NOISE THERMOMETRY FOR VERY HIGH PRESSURE USE

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ABSTRACT

The present paper describes a new method of balancing the Johnson noise of a sensing resistor with that of a reference resistor in the noise thermometry. In place of the conventional technique which measures the mean square voltage of the thermal noise, the present method is substantially to count the number of pulses exceeding an established constant gate voltage for a unit duration of time.

When an appropriate constant value was chosen as the gate voltage, an improved sensitivity in balancing both the noise voltages was obtained. The accuracy of this thermometry is such that 0.1 % at room temperature and 0.3 % at 900 K both at an atmospheric pressure.

The new method was applied to correct the output of the thermocouple imbedded in a girdle-type high pressure cell.

RÉSUMÉ

Nous décrivons ici une méthode thermométrique nouvelle consistant à équilibrer le bruit de Johnson d'une résistance détectrice à celui d'une résistance de référence. Au lieu de mesurer suivant les techniques conventionnelles le carré moyen de la tension du bruit thermique, la méthode que nous proposons revient à compter le nombre d'impulsions qui dépassent un seuil déterminé, au cours de l'unité de temps.

Après avoir choisi une valeur convenable du seuil, la sensibilité a été améliorée en équilibrant les deux bruits de fond. La précision de cette technique de thermométrie est voisine de 0,1 % à la température ambiante, 0,3 % à 900 K, sous la pression normale. Nous avons utilisé ce procédé pour corriger le signal du thermocouple introduit dans la cellule haute pression frettée.

1. Introduction

It is well known that the output of a noise thermometer is independent of pressure and free from any contamination of a sensing resistor within a high pressure and high temperature environment. Several authors have made experimental investigations of the noise thermometer [1-4].

The present paper describes a new method of balancing the Johnson noise of a sensing resistor with that of a reference resistor. The balancing point of the Johnson noises in the sensing and the reference resistors was detected by counting the rate of pulses surpassing a constant gate voltage. By means of this method, pressure correction was made to the outputs of thermocouples embedded in a girdle type high pressure cell.

2. Experiment

The absolute temperature T_s of a sensing resistor (the real part of an impedance : $\mathrm{Re}\,(Z_s)$) is determined by means of equalizing a mean square voltage $\overline{v_s^2}$ of the sensing resistor with that $\overline{v_r^2}$ of a reference resistor $\mathrm{Re}\,(Z_r)$. The sensing resistor is expressed in a parallel combination of resistance R_s and capacitance C_s.

According to Nyquist's law, $\overline{v_s^2}$ is given by

$$\overline{v}_s^2 = \int_{f_1}^{f_2} 4kT_sR_s/(1 + (2\pi f C_s R_s)^2)\, df\,, \qquad (1)$$

where k is Boltzmann's constant, f_1 and f_2 lower and upper frequency limits of the channel, and f the frequency of the measurement. If $\overline{v_s^2} = \overline{v_r^2}$, T_s is written as

$$T_s = \frac{\int_{f_1}^{f_2} R_s/(1 + 2\pi f R_s C_s)^2)\, df}{\int_{f_1}^{f_2} R_r/(1 + 2\pi f R_r C_r)^2)\, df}\, T_r \qquad (2)$$

If the two channels of measurement are equivalent, and the time constants $R_s C_s$ and $R_r C_r$ are made equal, T_s is expressed as $T_r R_r / R_s$.

2.1. *Balancing of the noise signal.*

The following method was adopted to detect the balance between $\overline{v_s^2}$ and $\overline{v_r^2}$. The thermal noise was amplified by a low noise preamplifier with double triode (7308) cascode circuits, and was discriminated so as to pass the pulses exceeding an established constant gate voltage v_g by means of the Schmitt circuit. $\overline{v_s^2}$ was balanced to $\overline{v_r^2}$ by integrating the pulse counts for a unit duration of time for both the discriminated noise pulses of Re (Z_s) and Re (Z_r). Since the thermal noise is a white one, the number N of pulses, exceeding the gate voltage v_g for a unit time, is expressed as follows [5].

$$N = \sqrt{\frac{1}{3}\,(f_1^2 + f_1 f_2 + f_2^2)}\, \exp\left(-\frac{v_g^2}{2\overline{v}_s^2}\right) \qquad (3)$$

This relation is shown by the broken line in Fig. 1 in which f_1 and f_2 are assumed to be 20 kHz and 300 kHz respectively, and C_s is to be 200 pF. If we take about 700 Ω as the equivalent noise resistance of the preamplifier used, the observed value agrees to the theoretical one.

The relative error ΔR/R of the observed values is estimated from the statistical error of the fluctuation of N. This relation serves to find the appropriate range for the sensing resistance.

Care must be taken to ensure that both the amplification and detection of the two noise signals are identical. This was accomplished by employing the same channel, which carried the two signals in time separation. In this pulse-counting method, the accuracy of the contact times (the duration of the integrating time) governs the total accuracy of the thermometry. The solid state switching circuit employed here is controlled by the crystal clock with the relative error of 2×10^{-5}.

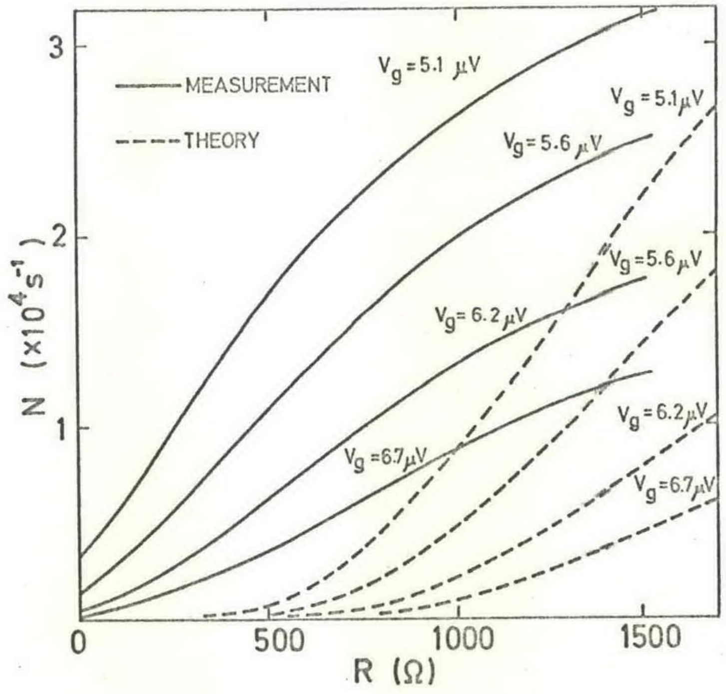

FIG. 1

Relationship between input resistance and pulse count rate.

2.2. *Method of RC balance.*

Two methods were adopted to establish the condition

$$R_s C_s = R_r C_r.$$

a) *Reference resistor at a fixed temperature.*

This method is a conventional one [1]. By means of the second channel, 30 kHz wide, centered at 455 kHz, the two noise signals were balanced.

b) *Reference resistor at an elevated temperature.*

This new method is appropriate to the high pressure use. The temperature T_r at the atmospheric pressure was equalized to the temperature T_s under high pressure, until N_s was consistent with N_r under the condition $R_s = R_r$. When $R_s = R_r$, the balance of the real parts of the parallel combination of R_s and C_s leads to the condition

$$R_s C_s = R_r C_r .$$

This balance condition was easily attained by means of an AC bridge.

2.3. *Sensing resistor.*

A ceramic-moulded solid carbon resistor made by Allen and Bradley was used as a sensing resistor. The resistor has advantages claimed for the use in the confined environment of high pressure and high temperature. The resistor was shielded completely by a copper tube as shown in Fig. 2. The estimated current noise of the sensing resistor by a grid current is 0.05 μV at most. The comparison between the thermal noise of the sensing resistor and that of he metal wire indicates a good agreement within the limit of error.

2.4. *Pressure generator.*

A girdle type press was employed in this experiment as the high temperature and high pressure generator. Fig. 2 shows the assembly of the pressure cell. The sensing resistor passing through the core of the anvil was brought into contact with the thermocouple at the center of the pressure cell. The temperature difference between the sensing resistor and the thermocouple was estimated within ± 0.8 K at 700 K. To avoid the induction noise arising from the heater, DC current from the battery was applied.

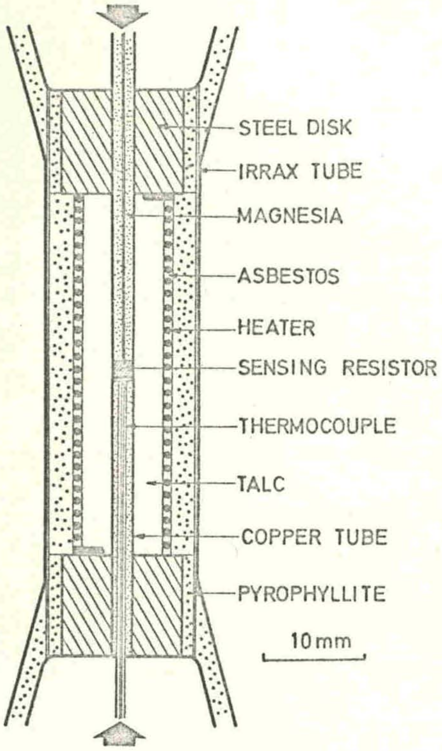

FIG. 2

Pressure cell assembly.

3. Results and discussion

3.1. *Experimental confirmation of pressure independence of the noise thermometry.*

The theoretical statement that the output of the noise thermometer does not depend on the pressure was confirmed experimentally up to 30 kbar at room temperature as listed in Table 1.

3.2. *Pressure effects on the outputs of Chr/Alu and Cu/Const thermocouples.*

The thermometry with the balancing method (b) was applied to the correction of Chr/Alu thermocouple at an elevated temperature. The precise balancing point of N_s and N_r was determined from reading the count-integrator over a period of 60 s. R_s was about 600 Ω under high pressure. The plotted points in Fig. 3 are the average values of $5 \sim 10$ measurements. The result was converted to the standard pressure correction of the thermocouple introduced into a hydrostatic pressure

TABLE 1
Noise thermometry under high pressure at room temperature

		Balanced resistance (Ω)	Temp. obtained by noise (K)	Temp. obtained by thermocouple (K)
Atmospheric pressure	R_s	601.1	294.2	294.5
	R_r	602.1	294.7	294.7
30 kbar	R_s	509.1	294.2	294.7
	R_r	509.9	294.7	294.7

bomb. A broken line in Fig. 3 shows this standard pressure correction, and a chain line shows the Hanneman's result [6]. The trends of these curves agree with each other.

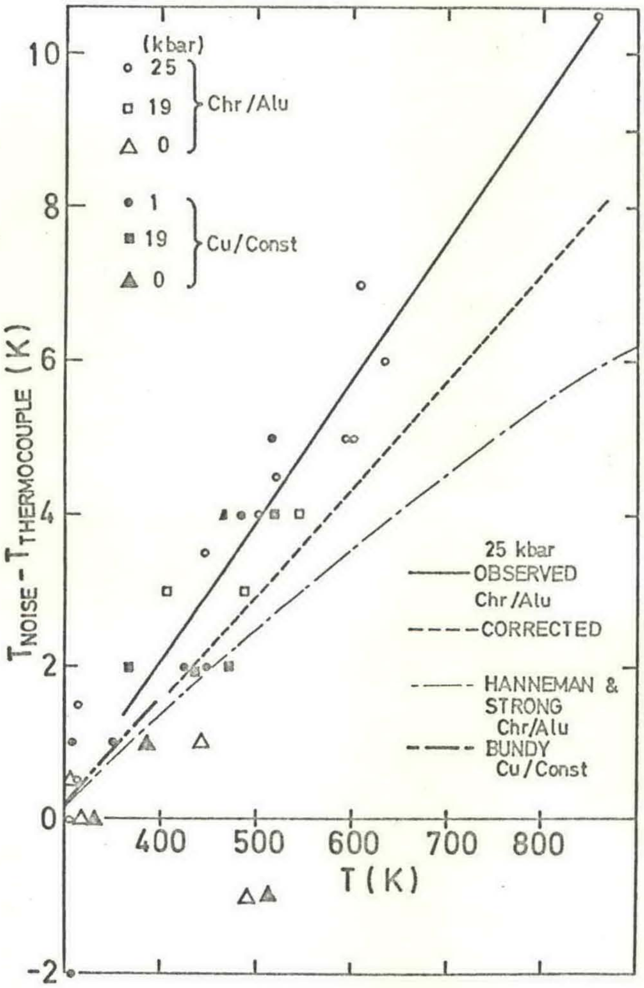

FIG. 3
Pressure correction of thermocouples.

As for the correction of Cu/Const thermocouple, the balancing method (a) was employed. The results are shown in Fig. 3. In this measurement, R_s was 800 Ω under high pressure, and the duration of integrating time is 60 s. The points represented are the average values of 5 ~ 10 measurements. The result almost agrees with the extrapolation of Bundy's measurement obtained by the Belt apparatus.

The outputs of the calibrated thermocouple and those of the noise thermometer showed agreement within the range of 0.1 % at room temperature and of 0.3 % at 900 K, under the atmospheric pressure for the integrating time of 15 min. In principle, the accuracy of the measurement is increased by the extension of the duration of integrating time, but in the high pressure experiment, the difficulty of maintaining the pressure and temperature conditions in the pressure cell may restrict the total accuracy of the experiment. For the full discussion of the problem, it is desired to make much more measurements by this technique at high pressures, far beyond 30 kbar.

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