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Short Communication

Development of a rocket payload with wire sensor for the measurement of upper air temperature

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Abstract

A rocket-borne instrument which can measure upper air temperature in the altitude range 70 to 20 km has been designed. The instrument essentially consists of a bridge amplifier in conjunction with a voltage-controlled oscillator and a pulse amplitude type telemetry system. The temperature sensor is made from nickel iron alloy wire. Platinum resistance thermometry is employed in determining the temperature surrounding the sensor. The information regarding temperature is transmitted on a carrier link of 1680 MHz from the dipole antenna of a cavity type transmitter tube (R.C.A. 6562). The instrument has been tested in the laboratory and calibration with the copper constantan thermocouple shows high accuracy in the temperature measurement

Key words: V.C.O., thermistor, platinum resistance thermometry, operational amplifier, transmitter tube, voltage regulator.

1. Introduction

In the present work, a bridge amplifier in conjunction with a voltage-controlled oscillator and a pulse amplitude type telemetry system is designed and developed in the laboratory for the measurement of upper air temperature in the altitude range 70-20 km. Nickel-iron alloy wire is used instead of conventional thermistor as temperature sensor. The resistance-temperature calibration of thermistor is generally used to detect unknown temperature in the rocket payload system which uses thermistor as temperature sensor[1]. In this method, a small error in the determination of thermistor resistance may cause an appreciable error in the determination of corresponding temperature due to non-linear relationship between the two parameters[2].

In the present work, the temperature surrounding the wire sensor is determined more accurately from various mathematical relationships which are described in sections 2 and 3. The electronic circuit, calibrated in the laboratory in the temperature range -40 to $+40°$ C, shows high accuracy (0.2 to 1.0° C).

2. Sensor

The sensing wire made of a nickel iron alloy 18 cm in length and 50 μ in diameter is stretched in a zigzag fashion between two thin nylon strings supported by two brass posts plated with

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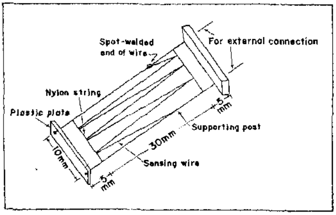

FIG. 1. The front view of sensing wire mounting.

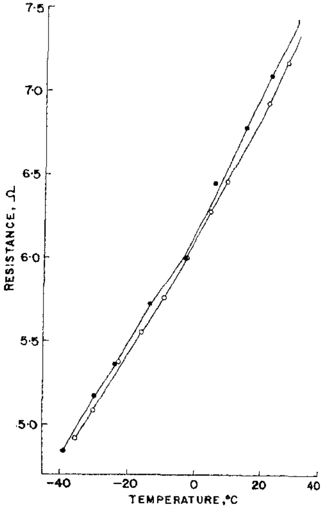

FIG. 2. Resistance-temperature variation of the —, sensing wire.

silver of 2 mm diameter. Relatively low thermal inertia is not necessarily a drawback for these applications as correlations can be made to allow for this[3]. The sensor of the payload is shown in fig. 1. Platinum resistance thermometry is employed in determining the temperature surrounding the sensor[3]. Sensing wire resistance increases with temperature and can be expressed as a quadratic equation of the sensor temperature[3]. Resistance temperature variation of the sensor is shown in fig. 2. The following method of computation in platinum resistance thermometry is used to determine the temperature in centigrade scale.

$$(t-t_{pt}) = \delta \{ (t/100)^2 - (t/100) \} ; \quad \text{(range 0 to } 630^\circ \text{C)} \tag{1}$$

$$(t-t_{pt}) = \delta \{ (t/100)^2 - (t/100) \} + \beta \{ (t/100)^4 - (t/100)^3 \} \quad \text{(range 0 to } -183^\circ \text{C)} \tag{2}$$

where δ and β are constants of the wire sensor, the values of the constants δ and β are 1.5 and −0.23 respectively[4], t is the temperature in the centigrade scale, t_{pt} is known as the 'platinum' temperature and is given by

$$t_{pt} = \frac{R_t - R_0}{R_{100} - R_0} \times 100 \qquad (3)$$

where R_0 is the sensor resistance at 0° C
R_{100} is the sensor resistance at 100° C and
R_t is the sensor resistance at t° C
the temperature to be measured.

The method of successive approximation is applied in eqns. (1) and (2) to determine the value of t.

3. Electronic circuit

The first part of electronic circuit consists of a bridge-amplifier as shown in fig. 3. The output of the bridge-amplifier is a positive d.c. voltage depending upon the value of sensor resistance R_s. The sensor is kept in one arm of the Wheatstone bridge as shown in fig. 3. While R_1 has a precision resistance of 10 Ω, both R_2 and R_3 have 3.257 K Ω each. The unbalance voltage of the Wheatstone bridge is amplified by an operational amplifier (μA741) which is used as a differential amplifier. The input differential voltage of the operational amplifier is given by the following equations

$$(e_1 - e_2) \frac{V_{RE}}{R_s + R_3} R_3 - \frac{V_{RE}}{R_1 + R_2} R_2 = \frac{V_M}{G}$$

where $G = \frac{R_6}{R_4} = \frac{R_7}{R_5}$ is the gain of the differential amplifier, V_m is the output voltage of the amplifier and V_{RE} is the d.c. voltage across the Wheatstone bridge. Thus

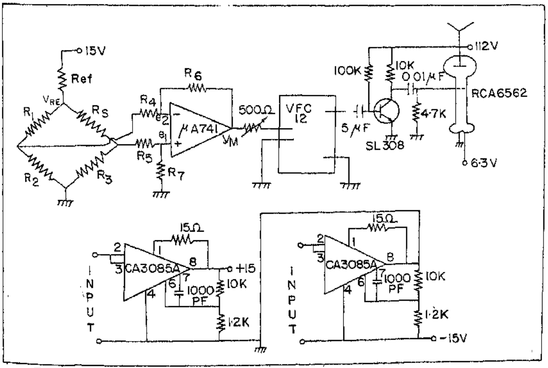

FIG 3. Electronic circuit for the temperature payload.

$$\frac{V_{RE}}{R_s + R_3} R_3 = \frac{V_{RE}}{R_1 + R_2} R_2 + (e_1 - e_2)$$

$$R_s = \frac{V_{RE}\ R_3}{\dfrac{V_{RE}\ R_2}{R_1 + R_2} + \dfrac{V_M}{G}} - R_3 \tag{4}$$

Equation (4) is used to determine the sensor resistance R_s, when V_m is known. The d.c. output of the bridge amplifier is connected to a Burr-Brown model V.F.C. – 12, a voltage-controlled oscillator. The transfer equation of V.C.O. is given by the following relation

$$f_{out} = 10^4\ V_m / 10.0 \text{ Hertz} \tag{5}$$

The V.C.O. operates from d.c. to 10 K Hz and requires ± 15V d.c. power supply. Normally offset need not be adjusted unless absolute accuracies better than ± 0.004% of the full scale are required. The unit is calibrated to provide 10 KHz output frequency for an exact input voltage of 10 volts by a 500 Ω preset potentiometer in series with the input voltage. The output of V.C.O. is connected to an amplifier with SL 308 transistor which is used as a grid modulator and finally to the grid of a cavity type 1680 MHz transmitter tube (RCA 6562). Radio wave is emitted from the dipole antenna of the transmitting tube as pulse amplitude modulation with an average power of 400 mW at 1680 MHz.

A metro data receiver MR 17C located at the other end of the laboratory room has been used for testing the total system. The output of the receiver is connected to a tape recorder for recording the signal. The information thus stored in the tape recorder is printed on the paper tape with the help of a Hewlett Packard digital printer.

Equations (4) and (5) are used to compute the sensor resistance by noting the transmitting frequency of V.C.O. Finally eqns. (1) and (2) are used to determine the corresponding temperature.

The dual power supply requirement of ± 15 volt for the V.C.O. (V.F.C.-12) and the operational-amplifier (μA 741) are obtained from a pair of CA-3085 A voltage regulator as shown in fig. 3. Radiosonde battery of 25 volt ± 20% are used in the unregulated voltage of the regulator circuit. Similar battery of voltages 112 volts and 6.3 volt, with current ratings of 350 and 200mA. respectively, are used for the anode and filament of the transmitting tube (RCA 6562).

4. Calibration

The sensor resistance variation with temperature for two identical sensors is shown in fig. 2. In both the cases the sensing wire resistance variation was observed from −40 to +40° C. The instrument was also calibrated with the help of copper constantan thermocouple in the same temperature range, *viz.* −40 to +40° C. Calibration is reported for a single wire sensor. The

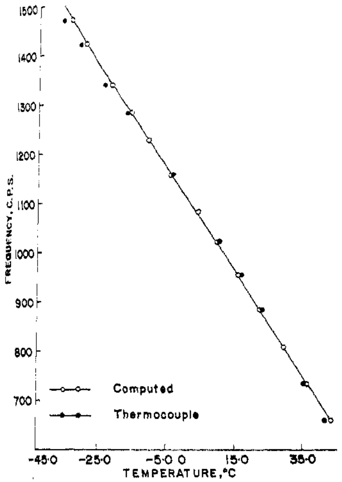

FIG. 4. Linear calibration of the temperature payload.

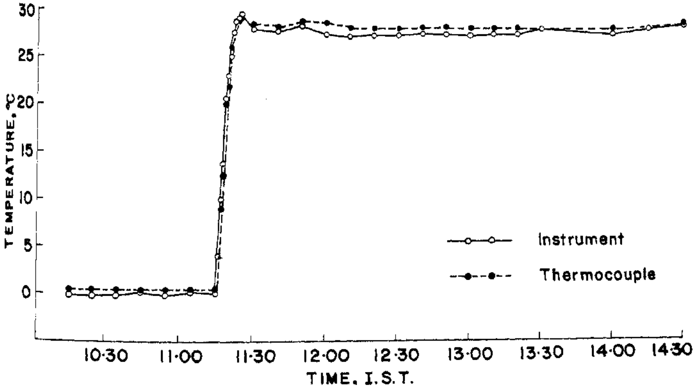

FIG. 5. A typical record of temperature data obtained from the temperature payload.

temperature surrounding the wire sensor and the thermocouple temperature are found to agree within 0.1 to 2 °C. The straight line in fig. 4 shows the linear calibration of the instrument using thermocouple temperature as well as computed temperature. In this calibration solid carbon dioxide (CO_2) was thoroughly mixed inside the mineral oil bath to get the negative temperature side of the calibration. A typical record of temperature data obtained from the payload is shown in fig. 5. The sensor was first kept inside the ice bath from 10-45 a.m. to 11-15 a.m. and at 11-15 a.m. was transferred to a water bath at room temperature. The rapid rise of temperature was noted up to 11-25 a.m. At this time the sensor recorded almost room temperature. A continuous record of room temperature was taken up to 14-30 h I.S.T. The continuous and dotted curves of fig. 5 indicate the temperatures recorded by the payload and the thermocouple respectively. The two readings are almost identical.

5. Conclusions

The temperature payload is found to work satisfactorily in the printed circuit board designed and developed in the laboratory.

The precision resistance in the three arms of the Wheatstone bridge and also in the bridge amplifier is so designed that changes, if any, in the precision resistance with temperature will be balanced.

In order to increase the resolution in the temperature measurement, lower diameter (20 μ) sensing wire should be chosen. In this case small drift in the sensing wire resistance will not cause serious error in the temperature as the lower diameter wire is having large resistance variation per unit temperature change.

The wire sensor payload designed and developed in the laboratory will go through different stringent environmental tests like shock test, vibration test, etc., shortly before its actual rocket flight test.

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