April 15, 1947. B. CASSEN ET AL 2,419,116

APPARATUS FOR HIGH-FREQUENCY INDUCTION HEATING OF STRIPS

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Fig. 1.

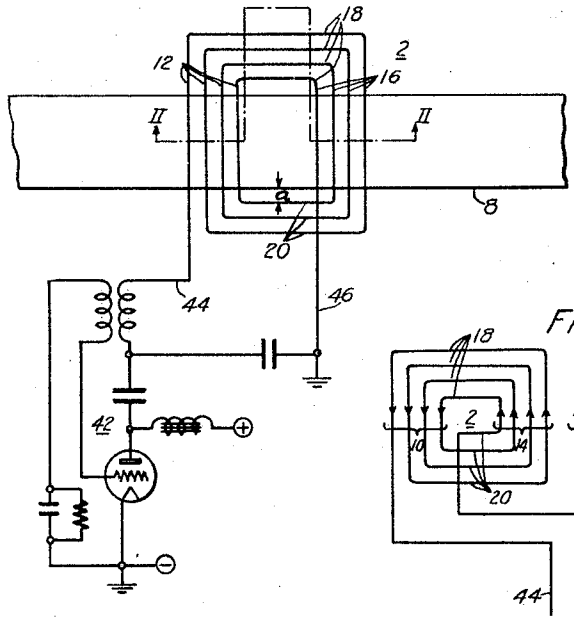


Fig. 3.

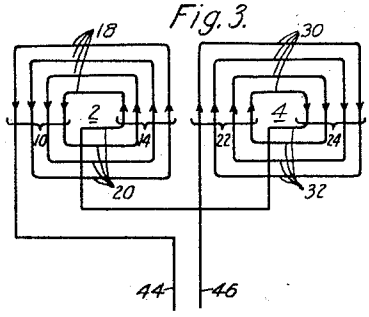


Fig. 2.

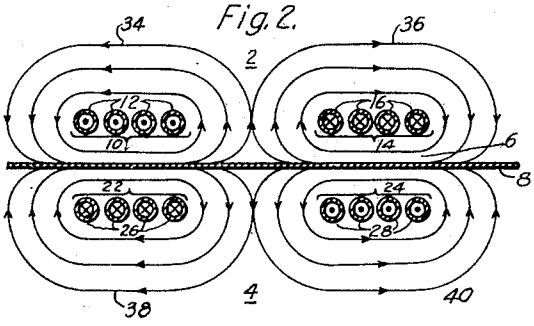


Fig. 4.

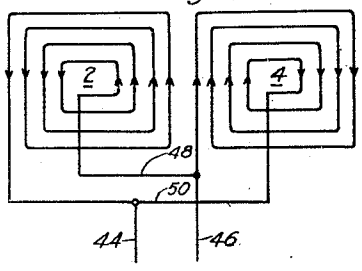
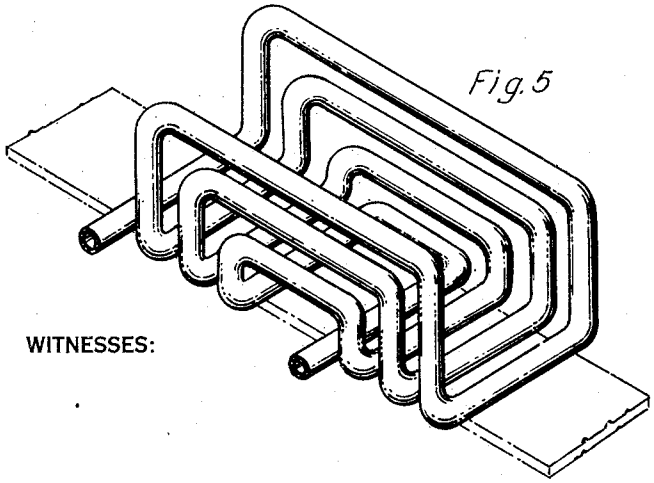


Fig. 5



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APPARATUS FOR HIGH-FREQUENCY INDUCTION HEATING OF STRIPS

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5 Claims. (Cl. 219—13)

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Our invention relates, generally, to induction heating without the use of iron-cores; and, more particularly, is in the nature of an improvement in coreless or air-cored induction heating furnace apparatus for inducing heating electrical currents in traveling elongated material, such as strips, sheets, rods, and the like, by a pulsating magnetic field or fields having magnetic lines longitudinally interlinking the material. By longitudinally, I mean extending generally in the direction of the length of the material, or on a line in which a material moves.

In present apparatus of this kind, elongated material is inductively heated by longitudinal magnetic flux in order automatically to provide uniformity of temperature distribution transversely across the moving material, with reference to its direction of movement. A helical coil or coils are used for producing this flux. Such a coil when energized provides an inner, axial flux; and by passing the material lengthwise through the inside of the coil, heating of the material is effected. A disadvantage of such helical heating-coil means resides in the fact that the elongated material must be threaded through it, and adjustments in induced power can not be readily made by changing the interlinking of the magnetic flux with the material which is centrally inside the coil or coils.

It is an object of our invention to provide a coreless induction furnace apparatus which can be energized with relatively high-frequencies, not obtainable with common rotating generators, but which will provide satisfactory longitudinal flux induction heating without the use of a helical coil.

It is another object of our invention to provide means for electromagnetically heating elongated continuously traveling flat material, such as strip, etc., with longitudinal flux obtained through the use of two non-magnetic spiral- or pancake-type induction heating coils, each on a different side of the material so that it can be threaded sidewise or edgewise into the work-receiving passage between the two heating coils.

A primary object of our invention is to provide an induction furnace apparatus of the type described which requires no magnetic material for concentrating or otherwise guiding the heat-inducing magnetic flux.

A further object of our invention resides in the provision of heating-coil means on each side of the traveling material, which mutually cooperate to provide, in effect, longitudinal magnetic flux for uniformly heating the material throughout.

An important advantage of our apparatus resides in the fact that the energy or power put into the material can be controlled or adjusted

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by varying the distance between the heating coils and, therefore, with respect to the material being heated, thereby affording an easy method for regulating the power input into the material without requiring controlling operations on the tube-oscillator generator or other generating power source with which it is desirable to energize the induction heating coils.

Other features, apparatus, means and methods of our invention, in addition to the foregoing, may be discernible from the following description thereof, to be taken in connection with the accompanying schematic drawing.

In the drawing:

Figure 1 is a diagrammatic view of an embodiment of our invention, looking at the face of a strip being heat-treated;

Fig. 2 is a longitudinal section, transverse to Fig. 1, substantially on the lines II—II thereof;

Figs. 3 and 4 are wiring diagrams showing manners in which the cooperating heating coils on opposite sides of the strip can be electrically connected for providing the type of electromagnetic heating of our invention; and

Fig. 5 is a perspective view of a modified form of a heating coil.

Referring more particularly to Figures 1 and 2, the induction heating furnace apparatus comprises a pair of similar planar nonmagnetic air-cored heating coils 2 and 4 parallelly disposed on opposite sides of a work-receiving passage 6 through which a relatively wide and relatively thin continuous strip 8 may be continuously passed or moved longitudinally in the direction of its length, for heat-treating the portion moving between the heating coils. Each of the coils is of the flat, pancake type, being spirally wound with slightly rounded corners.

Each coil has two groups of active conductors which extend across the width of the strip, the conductors in each group being parallel and interconnected by end-turns or end conductors to complete the spirals. More specifically, the heating coil 2 comprises a group 10 of active conductors 12 for one active turn-side, and a group 14 of active conductors 16 for the other active turn-side. The conductors of the groups are connected by end conductors 18 along one side of the strip-passage and end conductors 20 along the other. The heating coil 4, being similar, comprises spaced groups 22 and 24 consisting of spaced parallel active conductors 26 and 28, respectively, connected by end-turns 30 and 32.

The conductors of the group 10 of the heating coil 2 are transversely aligned with and parallel to the conductors of the group 22 of the heating coil 4. Similarly, the conductor-group 14 of the heating coil 2 and the conductor-group 24 of the

heating coil 4 are aligned on opposite sides of the strip 8, as more particularly shown in Fig. 2.

The coils are energized so that the current, at any instant, in a group of active conductors is in the same direction, but opposite in direction to the current in the group of conductors on the other side of the strip 8 and in the other group of active conductors of the same heating coil.

Referring to Fig. 2, the current directions are represented by dots to indicate current assumed to be flowing upwardly perpendicular to the plane of the drawing and by crosses to indicate current flowing downwardly perpendicular to the plane of the drawing. With current-flow in the active conductors as indicated by these dots and crosses, a magnetic field will be established in accordance with the flux lines 34, 36, 38 and 40 around the groups 10, 14, 22 and 24, respectively. It will be observed that flux lines flow longitudinally in the strip, these flux lines extending in opposite directions substantially from the center of the heating coils, between the groups of conductors of each.

Preferably, the heating coils are made of bare, hollow, copper tubing, so that they can be readily water-cooled, if necessary. As to the spacing between conductors of a heating coil, relatively wider spacing decreases the magnetizing force for a given current, so that the spacing between the conductors should be as close as possible, limited only by the requirement for providing adequate insulation between the conductors. Generally, for ordinary use, one-eighth of an inch spacing or more should be satisfactory. The opposite coils should be spaced as close as possible, but suitable allowance should be made for mechanical requirements of clearance so that slapping or weaving of a strip or the like passing between the coils will not be detrimental to the heating apparatus.

The number of active conductors in a group will depend on the amount of heat necessary to put into the strip passing through the field length; and, in general, a greater number of active conductors requires a wider spacing between the groups of a heating coil. This spacing between groups of a heating coil should, in general, be about four times the spacing between the different heating coils on the opposite sides of the strip, so as to obtain a satisfactory flux-distribution in opposite directions between the coils. If the groups of active conductors of a heating coil are too closely spaced, the magnetomotive forces produced by the energized coils tend to neutralize, so that the longitudinal flux will not be as great as it would be with a larger distance between the innermost active conductors of the two groups of a heating coil. The inner loop of a heating coil, which is the smallest in area, should preferably be as wide, or wider, than the width of the widest strip expected to be heat-treated. This means that all of the active conductors will be longer than the width of the strip, except perhaps for conductors to which the power source is connected. In general, the end-turn closest to the strip should be from two to four inches away from it to prevent nonuniform heating of the strip. With reference to Fig. 1, this distance between the innermost end-turn and the nearest edge of the strip is indicated at *a*. However, the active conductors of the heating coil may be less in length than the width of a strip, but in such case nonuniform heating transversely across the strip might result.

The heating coils should be energized from an alternating-current source capable of delivering the necessary heating power at higher frequencies, above several thousand cycles. Oscillating resonant circuit apparatus, such as a tube-oscillator or a spark-gap oscillator, is recommended. The frequencies may range as high as 500,000 cycles and above and still deliver the required power for heating the material, although no iron is used in the heating apparatus. In general, the most desirable frequency to use will depend on the physical properties of the material being heat-treated, the speed at which it is moving through the induction heating apparatus, and the required temperature rise.

In Fig. 1, a tube oscillator equipment indicated in its entirety by the reference numeral 42 is shown in simplified form for energizing the heating coils. The tube-oscillator generator comprises a high-frequency circuit including power leads 44 and 46 to which the heating coils may be connected in different manners, for obtaining a current-flow, such as described, producing the oppositely directed magnetic flux portions in the strip portion between the heating coils.

In Fig. 3, the coils are connected in series. The outer conductor of the conductor group 10 of the heating coil 2 is connected to the power lead 44, and the inner conductor of the conductor group 14 of this coil is connected directly to the inner conductor of the conductor group 24 of the heating coil 4; the outer conductor of the conductor group 22 of this coil being connected to the power supply lead 46. The aforesaid conductors are, of course, the terminating portions of the respective heating coils.

In Fig. 4, the heating coils are connected in parallel to the power supply leads 44 and 46. For this embodiment, the outer end of each heating coil is directly connected to the inner end of the other heating coil, and the connecting conductors 48 and 50, respectively, are connected to the power supply leads. The arrowheads in Figs. 3 and 4 indicate the current-direction at some instant when the supply lead 46 can be considered positive, so that the current will flow toward the supply lead 44.

In both Figs. 3 and 4, the heating coils are wound in the same direction, but obviously if they are wound in opposite directions the connections can be altered so as to produce the necessary current directions at any instant, in accordance with Fig. 2.

Where a heating coil extends completely across the strip, the end conductors between its active groups may take any desired form. In Fig. 1, we have shown the heating coil generally in the form of a flat spiral or pancake so that the end conductors are in the same plane as the active conductors. This means that the active conductors will be of gradually greater length in a direction outwardly from the center of the coil. However, the active conductors may be made of the same length, and the end-turns or end conductors disposed one above the other, such as shown in Fig. 5, so that the tubing of which the upper heating coil is made will be bent upwardly from an active conductor of a group, then longitudinally, and then down again to an active conductor of the other group. The lower heating coil is, of course, similar but with the turns for the end connections extending downwardly from the strip-passage.

By using two pancake coils on opposite sides of the strip as described, a magnetizing force is

obtained producing magnetic flux parallel to the strip, with the flux portions between the cooperative group of conductors on the two different heating coils in opposite directions at any instant. Each flux portion will induce approximately the same amount of heat if the heating coils are symmetrically constructed.

Such an arrangement, besides permitting ready insertion or removal of the strip edgewise, also affords an easy method of regulating the power put into the strip without requiring regulation of the tube oscillator through an expensive regulator of some kind. To vary the power to the strip, the two coils can be moved toward or away from it, normally to its face, or they may be hinged to increase or decrease their mutual coupling with the strip and their coaction with each other.

While we have described our invention in different forms and different embodiments, it is obvious that further changes can be made and embodiments utilized which embrace the teachings and principles of our invention.

We claim as our invention:

1. Coreless induction heating apparatus of a type described, comprising nonmagnetic means providing a flat work-passage having an open edge for receiving strip and the like, said means comprising a plurality of single-layer pancake heating coils on opposite sides of said work-passage, said heating coils having active substantially straight conductors spanning said work-passage, with conductors on opposite sides of the work-passage being parallel and lying in planes substantially perpendicular to the work-passage, and means for energizing said heating coils for producing a longitudinal magnetic flux in opposite directions in said work-passage between said heating coils, the last said means comprising conductors for causing the current-flow in one of said heating coils to be clockwise at the same time that the current-flow in the other heating coil is counterclockwise.

2. Induction heating apparatus comprising coreless induction furnace-means providing a work-passage, said furnace-means comprising a pair of similar heating coils on different sides of said work-passage, each heating coil having an axis intersecting said work-passage and having active spaced substantially coplanar turn-sides on the same side of said work-passage, one of said heating coils having nested end-turns connecting the active-turns of the heating coil, said end-turns being farther from said work-passage than the associated active turn-sides, and a resonant circuit alternating-current generating source having a pair of power supply leads connected to said heating coils.

3. An induction heating apparatus of a type described, having nonmagnetic pancake-type coils of hollow piping providing a flat, narrow work-passage for heating elongated flat material, said pancake-type coils of hollow piping comprising a plurality of similar groups of generally parallel coplanar spaced conductors extending transversely across said work-passage, there being a plurality of groups on one side of said work-passage and a plurality of groups on the other side of said work-passage, a group of conductors on one side of the work-passage being directly opposite a group in the other side, the spacing between groups on the same side of the work-passage being greater than that between adjacent conductors of such groups, means for passing alternating-current through said conductors so that the current at any time will flow in the same direction in the conductors of the same group, but in opposite directions in juxtaposed groups.

4. An induction heating apparatus of a type described, having nonmagnetic means providing a flat, narrow work-passage for heating elongated flat material, said means comprising a plurality of similar groups of conductors, each group comprising a plurality of generally parallel coplanar spaced substantially straight conductors extending transversely across said work-passage, there being a pair of conductor-groups on each side of said work-passage, and associated conductor-groups on opposite sides thereof, the spacing between the groups on the same side of said work-passage being greater than the spacing between adjacent conductors of each such group, and means connecting the conductors of said groups so that current in the conductors of any one group will generally flow in the same direction, but opposite to the direction of the current in the conductors of the associated group on the opposite side of said work-passage and in the conductors of the other group on the same side of said work-passage.

5. An induction heating apparatus of a type described, having nonmagnetic means providing a flat, narrow work-receiving passage for heating elongated flat material, said means comprising a plurality of similar groups of water-cooled conductors, each conductor being longer than the width of the material to be heated, each group comprising generally parallel coplanar spaced conductors extending transversely across said work-passage, there being a pair of conductor-groups on each side of said work-passage, and associated conductor-groups on opposite sides thereof, the spacing between the groups on the same side of said work-passage being greater than the spacing between adjacent conductors of each such group, and means for energizing the conductors of said groups with high-frequency current so that the high-frequency current in the conductors of any one group will generally flow in the same direction, but opposite to the direction of the high-frequency current in the conductors of the associated group on the opposite side of said work-passage and in the conductors of the other group on the same side of said work-passage.

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