Response characteristics of a negative temperature coefficient thermistor

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ABSTRACT

This article focuses on the thermistor as a device that is widely used for temperature measurement and control in most electrical and electronic devices and appliances. The research is based on the type of thermistor used in photocopiers with particular reference to Minolta Bizhub (model-210) photocopier. The resistance and temperature were recorded by the application of conventional heat to deduce the response curves of resistance versus temperature and resistance/time. Results obtained from the characteristics show that the thermistor employed in the photocopier is a negative temperature coefficient (NTC) device. Also, there was a time variation in the response of the thermistor resistance to temperature changes, which indicates that the thermistor under test functions as a temperature control device. The shape of resistance versus temperature curve appeared to be similar to that of a typical NTC thermistor characteristic.

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1. Introduction

A system is said to be time variant if the time response (time advance or time delay) of the input signal leads to a time shift in the output in response with the input signal. In other words, the characteristics of a time variant system changes with time [1]. A thermistor is a thermally sensitive resistor whose resistance depends on its temperature at a given time. It is one of the most popular temperature sensors, commonly used for measuring temperature. Some materials exhibit appreciable changes in resistance when their body temperature changes, in accordance to the nature of materials they are made of.

Thermistors utilized in photocopiers are used for temperature monitoring and control. Their basic function is temperature control of the heater/fusing unit of the copier to prevent over heating of the heater/fuser lamp located right inside of the heat roller. The heat roller performs the function of dry heating of the toner image transferred to the photocopying paper during the process of copying. This prevents the dry ink (toner) used for printing to be deleted or cleaned

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immediately after photocopy [2]. During the early stages of Xerographic technology, operators were constrained to manual drying, where the toner image (ink prints) on paper is spread under the heat from the sun for a period of time before the photocopies are sorted or arranged. The function of the thermistor is to sense the amount of heat dissipation on the heater unit. At a temperature range of about 150°C to 200°C, the thermistor brakes conduction of current in the heater lamp circuit. Until the temperature falls below this value, the thermistor switches on the heater lamp to maintain the fusing of the photocopies [2].

There are two types of thermistors: the type whose resistance decreases with increase in temperature, known as the negative temperature coefficient (NTC) thermistor; and those whose resistance increase with increase in temperature, otherwise called the positive temperature coefficient of resistance (PTC) thermistors.

PTC thermistors can be categorised as fundamental, switching and polymeric type PTC thermistor. The fundamental type PTC thermistors are made from heavily doped semi-conductors such as silicon. It is doped in such a way that the charge carries concentration is almost independent of temperature so that the material properties will be similar to that of a metal. The carrier mobility decreases with increase in temperature, thereby leading to increase in resistance. They have resistance-temperature coefficient of about 0.7%/°C over a temperature range of – 65°C to + 150°C [3]. The switching type PTC thermistors are made of Barium titanate and doped with small quantities of such elements as antimony bismuth, lanthanum, niobium or cerium. The behaviour is similar to NTC thermistors with a temperature range of about – 200°C to 40°C, where 40°C is the Ferro electric curie temperature of the material. At this temperature, the thermistor switches into PTC characteristics with the resistance increasing rapidly with temperature. At a higher temperature, it again returns to NTC-type characteristics. The switching temperature is controlled by the impurities employed in doping. The temperature at which a material loses its ferromagnetic property is known as Curie temperature [4]. Conversely, the polymeric positive temperature coefficient (PPTC) thermistor is a type of PTC thermistor, also known as a resettable fuse, which shows a non-linear PTC effect. Owing to the fact that they are thermally activated devices, their performance is affected by fluctuation in ambient temperature. They indicate lower resistances under normal working conditions than any other part of a circuit where they are applied so, they have little or no effect on the overall performance of the circuit. But when there is a fault on the circuit, the polymeric PTC thermistor will exhibit a high resistance to trip-off power supply to the circuit pending when the fault condition is cleared, after which the thermistor automatically resets its effect. Thereafter, the circuit is switched to its normal operating conditions [5]. PPTC is made of plastic with carbon grains inside of which at normal temperatures (when the plastic is cool), the carbon grains are all in contact with one another, resulting in current conduction through the device. They exhibit a passive approach to inrush current by limiting the amount of current flow in a circuit (PTC Thermistors). During fault condition in a circuit, the PPTC attains a high resistance to trip-off the circuit. And after clearing the fault the thermistor resets itself to connect the circuit back to its normal operating conditions. They exhibit a small negative temperature coefficient shortly before the Curie point temperature due to the prevention of potential barriers between the crystal grains. This however leads to low resistance, until the Curie point temperature is reached where the dielectric constant drops sufficiently to potential barriers at the boundary of the grain [6]. Thus, the resistance rises sharply as the temperature increases. When the polymer is cool, the

carbon grains are in contact with each other to allow conduction through the device. And the plastic begins to expand when it is heated up resulting in the separation of the carbon grains, which in turn causes the resistance of the thermistor to increase. The resistance increases rapidly with more heating [7]-[8].

NTC thermistors are made from semiconducting materials where the number of active charge carriers is increased when the temperature of the semiconductor increases, resulting in shift to the conduction band. The higher the number of charge carriers, the higher current conduction of the material. This makes them rugged, reliable and stable with the capability of handling extreme temperatures and noise. Moreover, these thermistors can handle extreme environmental conditions [9]. For materials such as ferric oxides (Fe_2O_3) doped with titanium (Ti), an n-type semi-conductor is formed where electrons are the charge carriers. Also, for materials like nickel oxide (NiO) doped with lithium (Li), a p-type semi-conductor is created with holes as the charge carriers. The current through such a device is given by the equation (1); Where, n is the density of charge carriers, e ($= 1.602 \times 10^{-19}$ Coulomb) is the charge of an electron, v is the drift velocity of electrons and A is the cross-sectional area of the inter material.

$$I = nevA \quad (1)$$

Materials having wide range of changes in temperature require the calibration in measurement whereas for materials with small changes in temperature, semiconductors with linear resistance temperature characteristics are preferred. Thermistors made of semiconductor materials with temperatures range from -273.14°C to $1,700^\circ\text{C}$ are available [7], [8].

2. Methodology

The resistance of a thermistor varies with time due to temperature changes. Let $R(t)$ denotes the resistance of the thermistor as a function of time. Associating the input signal $x_1(t)$ with the voltage applied across the thermistor and the output signal $y_1(t)$ with the current flowing through the thermistor; then, the input – output relation of the device can be expressed as [1]:

$$y_1(t) = x_1(t) / R(t) \quad (2)$$

Let's represent the time response of the thermistor produced by a time-shift $x_1(t - t_o)$ of the original input signal by $y_2(t)$, then it follows that [1]:

$$y_2(t) = x_1(t - t_o) / R(t) \quad (3)$$

Also, let $y_1(t - t_o)$ represents the original output of the thermistor due to the input $x_1(t)$ time shift from t_o that is:

$$y_1(t - t_o) = x_1(t - t_o) / R(t - t_o) \quad (4)$$

This implies that $R(t)$ is not equal to $R(t - t_o)$; then, t_o is not equal to zero ($t_o \neq 0$); hence,

$$y_1(t - t_o) \neq y_2(t), \quad \text{for } t_o \neq 0$$

2.1. Experimental Set-up

The thermistor was placed under the application of conventional heat, and an infra-red thermometer was used to measure the amount of heat dissipated by a 240V/1200W heating element, connected in the surrounding of the thermistor. The testing probes of an ohmmeter was connected across the terminals of the thermistor to measure its resistance, as temperature changes. Fig. 1 shows the schematic of the experimental setup. Samples of

thermistors used in Minolta photocopiers (Bizhub Models 152 and 210) were obtained in addition to industrial heaters.

Fig. 1 Schematics of experimental setup

Resistance values were measured in accordance with temperature variations to determine their response characteristics. Measured values were plotted to ascertain the linearity or pattern of the resistance/temperature curve. The measured values were analysed in relation to the behaviour of the response. The experiment was carried out in the electronic laboratory (Ambrose Alli University, Nigeria) on the 27th of March, 2019. Table 1 shows the main characteristics of measuring instrument used.

Table 1 Characteristics of measuring instrument used

Instrument Used	Measurement range	Recording resolution	Accuracy
Infra-red thermometer	- 20°C – 6000°C	0.00001°C	±0.0005%
Digital multi-meter	0 – 20MΩ	0.00001	±0.0005%-

3. Results and Discussion

Fig. 2 shows the response characteristics of the thermistor under study. As observed, the thermistor demonstrated the basic characteristics of a negative temperature coefficient of resistance. As observed (Fig. 2a) during the period of cooling, when the heater voltage supply was switched off it was observed that resistance began to increase as temperature decreases at some time interval. This behaviour further indicates that this thermistor is used for temperature control, at a temperature of about 200°C. Though no research of this kind is known to have been done by the authors, but there seems to be some similarities in the shape of the graphs in comparison to the resistance/temperature curve obtained from existing literatures.

Fig. 2 Response characteristics of the thermistor (a) cooling (b) heating

This is so because as temperature increases (Fig. 2b), the resistance decreases though, in a non-linear pattern. In table 3, the thermistors resistance decreased from about $1\text{M}\Omega$ at a temperature of 30°C to as low as $4\text{k}\Omega$ at a temperature of 220°C . This behavior further demonstrates that the thermistor can compensate for losses in temperature, and it can be used as a sensor to determine a standard for temperature measurement. The shape or pattern of the Resistance/Temperature curves shown in Fig. 2 is similar to a typical characteristic of a negative temperature coefficient (NTC) type of thermistor.

4. Conclusion

The thermistor under test demonstrated the characteristics of a negative temperature coefficient (NTC), as the resistance decreased with increase in temperature. And test results show that the thermistor possesses non-linear resistance/temperature characteristics. Also, the overall thermistor behaviour proves that there is a time delay in responding to temperature increase and decrease at the output of the signal. This is suggestive of the fact that the thermistor function as a temperature monitoring and control device in Minolta photocopier by,

sensing the inrush current flowing into the heater rod (lamp) to attain a resistance which is capable of switching off the lamp when a temperature of about 200°C is reached.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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