

Design and Construction of an Automatic Variable Temperature Controller for 2 kW Electric Oven

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Abstract

Design and construction of an automatic variable temperature controller for 2kW electric oven is presented in this paper. Most ovens use thermostat for temperature control which result in percentage error of about 40%. The designed and constructed controller has an absolute percentage error of 5% after it was calibrated and tested with a 2kW electric oven. The controller performance is superior compared with some tested controller with percentage error of 40%.

Keywords: Design, Automatic Temperature Controller, Oven.

1. Introduction

Temperature is one of the most frequently used parameters in process measurement; this is because it determines the quality of the output of any process that is temperature dependent (Boyes, 2002). To control the quality of such a process it is therefore necessary that the temperature is within an acceptable range without allowing too much variation in temperature difference for the intended purpose.

In temperature control exercise, the temperature must be measured to know its magnitude. A number of events that are temperature dependent can be used for their measurements and/or control purpose (Boyes, 2002). To work on some agricultural materials, there is the need to dry the material to acceptable moisture level that will not aid microbial activities. The drying activity is always expected to be done with caution in order not to damage the material.

Chesmond (1998) reported that the simplest form of temperature sensing and controlling is by using the bimetallic strip. The changes in its shape resulting from temperature changes cause the electrical contact which has mechanical adjustment to effect changes in the temperature by closing or opening. Most ovens use thermostat for their temperature control which was found to be inadequate in a situation where percentage error is expected to be less than 10%. Out of many methods by which temperature can be measured or controlled, the most suited to indication and control application are those most capable of remote electrical transmission without appreciable transmission loss. Therefore, in any temperature measurement and control that requires high accuracy; electrical transduction thermometer is most preferred. Electrical transduction thermometers convert temperature into an electrical quantity like resistance, current or voltage. Thermocouple, resistance thermometer, thermistor and semiconductor temperature sensors fall under this category.

The thermocouple voltage versus temperature characteristics bears a linear relationship but the problem of cold junction compensation is a major drawback as reported by RS data (1983). Although the thermistor resistance temperature relationship is generally nonlinear compared with resistance-temperature sensor, but it has a very large negative temperature coefficient which makes it to be more sensitive (Doebelin, 1975). Semiconductor temperature sensors require a more involving circuit for it to function well and it covers lower temperature ranges.

Since the temperature control of an oven is not extremely critical like that of incubator, requirement can be satisfied with low cost sensors like thermistor, (Doebelin, 1975). Thermistor was used because it has high temperature sensitivity, physical and chemical stability, no reference junction compensation, negligible contact and lead wire resistance change across the semiconductor, and wide operating temperature range -251.1°C to 648.9°C. (Doebelin, 1975). An additional advantage is that it has high variation of resistance with temperature which allows it to be controlled to a very high resolution of temperature difference (Boyes, 2002). However, for laboratory experiment involving crop handling and soil tillage experiment, there is the need to effectively monitor the temperature at which the experiment is being carried out in order not to vary widely from the intended temperature.

Any of the various established techniques of resistance measurement may be used to measure the resistance of thermistor with the Wheatstone bridge being the most common whereby the unbalanced voltage is conditioned and used as the feed-back signal.

2. Theoretical background

The block diagram of Fig. 1 shows the stages involved in the design and construction of variable temperature controller. The sensor is incorporated into the bridge circuit which converts the temperature into voltage. Thermistor was used as the sensor because it is more sensitive to temperature changes than any resistance temperature sensor, cheaper and readily available, although its temperature characteristic is non linear but the linear region can be utilized, (Chesmond, 1998).

The output of the bridge is in differential form and it varies as the temperature sensed by the thermistor varies. The variation in the output voltage is normally small; therefore, there is a need for a differential amplifier to amplify the output voltage. The output of the differential amplifier is usually negative, to make it positive it must be inverted by feeding it into an inverting amplifier which may have unity gain or higher depending on the level of voltage that is expected at its output.

Output voltage from inverter represents the feed back from the heating process, which is fed to the input of the comparator for comparison with the reference input so that decision can be made as to whether the comparator output should go high or low. The load (heater) is powered via the relay whose coil is engaged by the comparator output through transistor switching circuit.

The bridge requires +5V d.c to function and the differential amplifier, inverting amplifier, comparator and transistor switching circuit needs +12V and -12V d.c for proper operation. therefore, there is a need for a power supply that gives +5V, +12V and -12V regulated d.c voltage at 500mA with maximum ripple of about 10%.

3. Design and Construction

3.1 Design

The design of the controller circuit was carried out in such a way that the circuit will give better over all performance. Glass-coated bead type thermistor with -5°C to 150°C working temperature range was chosen as the sensing element. According to Doebelin (1975), the resistance temperature relation is as shown in equation 1.

$$R_t = R_o e^{B \left(\frac{1}{T_t} - \frac{1}{T_o} \right)} \quad (1)$$

where,

R_t = resistance at temperature T in ohms

R_o = resistance at temperature T_o in ohms

B = constant, a characteristic of material, in °K

e = base of natural logarithm

T_t = process temperature, in °K

T_o = reference temperature, in °K

With $R_o = 2000$ ohm, $B = 2420$, $T_o = 302^\circ\text{K}$ at room temperature (29°C) thermistor resistance R_t will be 2000 ohms and T_t is range between 29°C and 150°C .

The maximum power rating of the selected thermistor is 3 miliwatts, therefore the maximum current ($I_{\max}$) the thermistor can carry without self heating was determined to be 1.225mA. The selected thermistor resistance temperature characteristic is linear between 0°C and 125°C ; therefore, the operating temperature range for this controller is limited to this range to forestall linearity of the controller.

3.1.1 The bridge circuit

Figure 2 is the circuit diagram of Wheatstone bridge with one of the arm resistor replaced with thermistor. The excitation voltage V_i is +5 volts d.c.

Resistors R_1 , R_3 and R_4 were selected in such a way that their resistance values are equal to the resistance of the thermistor at room temperature (29°C), that is 2kΩ. The bridge is expected to be balanced at room temperature; that is V_o should be equal to 0 volt. Any out of balance voltage will be taken care of by resistors R_5 , R_6 and R_7 whose values are 1KΩ, 10kΩ, and 1KΩ respectively. When there is change in temperature the thermistor resistance will also change by certain amount (ΔR). Under this condition the change in the output voltage V_o is given by equation 2.

$$V_o = \frac{V_i \Delta R}{4R} \quad (2)$$

At maximum operating temperature of the oven (120°C), thermistor resistance is 360 ohms. The change in the thermistor resistance between the values at room temperature (29°C) was obtained as follows:

$$\Delta R = 2000\Omega - 360\Omega = 1640\Omega$$

Therefore, the maximum output voltage obtained from the output of the bridge circuit was calculated as follows:

$$V_o = \frac{5 \times 1640}{4 \times 2000} = \frac{8200}{8000} = 1.05 \text{Volts}$$

To get a reasonably high voltage the output of the bridge circuit was fed to a differential amplifier with closed loop gain of 10

3.1.2 Differential amplifier

The circuit diagram of a differential amplifier is shown in Figure 3 R_1 and R_2 are the input resistances while R_f and R_i are the feedback and the amplifier balancing resistances respectively.

The amplifier V_{cc} was supplied from $\pm 12V$ dc power supply. The closed – loop gain G of the amplifier of Fig. 3 is expressed as:

$$G = \frac{R_f}{R_i} \dots\dots\dots (3)$$

Since $G=10$ and R_i was taken to be 10kΩ for improvement of amplifier input resistance, from equation (3) R_f was determined to be 100kΩ. The output voltage from the amplifier is negative; therefore there is a need for inversion of this voltage before feeding it into the comparator.

3.1.3 Inverting amplifier

Figure 4 shows the circuit diagram of an inverting amplifier which was realized by connecting the input resistance R_i and feedback resistance to an operational amplifier (LM324).

Since the intention was to use this circuit as voltage inverter a closed-loop gain of unity was used. The expression for closed loop gain 'G' for this circuit as obtained in equation 3.

For a gain of unity, $R_f = R_i$

R_1 was made to be equal to $10k\Omega$ to improve the input resistance of the amplifier therefore $R_f = 10k\Omega$.

3.1.4 Comparator

The controller must be able to compare the actual measurand with the set value. Figure 5 shows the circuit diagram of such a comparator using operational amplifier in open loop mode. A general purpose operational amplifier (LM324) was used for the comparator circuit. The output voltage V_{O2} of the comparator is either $+V_{cc} = 12V$ or $-V_{cc} = -12V$ respectively. If the inverting input V_{i2} is higher than the non-inverting input V_{ref} the output voltage V_{O2} will be $-12V$ and if the non-inverting input is higher than the inverting input, the output will be $+12V$. The output has just two states: high and low.

3.1.5 Transistor switching circuit

The output of the comparator was fed into the relay circuit via transistor switching circuit in order to power the high voltage and high current load (heater) from low voltage and low current section. The transistor switching circuit diagram is shown in Figure 6.

The NPN transistor used will only be in saturation state if the base voltage V_{BB} is greater than base emitter voltage, V_{BE} which is $0.7V$. However V_{BB} in this case will either be equal to $+12V$ or $-12V$. This implies that the transistor will always be in either saturation (ON) state or cut-off (OFF) state depending on the value of the base voltage. It is only when the transistor is in ON state that current flows in the transistor. Collector current, I_c , collector load resistance, R_c and collector voltage, $+V_{cc}$ are related together by the expression in equation 4.

$$I_c = \frac{V_{cc}}{R_c} \quad (4)$$

R_c is the resistance of the relay coil which is 177Ω for the selected relay. V_{cc} is the relay coil voltage and the value is $12V$.

$$I_c = \frac{12}{177} = 68.8mA$$

BC182NPN transistor was used for this circuit because of its good switching ability and reasonably high collector current ($200mA$). The base resistance (R_{BB}), base voltage (V_{OB}), collector load resistance (R_c), transistor current gain (h_{fe}) and collector voltage (V_{CC}) are related to obtain the following equation.

$$R_{BB} = \frac{V_{ob} \times h_{fe} \times R_c}{V_{cc}} \quad (5)$$

$h_{fe} = 10$ for BC182 transistor; therefore,

$$R_{BB} = \frac{12 \times 10 \times 177}{12} = 1.77K\Omega$$

3.1.6 Relay

The rating of the oven whose temperature is to be controlled is $2kW$, $230V.a.c$ at $50Hz$. From the rated power and voltage, the current was calculated to be $8.7Amps$; therefore, a $10Amp$ relay was considered for the controller.

3.1.7 Reference temperature selection

Selection of reference temperature was carried out with the use of $5K\Omega$ variable potentiometer to set the reference voltage that corresponds to various set temperature and feed the voltage to non-inverting input of the comparator.

The complete circuit diagram of the designed automatic variable temperature controller for 2kW electric oven is as shown in Figure 7.

3.2 Construction

The first step in the construction of electronic circuit is testing of the components to be used for the circuit and this was done to ascertain the condition of the components. After testing, the components were positioned on the vero board and soldered. Conformance tests were carried out on the output of the Wheatstone bridge, differential amplifier, inverting amplifier and the comparator. The switching operation of the transistor and relay circuit was also tested. The results obtained from the tests were adequate.

4. Calibration

In this case, calibration is the process by which the output voltage of the inverting amplifier was recorded as the applied temperature was varied in a pre-defined environment (Mamman et. al., 2002).

For the purpose of this work, a standard oven with digital thermometer of 0-300°C range that can read to two decimal places was used. The calibration curve was obtained by plotting the value of output voltage against the temperature as shown in Figure 8.

5. Results and Discussion

The automatic temperature controller was tested on a 2kW Heraeus oven which has temperature range between 0°C and 240°C. The thermostat of the oven was disconnected and the constructed automatic temperature controller was installed. The oven temperature was monitored by using digital thermometer. The temperature was monitored in order to know the percentage error or deviation from the preset temperature. The result obtained is as presented in Table 1. From the result obtained, it was observed that the automatic temperature controller was able to reduce the error from about 40% to as low as 5%.

6. Conclusion

An automatic variable temperature controller was designed and constructed with the aim of reducing the percentage error that is normally associated with thermostat controlled oven. The automatic variable temperature controller was able to reduce the error associated with thermostat controlled oven from about 40% to 5%. When tested with a 2KW oven it gives approximately linear characteristics. The controller is suitable for domestic and laboratory ovens with maximum power rating of 2kW and tolerance of up to $\pm 5\%$ error (overshoot).

References

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Table 1: Automatic temperature controller testing data

Set Temperature	Measured Temperature(°C)	Percentage Error(%)
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(°C)	Minimum	Maximum	Minimum	Maximum
40	38	40	-5.00	0
60	57	60	-5.00	0
80	78	82	-1.25	+2.5
100	98	102	-2.00	+2.0
120	118	121	-1.67	+0.83

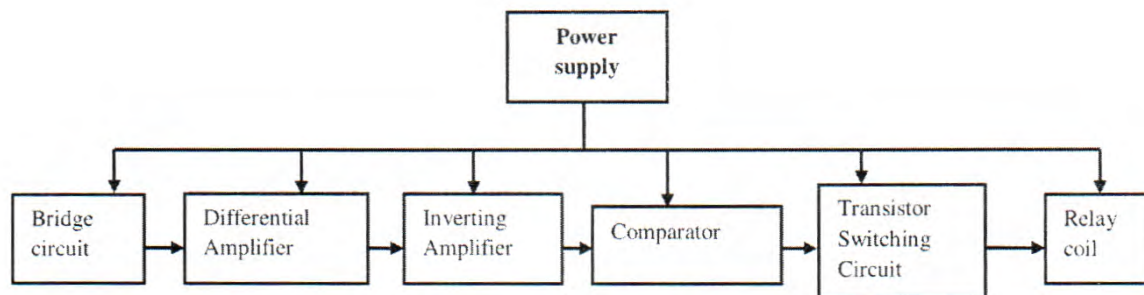


Fig. 1: Block diagram of variable automatic temperature controller

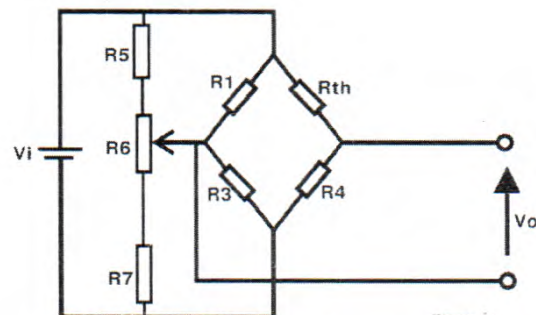


Fig 2: Circuit diagram of wheatstone bridge

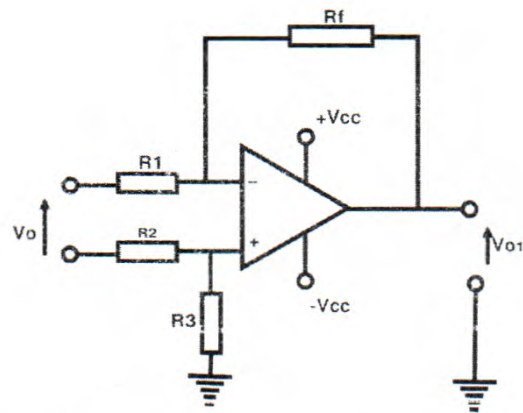


Fig 3: Circuit diagram of a differential amplifier

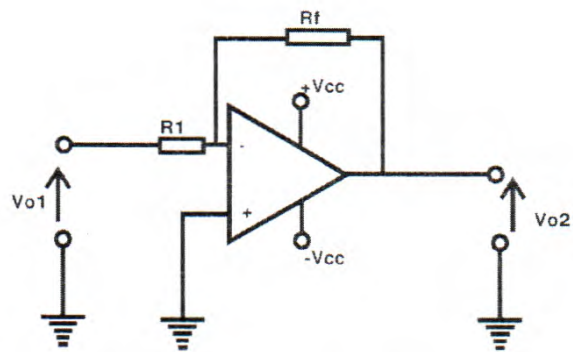


Fig 4: Circuit diagram of an inverting amplifier

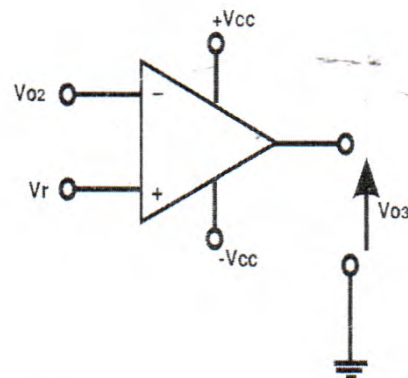


Fig. 5: Circuit diagram of a comparator

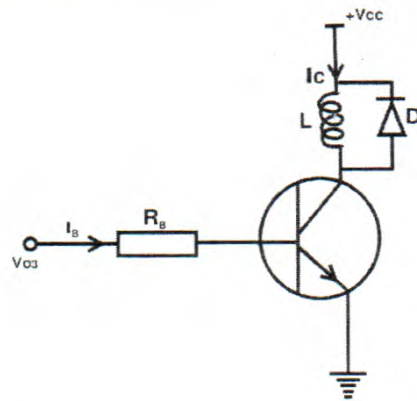


Fig. 6: Transistor switching circuit

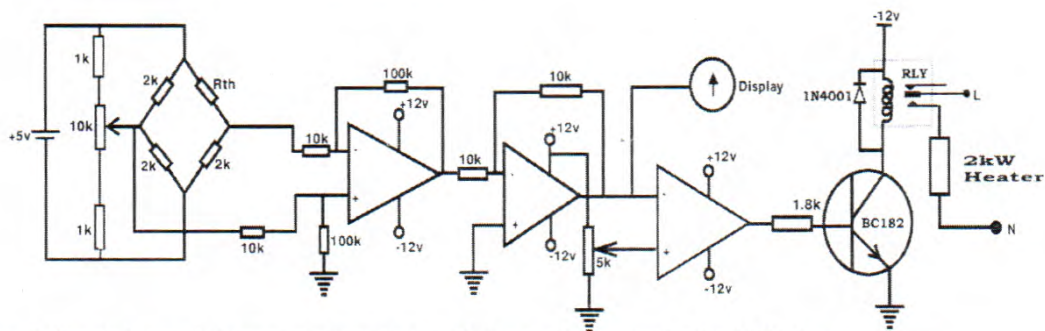


Fig. 7: Complete circuit diagram of automatic variable temperature controller for 2 kW electric oven

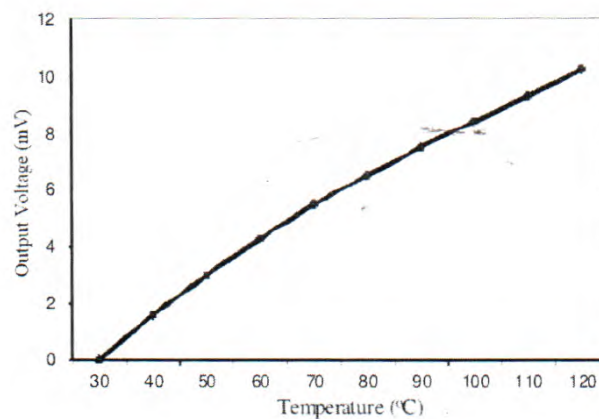


Fig. 8: Calibration curve of the temperature controller