

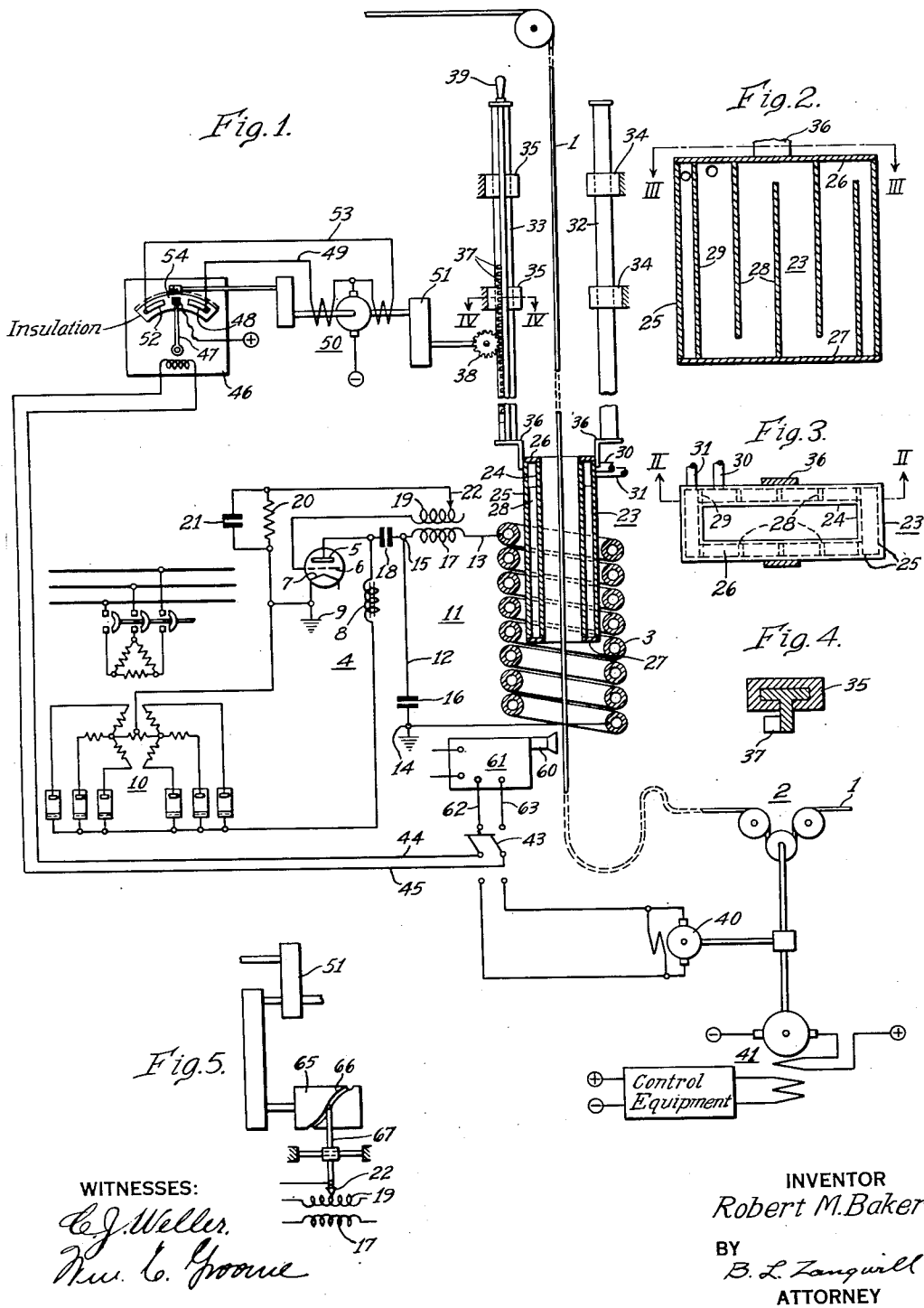
Aug. 31, 1948.

R. M. BAKER

2,448,008

CONTROLLED INDUCTION HEATING

Filed Dec. 7, 1943



UNITED STATES PATENT OFFICE

2,448,008

CONTROLLED INDUCTION HEATING

Robert M. Baker, Pittsburgh, Pa., assignor to
Westinghouse Electric Corporation, East Pitts-
burgh, Pa., a corporation of Pennsylvania

Application December 7, 1943, Serial No. 513,260

5 Claims. (Cl. 219-13)

1

My invention relates, generally, to industrial induction heating which involves apparatus for inducing heat-producing electrical currents in the work or material being heat-treated; and, more particularly, relates to the regulation of the energy which can be magnetically induced in traveling work or material such as, for example, elongated collable strip, wire, and the like, or successively fed units such as large or small bars, rods, sheets, and the like.

My invention may be applied to those types of apparatuses which transfer energy to the material through the medium of an electrical field of energy, particularly a pulsating magnetic field. It is the practice in induction heating to produce such a magnetic field with the aid of a heating coil capable, when energized, of producing a magnetic field interlinking or cutting the material, the heating coil being a part of, or energized by, a proper source of alternating-current energy delivering a frequency selected from factors involving the manner in which the material is to be treated, the physical characteristics of the material itself, and other factors. For some applications, low frequencies represented by a number with two or three digits can be successfully used. Other applications may require frequencies in the order of several thousands of cycles per second, which are best obtained by motor-generator sets. My invention, while useful with lower frequencies, is, however, particularly advantageous when used in connection with frequencies which are more readily obtained from tube-oscillator generators.

It is believed that my invention will be better understood when described in connection with particular inductive-heating apparatus; and I have chosen to describe my invention in a preferred form in which it is applied to inductive-heating equipment for metallic strip; but it is to be understood that my invention is not limited to the specific system herein described, and can be used in any other suitable apparatuses and in other processes. One of such apparatuses is that described and claimed in Patent No. 2,381,323, dated August 7, 1945, in the name of M. P. Vore. The patent pertains, specifically, to the reflowing of tin electrolytically deposited on steel-strip. In the process described, the span of strip between rolls or coils of the strip is treated by steps which include passing the strip through an electroplating bath in which it is electrolytically thinly coated with tin, subsequently passing the tin-coated strip through an inductive heating coil-means for quickly raising it to temperatures at

2

which the matte surface of the electrolytically deposited tin reflows, and then cooling it, so that a more desirable shiny impervious coating remains spread over the strip.

In commercial practice, for adequately and practicably heating the strip-span which may travel through the inductive heating coil-means at speeds as high as 1000 feet per minute and higher, a large amount of power must be concentrated in a comparatively short length of the strip. This means that temperatures of the strip are sensitive to changes in the power input thereto, to changes in the speed of the strip or in the physical dimensions of the strip, and to changes in other variables of the strip which determine the rate at which heat must be put into the strip as it passes through the inductive heating coil-means. Accordingly, in order to keep the strip-temperature within a predetermined range for satisfactory heat-treatment, a control apparatus is generally desirable and frequently essential.

Control apparatus has advantages in strip-treating processes where the leading end of a new coil of strip must be fastened to the trailing end of the preceding strip-portion, originally on a coil which has just been unrolled, but which is then passing into the treatment-line. This entails a slowing-down of the strip-line to a small fraction of its normal operating-speed. For example, the strip might be slowed down from 1000 feet per minute to a speed of but 60 or 100 feet per minute.

Control apparatus is also desirable where the heat-demand for satisfactorily heating the strip passing through the heating coil-means may depend on changing physical factors. Thus, although the strip may be traveling at a constant speed, its variations in gauge or in width change the heating input demand thereto for raising it to the desired temperature. As another alternative, it may be desirable to use the same heating coil-means, energized by the same tube-oscillator equipment, for heating different widths of strip.

Control apparatus is particularly important with tin-plate in which the tin-coating may be burnt or damaged if the strip is heated too hot, or may not be satisfactorily reflowed if not heated sufficiently. It is known to provide induction regulating means which operates on the low-frequency power input to the tube-oscillator generator for controlling the power that can be delivered to or produced in the inductive heating coil-means, which is magnetically coupled throughout its length to the tin-plated strip, in order to lower the power available in the coil-

3

means when less strip-material is being treated per unit time, and vice versa.

In one of its embodiments, my invention involves controlling the power that can be put into the strip by the heating coil-means, by means and methods which do not involve any direct manipulations of any kind on the tube-oscillator generator or its power supply. I accomplish this by acting on the magnetic field of the heating coil-means without in any way directly manipulating parts for controlling the field-establishing current flowing in the heating coil-means, but preferably in such a manner that the heating coil-means is partially or completely "unloaded" or incapable of delivering real-power energy to the material, although the wattless power in the coil-means may actually increase. In another embodiment, however, the current in the heating-coil is controlled.

It is an object of my invention to provide an induction heating system of the type described, in which the power-input to the material can be regulated by means entirely external to and disconnected from the tube-oscillator generator and its power supply.

It is a primary object of my invention to provide an induction heating system of a type described, in which the power supply to the material being heat-treated can be easily controlled, and with relatively inexpensive equipment.

It is a further object of my invention to provide an induction heating system utilizing tube-oscillator equipment having a tank-circuit supplying energy to the inductive heating coil-means, with the power taken from the tank-circuit controlled by an independent screen or shield acting in the field-region of the inductive heating coil-means.

It is a still further object of my invention to control the heat deliverable from an energized inductive heating coil-means to material in its magnetic field by a field-affecting means in the form of a screen variably associable with the coil-means, so as to control the action of the magnetic field on the material, the screen having physical characteristics bearing some particular relation to similar characteristics of the material being heat-treated.

It is an important object of my invention to reduce the cost of an induction heating system of a type described by eliminating the expensive induction regulator controlling equipment.

The above and other objects, features, innovations, and methods of my invention, which I achieve by a very simplified means, will be apparent from the following description of a preferred form thereof, which is to be taken in connection with the accompanying drawing which is symbolically representative of the invention.

In the drawing, which is not to scale:

Figure. 1 is a view, with the screen and heating-coil in longitudinal section, schematically showing a tin reflowing treatment-line embodying my invention;

Fig. 2 is a longitudinal sectional view of the screen at right angles to the longitudinal section thereof shown in Fig. 1, taken substantially on the line II—II of Fig. 3;

Fig. 3 is a top-plan view of the screen, taken substantially on the line III—III of Fig. 2;

Fig. 4 is an enlarged sectional view on the section-line IV—IV of Fig. 1; and

Fig. 5 is a detail view of a modified form of control applicable to the system of Fig. 1.

A preferred form of my invention is shown

4

applied to an elongated metallic material comprising a strip 1 which is pulled through a treatment-line by a pull-unit 2, with its tension controlled by a drag-unit (not shown). The strip 1 is originally unwound from one or more coils for passage through the treatment-line which comprises treating equipment including an electrolytic plating-bath, inductive heating coil-means in which the tin-plate is reflowed, and a quenching means. The inductive heating coil-means is indicated in the drawing as a single helical coil 3 through which the strip 1 passes downwardly, the dotted lines for the strip 1 being indicative of additional length and of its passage through other treating equipment.

The heating-coil 3 comprises a water-cooled multi-turn coil of copper tubing, the turns of which are oblong so as to surround the largest width of strip 1 expected to be heated inside the coil, such strip sometimes being as much as several feet wide and a small fraction of an inch thick. When the heating-coil 3 is energized, it provides a magnetic field or flux lines which pass axially therethrough, being concentrated in the central space encompassed by the heating-coil. When the strip is interlinked by flux lines, electrical currents are induced in the strip so that it is heated to a temperature in some manner dependent upon the frequency and magnitude of the current flowing in the coil.

In accordance with my invention, in its preferred form, the heating-coil 3 is energized through a tube-oscillator generator which is shown in the drawing in a most elementary form, and is indicated in its entirety by the reference numeral 4. The tube-oscillator generator 4 may comprise a vacuum tube having a plate or anode 5, a grid or control element 6 and a filament or cathode 7. Suitable voltage is supplied to the anode from the positive terminal of a high-voltage unidirectional source of energy connected to the anode through a choke-coil 8. The other or negative terminal of this source of energy is connected to the cathode 7 in any suitable manner, through ground if such be desirable, the cathode being grounded as indicated at 9. In the embodiment shown, the direct-current high-voltage input power for the tube-oscillator generator is obtained from a three-phase step-up transformer and rectifier means 10 energized by a commercial three-phase power line in any suitable manner.

The tube-oscillator output-circuit, connected to the anode 5, comprises a frequency-determining tank-circuit 11 which includes a tank-capacitance branch 12 and a tank-inductance branch 13, connected in parallel between a grounded junction 14 and a plate-circuit junction 15. The tank-capacitance branch comprises a capacitor 16; and the tank-inductance branch comprises an inductive coil or winding 17 in series with the heating-coil 3 which is, of course, also inductive. The junction 15 of the tank-circuit is connected to the anode 5 through a blocking capacitor 18, and since the other junction 14 of the tank-circuit is grounded, the high-frequency alternating-current anode-cathode circuit is completed to the grounded cathode 7. The grid-cathode circuit comprises a feed-back winding 19, magnetically coupled to the inductive coil 17, in series with the parallelly connected grid-leak resistor 20 and grid-capacitor 21. The feed-back to the grid can be controlled in any suitable manner such as for example by variable coupling between the windings 17 and 19. A control is symbolically

indicated by the adjustable connection 22 acting on the turns of the winding 19.

The strip preferably is continuously fed through the treatment-line so that it is necessary to secure the leading end of a coiled strip-portion to be unrolled for passage into the treatment-line, to the trailing end of a strip-portion which has just been unrolled. A common manner of doing this involves slowing down the strip-line while the two ends are automatically spliced, and immediately thereafter restoring the strip-speed. During this time of splicing, the strip-speed may vary in a ratio of as much as ten to one and more, being decreased from a speed of, say, 1000 feet per minute to, say, 100 feet per minute. With the tube-oscillator generator continuously energized, it is necessary to regulate the power-input to the strip somewhat proportional to its speed so that the temperature to which the strip is heated will be kept within a desirable or narrow range. In prior practice, induction regulators were used in the input-side of the transformer and rectifier means 10 to control the direct-current voltage supplied to the anode-cathode circuit of the tube-oscillator generator so that the power it could generate was regulated.

In accordance with my invention, I control the power-input to the tube-oscillator generator by utilizing a copper screen 23 insertable to varying extents into the heating-coil 3 for variably shielding the strip 1, which passes through the screen, from the magnetic field established by the energized heating-coil; the screen being withdrawable completely from the heating-coil for maximum power transfer from the heating-coil to the strip.

By variably inserting a suitable screen into the heating-coil the power-output of the tube-oscillator generator actually can be decreased, with the effect of unloading it in accordance with the lesser power requirements for heating the strip, arising out of its slower speed or perhaps out of a substitution of a different size strip, or for any other reason. This control of the power input required by the tube-oscillator generator in accordance with the heat-rate demand of the strip passing through the heating-coil 3, is automatically accomplished, in the embodiment shown in Fig. 1, without requiring any control mechanism or regulating mechanism operating directly on the elements of the tube or tubes of the tube-oscillator generator, or on the source from which it derives its power.

Referring to the drawing, the screen 23 comprises a generally oblong, tubular, hollow, copper cylinder having spaced walls comprising an inner wall 24 and an outer wall 25, the space between which is closed by a top wall 26 and a bottom wall 27. Spaced baffles 28 and a partition 29 between the walls 24 and 25 provide a tortuous path inside the screen for a cooling flow of water supplied through inlet pipe 30 and withdrawn through an outlet pipe 31, both pipes being connected to flexible hoses for permitting movement of the screen.

The screen is axially substantially as long as the heating-coil 3, and has the same general shape as the heating-coil in which it is held in substantially coaxial relation by means of a pair of guide bars 32 and 33, respectively, guided in fixed bearings 34 for the bar 32, and 35 for the bar 33. Brackets 36 secure the screen to the guide bars.

The guide bar 32 may be round, while the guide bar 33 is provided with a rack 37 engaged by a gear 38 for automatically positioning the screen

in different positions with respect to the heating-coil 3; although this may also be done manually by disengaging the gear 38 from the rack 37, and applying force to a handle 39 on the guide bar 33, any suitable latching means being used to hold the screen in manually adjusted position.

For automatic control, the gear 38 may be actuated in response to any variable responsive to the heat demand of the strip. In Fig. 1 I have shown two devices selectively connectible to apparatus for this purpose, the first comprising a device responsive to the speed of the strip, and the second a device responsive to the temperature of the strip.

The speed responsive device comprises a magneto or generator 40 coupled to rotate at a speed in direct proportion to the speed of the driving motor 41 for the pull-unit 2, the field and armature of which can be automatically or manually controlled for obtaining the desired operating speed of the strip. The voltage of the magneto is directly proportional to its operating speed which is, in turn, proportional to the speed of the strip. This voltage is applied, when the switch 43 is in down position, to conductors 44 and 45 leading to any suitable control mechanism 46, shown in a simplified and schematic way in Fig. 1 as a follow-up mechanism having a deflectable circuit-controlling pointer 47 deflectable in proportion to the voltage across the conductors 44 and 45. When the voltage increases, the pointer 47 closes a circuit to a contact 48 which energizes one field-circuit 49 of a small reversible drive-motor 50 geared, through gearing 51, to the drive gear 38, for moving the guide bar 33 in a direction away from the heating-coil 3; and when the voltage of the magneto decreases, the pointer 47 engages a contact 52 for energizing a second field-circuit 53 of the drive-motor 50 for moving the guide bar in the opposite direction.

The contacts 48 and 52 are carried in spaced relation on a movable insulating segment 54 which is geared to the drive-motor 50 so that it moves in proportion to the movement of the screen 23. When the segment 54 is moved by the drive-motor 50 until the insulation between the contacts 48 and 52 matches the position of the pointer 47, whatever such position may be, the energizing circuit for the drive-motor is interrupted, fixing the position of the screen in accordance with the voltage across conductors 44 and 45, which in this case depends on the strip-speed.

When a new strip-portion on a coil is to be spliced on the strip in the treatment-line, the speed of the drive-motor 41 for the pull-unit 2 is lowered, thereby lowering the voltage generated by the magneto 40, and causing the screen to be inserted into the heating-coil 3. When the speed of the strip-line is restored, the voltage generated by the magneto increases, and the screen 23 is moved in a direction outwardly out of the heating-coil 3.

The second control device includes a photo-cell or radiation pyrometer 60 which responds variably in accordance with variations in the temperatures of strip 1, the response of this pyrometer being amplified in the amplifier 61 to yield a voltage across conductors 62 and 63, which depends on the temperature of the strip. By throwing the switch 43 upwardly, this voltage will be applied to the conductors 44 and 45 for controlling the position of the screen 23 in response to the temperature of the strip, which, of course, depends upon the power-input thereto. If too much

power is supplied to the strip, the screen is correspondingly inserted into the heating-coil 3; and if too little power is being supplied, the screen is correspondingly withdrawn from inside the heating-coil 3.

The position of the screen 23 inside the heating-coil 3 varies with the position of the pointer 47 which responds either to the speed of the strip or to its temperature, in the embodiment shown. By moving the screen 23 to different positions inside the heating-coil 3 continuous regulation of the power capable of being delivered to the strip can be obtained. The field lines beyond the ends of the heating-coil tend, of course, to spread out so that a portion of the screen, outside the heating coil, is in a region in which the flux is less concentrated than it is inside the heating-coil.

For best screening, the wall thickness of the screen should be greater than the physical parameter called the depth of current penetration, and which is generally represented as equal to

$$5030 \sqrt{\frac{\rho}{f}}$$

centimeters; where ρ and f are, respectively, resistivity in ohm-centimeters of the material and frequency in cycles per second of the inducing current.

Where wall thicknesses are greater than the depth of current penetration, the power-input from the heating-coil 3 to the strip 1 may be roughly represented by the equation:

$$\frac{W_w}{W_c} = K \frac{P_w L_w}{P_c L_c} \sqrt{\frac{\rho_w U_w}{\rho_c U_c}}$$

where K is a constant, W_c is the copper loss in watts in a heating-coil having a length L_c , a transverse girth or periphery of P_c , and formed of a metal having a resistivity ρ_c and a magnetic permeability of U_c ; and W_w is the maximum power that can be transferred from such a heating-coil to work inside it, the work having a length L_w , a transverse girth or periphery of P_w , a resistivity of ρ_w and a magnetic permeability of U_w . In the case of strip, the girth is twice the sum of its width and thickness. For copper, the permeability is unity.

In strip-heating, the length of the strip-portion being heated is for practical purposes equal to the coil length so that if the product of the transverse periphery of the material or work inside the heating-coil multiplied by the square-root of the product of its resistivity and permeability is decreased, that is, the quantity $P\sqrt{\rho U}$ of the material or work on which the field acts is decreased, the wattage which can be produced by electrical induction in the material or work with a given coil is also decreased, so that the heating-coil is, in effect, unloaded. Decreasing the effective length of the strip-portion subjected to magnetic induction also decreases the heat supplied to the strip, other conditions being the same.

Utilizing a screen causes a transfer of heating action from the strip to the screen, with the power demand on the heating-coil changed in accordance with the relation of the aforesaid physical quantities of the material to be treated and the screen. In a device of the type herein disclosed, the periphery of the copper screen is somewhat greater than that of the ferrous strip 1, but its resistivity and permeability are considerably lower so that inserting the copper screen into the heating-coil not only magnetically shields the strip 1, but also unloads the heating-coil 3 to

an extent dependent upon the distance the screen is inserted inside the heating-coil.

In case the permeabilities of the screen and material being treated are about the same, the resistivity of the screen, in ohm-centimeters, should preferably be appreciably less than that of the material being treated, so that the demand for power from the tube-oscillator generator decreases as the screening of the material being treated increases. If the screen's resistivity were close to or greater than that of the material being treated, the latter could still be screened or shielded but the tube-oscillator generator would not be unloaded.

In an apparatus for reflowing of tin or tin-plated strip-steel about 90% of the power supplied to the heating coil-means goes into the unshielded plated strip, the remaining 10% constituting the losses in the heating-coil. By completely shielding the strip with a copper screen, the power to the strip can be reduced to substantially zero, and the power supplied to the heating-coil reduced to that necessary to supply the losses in the heating-coil and in the screen, or about 20% of the original power supplied for heating the unshielded strip.

Although inserting the copper screen 23 actually reduces the power-output of the tube-oscillator generator 4, it may raise the current in the tank-circuit 11, that is, it may raise the "Q" factor of the tank-circuit as compared to its "Q" factor when heating an unshielded strip; by "Q" factor meaning the ratio of volt-amperes to real power consumed.

When the tube-oscillator generator is such that it is desirable to control the current in the tank-circuit, an embodiment having a feed-back control can be utilized. Such a device is indicated in Fig. 5 where the gearing 51 also controls a cam 65 having a cam-groove 66, of predetermined contour, which controls an arm 67 in definite relation to the position of the pointer 47. The arm 67 is rigidly connected to the connection 22 which moves therewith. Such control can be used alone or can augment that of the screen 23, controlling the voltage across the tank-circuit and the power available for heating the strip.

While I have illustrated and described my invention in substantially its simplest symbolic forms, it is obvious that various changes, by way of equivalents, substitutions, additions, and omissions, may be made without departing from the essential features of my invention. I desire, therefore, that the appended claims be accorded the broadest construction consistent with their language and the novel teachings and applications of my invention.

I claim as my invention:

1. An electrical heating system for heating traveling material, comprising in combination: an energizable electrical means along a portion of the path of travel for the material, said electrical means being of a type for producing, when energized, a pulsating spacial field of electrical energy in a region in said path-portion for heating the material as it passes through said region; a tube-oscillator generator for electrically energizing said electrical means; means for moving the material through said region; load-controlling means for controlling the output load of said tube-oscillator generator, said load-controlling means comprising movable electricity-conducting screen-means; and means for variably positioning said screen-means with respect to said electrical means and the field adapted to be estab-

lished thereby so as to control the heating action of said electrical means and the field adapted to be established thereby on the material, the last said positioning means comprising responsive means moving said screen-means in response to a measure of the heat needed for heating the material.

2. An electrical heating system for inductively heating materials, comprising, in combination: a heating coil-means having a material-receiving passage; a tube-oscillator generator having a tank-circuit for energizing said heating coil-means so as to establish a pulsating magnetic field in said passage; a metallic screen-means, means for reciprocally supporting said screen-means for movement in a predetermined path to different positions with respect to said heating coil-means and the field adapted to be established thereby for varying the concentration of said field in said passage; said system being such that material in said passage will be inductively heated to a degree dependent on the strength of said field and the position of said screen-means with respect to said heating coil-means; means for continuously passing elongated material lengthwise through said passage; and means, responsive to a measure of the heat needed for heating the material passing through said passage, for controlling the position of said screen-means.

3. An electrical heating system for inductively heating metallic materials, comprising in combination: an energizable helical heating-coil for providing a pulsating magnetic field axially therein, a metallic tubular screen of a size to extend beyond said heating-coil, means for movably supporting said screen with an end of the screen inside said heating-coil and the other end of the screen outside said heating-coil, the screen-material having a wall-thickness which is greater than the depth of current penetration therein, at the frequency of the pulsations of said field, and means for continuously moving elongated material lengthwise through said heating-coil and said tubular screen.

4. An electrical heating system for inductively heating metallic materials, comprising in combination: a tube-oscillator generator comprising a tank-circuit means including a heating coil-means for providing a pulsating magnetic field, said heating coil-means comprising a coil provided with a material-receiving passage in the region for said magnetic field, a metallic screen-means comprising a metallic member having a predetermined length and so disposed as to have one end inside said coil and another end outside

said coil, said member being movable in said region to different positions with respect to said heating coil-means, for screening variable portions of said magnetic field from the axial center of said passage, and for varying the inductance reflected in said tank-circuit by said heating coil-means, and means for moving said screen means.

5. An electrical heating system for inductively heating metallic material, comprising, in combination: a tube-oscillator generator comprising a tank-circuit means including a heating coil-means for providing a pulsating magnetic field, said heating coil-means comprising a coil having a material-receiving passage in the region for said magnetic field, an adjustable metallic screen-means inside said coil adapted to present an area of variable longitudinal amounts inside said coil, and means arranged for adjusting said screen-means for changing said area, whereby to screen various portions of said magnetic field from said material-receiving passage, and to vary the inductance reflected into said tank-circuit by said heating coil-means.

ROBERT M. BAKER.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,937,420	Wood et al. _____	Nov. 28, 1933
2,059,300	Adams _____	Nov. 3, 1936
2,073,597	Northrup _____	Mar. 9, 1937
2,125,316	Ronci _____	Aug. 2, 1938
2,133,492	Vatter _____	Oct. 18, 1938
2,223,970	Stansel _____	Dec. 3, 1940
2,293,047	Denneen et al. _____	Aug. 18, 1942
2,299,934	Sherman et al. _____	Oct. 27, 1942
2,325,401	Hurlston _____	July 27, 1943
2,341,120	Rudd et al. _____	Feb. 8, 1944
2,371,459	Mittelmann _____	Mar. 13, 1945
2,381,246	Baker et al. _____	Aug. 7, 1945
2,381,278	Gregory et al. _____	Aug. 7, 1945

OTHER REFERENCES

Babat, "Construction of Heating Coils for Induction Surface Hardening," Heat Treating and Forging, April, 1941, page 192.

Stoltz et al., "Electric Apparatus Used in Electro-Tinning," Transactions of the Electrochemical Society, vol. 84 (1943), page 274.

Humphrey, "Electronic Generators Extend Induction Heating Field," Electronics, January, 1943, page 58.