GEM TN-93-409

GEM Solenoid Vacuum System Design Study

May 20, 1993

GEM SOLENOID VACUUM SYSTEM DESIGN STUDY

Pump Down Curve For GEM Solenoid Turbmollecular Pumps

SOLENOID PARAMETERS

Outer Diameter of Vacuum Vessel	20.3 m.
Inner Diameter of Vacuum Vessel	18.2 m.
Length of Vacuum Vessel	30.0 m.
Length of Coil	28.5 m.
Diameter of Coil	19 m.
Thickness of Coil (approx.)	0.15 m.
Length of Radiation Shields	29.17 m.
Diameter of Radiation Shields (average)	19.22 m.
Thickness of Radiation Shields	0.0032 m.
Length of Radiation Shield Cooling Channel (approx.)	933 m.
Area of Cross Section of Cooling Channel	0.0012 sq.m.
Volume of Vacuum Vessel	1905 cu.m.
volume of Coil and Radiation Shields	262 cu.m.
Pumped Volume of Vacuum Vessel	1643 cu.m.

OUTGASSING LOAD

Radius of Solenoid	8.5 metres
Length of Solenoid	28.5 metres

Number of Complete Cylindrical Surfaces Exposed to Vacuum

Rusty Steel	2
Aluminium Alloy	7
Stainless Steel	0
Aluminium	0
Glass Epoxy Resin	1
Number of Layers of MLI	60
Number of Layers of Nylon Net	62

AREA OF AURFACES EXPOSED:

Rusty Steel	3044 sq.m.
Dualuminium	10655 sq.m.
Stainless Steel	0 sq.m.
Aluminium	0 sq.m.
Glass Epoxy Resin	1522 sq.m.
MLI Sheet	91326 sq.m.
Nylon Net	94370 sq.m.

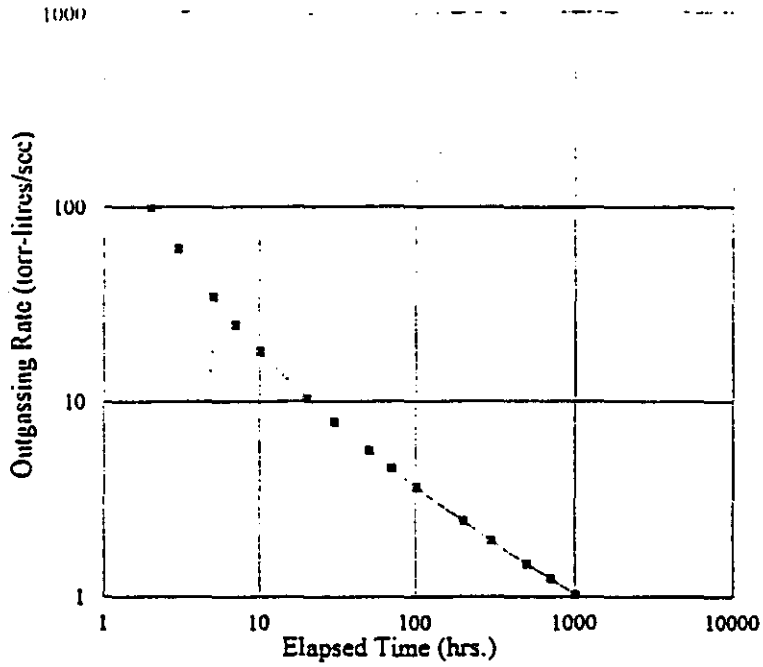
Curves (1), (2) and (4) are taken from B B. Dayton. 1961 Vacuum Symposium Transactions
Curve (4) is for aluminium, bright rolled and cleaned in stergene

Time (hr.)	Rusty Steel	Alum. Alloy Curve (2)	Stain Steel Curve (1)	Alum. Curve (4)	Glass Epoxy Resin	MLI	Nylon Net
2	1.95E-02	1.33E-03	1.06E-03	1.96E-03	2.10E-02	2.00E-04	9.33E-05
3	1.15E-02	9.80E-04	7.00E-04	4.80E-04	1.62E-02	5.00E-05	6.40E-05
5	5.60E-03	6.90E-04	4.50E-04	2.27E-04	1.17E-02	1.60E-05	2.40E-05
7	3.50E-03	5.60E-04	3.50E-04	1.60E-04	9.33E-03	9.50E-06	1.27E-05
10	2.15E-03	4.60E-04	2.80E-04	1.17E-04	7.50E-03	5.80E-06	7.47E-06
20	8.80E-04	3.17E-04	1.90E-04	6.30E-05	4.67E-03	2.30E-06	4.27E-06
30	5.40E-04	2.60E-04	1.55E-04	4.40E-05	3.67E-03	1.35E-06	3.30E-06
50	3.05E-04	2.05E-04	1.20E-04	2.75E-05	2.63E-03	6.90E-07	2.66E-06
70	2.12E-04	1.80E-04	1.02E-04	2.05E-05	2.12E-03	4.45E-07	2.40E-06
100	1.47E-04	1.53E-04	8.50E-05	1.47E-05	1.67E-03	2.76E-07	2.00E-06
200	7.60E-05	1.16E-04	6.20E-05	7.80E-06	1.07E-03	1.12E-07	1.60E-06
300	5.20E-05	9.80E-05	5.00E-05	5.40E-06	8.16E-04	6.50E-08	1.33E-06
500	3.30E-05	8.10E-05	3.90E-05	3.40E-06	5.83E-04	3.30E-08	1.10E-06
700	2.40E-05	7.20E-05	3.30E-05	2.50E-06	4.75E-04	2.20E-08	9.50E-07
1000	1.80E-05	6.20E-05	2.75E-05	1.80E-06	3.75E-04	1.35E-08	8.00E-07
1 Day	7.10E-04	2.90E-04	1.70E-04	5.30E-05	4.20E-03	1.80E-06	4.00E-06
1 Week	9.00E-05	1.23E-04	6.70E-05	9.00E-06	1.20E-03	1.40E-07	1.70E-06
1 Month	2.37E-05	7.10E-05	3.40E-05	2.55E-06	4.80E-04	2.25E-08	9.30E-07

TOTAL OUTGASSING RATES (litre mbar/sec.)

Time (hr.)	Rusty Steel	Alum. Alloy	Glass Epoxy Resin	MLI	Nylon Net	Total
2	5.94E+01	1.42E+01	3.20E+01	1.83E+01	8.80E+00	1.33E+02
3	3.50E+01	1.04E+01	2.47E+01	4.57E+00	6.04E+00	8.07E+01
5	1.70E+01	7.35E+00	1.78E+01	1.46E+00	2.26E+00	4.59E+01
7	1.07E+01	5.97E+00	1.42E+01	8.68E-01	1.20E+00	3.29E+01
10	6.55E+00	4.90E+00	1.14E+01	5.30E-01	7.05E-01	2.41E+01
20	2.68E+00	3.38E+00	7.11E+00	2.10E-01	4.03E-01	1.38E+01
30	1.64E+00	2.77E+00	5.59E+00	1.23E-01	3.11E-01	1.04E+01
50	9.28E-01	2.18E+00	4.00E+00	6.30E-02	2.51E-01	7.43E+00
70	6.45E-01	1.92E+00	3.23E+00	4.06E-02	2.26E-01	6.06E+00
100	4.47E-01	1.63E+00	2.54E+00	2.52E-02	1.89E-01	4.83E+00
200	2.31E-01	1.24E+00	1.63E+00	1.02E-02	1.51E-01	3.26E+00
300	1.58E-01	1.04E+00	1.24E+00	5.94E-03	1.26E-01	2.58E+00
500	1.00E-01	8.63E-01	8.87E-01	3.01E-03	1.04E-01	1.96E+00
700	7.31E-02	7.67E-01	7.23E-01	2.01E-03	8.97E-02	1.65E+00
1000	5.48E-02	6.61E-01	5.71E-01	1.23E-03	7.55E-02	1.36E+00
1 Day	2.16E+00	3.09E+00	6.39E+00	1.64E-01	3.77E-01	1.22E+01
1 Week	2.74E-01	1.31E+00	1.83E+00	1.28E-02	1.60E-01	3.58E+00
1 Month	7.21E-02	7.56E-01	7.31E-01	2.05E-03	8.78E-02	1.65E+00

Time (hr.)	Outgassing Load (l.-torr/sec.)
2	9.94E+01
3	6.05E+01
5	3.45E+01
7	2.47E+01
10	1.81E+01
20	1.03E+01
30	7.83E+00
50	5.57E+00
70	4.54E+00
100	3.63E+00
200	2.44E+00
300	1.93E+00
500	1.47E+00
700	1.24E+00
1000	1.02E+00
1 Day	9.14E+00
1 Week	2.69E+00
1 Month	1.24E+00



Pumping speed of turbomolecular pump 6000 litres/sec

Time (hr.)	Outgassing Load (l.-torr/sec.)	Number of turbomolecular pumps 1	2	3	4	5	
2	9.94E+01	1.66E-02	8.29E-03	5.52E-03	4.14E-03	3.31E-03	
3	6.05E+01	1.01E-02	5.04E-03	3.36E-03	2.52E-03	2.02E-03	
5	3.45E+01	5.74E-03	2.87E-03	1.91E-03	1.44E-03	1.15E-03	
7	2.47E+01	4.11E-03	2.06E-03	1.37E-03	1.03E-03	8.22E-04	
10	1.81E+01	3.01E-03	1.51E-03	1.00E-03	7.53E-04	6.02E-04	
20	1.03E+01	1.72E-03	8.61E-04	5.74E-04	4.31E-04	3.44E-04	
30	7.83E+00	1.30E-03	6.52E-04	4.35E-04	3.26E-04	2.61E-04	Vessel
50	5.57E+00	9.29E-04	4.64E-04	3.10E-04	2.32E-04	1.86E-04	Pressure
70	4.54E+00	7.57E-04	3.79E-04	2.52E-04	1.89E-04	1.51E-04	(torr)
100	3.63E+00	6.04E-04	3.02E-04	2.01E-04	1.51E-04	1.21E-04	
200	2.44E+00	4.07E-04	2.04E-04	1.36E-04	1.02E-04	8.14E-05	
300	1.93E+00	3.22E-04	1.61E-04	1.07E-04	8.05E-05	6.44E-05	
500	1.47E+00	2.45E-04	1.22E-04	8.16E-05	6.12E-05	4.89E-05	
700	1.24E+00	2.07E-04	1.03E-04	6.90E-05	5.17E-05	4.14E-05	
1000	1.02E+00	1.70E-04	8.52E-05	5.68E-05	4.26E-05	3.41E-05	

PUMPED VOLUME OF VACUUM VESSEL 1643 cu.m

Parameters:

Line o.d.	168.3 mm.	=	6.63 in.
Line wall	2.77 mm.	=	0.11 in.
Line i.d.	162.76 mm.	=	6.41 in.
Length of line	146.2 m.		
Volume of line	3.04 cu.m.		
Total pumped volume	1646 cu.m.		
Pumping Speed	450 cu.m./hr.		
Pump Down Factor (1 bar - 0.1 mbar	12		
Pump Down Time (1bar-0.1 mbar.)	43.90 hr.		

Roughing system pumped by rotary pump
Stokes 412H 450 cu.m./hr. single stage pump

Iteration 13

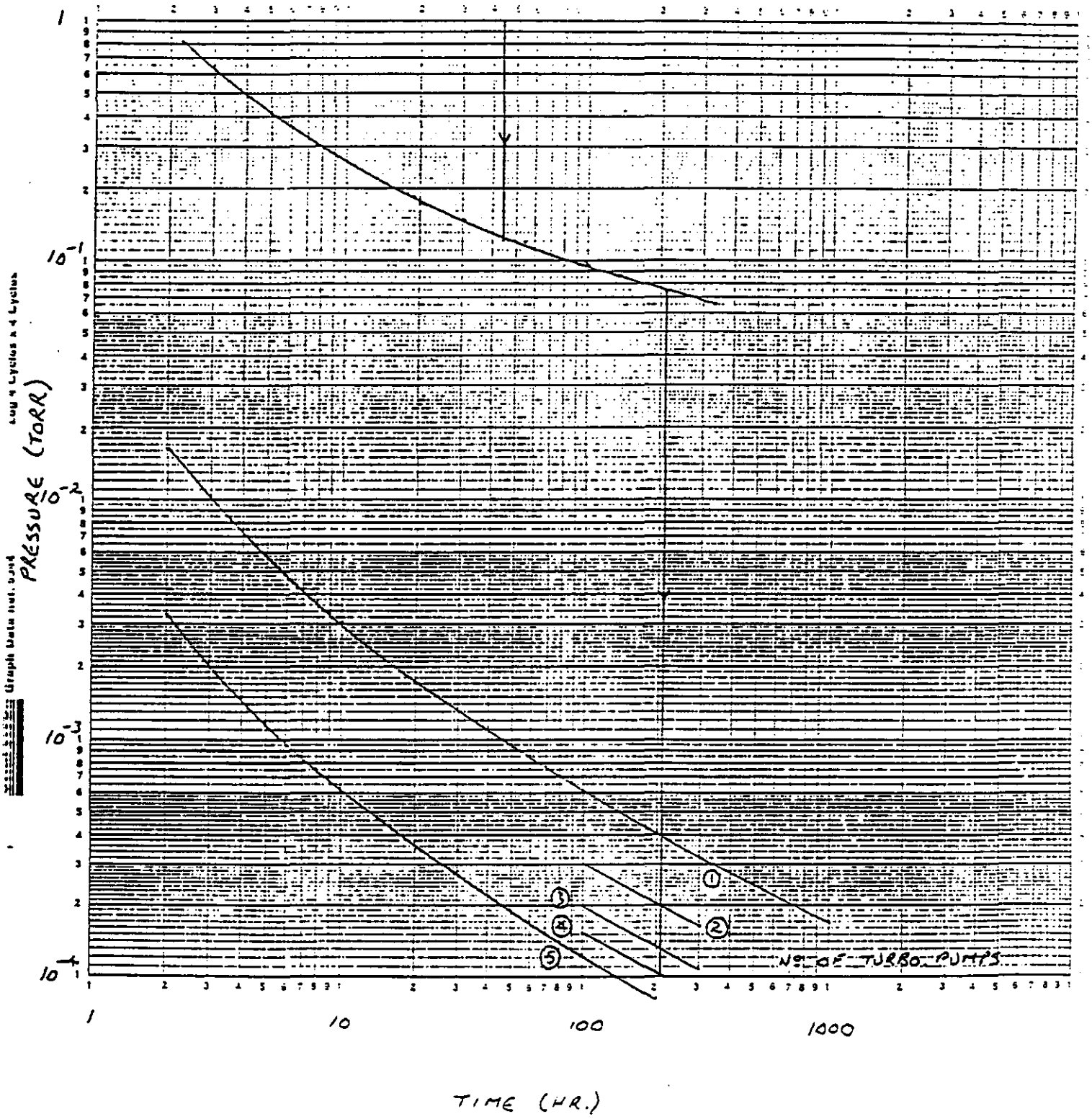
Pump Pressure (mbar)	Pump Speed (l./sec.)	Throughput (l.- mbar/sec	Visc. Cond. (l./sec.)	Mol. Cond. (l./sec.)	Total Cond. (l./sec.)	Vessel Pressure (mbar)	Speed at Vessel (l./sec.)	Interval Pump Down Time (hrs.)	Cumulative Pump Down Time (hrs.)
10	126	1.260E+03	8640.2	2.9	8643.1	10.1458	124.2		43.90
7	126	8.820E+02	6066.7	2.9	6069.6	7.1453	123.4	1.29	45.19
5	126	6.300E+02	4350.9	2.9	4353.8	5.1447	122.5	1.22	46.41
3	126	3.780E+02	2634.8	2.9	2637.6	3.1433	120.3	1.85	48.26
2	126	2.520E+02	1776.3	2.9	1779.2	2.1416	117.7	1.47	49.73
1	126	1.260E+02	916.5	2.9	919.4	1.1370	110.8	2.53	52.26
0.7	126	8.820E+01	657.7	2.9	660.6	0.8335	105.8	1.31	53.57
0.5	122	6.100E+01	482.8	2.9	485.6	0.6256	97.5	1.29	54.86
0.3	119	3.570E+01	306.8	2.9	309.7	0.4153	86.0	2.04	56.90
0.2	117	2.340E+01	217.2	2.9	220.1	0.3063	76.4	1.71	58.61
0.1	111	1.110E+01	123.5	2.9	126.3	0.1879	59.1	3.30	61.90
0.07	110	7.700E+00	94.1	2.9	97.0	0.1494	51.5	1.89	63.79
0.05	107	5.350E+00	73.1	2.9	76.0	0.1204	44.4	2.05	65.84
0.03	100	3.000E+00	50.0	2.9	52.9	0.0867	34.6	3.80	69.64
0.02	89	1.780E+00	36.5	2.9	39.4	0.0652	27.3	4.21	73.85
0.01	56	5.600E-01	19.4	2.9	22.3	0.0352	15.9	13.03	86.87

DATA FOR ROUGHING PRESSURE WHEN OUTGASSING DOMINATES

Pump Pressure (mbar)	Pump Speed (l./sec.)	Throughput (l.- mbar/sec.)	Vessel Pressure	Time (hr.)	Outgassing Load (l.-torr/sec.)	Time (hr.)
10	126	1.26E+03	1.01E+01		9.94E+01	2
7	126	8.82E+02	7.15E+00		6.05E+01	3
5	126	6.30E+02	5.14E+00		3.45E+01	5
3	126	3.78E+02	3.14E+00		2.47E+01	7
2	126	2.52E+02	2.14E+00		1.81E+01	10
1	126	1.26E+02	1.14E+00		1.03E+01	20
0.7	126	8.82E+01	8.34E-01	2.2	7.83E+00	30
0.5	122	6.10E+01	6.26E-01	3.0	5.57E+00	50
0.3	119	3.57E+01	4.15E-01	4.9	4.54E+00	70
0.2	117	2.34E+01	3.06E-01	7.5	3.63E+00	100
0.1	111	1.11E+01	1.88E-01	18.5	2.44E+00	200
0.07	110	7.70E+00	1.49E-01	30.0	1.93E+00	300
0.05	107	5.35E+00	1.20E-01	54.0	1.47E+00	500
0.03	100	3.00E+00	8.67E-02	135.0	1.24E+00	700
0.02	89	1.78E+00	6.52E-02	335.0	1.02E+00	1000
0.01	56	5.60E-01	3.52E-02			

PUMP DOWN CURVE FOR GEM SOLENOID

TURBOMOLECULAR PUMPS



GEM SOLENOID VACUUM SYSTEM DESIGN STUDY

Cost Analysis For GEM Solenoid Vacuum Systems

COST ANALYSIS FOR GEM SOLENOID VACUUM SYSTEMS

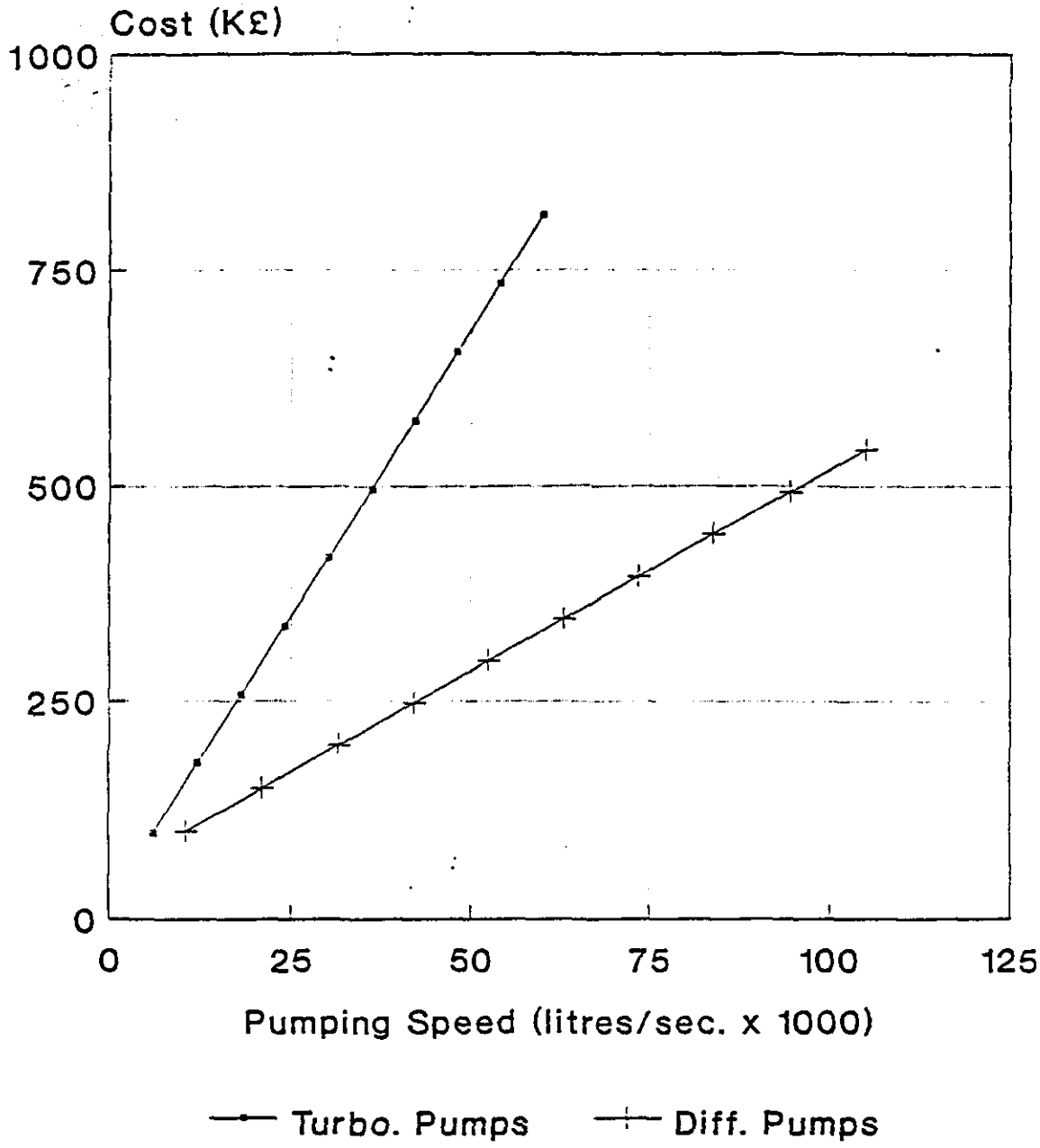
DIFFUSION PUMPED SYSTEM Speed 10500 litres/sec			Number	Unit	Unit Cost £	Cost £
Diffusion pump and integral baffle	Varian	HS-20	1	each	11875.00	11875.00
Thermal switches	Varian		2	each	44.00	88.00
High vacuum isolation valve ISO 500	Nor-Cal	GVP-20002-1SO	1	each	16329.00	16329.00
Pressure measurement spacer	Nor-Cal	2N-ISO-500-GC	1	each	1328.00	1328.00
Centring rings and O-rings	Nor-Cal	ISO-500-CR-AB	3	each	84.00	252.00
Clamp bolts	Nor-Cal	ISO-500-DCP	16	each	7.70	123.20
Centring rings and O-rings, 25 KF	Nor-Cal	NW-25-CR-AB	1	each	2.45	2.45
Clamp ring, 25 KF	Nor-Cal	NW-25-CP	1	each	4.90	4.90
Centring rings and O-rings, 10 KF	Nor-Cal	NW-10-CR-AB	1	each	1.75	1.75
Clamp ring, 10 KF	Nor-Cal	NW-10-CP	1	each	3.68	3.68
Backing pump	Stokes	212H	1	each	5994.00	5994.00
<u>Backing Line ISO 160</u>						
Backing valve	Nor-Cal	ESVP-6002-ISO	1	each	1155.00	1155.00
Elbows	Nor-Cal	SE-ISO-160-OF	2	each	367.50	735.00
Tees	Nor-Cal	3T-ISO-160-OF	2	each	371.00	742.00
Gauge point flanges	Nor-Cal	AN-ISO-160-NW-1	2	each	181.00	362.00
Flexible 7 in.	Nor-Cal	2FC-ISO-600-4	1	each	350.00	350.00
Centring rings and O-rings	Nor-Cal	ISO-160-CR-AB	9	each	26.60	239.40
Clamp bolts	Nor-Cal	ISO-160-DCP	36	each	3.68	132.48
Centring rings and O-rings, 10 KF	Nor-Cal	NW-10-CR-AB	2	each	1.75	3.50
Clamp ring, 10 KF	Nor-Cal	NW-10-CP	2	each	3.68	7.36
<u>Gauges</u>						
Thermocouple gauges controller and head	Varian	810-2	3	each	532.00	1596.00
Cold cathode gauge controller	Varian	860A-2	1	each	850.50	850.50
Cold cathode gauge	Varian	525	1	each	297.50	297.50
Automatic control system			1	each	3000.00	3000.00
Framework			1	each	750.00	750.00
Electrical wiring			1	each	1000.00	1000.00
Manpower			3	man weeks	600.00	1800.00
				Total:		49022.72
<u>Roughing System ISO 200</u>						
Rootes blower	Stokes	622-1	2	each	8773.00	17546.00
Backing pump	Stokes	412H	2	each	10601.00	21202.00
High vacuum isolation valve	Nor-Cal	GVP-8002-ISO	2	each	2545.00	5090.00
Pressure measurement spacer	Nor-Cal	2N-ISO-200-GC	2	each	520.00	1040.00
Centring rings and O-rings	Nor-Cal	ISO-200-CR-AB	6	each	36.40	218.40
Clamp bolts	Nor-Cal	ISO-200-DCP	36	each	3.68	132.48
Thermocouple gauges controller and head	Varian	810-2	2	each	532.00	1064.00
Centring rings and O-rings, 10 KF	Nor-Cal	NW-10-CR-AB	2	each	1.75	3.50
Clamp ring, 10 KF	Nor-Cal	NW-10-CP	2	each	3.68	7.36
Framework			2	each	750.00	1500.00
Electrical wiring			1	each	500.00	500.00
Manpower			1	man weeks	600.00	600.00
				Total:		48903.74

TURBOMOLECULAR PUMPED SYSTEM Speed 6000 litres/sec			Number	Unit	Unit cost £	Cost £
Turbomolecular pump	Varian	Turbo-V6000	1	each	9940.00	38000.00
Control unit	Varian		1	each	5830	6830.00
Inlet protection screen	Varian		1	each	365	365.00
Vent valve	Varian		1	each	780	780.00
High vacuum isolation valve ISO 500	Nor-Cal	GVP-20002-1SO	1	each	16329.00	16329.00
Pressure measurement spacer	Nor-Cal	2N-ISO-500-GC	1	each	1328.00	1328.00
Centring rings and O-rings	Nor-Cal	ISO-500-CR-AB	3	each	84.00	252.00
Clamp bolts	Nor-Cal	ISO-500-DCP	48	each	7.70	369.60
Centring rings and O-rings, 25 KF	Nor-Cal	NW-25-CR-AB	1	each	2.45	2.45
Clamp ring, 25 KF	Nor-Cal	NW-25-CP	1	each	4.90	4.90
Centring rings and O-rings, 10 KF	Nor-Cal	NW-10-CR-AB	1	each	1.75	1.75
Clamp ring, 10 KF	Nor-Cal	NW-10-CP	1	each	3.68	3.68
Backing pump	Stokes	V-023	1	each	3394.00	3394.00
Backing Line ISO 100						
Backing valve	Nor-Cal	EAVP-4002-ISO	1	each	682.50	682.50
Elbows	Nor-Cal	2E-ISO-100-OF	2	each	175.00	350.00
Tees	Nor-Cal	3T-ISO-100-OF	2	each	238.00	476.00
Gauge point flanges	Nor-Cal	AN-ISO-100-NW-1	2	each	154.00	308.00
Flexible	Nor-Cal	2FC-ISO-400-4	1	each	245.00	245.00
Centring rings and O-rings	Nor-Cal	ISO-100--CR-AB	9	each	22.40	201.60
Clamp bolts	Nor-Cal	ISO-100-DCP	36	each	3.50	126.00
Centring rings and O-rings, 10 KF	Nor-Cal	NW-10-CR-AB	2	each	1.75	3.50
Clamp ring, 10 KF	Nor-Cal	NW-10-CP	2	each	3.68	7.36
Gauges						
Thermocouple gauges controller and head	Varian	810-2	3	each	532.00	1596.00
Cold cathode gauge controller	Varian	860A-2	1	each	850.50	850.50
Cold cathode gauge	Varian	525	1	each	297.50	297.50
Automatic control system			1	each	3000.00	3000.00
Framework			1	each	750.00	750.00
Electrical wiring			1	each	1000.00	1000.00
Manpower			3	man weeks	600.00	1800.00
				Total:		79354.34
Roughing System ISO 160						
Backing pump	Stokes	412H	1	each	10601.00	10601.00
High vacuum isolation valve	Nor-Cal	GVP-6002-ISO	1	each	1865.00	1865.00
Pressure measurement spacer	Nor-Cal	2N-ISO-160-GC	1	each	452.00	452.00
Centring rings and O-rings	Nor-Cal	ISO-160-CR-AB	3	each	26.60	79.80
Clamp bolts	Nor-Cal	ISO-160-DCP	36	each	3.68	132.48
Thermocouple gauges controller and head	Nor-Cal	810-2	1	each	532.00	532.00
Centring rings and O-rings, 10 KF	Nor-Cal	NW-10-CR-AB	1	each	1.73	1.73
Clamp ring, 10 KF	Nor-Cal	NW-10-CP	1	each	4.49	4.49
Framework			2	each	750.00	1500.00
Electrical wiring			1	each	500.00	500.00
Manpower			1	man weeks	600.00	600.00
				Total:		16268.5
SOLENOID PRESSURE MEASUREMENT						
Thermocouple gauges controller and head	Varian	810-2	2	each	532.00	1064.00
Cold cathode gauge controller	Varian	860A-2	2	each	850.50	1701.00
Cold cathode gauge	Varian	525	2	each	297.50	595.00
				Total:		3360

SYSTEM PUMPING SPEED REQUIRED 40000 litres/sec.

	Number	Unit Cost £	Cost £
Diffusion Pump System			
High vacuum system	4	49022.72	196090.88
Roughing system	1	48903.74	48903.74
Solenoid pressure measurement	1	3360.00	3360.00
Total:			248354.62
Turbomolecular Pump System			
High vacuum system	7	79354.34	555480.38
Roughing system	1	16268.50	16268.50
Solenoid pressure measurement	1	3360.00	3360.00
Total:			575108.88

GEM Solenoid
Comparative Costs of Pumping Systems



Dollar price = £/0.7

GEM SOLENOID VACUUM SYSTEM DESIGN STUDY

Pump Down Curve For GEM Solenoid Diffusion Pumps

SOLENOID PARAMETERS

Outer Diameter of Vacuum Vessel	20.3 m.
Inner Diameter of Vacuum Vessel	18.2 m.
Length of Vacuum Vessel	30.0 m.
Length of Coil	28.5 m.
Diameter of Coil	19 m.
Thickness of Coil (approx.)	0.15 m.
Length of Radiation Shields	29.17 m.
Diameter of Radiation Shields (average)	19.22 m.
Thickness of Radiation Shields	0.0032 m.
Length of Radiation Shield Cooling Channel (approx.)	933 m.
Area of Cross Section of Cooling Channel	0.0012 sq.m.
Volume of Vacuum Vessel	1905 cu.m.
volume of Coil and Radiation Shields	262 cu.m.
Pumped Volume of Vacuum Vessel	1643 cu.m.

OUTGASSING LOAD

Radius of Solenoid	8.5 metres
Length of Solenoid	28.5 metres

Number of Complete Cylindrical Surfaces Exposed to Vacuum

Rusty Steel	2
Aluminium Alloy	7
Stainless Steel	0
Aluminium	0
Glass Epoxy Resin	1
Number of Layers of MLI	60
Number of Layers of Nylon Net	62

AREA OF AURFACES EXPOSED:

Rusty Steel	3044 sq.m.
Dualuminium	10655 sq.m.
Stainless Steel	0 sq.m.
Aluminium	0 sq.m.
Glass Epoxy Resin	1522 sq.m.
MLI Sheet	91326 sq.m.
Nylon Net	94370 sq.m.

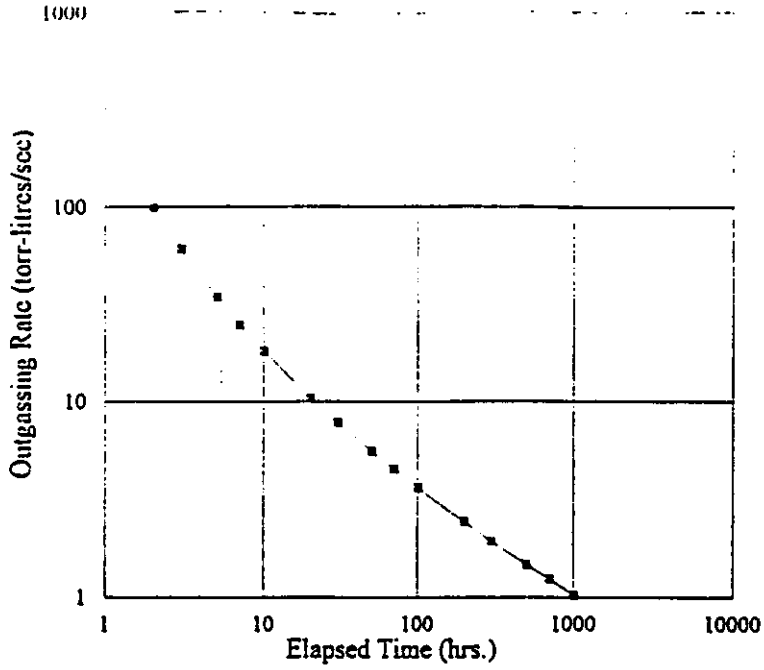
Curves (1), (2) and (4) are taken from B B Dayton 1961 Vacuum Symposium Transactions
Curve (4) is for aluminium, bright rolled and cleaned in stergene

Time (hr.)	Rusty Steel	Alum Alloy Curve (2)	Stain. Steel Curve (1)	Alum. Curve (4)	Glass Epoxy Resin	MLI	Nylon Net
2	1.95E-02	1.33E-03	1.06E-03	1.96E-03	2.10E-02	2.00E-04	9.33E-05
3	1.15E-02	9.80E-04	7.00E-04	4.80E-04	1.62E-02	5.00E-05	6.40E-05
5	5.60E-03	6.90E-04	4.50E-04	2.27E-04	1.17E-02	1.60E-05	2.40E-05
7	3.50E-03	5.60E-04	3.50E-04	1.60E-04	9.33E-03	9.50E-06	1.27E-05
10	2.15E-03	4.60E-04	2.80E-04	1.17E-04	7.50E-03	5.80E-06	7.47E-06
20	8.80E-04	3.17E-04	1.90E-04	6.30E-05	4.67E-03	2.30E-06	4.27E-06
30	5.40E-04	2.60E-04	1.55E-04	4.40E-05	3.67E-03	1.35E-06	3.30E-06
50	3.05E-04	2.05E-04	1.20E-04	2.75E-05	2.63E-03	6.90E-07	2.66E-06
70	2.12E-04	1.80E-04	1.02E-04	2.05E-05	2.12E-03	4.45E-07	2.40E-06
100	1.47E-04	1.53E-04	8.50E-05	1.47E-05	1.67E-03	2.76E-07	2.00E-06
200	7.60E-05	1.16E-04	6.20E-05	7.80E-06	1.07E-03	1.12E-07	1.60E-06
300	5.20E-05	9.80E-05	5.00E-05	5.40E-06	8.16E-04	6.50E-08	1.33E-06
500	3.30E-05	8.10E-05	3.90E-05	3.40E-06	5.83E-04	3.30E-08	1.10E-06
700	2.40E-05	7.20E-05	3.30E-05	2.50E-06	4.75E-04	2.20E-08	9.50E-07
1000	1.80E-05	6.20E-05	2.75E-05	1.80E-06	3.75E-04	1.35E-08	8.00E-07
1 Day	7.10E-04	2.90E-04	1.70E-04	5.30E-05	4.20E-03	1.80E-06	4.00E-06
1 Week	9.00E-05	1.23E-04	6.70E-05	9.00E-06	1.20E-03	1.40E-07	1.70E-06
1 Month	2.37E-05	7.10E-05	3.40E-05	2.55E-06	4.80E-04	2.25E-08	9.30E-07

TOTAL OUTGASSING RATES (litre mbar/sec.)

Time (hr.)	Rusty Steel	Alum. Alloy	Glass Epoxy Resin	MLI	Nylon Net	Total
2	5.94E+01	1.42E+01	3.20E+01	1.83E+01	8.80E+00	1.33E+02
3	3.50E+01	1.04E+01	2.47E+01	4.57E+00	6.04E+00	8.07E+01
5	1.70E+01	7.35E+00	1.78E+01	1.46E+00	2.26E+00	4.59E+01
7	1.07E+01	5.97E+00	1.42E+01	8.68E-01	1.20E+00	3.29E+01
10	6.55E+00	4.90E+00	1.14E+01	5.30E-01	7.05E-01	2.41E+01
20	2.68E+00	3.38E+00	7.11E+00	2.10E-01	4.03E-01	1.38E+01
30	1.64E+00	2.77E+00	5.59E+00	1.23E-01	3.11E-01	1.04E+01
50	9.28E-01	2.18E+00	4.00E+00	6.30E-02	2.51E-01	7.43E+00
70	6.45E-01	1.92E+00	3.23E+00	4.06E-02	2.26E-01	6.06E+00
100	4.47E-01	1.63E+00	2.54E+00	2.52E-02	1.89E-01	4.83E+00
200	2.31E-01	1.24E+00	1.63E+00	1.02E-02	1.51E-01	3.26E+00
300	1.58E-01	1.04E+00	1.24E+00	5.94E-03	1.26E-01	2.58E+00
500	1.00E-01	8.63E-01	8.87E-01	3.01E-03	1.04E-01	1.96E+00
700	7.31E-02	7.67E-01	7.23E-01	2.01E-03	8.97E-02	1.65E+00
1000	5.48E-02	6.61E-01	5.71E-01	1.23E-03	7.55E-02	1.36E+00
1 Day	2.16E+00	3.09E+00	6.39E+00	1.64E-01	3.77E-01	1.22E+01
1 Week	2.74E-01	1.31E+00	1.83E+00	1.28E-02	1.60E-01	3.58E+00
1 Month	7.21E-02	7.56E-01	7.31E-01	2.05E-03	8.78E-02	1.65E+00

Time (hr.)	Outgassing Load (l.-torr/sec.)
2	9.94E+01
3	6.05E+01
5	3.45E+01
7	2.47E+01
10	1.81E+01
20	1.03E+01
30	7.83E+00
50	5.57E+00
70	4.54E+00
100	3.63E+00
200	2.44E+00
300	1.93E+00
500	1.47E+00
700	1.24E+00
1000	1.02E+00
1 Day	9.14E+00
1 Week	2.69E+00
1 Month	1.24E+00



Pumping speed of diffusion pump 10500 litres/sec.

Time (hr.)	Outgassing Load (l.-torr/sec.)	Number of diffusion pumps 1	2	3	4	5	Vessel Pressure (torr)
2	9.94E+01	9.47E-03	4.73E-03	3.16E-03	2.37E-03	1.89E-03	
3	6.05E+01	5.77E-03	2.88E-03	1.92E-03	1.44E-03	1.15E-03	
5	3.45E+01	3.28E-03	1.64E-03	1.09E-03	8.20E-04	6.56E-04	
7	2.47E+01	2.35E-03	1.17E-03	7.83E-04	5.87E-04	4.70E-04	
10	1.81E+01	1.72E-03	8.61E-04	5.74E-04	4.30E-04	3.44E-04	
20	1.03E+01	9.84E-04	4.92E-04	3.28E-04	2.46E-04	1.97E-04	
30	7.83E+00	7.45E-04	3.73E-04	2.48E-04	1.86E-04	1.49E-04	
50	5.57E+00	5.31E-04	2.65E-04	1.77E-04	1.33E-04	1.06E-04	
70	4.54E+00	4.33E-04	2.16E-04	1.44E-04	1.08E-04	8.65E-05	
100	3.63E+00	3.45E-04	1.73E-04	1.15E-04	8.63E-05	6.91E-05	
200	2.44E+00	2.33E-04	1.16E-04	7.76E-05	5.82E-05	4.65E-05	
300	1.93E+00	1.84E-04	9.20E-05	6.13E-05	4.60E-05	3.68E-05	
500	1.47E+00	1.40E-04	6.99E-05	4.66E-05	3.50E-05	2.80E-05	
700	1.24E+00	1.18E-04	5.91E-05	3.94E-05	2.96E-05	2.36E-05	
1000	1.02E+00	9.74E-05	4.87E-05	3.25E-05	2.43E-05	1.95E-05	

PUMPED VOLUME OF VACUUM VESSEL 1643 cu.m

Parameters:

Line o.d.	406.4 mm.	=	16.00 in
Line wall	4.19 mm.	=	0.16 in
Line i.d.	398.02 mm.	=	15.67 in
Length of line	35 m.		
Volume of line	4.35 cu.m.		
Total pumped volume	1647 cu.m.		
Pumping Speed	850 cu.m./hr.	236 litres / sec.	500 cu.ft. / min.
Pump Down Factor (1 bar - 10 mbar)	4.6		
Pump Down Time (1bar-10 mbar.)	8.92 hr.		

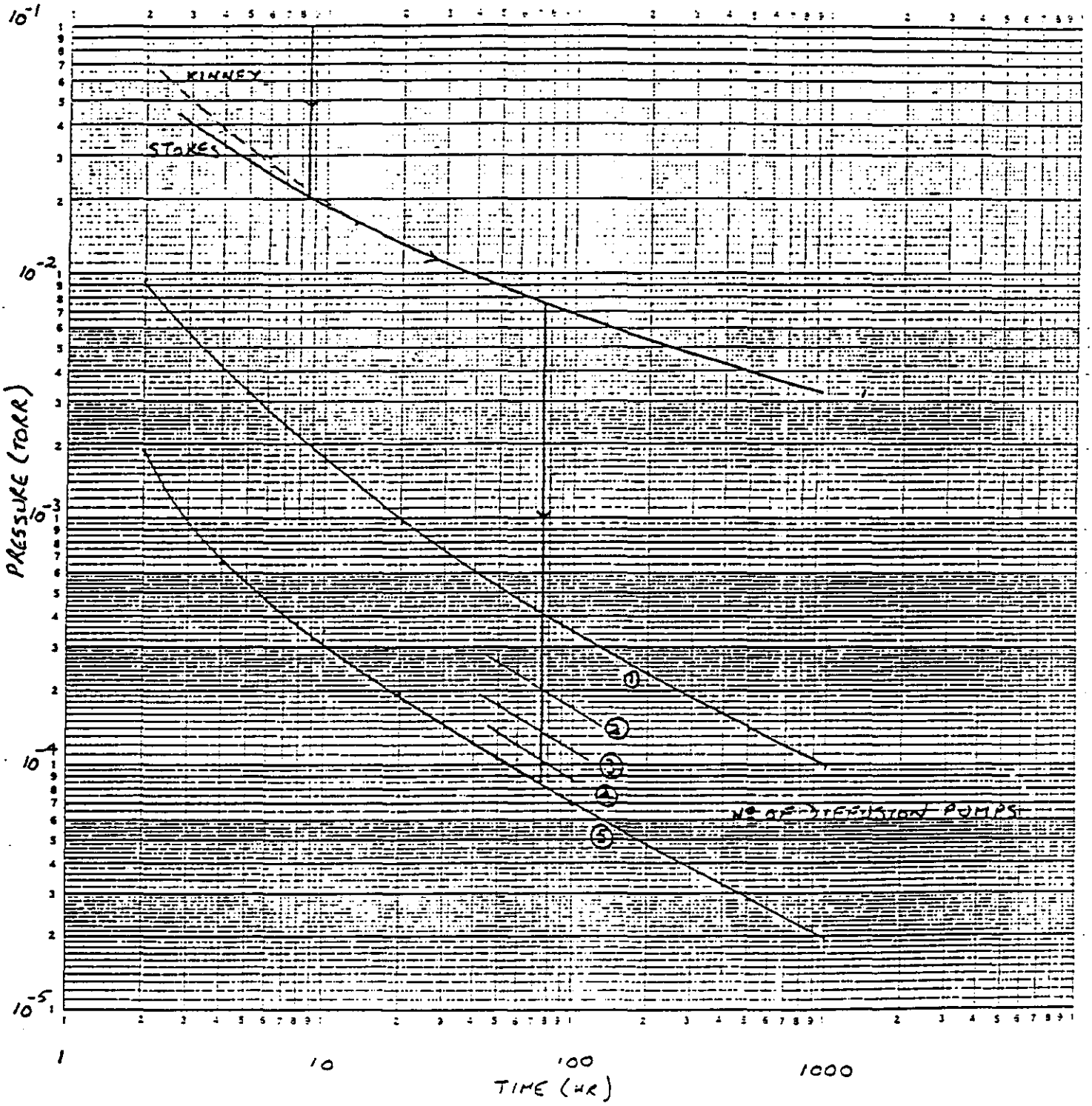
Roughing System Pumped by Rootes Pump
Kinney Model KMBD-4000 backed by Kinney KT-500.

NOTE: Target vessel pressure is 0.01 mbar = 0.0075 torr.

Iteration 13

Pump Pressure (torr)	Pump Speed (l./sec.)	Throughput (l.- torr/sec.)	Visc. Cond. (l./sec.)	Mol. Cond. (l./sec.)	Total Cond. (l./sec.)	Vessel Pressure (torr)	Speed at Vessel (l./sec.)	Interval Pump Down Time (hrs.)	Cumulative Pump Down Time (hrs.)
10	1213	1.213E+04	1281980.6	176.6	1282157.2	10.0095	1211.7		8.92
7	1303	9.118E+03	897612.8	176.6	897789.4	7.0102	1300.6	0.13	9.05
5	1373	6.866E+03	641373.0	176.6	641549.6	5.0107	1370.4	0.11	9.16
3	1465	4.396E+03	385143.3	176.6	385319.9	3.0114	1459.8	0.16	9.33
2	1529	3.058E+03	257036.6	176.6	257213.2	2.0119	1520.0	0.12	9.45
1	1605	1.605E+03	128933.7	176.6	129110.3	1.0124	1584.8	0.20	9.65
0.7	1628	1.140E+03	90501.5	176.6	90678.1	0.7126	1599.4	0.10	9.76
0.5	1642	8.211E+02	64877.4	176.6	65054.0	0.5126	1601.8	0.09	9.85
0.3	1661	4.983E+02	39251.0	176.6	39427.6	0.3126	1594.0	0.14	9.99
0.2	1661	3.322E+02	26427.6	176.6	26604.2	0.2125	1563.5	0.11	10.10
0.1	1642	1.642E+02	13578.7	176.6	13755.3	0.1119	1467.1	0.19	10.29
0.07	1623	1.136E+02	9706.3	176.6	9883.0	0.0815	1394.4	0.10	10.40
0.05	1605	8.023E+01	7112.1	176.7	7288.7	0.0610	1315.0	0.10	10.49
0.03	1557	4.672E+01	4486.1	176.7	4662.8	0.0400	1167.4	0.16	10.65
0.02	1510	3.020E+01	3145.3	176.7	3322.0	0.0291	1038.2	0.13	10.78
0.01	1402	1.402E+01	1747.9	176.8	1924.8	0.0173	811.0	0.25	11.04
7E-03	1331	9.316E+00	1300.8	176.9	1477.8	0.0133	700.2	0.16	11.20
5E-03	1246	6.229E+00	984.3	177.0	1161.4	0.0104	601.1	0.18	11.37
3E-03	1123	3.370E+00	646.5	177.3	823.7	0.0071	475.2	0.32	11.69
2E-03	1000	2.001E+00	458.0	177.5	635.5	0.0051	388.6	0.34	12.03
1E-03	1227	1.227E+00	294.5	178.0	472.5	0.0036	341.1	0.45	12.48
7E-04	609	4.261E-01	168.3	179.0	347.3	0.0019	221.1	1.01	13.49
5E-04	472	2.360E-01	115.3	180.0	295.3	0.0013	181.6	0.89	14.39
3E-04	231	6.937E-02	57.0	183.0	240.0	0.0006	117.8	2.41	16.80
2E-04	0	9.438E-05	25.7	188.6	214.2	0.0002	0.5	8.32	25.12
1E-04	0	4.719E-05	12.8	195.2	208.0	0.0001	0.5	671.79	696.91

Pump Pressure (torr)	Pump Speed (l./sec.)	Throughput (l.- torr/sec.)	Vessel Pressure (torr)	Time (hr.)	Outgassing Load (l.-torr/sec.)	Time (hr.)
10	1.21E+03	1.21E+04	1.00E+01		9.94E+01	2
7	1.30E+03	9.12E+03	7.01E+00		6.05E+01	3
5	1.37E+03	6.87E+03	5.01E+00		3.45E+01	5
3	1.47E+03	4.40E+03	3.01E+00		2.47E+01	7
2	1.53E+03	3.06E+03	2.01E+00		1.81E+01	10
1	1.60E+03	1.60E+03	1.01E+00		1.03E+01	20
0.7	1.63E+03	1.14E+03	7.13E-01		7.83E+00	30
0.5	1.64E+03	8.21E+02	5.13E-01		5.57E+00	50
0.3	1.66E+03	4.98E+02	3.13E-01		4.54E+00	70
0.2	1.66E+03	3.32E+02	2.12E-01		3.63E+00	100
0.1	1.64E+03	1.64E+02	1.12E-01		2.44E+00	200
0.07	1.62E+03	1.14E+02	8.15E-02		1.93E+00	300
0.05	1.60E+03	8.02E+01	6.10E-02	2.4	1.47E+00	500
0.03	1.56E+03	4.67E+01	4.00E-02	3.8	1.24E+00	700
0.02	1.51E+03	3.02E+01	2.91E-02	6.0	1.02E+00	1000
0.01	1.40E+03	1.40E+01	1.73E-02	10.7		
7E-03	1.33E+03	9.32E+00	1.33E-02	23.0		
5E-03	1.25E+03	6.23E+00	1.04E-02	42.0		
3E-03	1.12E+03	3.37E+00	7.09E-03	110.0		
2E-03	1.00E+03	2.00E+00	5.15E-03	270.0		
1E-03	1.23E+03	1.23E+00	3.60E-03	650.0		
7E-04	6.09E+02	4.26E-01	1.93E-03			
5E-04	4.72E+02	2.36E-01	1.30E-03			
3E-04	2.31E+02	6.94E-02	5.89E-04			
2E-04	4.72E-01	9.44E-05	2.00E-04			
1E-04	4.72E-01	4.72E-05	1.00E-04			

PUMP DOWN CURVE FOR GEM SOLENOID

DIFFUSION PUMPS