

STUDY OF DENSITY CALIBRATION IN SPACE

by F. Feakes and F. J. Brock

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FOREWORD

This Final Report covers the work performed under contract NAS5-3959 from 18 June 1964 to 18 August 1965.

The contract with National Research Corporation, Cambridge, Massachusetts was initiated by National Aeronautics and Space Administration, Goddard Space Flight Center for the "Study of Density Calibration in Space." The work has been accomplished under the technical direction of Mr. George P. Newton (Code 651) of the Goddard Space Flight Center, Greenbelt, Maryland.

Mr. F. J. Brock of National Research Corporation's Research Division was the Program Director. Others who have contributed to the research covered in this report include Dr. F. Feakes (principal investigator), Mr. F. L. Torney, Jr. and Mr. J. R. Roehrig.

PUBLICATION REVIEW

Approved by:



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SUMMARY

Under National Aeronautics and Space Administration Contract NAS5-3959, during the past year, the National Research Corporation has developed a method of in-flight calibration for satellite mass spectrometers and pressure gauges. In this method, a precise gas flux is generated by diffusing hydrogen from a small supply vessel through the wall of a small, thin wall, stainless steel diffuser tube. The hydrogen flux is a function of the temperature of the diffuser tube and the hydrogen pressure in the diffuser tube; however, the flux is so small that the pressure in the supply volume is substantially constant for the anticipated life of the calibrator. Thus, the hydrogen flux is reduced to a function of temperature only. The diffuser tube temperature is controlled by applying a specified power for a prescribed time interval to a small tungsten heater inside the diffuser tube. The hydrogen flux, thus generated, flows directly into the mass spectrometer or gauge enclosure and is finally exhausted overboard through a restrictive conductance. Thus, during the time interval that the diffuser tube is at equilibrium temperature, the hydrogen pressure in the instrument enclosure is maintained constant at an elevated level which is equal to the ratio of diffuser throughput to exhaust conductance.

Under the program, a prototype in-flight calibration system was designed, constructed, and experimentally evaluated. The system consisted of a controlled pressure hydrogen storage volume having provisions for vacuum degassing, the hydrogen diffuser, the diffuser internal heater (with associated thermometers, power supplies, control circuits and recorders), a Nottingham ion gauge (with associated power supplies, electrometer and recorder), a restrictive conductance of known value, and an ultrahigh vacuum system.

The results obtained from the experimental evaluation of this first (Mark I) prototype in-flight calibrator were applied to the design of a second generation, Mark II prototype to improve the performance characteristics. The Mark II calibrator was experimentally evaluated with the following results: power consumption was less than 5 watts; the dynamic range (H_2 flux at maximum diffuser temperature/ H_2 flux with diffuser cold) was approximately 2×10^3 ; the heating period to reach maximum hydrogen flux was less than 3.5 minutes; the cool-down period was less than 15 minutes (except for maximum temperature operation); a prescribed hydrogen flux was maintained constant to $\pm 1\%$ for periods greater than 10 seconds; and, prescribed hydrogen fluxes were repeatable within $\pm 1\%$.

While these performance characteristics satisfied the initial objectives of the program, it appeared desirable to increase the dynamic range for proposed flight applications. Consequently, a Mark III prototype in-flight calibrator was designed and constructed.

A number of basic changes were included in the Mark III calibrator in order to improve the operating characteristics, especially those pertaining to reproducibility, rate of response and low pressure performance. Further work is required to experimentally evaluate the Mark III design.

INTRODUCTION

The objective of this program was to design, construct and test the prototype of an in-flight calibration system for use with an ion gauge or mass spectrometer on an orbiting satellite. The method of calibration selected was based on the production of a known pressure in the gauge envelope by controlling the rate of flow of gas into and out of the gauge volume. The general system is shown in Figure 1. During periods when the gauge would be used for measuring the pressure external to the satellite (P_0), gas would not be added to the gauge volume so that the pressure in the gauge volume (P_G) would be equal to P_0 .

During calibration, a flow of gas Q would be added to the gauge volume such that

$$Q = C(P_G - P_0),$$

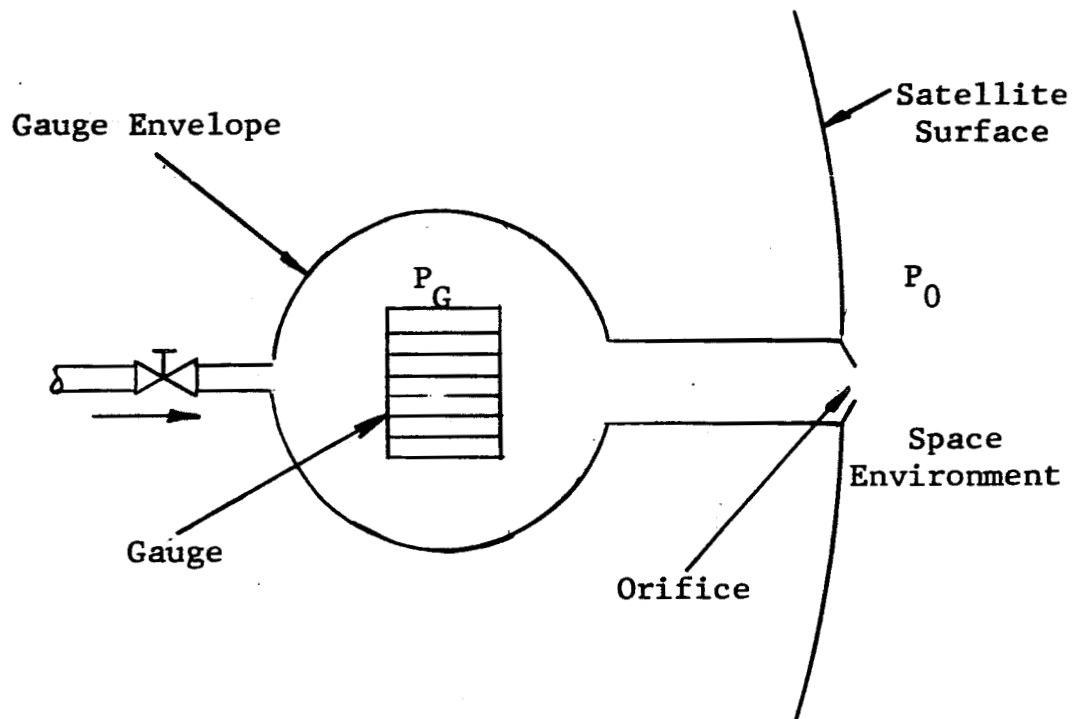
where C = conductance between gauge and satellite exterior.

Therefore:

$$P_G = Q/C + P_0.$$

Consequently, by regulating the ratio of Q/C , the gauge pressure P_G may be brought to any desired value for calibration. If required, P_G may be increased such that P_0 is negligible compared to P_G .

Although the design details are dependent on the specifics of a satellite mission, gauge system, etc., it was necessary to include a number of general requirements in the prototype



$$Q = C(P_G - P_0)$$

or

$$P_G = Q/C + P_0$$

P_0 = Pressure outside satellite (Torr).
 P_G = Pressure in gauge volume (Torr).
 C = Effective conductance of orifice and tubulation (liters/sec.).
 Q = Flow rate of calibration gas (Torr liters/sec.).

FIGURE 1
 SYSTEM FOR GAUGE CALIBRATION IN SPACE

design. The most important considerations were the following:

Since a satellite may spin at a relatively high rate, the gauge system must have a short response time in order to accurately measure pressure variations during satellite rotation. This required that the gauge volume be small and that the value of the conductance (C) between the gauge volume and the outside of the satellite be large.

It was also important that both the pumping action of the gauge and outgassing of both the gauge envelope and the calibration apparatus be kept at very low values. With the use of good ultrahigh vacuum techniques involving high temperature bakeout and vacuum grade materials, the outgassing rate should be less than 10^{-12} Torr ℓ /sec. cm^2 . (Shrank, Benner, and Das obtained an outgassing rate of 6×10^{-13} Torr ℓ /sec. cm^2 for a glass system which had been outgassed at 400°C for 8 hours.)

In this program, a hot cathode Nottingham gauge was used. The pumping speed was approximately 0.1 ℓ /sec. Hence, in order that the effect of gauge pumping would produce errors of less than 1% in pressure measurements, the conductance (C) of the tubulation and orifice between the gauge and the outside of the satellite was greater than 100×0.1 or 10 ℓ /sec. Such a conductance did not impose any practical limitations - it was equivalent to the conductance of a circular orifice with a diameter of 1.06 cm. for air at 20°C .

However, pressure variations would be produced by satellite roll and it was desirable that the time constant of the gauge system be small enough so that these pressure variations may be measured with reasonable accuracy. It was assumed that the roll frequency of the satellite would not be greater than 3 cycles/sec. A time constant (τ) for the gauge system of 10% of the roll period or $1/30$ of a second was considered low enough to give adequate accuracy. This time constant, together with the required conductance (C) of 10 ℓ /sec. between the gauge and outer space, then required that the volume (V_T) of the entire gauge and calibration system be less than:

$$V_T = C\tau = 10 \times 10^3 \times \frac{1}{30} = 333 \text{ c.c.}$$

A total volume of approximately 300 c.c. was used in the prototype system. The outgassing load of this volume may then be estimated as follows:

Assume the calibration and gauge volume to be a sphere. A sphere of volume 300 c.c. has an internal surface area of approximately 220 cm.² If the outgassing rate is 10⁻¹² Torr ℓ /sec. cm.², and the conductance is 10 ℓ /sec., this would produce a pressure error (P_{OG}) due to outgassing of:

$$P_{OG} = Q_{OG}/C = 220 \times 10^{-13}/10 = 2.2 \times 10^{-11} \text{ Torr.}$$

Such an outgassing load would be negligible at 1 x 10⁻⁹ Torr, the lowest pressure at which calibration was required in this program.

For a gauge operating at 1 x 10⁻⁹ Torr, it was considered desirable to increase the pressure in the gauge system to 1 x 10⁻⁷ Torr for accurate calibration. Under these circumstances, the throughput of gas required to be added to the system was:

$$\begin{aligned} Q &= C(P_1 - P_2) \\ &= 10 \times (10^{-7} - 10^{-9}) \\ &= 9.9 \times 10^{-7} \text{ Torr } \ell/\text{sec.} \end{aligned}$$

For calibration at 10⁻⁷ Torr, the pressure was raised to 1 x 10⁻⁶ Torr. Hence, an addition of 9.0 x 10⁻⁶ Torr ℓ /sec. was required.

METHOD OF CONTROLLING FLOW RATE OF CALIBRATING GAS

The success of the calibration procedure outlined above was largely dependent upon the development of a method of adding the small amounts of gas required for calibration. The method must be reliable, have a high degree of reproducibility and not jeopardize the pressure measurements during periods when calibration is not required. It was also imperative that the calibration be completed within the time that the satellite is in direct communication with a single telemetry station. This required that the calibration period be relatively small - preferably considerably less than, say, the 10 minute period of radio communication with a satellite in circular orbit passing overhead at an altitude of approximately 100 miles.

In order to meet these requirements, a number of methods of controlling low flow rates of calibration gas were studied.

In addition to the use of a calibrated leak and an electrically operated valve, less conventional gas sources and methods of rate control were investigated. Some of these were based on the following principles:

- 1) Variation of the rates of permeation of gases through solids by temperature control.
- 2) Vaporization (sublimation of a solid).
- 3) Thermal desorption of gases from solids.
- 4) Thermal decomposition of a solid to produce a gas.
- 5) Catalytic and electrolytic generation of a gas.

From the various possibilities, two methods were selected for more detailed consideration. They were:

- 1) Addition of gas by means of a small solenoid valve. The required pressure drop would be achieved by either a capillary or porous plug.
- 2) Addition of hydrogen through a metal permeable to hydrogen. The required flow rate and pressure drop would be obtained by varying the temperature of the permeable metal - the permeability of the metal being a single-valued function of its temperature.

Both of these systems have their advantages and disadvantages. For instance:

The procedure involving the use of a solenoid valve would require relatively small amounts of power and would have short response times. It should be possible to approach a step change in gas pressure in the calibration volume using this approach. The choice of the calibration gas is not restricted. However, the design requirements on the valve are stringent. Leakage through the valve may affect pressure measurements at times when calibration is not being carried out. This problem may be circumvented by using a three-way valve and venting the gas from the inlet side of the capillary or porous plug to space. However, this requires that either a much larger gas volume be carried or the number of useful calibrations reduced. In addition, only single point calibration would be possible unless multiple orifices were used.

On the other hand, the thermal valve based on hydrogen permeability should be reliable and free from leakage problems. It would have a low mass. Hydrogen would be a desirable gas for gauge calibration in space. Although the power requirements are probably larger than those for the solenoid valve, early calculations indicated that several watts would probably be sufficient power for a thermal valve.

The rate of response of a thermal valve would be lower than the solenoid valve. However, this may be an advantage in that if continuous data transmission were provided, a number of pressure calibration points would be available. This would give a check on the linearity of the gauge. Calculations indicated that the dynamic response of the thermal valve should give an increase in pressure of 1 to 2 decades within one minute. Theoretically, for a maximum power consumption of 1 watt, a thermal valve using, say, stainless steel or nickel, was expected to give a controllable throughput range of 4 to 5 orders of magnitude. This implied that for a prescribed minimum gauge pressure in orbit, the thermal valve could be designed such that the throughput corresponding to the "off" permeability would induce an error no larger than 1% of the minimum pressure while the throughput corresponding to the "on" permeability would induce a pressure increase in the gauge that is 1 to 2 orders of magnitude above the minimum pressure.

For a thermal valve, relatively small amounts of calibration gas are required to be carried by the satellite. For instance, if a throughput rate of 1×10^{-6} Torr ℓ /sec. is required during calibration, and each calibration takes 1 minute, the volume of gas required for each calibration is 60×10^{-6} Torr ℓ or approximately 10^{-4} std. c.c. This means that 100 calibrations would use only 1% of 1 c.c. of gas. Consequently, with an initial volume of 1 c.c. of hydrogen, 100 calibrations could be made before the pressure of the hydrogen source decreased 1%. Since the permeation rate is proportional to the square root of the pressure for molecular hydrogen, the change in permeation rate would be approximately half of 1%.

The above consideration suggested that a thermal valve based on hydrogen permeation warranted experimental testing. The initial work was encouraging and it became possible to set up a number of design criteria and performance goals which would be compatible with a calibration system for a pressure sensor on a satellite with a highly elliptical orbit. These criteria were as follows:

- 1) System to calibrate a gauge at pressures of 1×10^{-7} Torr and 1×10^{-9} Torr by increasing the pressure with gas addition to 1×10^{-6} Torr and 1×10^{-7} Torr, respectively.
- 2) The calibrating pulses to have less than a 1% effect in subsequent pressure measurements.
- 3) The "rise" time of the calibration pulse to be less than 3.5 min. The pressure then to remain steady at the calibrating level for 10 secs. The pressure level due to calibrating gas must then decrease to negligible values in less than 15 minutes.
- 4) Maximum power consumption of the thermal valve to be less than 5 watts.
- 5) Number of calibrations required: 12. One per month over a 12-month period.
- 6) Volume of gas to be carried: less than 100 c.c.
- 7) Telemetry rate for pressure data: 20-60 samples/sec.
Telemetry rate for temperature data: 20 samples/sec.
- 8) Satellite temperature: -10 to $+50^{\circ}\text{C}$.
- 9) Volume of gauge and conductance to be less than 330 c.c.
- 10) Conductance to exterior of satellite to be greater than 10 ℓ/sec .
- 11) Time constant of system for pressure variations to be less than 0.03 sec.
- 12) Roll frequency of satellite: 3 cps.
- 13) Mass of system to be a minimum.

RESULTS

During the course of this program, three gauge calibrator systems were built. They were designated Mark I, Mark II and Mark III. Experimental results were obtained for the first two designs but further work is required for the detailed evaluation

of Mark III. The basic design features and the major results of each of the designs are discussed below.

Mark I Calibrator

The most important features of the design of Mark I are shown in Figures 2 and 3.

A conventional Nottingham gauge was tubulated onto a vacuum system so that the conductance of the tubulation was approximately 10 ℓ /sec. The hydrogen diffuser with its associated thermocouples was connected onto the main gauge tubulation. The details of the construction of the diffuser are shown in Figure 3. A small tungsten heater was sealed into and insulated from the thin-walled stainless steel (304) tube. A copper-constantan thermocouple was attached to the sealed end of the diffuser. The base of the diffuser was connected to the valves and lines necessary for evacuating and back-filling the interior of the diffuser with hydrogen. The most pertinent results obtained with the Mark I calibrator may be summarized as follows:

- 1) After degassing the gauge and diffuser at approximately 300°C, the pressure in the Nottingham gauge was 2×10^{-10} Torr with the diffuser filled with 1 atmosphere hydrogen at 25°C.
- 2) Pressure variations were introduced within the diffuser tube while held at a constant temperature of 25°C. Hydrogen leakage and hydrogen permeation were below the experimental limit of detectability, although the background pressure in the Nottingham gauge containing the diffuser was 1×10^{-10} Torr.
- 3) An increase in the temperature of the diffuser caused a rapid increase in the pressure within the system. Experimental results clearly indicated that the effect was not the result of surface degassing of the diffuser but rather was hydrogen permeation.
- 4) The pressure in the Nottingham gauge could be increased to approximately 1×10^{-6} Torr by heating the diffuser to about 450°C. The maximum pressure ($P_{\max}$) and the maximum temperature ($T_{\max}$) reached during pulses with heating times of 3 to 5 mins. were related as follows:

$$\log P_{\max} = A + B T_{\max}, \text{ with } A \text{ and } B \text{ constants.}$$

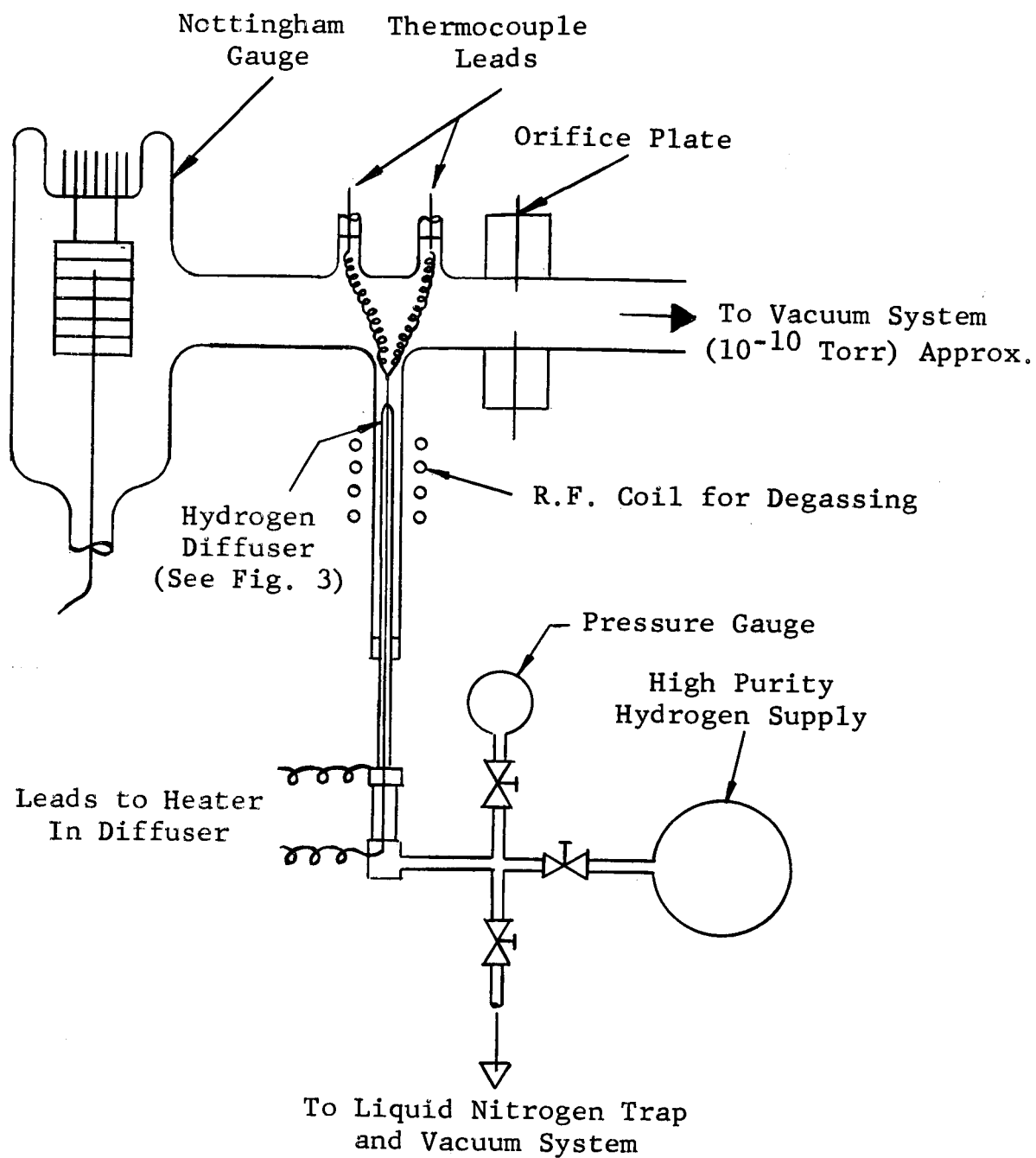


FIGURE 2

APPARATUS FOR MEASURING HYDROGEN PERMEATION RATES (Schematic)

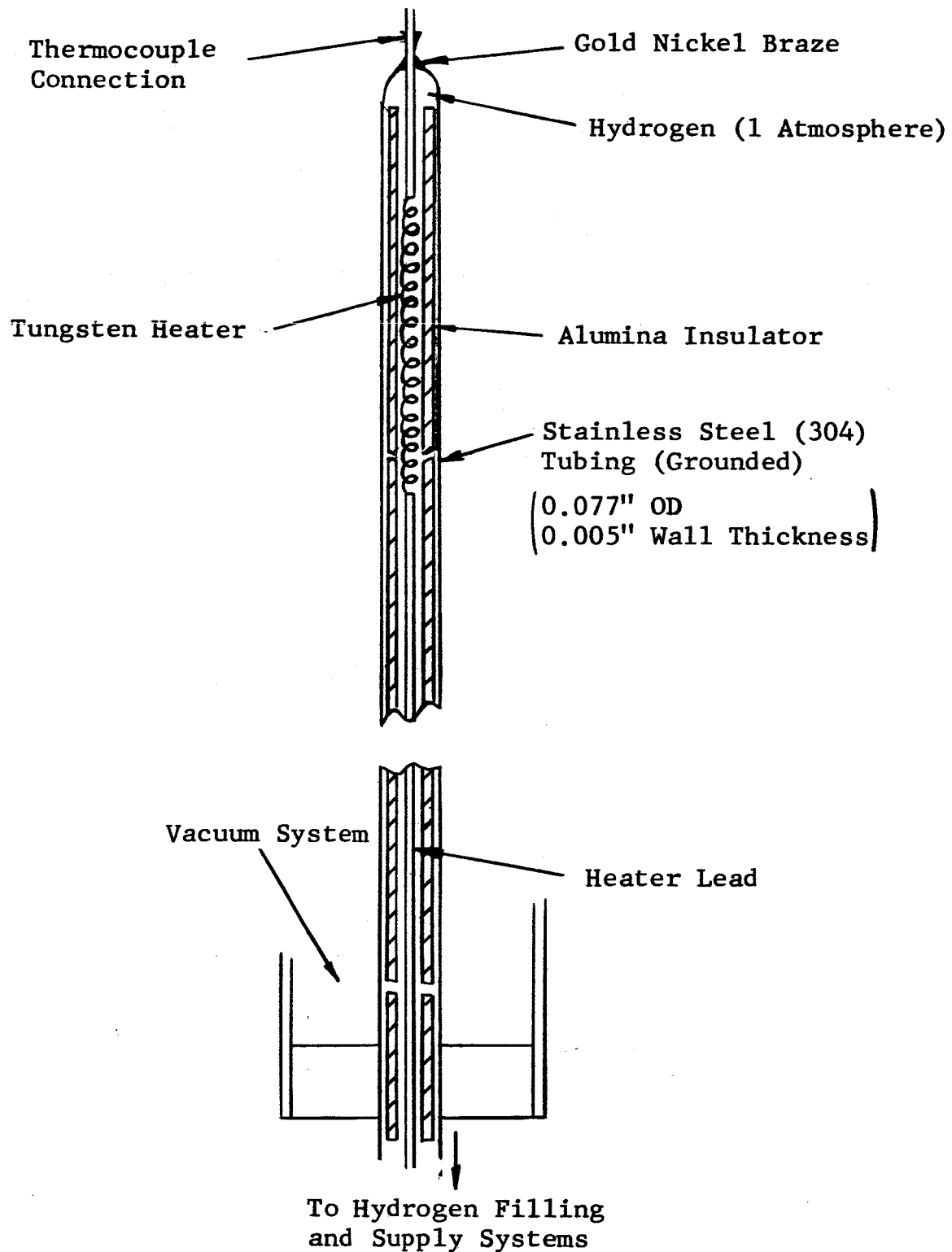


FIGURE 3 PERMEATION APPARATUS AND HEATER ASSEMBLY (Schematic)

- 5) Steady state heating of the diffuser at 400°C for 24 hours showed no change in permeation rate; that is, the permeation rates before and after the 24 hour permeation interval were the same. Within the conditions of the tests conducted to date, the permeation rate appears to be reproducible and a function of temperature only (for a constant hydrogen pressure in the diffuser).
- 6) The following results are typical of the increase in pressure obtained at various power levels, each for heating periods of 60 seconds.

<u>Initial Pressure</u>	<u>Maximum Pressure</u>	<u>Power</u>
4 x 10 ⁻¹⁰ Torr	8.5 x 10 ⁻¹⁰ Torr	0.57 watts
6.5 x 10 ⁻¹⁰ Torr	3.5 x 10 ⁻⁹ Torr	0.96 watts
7.5 x 10 ⁻¹⁰ Torr	8.0 x 10 ⁻⁹ Torr	1.16 watts
9.0 x 10 ⁻¹⁰ Torr	3.8 x 10 ⁻⁹ Torr	1.6 watts

Mark II Calibrator

The analysis of the data from Mark I calibrator suggested that improved performance would be obtained if the diffusing section of the stainless steel tube could be restricted to an isothermal section close to the heater. The Mark II calibrator was constructed to incorporate these changes. The main features incorporated in the new design were:

- 1) An OFHC copper plate was brazed onto the high temperature region of the diffuser. The function of the copper plate was to force that portion of the diffuser through which hydrogen permeation occurred to be isothermal.
- 2) The area of the diffuser through which permeation was not desired was coated with gold by vacuum deposition. The thickness of the gold coat was estimated to be in excess of 1000Å.
- 3) The diffuser was made from 304 LC instead of 304. It was considered that the low carbon 304 stainless steel would reduce the possibility of methane formation which could cause the hydrogen permeability to vary with amount of hydrogen passed through the diffuser.

- 4) The thermal isolation of the diffusing area was reduced in order to increase the rate of cool-down after heating to the required temperature. This was done at the expense of the thermal efficiency but it was expected that the power requirements would still be less than 5 watts.

Before making any measurements with this diffuser, the permeation area was thoroughly degassed at temperatures up to about 650°C with RF and resistance heating. Figure 4 is a time history of the first hydrogen pulse with this diffuser. The data show that there were no gross leaks in the diffuser and that the general performance was satisfactory.

The main emphasis of the experimental work was placed on determining the steady-state permeation rate as a function of temperature. By increasing the temperature to about 430°C, pressures of 1×10^{-6} Torr (N_2) could be produced in the ionization gauge. The heating power required was about 2.9 watts. In all, six steady-state runs were made in order to determine the effect of temperature on permeation rate. The data are summarized in Figure 5. It should be emphasized that in the early runs in the series, the low pressure performance of the system was not as good as for later runs. After repeated degassing of the gauge, diffuser, and sections of the main pumping system, the vacuum performance gradually improved as is evidenced by the data in Figure 5. At the higher temperatures, the data for Run VI are considerably different from previous runs. Shortly after Run No. VI the heater in the diffuser failed and there was evidence that a partial electrical short in the heater may have occurred during Run VI. This could have affected the temperature measurements. Hence, the data of Run VI, particularly at the higher temperatures, is open to doubt. The best data are probably those from Run IV. These have been replotted in Figure 6. According to permeation theory, a plot of permeation rate (or pressure) versus $1/T$ should be linear. At the higher temperatures, the linearity is reasonable and the slope is consistent with published data for stainless steel. At the lower temperatures, the departure from linearity appears to be caused by the following factors:

- 1) The hot filament ion gauge has an X-ray limit of approximately 6×10^{-11} Torr (N_2).

- 2) The background pressure of the vacuum system used to pump the ionization gauge was about 1.8×10^{-10} Torr (N_2). This was confirmed by a magnetron gauge measuring pressure in that system.

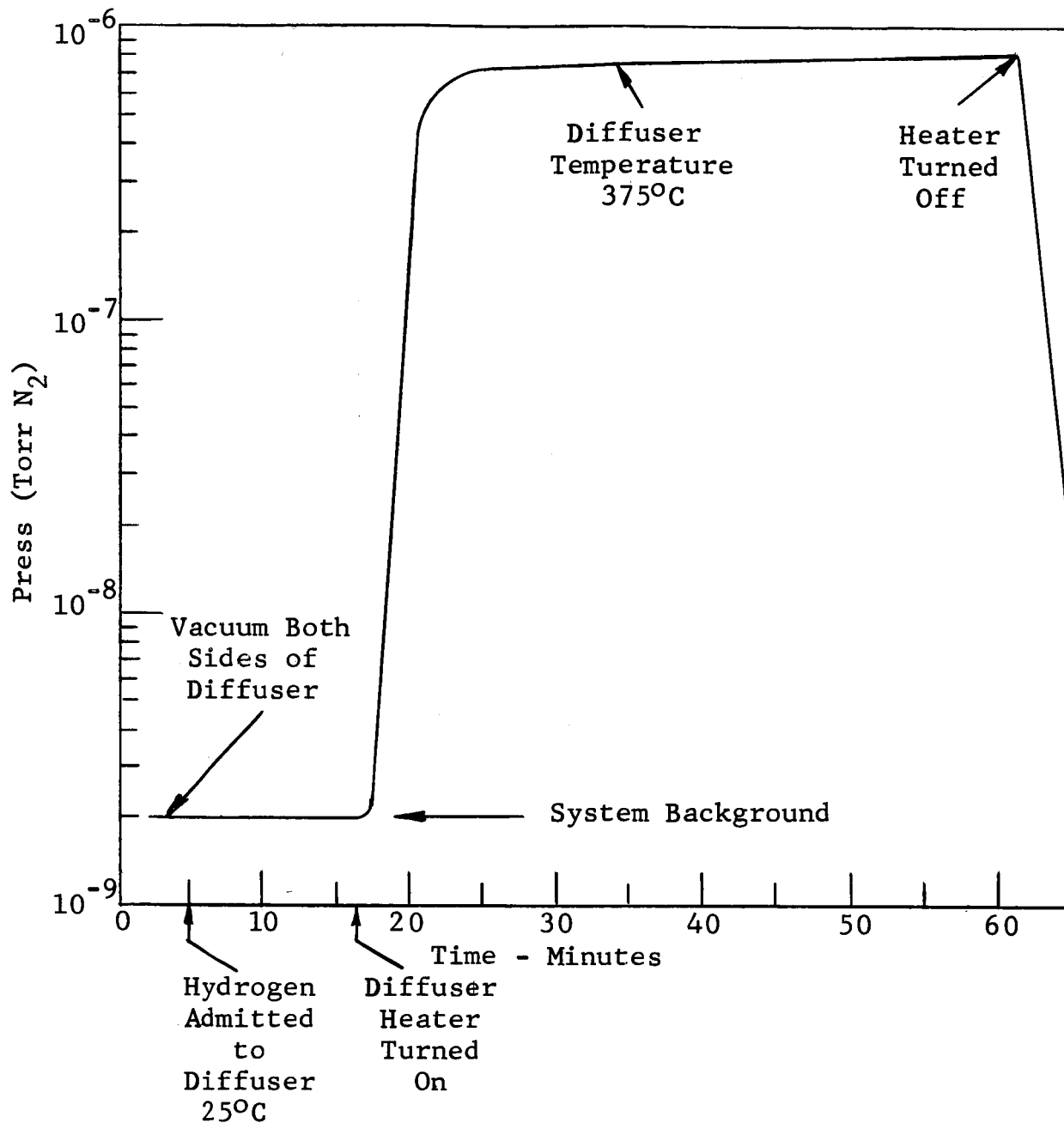


FIGURE 4 TIME-HISTORY OF FIRST HYDROGEN PULSE WITH DIFFUSER II
(Prior to Preliminary Run 0)

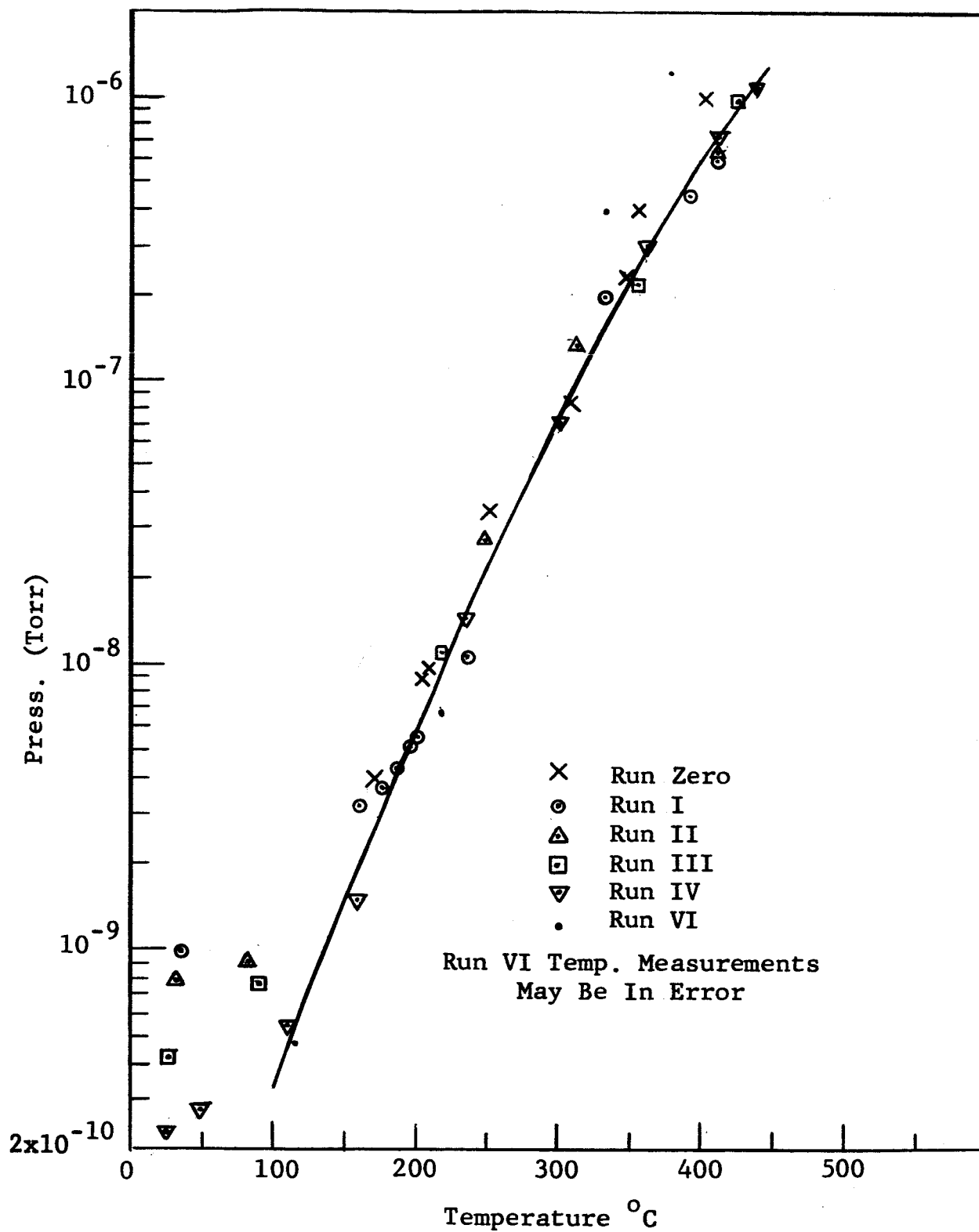


FIGURE 5 CALIBRATION IN ORBIT (Summary of Data)

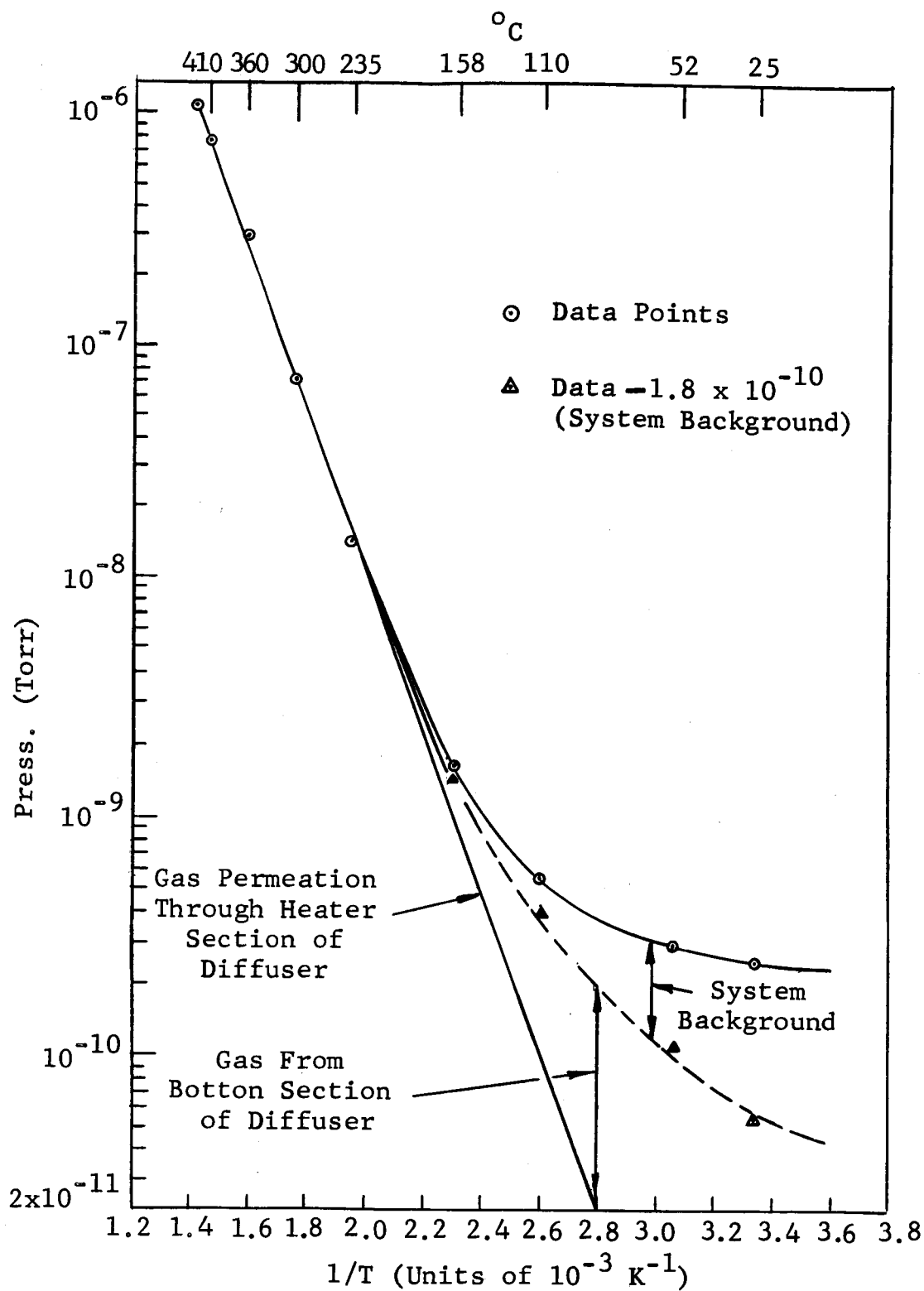


FIGURE 6 CALIBRATION IN ORBIT. RUN NO. IV

3) At the higher temperatures the area through which significant diffusion occurred was restricted to that in the proximity of the heater. However, at room temperature the total area of the diffuser in the vacuum system was available to H_2 diffusion. The ratio of the total area to that adjacent to the heater was approximately 10:1. Apparently the gold coat on the lower part of the stainless steel tube did not prevent hydrogen diffusion. It is possible that the gold coat was not impervious but a further limitation was that the gold diffused into the stainless steel during brazing and degassing operations.

In addition to the steady-state data, a number of tests were made in which pressure pulses were produced. Typical pulses are shown in Figure 7. The conditions and results for pulses up to 1×10^{-7} and 1×10^{-6} are outlined in Table 1. In some of this work, the heating power to the diffuser was varied by switching in resistors of various sizes. The details of the shape of the pressure pulses obtained by resistance switching are shown in Figures 8 and 9. The data of Figure 8 were obtained at pulse peak values of 1×10^{-7} Torr. It will be noticed that the shape of the pulse peak could be varied by altering the value of the series resistance. With a resistance of 9.35 ohms the peak pressure variation was approximately $+ 1 \times 10^{-9}$ Torr. Figure 9 shows the detailed shape of a pulse to approximately 1×10^{-6} Torr. A series resistance of 2 ohms gave a pressure peak with flat-top value which was essentially constant for more than 10 secs.

The data indicate that 3 watts is adequate to establish 1×10^{-6} Torr within 3.5 mins. However, the rate of pressure decrease from the 1×10^{-6} pulse is somewhat lower than desired.

When the pressure in the gauge was increased to 1×10^{-6} Torr, there was evidence that the gauge was severely contaminated. It was considered likely that this effect would be substantially reduced with a cold cathode magnetron gauge. An added advantage of the magnetron gauge would be the absence of an X-ray limit and a much lower limit for pressure measurement. It was also believed that the rate of pressure decrease after a pulse could be increased by better conductance from the heater and diffuser to the base of the diffuser. Although this would increase the power requirements, the maximum allowable power rating - 5 watts - had not been required in the Mark I and Mark II designs. The above alterations were among those incorporated in the Mark III design.

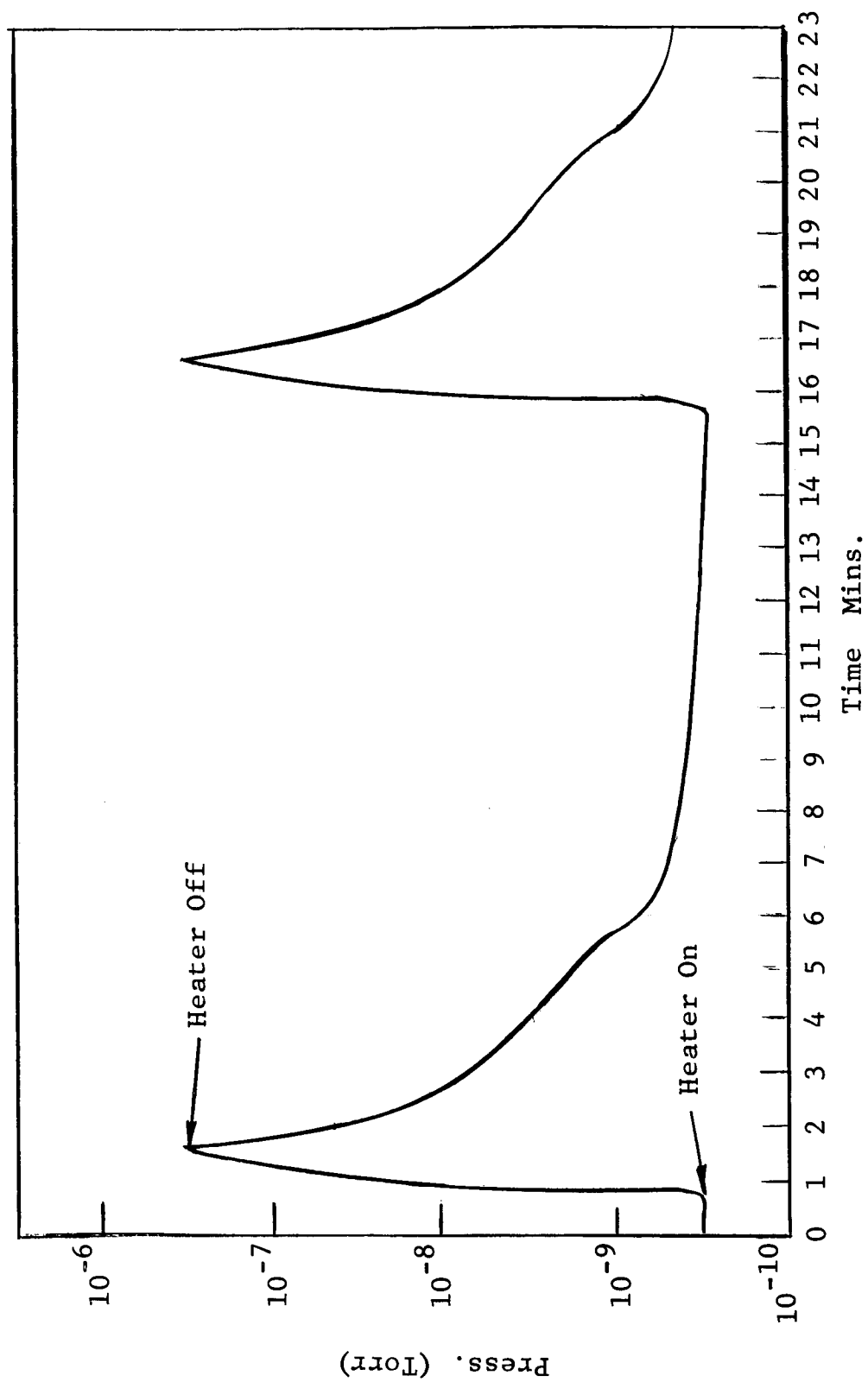


FIGURE 7

PRESSURE PULSES (HEATING TIME 60 SEC., POWER 2.6 WATT)

TABLE 1

TYPICAL CONDITIONS AND RESULTS FOR PRESSURE PULSE TESTS

Pulse to 1×10^{-7} Torr (N_2)

Initial pressure 2.2×10^{-10} Torr. Initial temperature 50°C .

Heater on for 40.5 sec. at 13V and 0.33 - 0.22 amps.

After 40.5 sec., resistance of 9.35 ohms switched into heater circuit for 10 secs.

Resultant pressure $1.00 \pm 0.01 \times 10^{-7}$ Torr.

Heater switch off.

After 13.75 min., pressure 2.3×10^{-10} Torr. Temperature 50°C .

Pulse to 1×10^{-6} Torr (Approx.)

Initial pressure 5.2×10^{-10} Torr. Initial temperature 50°C .

Heater on for 3.0 min. at 13V and 0.33 - 0.21 amps.

After 3.0 min., resistance of 2.0 ohms switched into heater circuit for 10 secs.

Resultant pressure $9.5 \pm 0.1 \times 10^{-7}$ Torr.

After cooling for 15 mins: pressure 8.7×10^{-10}

After cooling for 20.8 mins: pressure 6.9×10^{-10} and
temperature 50°C .

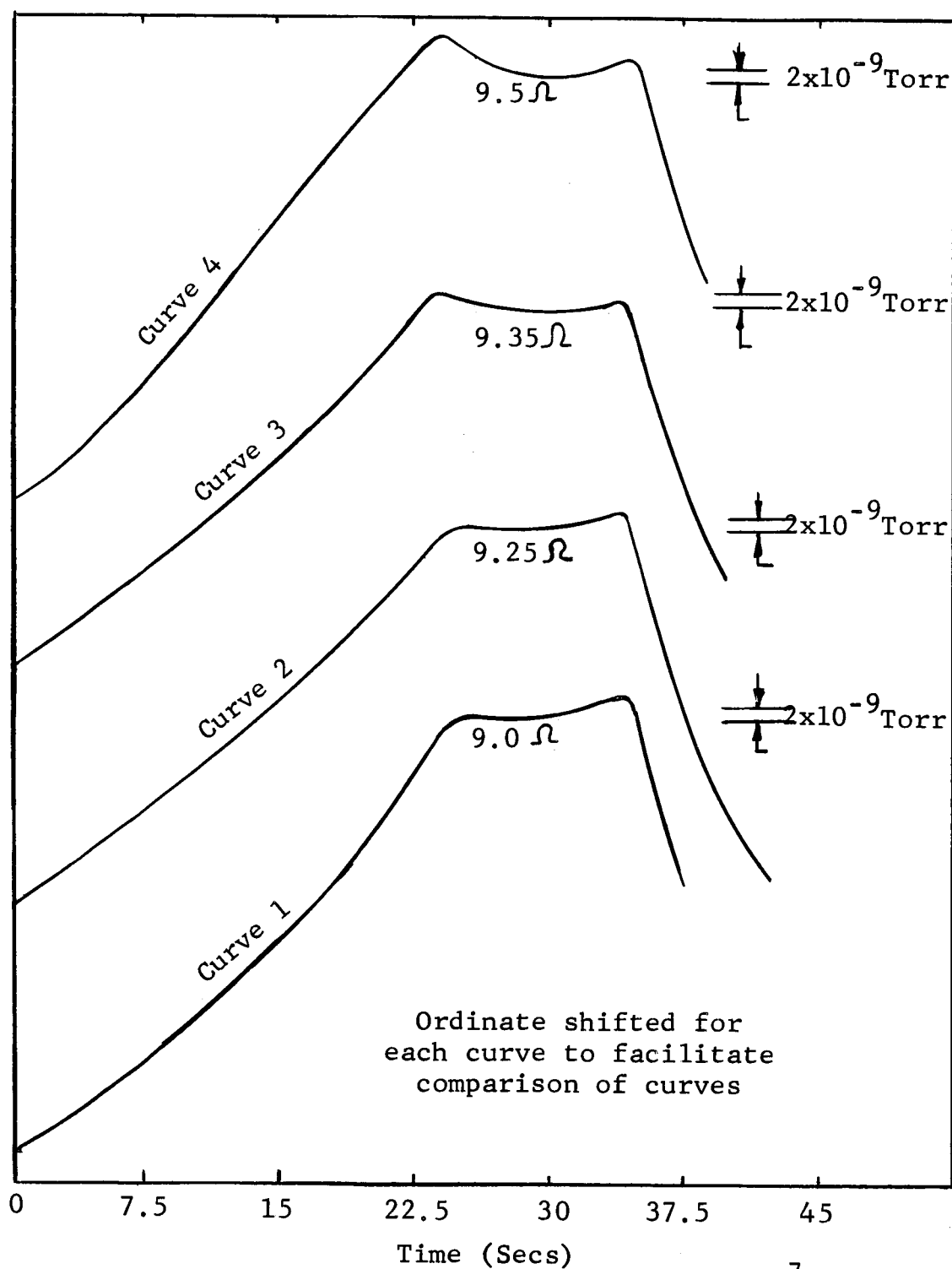


FIGURE 8 SHAPE OF PRESSURE PULSE AT 1×10^{-7} TORR
EFFECT OF SERIES RESISTOR VALUE

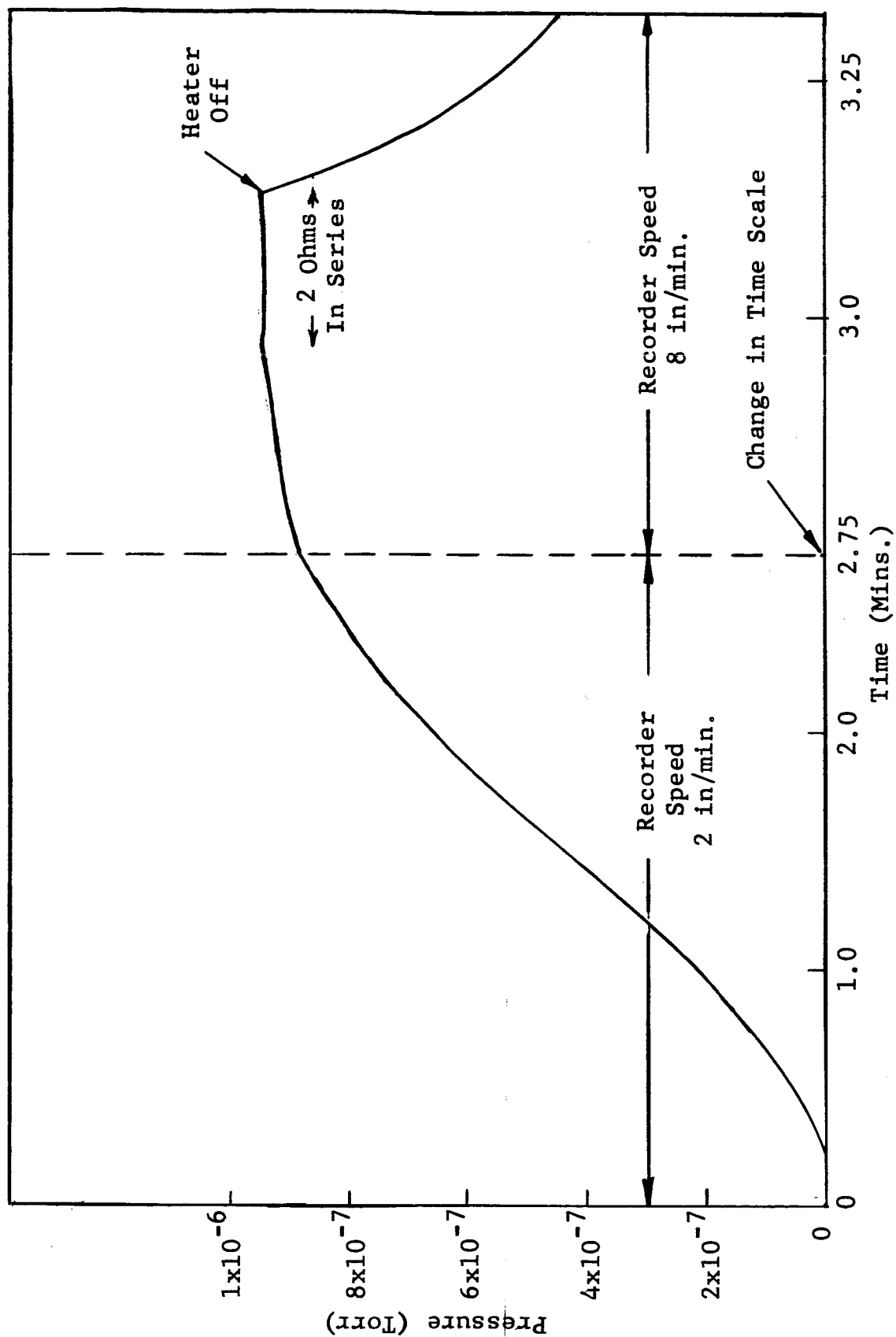


FIGURE 9
SHAPE OF PRESSURE PULSE AT 9.5×10^{-6} TORR

Mark III Calibrator

The main features of the Mark III are shown in Figures 10 and 11. The general design was similar to that used in the Mark I and Mark II calibrators, but the following changes were made:

1) A normal magnetron gauge (NRC 552) was used instead of the hot filament Nottingham gauge. The low pressure limit of the magnetron gauge has been measured down to about 3×10^{-13} Torr. This is nearly two decades below that of the Nottingham gauge.

2) A vacuum jacket was built around the stainless steel tube below the diffuser section. This jacket should serve several purposes. Firstly, any hydrogen which permeated through the lower section of the tube would not pass to the gauge volume. Consequently, with the area available for hydrogen diffusion restricted to that immediately adjacent to the heater, the low pressure performance (diffuser cold) should be considerably improved.

Secondly, the degree of thermal isolation of the diffuser section would be reduced. This should have the effect of increasing the rate of cool-down of the diffuser after a pulse.

3) The OFHC plate at the diffuser section was made of thicker material with a narrower section. The plate was attached to the diffuser tube with a more substantial fillet of gold nickel braze. These changes were made to make the diffuser area more nearly isothermal.

4) The thermocouple was located close to the diffusing area. This was expected to reduce errors in temperature measurement during rapid transients.

5) The gas conductance inside the diffuser was increased in order to increase the rate at which the inside of the diffuser could be cleaned up during degassing. In addition, more attention was given to admitting only highly purified hydrogen to the inside of the diffuser. (The evidence indicated that impurities in the hydrogen, probably carbon monoxide, caused the failure of the heater in the Mark II calibrator.)

6) Only the highest grades of vacuum materials were used in the construction of Mark III. For example, all braze joints required were made with gold-nickel braze (M.P. 950°C). It was anticipated that these changes would allow for higher degassing

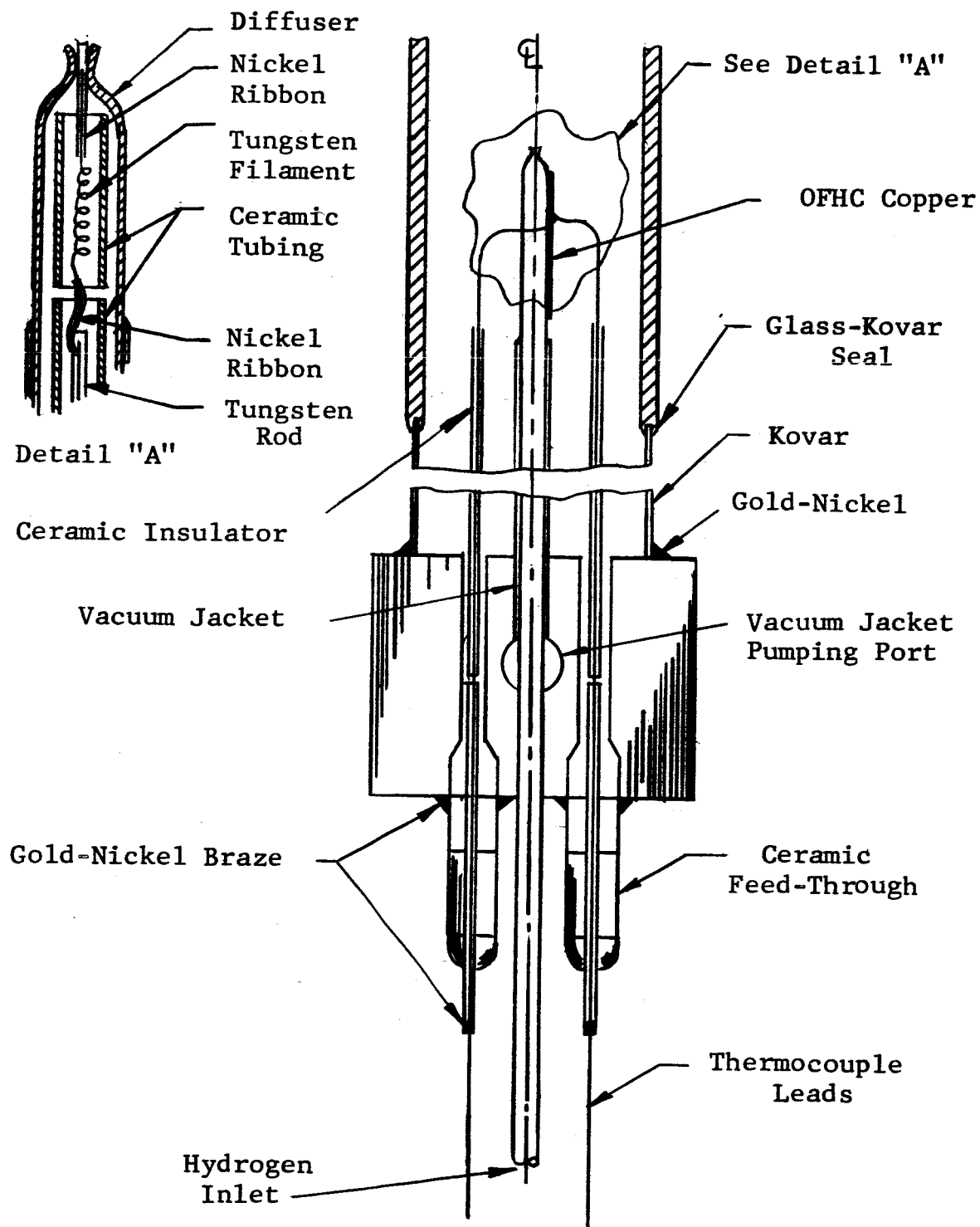


FIGURE 10

MARK III CALIBRATOR

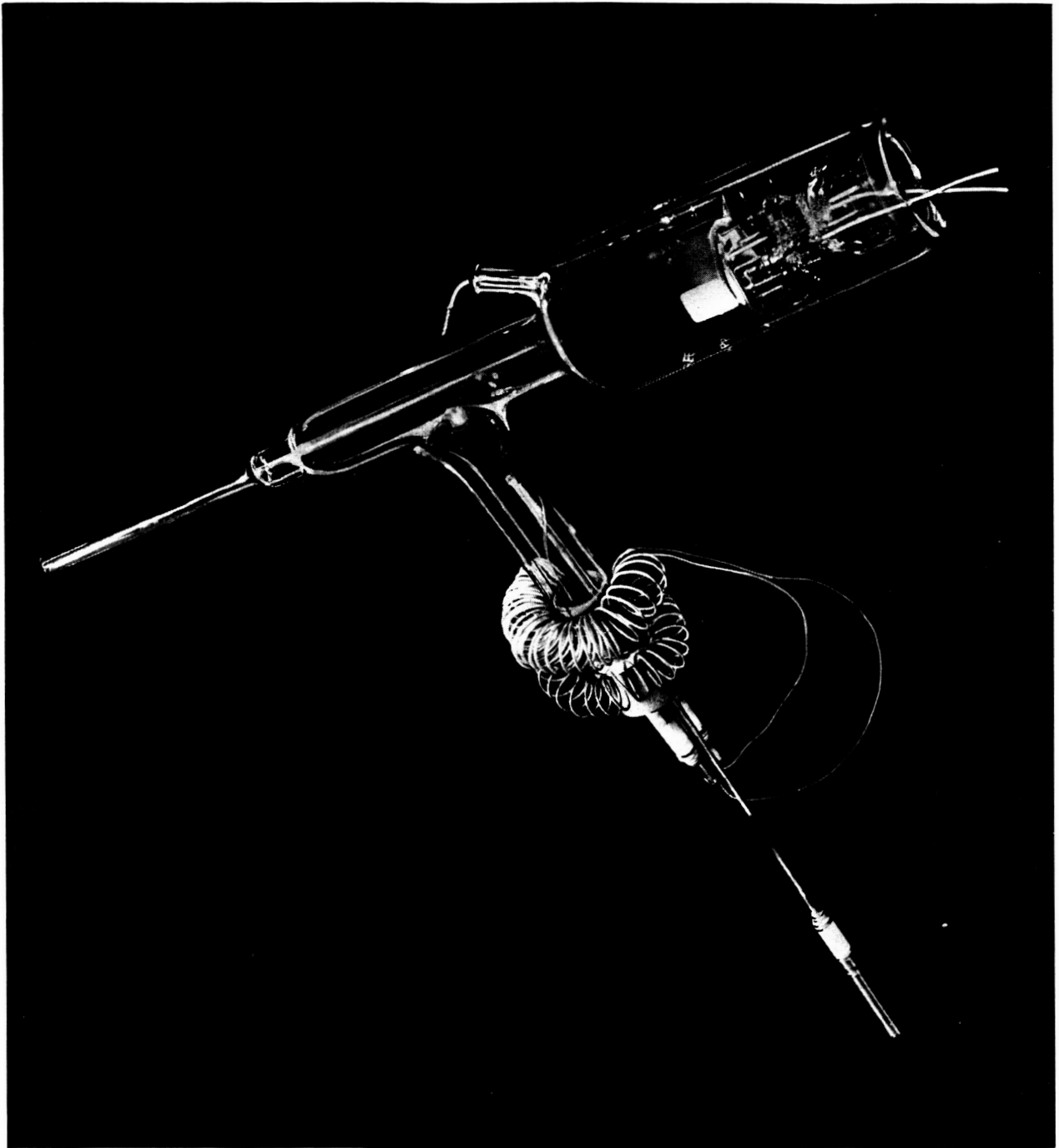


FIGURE 11

MARK III CALIBRATOR AND GAUGE

temperatures and improved low pressure performance of the calibrator.

7) The design of the calibrator was made more compact - a single tubulation onto the gauge was possible in lieu of the three required in the Mark I and Mark II calibrators.

The Mark III calibrator was constructed but more work is required in order to determine its performance parameters.

CONCLUSIONS

The data obtained in the testing of the Mark I and Mark II calibrators has demonstrated the feasibility of the method of gauge calibration based on the addition of controlled throughputs of gas to a gauge which is tubulated to a pumping system by means of a restrictive conductance. It has also been shown that controlled throughputs of gas can be obtained by using temperature variations to change the permeation rate of hydrogen through a thin-walled stainless steel tube.

The results obtained with the Mark II calibrator have been summarized in Table 2 where they are compared with the main performance objectives set during the program. Although most of the objectives were met, improvement is desirable in both the low pressure background and in the rate of pressure decrease after calibration at 1×10^{-7} Torr. The Mark III calibrator was designed and constructed with the aim of achieving significant improvements in these directions. Further work is required to experimentally evaluate the performance of the Mark III calibrator.

RECOMMENDATIONS

It is recommended that the performance characteristics of the Mark III calibrator be obtained. The work should concentrate on the reproducibility of the temperature-pressure relationship and its low pressure performance. The details of the transient behavior should also be investigated.

TABLE 2

COMPARISON OF GOALS AND PERFORMANCE OF MARK II CALIBRATOR

For Calibration at 1×10^{-9} Torr

<u>CRITERION</u>	<u>GOAL</u>	<u>SYSTEM PERFORMANCE</u>
Pulse Pressure	1×10^{-7} Torr	$1.00 \pm 0.01 \times 10^{-7}$ Torr
Heating Time	< 3.5 mins.	40.5 secs.
Steady Pressure	10 secs. at $\pm 2\%$	10 secs. at $\pm 1\%$
Background Pressure	1×10^{-11} Torr	2.3×10^{-10} Torr
Cool Down Time	< 15 min.	13.75 min.
Heater Power	< 5 watts	3 watts

For Calibration at 1×10^{-7} Torr

<u>CRITERION</u>	<u>GOAL</u>	<u>SYSTEM PERFORMANCE</u>
Pulse Pressure	1×10^{-6} Torr	$9.4 \pm 0.1 \times 10^{-7}$ Torr
Heating Time	< 3.5 min.	3.25 min.
Steady Pressure	10 sec. at $\pm 2\%$	10 sec. at $\pm 1\%$
Background Pressure	1×10^{-9} Torr	6.9×10^{-10} Torr
Cool Down Time	< 15 min.	20.8 min.
Heater Power	< 5 watts	3 watts