United States Patent [19]

Seyfried

[11] **3,842,234**

[45] **Oct. 15, 1974**

[54] **INDUCTOR FOR INDUCTIVELY HEATING METAL WORKPIECES**

[75] Inventor: **Richard F. Seyfried,** Parma Heights, Ohio

[73] Assignee: **Park-Ohio Industries, Inc.,** Cleveland, Ohio

[22] Filed: **Jan. 10, 1974**

[21] Appl. No.: **432,142**

[52] **U.S. Cl.**..... **219/10.79,** 219/10.43, 219/10.75, 266/5 EI, 336/77, 336/155

[51] **Int. Cl.** **H05b 5/06**

[58] **Field of Search**..... 219/10.79, 10.77, 10.75, 219/6.5, 10.57, 10.41, 10.13, 10.67, 10.73; 266/4 EI, 5 EI; 336/155, 160, 165, 75, 77

[56] **References Cited**

UNITED STATES PATENTS

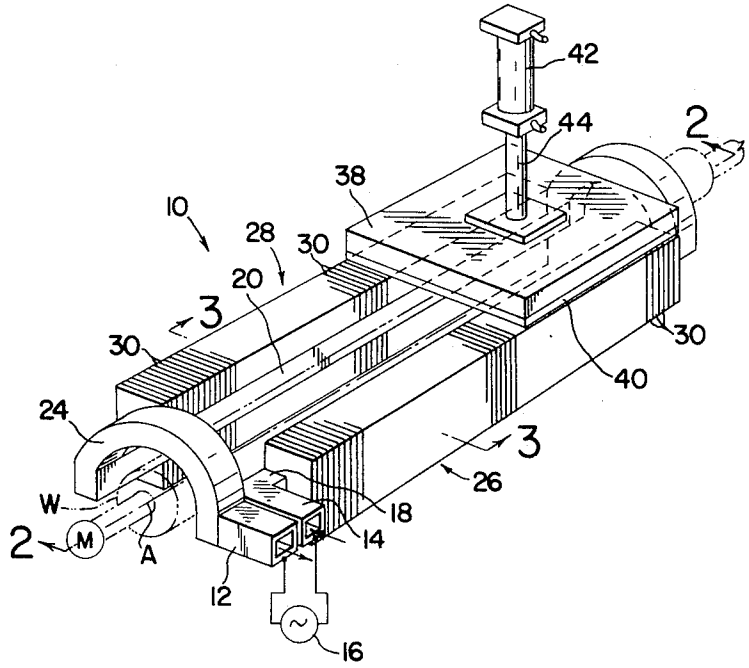
1,596,391	8/1926	Bell	336/75
2,383,992	9/1945	Sherman	219/10.57
2,475,348	7/1949	Black	219/10.43
3,064,219	11/1962	Gabor	336/155
3,423,557	1/1969	Lewis	219/10.79 X
3,483,346	12/1969	Seulen et al.	219/10.79 X
3,522,405	8/1970	Seulen et al.	219/10.79
3,649,798	3/1972	Seyfried et al.	219/10.79
3,659,069	4/1972	Balzer et al.	219/10.79

Primary Examiner—Bruce A. Reynolds

[57] **ABSTRACT**

A single-shot type inductor is provided with arrangements for selectively varying the current concentration along portions of the opposed faces of the inductor facing a workpiece therebetween. The arrangements provide for a single inductor to be employed to inductively heat workpieces which are of different contour, or to inductively heat different axial lengths of workpieces.

12 Claims, 8 Drawing Figures



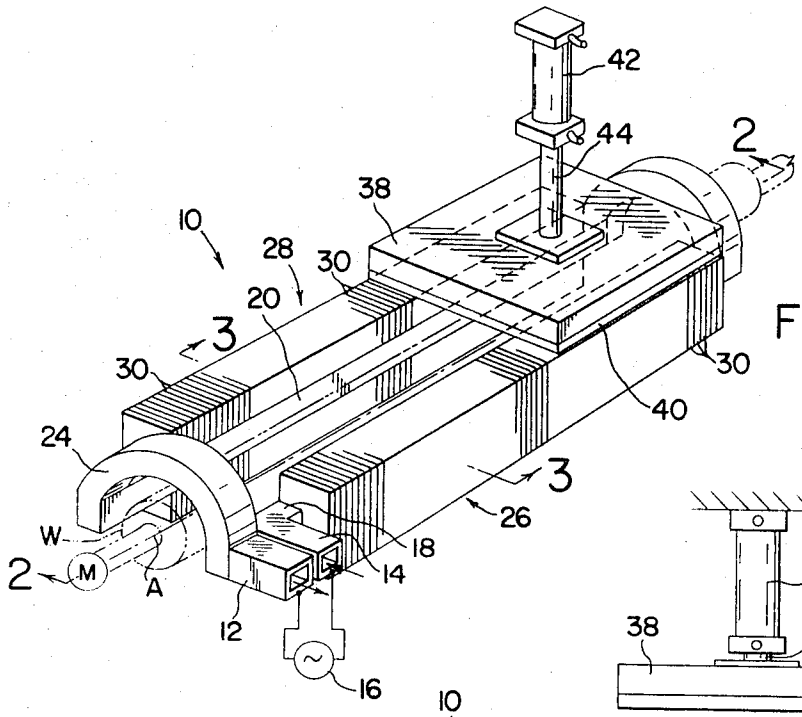


FIG. 1

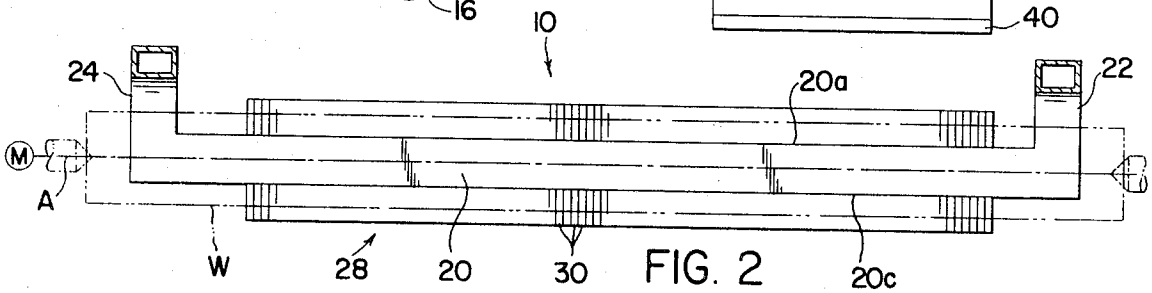


FIG. 2

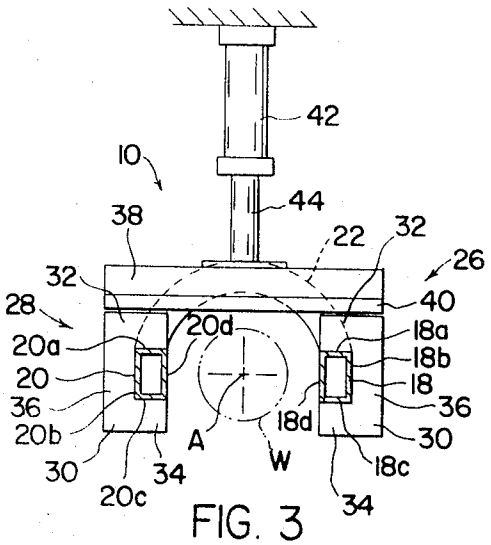


FIG. 3

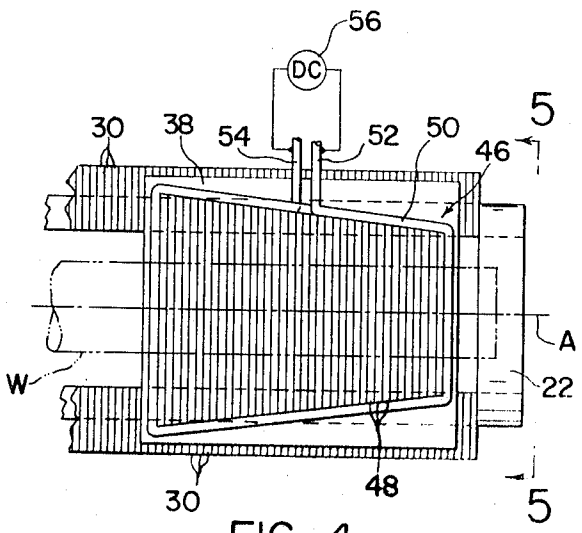


FIG. 4

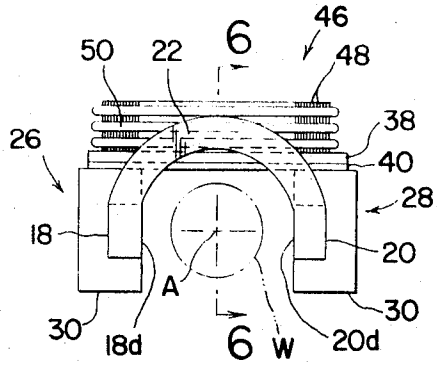


FIG. 5

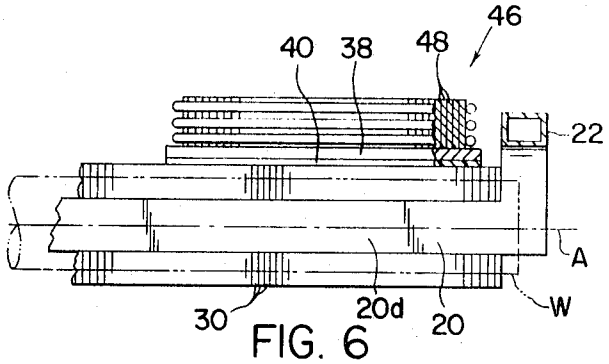


FIG. 6

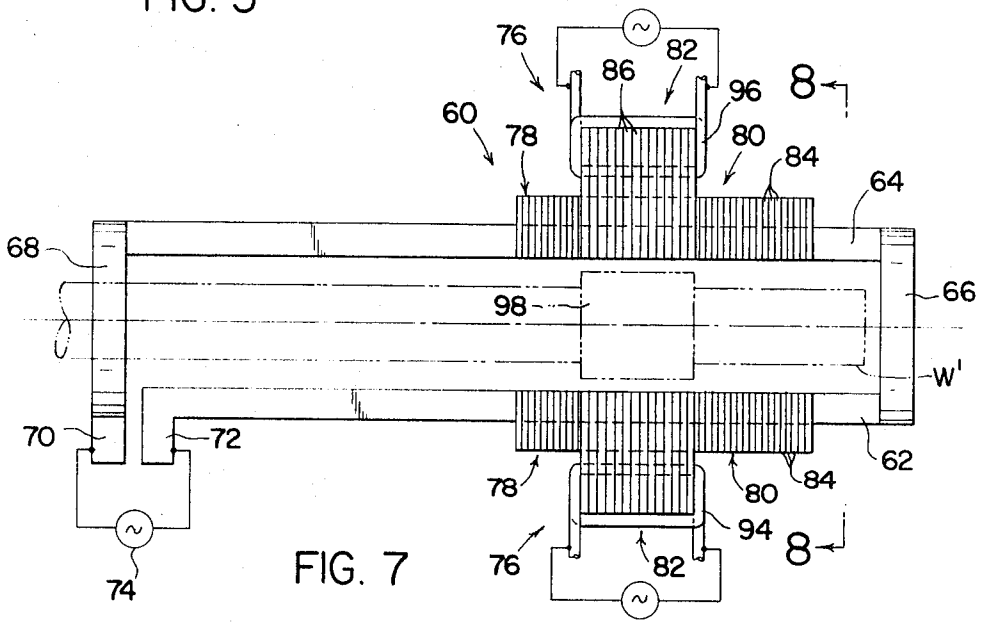


FIG. 7

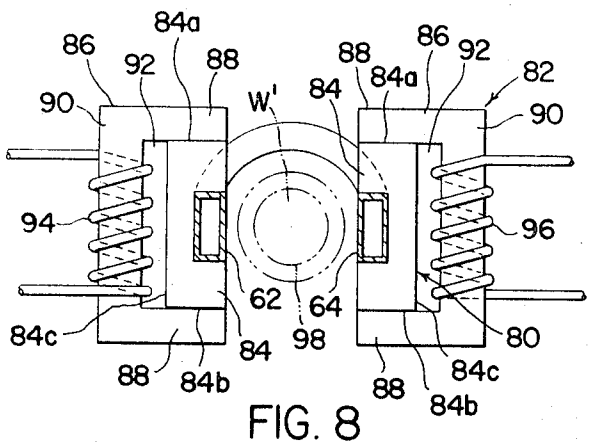


FIG. 8

INDUCTOR FOR INDUCTIVELY HEATING METAL WORKPIECES

The present invention relates to the art of induction heating and, more particularly, to inductor structures for use in induction heating system.

The present invention relates to inductore commonly known in the induction heating industry as single-shot inductors. Such inductors are comprised of a tubular conductor having spaced apart, generally parallel leg portions having corresponding opposite ends, a bridging conductor portion interconnecting at least one of the corresponding opposite ends of the legs, and terminal ends connectable across a source of alternating current for energizing the inductor. A metal workpiece to be heated is supported between the leg portions in magnetically coupled relationship with respect thereto, and the workpiece is rotated relative to the inductor to achieve uniform heating about the periphery of the workpiece. Such inductors are often used, for example, to inductively heat a given axial portion of a circular workpiece, such as an axle for a vehicle. Further, the spaced apart, parallel leg portions of the inductor are generally of a length corresponding to the axial length of the workpiece to be heated, whereby a given inductor can be employed only to heat a given axial length of a workpiece unless mechanical adjustments are made with respect to the feeding mechanism by which the given axial length of the workpiece is inserted into the inductor. It will be appreciated that the necessity of providing separate inductors for heating different axial lengths of similar workpieces, or the necessity of making mechanical adjustments in order to use the same inductor are undesirably expensive approaches for achieving the end result sought.

Further, separate one-shot inductors of the foregoing character have been required heretofore to inductively heat workpieces having different shapes or contours requiring different heating patterns along the heated length thereof. For example, the end of a vehicle axle to be heated may have a portion intermediate the ends of the area to be heated which is of a larger diameter than the axially adjacent portions of the axle, whereby the larger diameter portion is more tightly coupled magnetically with the leg portions of the inductor than are the portions of the axle on axially opposite sides of the enlarged diameter portion. Therefore, if such a workpiece is heated in an inductor having parallel leg portions adapted to uniformly heat a workpiece having a constant diameter, the enlarged diameter portion may be overheated, or the smaller diameter portions underheated. Both of the latter results are undesirable and heretofore have necessitated the use of a separate inductor designed to achieve uniform heating of the smaller and larger diameter portions of the workpiece. It will be appreciated too that an inductor designed to achieve uniform heating in the latter manner is not operable satisfactorily to achieve uniform heating of a constant diameter workpiece or a workpiece having a circumferential recess therein as opposed to a larger diameter portion.

In accordance with the present invention, singleshot inductor structures are provided which enable a single inductor to be used to achieve different heating patterns with regard to structurally similar workpieces and to achieve uniform heating of workpieces having different surface contours along the length thereof to be heated. More particularly, in accordance with a broad aspect of the present invention, current concentration in selected areas of the conductor leg portions can be varied to vary the magnitude of current induced in a corresponding portion of the workpiece, whereby different heating patterns are achieved in the corresponding portions of the workpiece. This enables, for example, the effective length of the inductor to be reduced to reduce the axial length of heating of a workpiece with respect to the full length of the inductor, or for selected axial portions along the workpiece to be heated to different extents with respect to one another. At the same time, variation in current concentration is selectable, whereby the basic one-shot inductor structure is operable to achieve uniform heating of a constant diameter workpiece along a length thereof corresponding to the length of the inductor.

In accordance with one aspect of the present invention, current concentration in the opposed conductor faces of the leg portions of the inductor is reduced by positioning an auxiliary electrical conductor or conductors in insulated but magnetically coupled relationship with respect to corresponding portions of the inductor legs. Thus, induced current flow in the auxiliary conductor or conductors reduces induced current flow in the underlying portion of the workpiece to minimize heating of the latter portion of the workpiece. The auxiliary conductor or conductors can be displaced into and from magnetically coupled relationship with respect to the leg portions of the inductor to provide for selective use of the effect of the auxiliary conductor. In accordance with another aspect of the present invention, the auxiliary conductor or conductors can be permanently positioned in magnetically coupled relationship with respect to the leg portions of the inductor and the effect of the auxiliary conductor eliminated when desired by raising the impedance thereof such as by the use of a saturable core and direct current winding arrangement.

In accordance with yet a further aspect of the present invention, current concentration can be varied through the use of flux concentrating elements associated with corresponding portions of the legs of the inductor. When the flux concentrating elements are positioned on the legs of the inductor, current concentration is increased in the corresponding portions of the opposed conductor faces of the legs. The effect of the flux concentrating elements, or portions thereof, can be eliminated such as by physically displacing the elements from the conductor leg portions, or by inducing flux to flow through the flux concentrating elements in opposition to the flow of flux resulting from current flow through the leg portions of the conductor. In this respect, for example, a winding connectable to a direct current source can be associated with the desired flux concentrating elements to induce flux flow therein for the latter purpose.

It is an outstanding object of the present invention to provide a single-shot inductor wherein current concentration in portions of the inductor along the length thereof is variable to achieve different heating effects with respect to structurally similar or dissimilar workpieces.

Another object is the provision of an inductor of the foregoing character which provides for a given inductor to be operable to effect different heating patterns with respect to structurally similar workpieces.

A further object is the provision of an inductor of the foregoing character which provides for a given inductor to be operable to effect a uniform heating pattern with respect to both structurally similar and structurally dissimilar workpieces.

Yet another object is the provision of an inductor of the foregoing character which provides for the effective length of the inductor to be selectively varied to achieve inductive heating of different lengths of workpieces.

Yet a further object is the provision of a singleshot inductor which is more versatile with respect to the heating of structurally similar or structurally dissimilar workpieces than single-shot inductors heretofore provided.

The foregoing objects, and others, will in part be obvious and in part pointed out more fully hereinafter in conjunction with the written description of preferred embodiments of the invention illustrated in the accompanying drawings in which:

FIG. 1 is a perspective view of an inductor made in accordance with the present invention;

FIG. 2 is a sectional elevation view of the inductor taken along line 2—2 in FIG. 1, and showing the auxiliary conductor in its inoperative position;

FIG. 3 is a sectional elevation view of the inductor taken along line 3—3 in FIG. 1;

FIG. 4 is a plan view of another embodiment of an inductor made in accordance with the present invention;

FIG. 5 is an end elevation view of the inductor illustrated in FIG. 4, looking the the direction of line 5—5 in FIG. 4;

FIG. 6 is a sectional elevation view of the inductor of FIGS. 4 and 5, the section being along line 6—6 in FIG. 5;

FIG. 7 is a plan view of a further embodiment of an inductor made in accordance with the present invention; and,

FIG. 8 is a sectional elevation view of the inductor of FIG. 7, the section being along line 8—8 in FIG. 7.

Referring now in greater detail to the drawings wherein the showings are for the purpose of illustrating preferred embodiments of the present invention only and not for purposes of limiting the invention, a single-shot inductor 10 is illustrated in FIGS. 1–3. Inductor 10 is comprised of a continuous tubular conductor of copper, or the like, having terminal ends 12 and 14 connectable across a suitable source of alternating current 16 for energization of the conductor. As is well known, the tubular structure of the conductor facilitates the circulation of cooling fluid therethrough and, accordingly, it will be appreciated that terminal ends 12 and 14 of the conductor are adapted to be connected to a source of cooling fluid, not illustrated, for this purpose.

Inductor 10 has an axis A, and the tubular conductor includes first and second leg pprtions 18 and 20, respectively, which are parallel and spaced apart on opposite sides of axis A. A first bridging conductor portion 22 interconnects one of the sets of corresponding ends of leg portions 18 and 20, and a second bridging conductor portion 24 interconnects the opposite end of conductor 20 with terminal end 12 of the conductor. While the tubular conductor is illustrated as being broken so as to have its terminal ends adjacent bridging portion 24, it will be appreciated that the conductor can be broken at any suitable point along the length thereof, such as at a point intermediate the opposite ends of one of the leg portions 18 and 20 to provide the terminal ends.

The tubular conductor of the inductor is generally uniform in cross-sectional configuration throughout the length thereof and, in the embodiment illustrated, the tubular conductor is rectangular in cross section, whereby conductor portions 18 and 20 and accordingly bridging portions 22 and 24 have opposed pairs of parallel spaced apart sidewalls. As best seen in FIG. 3, walls 18*a*, 18*b*, 18*c* and 18*d* provide opposed pairs of walls for conductor portion 18, and walls 20*a*, 20*b*, 20*c* and 20*d* provide opposed pairs of walls for conductor portion 20. Conductor portions 18 and 20 are laterally spaced apart for a workpiece W to be supported therebetween in coaxial relationship with respect to inductor axis A and in magnetically coupled relationship with respect to conductor portions 18 and 20. Walls 18*d* and 20*d* face workpiece W and define the conductor faces which are most tightly coupled matnetically with the workpiece.

Preferably, conductor portions 18 and 20 are provided along corresponding portions of the lengths thereof with flux concentrating arrangements 26 and 28, respectively. Each flux concentrating arrangement is comprised of a plurality of U-shaped laminations 30 of magnetic sheet metal, such as iron. As best seen in FIG. 3, laminations 30 include leg portions 32 and 34 interconnected by a bridging portion 36. Leg portions 32 and 34 extend inwardly of the corresponding conductor portion toward axis A of the inductor and terminate in generally coplanar relationship with respect to the inner surface of the corresponding walls 18*d* and 20*d* of conductor portions 18 and 20. Accordingly, the laminations overlie the sidewalls of the corresponding conductor portion other than the sidewall defining the conductor face thereof. As is well known, when the inductor is energized current flows through conductor portions 18 and 20 in a direction perpendicular to the plane of FIG. 3 and magnetic fields are established between each conductor portion and the workpiece, which magnetic fields have a direction parallel to the plane of FIG. 3. Laminations 30 concentrate the magnetic flux to increase the flux density in the workpiece and also operate to concentrate the current flowing through conductor portions 18 and 20 in walls 18*d* and 20*d* thereof, respectively. In this respect, the laminations increase the inductance in the walls of the corresponding conductor portion other than walls 18*d* and 20*d*, thus to increase the current density in the latter wall portions.

With the inductor thus far described, workpiece W is adapted to be inductively heated along a length thereof disposed within the inductor and corresponding to the effective length of the inductor as defined by the axial length of the flux concentrating arrangements. In accordance with the present invention, an arrangement is provided for reducing the current concentration in axial portions of conductor legs 18 and 20 to enable the heating of a length of the workpiece less than the entire length thereof disposed within the inductor.

In the embodiment illustrated in FIGS. 1–3, the reduction in current concentration is achieved by means of a plate 38 of electrically conductive material, such as copper, which is insulated from and magnetically coupled with conductor portions 18 and 20. Insulation

of plate **38** may be achieved by maintaining an air gap between the plate and the flux concentrating arrangements, or a layer of electrical insulating material **40** may be provided on the underside of plate **38** to assure against contact of the plate with the flux concentrating laminations. Plate **38** has an axial length less than the axial length of flux concentrating arrangements **26** and **28** and, in the embodiment illustrated, is disposed adjacent bridging conductor portion **22** of the inductor. When plate **38** is positioned as illustrated in FIGS. **1** and **3**, the flow of current through conductor portions **18** and **20** induces current in plate **38.** The induction of current in plate **38** reduces the current concentration in the axial portions of walls **18***d* and **20***d* underlying the plate and, in effect, pulls the current in conductor portions **18** and **20** towards walls **18***a* and **20***a* and away from the conductor faces facing the workpiece. Accordingly, induced current in the corresponding axial portion of the workpiece and inductive heating thereof is minimized.

With the arrangement illustrated, the axial portion of the workpiece between plate **38** and the ends of flux concentrating arrangements **26** and **28** in the direction toward bridging portion **24** is inductively heated upon energization of the inductor, and the heating pattern is effectively terminated at the axial location of the workpiece corresponding to the end of plate **38** facing bridging portion **24.** If the workpiece is introduced from the end of the inductor defined by bridging portion **22** it will be appreciated that plate **38** provides for reducing the length of the end of the workpiece heated by the inductor with the respect to the length heated in the absence of plate **38.** If the workpiece is introduced from the end of the inductor defined by bridging portion **24,** it will be seen that plate **38** provides for heating an axial portion of the workpiece spaced axially inward from the end of the workpiece. Further, by locating plate **38** in areas along the length of the inductor between the opposite ends thereof it will be appreciated that various heating patterns can be obtained with respect to a workpiece.

Preferably, suitable means is provided for mechanically moving plate **38** between the position thereof illustrated in FIGS. **1** and **3** in which it is magnetically coupled with conductor portions **18** and **20** and the position thereof illustrated in FIG. **2** in which the plate is positioned out of magnetically coupled relationship with respect to the conductor portions. Any suitable mechanism can be provided for so displacing plate **38.** For example, a hydraulic or pneumatic motor **42** having a reciprocable shaft **44** interconnected with plate **38** can be operated in a well known manner to reciprocate shaft **44** and thus selectively position plate **38** relative to the inductor. Further, it will be appreciated that additional plates similar to plate **38** and having corresponding operators such as motor **42** can be provided for the inductor, each of which plates would be independently positionable relative to the inductor to enable the heating of various lengths of workpieces or the achieving of various heating patterns along a workpiece.

In FIGS. **4–6** of the drawing there is illustrated a modification of the inductor and conductor plate arrangement illustrated in FIGS. **1–3.** The basic inductor structure in the two embodiments is the same and, accordingly, like numerals are employed in FIGS. **4–6** to designate corresponding components of the two embodiments. In the embodiment of FIGS. **4–6,** conductor plate **38** is provided with a core of magnetic material **46** defined, for example, by a plurality of iron laminations **48** parallel to one another and extending transversely of inductor axis A. Preferably, core **46** varies in cross section along the axial length of plate **38** so as to be laterally wider at the end thereof spaced from bridging portion **22** of the inductor.

A winding **50** extends around core **46** such that the winding axis is perpendicular to the plane of plate **38,** and the opposite ends **52** and **54** of winding **50** are adapted to be connected across a suitable source of direct current **56.** By flowing direct current through winding **50,** core **46** can be saturated, whereby the impedance of conductor plate **38** is increased to a value sufficient to make it ineffective for decreasing the current concentration in the underlying portions of the conductor faces **18***d* and **20***d* of the conductor portions **18** and **20.** Thus, the effective length of the inductor for inductively heating a workpiece is the full axial length of the flux concentrating arrangements **26** and **28** on conductor portions **18** and **20.** By providing for the cross section of the core to vary in the axial direction thereof, the core can be progressively saturated as the direct current through winding **50** is increased, whereby the effectiveness of conductor plate **38** in decreasing current concentration in the underlying portions of the conductor faces can be progressively decreased.

It will be appreciated that the variation in crosssectional area of the core can be other than by the tapered configuration illustrated and, accordingly, can be provided to achieve a desired heating pattern with respect to the underlying portion of a workpiece positioned within the inductor. Moreover, it will be appreciated that the cross-sectional area of the core can be the same throughout the axial length thereof for the saturation or progressive saturation thereof to uniformly affect the current concentration reducing capability of plate **38.** The core and winding arrangement advantageously enables conductor plate **38** to be maintained in a mounted position relative to conductor portions **18** and **20** and for the effect thereof to be eliminated without physically displacing the conductor plate to a position in which it is out of magnetically coupled relationship with conductor portions **18** and **20.** Moreover, it will be appreciated that more than one conductor plate and a corresponding core and winding arrangement may be provided along the length of the inductor, and that suitable controls, not illustrated, are provided for controlling the supply of direct current to the core windings.

A further embodiment of the present invention is illustrated in FIGS. **7** and **8** of the drawing. In this embodiment, an inductor **60** is provided which includes a tubular conductor of copper or the like which is rectangular in cross-sectional configuration and includes first and second conductor leg portions **62** and **64,** respectively, a first bridging portion **66** at one of the corresponding ends of leg portions **62** and **64,** a second bridging portion **68** at the opposite end of conductor portion **64,** and terminal ends **70** and **72** connectable across a suitable source of alternating current **74** for energization of the inductor. Identical flux concentrating arrangements **76** are provided on conductor portions **62** and **64** intermediate the opposite ends of the inductor as defined by bridging portions **66** and **68.**

Thus, the effective length of the inductor for heating a workpiece is the axial length of flux concentrating portions **76** and **78** along the corresponding conductor portions.

Each of the flux concentrating arrangements **76** includes axially spaced apart portions **78** and **80** and an intermediate portion **82.** Portions **78** and **80** are each defined by U-shaped laminations **84** of magnetic metal such as iron which are structurally similar to and associated with conductor portions **62** and **64** in a manner similar to that of laminations **30** described hereinabove in conjunction with the embodiment of FIGS. **1–3.** Intermediate portion **82** is comprised of a plurality of laminations **86** of magnetic metal, such as iron, notched to receive the corresponding conductor portion in a manner whereby the laminations overlie the sidewalls of the conductor other than the sidewall defining the conductor face facing a workpiece W′ between conductor portions **62** and **64.**

As seen in FIG. **8,** laminations **84** of flux concentrating portions **78** and **80** have upper and lower edges **84a** and **84b,** respectively. Laminations **86** of intermediate portion **82** are longer in the vertical direction than laminations **84** as viewed in FIG. **8** and accordingly have upper and lower portions **88** extending above and below the corresponding top and bottom edges of laminations **84.** Further, as seen in FIG. **8,** laminations **84** have outer edges **84***c*, and laminations **86** have portions **90** extending horizontally beyond the corresponding edges **84***c* of laminations **84.** Portions **90** of laminations **86** are slotted to provide a window **92** extending axially though the laminations. A winding **94** is provided about the outer leg of portion **90** of laminations **86** on conductor portion **62** and a winding **96** is provided on the outer leg of portion **90** of laminations **86** on conductor portions **64.** The ends of windings **94** and **96** are adapted to be connected to a source of direct current which may be common or separate with respect to the two windings.

If a workpiece having a uniform diameter is positioned within inductor **60** and the inductor is energized without energizing windings **94** and **96,** the workpiece will be uniformly heated along the length thereof corresponding to the length of the flux concentrating arrangement defined by sections **78, 80** and **82.** In this respect, as described hereinabove, the flux concentrating laminations operate to concentrate current flowing through conductor portions **62** and **64** in the wall thereof defining the conductor face facing the workpiece. By flowing direct current through windings **94** and **96,** laminations **86** can be saturated to eliminate the current concentrating effect of these laminations, whereby current flowing through conductor portions **62** and **64** in the portions thereof underlying laminations **86** will flow through all of the walls of the tubular conductor, thus decreasing the current concentration in the wall defining the conductor face. This advantageously enables the inductor to be employed to inductively heat a workpiece such as workpiece W′ having an axial portion **98** of enlarged diameter underlying laminations **86.** The larger diameter of portion **98** provides for the latter to be more tightly coupled magnetically with conductor portions **62** and **64,** and saturation of laminations **86** reduces the current concentration in the conductor faces opposite the enlarged portion and thus reduces the current induced in portion **98** of the workpiece. This enables uniform heating of workpiece W′ along the axial length thereof disposed within flux concentrating arrangements **76.**

Saturation of the flux concentrating portion **82** described hereinabove can also be employed to advantage to enable uniform heating of a workpiece having a circumferential recess along the length thereof as opposed to an enlarged diameter portion. In this respect, flux concentrating portions **78** and **80** can be eliminated, and laminations **86** serve to concentrate current flowing through conductor portions **62** and **64** and the axial portions thereof underlying laminations **86.** Accordingly, if the workpiece recess is in transverse alignment with laminations **86** the workpiece will be uniformly heated along the length thereof disposed within the inductor. With the same arrangement, laminations **86** can be saturated to eliminate the current concentrating effect thereof, whereby the inductor can be employed to uniformly heat a workpiece of uniform diameter disposed within the inductor.

While considerable emphasis has been placed herein on the specific sturctures of the components of the embodiments illustrated, it will be appreciated that many structural changes can be made in the components without departing from the principles of the present invention. In this respect, for example, the tubular conductor of the inductor can have a cross-sectional configuration other than rectangular, and flux concentrating elements other than iron laminations can be employed to achieve the same purpose. Further, with regard to the embodiments of FIGS. **1–3** and **4–6** it will be appreciated that the flux concentrating elements while preferred are not essential to varying current density in the conductor faces of the parallel conductor portions of the inductor.

As many possible embodiments of the present invention may be made, and as many possible changes may be made in the embodiments herein illustrated and described, it is to be distinctly understood that the foregoing descriptive matter is to be interpreted merely as illustrative of the present invention and not as a limitation.

What is claimed is:

1. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, each of said conductor portions being linear between said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said selectively operable means including electrically conductive generally planar plate means separate from said tubular conductor and having a length in the direction between said opposite ends equal to the lengths of one of said corresponding areas, said plate means being generally parallel to and overlying and spanning the space between said first and second conductor portions, and motor means to displace

said plate means into and out of magnetically coupled relationship with respect to said first and second conductor portions.

2. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said means selectively operable to vary the current concentration including electrically conductive means magnetically coupled with said first and second conductor portions, and means to vary the impedance of said conductive means.

3. The inductor according to claim 2, wherein said means to vary the impedance of said conductive means includes saturable core means and winding means therefor connectable across a source of direct current.

4. The inductor according to claim 2, wherein said conductive means is plate means overlying and spanning the space between said first and second conductor portions, and said core means overlies said plate means.

5. The inductor according to claim 2, wherein the cross section of said core means varies in the direction along said first and second conductor portions.

6. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said means selectively operable to vary the current concentration including flux concentrating means of magnetic material on corresponding axial portions of said first and second conductor portions, and means to selectively eliminate the flux concentrating effect of said flux concentrating means.

7. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said means selectively operable to vary the current concentration including flux concentrating means of magnetic material on corresponding axial portions of said first and second conductor portions, and means to eliminate the flux concentrating effect of said flux concentrating means, said means to eliminate the flux concentrating effect includes winding means on said flux concentrating means connectable across a source of direct current.

8. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, each of said conductor portions being linear between said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said tubular conductor having opposed pairs of parallel spaced apart sidewalls, flux concentrating means on said first and second conductor portions between the opposite ends thereof, said flux concentrating means including U-shaped elements of magnetic material overlying the sidewalls of each of said first and second conductor portions other than the sidewalls defining said opposed conductor faces, said means selectively operable to vary the current concentration including plate means of electrically conductive material movable between first and second positions with respect to said flux concentrating means, said plate means in said first position being disposed generally perpendicular to said opposed conductor faces and in magnetically coupled relationship with respect to said first and second conductor portions, said plate means having a length in the direction between the opposite ends of said first and second conductor portions less than the lengths of said flux concentrating means, said plate means in said second position being disposed out of magnetically coupled relationship with respect to said first and second conductor portions, and means to move said plate means between said first and second positions.

9. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart

for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said tubular conductor having opposed pairs of parallel spaced apart sidewalls, flux concentrating means on said first and second conductor portions between the opposite ends thereof, said flux concentrating means including U-shaped elements of magnetic material overlying the sidewalls of each of said first and second conductor portions other than the sidewalls defining said opposed conductor faces, said means selectively operable to vary the current concentration including plate means of electrically conductive material generally perpendicular to said opposed conductor faces and supported in magnetically coupled relationship with respect to said first and second conductor portions, said plate means having a length in the direction between the opposite ends of said first and second conductor portions less than the lengths of said flux concentrating means, and said selectively operable means further including saturable core means on said plate means and winding means on said core means connectable across a source of direct current.

10. The inductor according to claim **9,** wherein the core means has a cross section which varies in the direction between said opposite ends of said first and second conductor portions.

11. An inductor for inductively heating a metal workpiece comprising, a tubular conductor including spaced apart generally parallel first and second conductor portions having corresponding opposite ends and at least one bridging conductor portion interconnecting corresponding ones of said opposite ends, said conductor having terminal ends connectable across a source of alternating current for energizing said conductor, said first and second conductor portions being spaced apart for a workpiece to be supported therebetween in magnetically coupled relationship therewith and having opposed conductor faces facing said workpiece, and means selectively operable to vary the current concentration in corresponding axially adjacent areas of said conductor faces of both said first and second conductor portions when said conductor is energized, said tubular conductor having opposed pairs of parallel spaced apart sidewalls, flux concentrating means on said first and second conductor portions between the opposite ends thereof, said flux concentrating means including U-shaped elements of magnetic material overlying the sidewalls of each of said first and second conductor portions other than the sidewalls defining said opposed conductor faces, said means selectively operable to vary the current concentration including a corresponding portion of the U-shaped elements on each of said first and second conductor portions and winding means on said corresponding portions connectable to a source of direct current.

12. The inductor according to claim **11,** wherein said U-shaped elements are a plurality of thin metal laminations, the ones of said laminations defining said corresponding portions of said U-shaped elements having legs extending from the bridging portion of the U and defining an opening therewith, said coil means including a winding about the one of said leg parallel to said bridging portion.

* * * * *