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TEMPERATURE COMPENSATION OF A THERMAL FLOW SENSOR BY USING TEMPERATURE COMPENSATION NETWORK

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ABSTRACT

There has been a growing demand for flow-temperature sensors for industrial, automotive, domestic and medical applications, a quick response and low power consumption. The error of flow temperature measurement is one of the most important problems of sensors. In this paper, the Temperature Compensation Network has been developed for temperature compensation of a Thermal flow Sensor in the Wheatstone bridge circuit. The method allows for a broad range of temperature compensation from -20 to +70^{o}C. The proposed scheme leads to an error reduction of approximately 96.45% from temperature uncompensated value.

Key words: Temperature compensation; thermal flow sensor; temperature compensation network

INTRODUCTION

Thermal flow measuring technology has come a long way since the introduction of thermocouple technology and early hot wire anemometers. Thermal technologies depend on heat transfer and traditionally operate on differential temperature measurements between two temperature sensitive materials to generate a signal directly proportional to the temperature differential and mass flow rate. Over the years, Thermal type flow sensors have been utilized across a very wide spectrum of applications and feature an assortment of performance limits. Modern Thermal flow sensor designs have greatly evolved from laboratory devices to rugged process instruments with each new generation representing a breakthrough in sensing performance. The Hot wire method of bio-chemical sensing does not require any fluorescence tagging, therefore gets many attentions (ISO, 1991 and Göpel et al., 1989). As recent research efforts advance in several converging areas of science and technology, Hotwire based sensors have been proved to be quite versatile and sensitive devices and have been used mainly in the trace detection of bio-chemical materials.

In consideration of the possible flow sensing, there are two principles, which seem to be the most promising: i.e. differential pressure detection and thermal flow measurement (Pereira et al., 1998 and Baltes et al., 1993) Although differential pressure detection is very suitable for liquid flow measurement with high throughput, it is less applicable for low volume liquid flow and for gas flow. In this case, thermal measurement is superior. Thermal flow sensors are basically thermally isolated structures, which carry heaters and thermometers. The thermal flow sensor carry the heat transfer from a heated sensor, usually a small wire, measures the air velocity. The empirical relationship proposed by Park (2000) has proved popular and indeed forms the basis of many temperature compensation schemes. Analogue compensation techniques employing electronic circuits have been used, for example by Collis et al. (1959) and Nam (2004). In this paper we addressed the problem of hot-wire thermal flow temperature compensation using a temperature compensation network in the Wheatstone bridge. As the heat transfer process is sensitive both to the velocity and temperature of the air, any changes in temperature must be compensated for in order to achieve accurate velocity measurements. A hardware implementation of the proposed scheme is also described. A temperature sensor is used as a part of compensation network.

THEORETICAL BACKGROUND

Theory of Operation

The hot-wire thermal flow sensor using Wheatstone bridge equilibrium is shown in Figure 1.

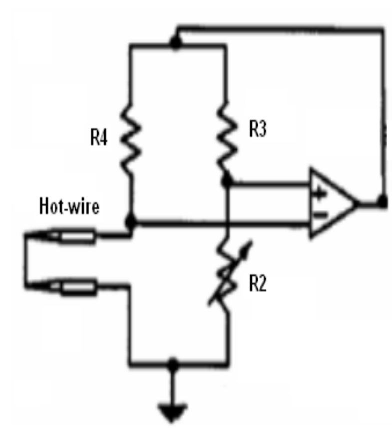


Figure 1: The hot-wire flow sensor based on Wheatstone bridge circuit.

The connection of four resistive components in a Wheatstone bridge configuration is used quite extensively in measurements of temperature. In this application, sensing resistors exhibit temperature sensitivity. For temperature measurements, this temperature dependence has highly undesirable effect, which must be compensated for. We consider all four arms in the bridge being responsive to a stimulus with the sensitivity coefficient, α. An output voltage from the bridge is Eq.(1).

$$V_{out} = V_e \alpha s + V_0 \qquad (1)$$

where V_0 is the offset voltage resulting from the initial bridge imbalance. If the bridge is not properly balanced, the offset voltage may be a source of error. However, an appropriate trimming of the bridge sensor during either its fabrication or in application apparatus may reduce this error to an acceptable level. If the offset voltage is not properly compensated for, its temperature variations usually are several orders of magnitude smaller than that of the transfer function.

Sensitivity α is generally temperature dependent for hot-wire sensor and is major source of inaccuracy. Thus, α may vary if R is temperature dependent. If the bridge has a positive temperature coefficient of resistivity, the coefficient α decreases with temperature. Taking partial derivative with respect to temperature T as in Eq.(2),

$$\frac{\partial V_{out}}{\partial T} = s\left(\alpha\frac{\partial V_e}{\partial T} + \frac{\partial \alpha}{\partial T}V_e\right) \quad (2)$$

If the output signal does not vary with temperature, $\partial V_{out}/\partial T = 0$, then, the following Eq.(3) holds;

$$\begin{aligned} &\alpha\frac{\partial V_e}{\partial T} = -\frac{\partial \alpha}{\partial T}V_e \\ &\frac{1}{V_e}\frac{\partial V_e}{\partial T} = -\frac{1}{\alpha}\frac{\partial \alpha}{\partial T} = -\beta \end{aligned} \quad (3)$$

Where β is the TCS (temperature coefficient sensitivity) of the bridge arm.

The above is a condition for an ideal temperature compensation of a fully symmetrical Wheatstone bridge. To compensate for temperature variations in α, the excitation voltage, V_e must change with temperature at the same rate and with opposite sign.

Time Response to Flow & Temperature Changes

Figure 2 shows the response of a TCN thermal sensor to a step change in velocity, while Figure 3 shows a typical response to a step change in temperature. This level of performance enables the TCN to be used for combustion air flow measurement and control in coal-fired power.

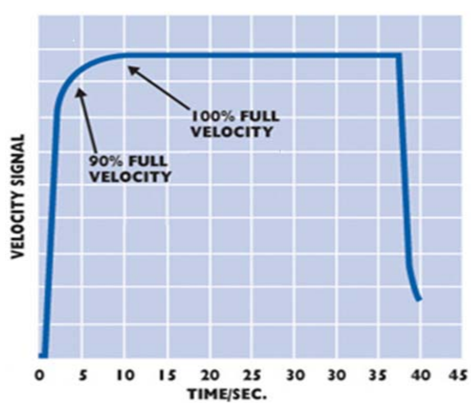


Figure 2: Sensor flow response

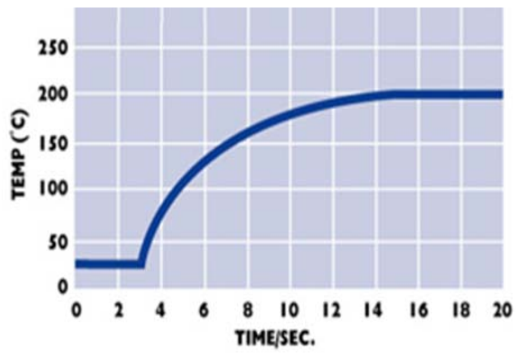


Figure 3: Sensor temperature response

THE PROPOSED METHOD

The thermal sensor uses a modified Wheatstone bridge in which the voltage difference across the bridge is amplified and fed back to the top of the bridge to maintain a constant temperature difference between the heated sensor and the temperature compensation sensor. The heated sensor is the active element in the control circuit. Temperature compensation network (TCN) are very repeatable, essentially linear with temperature, and can be self-heated to provide a known overheat temperature based on their standard resistance versus temperature table. The TCN is constructed using platinum because of its nearly linear characteristics. Thus, the TCN has the unique property of being a heater, as well as a very accurate temperature sensor.

The temperature compensation network method used to control V_e. Figure 4 shows a general circuit which incorporates a temperature compensation network to control voltage V_e across the bridge according to a predetermined function of temperature.

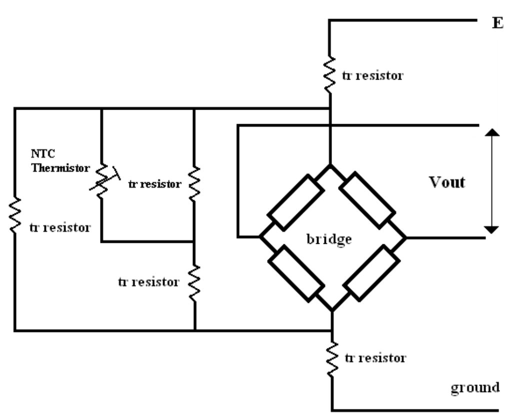


Figure 4: General circuit of bridge temperature compensation

This method used of a temperature sensor as a part of the compensation network. Such a network may be representing by an equivalent impedance R_t, and an entire bridge can be represented by its equivalent resistance R_B. The voltage across the bridge is Eq. (4).

$$V_e = E\frac{R_B}{R_B + R_1} \tag{4}$$

Taking the derivative with respect to temperature as Eq.(5),

$$\frac{\partial V_e}{\partial T} = E\left[\frac{1}{R_B + R_1}\frac{\partial R_B}{\partial T} - \frac{R_B}{(R_B + R_1)^2}\left(\frac{\partial R_B}{\partial T} + \frac{\partial R_1}{\partial T}\right)\right] \tag{5}$$

and with compensation condition Eq.(6);

$$\begin{aligned} \frac{1}{V_e}\frac{\partial V_e}{\partial T} &= \frac{1}{R_B}\frac{\partial R_B}{\partial T} - \frac{1}{R_B + R_1}\left(\frac{\partial R_B}{\partial T} + \frac{\partial R_1}{\partial T}\right) \\ -\beta &= \gamma - \frac{1}{R + R_1}\left(\frac{\partial R}{\partial T} + \frac{\partial R_1}{\partial T}\right) \end{aligned} \tag{6}$$

The heating element is built in a tube where air flows. This method is capable of measuring any flow rate by adopting tubes with suitable inner diameters. This states that such compensation is useful over a broad range of excitation voltage because *E* is not a part of the equation.

EXPERIMENTAL SETUP AND STANDARD TESTING PROCEDURE

Experimental Setup

The test setup is shown in Figure 5. The proposed method allowed for a broad range of temperature compensation from -20 to +70°C. This method requires a trimming of the compensating network to compensate not only for TCS and TCR but for V_e as well. The velocity of air flow was changed from 0 to 35m/s.

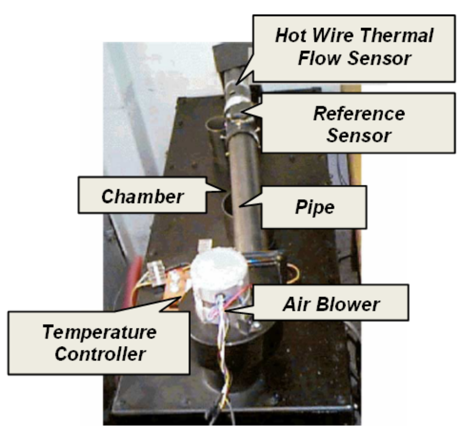


Figure 5: Experimental setup of hot-wire air flow sensor

Standard Testing Procedure

Also one of the primary focuses of the current research was to introduce a standard testing procedure for analyzing thermal flow sensor. When considering flow sensors performance, there are two variables that have the most substantial influence: Temperature and pressure. This is due to the fact that as temperature and pressure change, the density of the fluid passing through a sensor will vary a standard procedure that eliminated the variable of temperature was specially designed and constructed. This procedure, which is schematically shown in Figure 6, is outlined below:

1- Set a blower to a specific pressure and keep the pressure constant at all times when conducting the experiment.
2- Use enough tubing between the blower and the sensor to make sure the flow is laminar before it hits the sensor.
3- Use enough tubing after the sensor and before the valve to eliminate the effect of backpressure.
4- Use a calibrated flow sensor to link its reading, the flow output, to the voltage output reading of the voltmeter.
5- Make sure the flow sensor, the voltmeter, and the power supply have been recently calibrated.
6- Test all sensors in an environmental chamber at different temperatures, in our case 0, 20, 50, and 70°C.
7- Make sure all the equipment used and the sensor subject to testing are kept in the environmental chamber at all times. Wait at least half an hour after the chamber reaches the targeted temperature and then start the testing of the sensors.
8- Every time you open the chamber, repeat procedure 7.
9- It is recommended to have one person test all the sensors.

To conduct a test one must check that the tube is sealed and the environmental room is at the right temperature. After the blower and the sensor circuit board are on, the flow rate can be read on the thermal flow sensor and the voltage output of the sensor can be read on the voltmeter.

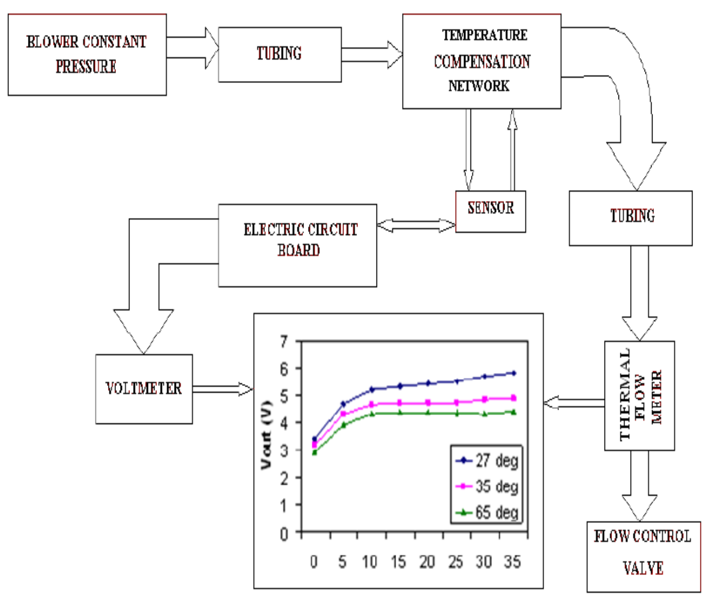
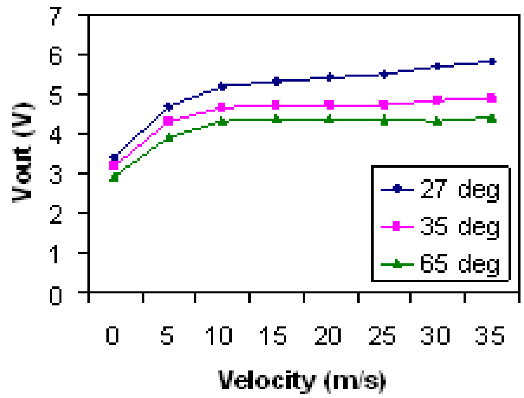


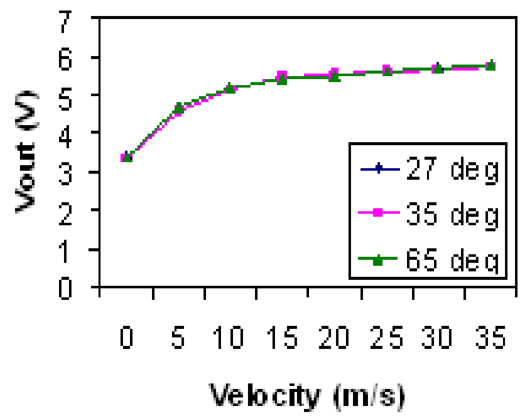
Figure 6: Diagram for Standard Testing Procedure

RESULTS AND DISCUSSION

This paper pointed out the error of temperature compensation that resulted from the Wheatstone-bridge equilibrium, and presented temperature-compensation method. In these flow sensors, the heating temperature of the element is compensated by a reference element, the resistance of which changes depending on the variations of the flow temperature. Figure 7(a) shows the output of the uncompensated circuit. Figure 7(b) shows the output of the compensated circuit using the temperature compensation network. The experiment result has a maximum error percentage of over the entire velocity range (0–35 m/s). The max error is 3.55% at 25m/s.



(a)



(b)

Figure. 7: (a) The uncompensated output voltages (b) The compensated output voltages

CONCLUSION

Thermal flow measurement technologies inherently utilize temperature sensing. Most Thermal flow instrument manufacturers have a reference sensor contained in the flow element that is either integrated with the delta temperature measurement or is independently placed to detect real time changes in process temperature. Thermal devices are designed for automatic correction of process temperature changes. Equal mass flow sensor designs, ensure those changes are free of lag effects and thus offer real time temperature compensation. As a result, most Thermal flow meters are inherently multi-variable and also provide the process temperature as an output. The proposed method allows a broad range of temperature compensation from -20 to +70^{o}C. The result shows that by using this method the error can be reduced to 3.55%

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Nomenclature

R	resistance Ω
R_B	equivalent resistance Ω
R_t	equivalent impedance Ω
S	stimulus
T	temperature ^{o}C
V_{out}	output voltage V
V_e	excitation voltage V
V_o	offset voltage V

Greek symbols

α	sensitivity coefficient
β	temperature coefficient sensitivity