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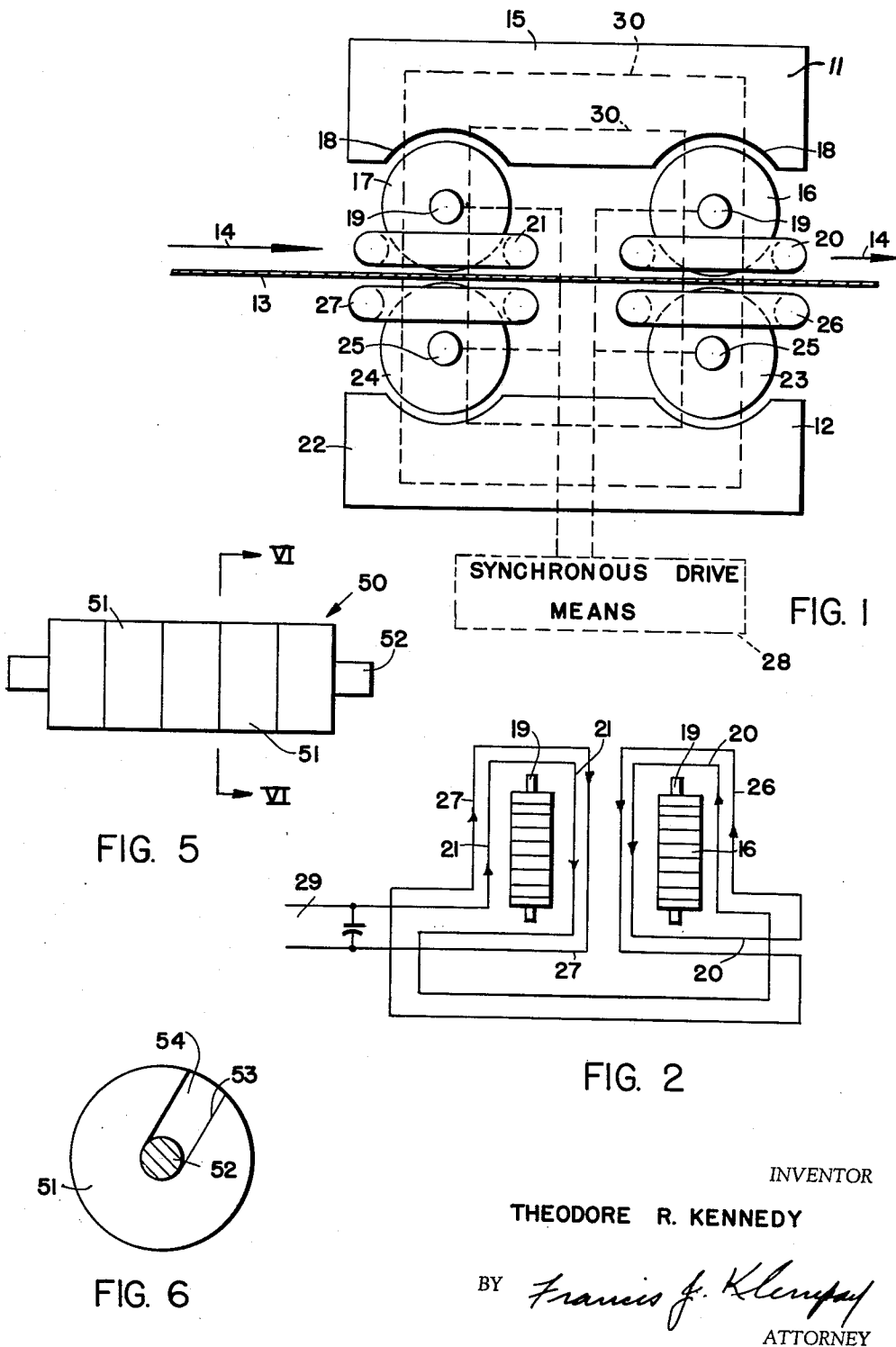
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INDUCTION HEATING OF METAL STRIP

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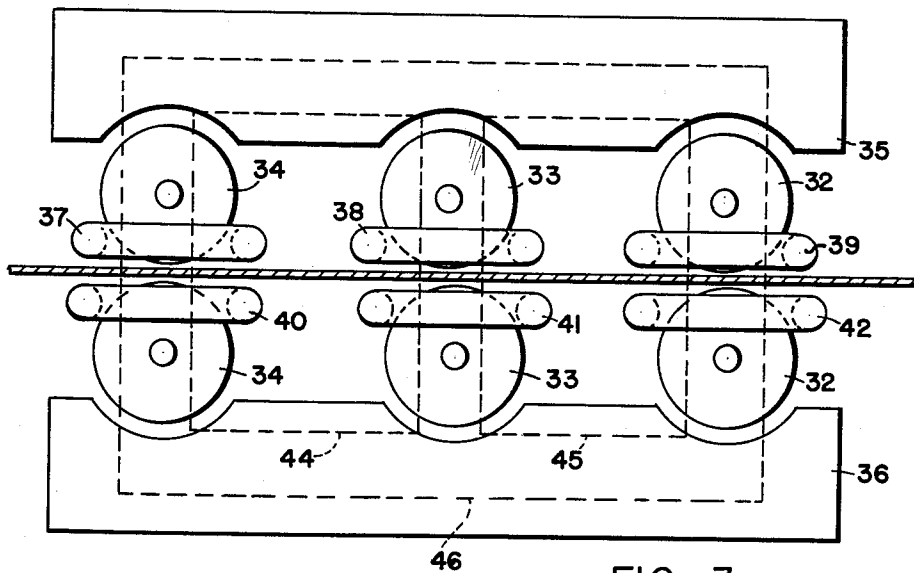


FIG. 3

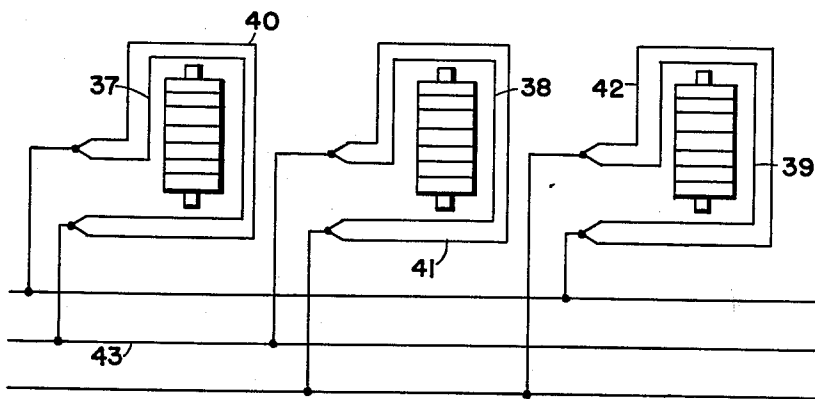


FIG. 4

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INDUCTION HEATING OF METAL STRIP

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10 Claims. (Cl. 219—10.61)

The present invention relates generally to the induction heating art and more particularly to apparatus for the induction heating of traveling metal strip.

As will be understood by those skilled in the art, it is often desirable to heat moving metal strip for various purposes; such as drying moisture from the strip, paint drying, electrolytic tin reflowing, heat treating, forming, etc. Heretofore it has been suggested to heat the moving metal strip by induction heating methods wherein the strip is continuously passed through a space in which an alternating magnetic flux is present. In most applications the alternating magnetic flux is disposed at right angles to or normally of the path of strip travel since this disposition between the traveling strip and the alternating magnetic flux permits the use of significantly lower frequencies and further, usually results in higher electrical efficiencies.

Although such methods have long been proposed in the art they have not been widely adopted due to the difficulty in adjusting the heating pattern of the induction apparatus to obtain the desired temperature distribution through the moving strip and due to the distortion of the strip material as it is moved past the induction apparatus caused by the forces of magnetic attraction or repulsion on the strip and the frictional engagement between the traveling strip and the induction heating apparatus. Also, considerable force is required to draw the strip through the alternating magnetic field and this has prevented the use of such prior art induction heating apparatus for providing high temperatures in very thin or otherwise mechanically weak strip material. The above problems and limitations have been recognized and various apparatus has been proposed for eliminating or mitigating the same. However, such apparatus is large and expensive and/or does not satisfactorily overcome these objections.

In view of the above, it is the primary or ultimate object of the present invention to provide induction heating apparatus for traveling metal strip which entirely eliminates any adverse mechanical effect, such as buckling or binding, on the moving strip due to the magnetic forces present but yet is characterized by its high electrical efficiency. The apparatus of the present invention comprises a plurality of cylindrical pole pieces that are adapted to have rolling engagement with the traveling strip. In this manner the traveling strip passes easily through the heating apparatus with a minimum of friction while yet the cylindrical pole pieces may be brought as close to the moving strip as desired. This arrangement not only guides the moving strip through the apparatus with a minimum of friction but also provides an extremely efficient electrical circuit and assists in controlling the heating pattern in the strip.

Another important object of the invention is to provide induction heating apparatus for traveling strip which is characterized by its improved ability to control and adjust the heating pattern across and along the moving strip to obtain the desired temperature distribution. The cylindrical pole pieces may be brought as close to the traveling strip as is desired for controlling the heating pattern. Also, the present invention envisions assembling the cylindrical pole pieces from a number of removable axially aligned disc-like sections and the individual sections may

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have different magnetic properties to very accurately control and adjust the heating pattern in the moving strip.

A further object of the invention is to provide induction heating apparatus for traveling metal strip which substantially eliminates the problems associated with prior art apparatus and which is characterized by its extreme simplicity in manufacture and use, relatively low cost and compactness. All of the above contribute in allowing the induction heating apparatus of the present invention to be employed in applications where induction heating methods heretofore could not be utilized.

The above, as well as other objects and advantages of the invention, will become more readily apparent upon consideration of the following specification and accompanying drawing wherein there are disclosed several preferred illustrated embodiments of the invention.

In the drawing:

FIGURE 1 is a side elevation of induction heating apparatus for traveling metal strip constructed in accordance with the teachings of this invention;

FIGURE 2 is a fragmentary plan view of a portion of the apparatus shown in FIGURE 1 depicting the electrical connections for the current conducting coils;

FIGURE 3 is a side view of induction heating apparatus for traveling metal strip adapted to be energized from a source of three phase alternating current;

FIGURE 4 is a schematic plan view of the apparatus shown in FIGURE 3 depicting the various electrical connections;

FIGURE 5 is an enlarged end view of one of the cylindrical pole pieces embodied in the apparatus of FIGURES 2 or 3; and

FIGURE 6 is an enlarged side sectional view taken along the section line VI—VI of FIGURE 5.

Referring now to the drawing, and initially to FIGURES 1 and 2 thereof, there is shown one embodiment of induction heating apparatus constructed in accordance with the teachings of the present invention which comprises an upper assembly 11 and a lower assembly 12 which are disposed above and below a normal path of strip travel 13. The strip to be heated passes between the upper and lower assemblies 11 and 12 in the direction indicated by arrows 14.

The upper assembly 11 comprises a suitably formed yoke 15 of magnetic material and a pair of longitudinally spaced generally cylindrical pole pieces 16 and 17. The yoke 15 and the cylindrical pole pieces 16 and 17 extend transversely across that portion of the moving metal strip 13 which is to be heated and the cylindrical pole pieces 16 and 17 are adapted to have rolling contact with the moving strip 13. As will be noted, the yoke 15 has longitudinally spaced recesses 18 therein for nestingly receiving a portion of the cylindrical pole pieces 16 and 17.

The cylindrical pole pieces 16 and 17 are fabricated from magnetic material, as will be later explained, and are mounted for rotation on the longitudinally spaced and transversely extending shafts 19. A series of current conducting coils 20, which are connected in parallel, extend in spaced parallel relation with respect to the axis of the cylindrical pole piece 16 transversely across the moving strip 13 and also about the ends of this cylindrical pole piece. A similar series of parallel connected coils 21 extends about the cylindrical pole piece 17.

The lower assembly 12 is similar to the upper assembly 11 and includes a yoke 22 magnetic material, a pair of longitudinally spaced and transversely extending magnetic cylindrical pole pieces 23 and 24 which are mounted for rotation on the shafts 25 and series of current conducting coils 26 and 27 which extend about the lower cylindrical pole pieces 23 and 24, respectively. It will be noted that the yoke 22 is provided with depressions for nestingly receiving portions of the cylindrical pole pieces

23 and 24 and that these last mentioned members are disposed adjacent the underside of the moving strip 13 in opposed vertically aligned relation with respect to the cylindrically pole pieces 16 and 17.

Of course, suitable apparatus, not shown, is provided for moving the strip 13 through the induction heating apparatus. This may include a pair of driven pinch rolls, for example, and it is preferred that the shafts 19 and 25 mounting the cylindrical pole pieces 16, 17 and 23, 24 be driven by synchronous drive means, indicated generally at 28, in such a manner that the peripheral speed of the pole pieces is always equal to the linear speed of travel of the traveling strip 13. Such synchronous drive means, in and of itself, does not form a portion of the present invention and any well known drive arrangement capable of synchronizing the peripheral speed of the cylindrical pole pieces with the linear speed of the traveling strip may be employed.

It will thus be seen that the strip 13 moves between vertically aligned and opposed longitudinally spaced pairs of cylindrical pole pieces which are rotated at a speed corresponding to that of the traveling strip. To induce an alternating magnetic field in the cylindrical pole pieces and the yokes the series of coils 20, 21 and 26, 27 are connected in series electrical relation between the two terminals of a single phase alternating current source 29 in the manner shown in FIGURE 2 of the drawing. The electrical connections are such that the adjacent and parallel transversely extending reaches of the coils 20 and 21 assume the same instantaneous polarity and this arrangement is also applicable to the adjacent and parallel transversely extending reaches of the series of coils 26 and 27. In FIGURE 2 of the drawing the direction of current flow is shown by the arrows—assuming that the upper terminal of the single phase alternating current source 29 is positive at this instant in time. The overall arrangement is such that the series of coils 20, 21, 26 and 27 generate and induce a magnetic field within the various cylindrical pole pieces and the magnetic circuit is completed through the cylindrical pole pieces, the yokes, the moving strip and the various air gaps between the moving strip, the yokes and the cylindrical pole pieces. The path of flux travel for this magnetic circuit is indicated by the broken lines 30 in FIGURE 1 of the drawing and it will be noted that an alternating magnetic field extends vertically through the traveling strip 13 at a pair of longitudinally spaced areas. In accordance with well known induction heating theory the alternating magnetic field in the traveling strip 13 induces eddy currents which very quickly heats the same. The instantaneous direction of the current flowing in the series coils extending around the cylindrical pole pieces is such that the pole pieces 16 and 17 are magnetized in substantially diametrical directions and this same arrangement also applies to the lower cylindrical pole pieces 23 and 24. This produces a closed magnetic circuit through the yokes, cylindrical pole pieces, the various air gaps and the traveling metal strip.

The yokes and series of energized coils are, of course, stationarily mounted while the various cylindrical pole pieces rotate at a speed corresponding to that of the traveling strip. The rotating cylindrical pole pieces of the induction heating apparatus provide for friction free movement of the traveling strip even though substantial forces of magnetic attraction or repulsion are present. The cylindrical pole pieces can therefore be adjustably moved to positions as close to the moving strip as is desirable for any given heating application whereby the electrical efficiency is maintained at a maximum and the heating pattern is properly controlled without in any manner effecting the easy passage of the strip through the heating apparatus. As will be understood, air is relatively non-magnetic and the air gaps must or should be relatively small whereby the overall reluctance of the closed magnetic circuit is kept within reasonable limits. The size

of the air gaps required for any given application is, of course, variable. In the present apparatus the required air gaps can always be obtained since the cylindrical pole pieces may be moved as close to the strip as required.

The cylindrical pole pieces may also be employed to support, move or restrain the traveling strip and when so employed they further eliminate any problem of strip buckling without adversely effecting the electrical efficiency of the heating apparatus. The above disclosed apparatus may, of course, be modified for working particular strip material. For low temperature heating of highly polished metal strip belts of spun glass, cloth or the like may encircle the upper and lower pairs of cylindrical pole pieces. Alternately, the peripheral surfaces of the cylindrical pole pieces may be coated with suitable refractory material. If desirable, the cylindrical pole pieces may be heated or cooled depending upon the heat transfer problems encountered in any given application. Other similar modifications will be apparent to those skilled in the art.

Since the rotating cylindrical pole pieces do not impede the longitudinal movement of the strip, as many opposed pairs thereof as are required to perform any desired heating operation may be employed. For example, two or more of the heating units shown in FIGURES 1 and 2 could be utilized in longitudinally spaced series relation along the path of strip travel.

Three opposed pairs of rotating pole pieces and the appropriate yoke construction as shown in FIGURES 3 and 4 would allow the use of three phase alternating current for powering the heating apparatus. In this embodiment of the invention the magnetic circuits are provided by the strip 13, the three pairs of opposed cylindrical pole pieces 32, 33 and 34, upper and lower yokes 35 and 36 and the associated air gaps. The magnetic fields are induced by the series of coils 37—42 encircling the cylindrical and rotating pole pieces 32—34. The preferred method of connecting the series of coils 37—42 to an alternating current three phase source 43 is shown in FIGURE 4 of the drawing while the flux paths are indicated by reference numerals 44, 45 and 46 in FIGURE 3. It should be apparent that any type source of alternating current can be employed by providing the correct number of pairs of opposed cylindrical pole pieces and properly connecting the series of coils associated therewith to the source. Also, if desired, the series of coils may be wrapped about the yokes rather than around the cylindrical pole pieces to induce the alternating magnetic field.

Referring now to FIGURES 5 and 6 of the drawing, there is depicted a preferred construction for the cylindrical pole pieces used in the induction heating apparatus of the present invention. A cylindrical pole piece 50 is shown to comprise a plurality of annular disc-like sections 51 mounted in axial alignment on a shaft 52. In order to control the pattern of heating in the moving strip various of the annular disc-like sections 51 may be made from materials having different magnetic properties and/or nonmagnetic spacers may be inserted between adjacent ones of the magnetic disc-like sections 51. In this manner the zones of the moving strip which are heated can be accurately controlled or adjusted in width or location by appropriate spacing and/or selection of the proper disc-like sections. Each individual disc-like section 51 is preferably formed of a material best adapted to give the heating pattern desired for any given application. Also, the yoke or yokes may be sectionalized in the same manner as the cylindrical pole pieces to provide further control and adjustment over the heating zones and the heating pattern.

A portion of the individual spacers 51 may be formed from anti-magnetic material for controlling the heating pattern in the moving strip. For example, the spacers adjacent the ends of the pole pieces may be of anti-magnetic material to properly limit the heating of the edges of the moving strip as is desired for certain appli-

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cations. The heating areas can be adjusted in width or location by appropriate selection and positioning of the spacers forming the cylindrical pole pieces.

The induction heating unit of the present invention is ideally suited for the heating of moving strip in a vacuum or a preferred atmosphere. Many of the newer and costly metals must be worked while in a preferred atmosphere as will be apparent to those skilled in those particular arts.

The location of like sections 51 in opposed pairs of the cylindrical pole pieces does not necessarily have to be the same nor do the various pairs of opposed pole pieces need to be the same as other pairs thereof. In this manner the flux can be properly and controllably distributed between the opposing sets of cylindrical pole pieces and also transversely across the heating areas of the moving strip. It is generally desirable, however, to maintain substantially equal numbers of similar sections on each of the cylindrical pole pieces in order to minimize stray field effects due to excessive magnetic flux leakage.

As shown in FIGURE 6, each of the disc-like sections 51 is provided with a radially extending slot 53 whereby the sections may be removed individually from the shaft 52 without disassembling the entire cylindrical pole piece. To improve the magnetic circuit when this construction is employed a removable and properly shaped filler piece 54 may be inserted in the slot 53. The filler pieces may also serve as the means for clamping the sections 51 to the shaft 52 or this can be accomplished in any other well known manner. The above described arrangement allows the sections 51 or the spacers to be changed in a minimum of time and with a minimum of effort.

The induction heating apparatus herein disclosed is characterized by its extreme versatility in that a design engineer is given wide latitude in selecting the correct materials, air gaps, etc. best adapted for any given strip heating operation. The spacing between the cylindrical pole pieces and the moving strip can be accurately controlled and adjusted. The sections of the pole pieces may be easily and readily changed to alter or control the heating pattern in the strip material. This is particularly advantageous in continuous processing lines or when it is desired to heat a different type of moving strip material. It is, of course, expected that in some applications it may be desirable to employ solid cylindrical pole pieces and this is within the purview of the present invention.

It should thus be apparent that I have accomplished the objects initially set forth. Although the illustrated embodiments have been shown and described in connection with flat moving strip material it should be understood that this term is also meant to apply to other moving workpieces, such as channel-shaped stock, etc. Since many changes may be made in the illustrated embodiments without departing from the teaching of the invention reference should be had to the following appended claims in determining the true scope and intent of the invention.

I claim:

1. Induction heating apparatus for heating of a longitudinally moving workpiece which comprises a magnetic circuit, said magnetic circuit comprising longitudinally spaced areas of said moving workpiece, a plurality of pairs of cylindrical pole pieces disposed on opposite sides of and closely adjacent said moving workpiece at said longitudinally spaced areas, said cylindrical pole pieces having their axes extending transversely with respect to the direction of travel of said moving workpiece, a pair of magnetic yokes, each of said magnetic yokes bridging the space between the ones of said cylindrical pole pieces disposed on one side of said moving workpieces, a coil extending about each of said cylindrical pole pieces, a polyphase alternating current source, and the coils extending about each of said pairs of said cylindrical pole

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pieces being connected across one phase of said polyphase alternating current source.

2. Induction heating apparatus for the heating of a moving workpiece which comprises a magnetic circuit and means for inducing magnetic flux to flow in said magnetic circuit, said magnetic circuit comprising said moving workpiece and at least one cylindrical pole piece having its peripheral surface positioned closely adjacent said moving workpiece, the axis of said cylindrical pole piece being disposed normally with respect to the normal path of travel of said moving workpiece, said magnetic flux entering and emerging from said cylindrical pole piece in such a manner to inductively heat said moving workpiece, said means for inducing magnetic flux comprising a series of electrical conductors extending around said cylindrical pole piece in generally parallel and transverse relation with respect to said axis of said cylindrical pole piece, and means connecting said series of electrical conductors to a source of alternating current potential.

3. Induction heating apparatus for the heating of a moving workpiece which comprises a magnetic circuit and means for inducing magnetic flux to flow in said magnetic circuit, said magnetic circuit comprising said moving workpiece and at least one cylindrical pole piece having its peripheral surface positioned closely adjacent said moving workpiece, the axis of said cylindrical pole piece being disposed normally with respect to the normal path of travel of said moving workpiece, said magnetic flux entering and emerging from said cylindrical pole piece in such a manner to inductively heat said moving workpiece, and said cylindrical pole piece comprising a plurality of removable and replaceable axially aligned disc-like sections.

4. Induction heating apparatus for the heating of a moving workpiece which comprises a magnetic circuit and means for inducing magnetic flux to flow in said magnetic circuit, said magnetic circuit comprising said moving workpiece and a pair of generally cylindrical pole pieces, said cylindrical pole pieces being disposed on opposite side of said moving workpiece in closely adjacent relation thereto, the axes of said cylindrical pole pieces being disposed normally with respect to the direction of movement of said moving workpiece, said magnetic flux passing through said moving workpiece in such a manner to inductively heat the same, means to rotate said cylindrical pole pieces about their own axes, and said means to rotate comprising means to synchronize the peripheral speed of said cylindrical pole pieces with the linear speed of travel of said moving workpiece.

5. Induction heating apparatus for the heating of a moving workpiece which comprises a magnetic circuit and means for inducing magnetic flux to flow in said magnetic circuit, said magnetic circuit comprising said moving workpiece and a pair of generally cylindrical pole pieces, said cylindrical pole pieces being disposed on opposite side of said moving workpiece in closely adjacent relation thereto, the axes of said cylindrical pole pieces being disposed normally with respect to the direction of movement of said moving workpiece, said magnetic flux passing through said moving workpiece in such a manner to inductively heat the same, said means for inducing magnetic flux comprising coils of conductors extending about each of said cylindrical pole pieces, said coils each having a pair of spaced reaches disposed in parallel relation to the axis of the cylindrical pole piece associated therewith, and means connecting said coils to a source of alternating current potential.

6. Induction heating apparatus for the heating of a moving workpiece which comprises a magnetic circuit and means for inducing magnetic flux to flow in said magnetic circuit, said magnetic circuit comprising said moving workpiece and a pair of generally cylindrical pole pieces, said cylindrical pole pieces being disposed on opposite side of said moving workpiece in closely adjacent relation thereto, the axes of said cylindrical pole pieces being dis-

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posed normally with respect to the direction of movement of said moving workpiece, said magnetic flux passing through said moving workpiece in such a manner to inductively heat the same, each of said cylindrical pole pieces comprising a plurality of removable and replaceable axially aligned disc-like sections, and the arrangement being such that said disc-like sections may be of materials having different magnetic properties to control the heating of said moving workpiece.

7. Apparatus according to claim 6 further characterized in that each of said disc-like sections has radially extending slots therein, said disc-like sections being mounted on a shaft, and said slots allowing said disc-like sections to be removed individually without disassembly of said cylindrical pole pieces.

8. Induction heating apparatus for the heating of a longitudinally moving workpiece which comprises a closed magnetic circuit, said magnetic circuit comprising longitudinally spaced areas of said moving workpiece, a first pair of cylindrical pole pieces disposed on opposite sides of and closely adjacent said moving workpiece at one of said spaced areas, a second pair of cylindrical pole pieces disposed on opposite sides of and closely adjacent said moving workpiece at the other of said spaced areas, said cylindrical pole pieces having their axes extending transversely with respect to the direction of travel of said moving workpiece, a pair of magnetic yokes, each of said magnetic yokes bridging the space between the ones of said cylindrical pole pieces disposed on one side of said moving workpiece, means for inducing magnetic flux in said magnetic circuit whereby said moving workpiece is inductively heated at said longitudinally spaced areas, means to rotate said cylindrical pole pieces, and said yokes having depressions therein for nestingly receiving portions of said cylindrical pole pieces.

9. Induction heating apparatus for the heating of a longitudinally moving workpiece which comprises a closed magnetic circuit, said magnetic circuit comprising longitudinally spaced areas of said moving workpiece, a first pair of cylindrical pole pieces disposed on opposite sides of and closely adjacent said moving workpiece at one of said spaced areas, a second pair of cylindrical pole pieces disposed on opposite sides of and closely adjacent said

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moving workpiece at the other of said spaced areas, said cylindrical pole pieces having their axes extending transversely with respect to the direction of travel of said moving workpiece, a pair of magnetic yokes, each of said magnetic yokes bridging the space between the ones of said cylindrical pole pieces disposed on one side of said moving workpiece, means for inducing magnetic flux in said magnetic circuit whereby said moving workpiece is inductively heated at said longitudinally spaced areas, said means for inducing comprising a coil extending about each of said cylindrical pole pieces, means connecting the coils to a source of alternating current, and said means connecting being such that said first and said second pairs of said cylindrical pole pieces are instantaneously dimensionally magnetized to provide said closed magnetic circuit.

10. Induction heating apparatus for the heating of a longitudinally moving workpiece which comprises closed magnetic circuit, said magnetic circuit including longitudinally spaced areas of said moving workpiece, a first pair of pole pieces disposed on opposite sides of and closely adjacent said moving workpiece at one of said spaced areas, a second pair of pole pieces disposed on opposite sides of and closely adjacent said moving workpiece at the other of said spaced areas, said pole pieces extending transversely with respect to the direction of travel of said moving workpiece, a pair of magnetic interconnecting means, each of said magnetic interconnecting means bridging the space between the ones of said pole pieces positioned on one side of said moving workpiece, means for inducing magnetic flux in said magnetic circuit, and said magnetic flux passing through said moving workpiece in a direction generally normal to said direction of travel of said moving workpiece at said spaced areas.

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