Oct. 28, 1958 L. B. KIMBROUGH ET AL 2,858,405

60-CYCLE INDUCTION FURNACE

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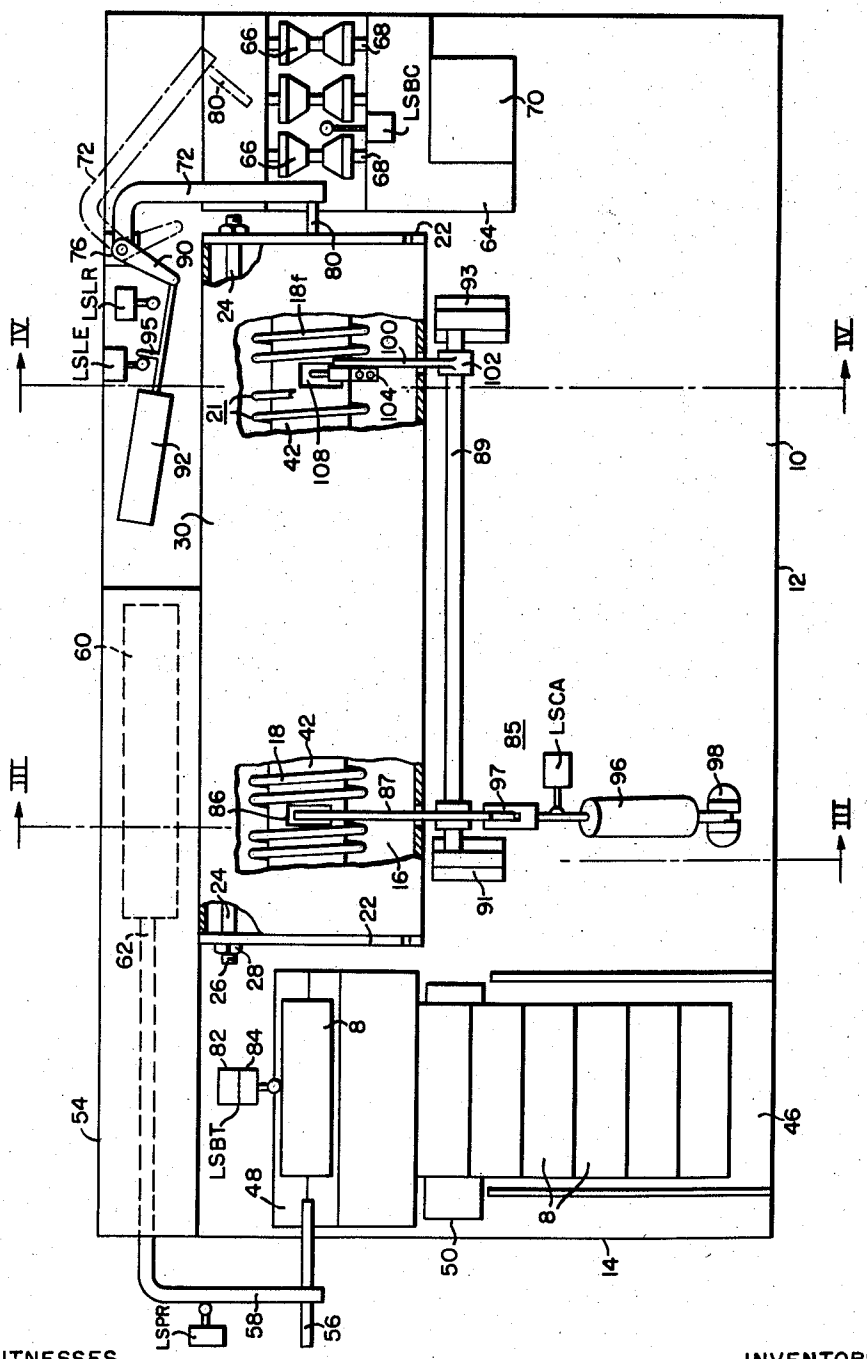


Fig. 1.

WITNESSES

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Fig.2.

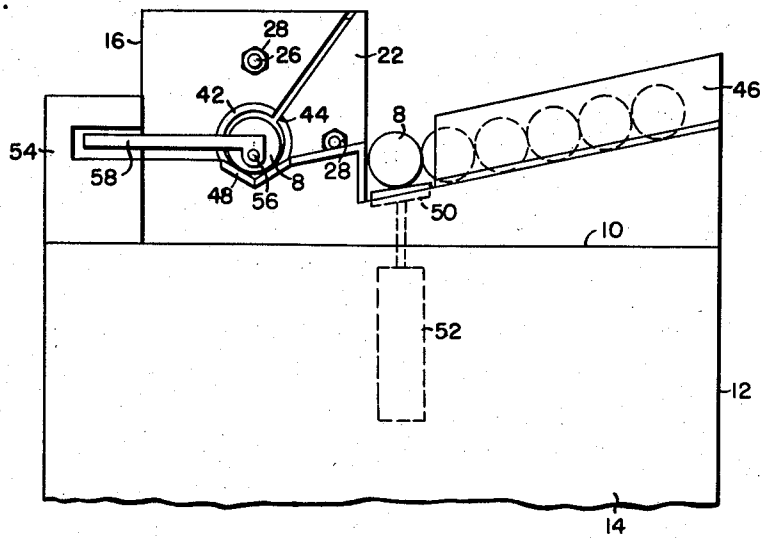


Fig.3.

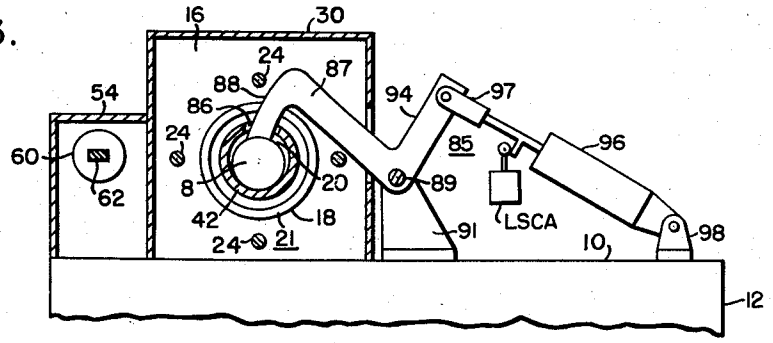
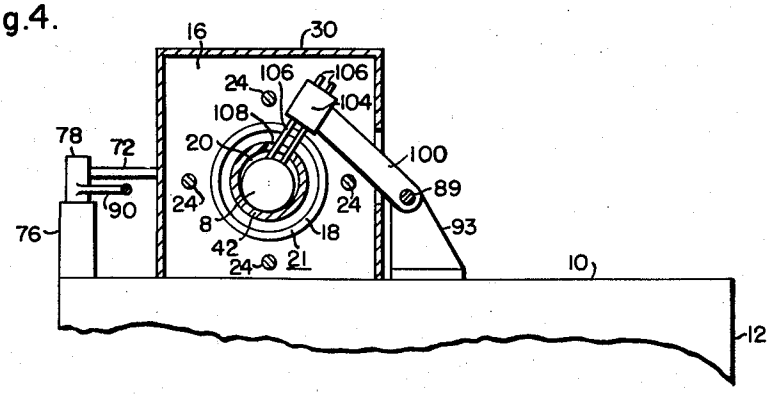


Fig.4.

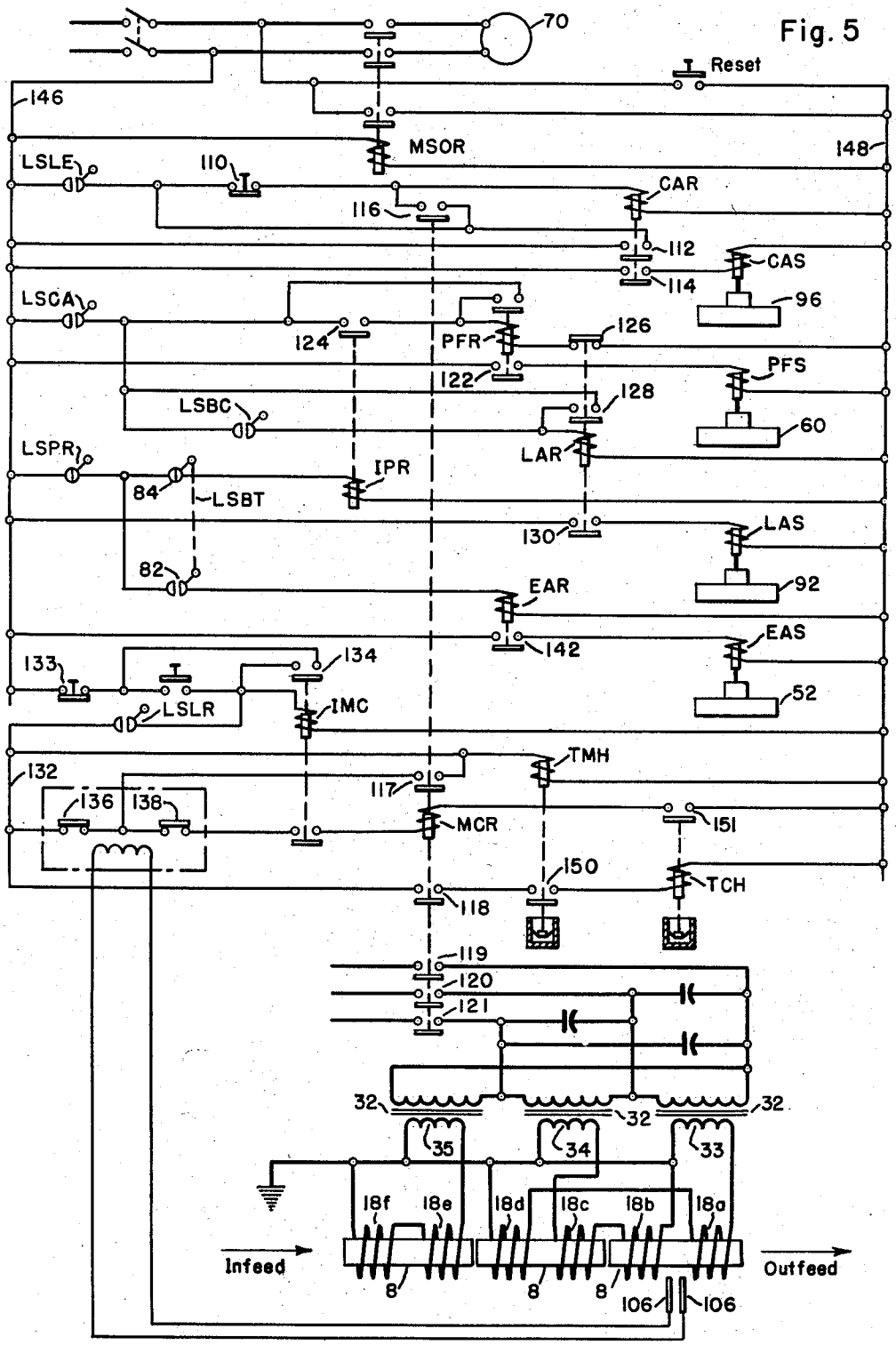


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Fig. 5



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60-CYCLE INDUCTION FURNACE

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Application December 24, 1956, Serial No. 630,367

13 Claims. (Cl. 219—10.67)

This invention relates to induction heating apparatus and more particularly to electric heating furnaces and workpiece feeding means adopted for automatically handling and heating bars, billets and the like workpieces for forging and forming operations.

It is an object of this invention to provide an improved induction heating apparatus to successively heat a plurality of objects to a predetermined temperature and to deliver said heated objects to a work station.

Another object of the invention is to provide an induction heating system in which a heated object is delivered to a work station at the instance of the controlling operator and in which the delivery of said object is automatically operative to initiate means for delivering a second unheated object to the induction heating apparatus and for initiating a second successive heating cycle.

A further object of the invention is to provide an induction heating furnace in which a temperature sensitive means is intermittently positioned to engage an object to be heated so as to monitor the surface temperature of the object heated and to interrupt the heating cycle when a predetermined temperature of the object is reached.

A different object of the invention is to provide an electric induction furnace for heating of metal workpieces in which a thermo-couple element is movably disposable for engagement with a surface of a workpiece to be heated and in which circuit means responsive to the thermal current in said element is operable to control the delivery of heating energy to said induction furnace.

An additional object of the invention is to provide an induction heating apparatus in which a temperature responsive device is disposed adjacent one side of the induction heating coil of said furnace and is adapted for movement transversely of said coil for impingement against a peripheral surface of said workpiece.

It is a still further object of the invention to provide improved in-feeding and discharging mechanism for sequentially supplying workpieces to the furnace and for discharging the same from the furnace in response to attainment of a predetermined desired surface temperature of each successive workpiece.

These and other objects of the invention will be apparent from the following description taken in accordance with the accompanying drawing, throughout which like reference characters indicate like parts, which drawing forms a part of this application and in which:

Figure 1 is a plan view of a furnace in accordance with a preferred embodiment of our invention having six coil sections to be energized from a polyphase current source, an enclosure for said coil sections with parts broken away therefrom, and related workpiece feeding mechanisms associated with the coil sections;

Figure 2 is an elevational view of the apparatus of Fig. 1, taken from the left-hand end of the apparatus as shown in Fig. 1;

Fig. 3 is a transverse vertical section taken on the line 3—3 of Fig. 1;

Fig. 4 is a transverse vertical section taken substantially on the line 4—4 of Fig. 1; and

Fig. 5 is a schematic and wiring diagram of the apparatus embodying the invention.

Referring now to the drawings, which show a preferred embodiment of the invention, the induction heating apparatus, as shown in Fig. 1, comprises a substantially rectangular table-like support structure **10** which has the dual purpose of supporting the workpiece heating and conveying apparatus and secondly provides an enclosure for three single-phase transformers and appropriate control circuit components for the workpiece heating apparatus. The support enclosure or table **10** is constructed of a welded structural steel framework having removable sheet steel side panels **12** and **14** and having hinged doors at least on one side and at one end for providing access to the electrical control compartment therein, and to the secondary connections to the transformers. The furnace **16** per se is mounted horizontally and longitudinally on top of the support cubicle **10** and preferably comprises six coil sections **18** formed of a single helical layer of a solid rectangular electrical conductor welded to a hollow water-cooled tube. The coil sections **18** are positioned in end-to-end relationship so as to provide an elongated tunnel **20** or workpiece pathway through the interior of the coils, and to comprise a furnace coil assembly **21**. The coils are supported above the table surface **10** by means of a pair of end plate weldments **22** which are positioned at opposite ends of the end-to-end aligned coil sections and are provided with a rectangular sheet metal cover **30** for excluding moisture and foreign material from the coils. A plurality of elongated tubular members **24** extend from the first end plate **22** to the second end plate longitudinally adjacent the coil assembly **21** and spaced circumferentially of the coil assembly. The tubular support members **24** are rigidly attached to the end plate members **22** by threaded portions **26** which permit the end plate members **22** to be drawn toward each other so as to suppress vibration of the energized coil, and to unitarily secure the coil sections **18** in contiguous end-to-end relationship. The elongated longitudinally extending support members **24** are preferably positioned in substantially parallel relationship, with a pair of said members **24** being spaced respectively above and below the central axis of the coil assembly and with a second pair being located on opposite sides of the coil axis. Appropriate transformers **32** and control relays and circuits for energizing the furnace coils are enclosed in the cubicle formed by the table top **10** and the side and end panels **12** and **14**.

The substantially cylindrical single layer coil sections **18** may have their exterior surface covered by a flexible heat-resistant insulating material such as, for example, a glass fiber insulating tape and additionally covered by a layer of insulating varnish, if so desired. The end conductors of each respective coil section **18** are bent outwardly from the cylindrical coil assembly **21** so as to provide convenient means for connecting water cooling hoses thereto and for appropriate electrical connections (not shown) from the transformers **32** to the coil sections **18**. The furnace coil assembly **21** is provided with an inner liner which comprises a substantially cylindrical stainless steel tube **42** extending from the first end plate **22** to the second end plate and which is split longitudinally at one circumferential position **44**, as shown in Fig. 2, so as to prohibit circulating currents therein. Preferably, austenitic stainless steel is used for the liner **42** because of its non-magnetic properties which allow the magnetic flux generated by the coil sections **18** to penetrate workpieces **8** positioned within the coil liner **42** in an unimpeded manner. Between the coil sections **18** and the stainless steel liner **42** there is provided a non-

metallic, non-magnetic, substantially cylindrical layer of heat and electrical insulating material, such as for example ceramic felt, asbestos cloth or the like.

At the left hand end of the furnace assembly, as shown in Fig. 1, there is provided a workpiece infeed apparatus for successively loading substantially cylindrical workpieces 8 in end-to-end relationship into the workpiece pathway or tunnel 20 formed by the interior of the furnace coil assembly 21 and the stainless steel liner 42. The workpiece infeed apparatus comprises an inclined rollway or chute 46 which extends from approximately one edge of the support cubicle 10 toward the infeed end of the workpiece pathway 20. A workpiece or billet trough 48 is provided in axial alignment with the infeed end of the workpiece tunnel or pathway 20. Between the infeed billet trough 48 and the inclined billet rollway 46 there is provided a movable billet elevator member 50 which is normally positioned slightly below the lower end of the inclined rollway 46 and which is movable upwardly by means of an appropriate air cylinder 52. The elevator is operative, upon actuation of the air cylinder 52 to raise a billet supported thereon to a position such that it will readily roll by gravity from the elevator member 50 to the adjacent billet trough 48 and will there assume a position in longitudinal alignment with the end of the billet tunnel 20.

When a plurality of workpieces, such as the generally cylindrical aluminum alloy billets 8 shown in Fig. 1, are positioned in the inclined rollway 46, the foremost of such billets will travel down the rollway 46 and will drop from the end of the rollway to rest upon the upper surface of the elevator plate 50. The elevator plate 50 is positioned below the end of the rollway 46 a selected distance such that the billet resting on the elevator 50 will serve as a gate to prevent the next adjacent billet in the rollway 46 from traveling further toward the billet trough 48.

Adjacent the billet trough 48 on the opposite side thereof from the inclined rollway 46 there is provided an infeed pusher mechanism 54 including a pusher rod 56 carried by a support arm 58. The pusher rod 56 is reciprocally movable, by means of an appropriate air cylinder 60, longitudinally toward and away from the infeed end of the billet tunnel 20. The air cylinder 60 for operating the pusher rod 56 is positioned above the surface of the support table 10 in substantially parallel alignment with the billet tunnel 20 and opposite the inclined billet rollway 46. The end of the reciprocal piston rod 62 of the air cylinder is connected to a portion of bracket member 58 which is supported by a pair of guide rods and is slidably movable for reciprocation toward and away from the entrance to the billet tunnel 20. The billet pusher rod 56 is rigidly secured to the movable support bracket 58 in substantially central alignment with the billet tunnel 20. The pusher cylinder 60 is operative to reciprocate the pusher rod 56 lengthwise of the billet trough 48 so as to successively push billets or workpieces from the trough 48 and into the entrance end of the furnace tunnel 20. The reciprocal pusher mechanism 54 is provided with an appropriate pusher ram limit switch LSPR which is arranged adjacent the bracket 58 so that its contacts are normally open but are maintained closed when the pusher rod 56 is fully retracted from the entrance to the billet tunnel 20. A billet trough limit switch LSBT is provided adjacent one side of the billet trough 48 so as to be contacted by a workpiece 8 resting in the trough 48 and comprises a pair of switches, with the first switch 82 being normally open and the second switch 84 being normally closed. When there is a workpiece resting in the trough 48, the first switch member 82 is maintained closed and the second switch member 84 is maintained open.

As the cold billets 8 are successively pushed into the furnace tunnel 20, each successive billet is engaged by the forward end of the next succeeding billet 8 and is pushed ahead by means of the pusher rod 56 acting on the end of the next succeeding billet. During successive periods in which the pusher rod 56 is maintained in its retracted position, power may be applied to the furnace coils 18 by means of control circuitry to be hereafter described, and the billets 8 positioned within the tunnel 20 will be heated by virtue of the magnetic flux generated by the coils 18 and threading through the workpieces. As additional successive billets are pushed into the tunnel 20, the foremost billet is heated to a predetermined temperature and is pushed out of the discharge end of the furnace tunnel 20 so as to be discharged onto an outfeed conveyor designated generally as 64 and comprising a plurality of motor driven conveyor rolls 66.

The outfeed conveyor 64 may be of any suitable type known in the art but is preferably comprised of a plurality of tapered pairs of conveyor rolls 66 mounted on spaced parallel shafts 68, which shafts are positioned substantially transversely to the longitudinal axis of the furnace coil assembly 21 and sufficiently below the workpiece tunnel 20 such that the tapered portions of the outfeed rollers 66 are positioned to support a heated billet 8 in substantial alignment with the exit end of the workpiece tunnel 20. The outfeed conveyor rolls 66 are driven by an electric motor 70 which is connected to the plurality of outfeed drive shafts 68 by means of an appropriate gear reducer.

It will be noted that the distance which pusher rod 56 travels during each cycle is always constant. Consequently, as the foremost billet is pushed onto conveyor 64, the next successive billet may be projected beyond the exit end of the coil, especially in cases where the length of successive billets varies. Since a most effective heating operation is obtained only when the billets are located at a predetermined position within the coil, some means must be employed to position the billets after they are inserted into the coil by pusher rod 56. For this purpose, there is provided a billet locator arm 72 and a locator arm actuating mechanism for intermittently moving the locator arm 72 from a retracted position to an extended position, in which extended position the locator arm projects into the exit end of the workpiece tunnel 20 as shown in Fig. 1 so as to engage the foremost end of the foremost billet 8 in the tunnel and to accurately position the foremost billet to a predetermined position within the tunnel. The locator arm 72 is supported for pivotal movement about a vertical axis on a bracket member 76 having a vertical shaft portion 78. The bracket member 76 is fixedly secured to the planer surface of the support table 10. The locator arm 72 extends horizontally from its support shaft 78 and carries at its outermost end a locator rod member 80 which is adjustably fixed to the end of the locator arm 72 such that when the locator arm 72 is pivoted to its most extended position, toward the exit end of the workpiece tunnel, the locator rod 80 will be axially aligned with the workpiece tunnel 20 and will extend a short distance into the exit end of the tunnel 20. The hub 78 of the locator arm has a bell crank portion 90 extending therefrom at approximately a 45° angle with respect to the locator arm 74. An appropriate air cylinder 92 for operating the locator arm 72 is mounted on the support table 10 adjacent one side of the furnace coil assembly and adjacent the locator arm support bracket 76. The piston rod of the air cylinder 92 is connected to the bell crank portion 90 of the pivotable locator arm 72 so that extension of the piston rod from the air cylinder 92 will pivot the locator arm 72 outwardly away from the exit end of the furnace tunnel 20 to its retracted position in which the locator rod 80 is retracted well away from the workpiece pathway on the exit conveyor rolls. By retraction of the air cylinder piston, the locator arm is pivoted back toward the exit end of the furnace coil to its locating position in which the locator rod 80 extends

slightly into the exit end of the workpiece tunnel **20** as heretofore described.

In the prior art apparatus for the induction heating of workpieces in through feed or continuous furnaces, it has been conventional to utilize a three section induction coil with each of the three sections being energized from a different phase of a three-phase voltage source. We have found that when three such induction coils are energized, the portions of a workpiece which are positioned opposite the junction between the intermediate coil and either of the end coils are heated more slowly than other portions of the workpiece. This uneven distribution of heating effect along the length of the workpiece is caused by a greater concentration of magnetic flux in the portion of the workpiece which is disposed opposite the center of each coil section than the concentration of flux in the portion of the workpiece which is positioned adjacent a juncture between two coil sections. The principal reason for this difference in flux concentration is the difference in phase of the three magnetic flux fields of the three coils which causes the flux from one coil to partially cancel the flux from another coil in the region where the two flux fields overlap. That is, the phase junctions are areas of lowest flux concentration with a resultant decrease in heating effects at the phase junctions. The net result achieved by the three section coils of the prior art is a temperature distribution in which a hot area appears near the center of each billet, while the ends of each billet which would ordinarily lie near the phase junctions are relatively cold.

In the present invention, the aforementioned undesirable characteristic of prior art induction furnaces is eliminated by utilizing a six section induction heating coil, with the six coil sections **18** being connected to the secondaries of three supply transformers **32** in a novel arrangement productive of the desired result. As shown in Fig. 5, the last coil section **18***a* at the outfeed end of the workpiece tunnel is connected in series with the third coil section **18***d*, and the outer ends of the last and third sections **18***a* and **18***d* are connected to a third transformer secondary **33**. The fifth and fourth successive coil sections **18***b* and **18***c* are connected in series across the secondary winding **34** of a second transformer **32**. The second and first coil sections **18***e* and **18***f* are connected in series and are connected across the secondary **35** of a first transformer **32**. The fifth and fourth coil sections **18***b* and **18***c* are connected to the second transformer in an inverse manner as compared to the second and first coil sections, so that the current flow through the second and first coil sections **18***e* and **18***f* is opposite to that through the fifth and fourth coil sections **18***b* and **18***c*. By means of the aforedescribed coil interconnections, as shown in Fig. 5, the alternating current phase junctions appear in the furnace coil between sections **18***a* and **18***b* between coil sections **18***c* and **18***d*, and between coil sections **18***d* and **18***e*. This positioning of the phase junctions effectively moves the phase junctions to the midpoints of the billets positioned in the billet tunnel **20**. The hot area in the center of each billet is eliminated, the heating effect near the ends of the billets where it is most needed is increased and the heating effect near the center of each billet is decreased.

The magnetic flux which threads through the three billets positioned in the billet tunnel **20** creates a traveling magnetic field moving lengthwise along the tunnel **20** from the exit and toward the entrance end. This traveling magnetic flux field is analagous to the rotating magnetic flux field generated in the rotor of the well known polyphase induction motor when supplied with three-phase currents in the stator windings. In the present apparatus the coil sections **18** are arranged in longitudinally aligned end-to-end relationship, and are interconnected such that the traveling magnetic field moves from the exit end of the furnace toward the entrance end and generates a lengthwise electromagnetic force on the billets **8** in the furnace tunnel **20**, which force tends to eject the billets toward the entrance end.

To assure that the billets **8** are maintained in the proper position for heating as determined by the locator rod member **80**, a clamping device **85** is provided for clamping billets **8** in the workpiece tunnel **20** so as to rigidly position the workpieces during the time in which the furnace coils **18** are energized. Slightly spaced from the entrance end of the workpiece tunnel **20** an opening **86** is provided transversely through the coil assembly **21** between adjacent coil turns and through the coil liner **42**, with the opening **86** in the liner **42** being sufficiently large to admit a clamping arm member **87** which may be forcibly inserted through the opening **86**, perpendicularly to the axis of coil **18**, to pressingly engage the cylindrical side surface of a billet **8** which is nearest the entrance end of the coil and to effectively clamp that billet against longitudinal movement within the workpiece tunnel **20**. The clamping arm **87** comprises a substantially L-shaped member having its shorter leg **88** positioned adjacent to the opening **86** in the periphery of the liner **42** and with the end of the leg **88** being adapted to pass through the opening **86** to engage the workpiece **8** within the tunnel **20**. Spaced from the coil assembly **21** and parallel thereto is a rotatable clamp arm support shaft **89** which extends slightly less than the full length of the induction coil assembly and is supported in self-aligning journal bearings on spaced journal brackets **91** and **93** attached to the planar surface of the support table **10**. The end of the longer leg of the clamp arm **87** is provided with an opening through which the clamp arm shaft **89** extends, with the clamp arm **87** being rigidly keyed to the clamp arm shaft **89** for pivotal movement therewith. Adjacent the point at which the clamp arm **87** is attached to the clamp arm shaft **89**, a bell crank member **94** is keyed to the shaft **89** and extends upwardly and outwardly away from the shaft. The bell crank member **94** and the clamp arm member **87** may, if so desired, be securely welded or otherwise fastened together or, if so desired, the bell crank member **94** and the clamp arm **87** may be formed from a single steel member shaped to the desired configuration, with the bell crank portion **94** extending from the shaft substantially at a right angle to the longermost leg of the clamp arm **87**. In order to provide for pivotal motion of the clamp arm **87** toward and away from the opening **86**, there is provided a clamp arm air cylinder **96** having one end of the cylinder pivotally attached to a bracket member **98** which is secured to the planar surface of the support table **10** so that the cylinder **96** is free to pivot through a small angle about an axis parallel to the clamp arm shaft **89**. The piston rod of the clamp arm air cylinder **96** is provided with a clevis member **97** and the end of the clevis member **97** is pivotally connected to the outermost end of the bell crank member **94** by means of a pin or the like.

In operation the clamp arm mechanism is energized by operation of a solenoid valve CAS which applies air to the clamp arm air cylinder **96** so as to project the piston rod and clevis member **97** outwardly from the cylinder **96**, thereby causing the bell crank member **94** and the clamp arm member **87** to jointly pivot about the clamp arm shaft **89** so that the shorter leg **88** of the clamp arm is projected downwardly through the opening **86** in the coil liner **42** to engage the workpiece **8** within the furnace. The air cylinder **96** maintains a sufficient torque on the clamp arm member **87** during the heating period of the furnace so that the workpiece **8** is securely clamped between the clamp arm member **87** and a wear strip in the bottom portion of the furnace tunnel **20**, thereby restraining the workpieces against any tendency to move longitudinally under the influence of the electromagnetic flux field threading through the workpieces.

As best shown in Figures 1 and 3, the clamp arm shaft **89** extends longitudinally along the side of and substantially parallel to the furnace coil assembly **21** and is jour-

naled in a bearing 93 near the exit end of the furnace coil assembly. Spaced a short distance from the exit end journal 93 of the clamp arm shaft, a second support arm 100 is provided on the shaft 89 and is keyed to the shaft so as to extend upwardly from the shaft and inwardly toward the furnace coil assembly 21 to a position on the periphery of the furnace coil assembly 21 approximately 45° from the vertical axis through the center of the furnace coils 18. The second support arm 100 preferably comprises a hub portion 102 which is keyed on the clamp arm shaft 89 and an arm portion 100 extending therefrom. The free end of the arm portion 100 is elevated or lowered through an arc whenever the clamp arm shaft 89 is rotated by the air cylinder 96. At the free end of the arm 100 there is attached a thermo-couple assembly comprising a block member 104 with two thermo-couple prod members 106 mounted therein in a position such that the thermo-couple prod members 106 extend substantially radially toward the furnace coil assembly 21 when the second support arm 100 is positioned toward the furnace coil. The thermo-couple support block member 104 has a pair of cylindrical openings extending therethrough, in which openings a pair of insulating tubular members are mounted as by means of set screws (not shown). The tubular members serve as insulator sleeves and support the two thermo-couple prods 106 which extend axially therethrough.

Spaced from the end of the last coil section 18*a* nearest the exit end of the furnace coil assembly 21 there is provided a second opening 108 through the periphery of furnace coil assembly 21 and the furnace coil liner 42, with the opening 108 being positioned in registration with the pointed ends of the thermocouple prods 106 so that when the clamp arm shaft 89 is rotated toward the clamping position the thermocouple prods 106 will project through the second opening 108 and will impinge against the heated billet 8 which is nearest the exit end of the workpiece tunnel 20. The thermocouple prod members 106 are of a type known in the art and may be, for example, a twin prod Chromel-Alumel thermocouple. A temperature controller unit (not shown) is provided having a cold junction thermocouple unit serially connected with the bimetallic prongs 106 of the thermocouple, with the control unit being located remotely from the thermocouple support arm 100.

The thermocouple prongs 106 are operative during the heating period of the apparatus to impinge against the billet nearest the exit end of the workpiece tunnel 20 and to continuously provide a control signal or thermally generated current which is indicative of the temperature of the metal near the surface of the billet being heated. By means of circuitry to be hereinafter described, the current signal derived from the thermocouple unit 104 is operative to effect actuation of a circuit breaker or switch means so as to disconnect the furnace induction coils 18 from the source of heating energy.

It is to be understood that the clamp arm air cylinder 96, the locator arm air cylinder 92 and the pusher rod air cylinder 60 are each provided with appropriate solenoid actuated double acting air valves of a type well known in the art. The only significant criteria of such valves for use in the present apparatus is that they be operative when the solenoid is energized to admit air to the air cylinder so as to project the piston outwardly from the cylinder and further operative when the solenoid is deenergized to reverse the flow of air to the cylinder so as to cause the piston to fully retract within the cylinder. An appropriate double-acting solenoid controlled air valve for use in the apparatus may be, for example, the Ross Comet Air Valve #1016–A–3002, two-position, spring return, for operation on 115 volts, 60 cycles.

Mounted adjacent the clevis member 97 of the clamp arm air cylinder 96, there is provided an industrial type limit switch LSCA which is positioned so as to be actuated by the clamp arm 87 when the clamp arm is in its fully retracted position. This clamp arm limit switch LSCA has a pair of normally open contacts which are closed when the clamp arm is fully retracted from the furnace side wall opening 86. As best shown in Fig. 5, the contacts of limit switch LSCA are connected in series with the coil of a pusher control relay PFR. Relay PFR is provided with contacts 122 connected in series with the pusher forward solenoid PFS so that relay PFR is operative when energized to cause forward motion of the pusher rod 56 toward the entrance end of the workpiece tunnel 20. Thus limit switch LSCA is operative to prohibit the insertion of a billet 8 into the workpiece tunnel 20 until after the clamp arm 87 has been fully retracted by operation of relay CAR and air cylinder 96.

The operation of the apparatus will be described in connection with the schematic diagram of Fig. 5 and in connection with Fig. 1. To initiate operation of the apparatus, the operator presses a billet eject push button 110, which may be provided at a control panel adjacent the work station. The eject push button 110 opens the circuit to the clamp arm control relay CAR, to initiate retraction of the clamp arm 87 and the thermocouple arm 100 from the heating coil openings. That is, deenergization of the control relay CAR opens the contacts 114 to deenergize the clamp arm solenoid CAS so as to retract the piston in the clamp arm air cylinder 96. The billet eject push button 110 as shown in Fig. 5 is short circuited during the heating period by contacts 116 of the main control relay MCR for the main power contactor. Thus, operation of the push button 110 will cause retraction of the clamp arm 97 only if the heating period has previously terminated. Upon complete retraction of the clamp arm 97 the clamp arm limit switch LSCA is closed to energize the control relay PFR for the pusher forward solenoid PFS. The pusher mechanism 54 normally is stopped in its retracted position, that is, toward the left as shown in Fig. 1. Upon closure of the clamp arm limit switch LSCA, current is supplied to the pusher control relay PFR through a circuit including contacts 124 of the pusher interlock control relay IPR and through normally closed contacts 126 of the locator arm relay LAR. The pusher relay PFR will not be energized unless the pusher mechanism 54 is fully retracted at the time that the clamp arm limit switch LSCA closes because the pusher interlock relay IPR will be energized only when the pusher retracted limit switch LSPR is closed. Likewise, the pusher interlock relay IPR will be energized only when there is a billet 8 in the billet trough 48 so as to close normally open contacts 82 of the billet trough limit switch LSBT. Thus, forward motion of the pusher rod 56 can be initiated only when there is a cold billet 8 in the billet trough 48 and only when the pusher 54 is fully retracted. As the cold billet 8 is inserted into the heating furnace, a heated billet is ejected from the exit end of the furnace onto the power driven out-feed rollers 66. When the hot billet has cleared the exit end of the furnace, it operates billet conveyor limit switch LSBC momentarily as the heated billet passes down the conveyor. Closure of the billet conveyor limit switch LSBC completes a circuit to energize the locator arm control relay LAR. When the locator arm control relay LAR pulls in, it is locked in by a completion of a holding circuit through holding-contacts 128 which are connected in parallel with limit switch LSBC. Energization of relay LAR also closes a third pair of contacts 130 to complete a circuit to locator arm solenoid LAS, which energizes air cylinder 92 to extend locator arm 72. In addition relay LAR, when energized, operates a pair of normally closed contacts 126 to open

the energizing circuit to the pusher control relay PFR, thereby opening the circuit to pusher solenoid PFS which operates its valve to initiate retraction of pusher rod **56**. The pusher rod **56** is retracted at substantially the same time that the locator arm **72** is inserted into the exit end of the billet tunnel. Such action is necessary because the pusher rod **56** must be retracted at least a few inches before the locator arm **72** can push the foremost billet backward in the tunnel to the most desirable heating position.

When the locator arm **72** has been fully extended to the locating position, it actuates the locator extend limit switch LSLE and closes the limit switch LSLE to complete a circuit through the billet eject switch **110** to energize the clamp arm control relay CAR which, in turn, energizes the clamp arm solenoid CAS by closing clamp arm control relay contacts **114**. When the clamp arm solenoid CAS operates, air pressure is supplied to the clamp arm cylinder **96** so that the clamp arm piston is extended, and operates to rotate clamp arm shaft **89** to thereby project the clamp arm **87** through its opening **86** so as to engage the periphery of the recently inserted billet and to securely clamp the billet to prohibit longitudinal movement thereof. Rotation of the clamp arm shaft **89** also projects the thermocouple support arm **100** toward the heating coil so as to project the thermocouple prods **106** inwardly through the opening **108** in the coil liner periphery to forcibly impinge against the peripheral side-surface of the adjacent billet. In this manner, the clamp and thermocouple will not project into the coil until after the locator arm **72** has positioned the billets to obtain a most effective heating operation.

When the clamp arm **87** has been fully projected into the opening **86**, it disengages the clamp arm limit switch LSCA allowing the limit switch to open its contacts, thereby deenergizing the locator arm control relay LAR. Deenergization of the locator arm control relay LAR deenergizes the locator arm solenoid LAS so that the locator arm **72** is retracted, by operation of cylinder **92**, from engagement with the end surface of the foremost billet.

It is to be noted that the clamp arm control relay CAR is interlocked with the locator arm control relay LAR by means of the clamp arm limit switch LSCA such that the locator arm **72** is not withdrawn from engagement with the billet to be heated until after the clamp arm has securely engaged the last billet inserted into the furnace tunnel **20**. When the locator arm **72** has reached the fully retracted position, a cam member **95**, associated with cylinder **92**, engages locator retracted limit switch LSLR so that the limit switch contacts LSLR, as best shown in Fig. 5, are closed to complete a circuit to the main contactor relay MCR through conductor **132**, the heat-off push-button switch **133**, contacts **134** of the interlock control relay IMC, and through a pair of low temperature thermostat contacts **136**, the high temperature thermostat contacts **138** and the heat cycle timer contacts TCH. The low temperature contacts **136** and the high temperature contacts **138** are located in the remotely located temperature controller unit (not shown) and are responsive to predetermined low and high temperatures of a workpiece within coil **18***a*, by virtue of the thermally generated current flowing in the circuit of thermocouple prods **106**.

Energization of the main contactor control relay MCR closes a circuit through relay contacts **119**, **120** and **121** to supply power from a three-phase sixty-cycle supply source **140** to the primary windings of the heating coil supply transformers **32**. Thus, power is supplied to the heating coils **18** for a period determined by means to be hereafter described.

When the pusher mechanism **54** reaches the fully retracted position, it closes the contacts of the pusher rod limit switch LSPR to energize the elevator arm control relay EAR through a circuit including the second contacts **82** of billet trough limit switch LSBT. The second contacts **82** of the limit switch are closed only when there is no billet in the billet trough **48**. Energization of the elevator arm control relay EAR closes contacts **142** connected in series with the elevator arm solenoid EAS to complete a circuit through conductor **146** and conductor **148** to energize the elevator arm solenoid EAS. The elevator arm solenoid initiates operation of cylinder **52** to cause the elevator **50** to ascend, thereby raising a billet **8** to a position such that it will roll by gravity into the billet trough **48** in front of the retracted pusher rod **56**. As soon as the billet is correctly located in the billet trough **48**, the first contacts **84** of the billet trough limit switch LSBT close and the second contacts **82** open, thereby deenergizing the elevator arm control relay EAS and energizing the pusher interlock control relay IPR. Thus, the system is oriented so that it is ready for a repetition of the heretofore described sequence of operation in response to a second subsequent operation of the billet eject push button **110** by the operator.

So long as the main contactor relay MCR is energized, its contacts **116** (connected in parallel with the billet eject push-button switch) are closed to maintain the clamp arm control relay CAR energized even though the billet eject push button **110** is open. Thus, recycling or repetition of the described sequence of operation cannot be initiated by means of the billet eject push-button switch **110** until the heat-on cycle is completed. The heat-on cycle is terminated by the temperature controller contacts **138** when the temperature of the billet within coil **18***a* reaches a predetermined temperature as measured by means of the thermocouple **106** and its associated circuit. When the predetermined maximum temperature is reached contacts **136** and **138** open to deenergize the main contactor relay MCR, to thereby open relay contacts **119**, **120** and **121** to interrupt the three-phase power circuit to the transformers **32**.

In the event that the temperature control circuit, including the thermocouple **106**, the temperature controller and the maximum temperature contacts **138**, fails to function properly, the heating period will be terminated by means of safety timers TMH and TCH which are energized consecutively (TMH with the main contactor relay MCR through a circuit including the locator retracted limit switch LSLR and conductors **132** and **148** and TCH when TMH times out). The safety timers TMH and TCH are a well known type of time delay relay having pairs of normally closed contacts **150** and **151**. **151** is connected in series with the main contactor relay MCR. Upon expiration of a predetermined period of time after the main contactor relay MCR has been energized, the safety timer TMH will open its contacts **150** to deenergize TCH. TCH will then open its contacts **151** after a predetermined time to deenergize the main contactor relay MCR if it has not already been deenergized by opening of the temperature contact **138**. The reason that two timers TMH and TCH are used instead of one is that timer TCH is also used as a safety timer during recycling, that is, when the billets are allowed to remain in the coil but have to be maintained at or near the required temperature by recycling of power. If contacts H or contacts **138** fail to open as previously described, the combined time interval TMH and TCH will shut off power at a safe maximum temperature and the temperature will fall. When a predetermined minimum temperature is reached, contacts **136** close, energizing relay MCR and reapplying power. Simultaneously, contacts **118** close and as contacts **150** have remained closed, TCH starts timing. When TCH times out, contacts **151** again open and the process repeats itself until the billet

eject button 110 is pressed during a cooling period to eject a hot billet.

If desired, the transformers 32 for use with the heating coil assembly may be of the water-cooled type described in application Serial No. 605,838, filed August 23, 1956, assigned to the same assignee, in which transformers the primary windings are provided with a tap changing arrangement so that the transformer ratios may be varied to apply, when desired, preselectable voltage to the various winding sections 18 of the induction heating coil assembly 21. By use of variable ratio transformers of the type described in the above-mentioned copending application, it is possible to provide for the heating of different portions of each workpiece 8 in such a manner that different longitudinal sections of the workpiece may be simultaneously heated to different predetermined temperatures. That is, by providing a competent number of taps for the transformer windings 33, 34 and 35, different sections 18 of the furnace coil assembly 21 can be energized at different power levels from different voltages of the different transformer secondaries and consequently tapered or variant heating of longitudinally displaced portions of the length of a workpiece 8 can be achieved.

While the present invention has been shown in one form only, it will be obvious to those skilled in the art that it is not so limited but is susceptible of various changes and modifications without departing from the spirit and scope thereof.

We claim as our invention:

1. In an induction heating furnace having an elongated workpiece pathway, a coil assembly including a plurality of multiturn induction coil sections surrounding said pathway in end-to-end aligned relation, a source of polyphase alternating current for energizing said coil sections, circuit means connected to said source and to said coil sections to cause alternating currents of different phases to flow in different ones of said coil sections so as to produce a traveling electromagnetic field along at least a portion of said pathway, workpiece clamping means positioned adjacent said coil assembly intermediate the ends thereof and reciprocally movable toward said pathway to clamp a workpiece in a fixed position within said coil sections so as to restrain said workpiece against motivation by forces created by said electromagnetic field, said clamping means including a clamp arm member having an advanced position in which said arm member extends transversely through one side of one of said coil sections to engage a longitudinal side surface of a workpiece within said pathway.

2. In an induction heating furnace having an elongated workpiece pathway, a coil assembly including a pluraility of substantially helical induction coil sections surrounding said pathway in end-to-end aligned configuration, a source of three-phase alternating current for energizing said furnace, said source being connected to said coil sections to cause separate single-phase alternating current to traverse at least three different ones of said coil sections, with said single phase currents being in such relatively timed sequence as to provide an electromagnetic flux field traveling longitudinally along said pathway within said coil sections, means for clamping a workpiece to be heated in a fixed position within said pathway so as to secure said workpiece against movement in response to forces created by said flux field, said clamping means including a workpiece engaging member located adjacent said coil assembly intermediate the ends thereof and having a first position and a second position with said positions being in a plane substantially perpendicular to said pathway and fluid operated positioning means connected to said workpiece engaging member and operable to reciprocally move said member between said first and second positions.

3. In an induction heating furnace having an elongated workpiece pathway, a coil assembly including a plurality of substantially helical induction coil sections surrounding said pathway in end-to-end aligned configuration, an elongated hollow liner member interiorly supporting said coil sections and surrounding said pathway to provide a support for workpieces within said pathway and having a substantially radial opening in one longitudinal surface thereof, a source of alternating current for energizing said coil sections, so as to provide an alternating flux field for inductively heating workpieces disposed in said pathway, a workpiece clamp member located adjacent said coil assembly intermediate the ends thereof and having first and second positions aligned with said opening in a plane transverse to said pathway, said second position being such that a portion of said clamping member extends through said opening to engage a longitudinal surface of a workpiece in said pathway, to thereby frictionally secure said workpiece against longitudinal movement in response to forces created by said flux field.

4. An electrical induction heating furnace having an elongated workpiece pathway therethrough comprising a support frame member, a longitudinally split thin-walled liner member supported near each end from said frame member, a plurality of substantially helical induction coil sections circuitously surrounding said liner member and positioned in end-to-end alignment along the length of said liner member, polyphase supply circuit means for periodically supplying separate single-phase alternating currents to said induction coil sections, said circuit means including a plurality of conductors connecting different ones of said coil sections to respectively different phases of a polyphase current source with said phases being so connected to said coil sections as to cause a magnetic force to be applied between said workpiece and said coil sections, which force is oriented to tend to impel said workpiece toward the in-feed end of said pathway, a workpiece clamping member located adjacent said liner member intermediate the ends thereof and having first and second positions in a plane substantially perpendicular to said pathway, and control circuit means connected to said clamping member for periodically actuating said clamping member from said first position to said second position with said second position being such that a portion of said clamping member is disposed in engagement with a workpiece in said pathway, with said control circuit means interconnected with said polyphase supply circuit means so as to permit energization of said coil sections only while said clamping member is in clamping engagement with a workpiece in said pathway.

5. In an induction heating furnace having a workpiece pathway in which elongated metallic billets may be heated; a plurality of inductor members formed of helically wound hollow conductor; a horizontally extending longitudinally split liner member surrounding said pathway and providing a support for said inductor members, with said inductor members being aligned in end-to-end relation in a single layer along the length of said liner member, and with said liner member having a first opening and a second opening extending through the surface thereof at horizontally spaced positions; a source of three-phase alternating current for energizing said inductor member to produce an alternating flux field within said liner member and said pathway for heating workpieces disposed therein; a plurality of electrical conductors for connecting different of said inductor members to said source so as to cause single-phase currents which are in three-phase timed relation to each other to flow in different of said inductor members, with said single-phase currents being cooperative to apply an electromagnetic force longitudinally to a workpiece in said pathway; a workpiece clamping member removably disposable at said first opening in said liner member to frictionally engage a longtudinal side surface of said workpiece so as to hold it in check against movement in response to said electromagnetic force; a temperature responsive means removably disposable at said second opening in

said liner member and operative to provide an electrical current signal corresponding to the temperature of a longitudinal side surface of a workpiece within said pathway.

6. In an induction furnace having a workpiece pathway in which elongated metallic workpieces may be heated, a plurality of electrically distinct induction coil windings surrounding said pathway in end-to-end aligned positions, a horizontally extending hollow metal liner having an exit end opening through which a heated workpiece may be discharged and having a first and a second radial opening at longitudinally spaced positions in the surface thereof, said metal liner being axially positioned within said aligned coil windings and surrounding said pathway to provide a support for a workpiece therein, supply circuit means for periodically energizing different ones of said induction coil windings with separate single-phase current flows which are in three-phase timed relation to each other, with said current flows being cooperative to produce within said metal liner a traveling magnetic field accompanied by an electromagnetic force applied longitudinally to said workpiece in a direction away from said exit end of said metal liner, a workpiece clamping member removably disposable to extend through said first opening to forcibly engage said workpiece so as to restrain it against movement in response to said force, a thermocouple element including a temperature responsive end portion movably disposable to extend through said second opening and operative when so extended to provide an electrical current corresponding to the surface temperature of a workpiece interiorly adjacent said second opening, power actuated motivating means for reciprocally moving said thermocouple element and said clamping member toward and away from said workpieces, electrical switch means disposed in circuit with said source and a plurality of said induction windings and adapted to interrupt the periodic energization of said windings, and control circuit means responsive to a predetermined magnitude of the current provided by said thermocouple element and operative to actuate said switch means and to thereafter actuate said motivating means so as to withdraw said clamping members and said thermocouple element from said workpieces.

7. The apparatus substantially as set forth in claim 6 further characterized by the provision of a power driven pusher means adapted to introduce an unheated workpiece into said liner member through an in-feed end opening and to thereby eject a heated workpiece through said exit end opening, with said control circuit being operative to initiate operation of said pusher means subsequently to withdrawal of said clamping member and said thermocouple element.

8. In an electric induction heater for metal workpieces and the like, an induction coil assembly, a clamping member positioned adjacent said coil assembly intermediate the ends thereof and movable in a plane transverse to the central axis of said coil assembly for clamping workpieces within the coil assembly during a heating operation, and means connected to said clamping member for moving the clamping member in said transverse plane from a position exterior to the coil assembly to a position such that it will abut a workpiece positioned therein.

9. In an electric induction heater for metal workpieces and the like, an induction coil assembly, a temperature-measuring device located adjacent said coil assembly intermediate the ends thereof and movable in a plane which is transverse to the central axis of said coil assembly, and means for moving the temperature-measuring device in said transverse plane from a position exterior to the coil assembly to a position within the coil assembly where it will abut a workpiece positioned therein.

10. In an electric induction heater for metal workpieces and the like, a generally cylindrical induction coil assembly, a member movable in a plane transverse to the central axis of said coil assembly for clamping workpieces within the coil assembly during a heating operation, a temperature-measuring device located adjacent said coil assembly intermediate the ends thereof and having first and second spaced positions lying in a plane which is transverse to the central axis of said coil assembly, and means for simultaneously moving the clamping member and the temperature-measuring device in their respective transverse planes with said first position being exterior to the coil assembly and with said second position being within the coil assembly where said temperature-measuring device will abut a workpiece positioned therein.

11. In an electric induction heater for metal workpieces and the like, the combination of a generally cylindrical induction coil assembly having an entrance end and an exit end, means at the entrance end of said coil assembly to feed workpieces axially forwardly into the interior of the coil assembly, means for clamping workpieces within the coil assembly against the thrust of a magnetic field, a device positioned at the exit end of the coil assembly to force workpieces axially backward into the interior of the coil assembly to a predetermined position, and a control means operatively connected to said device and to said clamping means so as to prevent actuation of the clamping means until said device has forced workpieces backward into said predetermined position.

12. In an electric induction heater for metal workpieces and the like, the combination of a generally cylindrical induction coil assembly having an entrance end and an exit end, means at the entrance end of said coil assembly to feed workpieces axially forwardly into the interior of the coil assembly, a temperature measuring device located adjacent said coil assembly intermediate the ends thereof and having first and second spaced positions lying in a plane transverse to the central axis of said coil assembly, apparatus for moving said temperature-measuring device between said positions to contact with a workpiece positioned within the coil assembly, a device positioned at the exit end of the coil assembly to force workpieces axially backward into the interior of the coil assembly to a predetermined position, and electrical control means operatively connected to said device and to said apparatus so as to actuate said apparatus to move the temperature-measuring device into contact with a workpiece after said device has forced workpieces backward into said predetermined position.

13. In an electric induction heater for metal workpieces and the like, the combination of a generally cylindrical induction coil assembly having an entrance end and an exit end, means at the entrance end of said coil assembly to feed workpieces axially forwardly into the interior of the coil assembly, a temperature-measuring device, apparatus for moving said temperature-measuring device into contact with a workpiece positioned within said coil assembly, a device positioned at the exit end of the coil assembly to force workpieces axially backward into the interior of the coil assembly, and control means operatively connected to said device and to said apparatus for preventing movement of the temperature-measuring device into contact with a workpiece until said device has forced workpieces axially backward into the interior of the coil assembly.

References Cited in the file of this patent

UNITED STATES PATENTS

2,325,638	Strickland	Aug. 3, 1943
2,415,376	Strickland	Feb. 4, 1947
2,676,234	Lackner et al.	Apr. 20, 1954
2,750,486	Howell	June 12, 1956