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Short Communication

An oscillator circuit with a linear relation between frequency and temperature

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Abstract

A simple instrument which measures point temperature in connection with the construction of thermal diffusion cloud-chamber and employs an oscillator circuit is designed and described. Bead thermistor is used as a temperature sensor. A new procedure is suggested for obtaining a linear functional relationship between temperature and frequency. Thermocouple is used to calibrate the instrument. The method offers high accuracy and valid for wide range of temperature measurement.

Key words : Thermocouple, thermistor, monostable multivibrator.

1. Introduction

Digital measurement of different physical quantities has gained a tremendous importance with the development of digital integrated circuit in instrumentation. Of the different physical quantities which are frequently required to be measured temperature is a very important one. Different electrical oscillator circuits using thermistor had been suggested by different workers[1,2] where attempts had been made to achieve linear relationship between the frequency or the time period of the oscillator and the temperature. In all these circuits linearization of thermistor was achieved at a certain fixed operating point to temperature-frequency function. But in these circuits error due to nonlinearity increases appreciably as temperature shifts away on either side of the chosen inflection point. A new procedure is suggested in this paper in which the linearization of thermistor is achieved by designing the oscillator circuit in such a way that the time period of oscillation is proportional to the natural logarithm of thermistor resistance. The range of the present instrument is from 15 to 65° C, having an accuracy of ± (0·1 to 0·7° C).

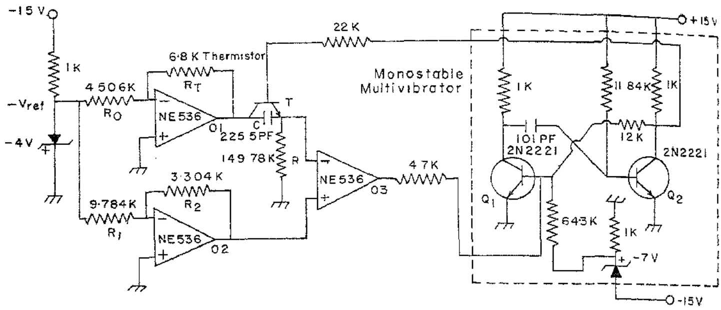

FIG. 1. The oscillator circuit.

2. Sensor

Small bead thermistor encapsulated in a glass tube near its tip is used as temperature sensor. The functional relationship between resistance and temperature for a thermistor is given by the following expression

$$R_T = Ae^{\beta/T} \qquad (1)$$

where R_T is the thermistor resistance in ohm at $T°$ Kelvin. A is a constant (ohm) of thermistor ; β a constant (Degree–Kelvin), typical of material and e is the base of Napierean logarithm 2·718.

3. Theory of oscillator circuit

The basic oscillator circuit is shown in Fig. 1. Three FET input operational amplifiers are used in this circuit. This operational amplifier need two supplies $\pm$ 15 V. The slew rate of this amplifier is 6 V/μ sec but the off-set voltage is relatively high of the order of 30 to 90 mV at room temperature. $-V_{ref}$ is a negative d.c., fixed voltage ($-$ 4V). R_T, a 6·8 $K\Omega$ tempo product thermistor is employed to measure the unknown temperature. The resistance variation for this type of thermistor is 2·4 to 11·25 $K\Omega$ corresponding to a temperature variation of 65 to 15° C (Fig. 2). The gain of the operational amplifier 01 is always more than that of the operational amplifier 02 even at the maximum desired temperature measurement. The output of the operational amplifier 01 and 02 are both positive and is given by

$$V_{01} = +\frac{R_T}{R_0} V_{ref} \qquad (2)$$

$$V_{02} = + \frac{R_2}{R_1} V_{ref} \tag{3}$$

where R_0, R_1 and R_2 are shown in Fig. 1.

At the initial instant of time $t = 0$, voltage across the condenser C is $V_C = 0$ and voltage across R is

$$V_R = \frac{R_T}{R_0} V_{ref}$$

Now c starts to charge through R and the expression for charging current is

$$I_c = \frac{\frac{R_T}{R_0} V_{ref} - V_c}{R}$$

$$= \frac{R_T}{R_0} \frac{V_{ref}}{R} - \int \frac{Icdt}{RC}.$$

As the quantities in the first term are constant.

$$\frac{dI_c}{dt} = - \frac{I_c}{RC}$$

$$\int \frac{dI_c}{I_c} = - \int \frac{dt}{RC}$$

$$\ln I_c = - t/RC + C$$

$$I_c = I_{co} e^{-t/RC}.$$

At $t = 0$; $V_c = 0$ and $I_c = I_{co} = \frac{R_T}{R_0} \frac{V_{ref}}{R}$.

Thus $I_c = \frac{R_T}{R_0} \frac{V_{ref}}{R} e^{-t/RC}$.

At any instant of time the voltage across R

$$V_R(t) = \frac{R_T}{R_0} V_{ref}\, e^{-t/RC}. \tag{4}$$

The output of the operational amplifier 03 changes from negative to positive voltage state when the two of its input voltages are equal and the output of monostable multivibrator rises from 0 to 15 volt momentarily ($0 \cdot 8\,\mu$ sec) which is determined by the RC time constant of the multivibrator. The monostable multivibrator is constructed with the help of two high speed *n-P-n* transistor (type 2N2221) as shown in Fig. 1. Due to this positive voltage level at the output of the monostable multivibrator, the transistor T saturates momentarily and enables it to discharge the condenser C completely. Due to this the input voltages of the operational amplifier 03 come back

Table I

Characteristics of the thermistor used

Thermistor	Nominal resistance $\pm 15\%$ $R_{30°C}$ K-ohms	Material constant calculated from calibration curve		Time constant sec	Dissipation constant mw/°C
		β°K	A ohm		
Tempo	6·8	2963·68	0·3859	12	0·43

to its initial condition. The process is repeated and an oscillation in the circuit i generated. The operational amplifier 03 changes its state when

$$V_{01}\, e^{-t/RC} = V_{02}$$

$$e^{-t/RC} = \frac{V_{02}}{V_{01}}.$$

The time period of oscillation in the circuit of Fig. 1. is given by

$$t = RC \ln \frac{V_{01}}{V_{02}}$$

substituting the values of V_{01} and V_{02} from eqns. (2) and (3)

$$t = RC \ln \frac{R_T R_1}{R_0 R_2} \tag{5}$$

substituting from eqn. (1) the value of R_T in the above equation

$$t = RC \ln \frac{R_1 A\, e^{\beta/T}}{R_0 R_2}$$

$$t = RC \left[2\cdot30258 \log \frac{R_1 A}{R_0 R_2} + \frac{\beta}{T} \right]. \tag{6}$$

The expression for the frequency of oscillation is

$$f = \frac{1}{RC} \left[\frac{1}{\text{constant} + \frac{\beta}{T}} \right].$$

Substituting the values of different circuit parameters and also the constants of thermistor (Table I) in the above equation

$$f = \frac{1}{3\cdot3775 \times 10^{-5}} \left[\frac{1}{-\,8\cdot27952 + \frac{2963\cdot6798}{T}} \right]. \tag{7}$$

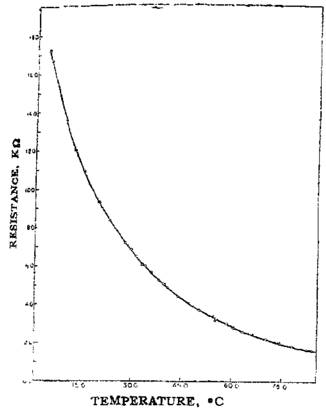

FIG. 2. Characteristic of a 6·8 K tempo product thermistor.

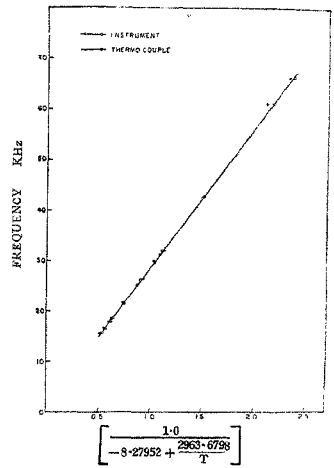

FIG. 3. A linear calibration of the instrument.

If the monostable delay t_m ($0 \cdot 835\,\mu$ sec) is considered in eqn. (6) the expression for temperature is

$$T = \frac{2963 \cdot 6798}{\dfrac{(1/f - t_m)}{3 \cdot 3775 \times 10^{-5}} + 8 \cdot 27952}. \tag{8}$$

Equation (8) is employed to measure temperature. Equation (7) is used to calibrate the instrument. Figure 3 shows a calibration which indicates straight line almost passing through the origin. The deviation from the ideal case, *i.e.*, straight line passing through the origin, is due to monostable delay and off-set voltage of the operational amplifiers.

4. Calibration

The temperature *vs*. resistance characteristic of a 6·8 $K\Omega$ thermistor is shown in Fig. 2. Table I shows the value of constants of the thermistor. The constants of thermistor are calculated by solving eqn. (1) at the two ends of the temperature range to be measured using Fig. 2. The instrument was calibrated using copper-constantan thermocouple in the temperature range 15–65° C. The thermistor bead temperature and the thermocouple temperature are found to agree within ± (0·1 to 0·7° C). The straight

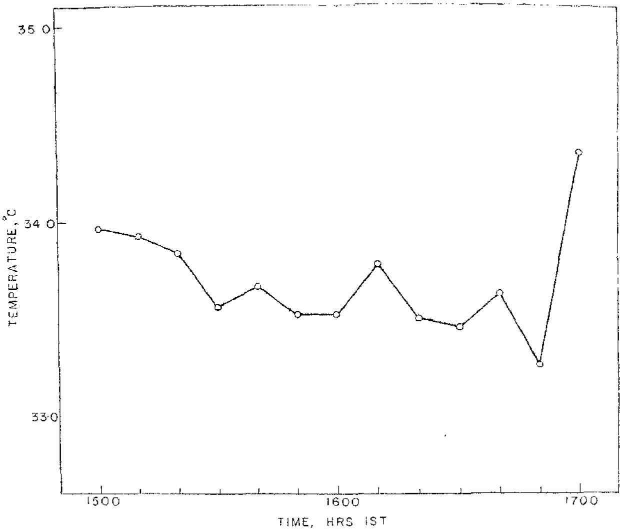

FIG. 4. A two-hour record of room temperature fluctuation on July 3, 1980.

line in Fig. 3 shows the linear calibration of the instrument using thermocouple temperatures as well as computed temperatures. The instrument was used to take two hour room temperature record from 1,500 to 1,700 hr I.S.T. on July 3, 1980, as shown in Fig. 4.

5. Conclusions

This method has shown excellent linearity in the temperature range 15–65° C. The main sources of error in this instrument are the off-set voltage of the operational amplifiers and the small monostable delay of the multivibrator apart from the drift in the passive components such as resistances and capacitances, etc. The effect of small monostable delay can be made non-existent by using I.C. monostable multivibrator (SN 74121). The off-set error can be reduced by proper off-set voltage adjustment of the operational amplifiers. The modern FET input operational amplifiers having low off-set voltage will give better result. Moreover the position of thermistor bead and the hot junction of thermocouple are not exactly identical inside the oil bath. This may create an error in the temperature measurement. If the circuit parameters in Fig. 1 are selected in such a way that $R_1A = R_0R_2$ and $\beta = 1/RC$ in eqn. (6) in that case the frequency of oscillation (f) is an exact linear representation of absolute temperature (T). The instrument can be used for continuous and precision measurement of temperature as an important physical parameter.

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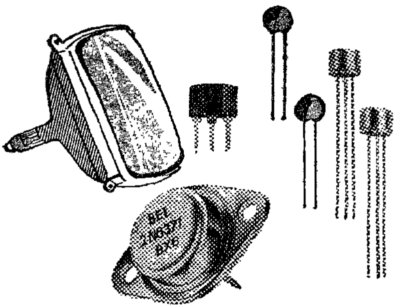

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