion Pump Inlets

Each of the diffusion pumps requires a cold baffle to limit oil migration into the VVS vessel, a right angle valve, and a spool piece connecting the valve to the vessel. Series conductances are calculated using equation (1). Each of the conductances are calculated using an Excel Spreadsheet. Copies of these spreadsheets are included as appendices. Given the conductance, the differential pressure across the inlet is found for an assumed throughput. The throughput is then calculated by using the advertised pumping speed for an assumed differential pressure across the inlet. The allowable pressure differential assumed in the design is 5.0E-7 Torr. This value is chosen to allow for the differential pressure across VVS detectors, the ultimate pressure of the vacuum pumps, the accuracy of the calculated conductance, and a safety margin for the system outgassing rate in order to meet the specification for a pressure of 1E-6 Torr around the detector rings. The results are summarized below.

4.1.1 Inlet Conductance for a 50,000 L/sec Pump with an 18 inch Port

This analysis considers the inlet conductance for a 50,000 L/sec pump which is connected directly to a single 18 inch port. See Appendix B.1.

The calculated conductance is 4632 L/sec for air. The throughput for this system design is 2.1E-3 Torr-L/sec.

4.1.2 Inlet Conductance for a 50,000 L/sec Pump with a Manifold

This analysis considers the inlet conductance for a 50,000 L/sec pump which is connected to the VVS by using a 36 inch diameter pipe running parallel to the VVS and having three 18 inch port connections to the VVS so as to increase the conductance from the pump to the VVS. See Appendix B.2.

The calculated conductance is 6684 L/sec for air. The throughput for this system design is 2.9E-3 Torr-L/sec.

4.1.3 Inlet Conductance for a 50,000 L/sec Pump with a 36 inch Port

This analysis considers the inlet conductance for a 50,000 L/sec pump which is connected directly to a 36 inch port. See Appendix B.3. This analysis is provided only for comparison to the analysis results shown in paragraphs 4.1.1 and 4.1.2. Due to experimental constraints, this geometry is not possible in the CKM VVS design.

The calculated conductance is 10,882 L/sec for air. The throughput for this system design is 4.4E-3 Torr-L/sec.

4.1.4 Inlet Conductance for a 20,000 L/sec Pump with an 18 inch Port

This analysis considers the inlet conductance for a 20,000 L/sec pump which is connected directly to an 18 inch port. See Appendix B.4.

The calculated conductance is 3243 L/sec for air. The throughput for this system design is 1.4E-3 Torr-L/sec.

4.1.5 Inlet Conductance for a 12,000 L/sec Pump with an 18 inch Port

This analysis considers the inlet conductance for a 12,000 L/sec pump which is connected directly to an 18 inch port. See Appendix B.5.

The calculated conductance is 2611 L/sec for air. The throughput for this system design is 1.1E-3 Torr-L/sec.

4.2.0 Turbo Molecular Pump Inlets

The port size required for Turbo Molecular Pumps is small enough that a close coupling to the VVS vessel is permitted. The only exception to this is in DMS region 2 where the DMS magnet is located. In this case, manifolding is required in order to position the pumps outside of the magnetic field.

4.2.1 Turbo Molecular Pump Inlets with Direct Connection to VVS

The analysis to determine the conductance from the Turbo Molecular Pump (TMP) inlet to the VVS vessel assumes a 'direct' connection. A port size equal to the pump flange size would be used for the connection. One of the largest TMP's that allows mounting in any orientation has a nominal pumping speed of 2000 L/sec [6]. The following calculation determines the conductance for this pump.

The pumping port assumed has a 12 inch diameter and a length of 3 inches. The transmission probability for this opening is 0.8. The conductance is found from equation (2),

where,

n = # of elements = 1
v = gas velocity = 445 m/s for air
a = transmission probability = 0.8
A = area = 730 cm^2

$$C = 6497 \text{ L/sec}$$

The system pumping speed at the vessel wall is found from,

$$\frac{1}{S_s} = \frac{1}{S_p} + \frac{1}{C} \qquad (5)$$

where,

S_s = pumping speed of the system
S_p = pumping speed of the pump = 1950 L/sec nitrogen
C = conductance = 6497 L/sec

S_s = 1500 L/sec for nitrogen

The throughput can be found from the relationship,

$$S = \frac{Q}{P} \qquad (6)$$

where,

S = pumping speed
Q = throughput
P = pressure

For a pressure at the vessel wall equal to 0.5E-6 Torr, the throughput is determined.

Q = 0.75E-3 Torr-L/sec

If a 12 inch gate valve is placed between the pump and the port flange, the overall length of the port increases to 7 inches. The transmission probability for this opening is then decreased to 0.67. From equation (2) the conductance for this configuration is 5441 L/sec. The pumping speed, found from equation (5), is equal to 1435 L/sec for nitrogen. The throughput, from equation (6), is reduced to 0.72E-3 Torr-L/sec. The addition of a gate valve to each TMP has roughly a 5% effect on the pumping speed.

4.2.2 Turbo Molecular Pump Manifolding for DMS Region 2

The manifold design for DMS Region 2 assumes a length of 12 inch pipe in series with a length of 18 inch pipe for each pump. The TMP's must be positioned outside of any high magnetic field. To achieve this requirement, 13 feet of 12 inch pipe and 7 feet of 18 inch pipe is assumed. The transmission probability, a, is calculated using equation (1),

where,

$a_1 = 0.1$
$a_2 = 0.1$
$A_1 = 730\ \text{cm}^2$
$A_2 = 1641\ \text{cm}^2$

$$a = 0.071$$

The conductance is found from equation (2), where,

n = # of elements = 2
v = gas velocity = 445 m/s for air
a = transmission probability = 0.071
A = area = 730 cm^2

$$C = 1150 \text{ L/sec}$$

The system pumping speed, using equation (5), is found,

where,

S_s = pumping speed of the system
S_p = pumping speed of the pump = 1950 L/sec nitrogen
C = conductance = 1150 L/sec

$$S_s = 720 \text{ L/sec for nitrogen}$$

From equation (6), the throughput for this TMP is found for a pressure at the vessel wall equal to 0.5E-6 Torr.

$$Q = 0.36\text{E-3 Torr-L/sec}$$

5.0 Foreline Piping Conductance

The Roughing System which was used for K-TeV will be suitable for CKM as well. The roughing system consists of a 2000 Series Roots Blower with a 400 Series Rotary-Piston Backing Pump. Two of these skids are available for the CKM system. The pumping speed available for this combination of pumps is taken from a Performance Curve provided by the pump manufacturer [7]. For a foreline pressure of 1.0E-2 Torr, the pumping speed is about 1000 CFM. Below this pressure, the pumping speed drops rapidly. See Appendix C. The ultimate pressure of this pumping system is about 2.5E-3 Torr. The throughput at 1.0E-2 Torr is, from equation (6), equal to 4.72 Torr-L/sec. Our total expected throughput for the VVS is 2.0E-2 Torr-L/sec. Thus, the foreline pressure should operate at less than 1.0E-2 Torr with only one vacuum skid running. Note that the gas pumped from the intermediate space of the downstream beam 'double window' is not included in this throughput value. This gas load is noted in paragraph 2.5 above.

The CKM chamber length is 34 meters. The roughing system described above will back all of the high vacuum pumps in the CKM system. It is desirable to understand that the foreline pipe size chosen will be large enough to impose only a small pressure drop along the length of the chamber. For this analysis, a 10 inch diameter pipe will be assumed.

The conductance for a long round tube in continuum flow can be found from the following formula [5].

$$C = (1.38E6)\frac{d^4}{l}\left(\frac{P_1 + P_2}{2}\right) \quad \text{L/sec for air} \qquad (7)$$

where,

C = Conductance
d = diameter = 0.254 meters
l = length = (1/2) (34 meters) = 17 meters
P = Pressure; P_1 = 1.0 Pa and P_2 = 0.99 Pa

For the dimensions stated above, the conductance is found to be 336 L/sec air. From equation (3), the differential pressure for a 17 meter length of 10 inch diameter pipe carrying one-half of the VVS gas load is equal to 0.03E-3 Torr. This value is small compared to a foreline design pressure of ≤ 1.0E-2 Torr. If the window throughput is included, the differential pressure becomes 0.2E-3 Torr.

6.0 Summary

The total outgassing rate of the CKM VVS components is estimated at 2.0E-2 Torr-L/sec. Changes to the system design will have a direct effect on this rate and subsequently the number of vacuum pumps required to meet the vacuum pressure specification. Other than the DMS regions, the center opening of the detector rings provide an adequate path for gas flow to the high vacuum pumps without imposing an excessive pressure drop. The largest impedance to gas flow is the available port size for the vacuum pumps. In addition, the diffusion pump pumping speeds are limited by the right angle valves and cold baffles required to prevent oil migration to the detectors. The reduction in pumping speed of turbo molecular pumps is much smaller as they may be mounted much closer to the VVS vessel wall. The only exception is for the pumps needed for DMS region 2 where the DMS magnet is located.

The roughing system pumps used in the K-TeV system are adequate for the CKM vacuum system as well. The additional load of the VVS downstream 'double window' is small relative to the capacity of the roughing system at 1E-2 Torr.

7.0 Appendices

Appendix A.1

Calculation to determine transmission probability
through 12 VVS upstream detector rings

Reference Equation (1)

Element #	Element	Quantity	A_i, cm^2	a_i	$[(1-a_i)/a_i]/A_i$
# 1	Detector Ring Inner Aperture	12	2827	0.557	0.000281
# 2	Detector Gap Aperture	12	22273	0.773	0.000013

Element #	Element	Quantity	A_i, cm^2	δ	$[(1/A_{i+1})-(1/A_i)]\delta_{i,i+1}$
Passing from Element #2 to #1	Subtraction due to decreasing cross-sectional area	11	A_2, A_1	$\delta_{i,i+1} = 1$	0.000309

$[(1-a_{1-n})/a_{1-n}]/A_1$
0.006931

$a_{1-n} =$	0.04856

Appendix A.2

Calculation to determine transmission probability through 8 VVS downstream detector rings

Reference Equation (1)

Element #	Element	Quantity	A_i, cm^2	a_i	$[(1-a_i)/a_i]/A_i$
# 1	Detector Ring Inner Aperture	8	5026	0.623	0.000120
# 2	Detector Gap Aperture	8	28652	0.794	0.000009

Element #	Element	Quantity	A_i, cm^2	δ	$[(1/A_{i+1})-(1/A_i)]\delta_{i,i+1}$
Passing from Element #2 to #1	Subtraction due to decreasing cross-sectional area	7	A_2, A_1	$\delta_{i,i+1} = 1$	0.000164

$[(1-a_{1-n})/a_{1-n}]/A_1$
0.002184

a_{1-n} =	0.08349

Appendix B.1

Pump Size = 50,000 L/sec Diffusion Pump
Pump Port Size = 36 inch
Chamber Port Size = 18 inch pipe

Reference Equation (1)

Element #	Element	A_i, cm^2	a_i	$[(1-a_i)/a_i]/A_i$
# 1	Pipe length, 17.6" ID x 24" length	1570	0.45	0.000778
# 2	90 degree angle valve	6207	0.38	0.000263
# 3	Chevron baffles	6207	0.25	0.000483
			Sum =	0.001525

a_{1-n} =	0.295

Assume 10% Error for entrance effects:

Then, a_{1-n} =	0.265

Conductance =	4632	L/sec for Air
For a throughput =	2.3E-03	Torr-L/sec Air
delta P =	5.0E-07	Torr

System Pumping Speed =	4220	L/sec Air
At 5E-7 Torr, the throughput =	**2.1E-03**	**Torr-L/sec Air**

Appendix B.2

Pump Size = 50,000 L/sec Diffusion Pump
Pump Port Size = 36 inch
Chamber Port Size = Three 18 inch Ports via Manifold

Reference Equation (1)

This model considers a 36" manifold positioned in parallel with the VVS having three 18" ports which connect the manifold to the VVS.
The path from the DP valve, which is mounted to the 36" manifold, to each of the three port inlets on the chamber have conductances in parallel.
Path #1 and Path #3 are identical. Path #2 is shorter.

Paths #1 & #3:

Element #	Element	Quantity, q	A_i, cm^2	a_i	$(q)[(1-a_i)/a_i]/A_i$
# 1	Pipe: 17.6" ID x 24" length	1	1570	0.45	0.000778
# 2	Pipe: 35" ID x 59" length	1	6207	0.4	0.000242
# 3	90 degree angle	2	6207	0.4	0.000242
				Sum =	0.001503

a_{1-n} =	0.298	
Conductance (1&3) =	5198	L/sec for Air

Path #2:

Element #	Element	Quantity, q	A_i, cm^2	a_i	$(q)[(1-a_i)/a_i]/A_i$
# 1	Pipe: 17.6" ID x 24" length	1	1570	0.45	0.000778
# 2	Pipe: 35" ID x 35" length	1	6207	0.51	0.000155
				Sum =	0.000933

a_{1-n} =	0.406	
Conductance (2) =	7085	L/sec for Air

Parallel Conductance through Paths #1, #2, and #3 to the Pump Valve inlet:

Conductance =	17480	L/sec for Air

Series Conductance:

Element #	Element	Quantity, q	A_i, cm^2	a_i	$(q)[(1-a_i)/a_i]/A_i$
# 1	90 degree angle valve	1	6207	0.38	0.000263
# 2	Chevron baffles	1	6207	0.25	0.000483
# 3	Short pipe length	1	6207	0.9	0.000018
				Sum =	0.000764

a_{1-n} =	0.174

Assume 10% Error for entrance effects:

Then a =	0.157

Conductance of Pump Inlet Components:

Conductance =	10822	L/sec for Air

Series Conductance Manifold and Pump Inlet Components:

Total Conductance =	6684	L/sec for Air

For a throughput =	3.3E-03	Torr-L/sec Air
delta P =	4.9E-07	Torr

System Pumping Speed =	5859	L/sec Air
At 5E-7 Torr, the throughput =	**2.9E-03**	**Torr-L/sec Air**

Appendix B.3

Pump Size = 50,000 L/sec Diffusion Pump
Pump Port Size = 36 inch
Chamber Port Size = 36 inch pipe

Reference Equation (1)

Element #	Element	A_i, cm^2	a_i	$[(1-a_i)/a_i]/A_i$
# 1	Pipe length, 17.6" ID x 24" length	6207	0.9	0.000018
# 2	90 degree angle valve	6207	0.38	0.000263
# 3	Chevron baffles	6207	0.25	0.000483
			Sum =	0.000764

a_{1-n} =	0.174

Assume 10% Error for entrance effects:

Then, a_{1-n} =	0.157

Conductance =	10822	L/sec for Air
For a throughput =	5.0E-03	Torr-L/sec Air
delta P =	4.6E-07	Torr

System Pumping Speed =	8814	L/sec Air
At 5E-7 Torr, the throughput =	**4.4E-03**	**Torr-L/sec Air**

Appendix B.4

Pump Size = 20,000 L/sec Diffusion Pump
Pump Port Size = 24 inch
Chamber Port Size = 18 inch pipe

Reference Equation (1)

Element #	Element	A_i, cm^2	a_i	$[(1-a_i)/a_i]/A_i$
# 1	Pipe length, 17.6" ID x 24" length	1552	0.45	0.000788
# 2	90 degree angle valve	2798	0.38	0.000583
# 3	Chevron baffles	2798	0.25	0.001072
			Sum =	0.002443

a_{1-n} =	0.209

Assume 10% Error for entrance effects:

Then, a_{1-n} =	0.188

Conductance =	3243	L/sec for Air
For a throughput =	1.6E-03	Torr-L/sec Air
delta P =	4.9E-07	Torr

System Pumping Speed =	2770	L/sec Air
At 5E-7 Torr, the throughput =	**1.4E-03**	**Torr-L/sec Air**

Appendix B.5

Pump Size = 12,000 L/sec Diffusion Pump
Pump Port Size = 20 inch
Chamber Port Size = 18 inch pipe

Reference Equation (1)

Element #	Element	A_i, cm^2	a_i	$[(1-a_i)/a_i]/A_i$
# 1	Pipe length, 17.6" ID x 24" length	1552	0.45	0.000788
# 2	90 degree angle valve	1927	0.38	0.000847
# 3	Chevron baffles	1927	0.25	0.001557
			Sum =	0.003191

$a_{1\text{-}n}$ =	0.168

Assume 10% Error for entrance effects:

Then, $a_{1\text{-}n}$ =	0.151

Conductance =	2611	L/sec for Air
For a throughput =	1.5E-03	Torr-L/sec Air
delta P =	5.7E-07	Torr

System Pumping Speed =	2124	L/sec Air
At 5E-7 Torr, the throughput =	**1.1E-03**	**Torr-L/sec Air**

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Performance Curves*

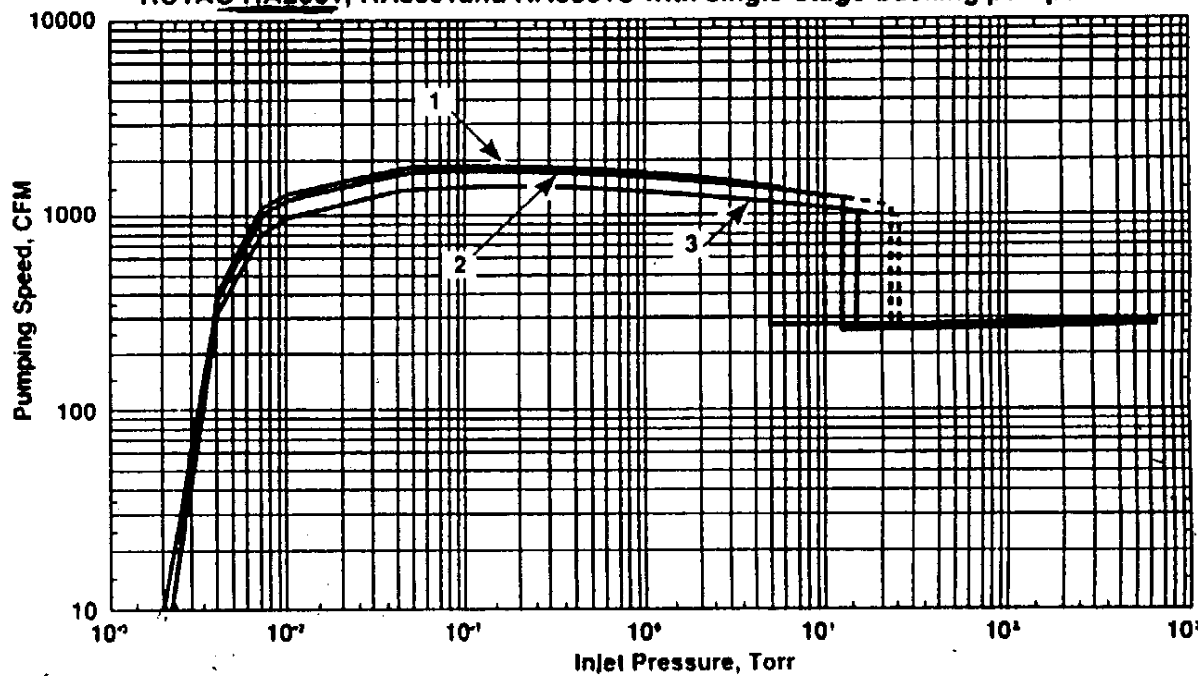
1) RA3001/S400F

2) RA3001S/S400F

3) RA2001/S400F

—— Continuous Duty
- - - - Intermittent Duty

RUVAC RA2001, RA3001and RA3001S with single-stage backing pumps



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