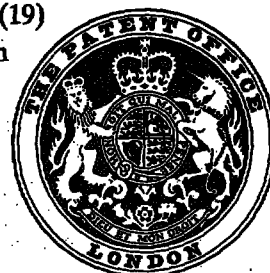


PATENT SPECIFICATION

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(54) ELECTRONIC TEMPERATURE SENSING SYSTEM FOR TOASTER APPLIANCES

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, of 1 River Road, Schenectady, 12305, State of New York, United States of America do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention pertains to temperature sensing electrical circuits and devices for use with automatic toaster appliances and the like. A great number of different temperature sensing and timing schemes have been developed for providing an automatic toasting operation. Of these, there are only a few which combine an economical construction with a reasonably satisfactory operation, and none that are known to combine these characteristics in a truly optimum manner.

The simplest timing mechanism is one that works entirely on a timing principle wherein the toast cycle is tied to a pre-set time interval that may be adjusted for different toast colors. Such mechanism will perform in a consistent fashion to provide a given toast color when all starting conditions are the same, such as toast compartment temperature, bread loading and bread condition. If any one condition is different, results may be different. For example, for the same toast color setting and bread condition, a second toasting operation begun before the toast compartment cools down will result in a darker piece of toast than in the initial operation because of the different initial toast compartment temperatures. Correspondingly, at this toast color setting a frozen slice of bread will be much lighter or perhaps not toasted at all. This is because the applied heat is used primarily to bring the temperature to ambient and remove moisture from the bread.

Perhaps the most commonly employed sensing mechanism used today is a bimetallic timer and switch, the sensor element of which is a bimetallic strip having its own heater wire in association with it. The bimetal strip is remotely located from the bread so as to respond principally to the heater wire and to the ambient. At the initiation of a toasting cycle the heater is turned on to heat the bimetal strip to a peak temperature set in accordance with a desired toast color, whereupon the heater is turned off and the bimetal strip cools to a second temperature which causes a switch to operate and end the toasting cycle. This form of mechanism acts to compensate for different toaster compartment initial temperatures and therefore consistent results may be produced for successive toasting operations. However, the bimetallic timer will not compensate for variations in bread loading or bread condition. Thus, with the operation set for a given toast color setting, two slices of bread will tend to toast to a lighter color than for a single slice of bread, and three slices will tend to toast lighter still. Similarly, if the setting is proper for dry bread, moist bread will toast to a relatively light color.

A third mechanism employed in contemporary toaster appliances is a bimetallic thermal sensor and switch which includes a bimetallic strip sensor element placed in proximity with the bread for sensing the temperature of the bread and moving a lever arm to actuate the switch. Upon reaching a pre-set temperature that corresponds to a desired toast color, the bimetallic strip actuates its switch for ending the toasting cycle. The mechanism includes compensating means, which can be a separate bimetallic strip or an integral part of the primary bimetallic strip, to compensate for the spurious effects of ambient heating. Although this form of mechanism is capable of providing a uniform toast color under all starting conditions, because of the very exacting mechanical tolerances required in the

construction and assembly of the mechanism, including an accurate spacing between the lever arm and the switch contacts and between the bimetallic strip and the bread surface, and the need to maintain these dimensions during continued use, it is difficult to avoid inaccuracies in the toasting operation.

In accordance with the present invention there is provided a toasting appliance having a control system for controlling the degree of toasting, the system comprising means providing a first electrical signal representative of the temperature of the food being toasted, means providing a second electrical signal representative of the ambient temperature in the vicinity of the said food, means providing a third electrical signal representative of the difference between the first and second electrical signals, means providing a fourth electrical signal representative of the required degree of toasting, and means responsive to the third and fourth signals for terminating the toasting operation when the required degree of toasting has been completed.

The first signal may comprise a voltage V_s , the second signal a voltage V_u , the third signal a voltage V_d , and the fourth signal a voltage V_c .

In accordance with a preferred embodiment of the invention, the electronic temperature sensing system includes a temperature sensor device exhibiting a varying electrical resistance versus temperature characteristic and located in close thermal coupling relationship with bread to be toasted, a first circuit for generating a voltage V_s as a function of the temperature of said device, integrating circuit means for generating a voltage V_u as a function of the integral of V_s , a difference circuit for taking the algebraic difference between V_s and V_u and thereby generating a voltage V_d , a potentiometer circuit for generating a voltage V_c which is invariant with respect to a given toast color but adjustable over a range of values for selecting one of several toast colors, and a comparator circuit for comparing the voltages V_d and V_c and thereby generating a control signal for terminating the toasting operation.

The temperature sensor device is preferably mounted so as to be in contact with the bread and thereby most closely represent the bread temperature, and the integrating circuit means includes resistor and capacitor components exhibiting an RC time constant corresponding to the thermal time constant of the toaster compartment, and further includes a resistor voltage divider network for generating the voltage V_u as a fraction of the total integrated voltage so as to correspond to that part of the ambient temperature which is due to radiation heating.

By way of example only, a toasting appliance embodying the invention will now be described with reference to the accompanying figures of the drawing in which:

Figure 1 is a perspective view of a toaster appliance which employs an electronic temperature sensing system;

Figure 2 is a cross sectional view, partially in dotted outline, of the toaster appliance in Figure 1 taken along the line 2-2;

Figure 3 is a schematic circuit diagram of the temperature sensing system of the present invention; and

Figure 4 illustrates a series of curves useful in explaining the operation of the system of Figure 3.

With reference to Figure 1, there is illustrated a perspective view of a toaster appliance 1 which incorporates an electronic temperature sensing system. The toaster 1 is a toaster oven type of appliance having a single compartment providing the versatility of bake and broil operations in addition to being able to toast from one to several slices of bread. The present temperature sensing system applies only to a toasting operation. While the specific toaster oven appliance illustrated is presented principally for purposes of completing the disclosure of the invention, it should be appreciated that the present temperature sensing system has application to single compartment toaster ovens of various constructions as well as to conventional pop-up toasters.

The toaster appliance 1 is shown to include left and right side walls 3 and 5, respectively, a back wall 7, top and bottom surfaces 9 and 11 and a swing out door 13, shown in the open position. Rack support wires 15 support the food article to be heated. In a toasting operation, one or more slices of bread are placed horizontally on the rack support wires. Heating is performed by parallel disposed cal rod heaters 17, of which there are two lower rods in the bottom region of the compartment and two upper rods in the top region of the compartment, the latter not appearing in the drawing.

The temperature sensor device 19 of the present system is fastened to the underside of the rack support wires 15, as more clearly shown in the cross-sectional view of Figure 2. In the exemplary embodiment of the invention being considered, the temperature sensor 19 has a positive temperature coefficient. Preferably, its resistance versus temperature characteristic is substantially linear over the range of temperatures in which it is operated.

The illustrated sensor device is of a wire construction having a U shape. It has dimensions of

approximately one half inch separating the legs of the U by three and one half inches in length so as to provide good thermal coupling to a single slice of bread placed over it. In the example under consideration, the toaster appliance 1 is of a size to accommodate a maximum of four bread slices at one time, each occupying approximately one quarter area of the support rack. The sensor 19 is centrally positioned in one of these areas, specifically in the right, front quarter of the support rack of the present construction, as best shown in Figure 2. Although the illustrated sensor has advantage in providing good thermal coupling to the bread, other types and configurations of temperature sensor devices can be employed for use in the present temperature sensing system, such as a conventional point sensor. In addition, the sensor can be of a type having a negative temperature coefficient as well as a positive temperature coefficient. The principal characteristics required of the sensor are that it exhibit a varying resistance versus temperature characteristic with a relatively high temperature coefficient, and that it provide relatively good thermal coupling to the bread.

In Figure 3 is illustrated a schematic circuit diagram of the inventive temperature sensing system. The system is of an all electronic type and, as will be described in detail, provides an automatic toasting operation in which completely consistent results may be achieved independent of the toaster compartment temperature at the initiation of each toasting operation, the condition of the bread to be toasted (principally moisture content of the bread) and the bread loading (the number of slices to be toasted at one time).

The temperature sensor 19', corresponding to the sensor 19 in Figure 1, has one side connected through a voltage divider resistor 21 to the output of a DC power supply and voltage regulator circuit 23 which is a conventional circuit having its input connected through an on-off switch SW1 to the AC power line at terminal 24. Power supply 23 provides a well regulated DC voltage, normally accurate to within 5%. The other side of sensor 19' is connected to a grounded terminal 25. The junction of the sensor 19' and resistor 21 is connected through an input resistor 27 to the positive input terminal of an operational amplifier 29. The negative input terminal of amplifier 29 is connected through a resistor 31 to ground and through a further resistor 33 to its output terminal so as to provide a gain of approximately four. Operational amplifier 29, and the other operational amplifiers in the circuit, are entirely conventional components. As previously indicated, the sensor 19' exhibits a positive temperature coefficient so that a voltage is generated across it as a function of the sensor's temperature, the voltage being a substantially linear function of temperature over the present range of operating temperatures. This voltage is amplified to appear as voltage V_s at the output of operational amplifier 29.

The output of amplifier 29 is connected to an integrating network comprising a resistor 35 and a capacitor 37, a second operational amplifier 39, and a voltage divider network including resistors 41 and 43. The integrating network functions to integrate the voltage V_s with an RC time constant that is approximately equal to the thermal time constant of the toaster compartment, which integral is coupled to the voltage divider network so as to generate a voltage V_u that is a predetermined fraction of the integrated voltage corresponding to the impact of radiation heating on the integral, as will be further described. One side of the resistor 35 is connected to the output terminal of amplifier 29 and the other side is connected through serially coupled capacitor 37 to ground. The junction of resistor 35 and capacitor 37 is connected to the positive input terminal of operational amplifier 39, the negative input terminal of which is connected directly to its output terminal. The output terminal of operational amplifier 39 is further connected to one side of resistor 41, the other side of which is connected through serially coupled resistor 43 to ground. The voltage V_u appears at the junction of resistors 41 and 43. Operational amplifier 39 supplies unity gain and is placed in the circuit primarily for the purpose of impedance matching.

Considering once again the output of operational amplifier 29, it is also coupled to a PNP transistor 45 for providing a rapid charge to capacitor 37 when power is first applied to the circuit by operation of the switch SW1. Thus, the output terminal of amplifier 29 is connected through a current limiting resistor 47 to the emitter of transistor 45, the collector of which is connected to the junction of resistor 35 and capacitor 37. The serial combination of a resistor 49 and a capacitor 51 is connected across the output of power supply circuit 23 and ground, the resistor 49 being connected to the power supply output and the capacitor 51 being connected to ground. The junction of resistor 49 and capacitor 51 is connected to the base of transistor 45 for causing the transistor to momentarily conduct when the power first comes on and to remain non-conducting thereafter.

The output of operational amplifier 29 is further coupled through a resistor 53 to the positive input terminal of a third operational amplifier 55. The junction of resistors 41 and 43 is connected through a resistor 57 to the negative input terminal of operational amplifier 55. A resistor 59 serves to couple the negative input terminal of amplifier 55 to its output terminal. Operational amplifier 55 provides a voltage V_d at its output terminal that is the

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algebraic difference of the voltages V_s and V_u applied to the amplifier's positive and negative input terminals, respectively, while providing a gain of about one and a half.

The output of amplifier 55 is connected through a resistor 61 to the negative terminal of a comparator network 63. The tap on a potentiometer 65 is connected through a resistor 67 to the positive input terminal of comparator 63. The tap on the potentiometer 65 provides a constant voltage which corresponds to a given toast color and is manually adjustable over a range of values for providing selection of one of several toast colors. The voltage across potentiometer 65 is supplied by the output of power supply circuit 23 which is connected through a fixed resistor 69 to one side of the potentiometer, the other side being connected through a fixed resistor 71 to ground for limiting the range of voltages that are subject to selection.

The comparator 63 functions to provide a first output signal when the voltage applied to its positive terminal exceeds the voltage applied to its negative terminal, and to provide a second output signal when these voltages are reversed, i.e., the voltage applied to its negative terminal exceeds the voltage applied to its positive terminal.

The output of the comparator is connected through a diode 77 to a control circuit for controlling the supply of power to the cal rod heaters 17', which correspond to the cal rod heaters 17 referred to in Figure 1. The control circuit includes a pair of NPN transistors 79 connected in a Darlington configuration. The base input electrode 80 of the transistor pair 79 is connected to the output of a conventional zero crossing detector pulse generator circuit 81, shown in block form. Pulse generator circuit 81 is supplied with DC voltage from power supply circuit 23 and in response to application of the AC supply voltage coupled from terminal 24 generates a pulse at each zero crossing of said AC voltage. The base input electrode of the transistor pair 79 is also connected to the anode of diode 77 and through a bias resistor 83 to the output of power supply circuit 23, which output is also connected to the joined collector electrodes of the transistor pair. The emitter output electrode 84 of the transistor pair is connected through a resistor 85 and a diode 87, poled in the forward direction, to the gate electrode of a triac device 89 which connects one end of cal rod heaters 17' to ground. The other ends of the cal rod heaters are connected through a switch SW2 and through switch SW1 to the AC voltage source. Switch SW2 is actuated, such as through closing of the toaster door, to initiate a toasting operation. The pulses from pulse generator circuit 81 are applied to the base input electrode of the transistor pair 79 together with the output of the comparator 63 for causing a pulsed conduction of the transistor pair when the first output signal is supplied by the comparator. This in turn causes triac 89 to conduct for energizing the cal rod heaters 17'. When the second output signal is supplied by comparator 63, the transistor pair 79 is prevented from conducting, resulting in the cal rod heaters being de-energized.

In accordance with one exemplary embodiment of applicant's invention as described with respect to Figure 3, the following component type and component values may be employed, which are given by way of example and are not to be construed as limiting of the invention.

	Amplifiers 29, 39, 55, 63	LM324 Operational Amplifier	
	Transistors 45 79	2N3012 2N5210	5
10	Diodes 77, 87	1N914	10
	Capacitors 37 51	22 uf tantalum 50 uf electrolytic	
15	Resistors 21 27 31 33 35 41 43 47 49 53 57 59 61 potentiometer 65 67 69 71 83 85	2.7K ohms 10K ohms 10K ohms 40K ohms 1.5M ohms 55K ohms 59K ohms 2K ohms 200K ohms 10K ohms 100K ohms 50K ohms 10K ohms 50K ohms 10K ohms 100K ohms 20K ohms 27K ohms 90 ohms	15 20 25 30 35
	Temperature Sensor 19'	250 ohms at 68°F to 650 ohms at 600°F	
40	Triac 89	16 Amps 200V. TI Type TIC236	40
45	AC voltage Regulated DC voltage	100v, 60Hz 6v	45

Considering now the operation of the temperature sensing system of Figure 3, the on-off switch SW1 is closed to supply power to the circuit. For the purpose of explanation, it will be assumed that the toaster appliance and bread to be toasted are at room temperature prior to initiation of the first toasting operation. Thus, the temperature sensor 19' is at room temperature and its resistance value and the voltage across it are a function of this temperature. The sensor voltage is amplified by operational amplifier 29 to provide the voltage V_s at its output. A plot of V_s expressed in volts, and the corresponding sensor temperature T_s expressed in degrees Fahrenheit, versus time expressed in seconds is illustrated by the curve A in Figure 4, covering two successive toaster operations. Upon closing of the switch SW1, the transistor 45 is caused to momentarily conduct and charge the capacitor 37 to substantially the full voltage appearing at the output of amplifier 29. The transistor is turned off by the voltage developed across capacitor 51 and remains off for so long as the power is on. Subsequently, capacitor 37 is charged and discharged through resistor 35, the principal discharge path being through amplifier 29 to ground. The voltage across capacitor 37 is coupled through amplifier 39 to the resistor divider network of resistors 41 and 43 to appear as the voltage V_u across resistor 43. In the exemplary embodiment of the invention under consideration, the RC time constant of resistor 35 and capacitor 37 is in the range of 20 to 25 seconds and typically 22 seconds, and resistors 41 and 43 are assigned values that result in V_u representing in the range of 50 to 55%, and typically

52%, of the voltage appearing at the output of amplifier 39. The reason for utilizing the noted time constant and this voltage fraction will be explained presently. A plot of V_u , which is a varying reference voltage, versus time is illustrated by the curve B in Figure 4.

As will be more fully described, applying power to the circuit through closure of switch SW1 results in turning on the triac 89. Thus, upon closing the switch SW2 to initiate a toasting operation, current is supplied to the cal rod heaters 17' from AC voltage source which causes them to rapidly heat, as shown by the curve C in Figure 4. This in turn causes the temperature of the sensor 19' to increase with time. Since the sensor's resistance is a substantially linear function of temperature over the range of operation, the voltage V_s will correspondingly increase with time, as shown by curve A. While the voltage V_s applied to the positive input terminal of difference amplifier 55 increases, the voltage V_u applied to the negative input terminal of amplifier 55 increases as a fraction of the integral of V_s in accordance with the following expression:

$$V_u = \frac{k}{RC} \int V_s dt \quad (1)$$

where k equals the ratio of the resistance of resistor 43 to the sum of the resistances of resistors 41 and 43, R is the resistance of resistor 35 and C is the capacitance of capacitor 37.

The increase in V_u is shown by curve B. A voltage V_d is generated at the output of difference amplifier 55 that is a function of the algebraic difference between voltages V_s and V_u . Since the value of V_s changes more rapidly than the value of V_u , as V_s increases the difference voltage V_d will increase. The manner in which V_d changes can be seen from an examination of curves A and B.

The magnitude of the voltage V_d is compared to the magnitude of a voltage V_c in the comparator 63. The voltage V_c is a constant voltage obtained from an adjustable tap on potentiometer 65 that corresponds to a selected toast color, the greater the magnitude of V_c the darker the toast color. During the initial heating stages, V_d is less than V_c and the comparator functions to generate a first digital signal. In the circuit under consideration this first signal is a sufficiently positive signal that prevents diode 77 from conducting in the presence of signal pulses supplied by the pulse generator circuit 81 so that these signal pulses cause the transistor pair 79 to conduct. Conduction of these transistors supplies trigger signals to triac 89 which keep it intermittently on to maintain an energized condition of the cal rod heaters 17'. At the instant voltage V_d exceeds voltage V_c the output state of the comparator 63 abruptly changes to a second digital signal which is a negative signal that causes diode 77 to conduct. Thus, the signal pulses from circuit 81 are effectively shunted through diode 77 and the transistor pair 79 cannot conduct. In turn, no trigger signals are supplied to triac 89 and it remains in an off condition so as to de-energize the cal rod heaters, which ends the toasting operation. At this time the switch SW2 is normally opened and the toast removed.

As the temperature sensor 19' cools, the voltage V_s decreases but the voltage V_u , since it is delayed with respect to V_s and slow to change direction, will continue to increase for some additional time and then gradually decrease. Thus, the magnitude of the voltage V_d rapidly falls below that of the voltage V_c and the output of comparator 63 changes to the first digital signal, which results in the triac 89 being triggered to its on condition. When the next toasting operation is commenced by closing the switch SW2, the cal rods 17' immediately begin heating and the process previously described is repeated. Thus, as the sensor 19' is heated the voltage V_d once more increases in magnitude until surpassing V_c and the triac 89 is again turned off, ending the second toasting operation.

The curves of Figure 4 will now be referred to to explain the thermal reactions that take place during the illustrated toasting operations, which may be considered as typical. With reference to curve A it is seen that at time $t=0$ the temperature T_s of the sensor 19' is at the ambient temperature, giving rise to a voltage V_s slightly below two volts. As to curve B, the voltage V_u is slightly below one volt. From curve C it is seen that the cal rod heater is also at the ambient temperature at $t=0$.

Upon closing of the switch SW2 at $T = 15$ seconds to initiate a toasting operation, current is supplied to the cal rod heaters 17' from the AC voltage source and, as shown by curve C, the temperature of the cal rods immediately increases. Upon reaching a temperature of about 1300°F, they begin to glow red. In the remainder of the first toaster operation the cal rods reach a maximum temperature of about 1600°F and during this time radiate substantial amounts of thermal energy. Prior to the glow temperature being reached, heating of the temperature sensor 19' is due principally to conduction and convection. During this part of the operation there occurs but a relatively small increase in temperature of the sensor 19', and of the bread which is in close thermal coupling with the sensor and closely approximates

the sensor temperature. Also during this time relatively little moisture is removed from the bread. Once the cal rods begin radiating, moisture is rapidly removed from the bread and the temperature of the sensor increases rapidly as the bread toasts.

The amount of toasting is found to be a function of the quantity of heat added to the bread due solely to radiation, Q_r , once the total moisture content is removed from the bread. This quantity of heat added may be expressed as follows:

$$Q_r = C \Delta t_r \quad (2)$$

where C is the specific heat of the bread and Δt_r is the increase in temperature of the bread due solely to radiation.

Curve A is a function of sensor temperature, and the corresponding voltage, due to the combined effects of radiation, conduction and convection heating. Curve B is a function of the integral of curve A having an RC time constant approximately equal to the thermal time constant within the toast compartment, curve B being the integral reduced by a fraction corresponding to the impact of radiation heating alone. Thus, curve B provides a varying reference voltage representing a varying reference temperature which may be considered as corresponding to that fraction of the ambient temperature within the vicinity of the sensor and bread that has resulted from radiation heating. The difference, then, between the curves A and B represents the increase in bread temperature due to radiation, Δt_r , thereby providing a measure of the heat added to the bread due to radiation. By comparing this change in temperature to a given value known to correspond to a given toast color, that toast color is consistently achieved irrespective of starting conditions.

By considering curves A and B, the voltage difference between them, V_d , which represents Δt_r , is seen to exceed the given value V_c at $t=120$ seconds. At this time the first toasting operation is terminated, switch SW2 is opened and the toast is removed. The cal rod heaters, the sensor 19' and the toast compartment begin to cool as show by curves in Figure 4. If it is assumed that bread is re-loaded into the toaster compartment and the switch SW2 again closed to begin the second toasting operation at $t=135$ seconds, heating will commence at this time. It is seen that during the brief cooling period, the integrated voltage V_u changes relatively little. Thus, its value is substantially higher at the initiation of the second toasting operation than for the first operation. It is also seen from curve C that cal rod heaters being to glow much sooner in time, about ten seconds into the heating period for the second operation. Accordingly, in the second toasting operation V_d is seen to reach the value V_c in a shorter time at about $t=210$ seconds, which is 75 seconds from the beginning of this operation.

It may be appreciated that numerous circuit changes and modifications can be made to the disclosed circuit without exceeding the basic scope of the present invention. For example, a temperature sensor device of different construction than that illustrated might be employed, such as a point sensor attached or placed in close proximity to the toaster rack support wires. A negative temperature coefficient sensor such as a thermistor, could also be employed, connected in the circuit of Figure 3 in place of the positive temperature coefficient element 19'. In such case, curves A and B of Figure 4 would be the mirror image of their present form, the sensor voltage V_s and its integral function V_u being of maximum positive value when cold and decreasing in value as the temperature should rise. The voltage V_d would then have a negative value but the principles of operation of the circuit would otherwise be the same. Alternatively, if a negative temperature coefficient sensor were interchanged in the circuit with resistor 21, operation would be similar to that of the illustrated embodiment.

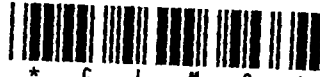
The appended claims are intended to include within their ambit these and all other modifications that fairly fall within the true scope and meaning of this invention.

WHAT WE CLAIM IS:-

1. A toasting appliance having a control system for controlling the degree of toasting, the system comprising means providing a first electrical signal representative of the temperature of the food being toasted, means providing a second electrical signal representative of the ambient temperature in the vicinity of the said food, means providing a third electrical signal representative of the difference between the first and second electrical signals, means providing a fourth electrical signal representative of the required degree of toasting, the means responsive to the third and fourth signals for terminating the toasting operation when the required degree of toasting has been completed.

2. An appliance according to claim 1 in which the second signal is derived as a time delayed function of the first signal.

3. An appliance according to claim 1 or claim 2 in which the third and fourth signals are compared to provide a fifth signal having one of two values depending upon the relative



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the sensor temperature. Also during this time relatively little moisture is removed from the bread. Once the cal rods begin radiating, moisture is rapidly removed from the bread and the temperature of the sensor increases rapidly as the bread toasts.

The amount of toasting is found to be a function of the quantity of heat added to the bread due solely to radiation, Q_r , once the total moisture content is removed from the bread. This quantity of heat added may be expressed as follows:

$$Q_r = C \Delta t_r \quad (2)$$

where C is the specific heat of the bread and Δt_r is the increase in temperature of the bread due solely to radiation.

Curve A is a function of sensor temperature, and the corresponding voltage, due to the combined effects of radiation, conduction and convection heating. Curve B is a function of the integral of curve A having an RC time constant approximately equal to the thermal time constant within the toast compartment, curve B being the integral reduced by a fraction corresponding to the impact of radiation heating alone. Thus, curve B provides a varying reference voltage representing a varying reference temperature which may be considered as corresponding to that fraction of the ambient temperature within the vicinity of the sensor and bread that has resulted from radiation heating. The difference, then, between the curves A and B represents the increase in bread temperature due to radiation, Δt_r , thereby providing a measure of the heat added to the bread due to radiation. By comparing this change in temperature to a given value known to correspond to a given toast color, that toast color is consistently achieved irrespective of starting conditions.

By considering curves A and B, the voltage difference between them, V_d , which represents Δt_r , is seen to exceed the given value V_c at $t=120$ seconds. At this time the first toasting operation is terminated, switch SW2 is opened and the toast is removed. The cal rod heaters, the sensor 19' and the toast compartment begin to cool as show by curves in Figure 4. If it is assumed that bread is re-loaded into the toaster compartment and the switch SW2 again closed to begin the second toasting operation at $t=135$ seconds, heating will commence at this time. It is seen that during the brief cooling period, the integrated voltage V_u changes relatively little. Thus, its value is substantially higher at the initiation of the second toasting operation than for the first operation. It is also seen from curve C that cal rod heaters being to glow much sooner in time, about ten seconds into the heating period for the second operation. Accordingly, in the second toasting operation V_d is seen to reach the value V_c in a shorter time at about $t=210$ seconds, which is 75 seconds from the beginning of this operation.

It may be appreciated that numerous circuit changes and modifications can be made to the disclosed circuit without exceeding the basic scope of the present invention. For example, a temperature sensor device of different construction than that illustrated might be employed, such as a point sensor attached or placed in close proximity to the toaster rack support wires. A negative temperature coefficient sensor such as a thermistor, could also be employed, connected in the circuit of Figure 3 in place of the positive temperature coefficient element 19'. In such case, curves A and B of Figure 4 would be the mirror image of their present form, the sensor voltage V_s and its integral function V_u being of maximum positive value when cold and decreasing in value as the temperature should rise. The voltage V_d would then have a negative value but the principles of operation of the circuit would otherwise be the same. Alternatively, if a negative temperature coefficient sensor were interchanged in the circuit with resistor 21, operation would be similar to that of the illustrated embodiment.

The appended claims are intended to include within their ambit these and all other modifications that fairly fall within the true scope and meaning of this invention.

WHAT WE CLAIM IS:-

1. A toasting appliance having a control system for controlling the degree of toasting, the system comprising means providing a first electrical signal representative of the temperature of the food being toasted, means providing a second electrical signal representative of the ambient temperature in the vicinity of the said food, means providing a third electrical signal representative of the difference between the first and second electrical signals, means providing a fourth electrical signal representative of the required degree of toasting, the means responsive to the third and fourth signals for terminating the toasting operation when the required degree of toasting has been completed.

2. An appliance according to claim 1 in which the second signal is derived as a time delayed function of the first signal.

3. An appliance according to claim 1 or claim 2 in which the third and fourth signals are compared to provide a fifth signal having one of two values depending upon the relative

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amplitudes of the third and fourth signals.

4. An appliance according to any one of the preceding claims further comprising an adjustable resistance for adjusting the required degree of toasting.

5. An appliance according to any one of the preceding claims in which the first signal is derived from a temperature sensor having an electrical characteristic that varies as a function of temperature.

6. An appliance according to any one of the preceding claims in which the first signal comprises a voltage (V_s), the second signal comprises a voltage (V_u) the third signal comprises a voltage (V_d), and the fourth signal comprises a voltage (V_c).

7. An appliance according to claim 6 in which the voltage (V_u) is a function of the integral of the voltage (V_s).

8. An appliance according to claim 7 in which the integral of voltage (V_s) is obtained by means of an integrated circuit which includes an RC integrating network the RC time constant of which is related to the thermal time constant of the toasting appliance whereby the integral of voltage (V_s) corresponds to the said ambient temperature.

9. An appliance according to claim 8 in which the integrating circuit further includes a voltage divider to which the integral of voltage (V_s) is applied for generating the voltage (V_u) as a predetermined fraction of the integral of voltage (V_s) so that the voltage (V_u) is substantially a function of that part of the ambient temperature which is due to radiation heating.

10. An appliance according to claim 9 in which the RC time constant is in the range of 20 to 25 seconds and the said predetermined fraction is in the range of 0.50 to 0.55.

11. An appliance according to claim 5 in which the said temperature sensor is located within a compartment of the appliance so as to provide close thermal coupling with a food article loaded in the compartment.

12. A toasting appliance according to claim 11 in which the temperature sensor is mounted within the compartment so as to be in physical contact with the food article loaded therein.

13. A toasting appliance substantially as herein described with reference to the accompanying drawings.

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