

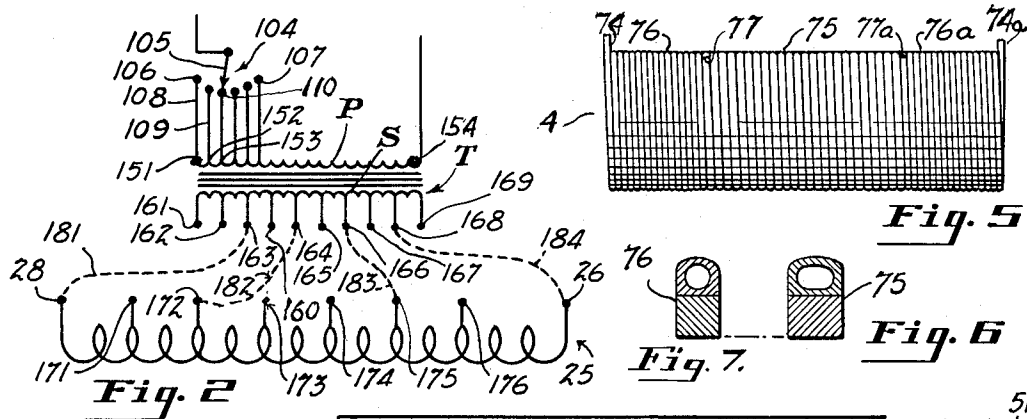
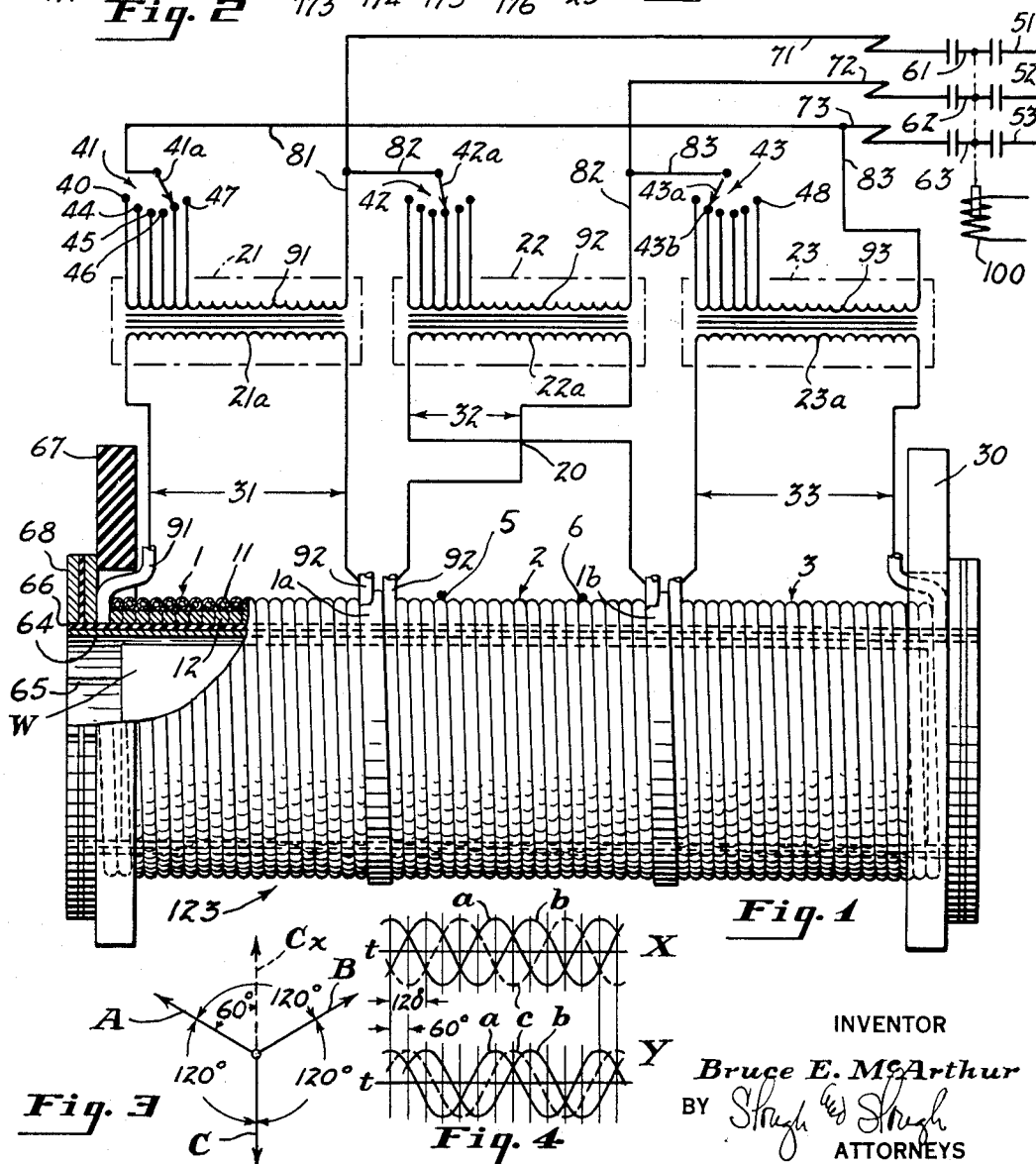
May 29, 1956

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2,748,240

INDUCTION HEATING SYSTEMS

Filed July 29, 1952



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1

2,748,240

INDUCTION HEATING SYSTEMS

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Application July 29, 1952, Serial No. 303,342

2 Claims. (Cl. 219—10.75)

The present invention relates to improvements in electrical induction furnaces, and relates more particularly to the provision of improvements adapted to effect differing advantageous distribution of the heating effect of alternating currents directed through the inductor coil or coils thereof, along the length of an elongated metal work-piece telescoped radially within the induction coil winding convolutions.

The invention hereof, although not limited thereto, finds ready application to that type of induction furnace of which that disclosed in the prior pending application of Lackner et al., Serial No. 205,766 filed January 12, 1951, now Patent No. 2,676,234 issued February 2, 1954, is an example, and which disclosed a furnace having a multi-section winding comprising a coil unit consisting of plurality of relatively axially aligned, induction heating coils, each said coil consisting of a helical conductor which is preferably disposed in a single layer of convolutions, and the coils of the unit being each energized by a different flow of single phase alternating current, and said coil unit being adapted for the reception of an elongated metal work-piece telescoped into a heating compartment provided within the conductor convolutions thereof.

In the operation of electrical induction furnaces of the general type exemplified by that of said prior application, wherein the coil unit comprises a set of three longitudinally successive induction heating coils, I find that, when the three induction coils of the coil unit are energized, the portions of an elongated metal work-piece, which are disposed nearer to those regions of the three-coil unit at which opposite longitudinal ends of the intermediate of said coils are respectively adjacent to a longitudinal end of a respectively different one of the other coils of the unit, are heated more slowly, and therefore do not, in the same period of time, achieve the same degree of heating as do the portions of the work-piece which are disposed radially within the middle convolutions of each coil of the unit.

The effect of a greater concentration of magnetic lines of force in the longitudinally medial regions of each energized coil of the unit, and the effects of variations in heat radiation in different longitudinal portions of the work-piece are contributing factors to the above result, but the principal contributing factor resides in the difference in phase of the three magnetic flux fields, which result from concurrent energization of the three aligned induction coils, and such factors is mainly adversely effective in the heating of portions of the length of the elongated metal work-piece which are nearer to the regions where opposite longitudinal ends of different of said coils are adjacent.

The improvements hereof are directed toward the amelioration and correction of such undesired factors, whereby an elongated metal work-piece may have different portions of its length heated more nearly to the same desired temperature.

Again it is often desirable to effect herein so-called

2

tapered heating of an elongated metal work-piece to achieve predetermined gradients of inductive heating effort in different portions of its length, whereby different relatively longitudinally displaced portions of the work-piece may be heated, either to the same, or to respectively different predetermined temperatures, under conditions wherein the said work-piece portions are of the same, or different cross-sectional areas.

Different of the present improvements are adapted to singly, or co-operatively, achieve the above recited desired results or any thereof.

An object of my invention, therefore, is to provide improved means to achieve concurrent heating of different longitudinally aligned portions of an elongated metal work-piece by directly alternating current through the winding convolutions of an induction heating coil unit in an improved manner to cause each of said portions to achieve closely corresponding elevated temperatures, in a desired period of time.

Another object of my invention is to achieve the foregoing object in an induction heating furnace and system, when the said portions of the work-piece are of variant cross-sectional area.

Another object is to provide for the heating of different longitudinal portions of an elongated metal work-piece by induction heating thereof, in such manner that portions of the work-piece which are relatively longitudinally displaced may be concurrently heated to predetermined variant temperatures.

Another object of my invention is to provide improved means which are adapted to effect avoidance of relative concentration of magnetic flux lines of force in the regions of a metal work-piece which are nearest the longitudinal middle of any single coil, or of a plurality of coils, of a coil unit, as a result of energization of said unit by a flow of alternating current directed through the unit.

Another object of my invention is to provide an improved induction coil means for an induction coil unit, which, when energized is adapted to effect improved distribution of different degrees of magnetomotive force to different portions of the length of a metal work-piece in which is surrounded by winding convolutions of said unit, to cause the different portions of the length of said work-piece to concurrently achieve predetermined relatively different temperatures in said work-piece portions.

Another object of my invention is to concurrently achieve at relatively low cost, predetermined degrees of heating temperatures, by an electrical induction method, in each of the differently longitudinally disposed portions of an elongated metal work-piece of uniform or variant cross-sectional form, in a relatively short, fixed period of time.

Another object of my invention is to achieve the above and other objects of my invention in an electrical and induction heating system through the use of three separate single phase currents derived from a three-phase readily available commercial source of power, without substantial unbalance of the load on each of the power leads extending from said source, in an electro-thermally efficient manner.

Other objects of the invention, and the invention itself, together with the instrumentalities employed to achieve the results thereof, will be obvious to those skilled in the induction heating art from the following exemplary descriptions of embodiments of the invention, and the accompanying drawings, whereof

Fig. 1 is a side elevational view of a three-coil unit of an induction furnace system which is an embodiment of my invention, said unit being shown in elevation and having a portion indicated as broken away to show an interior furnace compartment, and an electrical system

for delivering energizing electrical currents to said coils, said system being shown diagrammatically.

Fig. 2 is a diagrammatic view of electrical system means for achieving variant heating of different portions of the length of an elongated metal work-piece disposed in the furnace compartment of an induction furnace.

Figs. 3 and 4 are conventional graphs each of which illustrate the phase relationships of conventional three-phase voltage and/or of magnetomotive forces, which are employed in the electrical and electromagnetic systems which are involved in the operation of the furnace of Fig. 1.

Fig. 5 is a showing of an induction coil winding which is a modification of any of the coils of the unit of Fig. 1.

Figs. 6 and 7 are cross-sectional views of different portions of the water-cooled conductor employed in the coil winding of Fig. 5.

Referring now to the drawings, in all of which like parts are designated by like reference characters, the heating coil unit of Fig. 1 comprises three coils 1, 2 and 3 of separate helically wound electrical conductors 10, each conductor having a tubular portion, as indicated at 11, and each tubular portion 11 is preferably integrally bonded to a rectangular solid copper bar 12, to increase the conductivity of the conductor. The tubular portion 11 is adapted to receive a flow of coolant liquid to maintain the coil conductors cool during operation of the furnace, as fully explained in the said prior application of Lackner et al., previously referred to.

As in the induction coil unit shown in the said prior application, the coils 1, 2 and 3 are disposed in axial alignment being preferably telescoped over a heat and electrical insulating tube 66 which is impervious to moisture and which is preferably formed of a fiber-glass and plastic composition, and preferably providing a stainless steel tube 64 telescoped within the tube 66, said tube being split longitudinally as indicated at 65, the interior of said tube 65 affording an elongated cylindrical furnace compartment. Mounting and clamping elements for the conductors, as at 67 and 68, are provided as more fully disclosed in said prior application for patent.

At 21, 22 and 23, three different single phase step-down transformers are shown, the secondary windings 21a, 22a and 23a, thereof, being connected by respective pairs of conductors 31, 32 and 33 to different of the induction coils 1, 2 and 3 of the unit which is generally indicated by the reference character 123.

The energizing current from the three-phase power line conductors 51, 52 and 53 are led through contacts of the ganged switches 61, 62 and 63, which preferably are concurrently actuatable to "opened" and "closed" positions by the electromagnet as indicated at 10, and through the conductors 71, 72 and 73 and the different pairs of end terminals 81, 82 and 83 of the respective primary coils 91, 92 and 93 of the different transformers 21, 22 and 23, in the manner shown to cause three separate currents of different single phases derived from the three phase leads 51, 52 and 53 to be respectively communicated to different of the primary windings of the three transformers.

Electrical circuit changing means are provided by the switches at 41, 42 and 43 of Fig. 1, whereby the different longitudinal portions of the metal work-piece W, which are respectively enclosed by different of the coils 1, 2 and 3, may be heated to differing temperatures as a result of relatively increasing or decreasing the strength of alternating electrical current directed to different of the said coils.

The furnace which is herein shown and described, is thus adapted to be energized by low voltage alternating currents of the different three phases, each of the same low frequency such as 60 cycles, derived from a three-phase source, the latter being here represented in the drawings by the conductors 51, 52 and 53 of a three-

phase high voltage power line. The set of single phase step-down transformers 21, 22 and 23, serve to reduce the voltage of currents of each of the three phases which are respectively directed through the three induction coil windings 1, 2 and 3 of the furnace, and serve also to afford a ready means of separately delivering, as from the secondary windings of said transformers three different low voltage currents, each being of relatively different of the three phases of a three phase system, to different of the said induction coils, in such a manner as to facilitate reversal of the direction of current flow through an intermediate one of said coils, for the purpose of relatively reversing the phase of the magnetic flux induced by such current, and thereby improving the over-all efficiency of the electrical induction operation, as later herein set forth.

The first or left-hand conductor of the secondary coil 21a of the transformer 21, is shown as connected to the terminal 91 at the left end of the induction coil 1 and the second or right-hand conductor 31 is connected to the opposite terminal 92 at the right-end of the said coil 1.

The arrangement for the coil 3 is the same as that of said coil 1, the first and second of the conductors 33 being respectively connected to the left-hand and right-hand end terminals of said coil 3; however, in the case of the conductors 32 which lead from the secondary transformer winding 22a, the first or left-hand terminal of the secondary transformer winding 22a is connected to the right-hand terminal of the coil 2, and the right-hand terminal thereof of said winding 22a is connected to the left-hand terminal of said induction coil 2. While, therefore, separate flows of single phase current are thus directed respectively through the respective coils 1, 2 and 3; in the case of the coil 2, current is directed in the relatively reversed direction through the convolutions of said coil 2.

It will be understood that in the showing of Fig. 1 each of the coil windings is of like form and viewed from the left end of the coil unit 123, the conductors of each of the coils 1, 2 and 3 are wound in the same clockwise circuitous direction, but because of the transposition of the pair of conductors 32 leading from the secondary winding 22a to the coil 2, as at 20, current will traverse the winding 2 in an opposite circuitous direction to that prevailing in the case of coils 1 and 3, and opposite to the direction of flow which would prevail for coil 2 had the pair of conductors 32 not been transposed.

It will be understood that such reversal of the direction of circuitous flow of current through the convolutions of the coil 2, could alternatively be achieved in other ways, such as by winding the convolutions of said coil 2 in the relatively opposite or counter-clockwise direction, or by relatively transposing the conductors of the pair 82, which lead to opposite terminals of the primary winding 92 of the transformer 22, but the present invention is not restricted to any of the above or other obvious expedients, and any thereof may be employed to achieve the same purpose of reversing the direction of current flow through the intermediate of three successively disposed induction coils.

Each of the coils 1, 2 and 3 is essentially an electromagnetic winding and, with respect to the work-piece W, operates as would the primary winding of a transformer having a short-circuited secondary winding, the latter being represented by the metallic work-piece W, and the alternating current passing through each of said coils 1, 2 and 3 is effective to induce a separate field of magnetic flux of alternating polarity, which permeates the metallic material of that portion of said work-piece which is enclosed by the coil and induces therein, a heavy alternating current, of very low voltage, which causes electro-thermal heating of the work-piece.

5

Each single alternation, or impulse of single phase current through any of said coils 1, 2 and 3 creates magnetic poles of opposite polarity at the ends of the coil, said polarities being relatively reversed at each coil end during the next impulse.

Respectively north and south magnetic poles will be momentarily produced in the magnetic flux at a first and second of the opposite ends of the coil 2 during the period of any single unidirectional impulse of alternating current flowing through said coil, whereas except for the transposition of the conductors 32 at 20, said first and second coil ends would, at such time, be of opposite or respectively south and north polarities.

The phase relations of the three fields separately induced by different of the coils 1, 2 and 3 would, except for the previously described reversal of the direction of current flow through the coil 2, correspond to that of the three phases of a three-phase system, which is portrayed by the conventional vector diagram of Fig. 3, wherein the divergent solid lines A, B and C indicate a three-phase, 120° displacement between each pair of the separate single phases of the respectively different three fields of flux, under the assumed condition that there has been no reversal of the direction of current, which flows through the coil 2, and induces the magnetic flux of the phase C.

Under the condition of reversed current, as described, flowing through said coil 2, the phase relations between different of the three flux fields is so altered, that the resultant phase relationship between said three flux fields, may also be shown by the same vector diagram of Fig. 3 when the dotted line Cx is substituted for the line C, to indicate that, as a result of reversal of polarity of the magnetic flux which is induced by reversed direction of flow of alternating current passing through the coil 2, the phase C has been replaced by the relatively opposite phase Cx and is displaced by an angle of only 60°, respectively from the phases A and B, i. e. the phase relations between the three flux fields are now like those between three successive of the phases of a six-phase periodic system.

In considering the showings of the graphs X and Y of Fig. 4, as applied to the phase relations between three fields of magnetic flux, the horizontal line *t* is a so-called time line, the sinusoidal lines *a*, *b* and *c*, each of which alternatively extend above and below the line *t*, respectively relates to the respective fields of magnetic force induced by the relatively separate flows of alternating current passing through the respective coils 1, 2 and 3, to respectively show the periods, measured horizontally on the time line *t*, when the successive impulses of magnetic force of the respective fields of flux, are of positive polarity when above the line *t*, or of negative polarity when below the line *t*. In the graphs X and Y, the equally spaced vertical lines divide the time line *t* into 60°, i. e. $\frac{1}{6}$ cycle, time periods.

The graphs X and Y are alike with respect to the sinusoidal lines, or waves, *a* and *b* which respectively indicate the time and polarity relations of the fields of magnetic force respectively induced by the separate flows of alternating current through the induction coils 1 and 3, but differ with respect to the showing of the dotted line wave *c*, where graph X at *c*, shows relative time and polarity relations between the field of magnetic force induced by the flow of alternating current through the coil 2 to the fields induced by the flows through coils 1 and 3, under the assumption that the in-feed conductors 32 are not transposed at 20 as shown in Fig. 1, and where graph Y shows the effect of reversal of the direction of current flow through coil *w*.

Therefore, as also shown in Fig. 3, the graph Y by the dotted line *c* thereof, is shown to take a phase position which is displaced 180° along the time line *t*, from its position shown in graph X as a result of such reversal of the direction of current flow through the coil 2.

6

As shown in Y, the positive and negative impulses of said wave *c* are each interspaced in time, measured along the line *t*, from impulses of like polarity, of said waves *a* and *b*, by a period equal to $\frac{1}{6}$ of a complete cycle, and expressed otherwise as best indicated by Fig. 3, is relatively displaced from the like impulses of each of waves *a* and *b* by a phase angle of 60°.

Thus the successive waves, *a*, *c* and *b*, of alternating magnetic flux impulses in the three fields of flux are shown to be relatively in the same relative phase relations to each other, as are three successive phases of a six-phase periodic system.

In this manner the displacement in phase of the magnetic flux induced by current flow through coil 2, relative to the phases of flux induced by the current flows through coils 1 and 3 is so reduced, that the three fields of flux induced by currents through the coils 1 and 3, that the aggregate magnetization more closely approaches that which would take place were a single phase current passed through the three coils in the same circuitous direction of flow, and resultantly the electro-thermal efficiency of the furnace is very greatly improved, particularly with respect to those portions of the pair of fields of flux which are induced by respective of the pair of coils 1 and 3, or the pair of coils 2 and 3, in those regions where opposite ends of each coil of said pairs, are in adjacent relation; this result is achieved since heating of the portion of the work-piece in said regions, is much less adversely influenced by the effect of the reduction of relative phase displacement, as between adjacent portions of each of said pairs of flux fields.

Instead of a single set of coils 1, 2 and 3, a plurality of such sets may be employed for a single furnace, whereby there may be one, two, three etc. sets of three coils each, successively arranged in relative axial alignment with the coils of the set 123, corresponding induction coils of the different sets being preferably connected in parallel, or in series, with each other, so as to be energized preferably, by current of the same phase from a secondary winding of the same transformer, and in all cases, by any of the expedients above mentioned or by any equivalent expedient, current of the phase corresponding to that flowing through the coil 2, should be similarly reversely directed through each intermediate coil of each set. Alternatively, a duplicate set of transformers like those at 21, 22 and 23 or separate additional secondary windings of the same, may be provided for each of the sets of coils.

The above description relates more particularly to an electrical system, of which an embodiment is shown in Fig. 1, and which involves a reversal of the circuitous direction of single phase current flow traversing a medial one, only, of a set of three inductor coil sections, and to which system, the graphs of Figs. 3 and 4 are applied, the said electrical system being herein claimed.

I now proceed to describe structural features shown in Figs. 2, 5, 6 and 7 which relate to refinements in flux distribution which may be employed in connection with the above described electrical system or other electrical systems for low frequency induction furnaces.

To effect substantially like, or a desired variation of distribution of heating effect in different of the longitudinal portions of a work-piece which is telescoped within longitudinally successive of a plurality of induction coils which are respectively energized by alternating currents of differing phases of a multi-phase power system, or to improve the distribution of heating effect, by an induction furnace having one or more induction coil windings, over the length of a work-piece telescoped within induction coil convolutions, the instrumentalities now to be described adapted for the distribution of heating effect along the length of work-piece, may be singly, or conjointly employed to singly or co-operatively achieve advantageous results.

The phase of my invention relating, more particularly,

to the provision of so-called "distributed heating" of an elongated metal work-piece, may involve the use of the tap switches 41, 42 and 43 of Fig. 1, the switching jumpers of Fig. 2, and/or the coil winding of Fig. 5, or alternately, of obvious modifications and equivalents thereof, some of which being later described.

In each of the switches at 41, 42 and 43, the adjusted position of each of the switch blades 41a, 42a and 43a in selective engagement with any of the different of its associated switch contacts such as those shown at 48, 44, 45, 46 and 47 for the blade 41a, predetermines the number of effective convolutions in the primary winding 91, 92 or 93 of the transformer which is associated with any such switch.

The voltage across the terminals of the secondary winding is, as is well-known, increased in proportion to the resulting reduction of the number of effective primary turns, and vice versa.

Therefore, by means of operation of any of said switches such as the switch 43, by moving its blade 43a from a contact such as shown at 48 to the contact as shown at 43b, the secondary winding 23a will transmit through the conductors 33 to the coil 3 a lower voltage than if the switch blade were moved to a contact further to the right. In such a case, heating of that end of the work-piece W which is disposed within the encircling convolutions of the coil 3, will be heated to a lesser degree by the effect of lowered current flowing through the coil 3, than will that opposite end of the work-piece which is shown exposed in Fig. 1 at the left side of the drawing.

It will also be clear that, movement of any of the switch blades 41a, 42a or 43a to their extreme position toward the left, or to the right, the portion of the billet W enclosed by the associated induction coil 1, 2 or 3, will be heated to a respectively lower or higher temperature, in a given time, in response to the different voltages applied to any such coil, by any such adjustment of its controlling switch blade.

The three switch blades 41a, 42a and 43a, when adjusted to the position shown in Fig. 1, will progressively cause the portion of the billet W enclosed by the coil 1 to be hotter than that enclosed by the coil 2 and to cause the portion of the billet enclosed by the coil 2 to be also hotter than that enclosed by the coil 3, during a normal period of heating; such relative adjustments of the three switch blades are adapted to a condition where the billet, immediately after heating to a given temperature at that end which is enclosed by the coil 1, is to be then forced through extrusion with said end which is hottest being first directed through the extrusion dies; relatively following portions of the billet passing through the dies have their initially lower temperatures increased by the effect of heat generated by friction during the extrusion process, whereby the successively operated-upon portions of the billet, during extrusion, progressively achieve approximately like temperatures as they are passing through the extrusion process.

Under the conditions where the work-piece is of relatively different mass in different longitudinal portions, and uniformity of heating of the different portions is desired, it is highly advantageous to energize the coil winding which surrounds a portion of the work-piece which is of lesser mass at a relatively lower voltage, as predetermined by the adjusted position of its associated controlling switch.

In Fig. 2, an induction heating coil, which may alone provide the sole induction heating coil of a furnace, or alternatively, Fig. 2 may be considered as a disclosure of heat distributive instrumentalities for one or more of a plurality of coils employed in a coil unit such as that of Fig. 1, is shown at 25, said coil comprising a single circuitous coil winding which extends between end terminals 26 and 28 and surrounds a work-piece in the manner of the coil unit of Fig. 1, and is provided with intermediate tap connectors at 171, 172, 173, 174, 175 and 176.

The transformer T comprises a primary winding P and a secondary winding S, and may preferably, but not necessarily in most cases, be provided with a switch 104 corresponding to any of those at 41, 42 or 43 and having a blade 105 and a series of contacts including the terminal contacts 106 and 107 at its two sides, with conductors 108, 109 etc. extending between the successive taps 151, 152, 153 and so forth, proceeding inwardly from the terminal 106 to taps on different convolutions of the primary winding P, of the transformer T.

The energizing current from the transformer may be suitably varied by swinging the blade 105 toward the left or the right to respectively reduce or increase the voltage induced in the secondary winding S, in the manner of the above described switches 41, 42 and 43, and with the previously described results.

A plurality, such as the six successive taps 161 to 169 inclusive may be provided at intervals from end-to-end of the secondary winding S and similarly successive taps 171, 172, 173, 174, 175 and 176 may be provided for the induction heating coil which is generally indicated at 25. By further providing a series of detachably connected, cross-connecting jumpers such as 181, 182, 183 and 184, means are provided for relatively varying the heating effect of any portion of the length of the induction heating coil 25.

This is accomplished, for example, by so placing the jumpers 183 and 184 as to interconnect the transformer tap 165 to the induction coil tap 175 and to connect the transformer tap 168 with the induction coil tap 26, whereby the voltage delivered by the portions of the transformer secondary winding which is located between the taps 166 and 168, is delivered to that portion of the induction coil which extends between the coil taps 175 and the terminal 26. In such a case the heating effect of such portions of the coil would be substantially less than that which would be generated in said coil were the upper end of the jumper 183 moved to the tap 165 and the upper end of the jumper 184 moved to the tap 169 of the transformer.

Therefore, contemplating a sufficient number of jumpers and taps for the transformer secondary winding and for the induction coil, different portions of the induction coil can be heated by current resulting from different voltage, or the same, or different unit lengths of the induction coil may be energized by the application of like or variant voltages from selected portions of the transformer secondary, S, and, therefore, uniform, tapered, or variant heating of different portions of the length of a billet can be readily accomplished.

The tap switches and/or switching jumpers shown have various advantageous applications, for example, they can be adjusted to vary the input and consequently change the production rate, and when billets shorter than full coil lengths are used, the tap switch or switching jumpers controlling the empty or partially empty coil section can be adjusted to effect zero or any higher proper input of energization for that section or portion thereof to maintain the desired billet heat pattern. In such a case, the alternating currents directed to each of the above three successive groups of convolutions, proceeding from left to right, will be of relative respective strengths in the respective ratios of $7\frac{1}{2}$, 5 and 6.

Since first, second and third groups have convolutions in the respective relative numbers of 4, 5 and 6, and respectively occupy lengths of the coil 25 which are in direct proportion to the number of convolutions, the first group will be of $4x \times 7\frac{1}{2}$ or $30x$ ampere turn excitation and the magnetic effects thereof, will be distributed over only $\frac{1}{15}$ of the total length of the coil, whereas the second or middle group will be of $6x \times 6$ or $36x$ ampere turn excitation distributed over $\frac{2}{15}$ of the coil length, and the excitation by the third group will be by $5x \times 5$ or $25x$ ampere turns, distributed over $\frac{3}{15}$ of the coil length.

By such an arrangement, the respective excitations per unit length of the coil by currents through the three groups of convolutions, causes the work-piece enclosed by these portions of the coil, to be heated at commensurably different rates, whereby in a short predetermined heating period the left end of the work-piece will be of still lower temperature.

Thus, such an arrangement of taps of the transformer winding S, and coil 2, will afford tapered degrees of temperature proceeding from left to right, to an elongated work-piece disposed within the convolutions of the coil 25.

The above example shows how, with a sufficient number of variably adjustable jumpers and taps for the transformer secondary winding and for the induction coil, different portions of the induction coil can be heated by current resulting from different voltage, or the same, or different unit lengths of the induction coil may be energized by the application of like or variant voltages from selected portions of the transformer secondary, S, and therefore by suitable adjustment of the jumpers, uniform, tapered, or variant heating of different portions of the length of a billet can be readily accomplished.

The tap switches and/or switching jumpers shown have various advantageous application, for example, they can be adjusted to vary the input and consequently change the production rate, and when billets shorter than full coil lengths are used, the switching jumpers controlling the empty or partially empty coil section disposed at an end of the coil, can be adjusted to effect zero or any higher proper input of energization for that section or portion thereof, to economically maintain the desired degree of heating in the different longitudinal portions of the billet.

The positions of taps on each of the windings of each transformer secondary and on each of the induction heating coils, may be varied within the scope of this embodiment, and the relatively interconnected jumpers may be changed in number to meet different conditions, for instance in applying the system of Fig. 2 to an intermediate of the coils of a three-coil unit, such as the coil 2 of Fig. 1, jumper 181 may extend from the tap transformer 162 to the left hand terminal of the coil 2, jumper 184 may extend from the transformer tap 169 to the right hand terminal of coil 2, while jumper 182 may extend from the transformer tap 167 to a tap 5 on a convolution of the coil 2 which is near the left hand end of the coil, which the jumper 183 may extend from the tap 160 of the transformer to a tap 6 which is affixed to a convolution of the coil 2.

Thus such taps may be so located and said jumpers may so connect certain taps of the secondary transformer winding with taps of the coil 2 that not only will the groups of convolutions nearest the ends of the coil 2 be supplied with a flow of increased energizing current as compared to the flow of current through the larger number of convolutions disposed medially between said end groups of convolutions, but also the direction of current flow through all portions of the coil 2 will be reversed, as such term has been previously explained herein, and to achieve the previously described objective thereof.

Also by application of the jumper and taps system of Fig. 2, to the three-coil system of Fig. 1, the winding convolutions which are nearest the adjacent ends of all longitudinally adjoining of said coils may be energized at a greater voltage per convolution than other portions of said coils and therefore will afford a greater magnetizing force, due to increased ampere-turn effectiveness, than the same, or greater number of convolutions located in other portions of each coil length, which in the case of coil 2, would be the middle portion thereof.

The system of Fig. 2, when applied to that of Fig. 1, may either supplement the effect of the reversed current through the coil 2 of Fig. 1, or may be substituted therefor.

Another embodiment of distributive heat instrumentality shown in Fig. 5 is effective another way, to increase the induction heating effect on portions of a work-piece which are in regions of either or both ends, of any induction coil of an induction coil unit.

Fig. 5 shows a coil 4 whose continuous winding consists of convolutions of a conductor, which in the coil-end portions 76 and 76a of the winding, is narrower than in the middle coil portion 75. If preferred the conductor may be made from three sections of tubing, those for said end sections being shown, relatively enlarged in cross-section in Fig. 7, and in Fig. 6 the middle convolutions of the coil are, for comparison shown to be substantially wider, to cause the coil to have fewer convolutions per unit of coil length in its mid-portion than near its ends, where the convolutions are narrower, in proportion to the inverse value of flux density per convolution at the different coil portions. The middle section having its opposite ends integrally jointed by soldering, welding or the like at 77 and 77a to an end of each of the two end sections, 76 and 76a, to make the entire coil continuously liquid and electrical conducting throughout its length, each of the said end sections, in the exemplary embodiment shown, being designed to have three-fourths as many turns as is provided for the middle section 75.

In this example the width of the narrower portions of the conductor at 76 and 76a may be one-fourth inch whereas the width of the wider portion of the conductor at 75, is three-eighths inch, and when the longitudinal extent of the middle section is twelve inches, and the length of each of the two end sections is six inches, each end section will have fifty percent (50%) more turns per unit length than will the longer middle section. Consequently the ampere-turns per unit length of the coil, and consequently the relatively densities of magnetic flux induced by equal current flowing through each of the three coil sections will be greater at the end sections. It is contemplated that the ratios of ampere-turns in the different sections may be widely varied from the above described embodiment, and from that of the coil 4 of Fig. 5 as may be advantageous in satisfying different requirements of induction heating.

A useful modification of the disclosed coil of Fig. 5, involves a narrow convolution section as at 76 only, and with the wider convolution coil section of 75 being extended to the opposite end of the coil, with the end section 76a, of narrow convolutions, being thus eliminated. The obvious opposite construction may be had by merely reversing the positions of the two ends of the coil of said modification.

A useful application of the disclosures of Fig. 5, together with the modification thereof is to apply the coil construction of Fig. 5, as shown, to the coil 2 of Fig. 1, then to employ a coil embodying the first above described modification of the coil of Fig. 5, as coil 3 of Fig. 1, and to apply the aforesaid opposite coil construction, wherein the set of narrow convolutions is at the right end portion of the coil which is substituted for the coil 1 of Fig. 1. Such improvements may be applied to Fig. 1 preferably in connection with the previously described reversal of current flow through the coil 2 to achieve maximum efficiency. However, when employed in connection with a three-coil unit without said reversal of current flow, marked improvement in the heating of portions of the work-piece located in the regions of adjoining coil ends may be effected, by application of the above improvements, to increase the degree of electromagnetic energization in the said regions of adjoining coil ends.

Use is contemplated of coils such as that shown in Fig. 5, and of the alternate modifications thereof, singly or conjointly employed, wherein such a system of interconnecting jumpers and coil winding taps are provided to variably energize different longitudinal sections of such coil by the application of different alternating current volt-

11

ages to different of said described sections, and/or different portions of any, or all, of such sections.

Having thus described my invention relating to the art of predetermined distribution of heat to different longitudinal portions of an elongated work-piece by electrical induction equipment and wherein variant instrumentalities adapted therefor, may be employed separately or conjointly to effect various advantageous results, I am aware that the disclosures hereof will suggest to those workers in the art possessing mechanical skill obvious other embodiments and substantially equivalent instrumentalities which, however, are included within the invention hereof as claimed in a divisional application for patent in which I reserve the right to disclose and claim the portion of this specification which relates particularly to the subject matter of Figs. 2, 5, 6, 7, and the switches 41, 42, 43, when employed as described as means to adjustably vary the heating effects in different portions of the length of a metal work-piece disposed within the convolutions of the coil sections 1, 2, and 3.

I hereby claim:

1. In an electrical system for an induction heating furnace of the type described for the heating of metal work-pieces, which comprises an inductor which employs at least one set of three longitudinally aligned, successively arranged coil sections, each said coil section comprising a plurality of coil convolutions, said sections being disposed in end-to-end relationship to each other to jointly provide, interiorly of their convolutions, an elongated heating compartment within which metal work-pieces may be inductively heated in response to concurrent energization of all of said sections, each section being energized by the effect of a single-phase low-frequency current passed therethrough, electrical communicating means for deriving from a source of three-phase low-frequency alternating current, three separate flows of single phase low frequency current which are in three-phase timed relation to each other, and electrical means for so distributing said flows as to cause a first flow thereof to traverse the convolutions of a first endmost one of said set of coil sections, a second flow thereof to traverse the convolutions of the intermediate of said set of coil sections, and a third flow thereof to traverse the convolutions of the relatively third section of said set of inductor coil sections, the said first, second, and third single phase flows being in the same phase relation to each other as are three successive phases of a three-phase cyclic system, and said electrical

12

communicating means comprising means for causing the said second flow to traverse the convolutions of said intermediate coil section in that circuitous direction which is relatively reversed with respect to the relatively opposite circuitous direction in which said first flow traverses the convolutions of said first end coil section and also in which said third flow traverses the convolutions of said third section, of said set of three coil sections, to cause the phase of magnetomotive force of magnetic flux produced by energization of said second coil section to be relatively reversed, and thereby to cause the phase relations between the magnetomotive forces which are produced by energization of the three coil sections, and which are effective to cause inductive heating of, and to create magnetic force effects upon, any said work-piece which is disposed in said compartment, to be in that relatively timed relation to each other which characterizes three successive phases of a 6-phase cyclic system.

2. The electrical system for an induction heating system, substantially as set forth in claim 1, characterized by the recited electrical communicating means comprising a set of transformers having at least three primary windings energizable from said source of three-phase low-frequency alternating current, and at least one set of three electrically separated secondary windings, and by the recited electrical means comprising conductors leading from said secondary windings to said inductor coil sections, to effect the recited distribution of current flows through the recited said coil sections.

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