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Thermistor Pressure Gauge Design

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THERMISTOR pressure gauges[1] are characterized by large pressure range, good accuracy and stability, fast measurement, insensitivity to over-pressure, negligible out-gassing, ease in cleaning, and physical and electrical simplicity and ruggedness. A number of excellent papers have been published[2–6] describing these gauges. However, a detailed account of design procedure and characteristics for a specific gauge would eliminate much of the trial and error encountered in designing a gauge having prescribed range, sensitivity, and stability.

Maximum thermistor sensitivity is obtained when heat loss by gas conduction is large compared to loss by radiation and through support wires. Fast response requires low heat capacity. Thus, the thermistor should have a high dissipation constant[7] and small, low thermal conductance support wires. Thermistor resistance-value range is selected for compatibility with available power supplies and voltage measuring instruments. Thermistors having high resistance give greater sensitivity, but useful sensitivity may remain the same because of increased sensitivity to ambient temperature changes. Properly selected thermistors are currently available mounted in a Pyrex tube and surrounded by a water jacket.[8] The steps in system design[9] were as follows: (a) The thermistor was aged.[1] (b) Thermistor E, I, P, and R characteristics were determined as shown in Fig. 1. (c) Maximum operating temperature of the thermistor was selected to be 200°C and thermistor resistance $R(200)$ was computed using the thermistor equation

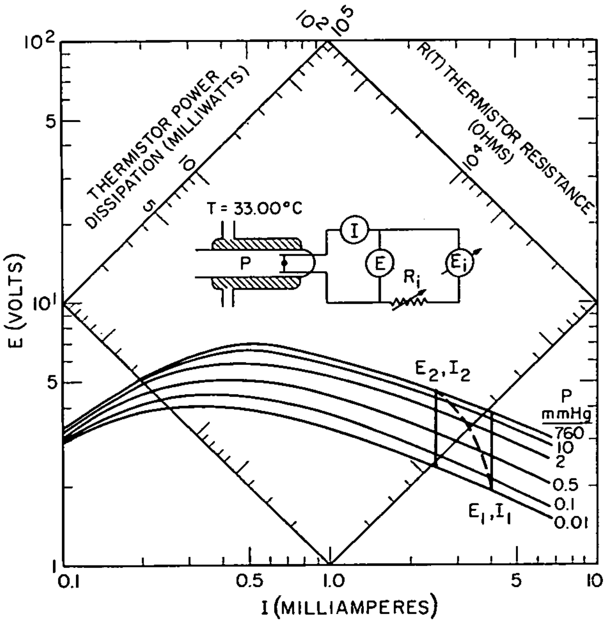

FIG. 1. Characteristics of a thermistor as a pressure sensor and the circuit used to obtain these characteristics. The dashed curve is a typical operation curve.

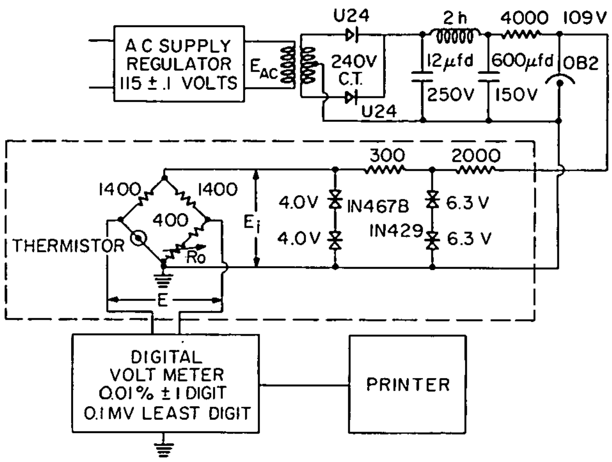

FIG. 2. Thermistor electronic circuitry.

$$R(T)=R_0 \exp \beta\left(\frac{1}{T}-\frac{1}{T_0}\right),$$

where R_0 is the measured thermistor resistance at reference temperature $T_0=298$°K, and $\beta=3900$°K is the thermistor-material constant. By using the computed value of $R(200)$, the values of E_1, I_1 were determined from Fig. 1. (d) Arbitrary point E_2, I_2 was chosen on the 760 mm Hg characteristic line. (e) Specific values of E_i and R_i were computed using E_1, I_1 and E_2, I_2. (f) By using the computed values of E_i and R_i in the circuit of Fig. 1, a rough calibration of E vs P was obtained and plotted. By using the same data, the thermistor operation curve may be plotted on Fig. 1. The success with which point E_2, I_2 was chosen was then determined. Should the thermistor operation curve which was obtained approach tangency to any thermistor characteristic curve P=constant, the value of dE/dP suddenly becomes abnormally large. This condition is noticed as a step increase in E on the rough plot of E

vs P and is remedied by increasing I_2 until the step increase in E has been eliminated.

The initial choice of I_2 as less than I_1 was made in order to obtain a thermistor operation curve which had an increased sensitivity in the region from 2 to 10 mm Hg, e.g. compare the dashed thermistor operation curve with the operation curve $I \sim I_1$.

If a low value for maximum thermistor temperature is selected, greater sensitivity is obtained at low pressure but at the expense of reduced sensitivity at high pressures. At high thermistor bead temperatures long term drift in resistance is related to the ability of the glass coating to prevent oxidation of the thermistor material. At 300°C one may expect drift of as little as 0.1% per month from a glass covered bead thermistor. Use of thermistors in vacuum gauges is conducive to low drift since maximum temperature of the bead occurs in a vacuum while at atmospheric pressure bead temperature is somewhat reduced.

With the thermistor operation curve defined, the values of E_i, R_i, E_1, I_1, E_2, and I_2 are sufficient to determine the design of the thermistor power and bridge circuitry (Fig. 2). In order to avoid ground loops a floating input to the digital voltmeter must be used and the thermistor bridge must be grounded.

Components located within the dotted lines of Fig. 2 were placed in thermal contact with the water jacket and potted as shown in Fig. 3. Thermistor beads are sensitive to radiation and thus the water jacket must be coated with an opaque material. Water bath[10] temperature was set at 33°C. Higher water temperature may reduce thermistor sensitivity at high pressures while lower water temperature required cooling the water bath. Thermistor pressure gauge

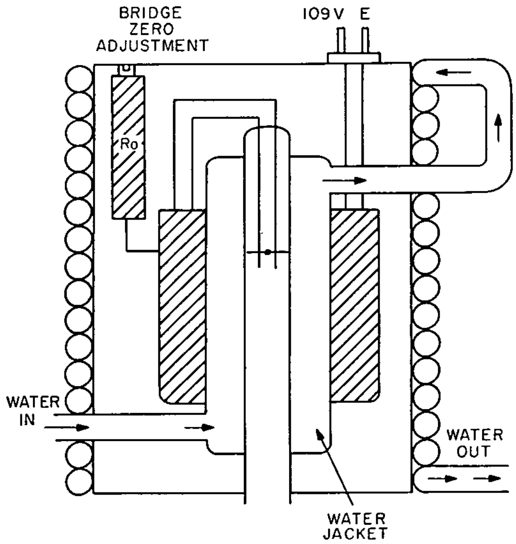

FIG. 3. Thermistor block. Water leaving the water jacket circulates around the block before returning to the constant temperature bath.

TABLE I. Thermistor pressure gauge electrical and thermal characteristics.

	$P=0$ mm Hg	$P=760$ mm Hg
dE/dP	2.0 mv/μ Hg	...
dE/dE_{ac}	-0.07 mv/v	-0.2 mv/v
dE_i/dT_{room}	-0.2 mv/°C	-0.2 mv/°C
dE/dT_{room}	-0.6 mv/°C	$+0.0$ mv/°C
dE_i/dT_{bath}	-5 mv/°C	-5 mv/°C
dE/dT_{bath}	-5 mv/°C	-50 mv/°C
dE/dE_i	-0.4	-1.1
ΔE_i for $\Delta P=760$	0.161 v	
Noise (0.1 to 5 cps) at E and E_1 less than 5 μv peak		
Water bath temperature regulation		±0.02°C
Thermistor block temperature excursion		±0.01°C
Water bath temperature error		±0.01°C
dT_{water}/dT_{room}		±0.00°/°C
dT_{block}/dT_{room}		±0.01°/°C

electrical and thermal characteristics are given in Table I.

At pressures of 5 mm Hg and above, air convection currents assume importance in cooling the thermistor, and the thermistor should be used in the same orientation in which it was calibrated. At 5 mm Hg the gauge pressure reading was 0.5% higher when the thermistor tube was vertical than when it was horizontal. From 10 to 50 mm Hg the gauge pressure reading was about 1% higher for this same change in orientation.

The time constant for the gauge is about 2.5 sec at 10^{-2} mm Hg and 1.5 sec at 10 mm Hg.

Long time repeatability is good. Three calibrations[11] over a period of 16 months were each followed by gauge disassembly and shipment. The calibrations showed a maximum pressure separation among themselves of 1% over the range from 10^{-2} to 10^1 mm Hg and indicated that, despite rough treatment, the gauge is capable of ±0.5% accuracy over this range. Short period repeatability of the gauge was about ±0.2% from 0.050 to 20 mm Hg. The thermistor gauge was designed and constructed hurriedly. We believe that with reasonable additional effort, significant improvements in range and repeatability could be obtained without sacrificing simplicity.

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[7] Thermistor time constant = heat capacity/power dissipation constant.
[8] Thermistor Assembly $L-252$C, Thermistor Division, Gulton Industries, Metuchen, New Jersey.
[9] Considerable information concerning thermistors and their use was furnished by M. Sapoff of the Victory Engineering Corporation and by Dr. A. Rosenberg of the Lincoln Laboratory.
[10] Labline Constant Temperature Circulating System #3052, Labline, Inc., Chicago, Illinois.
[11] NASA TN D-504.