April 6, 1971 W. C. RUDD 3,574,005

METHOD FOR HEAT TREATING WIRE OR THE LIKE

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Fig. 1.

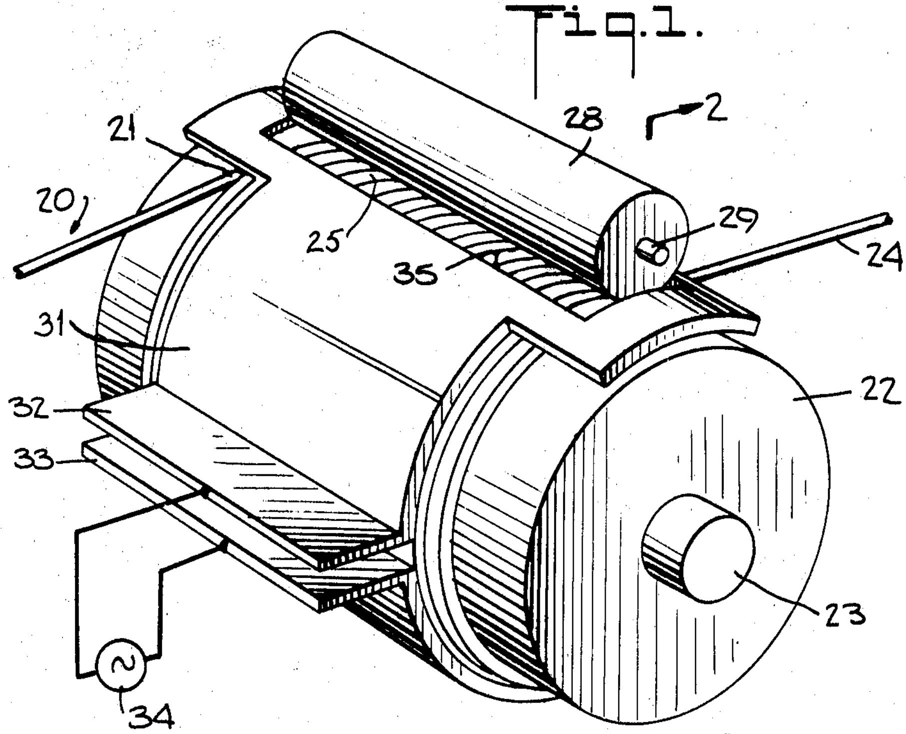

Fig. 2.

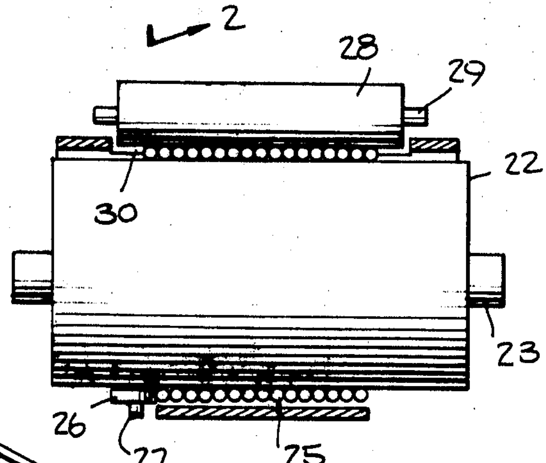

Fig. 3.

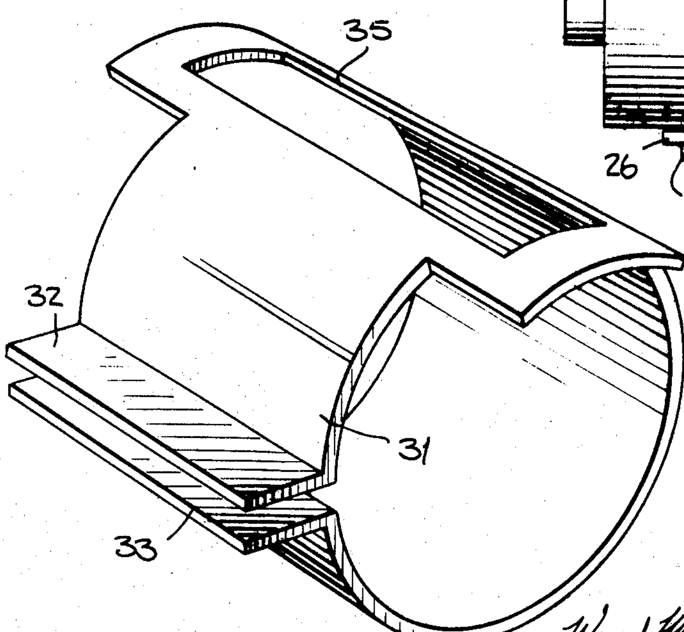

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Fig. 4.

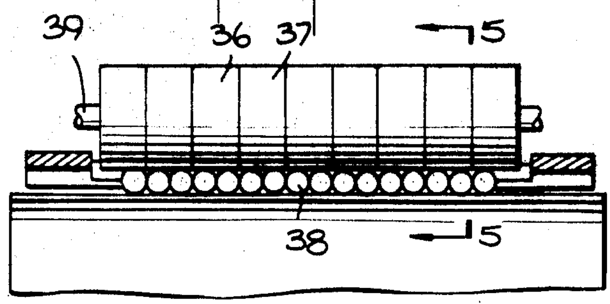


Fig. 5.

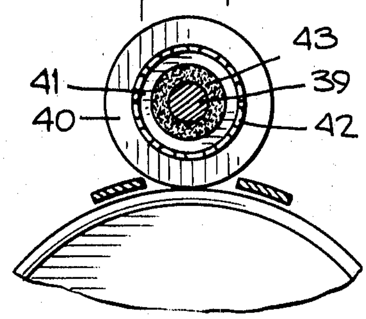


Fig. 6.

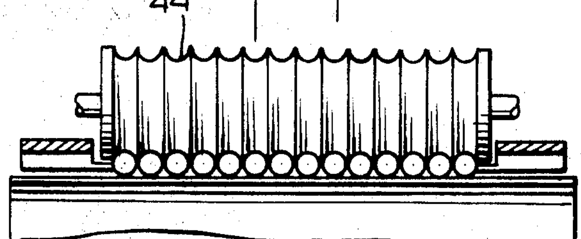


Fig. 7.

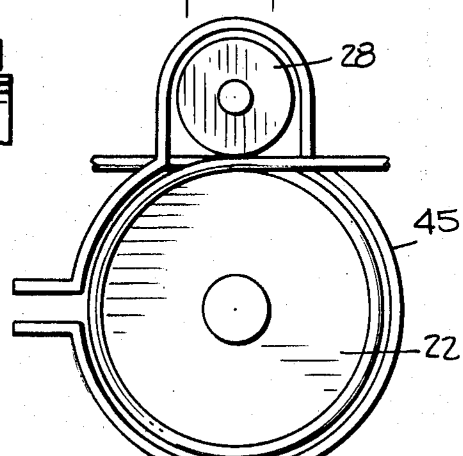


Fig. 8.

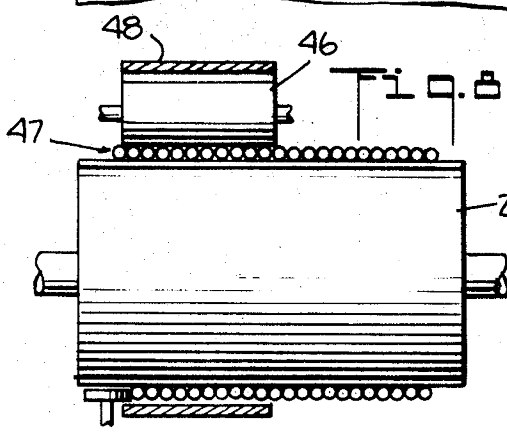


Fig. 10.

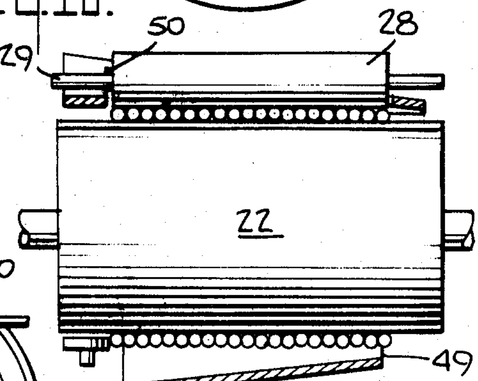


Fig. 9.

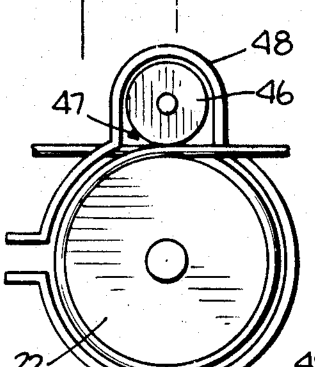
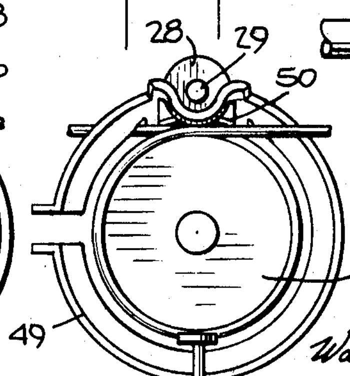


Fig. 11.



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METHOD FOR HEAT TREATING WIRE OR THE LIKE

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Int. Cl. C21d *1/42*
U.S. Cl. 148—150 4 Claims

ABSTRACT OF THE DISCLOSURE

Various arrangments and methods are described for electrically heating a rapidly traveling wire as it proceeds along a helical path around a guide roll. A pressure roll structure cooperates with the guide roll to maintain adjacent turns of the helix in intimate contact where required or in contact with itself and the guide roll. One, or both, or neither, of the roll members may have at least an electrically conductive surface for providing a path for bridging currents between the helical turns of the wire. The pressure roll structure may be segmented and floatingly mounted. The induction coil may be non-uniform in diameter to provide control of the heat generated over different portions of the wire helix.

The present invention relates to high speed heat treatment of metal in continuous form. More specifically, it relates to apparatus and methods for heat treating wire or metal ribbon for such purposes as forming, annealing or hardening.

In general, it is desirable that the heat treatment be performed while the wire or ribbon is being transported at high speed from a source of supply to a take-up or utilization device. While this might not seem to present a problem, the contrary is actually the case.

Considerable thermal energy must be generated in the metal to produce the desired temperature. Usually, space is limited and it becomes necessary to produce such thermal energy within the confines of such space restriction.

All materials change physical dimension when heated, and as the temperature of wire or metal ribbon is raised it will expand substantially in the longitudinal direction. At the same time, it loses tensile strength. Slack that is developed by the expansion must be taken up without unduly straining the softened material.

Where heat is produced by the passage of electric currents through zones of the wire or ribbon, cognizance must also be taken of the change in electrical resistance that occurs as the temperature increases, and of its effect upon the production of thermal energy. This is particularly significant and can pose a major problem in the heat treatment of iron or magnetic steel. When these materials are heated above the Curie point the slope of the resistivity versus temperature characteristic changes abruptly.

The problem is further complicated when it is desired to use high frequency current for electric heating. Skin effects or penetration phenomena are encountered. Changes in resistance are now even more significant. In addition, the relative permeability of the metal becomes a significant factor and, as is well known, the permeability of steel decreases abruptly when its temperature exceeds its Curie point.

The penetration problem in heat treating metal with high frequency currents and its control is discussed in detail in Letters Pat. No. 3,037,105 issued May 29, 1962 on an application of Fred Kohler and assigned to the same assignee as the present application. In summary, it can be stated that when a current of high frequency is caused to flow in a conductor of comparatively large cross-section, the conductor appears to present more resistance to its flow than it does to a direct current. The increase is due to E.M.F.'s which are set up by variations of magnetic flux within the conductor itself. These crowd the current toward the surface. The depth of penetration of the current in the conductor is a direct function of the resistivity of the conductor and an inverse function of both the relative permeability and the frequency.

Mention has been made separately of the change in resistance with temperature and the change in permeability with temperature. It can also be appreciated that an interrelationship exists which further complicates the problem. Thus, consider the application of electrodes to a magnetic steel wire. Assume that an alternating current source is coupled to the electrodes to cause current to flow through the wire between the electrodes and that the frequency is high enough to produce a significant skin effect. The current will be crowded towards the surface of the wire and the effective resistance as seen by the electrodes and source will be greater than the D.C. resistance.

Heat will be produced in the wire in accordance with the well known I^2R law. But as the wire temperature increases so does the resistance. All other factors remaining constant, this would result in a proportional decrease in current (it is assumed that the source voltage remains constant) and a decrease in the amount of heat generated. However, the resistance affects the penetration depth with the depth increasing as a function of the square root of the resistance, or more accurately the resistivity. The current distributes through a greater volume of the wire and the apparent resistance is thereby altered with its concomitant effect upon the current and so forth. Fortunately, below the Curie point the variation with temperature tends to be gradual. But when the Curie point temperature is exceeded there is an abrupt change in relative permeability causing an abrupt change in penetration depth with its associated change in effective resistance, change in current flow, and change in heat generation. Add to this the abrupt change in slope of the resistance characteristic and it can be seen that extremely precise control is necessary to provide any degree of control over the heat treatment given to the wire.

Because it avoids contact problems, electrical induction heating is often more desirable than electrical conduction heating. However, if an attempt is made to heat a small piece of wire by passing the wire coaxially through an induction coil, difficult loading problems are encountered. It is difficult to induce a large amount of power into the wire because of the limited depth of penetration of the current. For example, at 10,000 c.p.s. the wire diameter must exceed ½ inch before any appreciable power can be induced in it. Even at a frequency of 500 KC severe problems are encountered with diameters less than ¼ inch.

It has been suggested, heretofore, that wire can be heat treated by winding it on and off a mandrel to form a helix thereon and inducing electric current therein from a primary coil associated with the mandrel. As the mandrel is rotated, the wire is wound on one end and off the other end. However, the method has certain problems associated with it.

For the mandrel and helix method to merely function some conductive connection must be established between adjacent turns of the helix to permit the currents to bridge or jump from turn to turn at some point in circling the helix concentric with its axis. If the method is to be used for controlled heating of wire traveling over the mandrel at high speed, not only must contact be established between adjacent turns but such contact must be maintained uniform from turn to turn. Contact resistances must remain as constant as possible and should not vary from contact to contact. The length of turn between adjacent-turn contact should be controlled precisely. If uniform contact is not maintained, arcing may develop, burning the wire and interfering with uniform and controlled heat generation. Variation in contact resistance, either with or without arcing, alters the load on the power source with concomitant current change and heat variation. Therefore it should be evident that before this method can be put to practical use any tendency of the turns to separate, due to the flow of currents in the same direction in side-by-side turns (a significant phenomenon with heavy gauge wire) must be counteracted. Alternatively, the need for actual engagement between adjacent turns must be eliminated. Similarly, as the wire expands due to heating, the slack must be absorbed without applying sufficient force to the wire to deform it in its softened state, all with a view toward maintaining uniform electrical connection between the turns.

It is, therefore, an object of the present invention to provide apparatus and methods for overcoming the disadvantages enumerated above in the above described type of rapid heat treatment of wire or the like.

In accordance with an aspect of the invention there is provided a method of heat treating wire or the like which comprises the steps of feeding the wire to be treated into one end of a nip formed between a pressure roll and a guide roll mounted for rotation about substantially parallel axes, conveying the wire around a helical path passing through the nip once each turn then away from the nip near the other end thereof after a predetermined number of turns, moving the wire from the one end toward the other end of the nip while it traverses the helical path as additional wire is fed into the nip at the one end, pressing the rolls toward each other to confine the wire in the nip to establish and maintain uniform electrically conductive connections between adjacent turns at least in the region of the nip, and supplying high frequency electrical heating current to the wire while the wire traverses the helical path.

The invention will be better understood after reading the following detailed description of various embodiments thereof with reference to the appended drawings in which:

FIG. 1 is a perspective diagrammatic view illustrating one preferred form of the apparatus;

FIG. 2 is a sectional view taken along line 2—2 in FIG. 1;

FIG. 3 is a perspective view of the induction coil employed in the apparatus of FIGS. 1 and 2;

FIG. 4 is a fragmentary view similar to FIG. 2, showing a modification of the pressure roll therein;

FIG. 5 is a sectional view taken along the line 5—5 in FIG. 4;

FIG. 6 is a view similar to FIG. 4 showing a further modification of the invention;

FIG. 7 is an end view of apparatus similar to that of FIG. 1 showing a modified form of the induction coil;

FIG. 8 is a view similar to FIG. 2 showing a further modification of the invention;

FIG. 9 is an end view of the structure in FIG. 8;

FIG. 10 is a view similar to FIG. 8 showing a still further embodiment of the invention; and

FIG. 11 is an end view of the structure in FIG. 10.

Throughout the drawings the same reference numerals will be employed to designate the same or similar part.

Reference should now be had to FIGS. 1 to 3. There is shown therein an arrangement requiring comparatively little space for heating wire while it is traveling at a very high rate of speed. The wire to be heat treated is designated generally by the numeral **20** and is fed at **21** onto a metal drum **22** mounted for rotation about a shaft or axis **23**. After making a number of turns about the drum

22, the end of the wire, **24**, is withdrawn by known means not shown. As the end **24** of the wire is withdrawn, the drum **22** rotates, and the turns of wire **25** work themselves across the drum in "screw" fashion. A reaction roll **26**, best seen in FIG. 2, provides a reaction surface forcing the wire as it winds upon the drum to move away from the roll **26** toward the opposite end of the drum **22**. The reaction roll **26** may be mounted for rotation about a shaft **27**.

In order to ensure electric connection between adjacent turns of the wire while on the drum, there is provided a pressure roll **28** mounted for rotation about an axis or shaft **29** mounted parallel to the shaft **23** of the drum **22**. As best seen in FIG. 2, a nip **30** is formed between the pressure roll **28** and the metal drum **22**. The metal drum may be considered as a guide roll for the wire. The pressure roll **28** may be formed from either hard or soft material, conductive or insulating, depending upon the working temperature of the wire being treated and the current penetration and heat generation in the pressure roll itself.

In order to supply current to the helical section of the wire being treated, there is provided a single turn induction coil **31** having end terminals **32** and **33** to which a source of high frequency current **34** is connected, as shown. In the embodiment now being described with reference to FIGS. 1, 2 and 3, it is assumed that the pressure roll **28** is electrically conductive. In order to avoid inducing heat generating current in the electrically conductive pressure roll **28**, the induction coil **31** is provided with an aperture or slot **35** permitting the pressure roll to engage the wire being treated while remaining essentially outside of the magnetic field created by the induction coil.

By making the drum **22** reasonably large in diameter it is possible to induce very large currents into the helical turns **25** of the wire being treated. The generator **34** may operate at frequencies ranging from about 960 cycles to 500,000 cycles per second for best results. If a sufficiently large drum can be employed, current having a frequency as low as 60 cycles may be employed. Essentially, the frequency should be chosen so that the depth of penetration of the current, as explained above, is such that almost all of the current flows in the thickness of the wire layer around the drum **22** and very little current flows in the drum itself. The drum should be arranged to conduct current only to the extent necessary to ensure electric cross-over between adjacent turns.

To illustrate the effect of frequency, for a ¼ inch diameter steel wire heated above the Curie point, the depth of current penetration would be about ¼ inch at 10,000 cycles. Therefore, 10,000 cycles can be used satisfactorily. As another example, steel wire of 0.040 inch diameter can be heated above the Curie point using 500,000 cycles as the frequency of the source since the depth of penetration above the Curie point at this frequency is about 0.030 inch.

When the drum **22** is conductive, the induced current in the wire being treated crosses from turn to turn by contact both between the turns and through the metal drum. In addiion, if the depth of penetration of the high frequency current is greater than the diameter of the wire, some current is induced directly in the drum. Under certain conditions, the flow of current in the drum may prove a problem and can be avoided by making the drum of insulating material such as porcelain, Steatite, or Pyrex glass. In this case, the induced current is restricted to flow only in the wire layer. However, by virtue of the restraint provided by the pressure roll **28**, either or both of the following conditions may be established to provide for uniform cross-over current: (a) adjacent turns of the wire are maintained in intimate contact; (b) the cross-over current is caused to flow through the conductive surface layer of the pressure roll where it engages the wire.

A unitary pressure roll such as the roll **28** in FIG. 1 may not be able to provide the necessary restraint for or contact with the turns of wire if the diameter of the wire should vary or for other reasons. Under such circumstances, it may be preferred to employ a pressure roll constructed as shown in FIG. 4. As seen therein, the pressure roll is subdivided into a plurality of individual adjacent roll segments, such as segments **36** and **37**, arranged for independent rotation. Each segment has an axial length equal substantially to twice the diameter of the wire **38**. As seen in FIG. 5, the segments of the pressure roll of FIG. 4 are mounted on a unitary shaft **39** with each roll segment comprising a radial outer element **40** and an inner element **41** separated by an anti-friction bearing **42**. A layer of elastomeric material **43** is disposed between the shaft **39** and the inner element **41**. By virtue of this construction, the individual roll segments are able to float and adapt to variations in wire diameter. A further advantage of the individual roll segments is that the wire can slip around faster without frictional resistance as it lengthens with heat and progresses along the drum because each roll segment can turn independently.

The arrangement shown with reference to FIGS. 4 and 5 is well suited to the handling of small diameter wire, say, for example, less than ⅛ inch in diameter. Where larger diameter wire is to be heat treated, it will be found advantageous to employ the modification shown in FIG. 6. As shown therein, there is a separate independent roll segment, such as the segment **44**, for each passage of the wire through the nip. The axial extent of each roll segment is equal to the diameter of the wire. In addition, each roll segment is provided with a peripheral groove for receiving and guiding the wire. In all other respects, the segments of the pressure roll in FIG. 6 may be identical to those shown in FIGS. 4 and 5. That is, the segments may be resiliently mounted for friction free rotation and floating action.

It is to be understood that the modifications described above with reference to FIGS. 4, 5 and 6 relate to the construction of the pressure roll. The remainder of the apparatus may be the same as that shown in FIGS. 1, 2 and 3. On the other hand, where the pressure roll is nonconductive to electricity, it is possible to employ an alternative induction coil construction as shown in FIG. 7. As shown therein, the coil **45** encircles in close proximity the guide roll or drum **22** with the wire wrapped therearound. In addition, the coil **45** extends over and around in close proximity to the pressure roll **28**. The roll **28** is used merely as an example since any of the modified roll constructions can be employed.

The various embodiments described to this point employ a pressure roll having a length substantially equal to the length of the drum or guide roll. In addition, the width of the induction coil approximates the width of the helix formed by the wire wrapped upon the drum. Consequently, during operation of the device, heat is generated within the entire region of the helix. There are instances, however, where it is desirable to place a utilization device immediately after the heating station. An example is the situation where the wire is annealed immediately prior to drawing. Since the space between the drawing dies is limited, the heating and cooling steps of annealing must be compressed into a restricted area. This can be handled readily with the construction shown in FIGS. 8 and 9.

As best seen in FIG. 8, the pressure roll **46** is shorter than the guide roll **22** developing a nip **47** along only a part of the length of the guide roll. The helical path of the wire, however, extends both throughout the nip **47** and for a substantial distance beyond on the guide roll **22**. The induction coil **48**, here shown as extending around both the guide roll and the pressure roll, has an axial length substantially equal to the nip **47**. Thus, the wire is heated while it traverses the helical path coinciding with the nip **47** and cools while it traverses the remainder of the helical path. Cooling of the wire may be accomplished either by radiation to the atmosphere or by positive cooling with a quenching medium.

When wire is heated by the apparatus described herein, the resistance of the wire will increase with temperature. In addition, the wire will radiate more thermal energy as its temperature increases and, of course, with magnetic steel as noted above there exists the Curie point problem. Therefore, circumstances may arise requiring that power be introduced to the wire at varying rates from one end to the other end of the helix. For this purpose, the induction coil may be tapered as shown by the coil **49** in FIGS. 10 and 11. By making the diameter of the coil **49** smaller at the take-off end of the drum where the wire is hottest, maximum energy can be induced at this end with lesser energy induced at the point of entry. This arrangement is useful wherever the rate of temperature rise must be controlled for radiation, metallurgical, or other reasons. As shown in FIGS. 10 and 11, the coil is provided with an aperture **50** through which the pressure roll, for example the roll **28**, may extend. As best seen in FIG. 11, the larger diameter end of the coil which bypasses the end of the pressure roll is provided with a dip to clear the roll shaft **29**. Of course, if the pressure roll **28** is made of non-conductive material, the coil may extend around the roll as shown in FIG. 7.

What is claimed is:

1. The method of heat treating wire or the like comprising the steps of feeding the wire to be treated into one end of a nip formed between a pressure roll and a guide roll mounted for rotation about substantially parallel axes, conveying the wire around a helical path, the wire passing through said nip once each turn then away from said nip near the other end thereof after a predetermined number of turns, moving said wire from said one end toward said other end of the nip while it traverses said helical path as additional wire is fed into said nip at said one end, pressing said rolls toward each other to confine said wire in the nip to establish and maintain uniform electrically conductive connections between adjacent turns at least in the region of said nip, and supplying high frequency electrical heating current to said wire while the wire traverses said helical path.

2. The method according to claim **1**, wherein said high frequency current is supplied to said wire by means comprising an induction coil substantially encircling but spaced from said guide roll, and wherein said wire is fed to the nip so as to provide a substantially continuous layer of abutting turns intermediate the face of said guide roll engaging said turns and substantially all of the face of said coil nearest said guide roll, and wherein the frequency of said current is selected so as to provide a penetration depth in the metal of said wire substantially equal to the thickness of said wire.

3. The method according to claim **1**, wherein said high frequency current is supplied to said wire with varying power at different points along said helical path for controlling the heating therealong.

4. The method according to claim **1**, wherein the wire is conveyed around a continuation of the helical path after it leaves the nip, and wherein said high frequency current is supplied to the wire between the time it is fed to and leaves the nip, and wherein the wire is cooled after it leaves the nip and while it traverses the continuation of the helical path.

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RICHARD O. DEAN, Primary Examiner

U.S. Cl. X.R.

148—154; 219—10.41, 10.43