Aug. 9, 1955 P. N. SORENSEN 2,715,170

METHOD AND MEANS FOR INDUCTIVELY HEATING NARROW ELONGATED PORTIONS OF CYLINDRICAL BODIES

Original Filed April 7, 1949

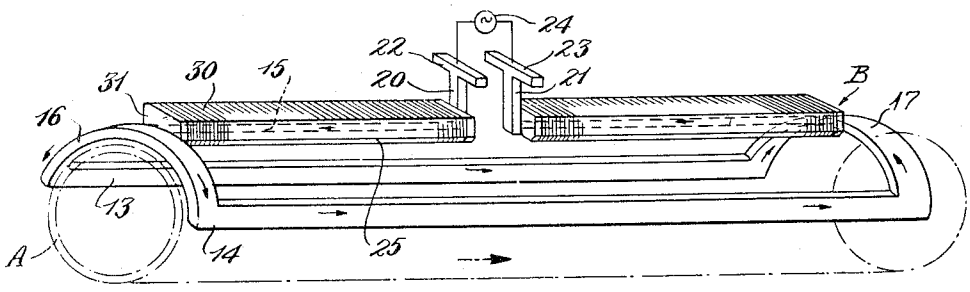


FIG. 1

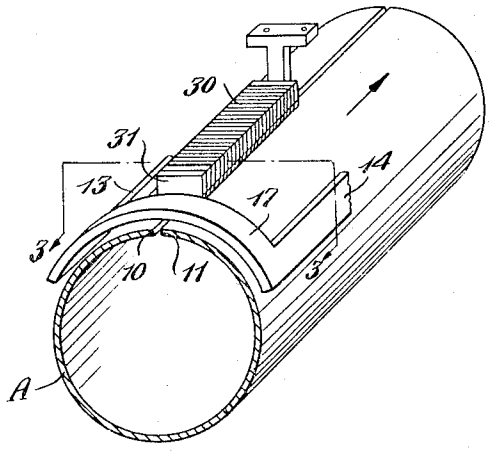


FIG. 2

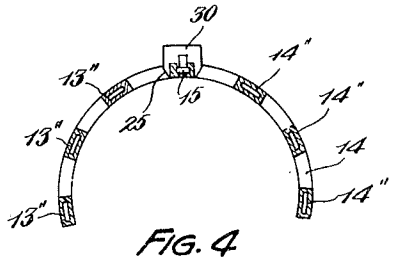


FIG. 4

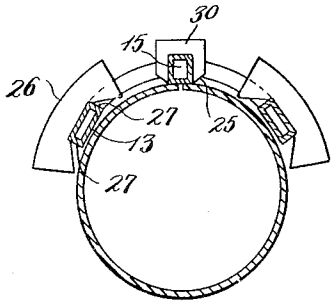


FIG. 3

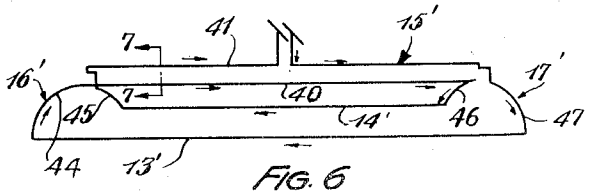


FIG. 6

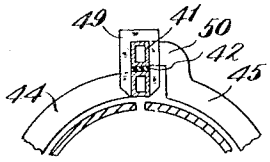


FIG. 7

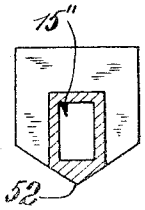


FIG. 8

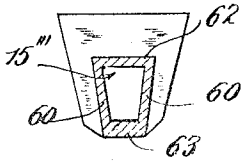


FIG. 5

INVENTOR.
PHILLIPS N. SORENSON
BY Alfred G. Baely
ATTORNEY

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METHOD AND MEANS FOR INDUCTIVELY HEATING NARROW ELONGATED PORTIONS OF CYLINDRICAL BODIES

Phillips N. Sorensen, Cleveland, Ohio, assignor to The Ohio Crankshaft Company, Cleveland, Ohio, a corporation of Ohio

Original application April 7, 1949, Serial No. 86,066. Divided and this application September 14, 1950, Serial No. 184,745

9 Claims. (Cl. 219—10.53)

This application pertains to the art of high-frequency electric induction heating and, more particularly, to an inductor for heating narrow elongated portions of generally elongated metallic bodies.

The present application is a division of my copending application Serial No. 86,066 filed April 7, 1949, now abandoned.

The present invention is in some respects an improvement on the invention shown and described in my copending application Serial No. 58,228, filed November 4, 1948, now Patent No. 2,632,840 dated March 24, 1953, and has many similar objects. In that application, a high-frequency inductor is shown adapted particularly for heating to a welding temperature the opposed edges of C-shaped skelp prior to the butt welding of the edges. The inductor there shown comprised two parallel conductors adapted to be disposed on diametrically opposite sides of the skelp with one of the conductors adjacent and parallel to the slit in the skelp. The two parallel conductors were electrically connected at their ends by peripherally-extending conductors in the form of complete rings. This inductor induces high-frequency, high-density electric currents to flow in the same direction in the opposed edges while allowing the return or opposite direction currents to spread out over portions of the skelp remote from the edges.

The inductor of the present invention induces a substantially similar current flow to this earlier inductor and has for its objects a somewhat simpler construction, enabling improved positioning of the pressure rolls for forcing the heated edges of the skelp into welding engagement, accommodating a plurality of skelp sizes and, in some respects, providing more efficient electrical relationship.

Another object is to provide an inductor having improved induced current-concentrating means on a portion only thereof.

A further object is to provide an inductor in close coupled electrical relationship to a substantial area of a workpiece to be heated in a limited portion of that area and having flux-concentrating means along a portion only which is adapted to be disposed adjacent the portion to be heated.

Additional objectives of the present invention are an inductor having improved and balanced current distribution throughout, including, in some instances, a plurality of generally parallel conductors all connected in series relationship, some of the conductors having means for increasing the flux concentration thereabout to provide increased concentration of heating adjacent thereto while the other provides improved overall electrical coupling without providing undue heating.

Another object is to provide an inductor of improved efficiency wherein the heating currents induced thereby flow longitudinally and concentrated while the return longitudinal currents are spaced a minimum amount so that I^2R losses of the transverse currents are kept to a minimum.

Generally speaking, the invention comprises a high-frequency inductor of three or more generally parallel-extending conductors with the central conductor adapted to be disposed opposite the edges to be heated and shaped, and provided with magnetically-permeable material so as to induce high-frequency currents therein of maximum concentration or density, the outer conductors adapted to be spaced from the edges but adjacent the surface of the skelp so as to improve the electric coupling to the skelp while inducing electrical currents of a minimum density.

The invention comprises certain parts and electrical conductors and arrangement of parts and electrical conductors, a preferred embodiment of which is described hereinafter and shown in the attached drawing which is a part hereof, and wherein:

Figure 1 is a side elevational view of a high-frequency electric induction-heating coil embodying the present invention in operative or heating relationship with a continuous length of skelp;

Figure 2 is an end elevational perspective view of the inductor shown in Figure 1;

Figure 3 is an end sectional view of the inductor shown in Figure 1 showing a modification for increasing the electrical coupling of the outer conductors to the workpiece without substantially increasing the concentration of currents thereunder;

Figure 4 is an end sectional view of a further modified form of inductor taken as though on the line 3—3 of Figure 2;

Figure 5 is a sectional view of a central conductor having a slightly modified cross-sectional shape;

Figure 6 is a schematic view of a further alternative arrangement of an inductor showing all the conductors connected in electrical series;

Figure 7 is a fragmentary sectional view of Figure 6 taken approximately on the line 7—7; and

Figure 8 is a still further modified shape of the central conductor particularly adapted to increase the current-carrying capacity of the conductor.

Referring now to the drawings wherein a preferred embodiment of the invention is shown for the purpose of illustration only and not for the purpose of limitation, Figures 1 and 2 show a skelp A, generally C-shaped in cross section, having opposed, slightly-spaced edges **10**, **11** to be welded in operative relationship with an inductor B, which inductor is adapted to heat the edges **10**, **11** to a welding or fusion temperature so that the edges **10**, **11** may, subsequently, be brought into pressure engagement and welded. The skelp A is only a fragmentary section of the total skelp length which may be, to all intents and purposes, substantially continuous for, with modern manufacturing techniques, strip as it is fed into the skelp-forming machine is welded end to end to form continuous lengths. The arrow indicates the direction of movement the skelp may take.

The inductor B shown comprises, generally, three spaced parallel conductors **13**, **14** and **15**, the last mentioned conductor being the central conductor of the three. The conductors **13**, **14** and **15** are connected at their ends in an electrically parallel circuit by means of arcuate conductors **16**, **17**, the conductor **16** being positioned on the left-hand end of the conductors shown in Figure 1 and the conductor **17** being on the right-hand end. The conductor **15** is formed in two parts in aligned relationship with the adjacent ends in slightly-spaced and insulated relationship. Fish-tail leads **20**, **21** extend generally perpendicularly from the conductor **15**, one from each part and in insulated relationship for a short distance. Terminal blocks **22**, **23** respectively are affixed to the end of these leads. These fish-tail blocks are adapted to support the inductor B and to provide an electrical con-

nection for the inductor to a high-frequency power source 24. For the purposes of clarity, the leads are shown in spaced relationship. In actual practice, they would be in close-spaced relationship as is shown in my above referred to application.

The various conductors just referred to are adapted to have high-frequency currents circulated, therethrough, the direction of the current flowing at any one instant being indicated by the arrows in Figure 1. These currents are relatively high and it is preferred that the conductors be a hollow copper shell to provide continuous water passages whereby cooling water may be circulated through the interior thereof.

Each conductor is disposed in close-spaced, current-inducing relationship to the sides of the skelp. The induced currents on each side of the edge flow generally in a big rectangular loop corresponding to the rectangular loop formed by each side conductor 13, 14 and the central conductor 15, and the end conductors. Normally, the heating would be uniform under each conductor. To obtain maximum efficiency of heating, the currents adjacent the edges 10, 11 must be concentrated to produce a maximum of heating while the currents remote from the edges; i. e., in the opposite direction and transversely relative to the edges, must be relatively unconcentrated to produce a minimum of heating.

The present invention contemplates an inductor having provision for effecting a maximum degree of electric coupling with the skelp, a maximum concentration of currents at the edges to be welded and a minimum concentration remote from the edges.

To concentrate the currents along the edges, the circumferential width of the conductor 15 is made as narrow as possible while, at the same time, still providing the desired current-inducing relationship.

For the purpose of further concentrating the heating effect only at the opposed edges, the conductor 15 is provided with magnetically-permeable material comprising, in the present embodiment, a plurality of inverted, U-shaped, thin, magnetic laminations 30 having their principal plane transverse of the length of the conductor 15. As shown, these laminations 30 cover both sides and top of the conductor 15, which are the sides away from the edges 10, 11. Preferably, the stack of laminations at each end; that is, adjacent the conductors 16, 17 and the fish-tails 20, 21 are terminated in inverted U-shaped copper laminations 31, the effect of which is to shield the magnetic laminations from the flux field about the fish-tail leads 20, 21 or the conductors 16, 17. The magnetically-permeable material is preferably artificially cooled. Thus, the copper laminations 31 may be brazed to the conductor 15, thus serving as a means of facilitating the cooling of the laminations 30. Other intermediate copper-cooling laminations brazed to the conductor could be provided. The laminations shown have the outer corners removed as at 25, thus narrowing the width of the surface of the laminations facing the skelp and providing a maximum concentration of the flux as it leaves the laminations to thread into the edges of the skelp.

The flux concentration in the laminations at this surface may be beyond the magnetic saturation point of the metal employed. Elsewhere, because of the increased width of the laminations, the flux concentration is less.

The spacing between the side conductors 13, 14 and the central conductor 15 should preferably be held to a minimum. As the side conductor is moved toward the central conductor, the length of the transverse current path relative to the edges and its resistance is lessened, thus reducing heating from the transverse currents. However, as the side conductors are moved closer to the main conductor, its flux then tends to thread through the laminations, heating them undesirably.

The side conductors have a relatively large circumferential width as shown in Figures 1 and 2 so as to distribute the induced currents over as wide a path or area as possible. The amount of heat developed under each conductor is in some ways directly proportional to the width of the induced current path as the total electrical resistance is less for wider paths. The total current remains the same.

The side conductors may also be provided with magnetically-permeable material to reduce the reluctance of the magnetic circuit therearound, such as laminations 26 in Figure 3.

The laminations 26, however, are formed in the opposite manner to the laminations 30; that is, instead of concentrating the flux pattern into the workpiece, the laminations are so shaped as to spread the flux pattern out as much as possible. Thus, the area of the surface of the laminations facing the sides of the skelp is quite substantial. To prevent flux crowding at the inner corners 27 of the conductors 13, the reluctance of the flux path is increased adjacent the corners by cutting away the surfaces of the laminations as at 25 and providing a varying clearance between the surface of the laminations and the sides of the skelp. Ideally, the reluctance of the flux path should be constant over the entire width of the laminations.

All of the conductors are in as close current-inducing relationship to the skelp as possible without electrically contacting and an efficient electrical coupling results. It will be appreciated that each ampere of current in the skelp induced by the conductors 13, 14 is relatively spread out in the skelp remote from the edges but the return-current path therefor is crowded into the edges themselves, thus further increasing the heating action therealong.

Figure 4 shows a modified construction for spreading out the return currents. Here, the side conductors are comprised of a plurality of spaced conductors 13'', all connected in parallel by end conductors.

It will be appreciated that the fish-tail leads 20, 21 may be located at any point along the conductor 15 or elsewhere, if desired.

Alternatively, the inductor may have an electrical circuit such as that shown in Figure 6. Here, the central conductor 15' is actually comprised of two parallel-extending conductors 40, 41 which may be either side by side or as shown in Figure 7 with the conductor 41 on top of the conductor 40 with a layer of insulation 42 therebetween. In a like manner, the conductors 16' and 17' are discontinuous, the conductor 16' being formed in two parts 44, 45 and the conductor 17' being formed in two parts 46, 47. The conductors 13' and 14' are substantially as shown in the principal embodiment.

In the embodiment shown in Figure 6, the lower central conductor 40 connects at its left end to the end conductor 44 and at its opposite end to the end conductor 46 which, as will be noted from the figure, is on the opposite side of the main conductor to that of the conductor 44. In a like manner, the conductor 41 at its left end is connected to the end conductor 45 and its right end to the end conductor 47. Each of these end conductors are on opposite sides of the main conductor 15'. In this embodiment of the invention, laminations 49 of a U-shape extend over both of the conductors 41, 42, combining their magnetic field and restricting, to a large extent, any leakage flux between the conductors 40, 41. As shown clearly in the cross-sectional end view of Figure 7, the end conductor 45 has an offset 50 so that it may connect to the conductor 41.

Figure 8 shows a cross-sectional view of a modified central or main conductor 15'' having a pointed edge 52 to provide a further concentrated heating at the edges of the pipe.

Figure 5 shows a further modification of the main conductor 15''' which provides an extremely narrow heat band on the edges 10, 11 while, at the same time, being capable of carrying extremely high electric currents. In this embodiment, the inductor 15''' is formed in the shape of a

trapezoid having parallel upper and lower walls **62, 63** and angularly-disposed side walls **60**. The width of the lower wall **63** is substantially less than the width of the upper surface. However, the thickness of the lower wall **63** is made substantially greater than the wall thickness of the other walls to provide an increased current-carrying capacity along this surface. The main portion of this current concentrates in this surface because of the proximity effect. It will be appreciated that the other wall thicknesses could be increased to correspond to that of the lower surfaces; but, if this were done, the area of the cooling passage would be considerably reduced. The conductor **15'''** shown in Figure 5 may be formed in any conventional manner, but, preferably, by machining the lower and two side walls from a piece of solid copper and, subsequently, brazing the upper wall **62** in place.

In operation, the central conductor is disposed in close, spaced, parallel relationship with the edges to be heated and high-frequency, high-density electric currents are flowed therethrough which, in turn, induces similar currents to flow in the edges. The currents at any one instant in both edges are in the same direction for the entire distance through the thickness of the metal, which means that the return-current flow must be elsewhere in the metal at a point remote from the edges partly because of the skin effect of high frequencies. The tendency of this current is to concentrate itself only at the extreme surface of the edge itself and a heating action in proportion to the amount of current results. As the currents induced are extremely high, the heating action is extremely high, the temperature change being on the order of 2300° F. to 2700° F. in from .3 to one second. In this extremely limited period of time, there is very little opportunity for the heat to flow circumferentially outwardly away from the edges so that the heat is truly concentrated at the surface of the edges. Immediately upon the edges having reached the welding temperature, they are brought into preferably relatively light pressure engagement sufficient to hold the highly heated edges in welding engagement but without causing a sufficient plastic flow such that the highly heated metal is displaced from the welded area and the slightly colder metal backing up the edges comes into engagement. This metal, while possibly at a plastic heat, is not at the welding heat. It has been found that if too much pressure is applied, the welded section is not as strong as when a moderate amount of pressure is used. This process is in contradistinction to resistance welding where, as the metal reaches the plastic state, it is under rather extreme pressure and rupturing of the metal structure results even before the true welding temperature has been reached. As a result of the need for continued pressure in the resistance weld, a relatively large amount of upset occurs and a breaking down of the grain structure of the metal at a point slightly remote from the welded area itself occurs. Accordingly, the present method of welding permits of a smaller wastage of metal in the welding bead formed.

Referring to Figure 7, it will be seen that the edges of the skelp during the heating operation may be slightly divergent. The density of the flux field about the conductor decreases in proportion to the distance away from the conductor. Thus, the amount of induced currents on the inner corner of the edge of the skelp will be slightly less than the current in the outer corner of the edge of the skelp. With this phenomena existing, the inner corner is heated to a slightly less amount than the outer corner. Thus, if the edges are brought into pressure-welding engagement, the tendency for the plastic metal at the edges is to flow radially outwardly forming a bead only on the outside of the pipe itself, which bead can there be readily controlled as desired. If the bead were formed on the inside, controlling it or machining it becomes an extremely expensive problem.

With the inductor shown, quite satisfactory and complete homogeneous welds have been obtained on one-inch pipe having a wall thickness of .029 inch and using 130 kw. of 10,000 cycles per second electric power and a pipe speed on the order of 60 to 100 feet per minute. The resultant welded bead is small and well rounded. It has no jagged edges. There are no scale inclusions, a partial explanation of which may be attributed to the fact that the very rapid heating effect expels the scale in a manner as taught in the patent to Strickland, No. 2,425,134, dated August 5, 1947.

The invention and embodiments shown are susceptible to many modifications; e. g., the inductor shown may also be used for heating the opposed edges of flat plates; in which cases, the end conductors **16, 17** would be substantially straight. The inductor may also be used for heating the base of long grooves or the like; in which case, the end conductors would be curved in the opposite direction; i. e., gull winged. If hardening by quenching is to be obtained, the inductor may be provided with integral spray-quench holes whereby a quench medium can be sprayed directly onto the heated surface. The inductor may be moved while the work remains stationary.

When the thickness of the material adjacent the edges is such that full penetration of the high-frequency flux through the entire thickness of the metal cannot be obtained, a second auxiliary inductor similar to the inductor described may be employed and positioned on the other side of the edge which, in the case of skelp, would be on the interior of the skelp and, in the case of flat plates, would be on the opposite sides of the flat plate from the principal inductor. In either event, the current in the principal or main conductor of this second inductor should be, at any one instant, in the same direction as the current in the main conductor of the principal inductor. Thus, the current flowing in the abutting edges will always be in the same direction over the entire width of the edge itself, preventing dead or neutral spots of current along the edge itself.

This second inductor would, of course, also have side conductors in coupled relationship to the interior walls of the tube. These side conductors should be displaced circumferentially from the side conductors of the outer inductor to keep the heating effect of all the side conductors to a minimum.

It is intended to use the term "skelp" throughout this specification in its broader connotation, including metallic strip formed into a substantial C shape by either hot or cold workpiece processes.

It will be appreciated that other modifications will occur to others upon a reading and understanding of this specification. It is my intention to include all such modifications as part of my invention insofar as they come within the scope of the appended claims.

Having thus described my invention, I claim:

1. An inductor for heating elongated narrow portions of metallic bodies, said inductor comprising a main conductor and at least a pair of auxiliary conductors, said auxiliary conductors extending in generally spaced, parallel relationship to said main conductor, at least one of said conductors being centrally divided whereby said inductor may be electrically energized, and a pair of transverse conductors, one at each end of said main and auxiliary conductors electrically connecting the respective ends of said conductors and a pair of rigid conductors extending transversely, one from each side of the conductor-division point, providing both electrical connections and physical support for said inductor.

2. In a high-frequency inductor, three parallel-extending, spaced conductors electrically connected in a parallel electric circuit at their respective ends, the central conductor only of said three conductors being generally centrally divided whereby said inductor may be electrically energized and a pair of rigid conductors extending transversely, one from each side of the conductor-division

point, providing both electrical connections and physical support for said inductor.

3. The combinations of claim 2 wherein said central conductor has a plurality of magnetic laminations stacked along its length.

4. The combination of claim 2 wherein said central conductors have magnetically-permeable material covering their sides thereof and said auxiliary conductors have magnetically-permeable material covering less than three sides of each.

5. In an inductor for heating the opposed edges of substantially C-shaped skelp, said inductor comprising a main inductor adapted to be disposed in slightly-spaced, parallel relationship to said edges, a pair of auxiliary conductors in spaced relationship to said main conductor disposed on opposite sides thereof, said auxiliary conductors extending in generally parallel relationship to said main conductor, arcuate conductors connecting the corresponding ends of said main conductor with the ends of said auxiliary conductors, at least one of said conductors being divided whereby said inductor may be energized, said main conductor having magnetically-permeable material about the sides thereof away from said opposed edges.

6. An inductor comprising a first, second, third and fourth conductor all extending in generally parallel relationship, said first and second conductors being in close spaced insulated relationship, said third and fourth conductors being disposed in spaced relationship to said first and second conductors, said first conductor being connected at one end to said third conductor and at the other end to said fourth conductor, said second conductor adjacent said last mentioned end of said first conductor being connected at its end to the end of said third conductor and at the other end to said fourth conductor, one of said conductors being divided whereby said inductor may be electrically energized from a power source.

7. The combination of claim 6 wherein the first and second conductors have magnetically-permeable material therearound.

8. A high-frequency inductor comprising an elongated, generally straight conductor adapted to be disposed throughout its length in close current-inducing relationship to a surface of a workpiece, said conductor being generally trapezoidal in cross section and including a plurality of side walls defining an interior passage, the narrower of the parallel side walls forming said trapezoidal shape being thicker than at least the two adjacent divergent side walls and forming the workpiece-adjacent side of said conductor.

9. A high-frequency inductor comprising a plurality of spaced conductors, all adapted to be in close spaced current-inducing relationship with the surface of a workpiece, some of these said conductors adapted to be opposite the surfaces of said workpiece to be heated, other of said conductors adapted to be opposite surfaces of said workpiece wherein heating is not desired, said other conductors having a magnetically-permeable material on the sides thereof other than the workpiece-adjacent side and having a surface adapted to face said workpiece, said surface being recessed at least adjacent said conductor to reduce the reluctance thereat.

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