THE DESIGN AND CONSTRUCTION OF A UHV TEST SYSTEM TO EVALUATE A MAGNETRON PUMP-GAUGE

THE DESIGN AND CONSTRUCTION OF A UHV TEST SYSTEM TO EVALUATE A MAGNETRON PUMP-GAUGE

by

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ABSTRACT

The design, construction, and initial operation of an ultra high vacuum testing system was undertaken. The final UHV system is equipped with a residual gas analyser (RGA).

The system was used to test a National Research Council of Canada magnetron pump-gauge. The pumping action of the device was adequate with speeds of litres/second for hydrogen and other chemically active species. A speed of ≈0.3 L/S was measured for methane (CH_4). The pressure measuring capabilities of this particular pump may be in question due to the presence of surface leakage currents.

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CHAPTER 1

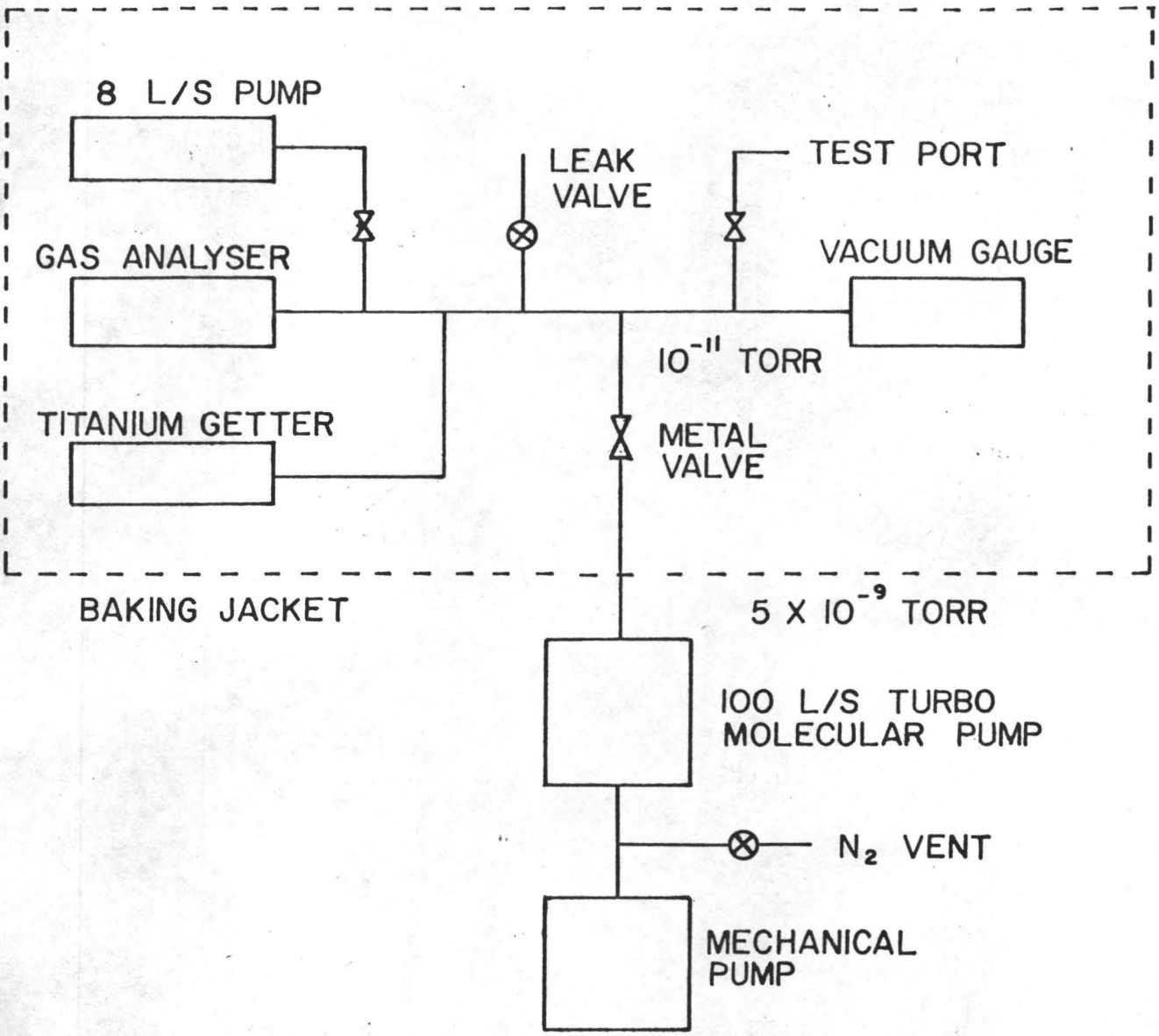
INTRODUCTION

1.1 Ultra High Vacuum Testing System

The importance of UHV (Ultra High Vacuum) conditions is only now beginning to be appreciated. The most noted area to derive benefit from the routine attainment of less than 10^{-8} Torr vacuum systems is surface science. The interference and distortion of surface analysis via residual gases has long been recognized, but only in recent years has the problem been partially eliminated due to improved techniques of vacuum technology.

The objective of this experimental work was to design, engineer and construct a UHV testing system. Upon the subsequent attainment of $<10^{-9}$ Torr, testing was to commence on a National Research Council (NRC) magnetron ion pump. E.V. Kornelson (1960) first tested the getter-ion pump based on the geometry of a magnetron gauge.[1] The magnetron pump, or similar versions, have been the "work-horse" of the NRC vacuum research facilities in Ottawa for some time.

Figure 1 shows a schematic of the constructed stainless steel testing system. The main features of the system are a 100 L/S Leybold Heraeus turbo-molecular pump, a modulated Bayard Alpert ionization gauage capable of monitoring pressures down to 10^{-11} Torr; and a Leybold Heraeus Quadravac Q200 residual gas analyser. Other components of the system



- GAS ANALYSER - 10^{-13} TORR PARTIAL PRESSURE
- VACUUM GAUGE (MODULATED) - 10^{-11} TORR
- TEST PORT FOR TESTING MAGNETRON

FIG. 1: SCHEMATIC OF THE TESTING SYSTEM

are a test port for the magnetron pump, a bakeout oven capable of 450°C and a precision leak valve for introduction of various gases into the system.

1.2 Design Considerations

In view of the face that the system was to attain 10^{-10} Torr routinely, it was necessary to design a chamber of minimum surface area to reduce the gas load due to ougasing of the stainless steel. The system had to be capable of being baked to 450°C in order to further degas the chamber walls. This requirement necessitated the use of all metal valves. It was essential to construct an oven which would safely provide the desired temperatures.

The final system has a volume of approximately 1.6 litres and a surface area of 2.02×10^3 cm^2.

1.3 Modular Bakeout Oven

To allow for system to system flexibility a modular concept was used when designing the bakeout oven. Insulated aluminum panels were designed to be fastened together into an oven of approximate dimensions 1m x 1m x 1m. The oven was resistance heated with incoloy sheathed elements. The oven was designed to attain 450°C within 2 hours, with a charge of 50 kg of stainless steel. The power consumption of the 240 volt, 3 phase unit was 6.5 k watts. See Appendix 1 for further design details.

1.4 Ultimate Pressure

One of the prime considerations in the design and initial pumpdown of a vacuum system is its final or ultimate pressure. In most cases the simple formula relating effective pump speed (S_E), total gas load (Q_T) and pressure is sufficient.

$$P_{ULTIMATE} = \frac{Q_{TOTAL}}{S_E} \quad (3) \qquad (1)$$

The effective speed S_E of a pump connected to a chamber via conductances C_1, C_2, ... C_R, is given as

$$\frac{1}{S_E} = \frac{1}{S} + \frac{1}{C_1} + \frac{1}{C_2} \cdots \frac{1}{C_R} \quad (3) \qquad (2)$$

The gas load pumped in a UHV system is a virtual leak formed by the outgassing of the materials under vacuum. A typical value for stainless steel which has been under vacuum for more than 6 hours is $\simeq 3.75 \times 10^{-10}$ (2) Torr L/S cm^2. Thus with an effective pumping speed of 17 L/S the ultimate pressure on the testing station was approximately 5×10^{-8} Torr. We then saw the value of instrumenting bakeout procedures to accelerate the outgassing of the stainless steel. After extended baking at elevated temperatures the outgassing rate of hydrogen (the major outgassed species) may be reduced to $\simeq 2 \times 10^{-12}$ Torr L/S cm^2.(3) This permits an ultimate pressure of 2.0×10^{-10} Torr. Details of calculations shown in Appendix 2.

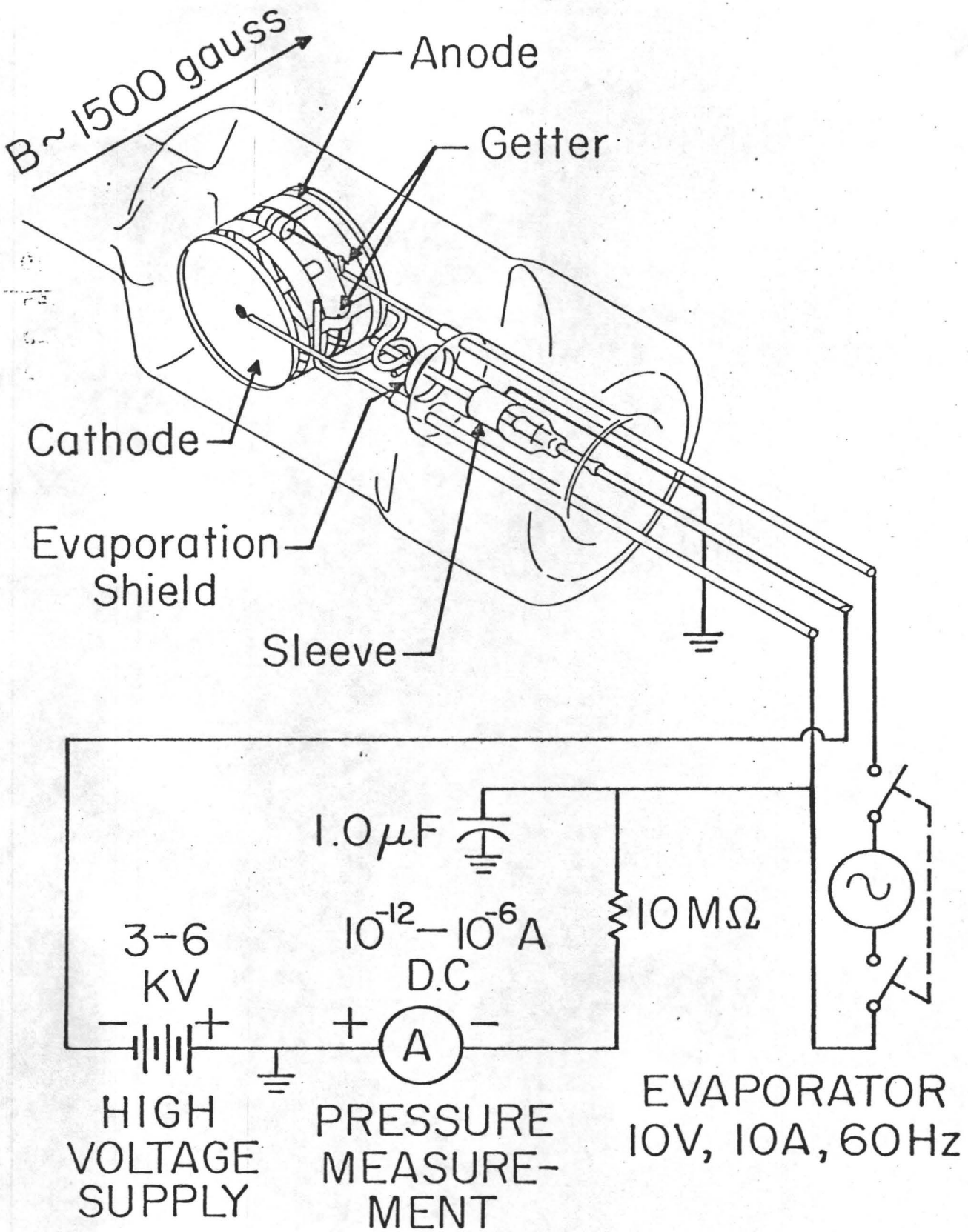


FIG. 3 Detailed schematic of the Magnetron Pump-Gauge with outline of electronics

1.5 The Magnetron Pump-Gauge

The magnetron pump-gauge is an ultra-high vacuum device which resulted from the combination of various NRC devices. These devices were (a) cold cathode magnetron geometry yielding a small ion pump, first proposed by Kornelsen,[4] and (b) cold cathode magnetron gauge developed by Redhead.[5] The complete unit is shown in Fig. 2.[6]

The pump is housed in a Pyrex glass envelope. The cathode-anode assembly create the desired radial electric field to which an external perpendicular magnetic field is applied via a permanent magnet. The strength of the magnetic field is approximately 1500 gauss, while the electric potential may be varied from 3 kv to 6 kv. The pump is also equipped with a titanium getter. This allows for the renewing of the cold cathode pumping surface by evaporation of the titanium element. The original electrons responsible for the spontaneous ionization of the gas phase may arise from field emission at the cathode or from some other spontaneous event such as photo-emission. The pumping speed for the chemically active gases is reported to be tens of liters per second, while speeds of approximately 0.5 liters per second have been reported for the inert gases.[1]

CHAPTER 2

PREPARATION, RESULTS, AND DISCUSSION

2.1 Attainment of Ultra High Vacuum

The first step in processing the UHV system from high vacuum ($<10^{-8}$ Torr) was a final outgassing of all interior surfaces. This was accomplished by baking the system for an extended period of time. The designed bakeout oven was not completed at this point and heating tapes were wrapped around the outside surfaces of the system. It was also necessary to outgas the ionization gauge and the residual gas analyser. Both of these devices were outgassed via electron bombardment of the internal surfaces, the source of the electrons being the hot filaments. Monitoring the residul gases during such an outgassing mode revealed large amounts of hydrogen, and hydrocarbons were released into the system and subsequently pumped by the turbomolecular pump. Table 1 shows the results of the above process.

The ultimate pressure attained by the system was 8×10^{-10} Torr, with the dominant gas being hydrogen. This would seem to indicate that the stainless steel walls of the chamber and components are continuing to release hydrogen from the bulk at a rate not conducive to UHV conditions.

Table 1

Residual Gases Before and After Bakeout

	Major Residual Gases		
Before Bakeout	H_2	$H_2O + CH_4$	N_2
$P_{TOTAL} = 5 \times 10^{-7}$ Torr	≃75%	≃19%	≃6%
Partial Pressures	8.2×10^{-7} Torr	7.9×10^{-8} Torr	3×10^{-8} Torr
After 12 hr. Bakeout			
$P_{TOTAL} = 8 \times 10^{-9}$ Torr	≃95%	≃2.5%	≃2.5%
Partial Pressures	1.7×10^{-8} Torr	1.7×10^{-10} Torr	2×10^{-10} Torr

Relative ionization sensitivity, S/S_{N2}: 0.46(H_z); 1.4(CH_4); 1.0(H_2O)

2.2 Processing of the Magnetron Pump-Gauge

At the same time that the ionization gauge and R6A were being outgassed a preliminary outgassing of the magnetron pump-gauge getter was undertaken. The procedure was to run a 2A current through the getter and allow it to heat up and subsequently release trapped or absorbed gas molecules. The pressure in the system was observed to rise to a maximum value and then decline. The 2A current was maintained until the pressure fell below 10^{-7} Torr. The same process was then repeated but with a 3A current until the total pressure was again below 10^{-7} Torr. The current was raised at the completion of each cycle in 1A intervals and the final cycle was to maintain 6A until the chamber pressure was below 1×10^{-8} Torr. The completion of this preliminary outgassing took

approximately 5 hours.

The final outgassing of the getter required further current cycling of the titanium element. The getter was flashed at 8A for 20 seconds with 40 seconds off until the peak pressure during a cycle did not rise above 1×10^{-8} Torr. It should be noted that above 6A the getter begins to evaporate and forms a thin film of titanium on the inside of the pump-gauge and on the wall of the device. The film was detectable visually, as a discolouration of the glass surface.

2.3 Leakage Current

Hobson established earlier[6] that the magnetron pump-gauge would be rendered useless as a pressure measuring device if the leakage current between the cathode and anode could not be routinely reduced to fairly insignificant values. A plot of the Fowler-Nordheim equation ($\log I/V^2$ vs. $1/V$) revealed that the leakage currents were consistent with field emission from the cathode. It was presumed that the evaporation of titanium on the cathode created whiskers from which field emission took place. Hobson reported that a DC pulse with polarity + on the anode and a total energy of ~50 millijoules was partially successful in removing the leakage current.

For this reason the leakage current was monitored during the final outgassing of the titanium getters. The leakage current in the pump-gauge was measured every 10 flashes of the getter. Figure 3(A) indicates the typical I-V characteristics of the pump-gauge prior to the application of the + anode pulse.

FIG. 3 - THE TYPICAL LEAKAGE CURRENTS.

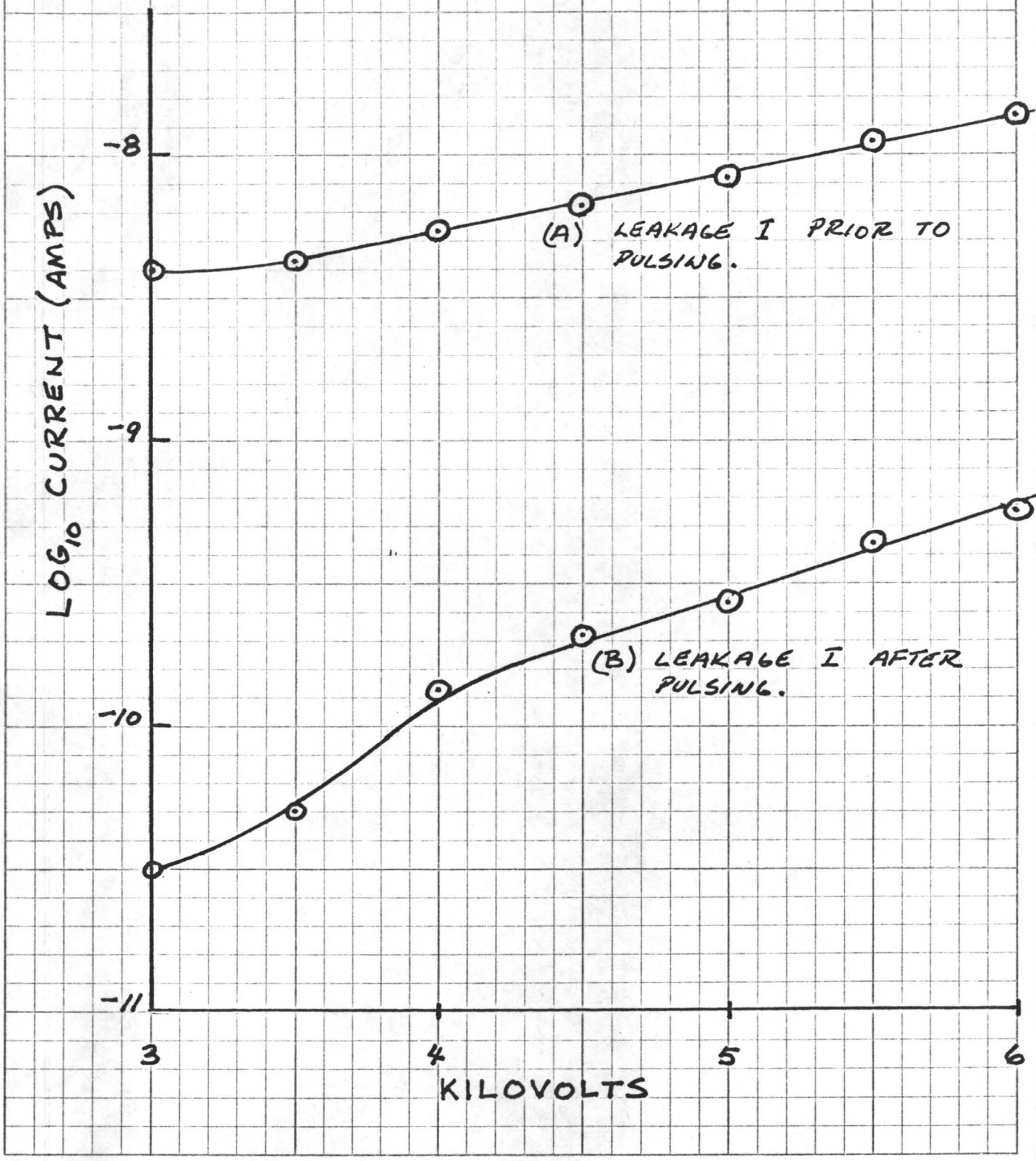
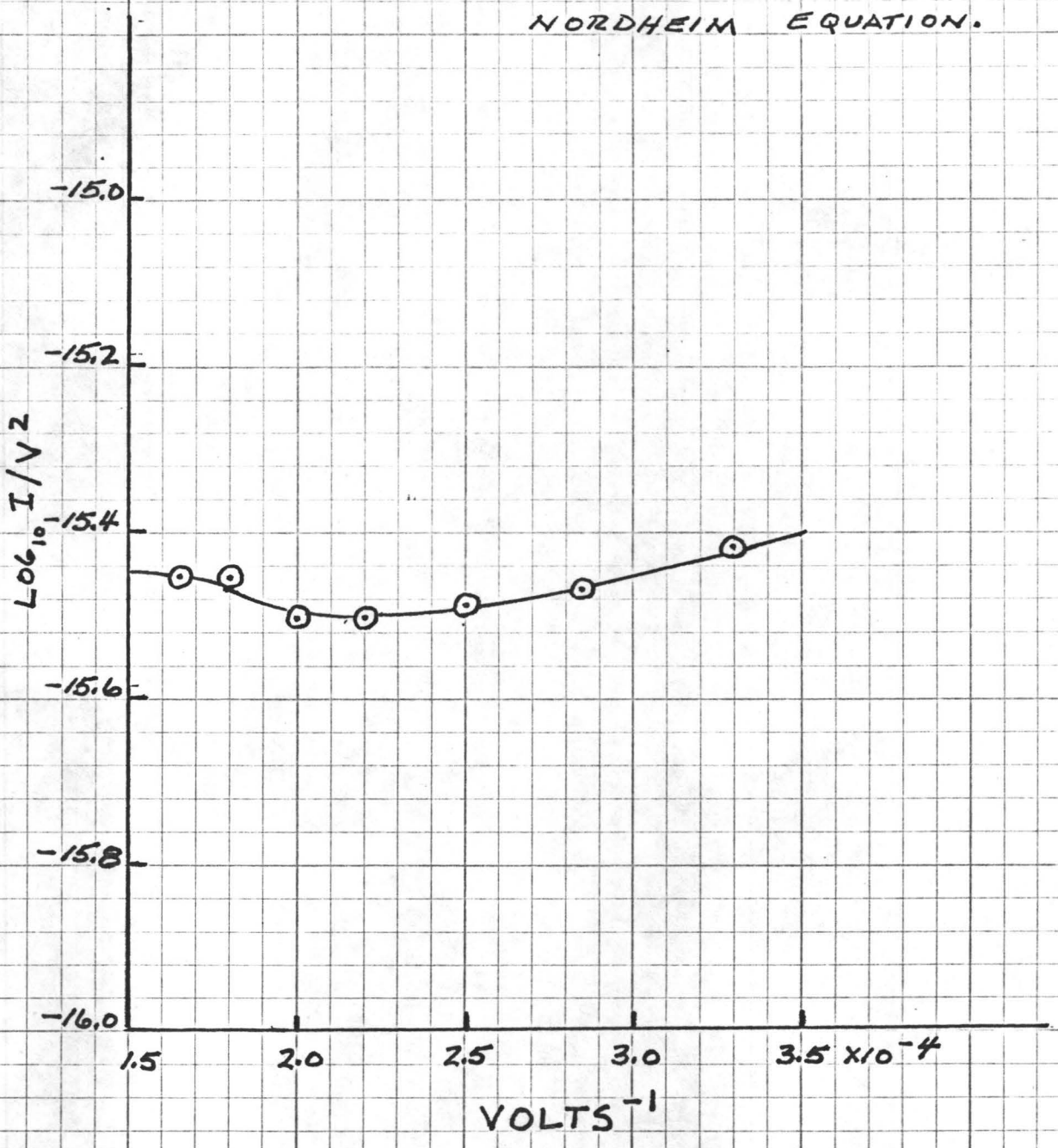


FIG. 4 - TEST OF DATA CONSISTENCY WITH THE FOWLER-NORDHEIM EQUATION.



Using the same criteria as Hobson,[6] the Fowler-Nodheim equation, it is not certain that the residual leakage current is consistent with field emission from the cathode. Figure 4 is a plot of the same data presented in Figure 3(a). If the residual current had been consistent with field emission, the plot of log I/V^2 vs. I/V would have been a straight line.

It may be possible that the leakage current, in the case of this magnetron pump, is caused or is dominated by surface currents between the connection pins for the anode and cathode. Unlike the pump-gauge illustrated in Fig. 2, this magnetron device did not have the protective shield in the form of a sleeve over the central cathode lead. The possibility exists that the central high voltage cathode lead may require shielding during the evaporation process to prevent the construction of conductive paths that will lead to surface current leakage.

2.4 Reduction of Leakage Current

Following the application of the + pulse to the anode it was apparent that the leakage current had been reduced significantly. The I-V characteristics shown in Fig. 3(b) now fall well within the guidelines established by Hobson.[6] The overall characteristic has been improved by an order of magnitude to place the residual current within a range that will prevent it from interfering with the pressure measurements. However, the origin of this residual current is still uncertain.

2.5 Pumping Capabilities

At this point the magnetron pump-gauge was ready to be used as the primary pumping on the main chamber. It should be pointed out that the system was hydrogen dominated due to the lack of a good 450°C bake. With the turbomolecular pump valved off the magnetron pump was able to maintain the system pressure at 5×10^{-9} Torr without renewal of the titanium deposits. It is thought that had the system received a good high temperature bake that much of the hydrogen and carbon monoxide would have been reduced, thus not saturating the gettering process. We can only estimate the pumping speed of these chemically active species to be of the order of liters per second because the magnetron pump was able to maintain approximately the same pressure as the turbomolecular pump which was limited by a 1 L/S conductance.

Methane (CH_4) was monitored to measure the ionic pumping capabilities of the magnetron pump. This is an inert species and can only be pumped ionically. The procedure was to let the total pressure in the system rise to an equilibrium value with the magnetron shut off. Then while observing the CH_4 peak on the residual gas analyser the pump was turned on at 6 kV. The pressure was measured as a function of time and the resulting values corrected from N_2 equivalents using the appropriate sensitivity factor. Using the simple formula

$$\frac{dp}{dt} = -\frac{s}{V} p + (p_o - p) f(t)^{(1)} \qquad (3)$$

in which:

$f(t)$ = re-emission probability = 0,

p_o = starting pressure = 8.0×10^{-10} Torr,

p = final pressure = 3.3×10^{-10} Torr,

$\frac{dp}{dt} = 7 \times 10^{-10}$ Torr/sec,

V = volume = 1.59L.

Therefore

$$S \simeq 0.3 \text{ L/S}$$

Thus the approximate pumping speed of methane (CH_4) is 0.3 L/S.

2.6 Conclusions

The system as designed was able to attain ultra high vacuum, with the ultimate pressure measured to date being 8×10^{-10} Torr (N_2 equivalents). It is felt that the low 10^{-10} Torr range will be routinely attained with the use of the designed bakeout oven and titantium getters to clean up the system.

The results of the magnetron pump testing:

1. The magnetron pump-gauge was able to maintain the system at a pressure of 5×10^{-9} Torr with the residual gas being hydrogen (>95%).
2. Using the Fowler-Nordheim equation it is not definite that the leakage current between the cathode and anode is due to field emission. The cause may in fact be surface leakage between the central cathode and anode because of inappropriate shielding during evaporation of the titanium getter.

3. The residual leakage current between the cathode and anode was reduced to acceptable levels[6] following the application of a + pulse to the anode. This reduction ensures that the device will be capable of operating as a pressure gauge.
4. The estimated overall pumping speed for a hydrogen dominated system is of the order of liters per second.
5. The estimated pumping speed of CH_4 is about 0.3 L/s.

APPENDIX 1

CALCULATION FOR BAKEOUT OVENS

Basic Heat Equations

1. Power Loss to Insulation = $\frac{\varepsilon \times A \times \Delta T}{t}$

   ε = thermal conductivity = 0.1 Watts/m°C

   A = area = $6m^2$

   $\Delta t = 7.5 \times 10^{-2}$ m

   Power Loss to Insulation = 3.2 kW.

2. Power Loss to S.S. Chamber = $\frac{S_1 \times W \times \Delta T}{\Delta t}$

   S_1 = specific heat of stainless steel = 0.12

   W = weight of S.S. ≃ 45.5 Kg

   ΔT = 400°C

   Δt ≃ 2 hrs.

   Power Absorbed by S.S. Chamber ≃ 1.5 kw.

3. Power Absorbed by air ≃ 0.

   Therefore: Total Power Consumption ≃ 4.7 k Watt

   Thus, this 4.7 k Watt oven should be able to attain temperatures of 400°C with a charge of 45 kg of stainless steel. The approximate rise time would be 2 hours.

APPENDIX 2

CALCULATION OF ULTIMATE PRESSURE

$$P_{ULTIMATE} = \frac{Q_{TOTAL}}{S_{EFFECT}}$$

$$\frac{1}{S_{EFFECT}} = \frac{1}{S} + \frac{1}{C_1} + \frac{1}{C_2} + \cdots \frac{1}{C_n}$$

(i) Under Vacuum of 6 Hours

AREA OF SYSTEM (S.S.) $\simeq 2.02 \times 10^3$ cm^2

$q_{(S.S)} = 3.75 \times 10^{-10}$ Torr L/$_S$ cm^2

Therefore

$Q_{TOTAL} \simeq 7.6 \times 10^{-7}$ Torr L/S

$S_{PUMP} = 30$ L/S at L 10^{-6} Torr

$C_{VALVE} = 42$ L/S

Therefore

$S_{EFFECT} \simeq 18$ L/S

Therefore

$S_{ULT} \simeq 5 \times 10^{-8}$ Torr

(ii) After extended bakeout of elevated temperatures

$$q_{S.S} \simeq 2 \times 10^{-12} \text{ Torr L/S cm}^2$$

$$Q_{TOTAL} = 4.0 \times 10^{-9} \text{ Torr L/S}$$

Therefore

$$P_{ULT} \simeq 2 \times 10^{-10} \text{ Torr}$$

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