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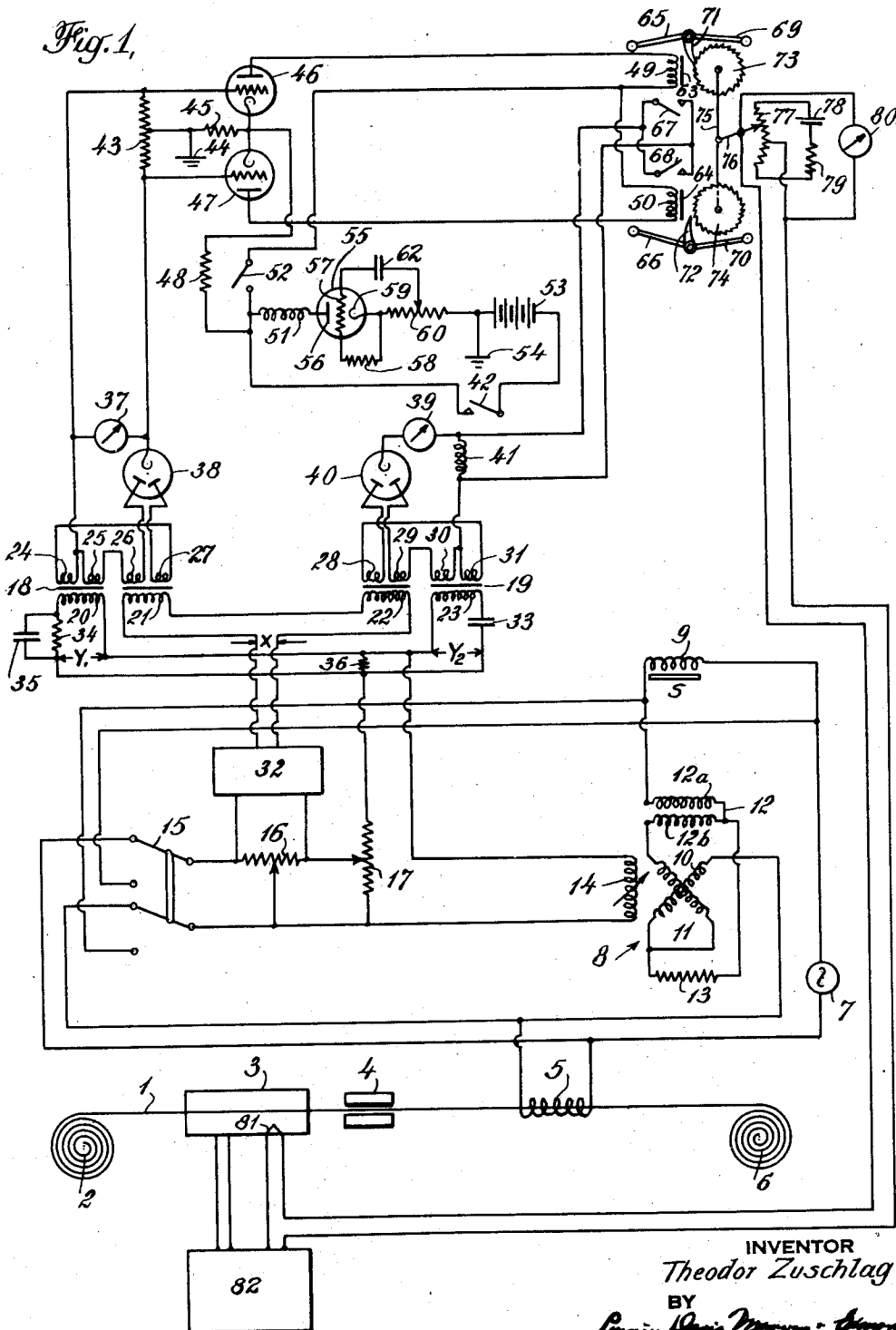
T. ZUSCHLAG  
HEAT TREATMENT APPARATUS

2,154,928

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2 Sheets-Sheet 1

Fig. 1,



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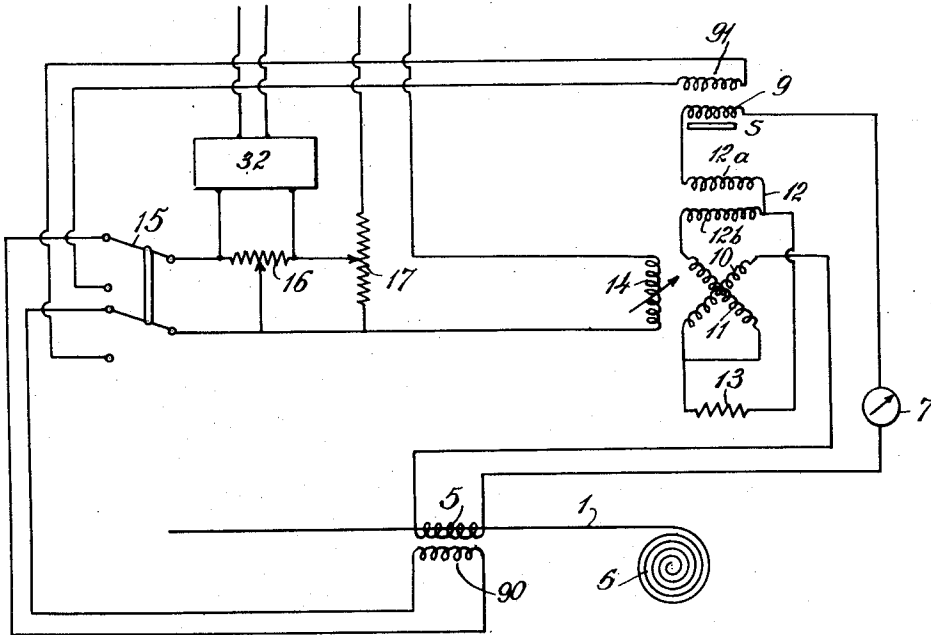
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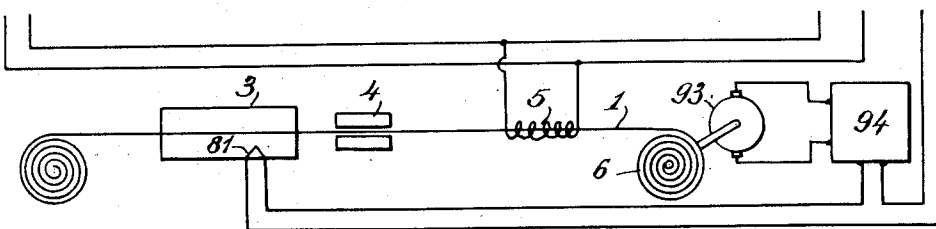
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2 Sheets-Sheet 2

*Fig. 2.*



*Fig. 3.*



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## UNITED STATES PATENT OFFICE

2,154,928

## HEAT TREATMENT APPARATUS

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Application August 3, 1935, Serial No. 34,553

7 Claims. (Cl. 266—3)

This invention relates to heat treatment, and is concerned particularly with the control of the amount of heat supplied to successive sections of elongated magnetizable bodies passing through a heating zone, with a view toward producing uniformity of physical or metallurgical characteristics throughout such bodies after heat treatment. In one of its aspects, the invention is concerned with the control of a heat treatment process wherein razor blade strip, steel wire or other like magnetizable bodies are passed successively and substantially continuously through a heating zone and a quenching means, so that successive portions of the bodies are first heated and then quenched to produce certain desired physical or metallurgical properties, such as predetermined degrees of hardness, ductility, tensile strength, impact strength, and strain.

I am aware that it has been proposed heretofore to employ automatic regulation of one form or another in the control of such continuous heat treatment processes, employed as a criterion standard bodies having some or all of the properties which were desired in the material undergoing treatment. The anticipated advantages of these prior proposals have not been realized in full. Lack of appropriate sensitivity in the means employed, failure of the means to respond to deviations in certain important physical properties of the material undergoing treatment, and conversely, excessive response to mere minor and immaterial changes in less important physical properties of the material, often have defeated the purpose for which the means was intended. Furthermore, the complexity of the proposed apparatus, the large number of moving parts, and the fact that expensive and fragile electrical instruments were required frequently have made the initial cost of equipment or the cost of operation prohibitive, at the same time introducing an element of uncertainty into the results obtained. Finally, the complexity of the apparatus of the prior art, with the correlative difficulty of adjustment, has required skill not possessed by the type of labor usually employed in metallurgical operations.

As a result of my investigations I have discovered a method of and apparatus for heat treatment regulation which overcome in large measure the difficulties imposed by prior proposals. My invention employs rugged and relatively inexpensive electrical instruments, and permits the construction of apparatus in which the number of moving parts is small. The rugged character of the apparatus, however, does not interfere with its sensitivity or with the accuracy of the results. On the contrary, the apparatus of my invention responds promptly and accurately to material deviations in the character of the material undergoing treatment, while im-

material deviations do not affect it. Finally, deviations which are momentary rather than persistent do not affect the control, due to the use of a time delay mechanism. In this way "hunting" or over-regulation is eliminated.

According to the method of my invention successive portions of a long magnetizable strip are first heated to an appropriate temperature, quenched, and passed in inductive relationship with a test coil through which an alternating potential is imposed. The amplitude and phase of the alternating potential in the test coil varies in response to variations in physical properties of the material disposed in inductive relationship therewith. The test coil potential thus influenced is opposed to a secondary artificial potential the phase and amplitude of which correspond to those which would be manifested in the test coil if the material passing through the test coil possessed the desired physical and metallurgical properties. If the two potentials thus opposed are identical the resultant potential is zero, indicating that proper conditions of heat treatment are being maintained. If the two potentials are unequal, a differential potential results which reflects deviations in both phase and amplitude. The differential potential for convenience of description is hereinafter designated as X.

The X or different potential is then utilized together with another potential, hereinafter designated as  $Y_1$ , to induce a secondary current, which is rectified, and measured. Simultaneously another secondary current is induced by means of the X potential and a third, or  $Y_2$  potential, which should preferably correspond in frequency to the X and  $Y_1$  potential but should be displaced in phase from the  $Y_1$  potential by a constant angle, say  $90^\circ$ . This secondary current is also rectified. For purposes of discussion the  $XY_1$  secondary current is hereinafter referred to as the "in phase component", while the  $XY_2$  secondary current is described as the "out of phase component."

Both in phase and out of phase components may be measured with appropriate direct current indicating means such as galvanometers. They may also be introduced into an electrical circuit so arranged that one component alone, or both together, depending upon the arrangement, will operate to adjust the amount and sign of a direct current potential introduced into a furnace control circuit. The resultant variation in the furnace control circuit in turn operates to change appropriately the amount of heat introduced into the magnetizable material passing through the furnace, either by varying the temperature of the furnace or the rate of travel of the material. In this way the degree of heat treatment is correlated to the physical proper-

ties of the product so that substantial uniformity between succeeding portions of the product is produced.

In the preferred practice of my invention regulation of the amount of heat introduced into the material in the furnace is deferred until it appears that a substantial, persistent, and undesirable change has occurred in the nature of the quenched material, thus preventing over-regulation.

In the practice of the above described method I prefer to employ an apparatus which comprises a test coil adapted to be energized by an alternating current and to be disposed in inductive relationship with successive portions of the magnetizable material almost immediately after quenching, a means for creating a secondary potential (for example, in coil 14) having a substantially predetermined phase and amplitude, a network wherein the potential of the test coil may be balanced against the secondary potential, a pair of mixer transformers equipped with appropriate rectifiers, a circuit or circuits with appurtenant apparatus, wherein the secondary currents derived from the mixer transformers may be made to vary the amount of heat introduced into the material in a furnace or other heating means. (Variations of current in the test coil 5 during operation may have a slight effect upon the phase and amplitude of the potential in the coil 14, but this is negligible as compared with the variations in the test coil itself.)

These and other features of the apparatus and method of my invention will be more thoroughly understood if reference is made to the following description, taken in conjunction with the accompanying drawings in which

Fig. 1 is a schematic representation of a presently preferred form of the apparatus of my invention,

Fig. 2 illustrates a modification of the apparatus of Fig. 1, employing a test coil of different construction and

Fig. 3 illustrates a further modification of the apparatus of my invention adapted to vary the time of heating of successive sections, rather than the temperature of the heating means.

The method of my invention is claimed in my copending application, Serial No. 34,552 filed August 3, 1935.

Referring now to Fig. 1, it will be seen that a strip or wire of steel or other magnetizable material 1 is unwound from a feed reel 2, and passed successively through a suitable furnace 3, quenching blocks 4, a test coil 5 and rewound on a receiving reel 6, which may be driven by a motor (not shown).

The furnace may be heated electrically, by a gas flame, or by other appropriate variable heating means. It should be of such design as to permit the continuous passage of the material undergoing treatment therethrough.

The quenching blocks may be of any suitable design as long as they are adapted to the rapid and continuous cooling of material passed through them.

The test coil is merely a coil of wire of low ohmic resistance, of sufficient diameter to permit the material undergoing treatment to pass through the coil freely.

One end of the test coil is connected directly with a source of alternating current 7. The other end of the test coil is connected with the alternating current source through the primary coils

of a phase shifter 8 in series with a standard primary coil 9.

The phase shifter 8 comprises a pair of primary stator coils 10 and 11, preferably of identical construction and disposed adjacent each other at right angles. The stator coils are connected in series with each other and with the test coil. They are also connected in series with a mutual inductance 12, having two inductance coils 12a and 12b disposed side by side and connected in series. A resistor 13 is shunted across one of the stator coils.

The mutual inductance and the resistor are so chosen as to cause a phase displacement of substantially 90° between the current flowing in the two stator coils.

The remainder of the phase shifter comprises a rotor coil 14, which is disposed inductively adjacent the two stator coils and is movable in a plane parallel to the axes of the two stator coils. Preferably, the rotor coil is disposed so that its center is adjacent the cross formed by the two stator coils. The phase of the current induced in the rotor coil is dependent upon its angular disposition with respect to the two stator coils. By varying this angular disposition, the phase of the secondary current induced in the rotor coil can be adjusted to any value. In other words, the phase displacement between the secondary current induced in the rotor coil and the primary currents flowing in either of the stator coils may be varied at will.

As has been noted, the primary side of the phase shifter is connected with the test coil, the standard coil, and the current source to form a series circuit. The standard coil is preferably the physical and electrical equivalent of the test coil, and is adapted to receive a specimen S having the physical or metallurgical properties which are desired in the material subjected to heat treatment.

The apparatus is provided with a quadruple pole, double switch 15 whereby both ends of either the test coil or the standard coil may be connected to a first potentiometer 16. The switch leads are so arranged that one end of either the test coil or the standard coil is connected to one end of this first potentiometer, while the other end of the respective coil is connected to its slider and also to an end of a second potentiometer 17 and to an end of the rotor coil of the phase shifter. The slider of the second potentiometer is connected to the end of the first potentiometer that is not connected directly to the switch—so that the network containing the switch, the first potentiometer, the second potentiometer and the rotor coil 14 may be connected with either the test coil 5 or the standard coil 9 depending upon the way the switch is thrown.

The apparatus is provided with two mixer transformers 18 and 19, to each of which two potentials are supplied. The mixer transformers and their appurtenant apparatus are described in greater detail and claimed in my copending application Serial No. 33,853, filed July 30, 1935. As used in the instant apparatus, each transformer is provided with two primary coils, 20—21 and 22—23 respectively. In turn, each primary coil is inductively associated with two secondary coils, so that mixing transformer 18 contains four such secondaries 24, 25, 26, 27 and the other mixing transformer contains four other secondaries 28, 29, 30, 31.

Potential is supplied to one primary coil in each transformer from the output side of an

amplifier 32, the input leads of which are connected to the ends of the first potentiometer.

Another potential is supplied to the remaining primary coil in each transformer, which coils are connected in parallel with each other, to the free end of the rotor coil of the phase shifter, and to the free end of the second potentiometer. A condenser 33 is connected in series with the primary coil 23, and a second condenser 35 is connected in series with the other primary coil of this pair. This second condenser is shunted by a resistance 34. A fixed resistance 36 is shunted across the circuit 23, 33, 34, 35, 29. The condensers 33, 35, the fixed resistance 36, and the resistance 34 are so arranged that the potential supplied to the primary coil 23 is 90° out of phase with that supplied to the primary coil 29, in the other mixer transformer. Because of this arrangement, "in phase" variations in the physical properties of the material undergoing investigation are reflected in mixer transformer 18, while "out of phase" variations are reflected in the other mixer transformer 19.

Now considering the secondary or output sides of the mixing transformers, it will be seen that the two outer secondary coils of each mixer transformer are connected to each other in series opposition, and that the two inner coils of each mixer transformer are connected to each other in series addition. Thus the coils 24 and 27 of the transformer 18 are connected to each other in series opposition; the coils 28 and 31 of the transformer 19 are connected to each other in series opposition; the coils 25, 26 of the transformer 18 are connected to each other in series addition; and the coils 29, 30 of the transformer 19 are connected to each other in series addition. Because of this arrangement, the pairs connected in series opposition have an induced current proportional to the vector difference of the electromotive forces introduced into the primary coils of each mixing transformer, whereas the pairs of secondary coils connected in series addition have a current flow proportional to the vector summation of the electromotive forces introduced into their primary coils of the respective mixer transformers.

To be more specific, secondaries 24 and 27 are connected in series opposition with a direct current indicating means 37 such as a galvanometer and a plate of a diode thermionic rectifier 38, this circuit being completed from the plate to a cathode of the diode rectifier, or thermionic valve. Secondaries 25 and 26 are connected in series addition with each other through the direct current indicating means 37 to another plate and the cathode of the diode rectifier 38.

The arrangement of the secondaries in the other mixer transformer is similar, coils 28 and 31 being connected in series opposition with each other through a direct current indicating means 39, such as a galvanometer, and through a cathode and one plate of a diode thermionic valve or rectifier 40, whereas secondaries 29 and 30 are connected in series addition through the direct current indicating means and the cathode and remaining plate of the diode rectifier 40. The secondary circuit transformer 18 differs from 19 in that a coil 41 of a solenoid switch 42 is included.

A pair of copper oxide rectifiers or other half wave rectifiers may be substituted for each diode or full wave rectifier if desired.

The full wave rectifiers naturally provide for rectification of the currents induced in the sec-

ondaries of the two mixer transformers. As a result, the reading of indicator 37 is a function of the rectified difference between the vector summation and the vector difference of the potentials imposed upon primaries 20 and 21, while the reading of indicator 39 is a function of the rectified difference between the vector summation and the vector difference of the potentials imposed upon primaries 22 and 23. If there are no "in phase" or "out of phase" differences between the physical characteristics desired and the physical characteristic actually manifested by the material passing through the test coil, neither of the indicating instruments will be moved, i. e., both instruments will read zero.

My experiences in the art of magnetic analysis have indicated that differences in the hardness and thickness of material such as razor blade steel are revealed by "in phase" variations, whereas differences in strain and hardness are manifested by "out of phase" variations. Now minor differences in thickness of the material undergoing treatment are relatively inconsequential, and in any event they cannot be remedied by changing the heat input in the tempering operation. Similarly, minor differences in strain, while producing marked variations in the "out of phase" readings do not actually affect the quality of razor blade steel except in unusual instances. For this reason, I have designed the apparatus of my invention in such a way that it does not disturb the heating conditions in the furnace except when both "in phase" and "out of phase" variations from the prescribed artificial potential are observed. In this way, the apparatus does not attempt to compensate for differences in thickness or strain alone. Much useless "hunting" or over-regulation by the apparatus is thus avoided. It will be understood, of course, that this feature is not essential to the operation of my invention. If it be found necessary or desirable, the automatic heat control mechanism can be made to function in response to "in phase" variations, or "out of phase" variations, or both.

With this in mind, and again referring to Fig. 1, the furnace control apparatus (which operates in response to currents flowing through the indicators 37 and 39) will be described.

Shunted across the indicator 37, so as to be connected in series with the rectifier 38 and the secondary coils of mixer transformer 18 is a center-tapped grid resistor 43. The center tap of the grid resistor is grounded (as shown at 44) and connected through a bias resistor 45 to the cathodes of a pair of grid-controlled glow tubes 46 and 47. The cathode circuit through the tubes is completed by leads which connect the grids of the two tubes respectively to the ends of the center-tapped grid resistor.

Plates of tubes 46 and 47 are connected respectively with the coils of a pair of contact arm relays 49 and 50. The free ends of these coils are connected together so as to form the series circuit 46, 49, 50, 47, 43.

The apparatus contains another control circuit adapted to energize a delay mechanism. This control circuit is connected to the common point between the cathodes of the tubes 46 and 47 through a bleeder resistance 48, and considered as a series circuit is comprised briefly of a delay relay 52, followed respectively by a triode thermionic valve 55, a potentiometer 60, a direct current source 53 and the relay controlled switch 42.

Considered more specifically, it will be seen that a field coil 51 of the delay relay 52 is con-

connected to a plate 56 of the thermionic valve 55. A cathode 59 of the valve 55 is connected to an end of the potentiometer 60, the other end of the potentiometer being connected to the direct current source, with a ground 54 disposed between the direct current source and the potentiometer. One side of a grid 57 of the valve 55 is connected to the slider of the potentiometer 60 through a charging condenser 62, and the other end of the grid 57 is connected to the end of the potentiometer adjacent the cathode 59 of the tube 55 through a high ohmic grid leak 58. The control circuit is completed by a lead which connects the relay controlled switch 42 with the coil 51 of the delay relay 52, the bleeder resistance 48 being connected into the delay control circuit between the switch 42 and the delay relay.

A contact point of the delay relay 52 is connected to a common point between the coils of the contact arm relays 49 and 50.

Now considering the contact arm relays 49 and 50, it will be seen that each is composed respectively of a coil 63, 64, at one end of which is disposed a pivoted armature 65, 66, with a relay controlled switch 67, 68 in juxtaposition with the other end. The armatures 65 and 66 and arms 69 and 70 pivoted thereto, are equipped with pawls 71 and 72 adapted on energization of the relays 49 and 50, respectively, to advance towards and rotate ratchet wheels 73 and 74. Both ratchet wheels are rigidly mounted on a rotatable shaft 75, which also carries a rigidly mounted slider 76 of a center-tap potentiometer 77.

Energization of the coil of one of the contact arm relays causes the pawl to engage and move the slider of the center-tap potentiometer. At the same time, however, one of the relay controlled switches 67, 68 is closed. These switches are shunted in parallel with each other across the coil 41 of the relay switch 42. The closing of either switch 67 or 68 thus acts to short circuit and de-energize coil 41, so that switch 42 opens.

The ends of the center-tap potentiometer 77 are connected in series with a direct current source 78, such as a dry cell and an adjustable resistance 79. A potential indicating means 80, such as a millivoltmeter, is connected between the center-tap and the slider of the potentiometer 77 and is thus enabled to measure the potential drop across that portion of the potentiometer lying between the slider and the center tap.

Also connected across the center tap and slider of the potentiometer 77 is a thermocouple 81, disposed within the furnace 3. The thermocouple is also connected to the furnace control mechanism 82 which is operatively associated with the furnace. This furnace control mechanism may be of any of the well-known types which operate to change the input of heat into the furnace in response to electrical impulse supplied to it.

As was noted at the outset, for purposes of discussion, the apparatus of my invention may be considered to comprise the following parts:

1. A test coil, in which a primary alternating current may be subjected to the inductive influence of a magnetizable body, and thus be caused to vary in phase and amplitude.
2. A standard coil in which alternating current may be subjected to the inductive influence of a specimen having the physical properties which are desired in the material passing through the test coil.
3. Means for creating a secondary potential

corresponding in amplitude and phase to that which would be produced in the test coil if the test piece inserted within it had the desired physical or metallurgical characteristics. This secondary potential may be described as an artificial electrical standard, and is set up in the rotor 14 of the phase shifter by induction from the field coils, its phase and amplitude being adjusted while it is opposed to the potential of the standard coil when the latter is inductively associated with the specimen having the desired physical properties (as described in paragraph 2, ante).

4. A network in which the primary potential in the test coil can be opposed to the secondary potential or artificial standard, with the result that a differential potential, representing both the difference in amplitude and the difference in phase between the potential of the test coil and the potential of the artificial standard is produced. For convenience, in discussion, let this potential be called X.

5. A pair of mixer transformers combined with appropriate rectifiers, into one of which is fed the differential potential produced as described above together with a second potential, designated hereinafter as  $Y_1$ . Into the second of the mixer transformers is fed the differential potential X, and another potential  $Y_2$  which is phase displaced from the potential  $Y_1$  by a constant phase angle (which for most purposes is conveniently maintained as  $90^\circ$ ). The secondary current product of the mixer into which the potentials X and  $Y_1$  are fed reflects "in phase" differences between the potential of the test coil, and the artificial standard (assuming X and  $Y_1$  to be in phase with each other). Conversely, the mixer into which the potentials X and  $Y_2$  are fed reflects "out of phase" differences.

6. An "in phase" control circuit into which the current of the  $XY_1$  mixer is fed so as to energize the relays operatively associated with a potentiometer connected with the heat input mechanism of the furnace.

7. An "out of phase" control circuit which is also operatively associated with the relays which move the aforementioned potentiometer.

8. A "delay" control circuit adapted to prevent the adjustment of the heat input mechanism of the furnace unless the deviation of the test coil potential from the artificial standard potential is sufficiently prolonged as really to require regulation.

9. A thermocouple circuit into which a variable amount of auxiliary direct current may be introduced by means of the aforementioned potentiometer, and

10. A heat control mechanism which will vary the amount of heat introduced into the furnace in response to variations in the current flowing in the thermocouple circuit.

(The parts of the apparatus noted in enumerated paragraphs 6, 7 and 8 are so arranged that they must cooperate to produce a movement of the potentiometer which is a part of the apparatus outlined in paragraph 9.)

A detailed explanation of the functions of the various portions of the apparatus is given hereinafter, together with an explanation of the mode of operation.

Let it be assumed that the material being heat treated is passing continuously through the furnace, the quenching blocks, and the test coil and is being rewound on the receiving reel. A standard specimen S having the desired hardness, tensile strength, impact strength, etc. and free from

flaws is inserted in the field of the standard coil 9, and the switch 15 is thrown to its lower position so that the standard coil is connected with the first potentiometer 16, the second potentiometer 17 and the rotor coil 14 of the phase shifter. When the switch 15 is in its lower position, the test coil 5 is connected in series with the artificial standard 10, 11, 12, 13 and the standard coil 9. Slight changes in potential of test coil 5 caused by the passing of the test strip there-through do not affect the potential set up in the rotor 14 to such an extent as to impair the measurement of the potential drop across standard coil 9. With the switch in its lower position, the sliders of the first and second potentiometer are moved, and the rotor coil is rotated until both of the galvanometers 37 and 38 give a minimum or zero reading. When this condition is obtained the amplitude and phase of the potential between the lower end and the slider of the potentiometer 17 coincide with the amplitude and phase of the potential in the standard coil 9. In other words an artificial secondary standard potential has been created in the bridge network including the two potentiometers, the rotor coil of the phase shifter, and the standard coil. This artificial standard potential balances and opposes the potential of the standard coil.

The balancing of phase is due to the construction of the phase shifter. The inductive effect of the two 90° phase displaced potentials in the primary coils 10 and 11 of the phase shifter upon the rotor coil 14 varies depending upon the angular disposition of the rotor coil, so that a phase of any angular displacement from an arbitrary base point may be set up. Amplitude of the secondary or artificial standard potential is varied by means of the two potentiometers, potentiometer 17 serving for large adjustments while potentiometer 16 acts as a vernier for finer adjustments.

The artificial standard potential having been established, the switch 15 is shifted so that the test coil 5 replaces the standard coil 9 in the network which now comprises 5, 16, 17, 14. If the condition of the material passing through the test coil is satisfactory, then the phase and amplitude of the two potentials in the network will balance. However, if either the phase or the amplitude of the test coil potential differs from that of the artificial secondary standard, this difference will be reflected in the secondary currents in the mixer-transformer rectifier circuit 18, 37, 38 or the rectifier circuit 19, 39, 40, or both. For purposes of discussion, it will be assumed that the phase of the differential potential X corresponds to the phase of the potential Y<sub>1</sub>, introduced into the primary coil 20 of the mixer 18 and that the potential Y<sub>2</sub> which is introduced into the primary coil 23 of the mixer 19 is 90° out of phase with the potential X. The mixer 18 will thus reflect approximate variations in amplitude while mixer 19 will reflect variations in phase. Usually, the phase of the differential current will not correspond to the phase of either the potential Y<sub>1</sub>, introduced into the primary coil 20 of the mixer 18 or with the potential Y<sub>2</sub> (usually 90° out of phase with potential Y<sub>1</sub>) which is introduced into the primary coil 23 of the mixer 19. Of course, if the potential X should correspond in phase with either potential Y<sub>1</sub> or Y<sub>2</sub>, then only the corresponding secondary circuit of one mixer would be energized. Usually, however, a change in the character of the material passing through the test coil will be manifested both "in

phase" and "out of phase." As previously noted, deviations in hardness and thickness are manifested "in phase," while deviations in hardness and strain are manifested "out of phase."

Even though the variations in physical character of the material passing through the test coil from the desired physical character are very slight, the galvanometers 37 and 38 will ordinarily indicate them. If desired, these galvanometers may be of the recording type so that a continuous record of all deviations may be kept. Ordinarily, however, it will not be desirable to let very minor deviations vary the heat treatment operation. Consequently, the resistances of the "in phase" control circuit, the "out of phase" control circuit and the "delay" circuit are made high enough to prevent their actuation by mere minor deviations of an immaterial character.

Assuming, however, that deviations of sufficient magnitude are manifest both in phase and 90° out of phase, the following play of forces takes place in the control circuit. The "90° out of phase" component current flowing in the secondary circuit 19, 41, 39, 40, of the mixer 19 will energize the coil 41 and close the switch 42. Current will thus tend to flow in the "delay" circuit 53, 42, 51, 55, 54. This current will be very slight at first and can only increase gradually for the reason that a charge builds up in the condenser 52 and impedes the increase of current flowing from the plate 56 to the grid 57 of the valve 55. Because the rate of current flow from the plate depends upon the adjustment of the charging condenser 52, the grid leak 58, and the potentiometer 60 which are operatively associated with it, the amount of current flowing in the time delay circuit may be varied by adjusting any one of these portions of the apparatus. In practice, however, it is most convenient to adjust the quantity of plate current, and hence the time of delay, by altering the potentiometer setting.

The potentiometer 60 having been set properly, there is a gradual increase in the amount of current flowing in the "delay" circuit to a point which permits the delay relay 52 to close. The closing of the delay relay 52 permits the energization of the grid controlled flow tubes 46 and 47 from the direct current source 53.

The function of the "in phase" component flowing from the secondary coils of the mixer transformer 18 will now be considered. The values of the bias resistor 45 and the bleeder resistance 48 have been chosen so that the grids of the tubes 46 and 47 are sufficiently negative to prevent a slight current (not indicative of a major defect in the material undergoing treatment) from tripping the tubes. If, however, current of a sufficient magnitude is induced in the secondaries of the mixer transformer 18, then one of the glow tubes will pass current, energize one of the contact arm relays, and cause the slider of the potentiometer to move in one direction or the other, depending upon the polarity of the actuating electrical impulse. Thus, if the direct current flowing in the circuit 38, 43, 18, is positive in sign one thyatron will pass current and eventually cause the potentiometer slider to move counterclockwise. If the current in this circuit is negative in sign, the other thyatron will pass an impulse which will cause the slider to move clockwise.

At the same time the energization of one of the contact arm relays closes one or the other of the short circuit relays and de-energizes coil 41. Switch 42 then opens to de-energize the delay

switch 52, which in turn cuts off the supply of current to the plates of the glow tubes. The original positions of all parts of the control circuits are thus resumed. If the displacement of the slider of the potentiometer has been sufficient to cause the correct change in the temperature of the furnace, no further regulation occurs. If not, the "in phase" and "out of phase" components induced in the secondaries of the mixer transformers will again operate (after an appropriate delay) to cause a further change in the temperature of the furnace.

It will be clear that each time the apparatus operates, the slider of the potentiometer is subjected to a predetermined constant angular displacement in one direction or the other. Assuming that at the beginning the slider was located on the center tap of this potentiometer, it will be apparent that any movement of the slider will cause a potential drop between the slider and the center tap. The magnitude of this drop is measured by the millivoltmeter 80, and at the same time this potential drop is superimposed upon the potential set up by the thermocouple 81 in the circuit 77, 81. This superposition of potential (depending upon its sign) may add or subtract from the total potential in the thermocouple circuit. In either case the total potential supplied to the furnace control device 82 is changed and this device will operate to supply more or less heat to the furnace.

The mere physical operation of the control device, considered apart from the rather complex cooperative functions of its various parts is simple. The razor blade strip passes continuously and successively through furnace, quenching blocks and test coil. Deviations from the desired physical characteristics of successive quenched sections is reflected in the current indicating means associated with the mixing transformer. A coincidence of "in phase" and "out of phase" deviations of sufficient magnitude actuates the control circuit if prolonged over a sufficient time interval. An auxiliary potential is thus introduced into the thermocouple circuit, and in response to the resultant current change the amount of heat supplied to the material passing through the furnace is appropriately increased or decreased.

The time delay feature of the apparatus is important in that it prevents the apparatus from operating when an irregularity of short duration, such as a weld, is encountered. On the other hand persistent deviations in hardness, tensile strength, impact strength, etc. are compensated for in an efficient manner.

The fact that at any moment the switch permits the measurement of potential across either the test coil or the standard coil inserted in the bridge network, is of great value in practical operation in that it enables the operator to balance the network and set up a new artificial secondary standard potential without interrupting the continuous flow of material through sequential operations of heat treatment. If at any stage of the operation it becomes desirable to produce material corresponding to a new or different standard, a standard coil containing the new standard is permitted to replace the test coil in the bridge network momentarily, or until a balance can be obtained with the new artificial secondary standard potential. In other words, there is in effect, a closed series circuit of the current source 7, one arm of the switch 15, the network, the other arm of the switch 15, the stationary phase shifter coils and either the

standard or the test coil, with the coil not in series connected in parallel across the switch 15. Thus, switch 15 is thrown to its lower position so that coil 14 in which the artificial standard potential is to be set up, is opposed to the potential in coil 9.

While I have described the invention on the assumption that the phase displacement of the currents  $Y_1$  and  $Y_2$  supplied to the mixing transformers are  $90^\circ$  out of phase with each other, the apparatus is not limited thereto. The phase displacement between these two potentials need not be precisely  $90^\circ$ , and in fact other angular displacements may prove more satisfactory in the heat treatment of some magnetizable materials, such as steel wire.

When the differential potential X coincides in phase with the potential  $Y_1$  the deviations indicated by the galvanometer 37 are solely those of amplitude, phase variations of the differential potential X being observed at the companion galvanometer 38. If, however, the value of the resistor-condenser combination 35, 34 is changed in such a manner that potential X and potential  $Y_1$  are no longer in phase, the galvanometer 37 will reflect an arbitrary mixture of phase and amplitude variations.

Although it is generally desirable, for reasons of simplicity, to employ simple induction coils as the test coil 5 and the standard coil 9, energizing these coils directly from a primary alternating current source 7 as shown, it is also possible (and it may be desirable) to replace either the single test coil or the single standard coil with a pair of coils, one a primary connected to the current source and to the primary coils of the phase shifter, the other a secondary inductively associated with the primary coil and connected into the bridge network in the same way as the primary coils are connected in Fig. 1. This type of construction is illustrated in Fig. 2, wherein a secondary test coil 90 and a secondary standard coil 91 are adapted to be connected to the bridge network 14, 15, 16, 17 and are respectively inductively energized by the primary test coil 5 and the primary standard coil 9.

If, in automatic regulation of the heat treatment, it is more convenient to regulate the time during which the material remains within the furnace, rather than the furnace temperature, it is a relatively simple matter to employ the means illustrated in Fig. 1 to vary the speed of the receiving reel 6, instead of the temperature. One modification of the apparatus of Fig. 1 to permit this type of regulation is illustrated in Fig. 3, wherein a variable speed motor 93 is employed to drive the receiving reel 6, and a controller 94 such as a rheostat is employed to vary the speed of the motor in response to changes of current in the thermocouple circuit.

Regulation of either time of contact or furnace temperature tends to accomplish the same net result in that the amount of heat introduced into successive portions of the magnetizable body is appropriately varied in either case.

Amplification devices can be inserted at various points in the several circuits of the apparatus should it be necessary to augment any of the electrical impulses employed to actuate the apparatus.

If mere analysis of magnetizable bodies is desired, one may dispense with the automatic regulation of the heat supplied to the material, and employ only the indicating means.

Other modifications of my invention may well

occur to those skilled in the art, without however, departing from my inventive concepts.

I claim:

1. In an apparatus for heat treating an elongated magnetizable body which includes means for heating successive sections of the body, means for thereafter cooling successive sections of the body and means for varying the amount of heat introduced into the body in the heating means in response to variations in the magnetism affecting properties of successive cooled sections of the body, the combination which comprises a test coil disposable in inductive relationship with successive cooled sections of the body, means for introducing a primary electrical potential into the test coil, means out of inductive relationship with any magnetizable body for creating an electrical potential corresponding in phase and amplitude to that which would be produced in the test coil were a magnetizable body of desired physical characteristics inductively associated therewith, means for opposing a potential in the test coil with said created electrical potential to produce a differential potential and means for changing the amount of heat introduced into the magnetizable body in the heating means in response to variations in said differential potential.
2. In apparatus for heat treating an elongated magnetizable body which includes a heating means, a cooling means, a test coil, a standard coil disposable in inductive relationship with a standard magnetizable body, means for energizing the standard coil with alternating current and means for conveying the magnetizable body successively through the heating means, the cooling means and into inductive relationship with the test coil, the improvement which comprises means for introducing a primary alternating potential into the test coil, means out of inductive relationship with any magnetizable body for creating an electrical potential corresponding in phase and amplitude to a potential in said standard coil, means for opposing a potential in the test coil to the potential thus created to produce a differential potential, and means for varying the amount of heat introduced into the body in the heating means in response to variations in said differential potential.
3. In an apparatus for heat treating an elongated magnetizable body wherein the amount of heat supplied to a portion of the body in a furnace is varied in response to the magnetism affecting properties of portions of the body after heat treatment, the combination which comprises a test coil connected to an alternating current source, means for conveying heat treated portions of the body into inductive relationship with the test coil, a circuit containing means for producing a secondary potential, means for adjusting the phase and amplitude of said secondary potential to correspond to the primary potential which would be set up in the test coil if a heat treated portion of said body having desired physical characteristics were in inductive relationship with the test coil, means for opposing in said circuit a primary potential set up in the test coil with a secondary potential produced by the secondary potential producing means to produce a differential potential, and means for varying the amount of heat supplied to the body in the furnace in response to variations in said differential potential.
4. In an apparatus for heat treating an elongated magnetizable body wherein the amount of

heat supplied to the body in a furnace is varied in response to the magnetism affecting properties of portions of the body after heat treatment, the combination which comprises a test coil adapted to be energized by alternating current, means for conveying heat treated portions of the body into inductive relationship with the test coil, potential producing means for creating an alternating potential to oppose a potential in the test coil, a bridge network, means for opposing the potential of the test coil and the potential created by the potential producing means in the bridge network, a transformer having a plurality of primary coils connected to the bridge network and a secondary coil, a rectifier connected to the secondary coil, a time delay circuit operatively connected with the secondary coil of the transformer, and means for varying the amount of heat supplied to the body in the furnace in response to variations in the output of the rectifier.

5. In an apparatus for heat treating an elongated magnetizable body wherein the amount of heat supplied to the body in a furnace is varied in response to the magnetism affecting properties of portions of the body after heat treatment, the combination which comprises a test coil adapted to be energized by alternating current, means for conveying heat treated portions of the body into inductive relationship with the test coil, means for creating an auxiliary potential, means for varying the phase and amplitude of said auxiliary potential, a bridge network, means for opposing in the bridge network the auxiliary potential with a potential in the test coil, a transformer having a plurality of primary coils connected to the bridge network and a secondary coil, a grid-controlled thermionic valve connected to the secondary coil, and means for varying the amount of heat supplied to portions of the body in the furnace in response to variations in the output of the thermionic valve.

6. In an apparatus for heat treating an elongated magnetizable body including a heating means, a cooling means, control means for automatically varying the amount of heat introduced into the body in the heating means in response to variations in a magnetism affecting property of successive portions of the body which have passed through the cooling means, and means for conveying portions of the body successively through the heating means, the cooling means and the control means, the improvement which comprises means for delaying the action of the control means for a relatively short period of time after a variation in a magnetism affecting property has been detected by said control means.

7. A magnetic analysis apparatus which comprises a test coil disposable in inductive relationship with a magnetizable body, means for energizing said test coil with alternating current, a standard coil disposable in inductive relationship with a standard magnetizable body of known physical character, means for energizing said standard coil with an alternating current, potential-producing means substantially out of inductive relationship with any magnetizable body for producing an electrical potential corresponding in phase and amplitude with a potential set up in said standard coil, a circuit, means for opposing in the circuit a potential in the test coil with a potential produced by the potential-producing means to produce a differential potential, and means for indicating said differential potential.

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