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HEAT TREATMENT APPARATUS

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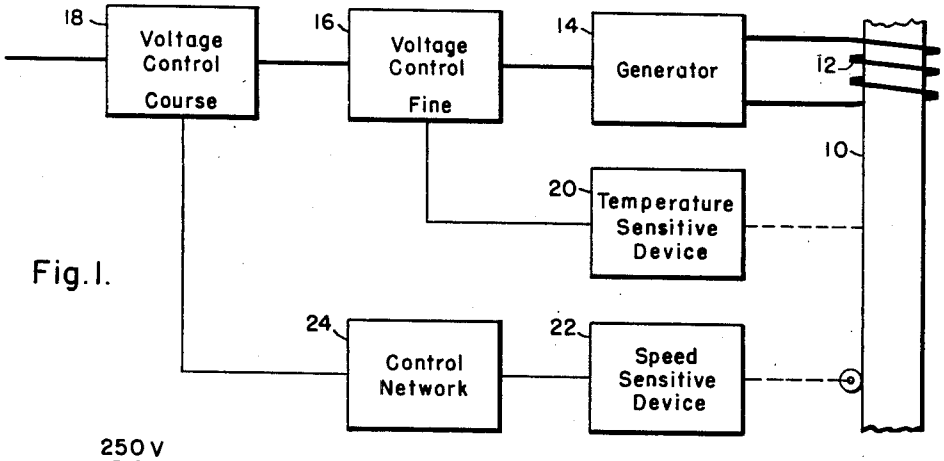


Fig. 1.

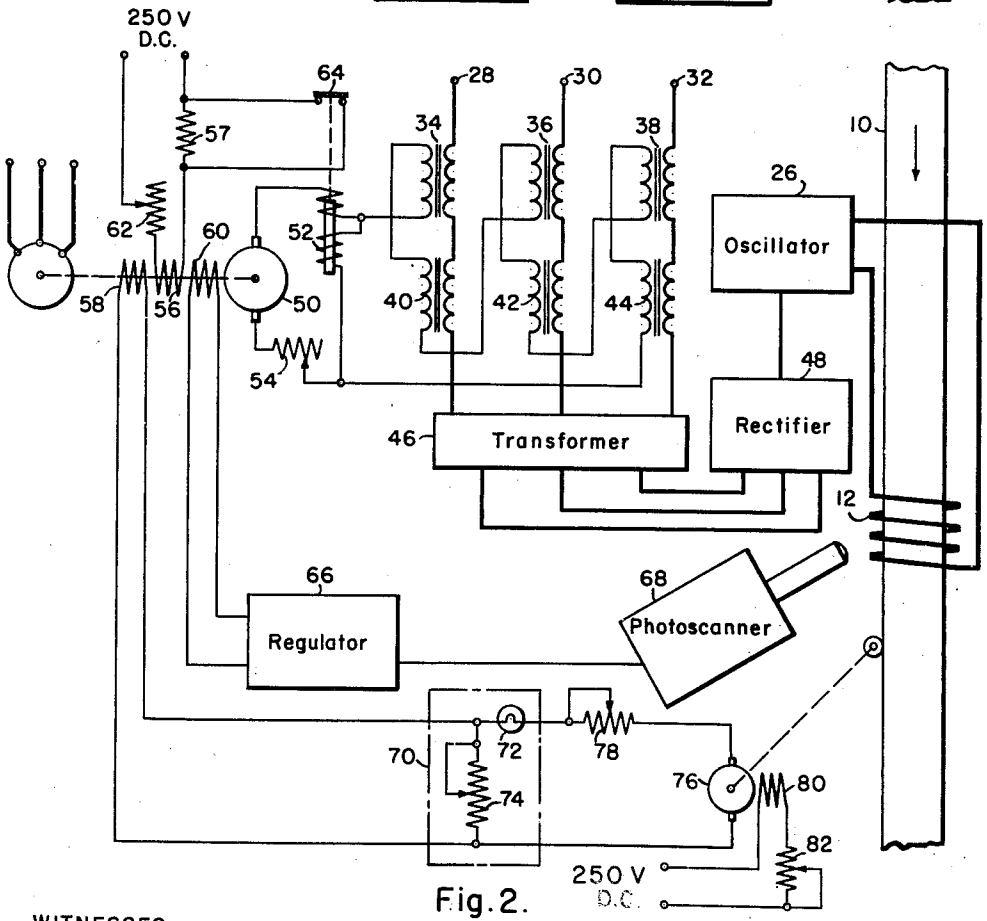


Fig. 2.

WITNESSES

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HEAT TREATMENT APPARATUS

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The present invention relates to an electrical control system for the heat treatment apparatus, and more particularly to an electrical control system for the flow-brightening of tin plate strip.

The invention in its broadest aspects is not limited to any particular field of application. However, an important field of application for this invention is in connection with the tin plate flowing apparatus such as described in Patent No. 2,381,323, August 7, 1945 of M. P. Vore; Patent No. 2,448,008, August 31, 1948 of R. M. Baker; and Patent No. 2,459,616, January 18, 1949 of S. L. Burgwin.

The strip is treated in steps which include passing the strip through an electroplating bath in which it is electrolytically and thinly coated with tin, and subsequently heating the tin coated strip to quickly raise the surface temperature of the strip such that the matte surface of the tin reflows, and then cooling it to provide a shiny and impervious coating which is spread over the surface of the strip.

In commercial practice for adequately and practically heating a strip span which may travel through the heating member, a large amount of power must be concentrated in a comparatively short length of the strip. The temperature of the strip is sensitive to changes in the power applied to the strip, to changes in the speed of the strip, to changes in the physical dimensions of the strip, and moisture and power line voltage conditions, among other things.

A control system is particularly important with tin plate in that the tin coating may be damaged if the strip is overheated, or the tin coating may not be satisfactorily reflowed if it is not heated sufficiently.

In accordance with the present invention for heating the strip to substantially constant temperature at variable speed, the power applied to the heating member should be automatically regulated in proportion to the speed of the strip. To practically effect this, the voltage applied to the heating member should be proportional to the square root of the speed of the strip. This latter relationship is commonly referred to as the root mean square characteristic. A first control signal proportional to strip speed is obtained from a tachometer or like device connected to the strip. This first control signal is linearly proportional to the strip speed and must be transformed into a square root function. A second control signal proportional to the temperature of the strip adjacent the heating member is obtained from a photoscanner or like device responsive to the position of the flow line of the tin plated strip. This flow line is a sharp line of demarcation between the melted and unmelted tin and runs across the strip width. The temperature at the flow line is substantially the melting point of tin in the order of 452° F. The photoscanner observes the position of the flow line and sends either a positive signal when the flow line moves in one direction from a predetermined position, and a negative signal or decreased signal

when the flow line moves in the opposite direction from the predetermined position. The output from the photoscanner is considerably amplified in the regulator circuit and applied to the voltage or power supply for the heater member to thereby determine the heat treatment of the moving strip.

It is an object of the present invention to provide an improved apparatus or control system for the heat treatment of continuous metallic strip in which the power applied to the strip can be more accurately regulated.

It is another object of the present invention to provide a simple and low cost control circuit which will automatically provide the desired control voltages for the power supply of the heater member.

It is a different object to provide apparatus for the heat treatment of moving metallic strip by which the temperature of the strip is maintained substantially constant for the purpose of flow-brightening the tin plate.

It is still another object of the present invention to provide improved apparatus for heat treating moving tin plate strip, wherein the power applied to the strip is made to vary substantially linearly relative to the movement speed of the strip.

It is a still different object of the present invention to provide improved apparatus for regulating the power applied to the moving strip such that the power is applied in accordance with the movement speed of the strip and other variable conditions.

It is a further object to provide improved apparatus for regulating the power applied to a work strip in accordance with the temperature condition of the work strip and the speed condition of the work strip.

Further advantages, methods, features and innovations of the present invention will be discernible from the accompanying description which is to be taken in conjunction with the attached drawings.

Figure 1 is a block diagram of the control apparatus in accordance with the present invention; and

Fig. 2 is a partial schematic diagram of the apparatus in accordance with the present invention.

In Fig. 1 there is shown a workpiece in the form of a continuous strip **10**, which is to be tin plated and may have a width up to forty inches wide. The strip passes through a heater member **12** which is supplied power from a power supply generator **14**, which in turn is controlled by a fine or vernier range voltage control circuit **16** and a coarse or broad voltage control circuit **18**. The fine voltage control circuit **16** is controlled by a temperature sensitive device **20** which is operative to respond to the temperature of the work strip **10** and apply a control signal to the fine voltage control circuit **16**. The coarse voltage control circuit **18** is controlled by a speed sensitive device **22** which is responsive to the movement speed of the work strip **10** and a control network **24** which is operative to provide an output control signal to the coarse voltage control circuit **18** which is made to vary as the square root of the output voltage from the speed sensitive device **22**.

In Fig. 2 there is shown the moving work strip **10** which passes through the heater member **12**, which latter heater member **12** is supplied energy from a suitable generator or oscillator circuit **26**. The latter oscillator **26** is connected to suitable power supply leads **28**, **30** and **32** through respectively saturable reactor control members **34**, **36**, **38**, **40**, **42** and **44**, and a transformer **46** and rectifier circuit **48**. The power supply leads **28**, **30** and **32** are adapted for connection to a suitable three-phase power source. Each of the saturable reactors are provided with direct current control windings which are connected to the output of an exciter generator **50** through a reverse current control relay **52** and an adjust-

able impedance member 54. The exciter generator 50 is provided with three field windings 56, 58 and 60. The first field winding 56 being connected to a suitable source of direct current control voltage such as a 250 volt source, through a series connected variable impedance member 62 and the control contacts 64 of the reverse current relay 52. The contacts 64 are operative to reduce the effective amount of ampere turns of the field winding 56 by inserting an additional impedance 57 into the circuit of the field winding 56.

The field winding 58 is operative as the main control field winding for the exciter generator 50 and the field winding 60 is operative as a differential winding in opposition to the field winding 56. The field winding 60 is connected to the output of an electronic regulator circuit 66 which in turn is connected to the output of a photoscanner device 68 which latter photoscanner device is operative to detect the physical position of the flow line on the tin plated workpiece strip 10. The main control field winding 58 is connected to the output of a control circuit 70 including a tungsten lamp device 72 and a parallel connected adjustable impedance member 74, which control circuit 70 is operative as a square root network and is connected to the output of a speed sensitive device such as a tachometer generator 76 through a series connected variable impedance member 78. The field winding 80 for the tachometer generator 76 is connected to a suitable source of direct current voltage, such as a 250 volt source, through an adjustable impedance member 82.

In the operation of the apparatus shown in Fig. 1, the tin plate strip is practically movable between a lower speed of approximately 400 feet per minute to a speed in the order of 2,000 feet per minute. The objective of the control circuit is to maintain the desired substantially constant strip temperature. To compensate for changes in the speed of the work strip 10, the power applied to the strip through the heater member 12 is varied linearly relative to the speed of the work strip 10. Since the power is to be varied linearly, this can effectively be accomplished if the voltage applied to the heater member 12 could be made to vary as the square root of the speed. To effect this, the output voltage of the speed sensitive device 22, which is in direct proportion to the movement speed of the work strip 10, is fed into the control network 24 which is operative as a square root network to provide an output control signal to the coarse voltage control circuit 18 which is proportional to the square root of the output voltage from the speed sensitive device 22. This output control signal causes the coarse voltage control circuit 18 to vary the output voltage applied o heater member 12 in proportion to the square root of the line speed such that the power applied to the work strip 10 thereby will be in direct proportion to the speed of the work strip 10.

To take care of other variations and conditions, such as changes in the power supply line voltage, moisture variations on the work strip 10 and thickness variations on the work strip 10, a second control circuit is provided including a temperture sensitive device 20 which provides an output control signal dependent upon the temperature of the work strip 10 which may be practically determined by the position of the tin flow line on the work strip 10. The output of the temperature sensitive device 20 is applied to a fine voltage control circuit 16 which is operative to vary the output voltage of the generator 14 over a smaller range of values than is the coarse voltage control circuit 18.

In the operation of the apparatus shown in Fig. 2, the tachometer generator 76 is operative to provide an output voltage which is in direct proportion to the movement speed of the strip 10. This output voltage is applied to the control circuit 70 such that a first control signal is applied from the control circuit 70 to the field winding 58 which control signal is proportional to the square root of the movement speed of the work strip 10. The latter first control signal causes the field current of the field winding 58 to vary as the square root of the movement speed of the work strip 10 to thereby cause the output voltage of the exciter generator 50 to vary in substantially the same way. This output voltage from the exciter generator 50 causes the direct current flowing through the direct current windings of the saturable reactors 34, 36, 38, 40, 42 and 44 to vary as the square root of the movement speed of the work strip 10. Since the current flowing in the alternating current windings of the latter saturable reactors varies in direct proportion to the current flowing in the direct current windings of these reactors, the input current applied through the transformer 46 and rectifier circuit 48 to the oscillator circuit 26 also varies as the square root of the speed of the work strip 10. Therefore, the output voltage of the oscillator 26 as applied to the heater member 12 similarly varies as the square root of the movement speed of the work strip 10, and accordingly the heating power applied to the work strip is thus made to vary in direct proportion to the line speed.

The above described portion of the apparatus is operative as a coarse regulation or control for the temperature of the work strip 10.

The photoscanner device 68 is operative to respond to the position of the tin flow line on the tin plated work strip 10 to send a positive second control signal to the regulator circuit 66 when the flow line moves in one direction from a predetermined position of the flow line, and a negative second control signal to the regulator 66 when the flow line moves in the opposite direction from this predetermined position of the flow line. This second control signal is considerably amplified in the regulator circuit 66 to a level several times the maximum excitation level of the exciter generator 50, such that the control system is thereby forced to change at a more rapid rate than it would change without this amplification feature, as is believed to be well known to persons skilled in this art.

With the position of the flow line in the desired predetermined position, the regulator circuit 66 provides a second control signal in the order of 200 volts from its output circuit and applies it to the field winding 60. This is opposed by field winding 56 which operates with a fixed bias and is connected differentially with relation to field winding 60. This latter opposition or cancellation effect is operative to allow the field winding 58 to operate as the main control winding for the exciter generator 50 when the flow line is in the desired predetermined position. If the position of the flow line moves such that, for example, a 10% increase in the power applied to the work strip 10 by the heater member 12 is needed, the regulator circuit 66 and photoscanner 68 are operative to provide up to a 400 volt signal to the field winding 60 until the desired 10% increase in power applied to the work strip 10 by the heater member 12 is accomplished; then the regulator circuit 66 returns to a voltage level above 200 volts that will supply and maintain the 10% increased level of power.

In the use of several control fields on the direct current generator 50, the polarity of the output voltage from the generator may reverse under certain conditions which will be undesirable. Accordingly, a reverse current relay 52 is provided to prevent such a polarity reverse in the output voltage, such that the amount of ampere turns of the field winding 56 may be reduced by inserting the extra impedance member 57 in the circuit.

A regular circuit suitable for use as the regulator circuit 66 may be found in application Serial No. 421,046, filed April 5, 1954 of Walter G. Roman et al. and entitled Dynamometer Control, now Patent No. 2,785,367.

The control circuit 70 may comprise an impedance device 72 which varies non-linearly with current. An example of a suitable practical device is a tungsten im-

pedance member in the form of a tungsten incandescent lamp.

The value of the impedance member **74** can be determined by a reference to the following table:

S	E Gen.	E output$=K_1\sqrt{S}$	IR	I	R
100	14.3	14.3	0	1.43	0
250	35.8	22.7	13.1	2.27	5.8
350	50.0	26.8	23.2	2.68	8.7
500	71.5	32.0	39.5	3.20	12.3
1,000	143.0	45.5	97.5	4.50	21.6
1,500	215.0	55.5	159.5	5.50	29.0
1,750	250.0	60.0	190.0	6.00	31.7
2,000	286.0	64.0	222.0	6.40	34.8
2,500	362.0	71.5	290.5	7.15	40.5

The resistor or impedance member **74** is chosen to give the desired coefficient of the equation E (output)$=K_1\sqrt{S}$, where S equals the speed of the tachometer generator **76** in revolutions per minute and E (output) the output voltage of the control circuit **70**. Referring to the table, the second column entitled "E Gen." refers to the output voltage of the tachometer generator **76**; the fourth column "IR" is the product of the fifth and sixth columns which respectively refer to the current and impedance of the non-linear device **72**. The equation for the tachometer generator voltage versus speed is the following:

$$E \text{ Gen.}=.143\ S$$

The value of the coefficient K_1 is chosen so that the curve for the equation E Gen.$=.143\ S$ and the curve for the equation E (output)$=K_1\sqrt{S}$ will cross or coincide approximately when the value of S equals 100. By making the value of the impedance member **74** equal to 10 ohms, and the value for the coefficient K .143 times 10 or 1.43, this will be realized.

The columns S and E Gen. in the table are existing linear characteristics of the tachometer generator **76**. E (output)$=K_1\sqrt{S}$ and IR are requirements set up to produce a desired square root relation between the output voltage of the control circuit **70** and the speed of the work strip **10**. The value of IR must be such that it equals the difference between E Gen. and E (output). The values for the current I and the impedance R are then determined by the solutions of the involved simultaneous equations.

Columns I and R reveal that the non-linear device **72** will vary approximately 7:1 in resistance value for a current variation of approximately 3:1. This required characteristic is well within the capability of tungsten lamps which are low in cost and reliable, practical devices.

It should be clear from the foregoing description of this invention that a control circuit **70** has been devised which, when inserted in the output of the tachometer **76**, will provide an output voltage proportional to the square root of the speed of the tachometer generator **76**, and hence the speed of the work strip **10**.

It should be understood that the embodiments of the present invention which have been shown and described are merely illustrative. For example, the generator or oscillator **14** may include a plurality of such units as necessary to provide the desired strip temperature. It will be apparent to those skilled in the art that many modifications can be made without departing from the spirit and scope of the present invention.

I claim as my invention:

1. In apparatus for heat treating a movable strip workpiece, said apparatus being operable with a suitable power source, the combination of a heater member for heat treating said workpiece, a voltage supply having an output voltage and being adapted for connection between said heater member and said power source, a first device responsive to the temperature of said workpiece, a second device responsive to the speed of said workpiece, a first control circuit connected between said voltage supply and said first device, a second control circuit connected between said voltage supply and said second device, with one of said control circuits being operable to change said output voltage through a first range of values and the other of said control circuits being simultaneously operative to change said output voltage through a smaller range of values.

2. In apparatus for heat treating a moving strip of metal, the combination of a heater member for heat treating said strip, a voltage supply having an output voltage and being connected to said heater member, a first device responsive to the temperature of said strip, a second device responsive to the speed of said strip, a first control circuit connected between said first device and said voltage supply, a second control circuit connected between said second device and said voltage supply, with said first control circuit being operative to change the value of said output voltage over a first range of values and said second device being concurrently operative to change the value of said output voltage over a second range of values, with said first range being larger than said second range.

3. In apparatus for heat treating a movable strip of metal, the combination of a heater member for heat treating said strip, a power supply for supplying power to said heater member, a first device responsive to the temperature of said strip, a second device responsive to the speed of said strip, a first control circuit connected between said power supply and said first device, a second control circuit connected between said power supply and said second device, with said first control circuit being operative to vary the power fed to said heater member by said power supply in inverse proportion to the temperature of said strip, and said second control circuit being operative to vary the power fed to said heater member in proportion to the speed of said strip.

4. The apparatus of claim 3 with said power supply having an output voltage and with said second control circuit being operative to vary said output voltage in proportion to the square root value of the strip speed.

5. In apparatus for heat treating a movable strip of metal, the combination of a heater member for heat treating said strip, a voltage supply connected to said heater member for supplying the voltage thereto, a speed device coupled to said strip and responsive to the speed of said strip, and a control circuit connected between said speed device and said voltage supply with said control circuit including a current responsive variable impedance member connected in series with said speed device and having an impedance exponentially related to the current flowing through the impedance member.

6. The apparatus of claim 5 including a temperature device responsive to the temperature of said strip, and a second control circuit connected between said temperature device and the voltage supply, with one of said control circuits being operative to control the value of said output voltage through a first range of values and with the other of said control circuits being concurrently operative to control the value of said output voltage over a second and smaller range of values.

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