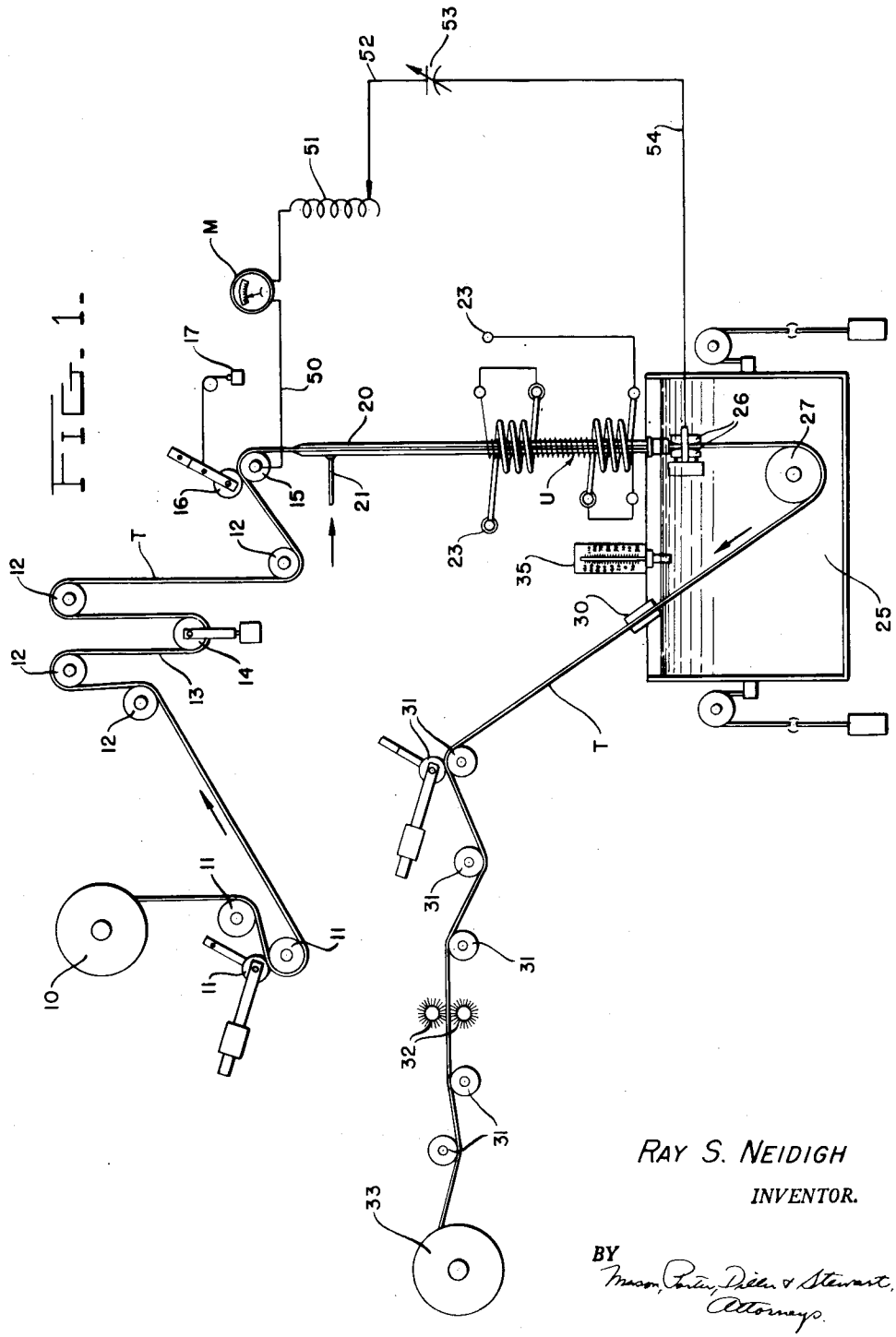
Jan. 22, 1952 R. S. NEIDIGH 2,583,227

INDUCTION HEAT TREATING

Filed Jan. 24, 1947 2 SHEETS--SHEET 1

FIG. 1.



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INDUCTION HEAT TREATING

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FIG. 2.

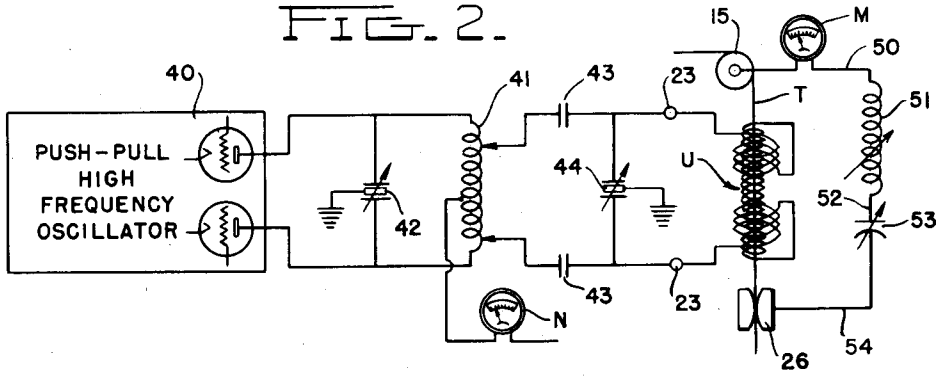
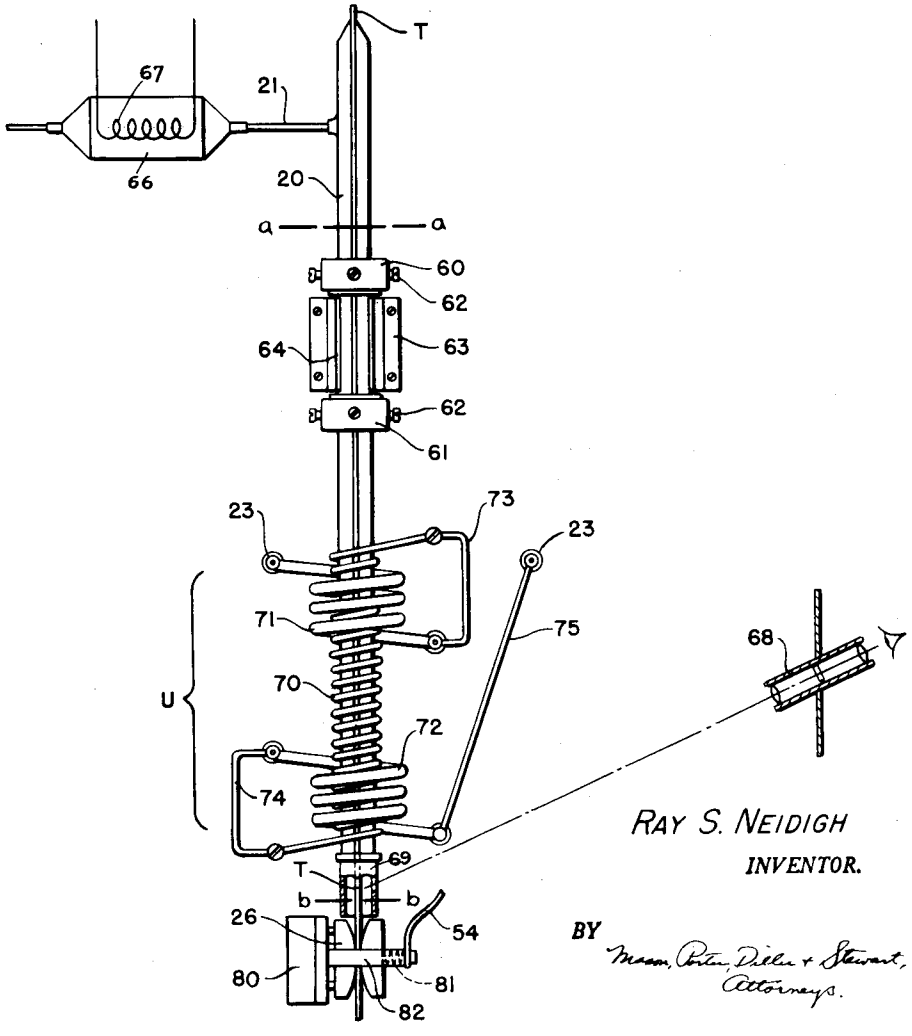


FIG. 3.



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Patented Jan. 22, 1952 2,583,227

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2,583,227

INDUCTION HEAT TREATING

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Application January 24, 1947, Serial No. 723,921

4 Claims. (Cl. 219—47)

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It is well known that various alloys may have their behavior modified by raising them to temperatures at which internal changes occur, and then cooling again under conditions for obtaining the desired characteristics. Among such heat treatments are so-called "annealing" operations, in which an alloy is raised to a temperature at which all internal strains are relieved and internal changes in ferrous alloys occur by which the hardness disappears, and then a slow cooling is used so that these desirable characteristics may be maintained in the article, to permit easy machining, for example. Another heat treating procedure is the so-called "hardening" operation by which a ferrous alloy is heated to obtain a conversion of carbides from one to another, followed by a quick cooling past a critical temperature in order to fix the carbide content in the desired form for producing the hardness. Another type of heat treatment involves the so-called tempering operations, in which an excessively brittle ferrous alloy has its temper drawn to increase the toughness or resistance to fracture, by heating to a closely controlled temperature, which is lower than the temperature utilized for annealing or hardening, and followed by a slow or quick cooling: the course of this "temper drawing" usually being followed by observing the oxidation colors appearing at a cleaned surface of the article. Another type of heating is that incident to working, as where a wire is to be hot-drawn, a skelp or tape to be hot-rolled to thickness or to have hot-forming or hot-punching operations performed thereon, etc.

A factor which must be considered and observed during heat treatment, outside of the production or control of the desired type and distribution of carbides in ferrous alloys, is the size of grains or crystals which are present. Thus, it has been found that prolonged heating of a ferrous alloy to temperatures in excess of 1450° F. is conducive of the development of large grain size, whereas shorter periods of heating or of maintenance at such high temperatures are conducive of maintaining existent small grain sizes. Since small grain sizes are preferable for many purposes, it is often desired to keep the grain size as small as possible, and to avoid having the material exposed to high temperature conditions over long periods of time. However, it has been found difficult in practice to attain this result because the heating is a time function of the rate and quantity of heat which is introduced to the alloy. Thus, when the heat is delivered into the body of the alloy by conduction, convection, and

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radiation methods from external hot bodies, the time required is often great enough to cause serious increase in grain size. When it is sought to heat a ferrous alloy by induction effects of a high frequency electric field, the heating occurs by the resistance of the material to the flow of eddy currents, and by the conversion to heat of the energy losses due to hysteresis in the alloy. Thus, the more magnetic the material, the greater the hysteresis losses, and correspondingly so much the greater is the heating effect by hysteresis. However, when ferrous alloys are heated to a temperature known as the magnetic critical temperature, around 1450° F. for spring steels, there is a change in the material so that its magnetic effects are lost. It is sometimes assumed that this is due to the conversion of magnetizable carbide into forms which do not have magnetic dipoles. The effect of this cessation of magnetic properties is that the hysteresis heating losses cease, and the material is heated under a continuing high frequency field by eddy currents only. If the cross sectional area of the material is large enough, the eddy current heating effects will be large enough to offset the heat losses of the material by conduction and radiation; and hence for articles of large cross sectional area, any desired temperature above the magnetic critical temperature can be obtained by the induction heating principles. With thin articles, such as spring tapes, it has been suggested that the inability to heat to the desired high temperature (e. g. above magnetic critical for steel) is due to cancelling out of magnetic orientations of the material by overlapping of the eddy current fields within the cross-section.

When the cross sectional area of the article to be heated is small, the number of lines of magnetic force through the material is less, and hence the eddy current effects are less. On the other hand, the ratio of superficial area to volume increases with decrease of area of the similarly shaped bodies, so that the heat losses at the surface are relatively increased.

When it is sought to heat tapes of various metal alloys, capable of heat treatment, such as in preparing the springs employed for watches and clocks, the cross sectional shape and area do not encourage the flow of induced eddy currents of such intensity as to permit heating to the temperatures required for heat treatment to obtain optimum conditions of hardness and resistance to wear, and heretofore the induction heating of such thin tapes has been limited to temperatures up to the magnetic critical tempera-

ture of the ferrous alloy or an insufficient temperature with other alloys. In order to have assurance of the desired heat treatment with ferrous alloys, the temperature maximum should not be limited to the magnetic critical; and with these and other alloys, temperatures up to that of fusion should be capable of production at closely determined levels, in order to follow a determined schedule of treatment. On the other hand, the input of energy, as heating effect, should be at a maximum rate, well in excess of heat losses, in order that the length of time at the higher temperatures shall be a minimum, whereby to avoid grain growth.

It has now been found that by employing and controlling certain inherent characteristics of induction fields which have conductive bodies therein, it is possible to carry the temperature to any desired level, even to the production of actual fusing of the tape; and to accomplish this by simple and easily controlled apparatus.

An illustrative form of apparatus, by which the procedure may be practiced, is illustrated on the accompanying drawings in which

Figure 1 is a conventionalized illustration of the assembly of mechanical apparatus.

Figure 2 is a conventionalized showing of the electrical circuit connections for Figure 1.

Figure 3 is a detail view, on a larger scale, of the furnace structures of Figures 1 and 2.

In these drawings, the apparatus and method are illustrated with respect to the heat treatment and quenching of a main spring tape for a watch. In particular, a so-called "8/0 size" tape of watch main spring steel will be employed as a specific example: this particular tape was 0.0044 inch thick and 0.065 inch wide.

A supply reel 10 of such tape delivers its contents through an input measuring and feeding assembly conventionally shown as rollers 11, and over guide rollers 12, with the formation of a depending loop or bight 13 in which is supported a weighted roller 14 and serving to regularize the feeding and tensioning of the tape T as it moves through the furnace. From the last guide roller 12, the tape passes over a guide roller 15 which preferably is of copper for electrically conductive relation with the tape. A pressure roll 16 is pivotally mounted and energized from a counterweight 17 for maintaining the tape in proper guided and conductive relationship with the roller 15.

From the roller 15, the tape passes vertically downward in the illustrated form and enters the upper end of a furnace chamber 20 which in the illustrated form is provided by a glass tubing of temperature-resistant glass, such as "Pyrex." Near the upper end of the furnace tube 20, it is provided with a side branch 21 through which may be introduced carbon dioxide or other inert gas under low pressure. The tube 20 is surrounded by an induction unit U which is described in detail below, and which is supplied with high frequency electric current from the terminals 23, so that a high frequency induction field acts upon the tape T as it moves downwardly in the furnace tube 20.

The lower end of the tube is illustrated as immersed in a quenching bath 25, for example, for one-half inch. Immediately below the lower end of the tube are the guide blocks 26 which press against the two faces of the tape and maintain electrical conductive relationship therewith. The tape T passes around the lower guide roller 27 within the quenching bath, and thence travels upwardly through a wiper 30 which strips adherent liquid from the tape, and thence over the outlet metering unit conventionalized as the rolls 31, and thence over other guide rolls and between the cleaning brushes 32, and finally the tape is rewound on a take-up reel 33.

A thermometer 35 is provided for observing the temperature in the quenching bath 25, and appropriate means (not shown) may be provided for maintaining the bath at a desired temperature. The bath may be of rape seed or other quenching oil, water, or like material, depending upon the selected hardening conditions. The bath may be supported by a counterweight system; and lowered while threading the tape, or when a quenching is not desired.

In Figure 2, the electrical supply system to the terminals 23 of Figure 1 is illustrated as comprising a high frequency oscillator 40 which is conventionalized as two electron discharge tubes. The anodes of these tubes are connected to the tank inductance 41 in parallel with the tuning condenser 42 which is illustrated as a three-section variable condenser with its central or rotatable plates grounded. It will be understood that when the oscillator is in service, the output circuit elements 41, 42 are tuned to the frequency of the oscillator 40, whereby potential differences are established in the inductor 41 in the usual way. Thus, the resonant combination of inductance 41 and capacitance 42 may be regarded as a primary output circuit. A secondary output circuit is connected to the inductor 41 by appropriate adjustable taps and includes the blocking condenser 43 to prevent direct current flow, and the variable three-section tuning condenser 44. The condensers 43, 44 and the portion of inductor 41 between the adjustable taps, are likewise tuned during operation essentially to resonance with the current flowing in the oscillator 40. The potential differences appearing across the outer terminals of the condenser 44, whose central movable plates are grounded, appears at the terminals 23 and acts in the furnace induction unit U as aforesaid.

It has been found that the tape T demonstrates potential differences along its length, when current flows in the induction unit U. A conductor 50 leads to an adjustable inductor 51, whose other terminal is connected by conductor 52 with a variable condenser 53. This condenser 53 in turn is connected by a conductor 54 with the contact blocks 26. It is preferred to include a meter M, such as a hot-wire ammeter, in this external or third circuit which comprises a series connection of the portion of the tape T including that which is within the furnace tube 20, the upper conductive contact roll 15, conductor 50 with the meter M, conductor 51, conductor 52, condenser 53, conductor 54, and the submerged lower contact blocks 26 back to the tape T. The effect of potential differences along the length of the tape T, which are in synchronism with the high frequency current from the oscillator 40 but not necessarily in phase coincidence, are thus apparent across the tunable elements 51, 53; and when these elements are adjusted into essential resonance to the oscillator frequency, the potential differences lead to the exhibition of high current densities in this third circuit.

In Figure 3, a preferred form of furnace unit is illustrated. The glass furnace tube 20 is supported and guided by the upper and lower heads 60, 61, which have adjusting screws 62 therein. These heads in turn are supported on a bracket

63 and are held spaced by an outer larger fibre tube 64. This figure also shows a chamber 66 connected in the gas supply conduit 21, with a wire heating coil 67 therein supplied by 60 cycle alternating current and serving to preheat the gas before it contacts the tape. Also, the optical pyrometer 68 is mounted so that the tape T is observed at a point about one inch above the oil level. An opaque tube 69 of non-conductive material is mounted around the lower end of tube 20, and has a window through which the hot tape may be viewed under black body conditions.

The tube 20 of heat-resistant glass had internal and external diameters of 0.68 and 0.78 inch, the wall thickness being 0.05 inch, the tube was 25 inches long. In operation, the distance from the upper end of the tube to the line *a*—*a* (Fig. 3) was about 6½ inches, and from line *a*—*a* to the upper end of coil 70 was about 8½ inches. The tube was immersed for about a half inch in the oil bath at its lower end. Surrounding the tube 20 beneath its support, is the inductor unit U, which is illustrated in a preferred form which has a total length of 8 inches and comprises a winding 70 of 23 turns of No. 6 copper wire to form a coil wound over the tube 20 for a total length of 8 inches. Immediately at the upper and lower ends of this coil are provided three turns each of 0.25 inch outside diameter copper tubing, wound in a coil of 3 inches outside diameter and length of 1.5 inches. The upper end of the upper large winding 71 is connected to one supply terminal 23, while the lower end thereof is connected by conductor 73 with the upper end of the winding 70. The lower end of the winding 70 is connected by conductor 74 with the upper end of the lower copper winding 72, and the lower end of the winding 72 is connected by the conductor 75 with the other terminal 23. This arrangement provides a total inductance of the series-connected windings 70, 71, 72 so that the condenser 44 can establish a resonant condition to the primary circuit. The arrangement has been found to provide an accurate impedance matching. These conditions exist when the electrical system is energized in the absence of steel tape T; e. g. with a copper wire or tape. Pre-adjustments may be required when the tape is introduced, and also after the system is in steady moving condition, to compensate the effect of the tape in changing the apparent inductance effect reflected by it into the driving system.

Figure 3 also shows the supporting member 80 for mounting the lower contact blocks 26. One of these blocks, adjacent the member 80, may be fixed, and the other block biased for conductive contact with the tape by the action of the spring 81 carried by the yoke 82.

In assembly, attention should be given to the grounding of metal parts of the structure, and adjacent metal. Thus, the feed reel 10, and the feed drive including rolls 11, 12, are electrically connected to one another and to rolls 31 and the take-up reel 33 (the conductors not being shown), and this reel 33 is connected to the ground. The primary and secondary circuits are also grounded through the tuning condensers 42, 44. It was found that the current demand at the meter N was reduced 50 to 100 milliamperes with the particular oscillator when this grounding was completed: and that standing waves appeared to be eliminated.

In operation, the liquid level in Figure 3 is

preferably at substantially the line *b*—*b*, and it has been found that a desirable heating for hardening and quenching can be effected when the tape first begins essentially to increase in temperature at about the line *a*—*a* of Figure 3.

In one practice, the vertical distance between lines *a*—*a* and *b*—*b* was 19 inches. The power input to the high frequency generator was 1 kilowatt and the tape T was of 8/0 size and was moved through the furnace tube 20 at a rate of 60 feet per minute. Upon observation by pyrometer, the tape had a temperature of 1400° F. at a point 11½ inches above the oil surface; 1425° F. at a point 6 inches above the surface; and 1450° F. at 1 inch above the surface. The measured current in the third circuit, at the meter M, was 9 amperes. The frequency generated in the oscillator 40 was about 7½ megacycles. When the third circuit was opened, a temperature in excess of the magnetic critical could not be exceeded, and the load conditions on the generator changed, indicated by a drop in the plate current.

In particular, it was found that when this size of tape was employed, and the speed reduced to 40 feet per minute, the flow of a current of over 10 amperes as indicated at the meter M would cause the tape to melt. This current was obtained by adjusting the condenser 53 more closely to circuit resonance.

Carbon dioxide gas under low pressure was admitted through the connection 21. The upper end of the tube 20 was circular, with an opening of 0.10 inch; a rectangular opening 0.01 x 0.09 inch has also been employed. It was found that the gas was carried along with this tape, and caused to bubble from the lower end of the tube 20 following heating by radiation and conduction from the tape T.

It is found that within a few seconds after starting from room temperature of all parts, the tape increases in temperature as it travels, until the desired illustrative top temperature of 1450° F. is reached, and thereafter the currents flowing in the several circuits remain essentially constant as long as the speed of the tape remains constant. The temperature of the glass tube gradually rises, and reaches a fixed temperature in about 20 minutes. In a test of the temperature of the glass furnace tube 20 at the center of the tube, it was found to be approximately 550° F. by a thermo-junction-pyrometer, but the leads from this pyrometer passed through the conductive field, so that this reading was probably too high.

This same apparatus has been employed successfully for the heat treatment of main spring tapes ranging in size from 0.0035 inch thick by 0.05 inch wide to 0.095 inch thick by 0.22 inch wide; with speeds of travel of, say, 5 to 80 feet per minute dependent upon the size and shape of the tape and upon the power available. The generator has been operated, for such work, with inputs of 100 to 1500 watts and at frequencies of 4 to 10 megacycles. Obviously, apparatus of different size or power, and operating at other high frequencies can be employed. In particular, it has been found that the operation can be so conducted that the tape is quickly raised at an essentially regular rate during its travel between the lines *a*—*a* and *b*—*b*, so that when a quenching is employed by use of a bath 25, this quenching is accomplished while the temperature is still rising, so to speak, and thus the time during which the tape is subjected to temperatures

above room temperature is restricted only by the delivery of a sufficient quantity of energy into the tape for conversion therein to the form of heat, and further it is possible to effect the quenching while the tape is still rising in temperature, so to speak.

In making tapes for main springs of watch movements, using the normal steels customary for the purpose, it has been found feasible to produce desired conditions along great lengths of the material and with essential uniformity. Because of the close controls which are possible, it has been found preferable for such main spring tapes to use a heat treatment which is terminated while undissolved carbide grains are still present, as this gives a better wear resistance than when all of the carbon is in essentially uniform solution. Thus, the heating is to a temperature and for a time short of that at which the maximum hardness would be produced by effecting dissolution of all carbide, followed by a quenching. This preferred choice of condition is feasible with the disclosed procedure, for the reason that the ferrous alloy is carried quickly from room temperature to the desired quenching temperature without lag or delay at the temperature corresponding to loss of magnetic properties. The time of exposure to heating is favorable in that the carbide tends to dissolve more quickly than grain growth occurs. The existence of the small grains of undissolved carbide, as revealed in metallographic studies, appears to limit and greatly restrain grain growth.

It is preferred to employ an upper contact roller **15** of copper or like material, so that this structure can rotate with essential freedom. On the other hand, it is preferred to form the lower contact elements **26** as pressure blocks or contact shoes located close below the surface of the quenching bath, when quenching is to be accomplished. These shoes act as guides for smoothing out and controlling tape warpage. They may be of steel or other metal affording adequate resistance to wear under the conditions of operation and serving to impart a chill block quenching to the tape, in addition to the oil quenching which is accomplished thereupon. Thus, the surface of the tape is quickly fixed in the desired condition for optimum wear resistance. In operation, the hot tape vaporizes the oil or other liquid of the quenching bath, immediately upon contact and is thereby given a primary cooling. By having the contact shoes **26** close to the surface of the quenching bath, the vapor blanket is continued around the tape until this hot tape comes into contact with the shoes, so that a very good electrical contact is thus established and maintained.

The frequency of the primary oscillator is adjusted to the effective distance between the upper contact roller **15** and the lower contact blocks **26**, so that these points are essentially an electrical half-wave apart. The action of the tuning condenser **53** and inductance **51** thus controls the relative phase conditions, wherewith the current nodes are close to the said contacts, considering the tape itself as a Lecher wire, so that essentially no tendency to current arcing is present. In practice, currents up to 25 amperes have been passed along a carbon steel ribbon without burning the contacts or ribbon surface. Correspondingly, the current loop, or maximum current effort at the tape, is at a point of the tape within the inductive heating field.

By way of demonstration of the effect of the flow of current through the external circuit including the tuning elements **51**, **53**, it may be pointed out that when this circuit is open, or is tuned greatly out of resonance with the current from the oscillator **40**, the tape does not become incandescent until it has traveled downward for about one-half of the length of the coil **70** of the furnace unit U, as compared with its attaining incandescence at the line *a—a*.

While magnetic or inductive coupling may be employed between the primary or secondary circuits and the inductor **51** or other component of the third or external circuit, it has been found that this is unnecessary, and that a more satisfactory control can be attained by the derivation of current flow along the tape as an incident of the magnetic, current and heat effects therein produced from the furnace induction windings **70**, **71**, **72**, with employment of the tuning elements **51**, **53** to adjust this external circuit to essential resonance and thereby determine a current flow as indicated by the meter M, which brings the tape quickly and with constantly rising temperature to the desired condition of upper critical temperature at the moment of its contact with the quenching bath. Thus, if the tape becomes undesirably overheated, a slight detuning permits quick correction for this: while an insufficient heating is corrected by the converse operation of bringing the external circuit more closely into resonance.

In the illustrative employment above, the admission of carbon dioxide was set out. This gas can be employed under such conditions, provided that it is pure: that is, the commercial gas should be so pure that it contains less than 1 percent of gaseous impurities, largely hydrogen and nitrogen, insoluble in KOH, and at most only traces of water vapor. If the commercial carbon dioxide gas is suspect, it should be passed through an externally heated tube containing steel and copper wools, and over caustic alkali, to decompose and fix the sulphur gases, water vapor, etc. The rate of feed with the stated apparatus was varied from 30 to 50 cubic feet per minute without essential change in behavior. Obviously, rare gases, such as helium, argon, etc., are not troublesome, can be voluntarily added: their cost, however, is not normally justified in treating carbon steels as stated.

The use of carbon dioxide atmosphere, as compared with air, has an advantage even with ribbon materials which are not attacked by air, in that less injurious arcing occurs at the lower contacts upon detuning.

It is obvious that the invention is not limited to the specific embodiment illustrated and described, but that it may be employed in many ways within the scope of the appended claims.

What is claimed is:

1. An apparatus for heat-treatment of long conductive articles, comprising an induction coil through which the article may be moved in the axial direction, means for supplying high frequency current to said coil, and separate circuit means including at least a part of the article as a series conductor portion of the circuit and including also a device in said circuit means to tune said separate circuit to the condition of essential resonance at the frequency of the current flowing in said coil.

2. An apparatus for heat treatment of a conductive tape, comprising an induction coil, means for feeding the tape along the axis of the induction coil, contacts adjacent each end of the

coil for conductive engagement with the tape, means of supplying high frequency current to said coil at a frequency whose half-wave length is essentially the same as the distance between said contacts, and conductive means connecting said contacts and including a tuning device for establishing said contacts essentially at the current nodes.

3. A high frequency induction heating unit for long metal articles comprising a main hollow coil of conductive material along the axis of which the article can be passed, and additional windings of large diameter located around the ends of the main windings, said coil and windings being connected in series for establishing individual magnetic fields all extending in the same direction along the axis, means for supplying high frequency current to said coil and windings, means effective for bringing the series-connected coil and windings into resonance with the said supplied current in the presence of the article, contacts located outside said coil and windings for electrically engaging parts of said article while other parts of said article are within the coil and windings, conductive means separate from said coil and windings and supplying means, said separate conductive means being connected to said contacts whereby a separate circuit is established including parts of the article located within the coil and windings, and a device in said separate conductive means effective to tune said separate circuit essentially to resonance with said supplied current.

4. An apparatus for heat-treatment of long conductive articles, comprising an induction coil through which the article may be moved in the axial direction, means for supplying high frequency current to said coil whereby to induce a high frequency magnetic field in at least a part of the length of the article, electrical contact members to engage with the article and spaced essentially an electrical half-wave apart at said current frequency, and high frequency conductor means connecting said conductor members to form an electrical circuit including said part of the article and including the said conductor means connected in series with said part, the electrical constants of said conductor means having values at which said circuit is essentially in the condition of resonance at the frequency of the current flowing in said coil and with said contact members at current nodes of said circuit.

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