

Aug. 7, 1945.

R. M. BAKER ET AL

2,381,246

INDUCTION HEATING COIL

Filed Oct. 31, 1942

Fig. 1.

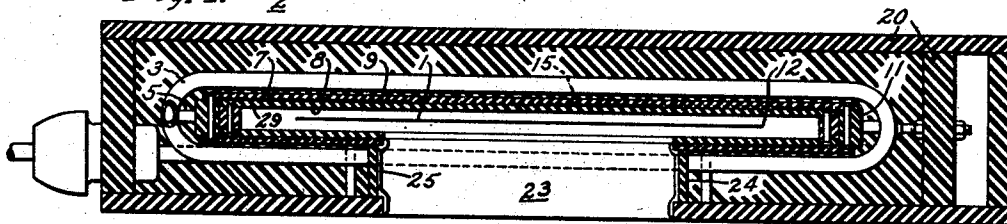


Fig. 2.

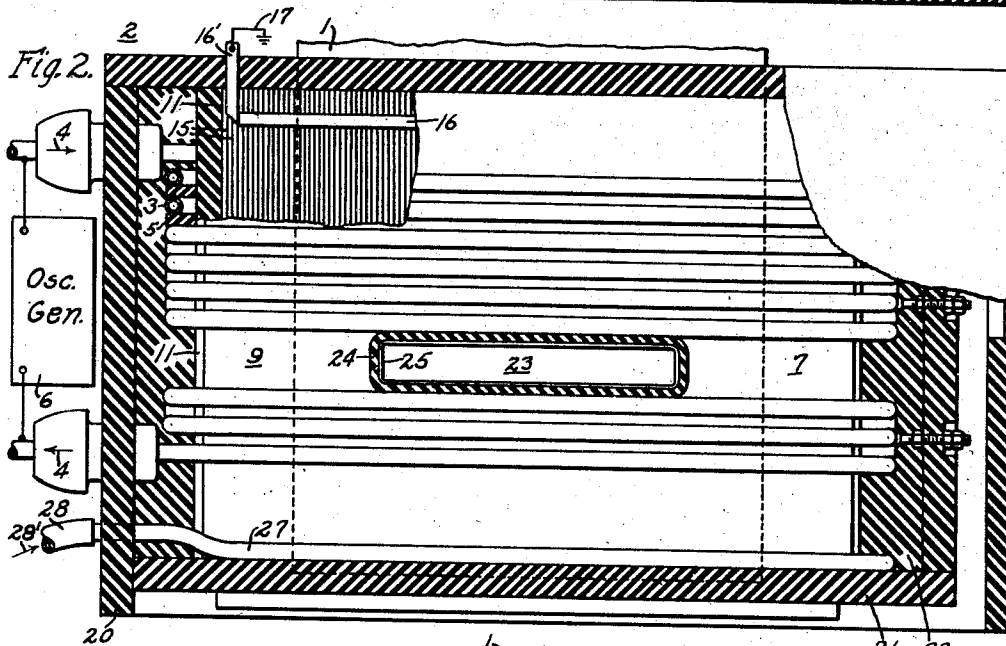


Fig. 4.

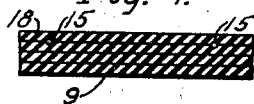
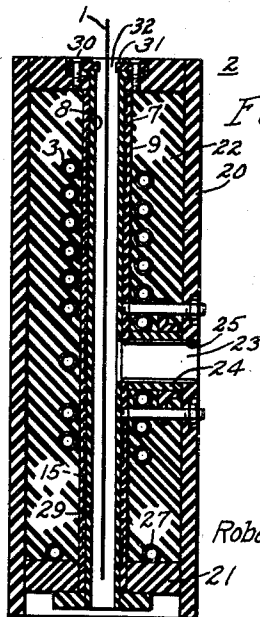


Fig. 3.



WITNESSES:

Leon M. Garman
David C. McKim

INVENTOR

Charles C. Whittaker,
Robert M. Baker & Harold G. Frostick

BY

C. B. Buchanan
ATTORNEY

UNITED STATES PATENT OFFICE

2,381,246

INDUCTION HEATING COIL

Robert M. Baker, Harold G. Frostick, and Charles C. Whittaker, Pittsburgh, Pa., assignors to Westinghouse Electric Corporation, East Pittsburgh, Pa., a corporation of Pennsylvania

Application October 31, 1942, Serial No. 464,041

10 Claims. (Cl. 219—13)

Our invention relates to inductive heating-coils, and particularly to such coils which are utilized to heat a rapidly moving, long, thin, flat, metal strip, or one or more wires, or other elongated member which is moving axially through the heating coil. In many inductive heating-coils of this nature, where very high power must be put into the coil, the voltage of the coil may be a distinct limitation as to its design, and particularly the maximum voltage appearing between the coil-terminals and the metal strip or other work to be heated, within the coil.

While our invention is not limited to any particular application, the special design of coil which we have introduced appears to find its most important present application in the tin-plate-flowing apparatus which is described and claimed in an application of Glenn E. Stoltz and Robert M. Baker, Serial No. 464,040, filed October 31, 1942, and assigned to Westinghouse Electric & Manufacturing Company.

In this application of our invention, a mile-long, thin, flat, electrolytically tin-plated steel strip, having a gauge usually of the order of 0.008 to 0.011 inch, and having a width of from 28 to 36 inches, is passed at a speed of the order of eleven or twelve miles per hour through an inductive heating-coil, which is required to heat the strip some 300 to 400° F. within as short a distance as possible, or at least within a distance which is within a reasonable factor of safety of the distance which would produce buckling of the strip as a result of the strains therein, from thermal expansion, exceeding the elastic limit or yield point of the strip. This high rate of heat-input into the strip is needed in order to make it possible to heat-treat the plated strip in the same "line" or manufacturing process in which the strip is electroplated, dried, heated, quenched, cleaned, and otherwise treated.

The heating is for the purpose of raising the tinplate to, or slightly above, its melting point, which is 452° F., so that the surface-tension of the molten tin will cause it to flow evenly over the steel, producing a solid, non-spongy, uniform texture, and making it possible to obtain as good a corrosion-resistant, shiny coating, with a tinplate only 30 millionths of an inch thick, as was previously obtained with a tinplate of three times that thickness, as applied by the old hot-dip process. The high concentration of heat, along a relatively small length of the strip, is needed in order to make it possible to heat-treat the strip in the same "line" in which it had been electroplated, so that separate manufacturing operations will not be needed; and the use of induction heating is necessary in order to be able to get enough heat into the strip in a small space, to make the strip-heating substantially independent of slight variations in gauge, to avoid physi-

cal contact with the easily marred tin surface, and to provide the high-speed heat-input control which is necessary for satisfactory operation on these high-speed tinning lines.

The object of our present invention is to provide a practical coil-design and construction, which is capable of serving in this new and important field of heating long tinned strips, or the like, with very large amounts of radio-frequency power.

A more specific object of our invention is to provide an improved embedded shield-construction which is associated with an open-ended box or liner which is disposed within the inductive heating coil, and through which the strip to be heated passes, said box or liner comprising solid molded insulation having a grounded shield embedded therein.

A more specific object of our invention is to provide a novel form of shield, for such a high-frequency, high-flux inductive heating-coil liner, said shield being in the form of a plurality of fine non-magnetic parallel spaced wires running in an axial direction, and having grounding-means joining the wires at one or both ends, at a point out axially beyond the end of the coil, so as to be out of the intensest portion of the magnetic field of the coil, said shield-wires having such a small diameter that they are not heated to any material extent at the frequencies and flux-densities which are utilized to heat the strip, particularly where the strip is made of steel or other magnetizable material.

A further object of our invention is to provide a flat, open-ended box-like insulating liner for such an inductive heating coil, the liner having an opening therethrough through which the strip to be heated passes, the two sides of the liner being flat, parallel, and closely spaced from the flat surfaces of the strip, and the two ends of the liner being spaced a greater distance from the edges of the strip, the two flat sides of the liner having grounded shielding-means associated therewith, extending axially beyond the axial extent of the coil, and extending transversely beyond the width of the strip, so as to adequately shield the edges of the strip.

A still further object of our invention is to provide a composite liner for such a coil, said liner comprising a relatively permanently secured outer box-portion, and an inner slot-liner removably secured in position along the inner surface of each of the two flat sides of the box.

A still further object of our invention is to provide an inductive heating coil having a shielded insulated liner therein, and having a window in the liner, an outwardly extending window-frame surrounding the window, and a grounded semi-conducting coating on the surfaces of the win-

dow and the window-frame, making contact with the shielding-means of the liner.

With the foregoing and other objects in view, our invention consists in the combinations, structures, parts, systems, and methods herein-after described and claimed, and illustrated in the accompanying drawing wherein:

Figure 1 is a somewhat diagrammatic horizontal or transverse sectional view through a coil-construction illustrating the principles of our invention,

Fig. 2 is a front elevational view thereof, with parts broken away to illustrate the construction,

Fig. 3 is a central longitudinal or vertical sectional view thereof, and

Fig. 4 is an enlarged fragmentary detail sectional-view showing the embedding of the fine wires of the shielding-means in the molded insulating box-side of the liner.

As shown in Fig. 2, our invention is illustrated as being applied to the heat-treatment of a rapidly moving tinned steel strip 1 which is rapidly moving downwardly through an inductive heating-coil structure which is indicated, in its entirety, by the numeral 2. The coil-proper is indicated at 3, and comprises a plurality of turns of a hollow conductor, wound in a single layer, and having water or other coolant circulating therethrough, as indicated by the arrows 4, successive turns of the coil being separated by annular insulating blocks 5. High-power high-frequency energy is supplied to the coil 3 from an oscillation-generator which is diagrammatically indicated at 6 in Fig. 2.

Within the coil 3, there is disposed an open-ended box-like liner 7 of strong hard solid insulating material, said box or liner 7 having an opening 8 therethrough, through which the strip 1 passes. The box or liner 7 has two flat parallel box-sides 9 which are closely spaced from the flat surfaces of the strip, and the narrow ends of the box are closed by two box-ends 11 which are spaced a greater distance from the edges 12 of the strip, so that the box-sides 9 are considerably wider than the strip 1. The box 7 extends, in a vertical or axial direction, considerably greater distance than the axial extent of the coil 3, so that the upper and lower ends of the box or liner 7 extend into a region where the axial magnetic field of the coil is not very strong, or not as strong as within the coil-proper.

Because of the large power-input into the coil 3, the voltages involved are quite high, so that, unless suitable shielding-means is provided, the high electrostatic voltage-gradients will produce excessive corona or space-current discharges, radiating out from the surfaces or edges of the strip 1.

An important feature of our invention is to provide a suitable grounded electrostatic shield which is economically feasible, and practically operative, to guard the strip 1 against space-current discharges or corona, while offering slight hindrance to the axial magnetic lines of force flowing in the strip, which is another way of saying that the shielding itself does not consume much of the magnetic energy of the coil, and is not itself heated to any considerable extent. In fact, the avoidance of excessive heating of the shielding-means is as important an object as the cutting down of the strength of the alternating magnetic flux flowing axially or longitudinally in the strip 1.

The shielding-means which we utilize is an embedded shield; and it is a shield composed of a

plurality of parallel fine non-magnetic wires running axially and having such small gauge that they are not materially or excessively heated at the frequency and field-strength which is utilized in the coil 3. Moreover, our shield is a shielding-means which is associated with the flat box-sides 9, and which extends laterally well beyond the edges 12 of the strip 1, so as to adequately shield these edges, without the necessity for extending the shielding-means completely around the periphery of the liner 7.

While, in the broadest aspects of our invention, we are not limited to any particular kind of shield, we have illustrated a very much preferred form of embodiment of the shield which, all things considered, seems to us at present to be far superior to any other available form of shielding-means for this high-frequency induction-heating application.

As shown, our shielding-means comprises a large number of closely spaced parallel non-magnetic wires 15 associated with each of the box-sides 9, and running in a longitudinal direction, that is, parallel to the axis of the coil 3. The wires 15 thus run from substantially the top to substantially the bottom of each box-side 9. These wires are of such small diameter that they are not significantly heated by the alternating flux flowing lengthwise therethrough, at the flux-density and the frequency involved. Copper wire of 0.005 inch diameter has proven to be very satisfactory, in one form of embodiment of our invention, although we are not limited, of course, to this size or material. Such fine wires are extremely fine and hard to manage, and they are applied in any convenient way which holds the wires in parallel strands, while being applied to the box-side 9 in the process of manufacture.

The box-side 9 is preferably made of a reinforced molded solid insulating material, preferably made up of a number of layers of glass cloth, impregnated with a moldable resin or heat-and-pressure-hardened insulating composition. In the process of manufacture, when nearly enough layers of impregnated glass cloth have been piled up to make a box-side 9, the plurality of closely spaced parallel wires 15 are then laid over the top of the partially prepared box-side, with a narrow cross-strip of thin copper foil 16, or other extremely thin conducting-means or high-resistance conducting-means, laid across the entire group of wires, preferably a strip or foil 16 near each end of the wires, with a length of strip 16' extending over for making a ground-connection as indicated at 17 in Fig. 2. The foil or strip 16 is preferably soldered to each individual wire 15. After this is done, with the wires laid in place on the partially completed box-side 9, as shown in Fig. 4, one or more additional glass-cloth layers 18 are added and cemented into place, preferably by subjecting the entire material to heat and pressure for setting the moldable insulating binding-material with which the glass cloth is impregnated. The result is a hard stiff strong insulating-board, with the wires 15 and their end-connected buses or foils 16 embedded within the solid molded material of the insulating-board 9.

Two boards 9, preferably prepared in the manner described, are assembled with the insulating end-pieces 11 to make the box or liner 7, the box-sides 9 being assembled with the parallel-wire shield 15 disposed near the inner surface, that is, the surface closest to the strip 1 to be heated, and farthest away from the in-

duction heating coil 3 which surrounds the box 7. Since the shield 15-16 is grounded (preferably at only one end), practically all of the voltage-drop between the coil 3 and ground appears between the coil and the shield 15-16, rather than between the shield and the strip 1 being heated. Since the box-side 9 is wider than the strip, and since the assembly of parallel shielding-wires 15 extends out over practically the whole width of the box-side, so as to extend the shield transversely considerably beyond the edges of the strip 1, said strip 1 is effectively shielded from excessive electrostatic field-gradients, thus effectually preventing corona from appearing on the strip 1.

In order to prevent corona from appearing on the coil 3, between the coil 3 and the outer portions of the box or liner 7, it is quite desirable for the coil to be immersed in solid insulating material which excludes any gaseous medium, because corona is a gaseous-ionization phenomenon, which cannot take place in a liquid or solid insulating medium. The shield 15, being an embedded shield, as described, is also immersed in solid insulating material which substantially excludes any gaseous medium, thus preventing the formation of corona on the shield, under the operating-conditions of the device. For solidly embedding the coil 3, we prefer to utilize a hardenable or moldable insulating material for filling all the spaces around the box or liner 7 and between said liner and the coil 3 and preferably outside of the coil.

As a convenient means for providing a suitable support for the coil 3 and the liner 7, and for at the same time providing a suitable mold for the moldable insulating-material which is to be flowed around the coil 3 and hardened in place, we preferably provide an outer box 20 surrounding the inner box or liner 7 and the coil 3, with a suitable space in between, and we close the space between the two boxes 7 and 20 with a bottom-member 21 so that we can pour a hardenable insulating resin or cement into place in such manner as to substantially fill the space between the two boxes, as indicated at 22, in such manner as to substantially exclude air or any gaseous medium, and to effectually embed the hollow conductors of the coil 3. When this insulating material sets or hardens, it provides an extremely strong and rigid support for the coil 3, as well as for the inner box or liner 7.

In some cases, as set forth in the previously mentioned Stoltz-Baker application, it is desirable to provide the coil-assembly 2 with a window or opening 23, which is provided in one of the box-sides 9, and in the corresponding side of the outer-frame 20, with a window-frame 24 disposed therebetween, so that the window-frame 24 extends outwardly from the window 23 in the inner box-side 9, in a direction away from the strip 1 being heated. In accordance with our present invention, the two windows 23, and the inner surface of the window-frame 24 are painted all around with a semi-conducting adherent coating 25, which is necessarily shown exaggerated in thickness, in Figs. 1 and 3. This coating makes electrical contact with the exposed ends of the wires 15, which are cut when the window 23 is cut in the shielded box-side 9, so that the semi-conducting coating 25 is grounded to the grounded shielding-wires 15. The grounded semi-conducting adherent coating 25 may be an aquadag coating, or any other semi-conducting adherent coating, such as a com-

pound of varnish, or other insulating binder, with a semi-conducting powdered material such as wood charcoal or powdered titanium dioxide which has been partially reduced in a hydrogen furnace.

As explained in the Stoltz-Baker application, the window 23 is utilized to accommodate light-sensitive scanning-means (not shown) for determining and fixing the location of the flow-line on the strip 1, which is the line of demarcation between the unmelted tin-plated surface having a matte surface, as it comes from the electroplating tanks (not shown), and the same tin-plate surface after it has been melted so that its surface-tension causes it to have the familiar bright metallic polished surface which is familiar in our so-called "tin" cans.

Our grounded semi-conducting coating 25 on the window 23 effectually cooperates with the grounded parallel-wire shield 15 in preventing corona at any point.

It will be noted that the cross-connecting foils or strips 16 which join the shielding-wires 15 at their upper and lower ends (or at either their upper end or their lower end, in the case of box-sides having no window) are disposed respectively above and below the axial extent of the coil 3, so that they are disposed out of the region of the strongest magnetic field of the coil 3, thus reducing the heating of the end-strips or foils 16.

It is also a feature of our invention to make up the liner 7 in two parts, or to place an inner slot-liner 29 in position along the inner surface of each of the two flat box-sides 9 of the previously described liner-member 7. The inner liner 29 is made of any suitable good-wearing insulating material which may be the same as the material of the permanent liner 7, but may also be a different material such as asbestos-board. This inner liner 29 is securely and removably inserted within the permanent liner 7, as by means of screws 30 (Fig. 3) at the top of the apparatus.

This removable inner liner 29 is provided because the liner of the induction-coil assembly is the part which is the most likely to fail, or to wear out, if there is any failure. Damage may be done to the liner, for example, if the tinned strip 1 which is being treated should break, when running at a high speed; or, if the strip 1 should frequently operate under conditions of insufficient tension on the strip, it might flop over and rub against the inner liner, to the detriment both of the liner and the surface-finish on the strip.

As an additional detail, we have also provided a soft rubber buffer or guard 31 at the top or entrance-end of the hole 8 through the liner, as indicated in Fig. 3. As shown, this rubber guard 31 produces a slightly reduced opening 32 at the entrance-end of the liner, where the strip starts into the induction heating-coil assembly, so as to prevent the strip from suffering the more serious damage to its surface, which would be encountered if the strip came into contact with the hard liner-material.

Near the bottom of the induction-coil assembly 2, where the heat is the greatest because of radiation from the hot strip 1, we provide a water-cooled coil 27 which is embedded in the insulating cement 22. One end of the coil 27 is insulated, as by means of a rubber-hose connection 28, to avoid short-circuiting the coil.

It is believed that the operation of our apparatus will be apparent from the explanations which have been given along with the descrip-

tion of the several parts and features of our apparatus.

While we have illustrated our invention in one illustrative form of embodiment, which has been considerably simplified or idealized for the purpose of illustrating the essential features of our invention, without encumbering the illustration with numerous constructional details which have no real part of the invention, we wish it to be understood that such illustration is only illustrative, and that our invention is susceptible of embodiment in a number of different forms. We desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language.

We claim as our invention:

1. Inductive heating apparatus for heating a long thin flat strip of conducting material which is continuously moving in the direction of its length, said apparatus comprising an open-ended box of strong solid insulating material having an opening therethrough through which the strip may pass, the two sides of the box being flat, parallel, and adapted to be closely spaced from the flat surfaces of the strip, the two ends of the box being adapted to be spaced a greater distance from the edges of the strip, an inductive heating-coil, the box being disposed within the inductive heating-coil and extending at each end axially beyond the end of the coil, and grounded electrostatic field-shielding means associated with each of the two flat sides of the box for guarding the strip against space-current discharges while offering but slight hindrance to the axial magnetic lines of force within the strip, said shielding-means extending axially beyond the axial extent of the coil and adapted to extend transversely beyond the width of the strip.

2. Inductive heating apparatus for heating a long thin flat strip of conducting material which is continuously moving in the direction of its length, said apparatus comprising an open-ended box of strong solid insulating material having an opening therethrough through which the strip may pass, the two sides of the box being flat, parallel, and adapted to be closely spaced from the flat surfaces of the strip, the two ends of the box being adapted to be spaced a greater distance from the edges of the strip, and an inductive heating-coil, the box being disposed within the inductive heating-coil and extending at each end axially beyond the end of the coil, the two flat sides of the box comprising solid molded insulation having a grounded conducting shield embedded therein so as to be immersed in solid insulating material which substantially excludes any gaseous medium from the embedded shield.

3. Inductive heating apparatus for heating a long thin flat strip of a magnetizable metal which is continuously moving in the direction of its length, said apparatus comprising an open-ended box of strong solid insulating material having an opening therethrough through which the strip may pass, the two sides of the box being flat, parallel, and adapted to be closely spaced from the flat surfaces of the strip, the two ends of the box being adapted to be spaced a greater distance from the edges of the strip, an inductive heating-coil, the box being disposed within the inductive heating-coil and extending at each end axially beyond the end of the coil, a plurality of fine

non-magnetic parallel spaced conducting wires running in an axial direction along each of the two flat sides of the box across a width which is adapted to be greater than the width of the strip, and extending axially beyond an end of the coil, and grounding-means joining the wires at an end, out of the intensest portion of the magnetic field of the coil.

4. Inductive heating apparatus for heating a long thin flat strip of conducting material which is continuously moving in the direction of its length, said apparatus comprising an open-ended box of strong solid insulating material having an opening therethrough through which the strip may pass, the two sides of the box being flat, parallel, and adapted to be closely spaced from the flat surfaces of the strip, the two ends of the box being adapted to be spaced from the edges of the strip, and an inductive heating-coil, the box being disposed within the inductive heating-coil and extending at each end axially beyond the end of the coil, said box comprising two portions comprising a relatively permanently secured outer box-portion, and an inner slot-liner removably secured in position along the inner surface of each of the two flat sides of the box.

5. The invention as defined in claim 1, characterized by a flat side of the box having a window therein, a window-frame surrounding the window and adapted to extend outwardly away from the strip, and a grounded semi-conducting coating on the surfaces of the window and the window-frame making contact with the shielding-means of the box-side.

6. The invention as defined in claim 2, characterized by a flat side of the box having a window therein, a window-frame surrounding the window and adapted to extend outwardly away from the strip, and a grounded semi-conducting coating on the surfaces of the window and the window-frame making contact with the grounded shield of the box-side.

7. The invention as defined in claim 3, characterized by a flat side of the box having a window therein, a window-frame surrounding the window and adapted to extend outwardly away from the strip, and a grounded semi-conducting coating on the surfaces of the window and the window-frame making contact with the fine wires of the box-side.

8. The invention as defined in claim 1, in combination with a solid mass of insulating material in which the coil is embedded and filling the space, to the substantial exclusion of any gaseous medium, between the coil and the box through which the strip may pass.

9. The invention as defined in claim 2, in combination with a solid mass of insulating material in which the coil is embedded and filling the space, to the substantial exclusion of any gaseous medium, between the coil and the box through which the strip may pass.

10. The invention as defined in claim 3, in combination with a solid mass of insulating material in which the coil is embedded and filling the space, to the substantial exclusion of any gaseous medium, between the coil and the box through which the strip may pass.

ROBERT M. BAKER.
HAROLD G. FROSTICK.
CHARLES C. WHITTAKER.