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# A PORTABLE CALIBRATOR FOR INTERMEDIATE RANGE VACUUM GAGES

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ARO, Inc.

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# FOREWORD

The work reported herein was done at the request of Headquarters, Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 62405334, Project 8953, Task 895306.

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This technical report has been reviewed and is approved.

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## ABSTRACT

A portable calibrator to facilitate "in-place" calibrations of intermediate range pressure transducers has been developed. The operating principle of the calibrator is to transfer gas, in controllable mass increments, into an initially evacuated vessel of known volume by use of a transfer volume. By adjusting the mass increments to specific predetermined levels, the pressure in the initially evacuated vessel can be increased in steps of $10^{-3}$, $10^{-2}$, $10^{-1}$, or 1 torr. The pressure ranges covered are from $10^{-3}$ to 1 torr and from 1 to 30 torr. The indicated corresponding limits of error applicable to each range are ±1.3 and ±0.76 percent of desired pressure level, respectively.

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## ILLUSTRATIONS



## TABLE



## NOMENCLATURE

| | |
|---|---|
| $M_{1A}$ | Mass of gas in $V_{1A}$ |
| $M_2$ | Mass of gas in $V_2$ |
| n | Number of mass additions to $V_2$ |
| $\Delta P$ | Differential pressure, $(P_3 - P_{2(n-1)})$ torr (0°C) |
| $P_{2(n)}$ | Absolute pressure in $V_2$ after the nth mass addition to $V_2$, torr (0°C) |

| | |
|---|---|
| $\Delta P_{2(n)}$ | Incremental pressure rise in $V_2 = P_{2(n)} - P_{2(n-1)}$, torr (0°C) |
| $P_{2(n-1)}$ | Absolute pressure in $V_2$ just before the nth mass addition to $V_2$, torr (0°C) |
| $P_3$ | Absolute pressure in $V_3$, torr (0°C) |
| $V_{1A}$ | Transfer volume, approximately 0.033 in.$^3$ (0.5408 cc) |
| $V_{1B}$ | Transfer volume, approximately 0.33 in.$^3$ (5.408 cc) |
| $V_{1C}$ | Transfer volume, approximately 3.33 in.$^3$ (54.08 cc) |
| $V_2$ | Reference volume, 1832 in.$^3$ (30,021 cc) |
| $\Delta V_2$ | Volume internal to the gage under calibration plus the volume of the external tubulation, in.$^3$ |
| $V_3$ | $N_2$ reservoir volume |

# SECTION I
# INTRODUCTION

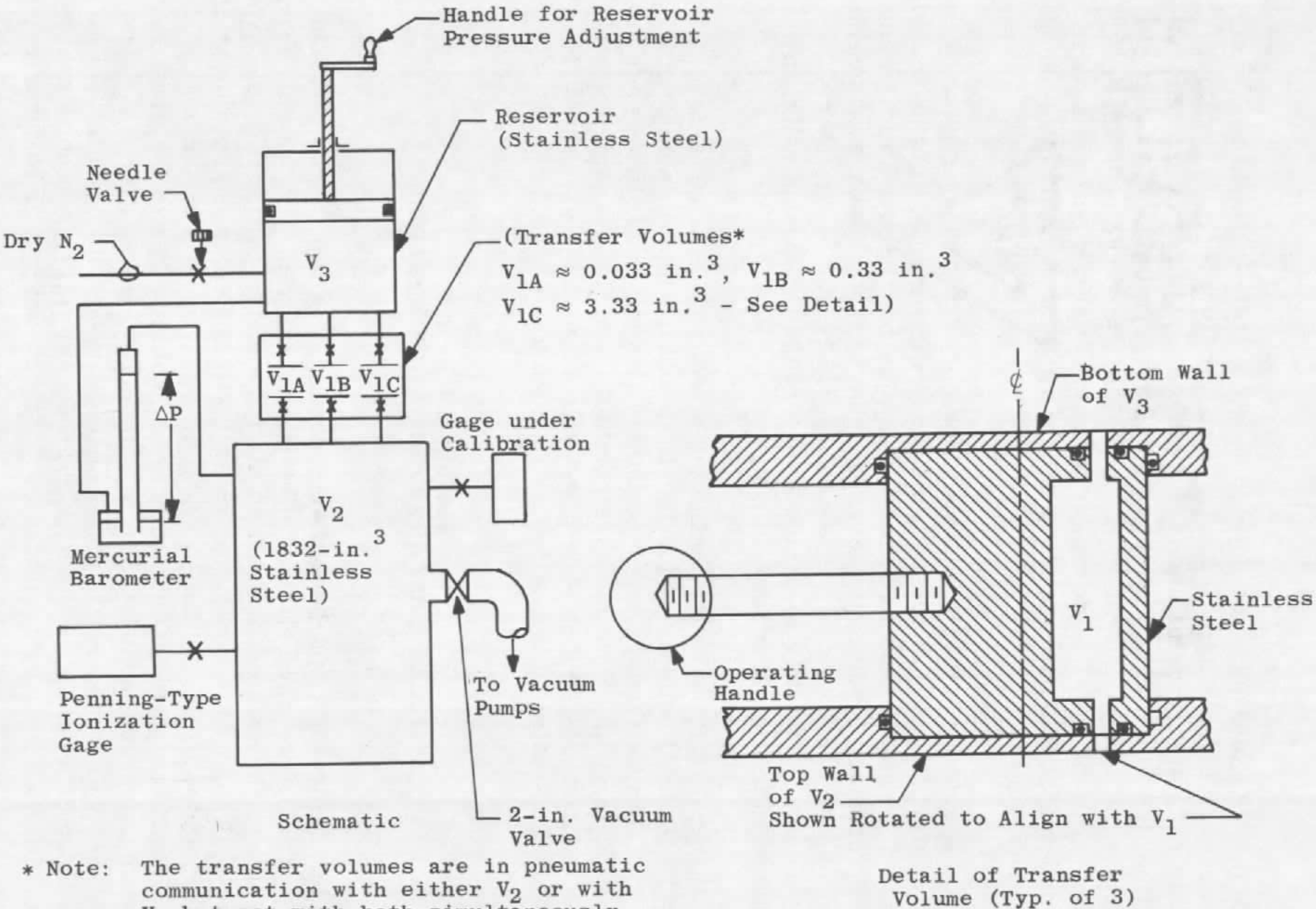
In the VKF Aerophysics Branch there is frequent need to measure pressures covering a span from 1 atm to $2 \times 10^{-2}$ torr. Precision, variable capacitance transducers with remote potentiometer readout constitute the most used pressure measuring systems. To facilitate frequent verification of system accuracy, in the range of pressures below roughly 30 torr, a portable calibrator, described herein, was designed and developed to make periodic "in-place" calibration checks of the transducers.

The operating principle of the calibrator is to transfer gas, by use of a transfer volume, in controllable mass increments, into an initially evacuated vessel of known volume. By adjusting the mass increments to predetermined levels, the pressure rise in the initially evacuated vessel can be controlled in steps of $10^{-3}$, $10^{-2}$, $10^{-1}$, or 1 torr. Consequently, it is easy to compute the pressure existing after any number of incremental mass additions.

Other calibrators operating on the above principle have been reported (Ref. 1), and in fact at least one device is sold commercially (Ref. 2). The calibrator reported herein is somewhat different from those in Refs. 1 and 2 in that it is portable, and the pressure rise in the initially evacuated vessel is always constant for a given transfer volume. This calibrator has been in use for over 1 yr.

# SECTION II
# SYSTEM DESCRIPTION AND THEORY OF OPERATION

The calibrator is presented schematically in Fig. 1 and pictorially in Fig. 2. Before any calibration steps are started, $V_{1A}$, $V_{1B}$, $V_{1C}$, $V_2$, $V_3$, and the volume internal to the gage under calibration are evacuated to less than $10^{-3}$ torr as measured with a Penning-type ionization gage connected to $V_2$. Then $V_{1A}$, $V_{1B}$, $V_{1C}$, and $V_3$ are closed off from $V_2$ and the gage under calibration. Volume $V_2$ and the gage under calibration are then evacuated to less than $10^{-6}$ torr. Using $V_2$ as a reference, $V_{1A}$, $V_{1B}$, $V_{1C}$, and $V_3$ are charged with dry nitrogen to the desired differential pressure, $\Delta P = P_3 - P_{2(n-1)}$, which is determined with the mercurial barometer. The object now is to transfer, in successive, controlled increments, a mass of gas from $V_3$ to $V_2$ using




* Note: The transfer volumes are in pneumatic communication with either $V_2$ or with $V_3$ but not with both simultaneously.

Fig. 1 Calibrator Schematic and Transfer Volume Detail

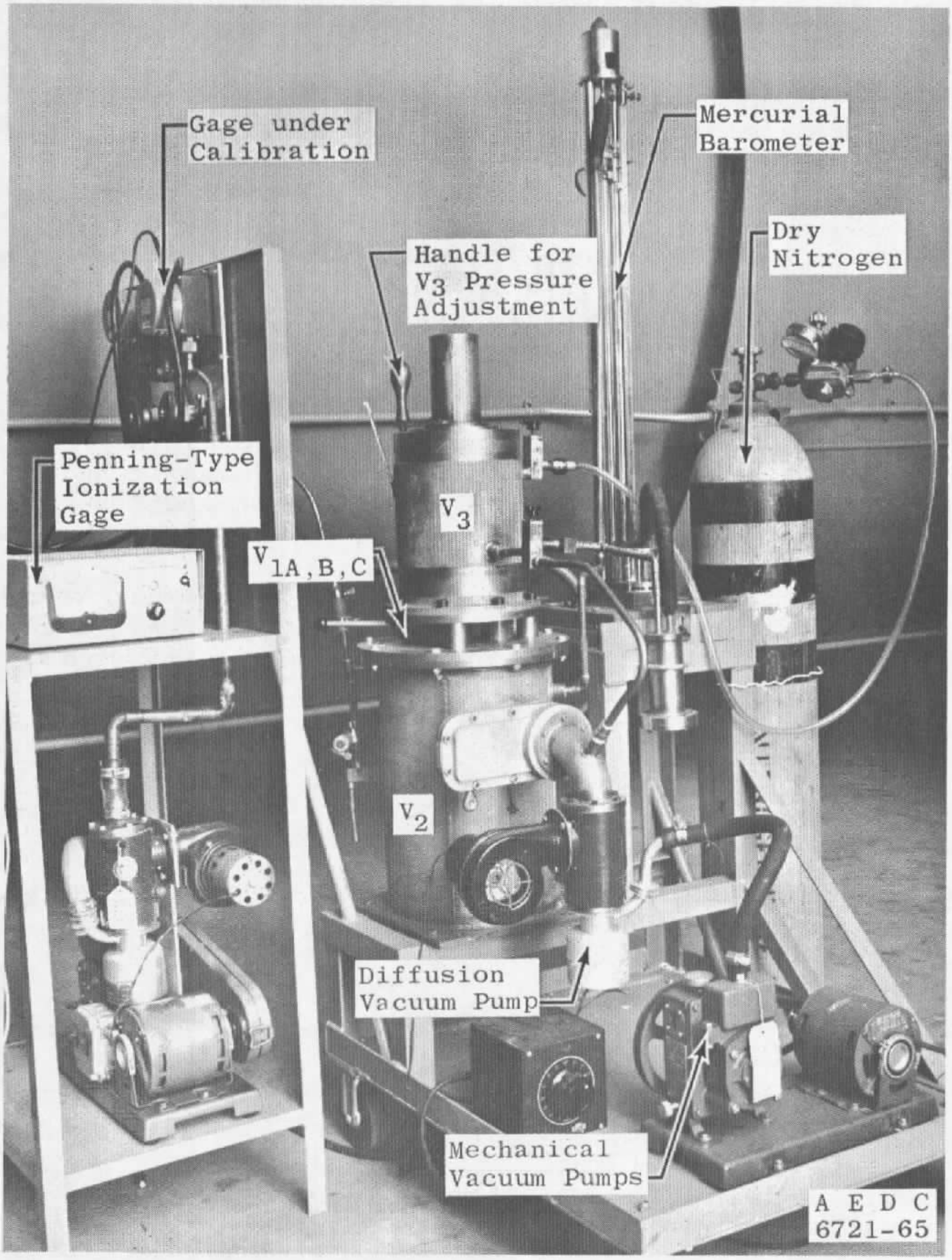



Fig. 2 Calibrator

any one of the three transfer volumes, $V_{1A}$, $V_{1B}$, or $V_{1C}$.* Each successive mass transfer establishes a new pressure level, $P_{2(n)}$ in $V_2$, which is used for calibration purposes.

Selection of the one transfer volume, of the three available transfer volumes to be vented to $V_2$, is determined by the pressure steps desired in $V_2$. By selecting the proper transfer volume and adjusting $\Delta P$ to the desired level, $P_{2(n)}$ can be increased in steps of $10^{-3}$, $10^{-2}$, $10^{-1}$, and 1 torr. After each mass transfer, the transfer volume used is again vented to $V_3$, and $\Delta P$ is restored to the desired level by simple manipulation of the manually controlled piston provided in $V_3$ and monitored using the mercurial barometer. To facilitate a very accurate measurement of $\Delta P$, the selection of volumes used in the system design is such that the desired steps in $P_{2(n)}$ can be attained by adjusting $\Delta P$ to a value not less than 50 torr.

If $\Delta P$ is restored to the same constant level before each mass transfer, if the same transfer volume is used for each pressure increase, and if the system is isothermal, then the successive pressure rises in $V_2$ will be in equal steps; the proof of this follows.

Before the nth incremental mass addition to $V_2$ by a transfer volume, say $V_{1A}$, the latter having been exposed to $V_3$ and charged to an absolute pressure of $\Delta P + P_{2(n-1)}$, the mass of gas in $V_{1A}$ can be expressed as

$$M_{1A(n-1)} = \frac{V_{1A}\left[\Delta P + P_{2(n-1)}\right]}{RT} \tag{1}$$

and in $V_2$,

$$M_{2(n-1)} = \frac{V_2 P_{2(n-1)}}{RT} \tag{2}$$

Now if $V_{1A}$ is repositioned so that a passage exists between $V_{1A}$ and $V_2$, $M_{1A(n-1)}$ and $M_{2(n-1)}$ are distributed through $V_{1A}$ and $V_2$ such that

$$M_{1A(n-1)} + M_{2(n-1)} = \frac{(V_{1A} + V_2)\, P_{2(n)}}{RT} \tag{3}$$

Substituting Eqs. (1) and (2) into (3) yields, for the isothermal case, the general equation

$$P_{2(n)} = \frac{V_{1A}\, \Delta P}{V_{1A} + V_2} + P_{2(n-1)} \tag{4}$$

*The transfer volumes are in pneumatic communication with either $V_2$ or $V_3$ but not with both simultaneously.

Or, where $\Delta P_{2(n)} = P_{2(n)} - P_{2(n-1)}$

$$\Delta P_{2(n)} = \frac{V_{1A}\,\Delta P}{V_{1A} + V_2} \quad (5)$$

In practice, the calibration mode described above is only used for calibrations at pressures below 30 torr. Calibrations above this pressure are accomplished by direct comparison with the mercurial barometer.

## SECTION III
## DETERMINATION OF SYSTEM VOLUME RATIOS

Because of the minuteness of the transfer volumes needed to produce the required volume ratios, it was not possible to fabricate these volumes to a high degree of accuracy. Hence, it was necessary to resort to experimental techniques to determine their relative sizes as compared to the computed 1832-in.$^3$ volume of $V_2$. This was accomplished by using an estimated value for $\Delta P$ and adding sufficient mass increments in $V_2$ such that the final $P_{2(n)}$ could be measured accurately with an oil manometer.* Dividing the final $P_{n(2)}$ by the number of mass transfer increments required to produce it yielded an average value for $\Delta P_{2(n)}$. Inserting these pressure relations into Eq. (5) produced the following:

$$(V_2 + V_{1A})/V_{1A} = 59{,}693.0$$

$$(V_2 + V_{1B})/V_{1B} = 5666.2$$

$$(V_2 + V_{1C})/V_{1C} = 560.0$$

This process was repeated many times with no noticeable change in the volume ratios.

In practice, the gage under calibration and its tubulation may significantly alter the volume $V_2$. Hence, in establishing calibration

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*The oil manometer used here is classified as a secondary standard and is calibrated against AEDC reference standards which are traceable to the National Bureau of Standards.

settings for $\Delta P$, it may be necessary to account for this.* The method of doing so is described in the following relations which were derived from Eq. (5) and the above volume ratios:

$$\Delta P = \frac{V_1 + V_2 + \Delta V_2}{V_1} \left(\text{desired } \Delta P_{2(n)}\right) \text{ torr}$$

For transfer volume $V_{1A}$:

$$\Delta P_A = \left(59{,}693 + \frac{\Delta V_2}{0.033}\right)\left(\text{desired } \Delta P_{2(n)}\right) \text{ torr}$$

For transfer volume $V_{1B}$:

$$\Delta P_B = \left(5666.2 + \frac{\Delta V_2}{0.33}\right)\left(\text{desired } \Delta P_{2(n)}\right) \text{ torr}$$

For transfer volume $V_{1C}$:

$$\Delta P_C = \left(560.0 + \frac{\Delta V_2}{3.33}\right)\left(\text{desired } \Delta P_{2(n)}\right) \text{ torr}$$

($\Delta V_2$ = in.$^3$ in these formulas.)

## SECTION IV
## DISCUSSION OF ERROR SOURCES

The first obvious question regards the experimental techniques for determining the volume ratios between the transfer volumes and $V_2$, i.e., is the mass transfer method sufficiently consistent to justify taking an average of many incremental additions. Since $\Delta P > 50$ torr and can be determined with an uncertainty no greater than ±0.3 torr, the question reduces to determining the consistency of the transfer volumes. The only conceivable variables in this case are O-ring slippage, wear, or deformation. Simple calculations have convinced the authors that for any of the transfer volumes, there should be no more than a ±0.5-percent inconsistency.

Since no method of temperature control is built into the system, another question concerns the assumption of an isothermal process. This was not considered to be a problem because the calibrator is used in an environment where the ambient temperature does not fluctuate more than ±3.0°F and because the thermal mass of the calibrator is

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*Though not previously mentioned, the volume of the oil manometer was accounted for in establishing the given volume relations.

sufficiently large that operation should not significantly alter its temperature. In addition, small temperature differences can be tolerated. For example, a 1.0°F variation in the temperature in $V_2$ leads to, roughly, a 0.2-percent variation in determining $P_{2(n)}$.

Other possible sources of error include condensables, surface adsorption, leaks, and uncertainty in system "zero". It was anticipated that the first two of these could be avoided by using dry nitrogen for the working gas and stainless steel for the walls of $V_{1,A,B,C}$, $V_2$, and $V_3$. Only extreme care, of course, could avoid leaks. As for the system zero, this does not pose a problem because $V_2$ is pumped down to an absolute pressure at least three orders of magnitude below the smallest calibration increment.

For want of better techniques for proving the adequacy of the calibrator, it was checked against the secondary standard oil manometer mentioned previously over the appropriate operating range (Fig. 3).

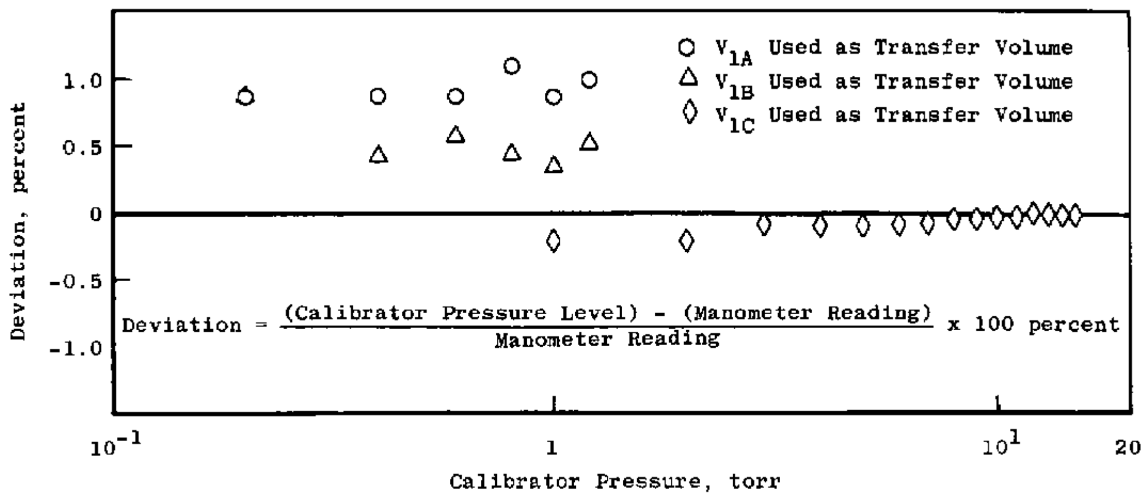


**Fig. 3 Comparison of the Calibrator with an Oil Manometer**

A later comparison of the calibrator with a variable capacitance pressure transducer which had been recently calibrated against an AEDC reference standard is presented in Fig. 4. The resolution of the variable capacitance pressure transducer is not sufficient to permit precise pressure measurements below $10^{-1}$ torr. This accounts for the deviation from the calibrator pressure below $10^{-1}$ torr evident in Fig. 4.

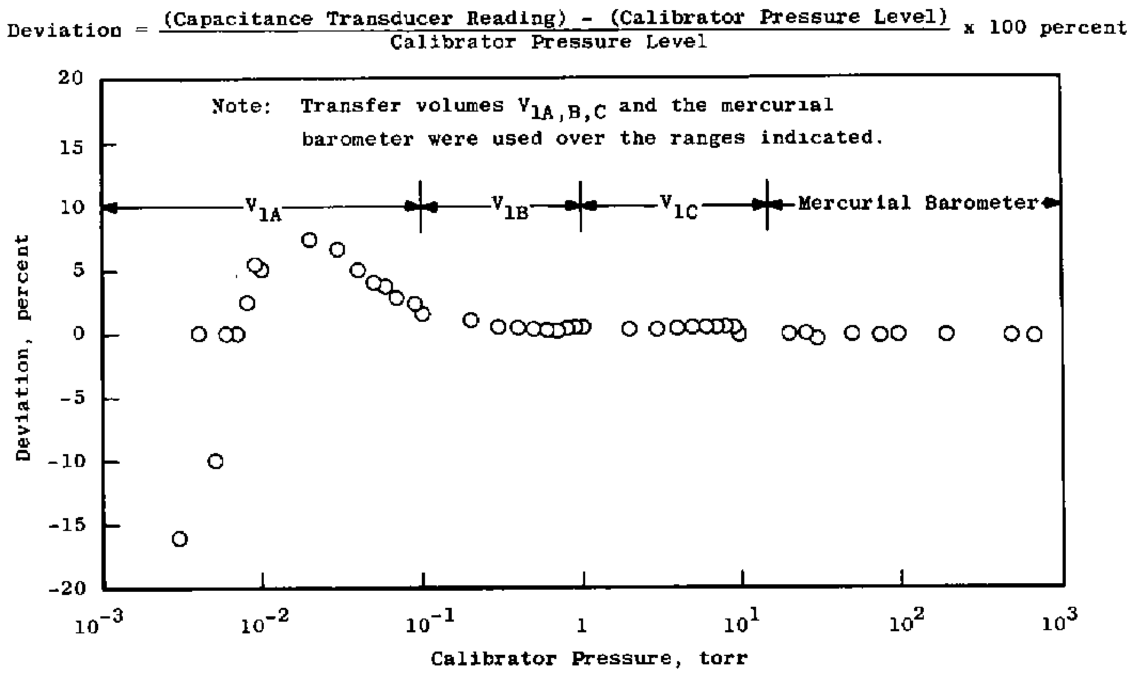


**Fig. 4 Comparison of a Variable Capacitance Pressure Transducer with the Calibrator**

An analysis of the sources and limits of error when calibrating with this system is summarized and presented in Table I.

**TABLE I**
**SUMMARY OF CALIBRATOR ERROR SOURCES**

| Error Source | Error*, percent — Calibration Range: $10^{-3}$ to 1 torr | Error*, percent — Calibration Range: 1 to 30 torr | Basis for Error Determination |
|---|---|---|---|
| Fluctuation in differential pressure ($\Delta P$) | ±0.5 | ±0.05 | Uncertainty inherent in the mercurial barometer |
| Uncertainty in volume ratio $V_1/(V_2 + \Delta V_2 + V_1)$ | ±0.5 | ±0.5 | Observations over many calibration runs |
| Fluctuations in system temperature | ±0.2 | ±0.2 | Observations |
| Fluctuations in system zero | ±0.1 | ±0.01 | Uncertainty in measuring residual pressure in $V_2$ |
| Maximum error in establishing a desired $P_{2(n)}$ | ±1.3 | ±0.76 | |

*The term "error", as used here, is in percent of the desired pressure level and is the uncertainty in establishing $P_{2(n)}$.

# SECTION V
# CONCLUSIONS

The incremental mass addition of gas to a fixed volume appears to be a suitable means of establishing pressure levels in the volume for the purpose of calibrating pressure gages. By an appropriate method, it is a simple matter to raise the pressure in known increments so that only simple addition is necessary to determine any pressure level.

No problem of condensables or adsorption seems to exist at pressure levels for which the calibrator was intended.

The calibrator is suitable for use as a portable calibration standard over the pressure range from $10^{-3}$ to 1 torr with the indicated capability to establish incremental pressure levels to within 1.3 percent of the desired level and over the pressure range from 1 to 30 torr with the indicated capability to establish incremental pressure levels to within 0.75 percent of the desired level.

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