# United States Patent

[11] **3,552,645**


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[54] **CONTROL SYSTEM FOR WEB HEAT TREATING APPARATUS**
**10 Claims, 6 Drawing Figs.**


[52] **U.S. Cl.** ..... **236/15,** 73/355, 219/502, 236/84, 250/210, 263/3
[51] **Int. Cl.** ..... **F27b 9/28,** G01k 7/14, G01k 13/04
[50] **Field of Search** ..... 73/355, 359, 360; 236/15B, 84; 34/30; 219/502; 317/153, 133.5; 250/210; 266/3; 263/3



[56] **References Cited**
UNITED STATES PATENTS

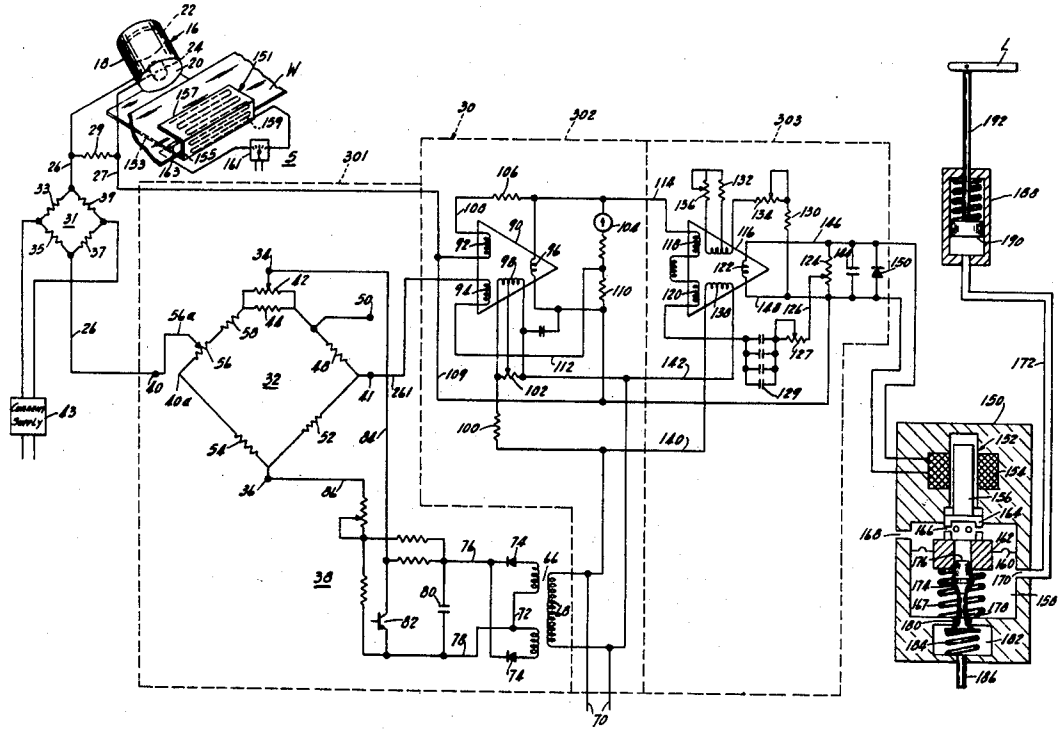
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|---|---|---|---|
| 2,244,732 | 6/1941 | Schmitt | 219/502X |
| 2,540,966 | 2/1951 | Swain | 236/15 |
| 2,611,541 | 9/1952 | Gray | 236/15 |
| 2,752,473 | 6/1956 | Hage | 236/15X |
| 3,163,406 | 12/1964 | Stelling, Jr., et al. | 236/15X |



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**ABSTRACT:** A temperature sensing means for ascertaining the temperature of a heated moving web includes a sensory means generating an electric signal responsive to the radiation emanating from the web. A control means generating a signal in opposition to the signal of the sensory means provides an error signal equal to the difference between the desired and sensed temperatures of the web. The temperature sensing means includes means for compensating for the emissivity of the web. The temperature sensing means may be incorporated in a temperature control system having an electromechanical means responsive to the error signal for controlling the heat supplied by a web heating apparatus to the web so that the actual temperature of the web equals the desired temperature.

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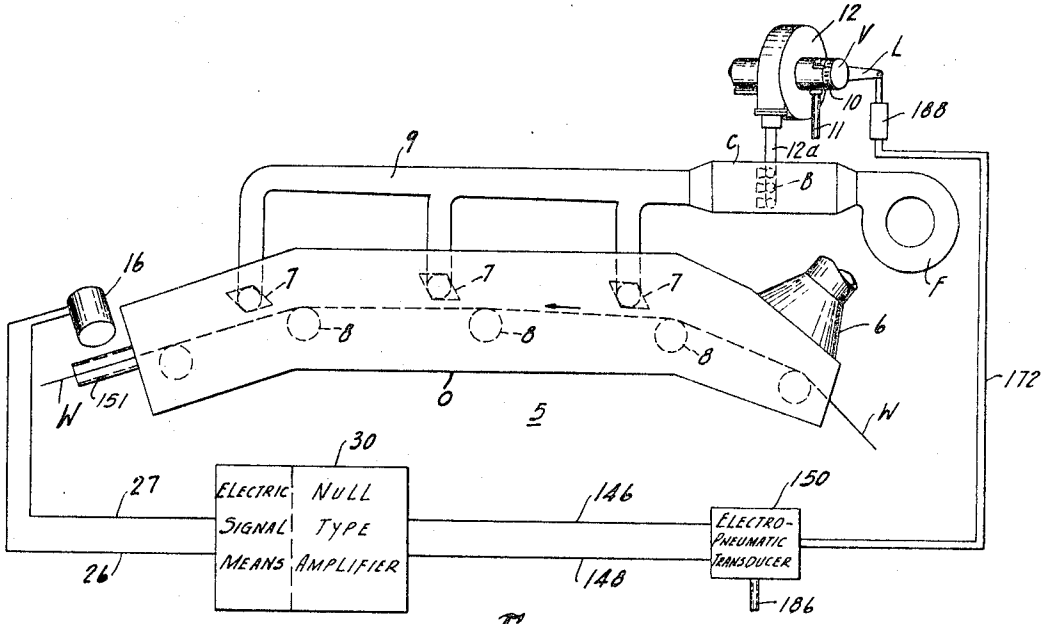



Fig. 1

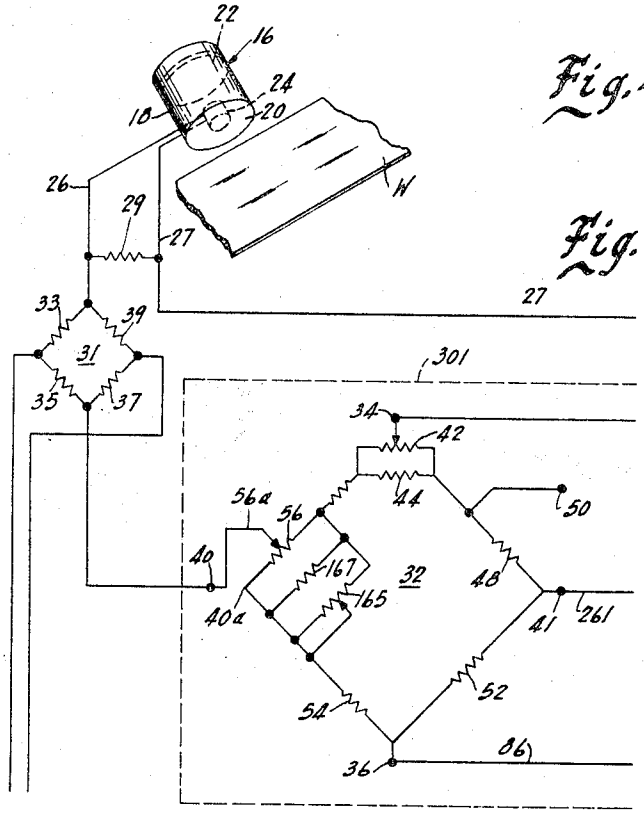
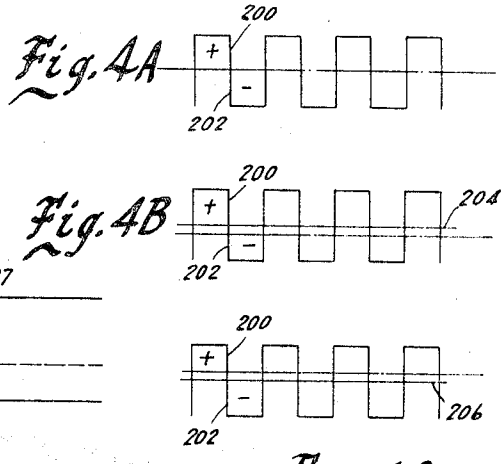



Fig. 3




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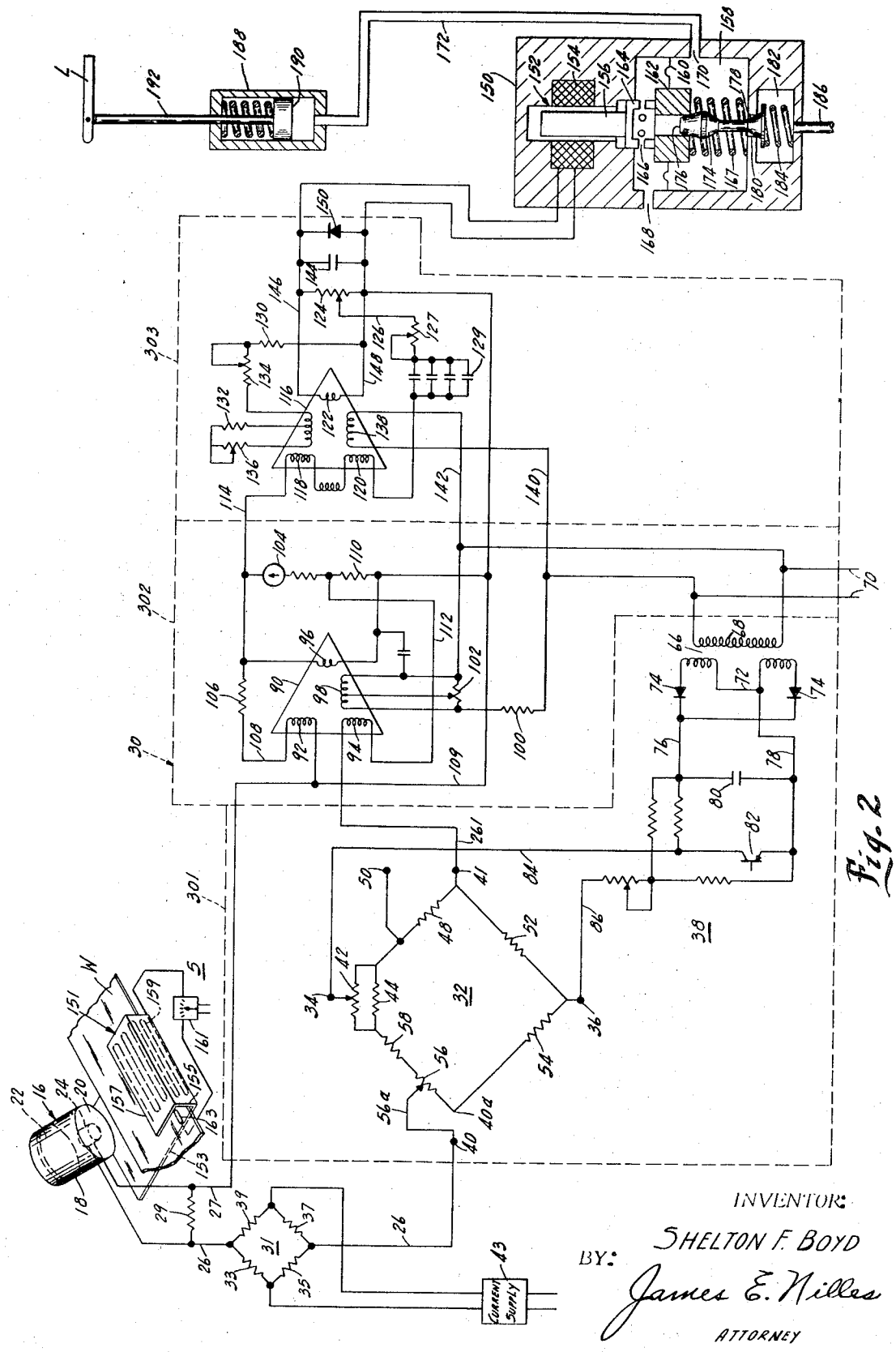


Fig. 2

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# CONTROL SYSTEM FOR WEB HEAT TREATING APPARATUS

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates, in general, to control systems and, more particularly, to temperature sensing means for measuring the temperature of a moving web.

2. Description of the Prior Art

The present invention may be employed with a web heating oven such as is employed as a web dryer in printing or converting apparatus. In such apparatus, the web is unwound from a storage roll, passed through the printing apparatus and down a web heating oven, and then rewound onto a rewind roll. The salient advantage of such web treating apparatus is the increased processing speed obtainable over equipment which handles the material in individual sheets, plates, or other forms.

Accurate temperature regulation or control is essential to obtaining the increased processing speed available from web treating apparatus. In the case of a web converting press, the upper limit in the speed at which the converting press may be run is often determined by the time interval during which it takes the ink, dye, or paint applied to the web to dry, since until such agents have dried, the web cannot be rewound. Drying of the web becomes extremely critical in cases in which the web is a plastic, such as polyurethane, as there is no absorption of the ink by the web to assist in drying the web. By raising the temperature of, or heating, the web, the ink drying time is lessened and the processing speed increased. However, if the temperature of the web is too low, the web will not dry prior to rewinding. On the other hand, if the temperature of the web is too high, the web may be damaged by the excessive temperature.

Accurate sensing of the temperature of the moving web is important to web temperature control. It will be readily appreciated, however, that accurate sensing of the temperature of a rapidly moving web is difficult. Contact sensors may be employed to sense the temperature of the web by conduction. However, the friction between the sensor and the web distorts the temperature sensings thus obtained. Means positioned adjacent the web to sense the temperature of the lamina of air moved by the web have also been employed to measure the web temperature by convection. In general, both conduction and convection temperature sensing means have left much to be desired in terms of both accuracy of the temperature sensing and the speed at which the devices detect changes in the temperature of the web.

To overcome the shortcomings of conduction and convection temperature sensors, attempts have been made to utilize radiation sensors which measure the temperature of the moving web by its emitted radiation, thereby avoiding contact with the web or the surrounding air. In the past, radiation sensors have generally been responsive to the infrared radiation of the web. Because the infrared radiation is but a small portion of the available radiation spectrum, a high degree of amplification was required in the temperature sensing apparatus to provide usable signal levels. The stability, drift, and noise problems encountered in providing such high amplification have caused serious defects in the operation of temperature control systems incorporating such sensors.

Further, the temperature range of such systems is limited in minimum temperatures which may be sensed, as the already small amount of infrared radiation becomes unusably small as the temperature of the web decreases. This limited temperature range lessens the application and utility of the apparatus. Lately, low temperature radiation sensing means have become available but only at an excessively high cost.

A further problem generally left unsolved by prior radiation temperature control systems is the compensation of the sensing means and the control system for the emissivity of the web and for variations in that factor. The emissivity of a material or surface is an expression of the relative ability of



the surface to emit radiation compared to an ideal surface. The ideal surface is termed in physics an ideally black surface, or more generally, a black body. The radiation from a less than ideal surface includes reflected as well as emitted radiation and, in the case of transparent or translucent material, may include transmitted radiation. It is generally difficult to predetermine the emissivity factor of a given web material in a form usable for control purposes. It will be appreciated that variations in the emissivity of the web due to changes in the material or other factors may cause variations in the temperature sensing of the radiation sensor, not reflected by actual variations in the true temperature of the web.

## SUMMARY OF THE PRESENT INVENTION

It is, therefore, the object of the present invention to provide an improved web temperature control system incorporating a temperature sensing means for measuring the temperature of the moving web by means of the emitted radiation of the web.

It is another object of the present invention to provide an improved web temperature control system which utilizes all the radiation emitted by the web so as to provide usable electric signals responsive to web temperature without undue amplification.

Yet another object of the present invention is to provide an improved web temperature control system which includes means for compensating for the emissivity of the web material, thereby to provide accurate sensings of true web temperature.

A further object of the present invention is to provide an improved web temperature control system incorporating the aforesaid temperature sensing means and means for altering heat applied to the web responsive to the sensed web temperature so as to bring the actual temperature of the web into accordance with a desired temperature.

A still further object of the present invention is to provide an improved web temperature control system which is not subject to drift, calibration errors, noise instabilities, and other operational shortcomings and which provides stable operation over a wide temperature range.

An additional object of the present invention is to provide an improved web temperature control system which is simple and inexpensive in construction and operation and which is capable of substantially trouble free operation for substantial periods of time.

Briefly, the control system of the present invention includes a temperature sensing means for ascertaining the temperature of a heated moving web. The temperature sensing means utilizes the radiation which emanates from the web in accordance with both its temperature and an unknown emissivity factor.

The temperature sensing means includes a sensory means positioned adjacent the web and exposed to the radiation emanating therefrom. The sensory means is responsive to the radiation for providing an electric signal corresponding to the amount of the radiation. This sensing means may include a radiation responsive thermopile for rendering the operation of the sensory means stable and substantially drift free.

Control means including electric signal means are connected to the sensory means for providing an electric signal of a preselected magnitude in electrical opposition to the electric signal of the sensory means. The control means also includes deviation sensing means responsive to the electric signals for indicating when the electric signals are in a condition of magnitude equality.

The temperature control system includes means for altering one of the electric signals from the sensory means or the electric signal means to compensate for the emissivity of the moving web, so that the electric signals are in the condition of magnitude equality when the temperature of the web equals the desired temperature. The deviation sensing means, in the form of a null balance, high gain amplifier, provides an error signal corresponding to any deviation of the electric signals from the condition of magnitude equality.

The error signal may be used to drive electromechanical means connected to a controllable heating means in the web heat treating apparatus for controlling the heating means in accordance with the error signal for causing the temperature of the web to equal the desired temperature.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic drawing of a web heating oven and the control system of the present invention;

FIG. 2 is a schematic diagram of one embodiment of the temperature sensing means and control system of the present invention;

FIG. 3 is a schematic diagram of another embodiment of the temperature sensing means; and

FIGS. 4*a*, *b*, and *c* are graphs illustrating the operation of an null type amplifier incorporated in the control system.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

### Web Heating Apparatus

### Oven

A drying oven O is of the enclosed tunnel type having an exhaust conduit **6** extending from adjacent the entry end of the tunnel. A series of blast tubes **7** extend inside the tunnel and across its width and act to produce a direct and localized blast of air on the web W as it moves rapidly through the tunnel on idler rolls **8** and in the direction indicated by the arrow in FIG. **1**. Web W may comprise plastic, paper paper, cloth, rubber, metal or other material which may be heat treated in the web form. The supply conduit **9** furnishes heated air to one end of each of the tubes from a heating chamber C in which is located burner B. If a more complete description of the structure and operation of the blast tubes or oven is deemed necessary or desirable, reference may be had to U.S. Pat. No. 3,074,179 issued on Jan. 22, 1963, entitled "Web Dryer," which shows a typical web heating apparatus.

### Air Supply

A fan F is provided for forcing air past the burner B through conduit **9**, out of the tubes and over the surface of the web. In the illustration shown, the burner is located on the pressure side of the fan F but of course the burner could be located on the suction side of the fan. The air supplied by the fan is preferably filtered and may consist of fresh air mixed with some of the air which has been exhausted from the oven O. In other words, the system may be of the recirculating or non-recirculating type, with the burner located on the suction or pressure side of the circulating fan.

### Fuel Valve

Means are provided for furnishing a properly proportioned mixture of air and fuel to the burner. This means consists of a conventional mixing or ratio valve mechanism V having an air inlet opening **10** and a fuel supply conduit **11** for supplying fuel, such as gas, to the valve mechanism. The valve mechanism is located on the inlet side of the blower **12**, and the gas and air are intimately mixed and then delivered by blower **12** through its outlet conduit **12***a* to the burner. These ratio valves are conventional and may be of the type shown in U.S. Pat. No. 2,286,173, issued July 9, 1942, and further description of them is not believed to be necessary except to say that the valve mechanism serves to vary the volume of air as received from a supply source at any pressure, and to vary the volume of the fuel as received from the supply source at any pressure, and to modify the proportioning so obtained, and to establish such modification for different stages of the feed flow of the proportioned air and fuel; by such facility, the combustible mixture ultimately resultant from said proportioning, being of consistency which is dictated by the conditions under which the burner is operated. In short, the fuel mechanism is opened or closed to vary the amount of fuel by a linkage L to thereby vary the heat delivered by the burner.

## WEB TEMPERATURE SENSING MEANS AND CONTROL SYSTEM

### Radiation Sensing Head and Associated Circuitry

Radiation sensing head **16** is positioned so as to be exposed to the radiation emitted by web W after it has been heated by the hot air from blast tubes **7**. As shown more clearly in FIG. **2**, radiating sensing head **16** may comprise a housing **18** suitable for mounting the head at the exit end of oven O, within oven O, or at some other suitable location. The front of housing **18** comprises a piece of clear glass or plastic **20** suitable for the transmission of the entire spectrum of emitted radiation from web W into the interior of housing **18**. The wavelength and frequency of the spectrum of emitted radiation in any given instance depends on the material and temperatures involved. In the case of a plastic web heated to a temperature of approximately 150°, the spectrum includes radiation having wavelengths of from approximately .2 microns up to 20 microns. Mirror **22** is provided at the rear of housing **18** for collecting the aforesaid emitted radiation and for focusing the radiation on thermopile **24** which may comprise a plurality of series connected thermocouples. The resulting rise in the temperature of thermopile **24** due to the impingement of the focused radiation caused causes the thermopile to generate a voltage proportional to its temperature, which in turn is proportional to the temperature of web W.

The output voltage of radiation sensing head **16** is provided to conductors **26** and **27**. Resistor **29** and resistor bridge **31** containing resistors **33**, **35** and **37** and negative coefficient resistor **39** are used to provide ambient temperature or cold junction compensation to radiation sensing head **16** to compensate for the temperature existing in oven O. Resistor bridge **31** is energized by current supply **43** to alter the magnitude of the output voltage of radiation sensing head **16** to effect the desired compensation.

The thermopile **24** of radiation sensing head **16** provides an output signal of a magnitude sufficient to be usable without amplification, thereby eliminating drift and calibration problems in the sensory means. A radiation head of the type which may be employed in the control system of the present invention is marketed by the Westronics Corp. of Fort Worth, Texas under the designation 9E7 Ardonox Radiation Unit.

The output of radiation sensing head **16** in conductors **26** and **27** are supplied to electric signal means **301** which provides an electric signal of a preselected magnitude in electrical opposition to the electric signal generated by radiation sensing head **16**.

The electric signal means **301** includes resistor bridge **32** located in conductor **26**, the input terminals **34** and **36** of which are connected to power supply **38**. Bridge terminal **40** is connected to conductor **26** while output terminal **41** is connected to conductor **261**.

Terminal **34** of rectifier bridge **32** is connected to the wiper of potentiometer **42** connected in parallel with resistor **44**. Resistor **48** and tap **50** are provided in the bridge leg between terminals **34** and **41**. The foregoing elements may be used to alter the range of the output signal, if desired. Resistor **52** is included in the bridge leg between terminals **36** and **41** and resistor **54** is inserted in the other leg terminating at terminal **36**. All resistors in rectifier bridge **32** are of a type having a low temperature coefficient and which are therefore relatively unaffected by the ambient temperature and changes therein. The operation of electric signal means **301** is therefore rendered stable over the operating range of the temperature sensing means and the control system.

A potentiometer **56** is connected between input terminal **34** and terminal **40**. The wiper **56***a* of potentiometer **56** is connected to terminal **40** and conductor **26**. Adjustment of potentiometer **56** provides a means of inserting the signal of preselected magnitude in electrical opposition to the signal from radiation sensing head **16** and for this purpose the potentiometer may comprise a precision wound, ten turn potentiometer. Potentiometer **56** may have a dial or other means

reading directly in degrees of temperature for relating the electric signal generated by the potentiometer to a temperature level.

The power supply **38** for resistor bridge **32** includes a transformer **66** having a primary winding **68** connected to alternating current supply lines **70** and a center tapped secondary winding **72**. A pair of diodes **74** are connected to the ends of secondary winding **72** and to positive bus **76**. A center tap of secondary winding **72** is connected to negative bus **78**. A filter capacitor **80** is connected across busses **76** and **78** and in parallel with transistor **82**. Transistor **82** clips the output of the power supply **38** at a low level so as to make the output of the power supply relatively unaffected by changes in line voltage and the like. A zener diode may be used for the same purpose, if desired. The output of power supply **38** is provided to terminals **34** and **36** and conductors **84** and **86**.

## The Amplifier

Amplifier **30** is preferably a null type amplifier which is responsive to deviation or difference in the opposing signals generated by radiation sensing head **16** and electric signal means **301**. The use of a null type amplifier avoids the linearity, noise, calibration and other problems encountered with the use of proportional amplifiers. A two-stage magnetic amplifier, as shown in FIG. **2**, may be used due to the inherently high signal noise rejection characteristics of such an amplifier. Electric signal means **301** may be conveniently incorporated in the input of amplifier **30**, also as shown in FIG. **2**.

Conductors **261** and **27** are connected to a low level, pulse amplitude modulation magnetic preamplifier circuit **302** which provides an amplified error signal corresponding to any difference between the electric signals produced by radiation sensing head **16** and electric signal means **301**. Null balance magnetic amplifier **90** of circuit **302** includes a saturable magnetic core (not shown) having input or control windings, output or lead windings, and bias windings wound thereon. Specifically, a pair of input windings **92** and **94** are connected to conductors **27** and **261**, respectively. Input windings **92** and **94** control the output of magnetic amplifier **90** in output winding **96**. Winding **98** provides the necessary operating bias to amplifier **90** from a bias supply comprised of resistor **100** and potentiometer **102**.

A meter **104** is connected across output windings **96** to provide a visual indication of the polarity of the error signal. Positive and negative feedback signals from output winding **96** are provided in magnetic amplifier **90** to control the gain and stability of the amplifier. A positive feedback signal, developed across resistor **106**, is provided to control winding **92** in conductor **108**. An overall amplifier **30** feedback signal is provided to control winding **92** in conductor **109**, as hereinafter described. A negative feedback signal developed across resistor **110** is provided to control winding **94** in conductor **112**.

The output of magnetic preamplifier circuit **90** is provided to operational amplifier circuit **303** in conductor **114**. Operational amplifier **116**, which may also be of the magnetic amplifier type, includes a saturable magnetic core (not shown) having input windings **118** and **120** wound thereon. The current signal output of operational amplifier **116** is developed in output winding **122**.

A negative feedback signal for operational amplifier **116** is developed in potentiometer **125** **124** and supplied to input winding **120** in conductor **126**. Conductor **126** includes additional resistive and capacitive elements, **127** and **129**, which provide and integrating characteristic to amplifier circuit **303** so that the magnitude and polarity of the amplifier circuit output signal is such as to tend to force the input signal to the amplifier circuit to zero. The feedback signal in conductor **109** supplied to the input of preamplifier circuit **302** is also developed by potentiometer **124**. Winding **128** provides the necessary operating bias to operate amplifier **116** from a bias supply including resistors **130** and **132** and potentiometers **134** and **136**. The amplifier may be energized by winding **138** connected to alternating current supply lines **140** and **142**.

Capacitor **144** between output conductors **146** and **148** removes ripple from the output signal of amplifier **30**. Breakover diode **150** prevents excessive output signals from overdriving subsequent portions of the control system.

## Emissivity Compensation Means

In almost all materials, the emissivity, that is, the efficiency of the material as a radiator, is less than ideal. In order to avoid false temperature sensing, means must be included in the control system to correct for this lessened efficiency.

In the embodiment of the invention shown in FIG. **2**, the emissivity compensation means comprises a means for physically compensating for web material emissivity so as to eliminate the effects of emissivity from the operation of the temperature sensing means and control system. For this purpose, a U-shaped trough **151** is provided in the control system through which web W may pass. Trough **151** is positioned opposite radiation head **16**, so that glass **20** views only trough **151**. Trough **151** may comprise a lower plate **153**, which lies below the web and is at least as wide as the web W, an end plate **155**, and an upper plate **157** which is narrower than lower plate **153**.

The plates forming trough **151** contain heating elements **159**, such as resistance wires, embedded in them for heating purposes. Elements **159** may be provided with power from adjustable power supply **161**. The temperature of the plates forming trough **151** is closely controlled by means of thermocouples **163**, also embedded in the plates, which regulate the operation of power supply **161**. The manner in which trough **151** eliminates the effects of the emissivity of web W is described infra under "Operation."

The embodiment of the control system of the present invention shown in FIG. **3** incorporates a means for compensating for the effects of emissivity electrically. Specifically, a potentiometer **165** is provided in shunt with potentiometer **56** so as to alter the operation of that potentiometer in a manner hereinafter described to compensate for the effects of web emissivity. An additional fixed resistor **167** may also be provided in shunt with potentiometer **156**.

## Electro-Pneumatic Transducer

The output signal of operational amplifier **30** is provided to an electropneumatic transducer **150** which receives the current signal in conductors **146** and **148** and alters the pneumatic output pressure of the transducer in direct proportion to the magnitude of the current input signal.

For such purposes transducer **150** may include a solenoid **152**, the coil of which is connected to conductors **146** and **148**. The position of plunger **156** of solenoid **152** is a function of the energization of coil **154**. Cavity **158** in the body of transducer **150** contains a diaphragm **160** positioned across the cavity and containing cylindrical valve seat **162**. A spacer **164** having a plurality of vents **166** is positioned between plunger **156** and valve seat **162** to couple the former to the latter. A spring **167** biases valve seat **162** against the force exerted by spacer **164**.

An exhaust port **168** connects the upper portion of cavity **158** to the surrounding atmosphere. An output port **170** is located in the lower portion of cavity **158** to provide the output pressure to air line **172**.

A valve stem **174** positioned in cavity **158** has a truncated conical portion **176** which closes valve seat **162** when the valve stem is in the upper position and the valve seat is in the lower position. A second conical portion **178** closes valve seat **180** between cavity **158** and chamber **182**. Spring **184** positioned in chamber **182** biases valve stem **174** upward. Supply air line **186** supplies inlet air to chamber **182**.

An electropneumatic transducer which may be employed in control system **5** as transducer **150** is made and sold by the Fisher Governer Company, Marshalltown, Iowa under the model designation type 546.

Actuator

The air pressure in air line **172** operates a pneumatic actuator **188**. Such an actuator is shown in FIG. **2** as a simple pneumatic cylinder having a spring loaded piston **190** therein. The amount by which piston rod **192** is extended is a function of the air pressure in actuator **188** acting on piston **190**. It will be appreciated that an actuator incorporating pneumatic amplification, in which the air pressure in air line **172** acts as a pilot pressure only, may be used, if desired.

Actuator **188** operates ratio valve mechanism V which controls the heat delivered by burner B through linkage L.

Operation

To initiate the operation of the temperature sensing means and the control system, electric signal means **301** is energized from alternating current supply lines **70**. Power supply **38** applies a voltage to input terminals **34** and **36** of resistor bridge **32** and wiper **56***a* of potentiometer **56** provides a portion of this voltage to the terminal **40**.

The emissivity compensation means is then operated to compensate the subsequent operation of the control system for the effect of the emissivity of the web material. In the embodiment shown in FIG. **2**, the temperature of trough **151** is initially raised to the desired temperature of web W and held at that temperature by means of thermocouples **163** and power supply **161**. For example, the temperature of trough **151** may be established at **150** degrees. Radiation sensing head **16** receives the emitted radiation from trough **151** and provides an output signal to electric signal means **301**.

The wiper **56***a* of potentiometer **56** is adjusted so that the potentiometer generates an electric signal which exactly opposes the output signal of radiation sensing head **16**. Under these conditions, no output signal is supplied to the input of preamplifier circuit **302** due to the condition magnitude equality in the opposing electric signals. This equality or null condition may be observed by meter **104** which senses any deviation between the output signal of the radiation sensing head and the signal generated by wiper **56***a* of potentiometer **56**.

With amplifier **30** in a null condition, the remainder of the control system and web heating oven are operated to provide heat to web W as it passes down oven O on idler rolls **8**. The web also passes through trough **151** and between the trough and radiation sensing head **16** so that the radiation now received by the head is a combination of the radiation emitted by trough **151** and the radiation emitted by web W.

Under such conditions, if the temperature of web W is the same as that of trough **151**, i.e. 150°, the output of the radiation sensing head **16** is not altered and the temperature sensing means continues to provide a signal to amplifier **30** indicating a temperature sensing of 150°. As the web W is at the same temperature as trough **151**, variations in the emissivity of the web do not cause variations in the output signal of radiation sensing head **16**, since any radiation reflected or transmitted by web W comes from trough **151** which is regulated by thermocouples **163** and power supply **161** to the desired temperature of 150° so that radiation sensing head **16** still sees only 150° temperature radiation. Thus, the emissivity of the web material is eliminated as a factor in the temperature sensing means and the control system.

If the temperature of web W is higher or lower than the temperature of trough **151**, the radiation received by radiation sensing head **16** is altered as the web passes between trough **151** and radiation sensing head **16**. The output signal of radiation sensing head **16** to electric signal means **301** is also altered. The altered output signal of radiation sensing head **16** causes an error signal to appear in conductors **27** and **261** between the signal generated by radiation sensing head **16** and the signal generated by wiper **56***a* of potentiometer **56**. The voltage polarity of the signal in conductors **27** and **261** depends on whether the temperature of web W is above or below the desired temperature. For example, a web temperature above the desired temperature may provide a positive voltage in conductor **261** while a web temperature below the desired temperature may provide a negative voltage in conductor **261**. As amplifier **30** operates around a null condition, the magnitude of the error signal is of lesser importance than its polarity.

The aforesaid error signal is applied to the remaining portions of amplifier **30** which operate electropneumatic transducer **150** and ratio valve mechanism V in a manner to reduce the input error signal to zero zero. Specifically, the error signal in conductors **27** and **261** is applied to control windings **92** and **94** of the magnetic preamplifier **302** which provides an amplified error signal in output winding **96**. Due to the pulse amplitude modulation characteristics of preamplifier **302**, the output signal in output winding **96** and conductor **114** will approximate a square wave, as shown in FIG. **4**. If the height of both the positive half cycle **200** and the negative half cycle **202** are equal, the net output of the amplifier will be zero, as shown in FIG. **4***a*. This condition exists when no input signal is applied to control windings **92** and **94**. An input signal to control windings **92** and **94** of one polarity operates magnetic preamplifier **302** to increase the height of one half cycle, for example, positive half cycle **200** and decrease the height of the negative half cycle **202**, forming an unsymmetrical wave form which has a positive direct current component **204** proportional to the error signal. (See FIG. **4***b*) An input signal to control windings **92** and **94** of the opposite polarity decreases the height of positive half cycle **200** and increases the height of negative half cycle **202**, forming an unsymmetrical wave form which has a negative DC component **206**. (See FIG. **4***c*)

The output signal in conductor **114** is provided to operational amplifier **303** for further amplification so that an amplified output signal appears in conductors **146** and **148** which is related in polarity to the input error signal signal.

The output signal in conductors **146** and **148** drives transducer **150**. Assume in an exemplary instance the output signal of amplifier **30** is of a polarity to indicate that the temperature of web W is below the desired temperature, as determined by the setting of wiper **56***a* of potentiometer **56**. The signal in conductor **146** and **148** energizes solenoid coil **154** to drive plunger **156** downward into cavity **158**. This causes spacer **164** to depress valve seat **162** and valve stem **174**. The depression of valve stem **174** increases the air flow through valve seat **180** from chamber **182**, connected to air supply line **186**, to cavity **158**, connected to air line **172**. This increases the air pressure in air line **172** and in cavity **158**. The increased air pressure in cavity **158** causes diaphragm **168** to flex upwardly, raising valve seat **162** and valve stem **174** against the downward force exerted by solenoid plunger **156**. The opposing forces on diaphragm **160** assume a state of balance so that the air pressure in air line **172** is a function of the energization of solenoid **152** by amplifier **30** and hence of the error signal between the desired and actual temperatures of web W.

The increased air pressure in air line **172**, when applied to piston **190** of air cylinder **188**, extends piston rod **192** to actuate linkage L. Linkage L operates ratio valve mechanism V to increase the gas to burner B and increase the heat provided to oven O and the temperature of web W so as to bring the actual temperature of the web into coincidence with the desired temperature of the web.

In the event the polarity of the output signal of amplifier **30** is such as to indicate that the temperature of web W is above the desired temperature, solenoid **152** is energized to withdraw solenoid plunger **156** from cavity **158**. This permits valve seat **162** to be raised off valve stem **174**, by means of spring **164**, and allows the air flowing from chamber **182** into cavity **158** to escape through valve seat **162** and out exhaust port **168**, reducing the air pressure in cavity **158** and in air line **172**. The reduced pressure in cavity **158** causes diaphragm to flex downward, restricting the flow of air through valve seat **162** so that the opposing forces on the diaphragm again balance when the air pressure in air line **172** has reached a value proportional to the magnitude of the output signal of amplifier **30**.

The decreased air pressure in air line **172**, when applied to piston **190** of air cylinder **188**, causes a retraction of spring loaded piston **190** and piston rod **192** to actuate linkage L to reduce the gas supplied by ratio valve mechanism V to burner B and decrease the temperature in oven O and the temperature of web W to bring the actual temperature of the web into coincidence with the desired temperature thereof.

In the embodiment of the temperature sensing means shown in FIG. **3**, the emissivity of the web material as a factor in the control system is compensated for electrically by potentiometer **165** connected in shunt with potentiometer **56**. In the operation of the sensing means of FIG. **3**, the web is heated to the temperature which is desired or necessary for the processing of the web. The web temperature is then measured as accurately as possible by a pyrometer or other means such as the conduction or convection temperature sensors mentioned, supra. The temperature so ascertained is then set on electric signal means **301** by adjusting the dial and the wiper of potentiometer **56***a*, even though it may not be the actual temperature of web W. Since it is not the actual temperature of web W as sensed by radiation head **16**, an error signal will be generated between conductors **27** and **261** which will be indicated by meter **104**. Potentiometer **165** is then adjusted to alter the relative parallel current flow between potentiometer **56** and potentiometer **165** and the signal generated at wiper **56***a* until meter **104** indicates a condition of null balance in amplifier **30**. With this compensation inserted in resistor bridge **32**, the control system will regulate the temperature of web W to the desired temperature in a manner similar to that described above. Potentiometer **165** may be provided with a dial or other indicating means on which the amount of emissivity compensation required may be read. In the event it is again desired to process the same type of web material, both potentiometer **56** and potentiometer **165** may be returned to their former settings so as to again control the temperature of the web to the same level.

It is appreciated that other modifications and variations may be made to the control system of the present invention and it is desired to include in the appended claims all such variations and modifications as come within the true scope and spirit of the invention.

I claim:

**1**. A temperature control system for regulating the temperature level of a heated moving web passing through web heat treating apparatus to a desired temperature level, said apparatus having a controllable heating means for applying heat to the web, said web emanating radiation in accordance with its temperature and an unknown emissivity factor, said system comprising:

a sensory means positioned adjacent said web and exposed to the radiation emanating therefrom, said means being responsive to said radiation for providing and an electric signal corresponding in magnitude to said radiation;

control means including electric signal means, said electric signal means being connected to said sensory means for providing an electric signal of a preselected magnitude in electrical opposition to the electric signal of said sensory means, said control means also containing deviation sensing means responsive to a said electric signals for determining when a condition of magnitude equality exists between said signals and for providing an error signal corresponding to a deviation from said condition of equality, said deviation sensing means comprising a null type, high gain amplifier;

means for altering one of said electric signals from said sensory means and said electric signal means to compensate for the emissivity of said moving web, so that said electric signals are in a condition of magnitude equality when the web is at the desired temperature level; and

electromechanical means responsive to the error signal from said deviation sensing means and connected to said heating means for controlling said heating means and the heat applied to the web in accordance with the error signal for causing the temperature level of said web to equal the desired temperature level.

**2**. The temperature control system of claim **1** wherein said means for altering one of the signals comprises means including a heatable body capable of emanating radiation in accordance with its temperature and a temperature control system connected to a said body for raising and maintaining the temperature of said body at the desired temperature level of said web, said sensory means being positioned with respect to said body for receiving only the radiation from said body, so that in the absence of said web, said sensory means provides a signal corresponding to the desired temperature level of said web, said web passing between said body and said sensory means so that deviations in the temperature thereof with respect to the desired temperature level cause corresponding deviations in the output signal of said sensory means and the condition of said electric signals.

**3**. The temperature control system of claim **2** wherein said heatable body comprises a U-shaped trough partially surrounding said web and providing an exposed portion of said web and trough which may be observed by said sensory means.

**4**. The temperature control system of claim **3** wherein said U-shaped through includes a portion lying on one side of said web, a portion positioned partially on the other side of said web, and a portion connecting the aforesaid portions, said portion positioned partially on the other side of said web exposing said web and trough for observation by said sensory means.

**5**. The temperature control system of claim **3** wherein said temperature control means includes an adjustable electrical power supply, an electric heater connected to the output of said power supply and to said body for heating said body, and temperature responsive means connected to said body for sensing the temperature thereof and for altering the output of said power supply for maintaining the temperature of said body at the desired temperature of said web.

**6**. The temperature control system of claim **1** wherein said means for altering one of said electric sing signals comprises means operatively associated with said electric signal means for altering electric signals produced by said means to bring the electric signals of said sensory means and said electric signal means into a condition of magnitude equality when said web is at the desired temperature level.

**7**. The temperature control system of claim **1** wherein said sensory means is responsive to the entire spectrum of radiation emanating from said web.

**8**. The temperature control system of claim **7** wherein said sensory means includes a thermopile exposed to the radiation emanating from the web for providing an electric signal corresponding to the amount of said radiation and also includes a means connected to said thermopile and responsive to the ambient temperature to which the thermopile is exposed for altering said electric signal to provide ambient temperature compensation to said sensory means.

**9**. The temperature control system according to claim **1** wherein said amplifier is of the pulse amplitude modulation type.

**10**. The temperature control system according to claim **1** wherein said electromechanical means includes an electric means responsive to said error signal, pneumatic means operable by said electric means for providing pneumatic pressure proportional to said error signal, and pneumatically operated mechanical means connected to said pneumatic means and to said heating means for controlling said heating means in accordance with the pneumatic pressure provided by said pneumatic means.