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Design and Performance Study of a Precise Temperature Control Module

M. Nazrul Islam, Kh. Asaduzzaman, Mahbubul Hoq and M.M. Abu Naser Waheed
Institute of Electronics, Atomic Energy Research Establishment,
Bangladesh Atomic Energy Commission, Savar, Dhaka, Bangladesh

Abstract: In this study, an attempt has been made to describe the design and performance study of a precise temperature control module using the integrated circuit transducer. The transducer produces an output current proportional to absolute temperature. The device acts as a high impedance constant current generator. The highest thermal overshot has been recorded at the lower set point and the lowest at the higher. This designed module shows 1.53°C (average) thermal overshot and negligible undershot from the set point. This module can be used in any temperature-sensing application between 0 and 150°C in which conventional electrical temperature sensors are currently used.

Key words: Temperature, control module, current, sensors, absolute temperature, integrated circuit transducer

INTRODUCTION

Control systems are used in all areas of industry. The process may encompass almost any conceivable operation ranging from operation of a machine tool to filling milk bottles. The components comprising a simple control system can be categorized as controller, final actuator or servo, the process and the sensor (Mazda, 1983). A precise temperature control module has been designed that consists of process means a simple electric heater; control variable is the temperature; proportional controller, triac as a servo and the IC sensor (Fig. 1). The module has been designed to meet industrial research, environmental, biotech and general laboratory applications which require close temperature control. Temperature range from 0°C above ambient to +100°C, uniformity being ±0.3°C.

Multi-turn potentiometer control for simple, accurate and repeatable operation. Digital Panel Meter (Islam *et al*., 2005) temperature display, simultaneously reads set point and water temperature.

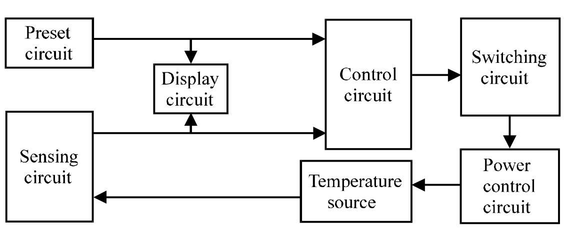

Fig. 1: The complete block diagram of the temperature control module

MATERIALS AND METHODS

Principle of operation: The operation of the precise temperature control module can be illustrated in electric heater operating in a TRIAC circuit (Fig. 2). The power is supplied until the set point is reached. Delays exist due to the thermal capacity of refectories, the load and the temperature sensor. When the power is switched off when the set point is reached, heat continue to flow resulting in overshot and when the temperature falls through the set point there is a delay before the power is switched on. The delay is known as lag.

The relative position of the sensor and load with respect to the heating element are critical. If the sensor is remote from the heating element, large relatively slow swings of temperature with possible overheating of the load will occur while if is close to the heating element rapid oscillation will occur and load may not reach the required temperature.

Oscillation about the set point is inevitable with on-off control since switching (Tocci, 1982) occur only at the set point when full power is applied. A small difference between the set point and the temperature at which the power is connected often exists and this may be increased to prevent rapid wear of switch contacts (Table 1). Proportional action is the basis of continuous control. The power input at any temperature θ within the proportional band is given by:

$$W = \frac{\theta - \theta_1}{\theta_2 - \theta_1} W_0 \quad (1)$$

Corresponding Author: M. Nazrul Islam, Institute of Electronics, Atomic Energy Research Establishment, Bangladesh Atomic Energy Commission, Savar, Dhaka, Bangladesh

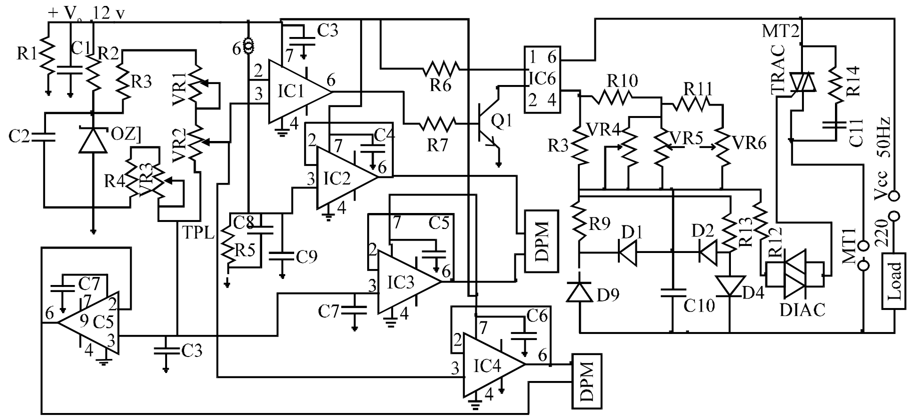

Fig. 2: The complete schematic diagram of the temperature control module

Table 1: The performance of the temperature control module

Normal/measure temperature (°C)	Set temperature (°C)	Water/thermometer temperature (°C)	Thermal overshot (°C)	Rise time (min)	Fall time (min)	Overshot time (min)
27.5	37.5	42.0	2.50	14.48	74	14.02
37.5	47.5	52.0	2.50	14.12	37	9.14
47.5	57.5	62.0	1.80	14.05	19	9.11
57.5	67.5	72.0	1.30	17.10	14	4.25
67.5	77.5	84.0	1.10	17.14	9	4.10
77.5	87.5	90.5	0.90	17.37	7	2.03
87.5	97.5	100.5	0.60	17.57	3	1.12

And the response is given by:

$$P = \frac{e}{b} \quad (2)$$

Where:

- θ_2 = Temperature of the upper limit of the proportional band
- θ_1 = Lower limit
- W_0 = Maximum power input at θ_2
- e = Error signal
- b = Constant for the system

The power can be varied by controlling the mark/space ratio by using thyristors (Mithal and Gupta, 2001; Sharma, 1987) to give rapid sequence or phase-shift control. The overshot is reduced by decreasing the power input as the set point is reached.

RESULTS AND DISCUSSION

For any control system, there is a small region either side of the set point over which no control action occurs. This may be due to mechanical backlash, thermal overshot, etc. If the dead space is made very small instability may occur. This is known as hunting and occurs when the control element is in effect oscillating about the set point and is an important consideration in the design of precision control systems.

The magnitude of the delays in a control system is often important factor governing the stability of the system as well as the degree of precision of control that may be obtained. Delays occur with each element of the system, e.g., sensor, controller, actuator and process. Delays also occur in transmission between each element, although this will often be small. Depending on the system involved the relative magnitudes of the delays may be important or not.

In precision applications, the actual errors encountered are usually dependent upon sources of error. These typically include: Trim error in the Calibration Technique used. This error arises from such causes as poor thermal coupling between the device to be calibrated and the reference sensor; repeatability errors arise from a strain hysteresis of the package. The magnitude of this error is solely a function of the magnitude of the temperature span over which the device is used. Long-term drift errors are related to the average operating temperature and the magnitude of thermal shocks experienced by the device.

Figure 3 shows the comparison between the measure value and the thermometer reading. It has been observed that direct thermometer reading is slightly greater than the former one. The cause is due to the different thermal resistance between the device case and transducer container as the process is heat treatment in a water bath. For smooth transmission of heat between them a thermal conductor has been used. Figure 4 shows the thermal

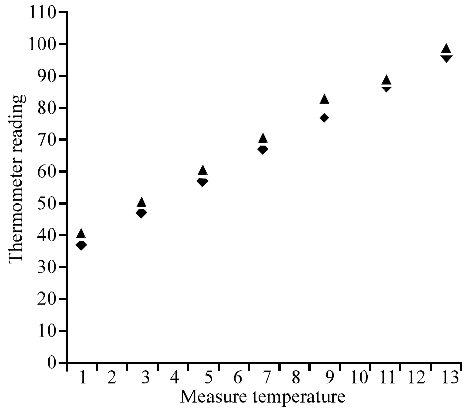

Fig. 3: The comparison between measure temperature and thermometer reading

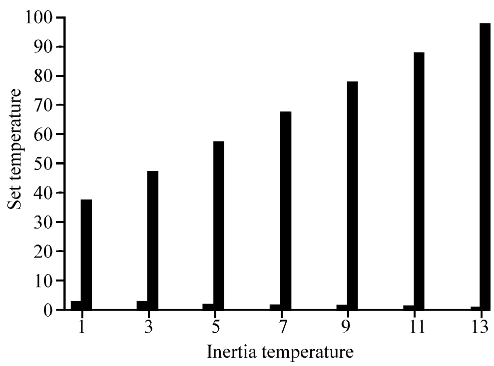

Fig. 4: The comparison between inertia temperature and set temperature

overshot at each set point. The highest thermal overshot has been recorded at the lower set point and the lowest at the higher. There exists a inverse relationship between the two temperature. Figure 5 shows information about the rate of rise of temperature for the designed temperature control module. It has been easily observed that the rise time for 1st three segments between 30-60°C is almost equal about 14 min and different for other four segments between 60-100°C is almost same 17 min only. The average rate of rise of temperature for this module is 1.60 min/°C. Likewise, the rate of fall of temperature from thermal overshot to at each set point has been closely observed from the third graph (Fig. 6). The fall time of temperature for the first segment is comparatively quite high. This is due to the 1st set point is very close to normal temperature and that's why cooling rate is very slow. Thereafter as the set point is increases and the fall time decreases gradually. The average rate of fall time for this module has been recorded as 1.48 min/°C. Finally, Fig. 7 shows the relation between the thermal overshot and time duration for that. It shows that near the normal

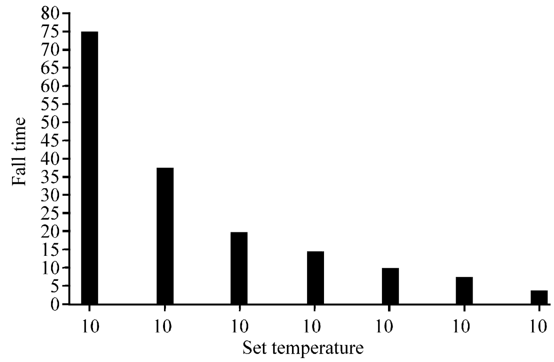

Fig. 5: Rise time vs set temperature

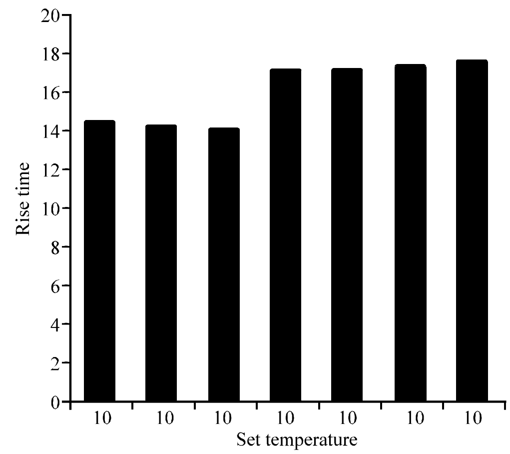

Fig. 6: Fall time vs set temperature

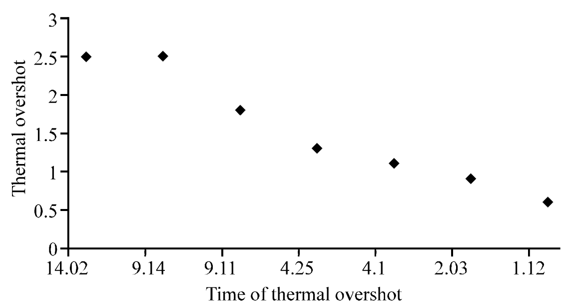

Fig. 7: Thermal overshot vs time of thermal overshot

temperature the thermal overshot as well as time is higher. Thereafter, they fall below towards the upper temperature. The average rate of thermal overshot has been observed as 0.62 min/°C.

CONCLUSION

The designed module has been tested repeatedly and its performance was found satisfactory. This designed module shows 1.53°C (average) thermal overshot and negligible undershot from the set point. The module is cost effective, simple and reliable in operation. This unit can be used in the autoclave, soft incubator, water bath and other industrial applications successfully where the precise temperature control is needed.

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