INT J APPL ELECTR PHYS & ROBOT, Vol. 2 No. 1 January (2014) pp. 8–12
ISSN: 2203-0069
International Journal of Applied Electronics in Physics & Robotics

Research-in-Progress

Design and Performance Evaluation of an Automatic Temperature Control System in an Incubator

Sani Mohammed Lawal[1,*], Mansur Umar[1], Idris Muhammad[2]

(1) Electrical/Electronic Engineering Department, College of Engineering, Kaduna Polytechnic, Kaduna, Nigeria.
(2) Computer Engineering Department, School of Technology, Nuhu Bamalli Polytechnic, Zaria, Nigeria.

doi:10.7575/aiac.ijaepr.v.2n.1p.8

Article history:
Received 13 December 2013
Reviewed 18 December 2013
Revised 24 January 2014
Accepted 26 January 2014
Published 29 January 2014

Abstract. *This paper aimed at designing and evaluating the performance of a circuit that can be used in an egg incubator, capable of controlling and monitoring of the required temperature automatically within the range of 32 to 39°C in a chamber using nonlinear sensor with possible linearization. Monitoring of temperature can be done using different types of sensors such as infrared sensors, thermal cameras, or any other alternative temperature measurement technique. This paper considers the use of thermistor due to its ruggedness and high level of sensitivity. Thermistor is a semiconductor device which senses the temperature in the chamber and the action of its output is send to a comparator which serves as a switching device in the circuit with the help of fast action of relay. The development of embryos in an incubator is highly sensitive to the environmental temperatures, studies shows that temperature manipulations around 38°C can be appropriate for hatching. The circuit consists of different stages: Power stage, stabilizing and amplifying stage, sensing and comparing stage, switching stage and loading stage respectively. All the stages work simultaneously to control the temperature in the chamber within the hatching period of 21 days with periodic turning of eggs manually. The performance evaluation and its output response show a favorable outcome as compared to standard hatching period.*

Keywords: Temperature, thermistor, comparator, control, incubator, chamber.

1 Introduction

The egg incubator is an equipment designed to give eggs the necessary condition for hatching such as temperature, humidity, ventilation and sanitation for a specified period of time before hatching. This paper aimed at improving the productivity of the Nation and the provision of a cheap source of protein. It is also aimed at simplifying the work in the farm and at the same time increasing the output. The incubator is constructed in form of a box that is made up of plywood for retaining the heat generated by the bulbs inside the box (chamber) and has two holes on both sides for proper ventilation. There is a water tray inside the chamber (box) which is in the incubator for the control of humidity, and the incubator has the capacity of hatching 50 eggs, which is placed inside the chamber by means of net arrangement. The supply to the control circuit of this incubator is 240 V (AC) which will step down to 24 V (AC) and later being rectified by bridge rectifiers to 22 or 23 DC voltage that will pass through the circuit. The bulbs are installed in the chamber, to provide heat at a conditioned temperature ranging between 32 to 39°C based on other ranges used [3]. The power-supply unit from the first stage which in employed to power the electronic circuit of the system. This stage provides the necessary DC voltage current required by the passive and component of the control unit. This sensing and comparators stage help to compare two voltages at its input and produce on output, which is a difference of the two input voltage. The next stage is switching stage where the switching actions in performed on the relay by opening and closing contact. Temperature control as far as this design is concerned, depends on the actions of the transducers mentioned. Those transducers are, for example, the thermistor which is the back bone of this design as compared with other designs which were done by Aliyu and Idris [1]. However, temperature control could either be on open loop control system or close loop control system, which can be called the on-off control system [2].

The sensitivity of the thermistor and its reliability in an incubation system [3], it compelled the choice and also behaves as a close-loop control system, by either oning the circuit or offing the circuit depending on the temperature set (voltage equivalent) on the operational amplifier. In this design where a certain temperature is to be maintained and controlled, therefore, it does have a specific or reference temperature, as said earlier, which depends on the temperature set (voltage equivalent) [4].

The Fig. 1 shows a simplified block diagram of a temperature controlled system. The essential of any control system is that the output is dependent on the control operation, i.e. the system is an error actuated control sys-

*Corresponding author: S.M. Lawal
☎: +234 (0)803 640 0068
✉: sanimlawal@gmail.com

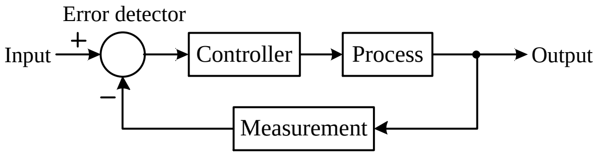

Fig. 1. Close-loop temperature control system

tem. In a close-loop controlled system, the output fed back and compared with the design input, and necessary correction action is taken[4]. Thermistor (temperature sensor) is a temperature-sensitive resistor; it is a special thermal resistor with a negative temperature coefficient of resistance[5]. There are various types of temperature sensing devices like bimetallic strip, but the one in this project is thermistor with a negative temperature coefficient of resistance because it has so many advantages over other types of temperature's sensors such as

1. Extremely high temperature sensitively,
2. Accuracy.

The circuit diagram of an egg incubator with automatic temperature control system is shown in Fig. 2. The power supply which is protected by the protective device (fuse) which fed from 240 V AC supply and step down to 24 V by the transformer. The secondary side (output) of the transformer is center tapped with output voltage of 24 V. Thus, 24 V is then rectified by using a bridge rectifier which consists of integrated four diodes, normally connected in bridge rectifier. Hence, the smoothing capacitor C_1 and C_2 in the circuit are used to filler the AC ripples flow into the circuit, so that almost perfect direct current (DC) is obtained at the output. The supply is of three rails power supply, that is producing ± 12 V and 0 V (ground) which are ideal for effective operation of OP-Amp used as a comparator in the circuit. Furthermore, Limiting resistors R_1 and R_2 are connected in Series to the LED and Zener diode. LED as a transducer coverts voltage to light shows the power-supply unit is properly rectified while zener diode (Z_1) is used in the circuit to stabilize, regulate and provide constant biasing voltage of 12 V to forward bias the transistor (Q_1). Since the transistor (Q_1) is permanently ON, which make the transistor (Q_2) to be at saturated position and zero voltage at the base of Q_2, this results that transistor Q_2 not conducting, which, consequently, make the voltage at collector of Q_2 to be almost 6 V (that is voltage formation produced by a potential divider formed by supply voltage and voltage at collector Q_2). Limiting resistor R_3 formed the divider point and voltage at this point refers to reference voltage (-) at comparator. Henceforth, voltage at pin 3 of the comparator is to be compared with reference voltage at pin 2 of Op-

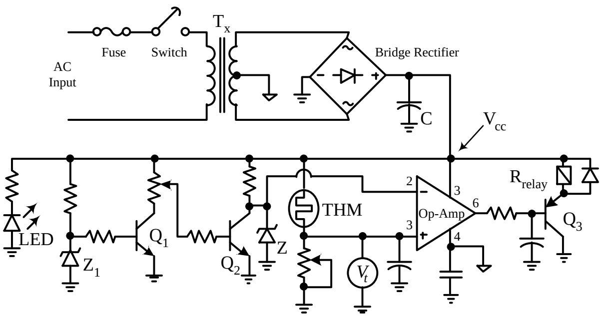

Fig. 2. Circuit diagram of an egg incubator with automatic temperature control system

Amp. The compared voltage at pin 3 is determined by the potential divider formed by the thermistor (THM) and variable resistor (VR) in the circuit. Also Non-reference voltage (+) will be determined by the amount of charging and discharging levels of capacitor C_3 at a period of time.

According to the above explanation, non-reference voltage at pin 3 of Op-Amp will now produce voltage variance depending on changes in the thermistor resistance which is subjected to change by the applied heat in the chamber. The difference of the compared voltage ($\pm$) produced an output voltage that formed square wave when tested thought oscilloscope in a digital form represents 0 or 1. It is this output that will determine the operation of the next stage. The last action is performed by triggering the circuit either ON or OFF by PNP transistor (Q_3) and consequently, energizes or de-energizes the relay that operates the bulb (Heater) inside the chamber. This is a simple way that the circuit works to attain the desired temperature in the chamber as it was presented by French[3].

2 Methodology

The flow chart of step by step design methodology is shown in Fig. 3. The methodology involved is the realization of the following stages; such as circuit design which consists of power-supply and rectification stage, stabilizing and amplifying stage, sensing and comparison stage, switching and heating stage.

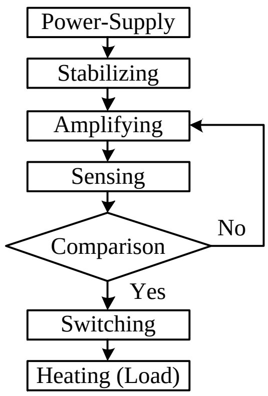

Fig. 3. Flow chart of step by step design methodology

3 Circuit Design Analysis

The analysis of this design is sub-divided into five major stages. These stages work hand-in-hand to produce desired function. The block diagram simply illustrates the conjunctional operation of the design. Thus, the main five stages are

1. Power-supply stage,
2. Stabilizing and amplifying stage,
3. Sensing and comparating stage,
4. Switching and,
5. Heating stage.

3.1 Design Specifications

The design was based on the following technical specifications. The input DC voltage is 12 V; the heat energy is 191 J; AC output is 220 V; the output power is 120 W; the frequency is 50 Hz; and the efficiency is 80%.

3.2 Power Supply Stage

The power-supply unit is made up of a transformer with full wave bride rectifier and efficient filtering device for smoothening the ripples. The rectification is the first part to be considered by simple conversion of AC to DC, while filtering part allow the pure signal to flow for the optimum operation of an Op-Amp in the circuit. The generated DC voltage from 220 V AC supply that step down to 24 V with 500 mA current rating before flow to the rectification part[6].

3.3 Rectification

The objective of this part is to ensure AC signal is properly converted to digital, which is the base supply for electronics devices[7]. A full wave bridge rectifier used for the rectification and 14 V DC supply is produced. The following parameters illustrate the design analysis of it.

The percentage of voltage regulation ($V_{Reg}\%$) can be calculated via (1).

$$V_{Reg}\% = \frac{V_n - V_f}{V_f} \times 100 \tag{1}$$

where, V_n is the voltage at nominal load and V_f is the voltage at full load. Therefore, for a full wave rectifier used in this design, direct current supply (V_{dc}) is given as (2).

$$V_{dc} = \frac{2V_m}{\pi} \tag{2}$$

where, V_m is the peak of input AC voltage.

Another part in the power-supply stage is filtering, which is achieved by using electrolytic capacitors of 2200 μf and 25 V. This capacitor is purposely meant of filter the ripples flow into the circuit. For full wave rectification acquired above, and the analysis of it is as follows.

Filtering capacity ($V_{r,rms}$) can be calculated by using (3).

$$V_{r,rms} = \frac{X_c V_{rms}}{R} \tag{3}$$

or

$$V_{r,rms} = \frac{V_{rms}}{2\pi f CR} \tag{4}$$

where π is a constant value of 3.142, f is the frequency (50 Hz), CR is time constant for changing (τ), V_{rms} is the rms voltage of the input AC supply.

3.4 Stabilizing Stage

The supply voltage (V_{dc}) passes through filtering capacitor, but as far as this part is concerned, the capacitors act as an open-circuit in the part. Therefore, the voltage across zener diode (V_z) is as (5).

$$V_z = V_L = \frac{R_L}{R_+} \times \frac{V_I}{R_L} \tag{5}$$

where

$$R_L = \frac{R_1 V_z}{I} \tag{6}$$

where

$$I_L = \frac{V_z}{R_L} \tag{7}$$

and

$$I_R = \frac{V_R}{R} \tag{8}$$

where

$$V_R = V_i - V_z \tag{9}$$

Therefore,

$$I_R = \frac{V_R}{R_1} \tag{10}$$

Hence, the maximum load resistance that will allow zener diode to put ON is (11).

$$R_{1,max} = \frac{V_z R}{V_R} \tag{11}$$

The resistance R_1 is known by the design parameters as (12).

$$R_1 = \frac{V_R}{I_R} \tag{12}$$

3.5 Amplifying Stage

The amplifying unit of the design consists of limiting resistors, and NPN transistors work in conjunction to produce a fixed voltage as reference voltage to the input of comparator. By using KVL expression for collector current,

$$V_{cc} - I_C R_C - V_{CE} - I_E R_E = 0 \tag{13}$$

where $I_E R_E$ is 0 and assume that I_C is approximately equal to I_E. Therefore

$$V_{cc} - I_C R_C - V_{CE} = 0 \tag{14}$$

where

$$I_C = \frac{V_{cc} - V_{CE}}{R_C} \tag{15}$$

or

$$I_C = \beta I_B \tag{16}$$

hence

$$I_B = \frac{I_C}{\beta} \tag{17}$$

For the base current equation,

$$V_{bb} - I_B R_B - V_{BE} - I_E R_E = 0 \tag{18}$$

where $I_E R_E$ is 0, therefore,

$$V_{bb} - I_B R_B - V_{BE} = 0 \tag{19}$$

Therefore, I_B of the amplifying unit is

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \tag{20}$$

where, V_{BE} is biasing voltage and it is 0.8 V, β is the gain (hfe) and

$$V_B = \frac{I_B}{R_B} \tag{21}$$

doi:10.7575/aiac.ijaepr.v.2n.1p.8

3.6 Sensing and Comparator Stage

The thermistor and variable resistor form the potential diode to give a compared voltage (reference voltage) into the comparator.

$$V_t = \frac{THM}{THM + V_R} \tag{22}$$

and

$$V(y) = V_t \tag{23}$$

where THM is the Thermistor, V_R is the variable resistor, $V(y)$ is the comparable voltage and V_t is the reference voltage. The maximum non-reference is 8.4 V and the voltage to be compared is also 8.4 V. This stipulated voltage is subject to changes, depending on the variable state of thermistor with the variable resistor. Therefore, the output of comparator gives

$$V_O = k\left(V^+ - V^-\right) \tag{24}$$

or

$$V_O = \left(1 + \frac{R_1}{R_2}\right) V_z \tag{25}$$

3.7 Switching Stage

The triggering operation of this design is done by transistor automatically (PNP type). The operations solely depend on the voltage fed into the base of the transistor from the output of comparator[8].

From KVL method,

$$R_B = \frac{V_O + V_{BE}}{I_B} \tag{26}$$

By replacing (17) with I_B in (26),

$$R_B = \frac{(V_O + V_{BE})\beta}{I_C} \tag{27}$$

Furthermore, the relay operational system which fed from the based voltage through the PNP transistor (Q_3) notes by

$$I_{C_{sat}} = \beta I_{B_{sat}} \tag{28}$$

Therefore, relay resistance is

$$R_{relay} = \frac{V_{cc}}{I_{C_{sat}}} \tag{29}$$

3.8 Heating Stage (Load)

The last unit in this design is the heater (Load). A 120 W tungsten lamp is used as the heat source to the chamber which determines the required temperature into the chamber.

The heat contents in the chamber could be determined by applying first law of thermodynamics as (30).

$$Q = MC\theta \tag{30}$$

where Q is quantity of heat, M is mass of air in the chamber, C is specific heat capacity of air and θ is temperature changes.

To determine the mass of air in the incubator, density of air in the incubator (31) should be applied[9].

$$\vartheta = \frac{m}{\upsilon} \tag{31}$$

where ϑ is density of air in incubator, m is mass of air in incubator and υ is volume of the incubator. Therefore,

$$m = \upsilon \times \vartheta \tag{32}$$

The height (h) of the incubator is 0.25 m, the length (l) is 0.21 m and the breadth (b) is 0.18 m. Therefore, the volume of the incubator can be calculated via (33).

$$\upsilon = h\,l\,b \tag{33}$$

Density of air is 1.2 $\frac{kg}{m}$ at room temperature of 35°C and normal atmospheric pressure of 750 $mmHg$. Specific heat capacity of air is 0.24 $\frac{kJ}{kg°K}$, mass of air in the incubator is 113.4 kg and difference between temperature of the incubator and the normal room temperature is as follows

$$(39+273)°K - (32+273)°K \Rightarrow 7°K \tag{34}$$

where 39°C is the temperature of the incubator, 35°C is the room temperature and 273 is the absolute zero temperature. Therefore, substitute all the above data in (30), yields 191 J. Hence, 1 J equivalent to 1 $\frac{W}{s}$, then 120 W bulb will distribute 191 J of heat. Therefore, a bulb of 120 W can raise the temperature in the incubator from the normal room temperature to 39°C. For the purpose, 120 W bulb was used to discharge 190.5 J of heat content to the chamber in a second.

To determine the power (W) of the bulb required in the chamber is known by given project specification, i.e. AC supply is 240 V at 50 Hz and the current rating is 500 mA. Hence, power in watts is the product of given voltage (AC supply), the given current and power factor via (35).

$$P = V\,I\cos\phi \tag{35}$$

where ϕ is 0. Hence, $\cos\phi$ is one. Therefore, bulb of 120 W is suitable to withstand the design specification with respect to the desired heat content to the chamber.

4 Results and Discussion

In order to be convinced and also to actualize the target, testing must be carried out, which will definitely give correspondent output. The potentiometer value was set, and corresponding temperatures were recorded as shown in Table 1.

Table 1, shows that the thermistor resistance is indirectly proportional to the temperature in the incubator

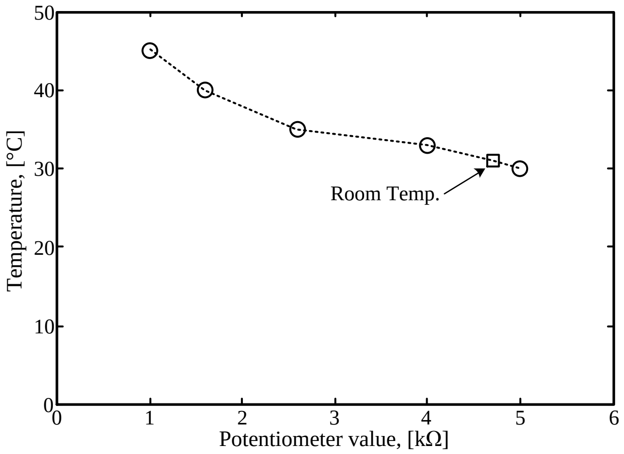

Fig. 4. Temperature vs potentiometer value

Table 1. Thermistor resistance against temperature

Potentiometer value (kΩ)	4.7	5.0	4.0	2.6	1.6	1.0
Thermistor Temp. (°C)	RT‡	30	33	35	40	45
Thermistor voltage (V)	4.7	4.7	3.7	2.6	1.6	1.0

‡ RT is the room ambient temperature.

chamber. Based on data points in Table 1, the behavior of temperature versus potentiometer values is shown in Fig. 4.

The second test was conducted by testing the temperature against time as shown in Table 2.

From Table 2, it can deduce that temperature increases and decreases due to an instantaneous response of the thermistor with respect to time variant. And this proves that sensitivity of thermistor as compared to other types of temperature senses' devices. Moreover, Fig. 5 shows the behavior of both temperature (left axis) and potentiometer values (right axis) as a function of time.

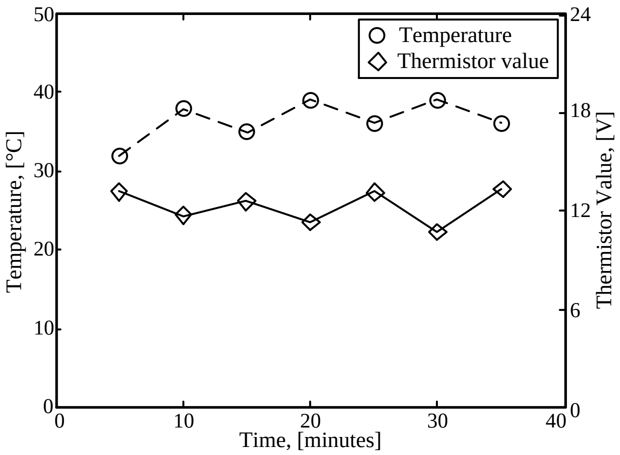

Fig. 5. Temperature and potentiometer value vs time

Table 2. Temperature against time

Temperature (°C)	32	38	35	39	36	39	36
Thermistor voltage (V)	13.2	11.7	12.6	11.3	13.1	10.7	13.3
Time (minutes)	5	10	15	20	25	30	35

5 Conclusion

This design has been implemented and found to be working effectively with limited or zero hindrance, even in case of power failure, another source of heat has been a device i.e. through the use of a lantern which feeds the heat to the chamber through the chimney constructed to filter the deposited carbon monoxide which harmful to the respiration of the embryo during development. And also the implementation can be maintained at a lower cost and there is going to be a high profit margin when the design is commercialized.

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