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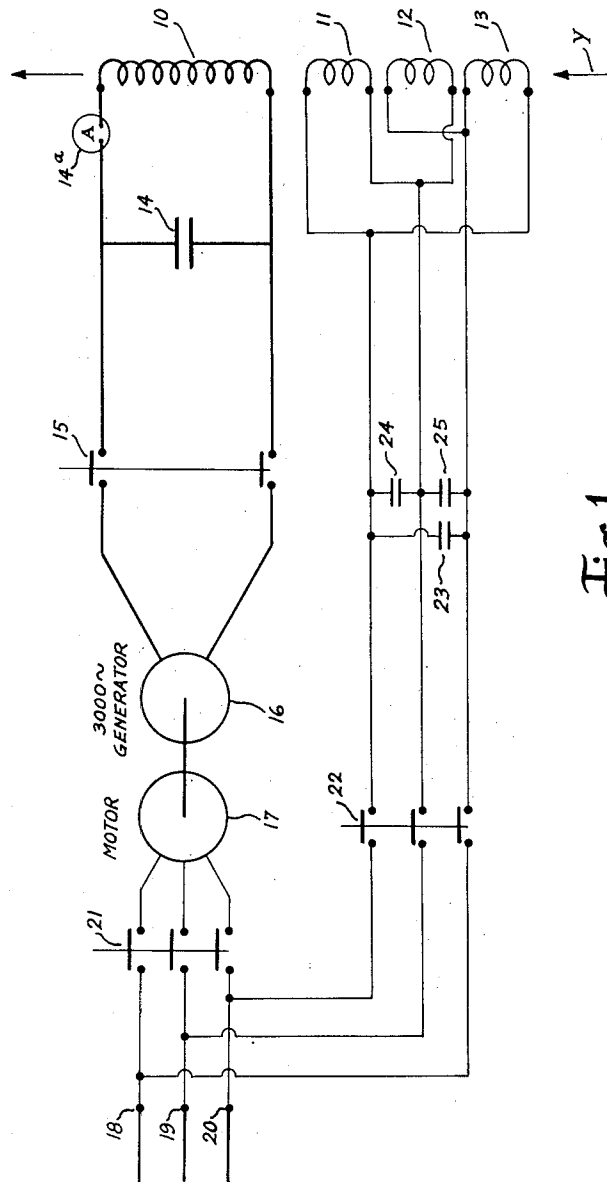
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2,669,647

DUAL FREQUENCY INDUCTION HEATING APPARATUS

Filed June 13, 1952

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

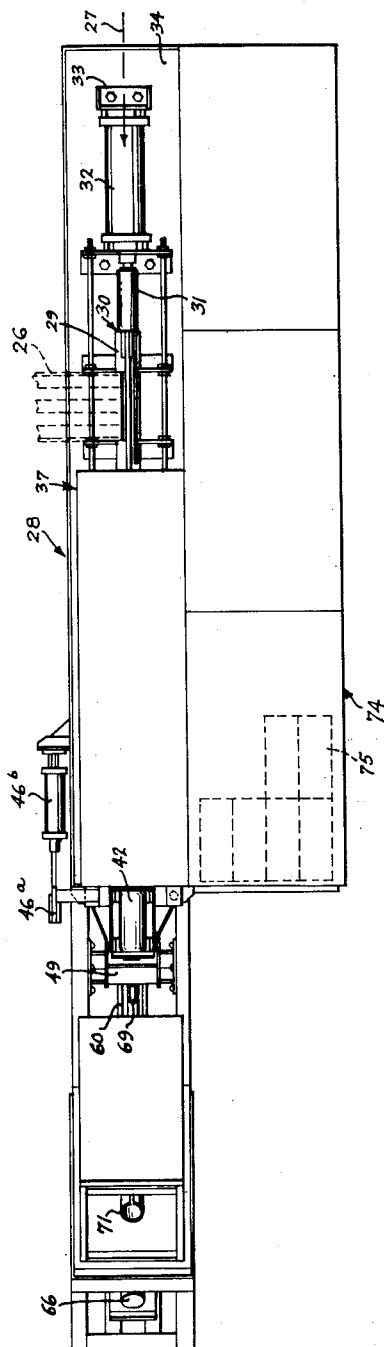


Fig. 2

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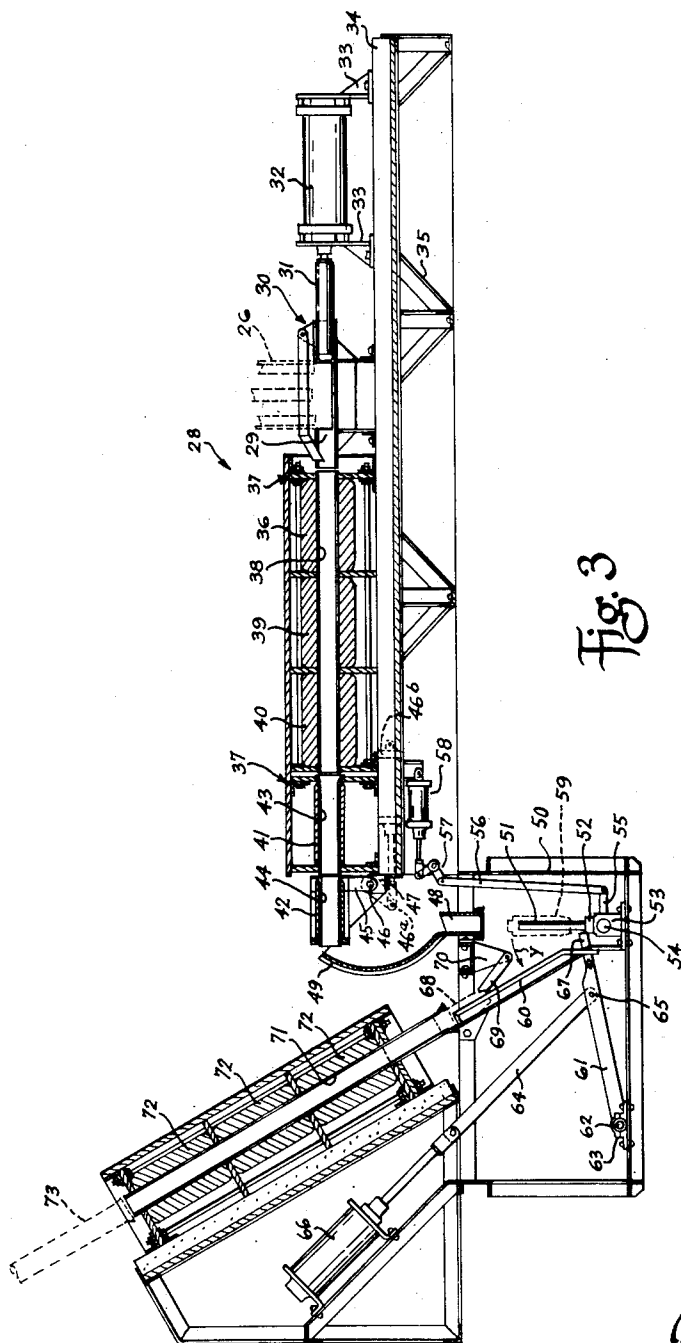
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UNITED STATES PATENT OFFICE

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DUAL FREQUENCY INDUCTION HEATING APPARATUS

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Application June 13, 1952, Serial No. 293,274

8 Claims. (Cl. 219—10.71)

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This invention relates to combined low-frequency high-frequency induction heating apparatus.

This application is co-pending with my applications filed on even date herewith: Dual Frequency Induction Heating Method, Serial No. 293,273; Method and Apparatus for Heating Stacked Plates, Serial No. 293,275; Induction Heating Coil Construction, Serial No. 293,276.

Accordingly, hollow shells and like irregularly shaped articles are usually heated in gas fired furnaces and the like. Any attempt to inductively heat such articles by prior methods and apparatus is limited by the non-uniform generation of heat in the article having regard to the characteristic of the effect of frequency on the depth of penetration of the magnetic flux.

The induction apparatus of the invention avoids the disadvantages of non-uniform heating effect on the article and is, accordingly, adaptable to the heating of hollow shells and other irregularly shaped articles.

The apparatus of the invention generally comprises low and high frequency induction heating coils combined and arranged in such manner that the article to be heated is first passed through the low frequency coils to cause the article or a part thereof to be heated to a predetermined temperature and then passed through a higher frequency coil or coils to increase the heating effect on or selectively heat other portions of the article. Means are provided for feeding the article on a through path extending through the influence of the magnetic fields of the low and high frequency coils. Preferably, the article is passed along the co-axial line of the coils, the latter being arranged end to end. Means are provided for guiding the article after discharge from the high frequency coil to a supporting means associated with means for controllably cooling the article. The apparatus may also include a further low frequency coil or coils through which the cooled article may be fed for further heat treating.

The invention will be appreciated in more detail by a study of the following specification taken in conjunction with the accompanying drawings.

In the drawings:

Figure 1 is an electrical schematic of induction heat treating apparatus according to the invention.

Figure 2 is a plan view of one form of heat treating apparatus according to the invention.

Figure 3 is a sectional view of the apparatus of Figure 2 illustrating the mechanical features thereof.

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A combined low-frequency high-frequency induction heating system is provided in accordance with the invention in a manner illustrated in Figure 1 wherein the high frequency induction heating coil 10 is placed on an axial line with low frequency induction heating coils 11, 12 and 13, the arrangement being adapted for the passage of a metal object (not shown) in the direction of the arrow Y.

The high frequency induction heating coil 10 is in parallel circuit with the high frequency capacitor 14 and switching means 15 to be energized by a suitable high frequency generator 16, the latter being driven by a suitable motor 17. Other equivalent sources of high frequency power known to skilled persons may be employed without departing from the concept herein of cooperating low and high frequency induction heating systems. In the illustration disclosed, three phase power is fed from industrial power lines to the terminals 18, 19 and 20 which are electrically connected to the motor through a suitable switch device 21. These terminals also are connected electrically through the switching device 22 to the low frequency coils 11, 12 and 13 in a special way.

Observe that the centre coil 12 is connected in reversed manner as one provides the connection of a medial winding in a three phase squirrel cage motor. Low frequency capacitors 23, 24 and 25 are provided, the electrical arrangement illustrated being in delta connection, it being understood that a star connection of three phase power may also be employed.

It is intended that the low frequency coils 11, 12 and 13 will operate at line frequency of about sixty cycles per second. In the commercial heating of steel with the apparatus of the invention, it has been shown that in excess of 90% of the electrical energy as supplied to the low frequency coils can be converted into useful heat in the metal object being heated up to a temperature approaching the Curie point.

A preferred form of apparatus for heating a hollow shell is illustrated in Figures 2 and 3. An inclined hopper 26 is disposed transversely of the axial line 27 of the heat treating apparatus 28. A plurality of shell casings may be arranged in side-by-side relationship in the hopper 26, the lowermost resting in the breach 29 of the feed apparatus 30, the latter including an axially disposed ram 31 actuatable by the air cylinder 32 supported by brackets 33 on the rigid longitudinally disposed concrete panel 34 supported by frame 35. Upon actuation of the air cylinder under air pressure a shell is fed from the breach into the first low frequency coil 36, this first coil being one of

a series of three all supported by a common frame 37 and having a continuous steel liner 38 there-through disposed about said axial line 27. The low frequency coils 36, 39 and 40 are preferably of a construction disclosed in my co-pending application, Induction Heating Coil Construction, Serial No. 293,276, previously referred to. In the apparatus illustrated, each coil may comprise six layers of $\frac{1}{4}$ " diameter copper tubing of 52 turns per layer wound over two layers of asbestos cloth separating the innermost winding from the liner 38. The voltage is adjusted to suit the heating rate desired and has a maximum value of about 575 volts at 60 cycles. In accordance with the schematic of Figure 1, the coils may be energized by a three phase source. The windings must be insulated preferably with a resin bonded glass tape with an asbestos paper between layers. The coil must be mechanically sound against the effects of vibration and, accordingly, the windings and insulation must be well bonded with a suitable resin and baked. In some applications it may be desirable to proportion the windings between the low frequency coils to balance the load on the three phase line because it will be apparent that the last coil 40, for example, will be operating on a material which, because of its higher temperature, is different in electromagnetic properties from the material at a lower temperature in, say, coil 36.

The higher frequency coils 41 and 42 may be constructed in accordance with conventional practice. In one particular case, however, it was found that a frequency of 360 cycles was an optimum for the desired heat pattern on a three inch diameter shell and, accordingly, multi-layer coils were formed in a manner following the construction of the low frequency coils and comprised in coil 41, four layers at 52 turns per layer of $\frac{1}{4}$ " diameter copper tubing; in coil 42, five layers at 37 turns per layer of $\frac{1}{4}$ " diameter copper tubing. In this special construction, the high frequency coils were connected in parallel on a single phase line of 400 volts, 360 cycles.

The coil 41 and the liner 43 are supported rigidly in the frame 37. The coil 42 and liner 44 are disposed upon a swingable mounting 45 pivoted as at 46 on a bracket 47 fixed to the panel 34. Accordingly, as an article such as a shell arrives at final temperature in the coil 42, the latter may be swung counterclockwise by means of a crank arm 46a actuated by air cylinder 46b to cause the casing to fall through the guide 48, the latter carrying the arcuately formed guide plate 49 against which the outward projectable end of the casing within the coil 42 may slide as the coil rotates downwardly to the vertical position.

The casing then falls through the guide 48 into suitable apparatus for controlling the cooling thereof, such as a quenching tank 50 wherein supporting means 51 are provided and which may include a swingable post 52 over which the casing may rest during the quenching operation.

After the casing has been quenched or controllably cooled, such as in the quenching tank 50, for a desired period of time, the swingable post and its base 53 pivoted on the axle 54 in brackets 55 is swung counterclockwise in the direction of the arrow Y by movement of the arm 56 fastened to the base and actuated by the linkage 57 operated by the air cylinder 58 to cause the casing 59 to lie in the guideway 60.

A swingable feed arm 61 pivoted as at 62 in brackets 63 is drawn by the arm 64 pivoted as at 75

65 under action of the inclined air cylinder 66 to cause the bifurcated arms 67 thereof to ride about the post 52 and to engage the shell 59 and move it upwardly to a position indicated in chain lines at 68 supportable by the spring-biased deflectable locking arm 69 mounted on brackets 70. The casings then pass progressively under action of this feeding apparatus through the stainless steel tube 71 about which I preferably form a series of low frequency coils 72 similar in all respects to the low frequency coils 36, 39 and 40. As indicated, a conveying tube 73 may extend upwardly from the inclined low frequency coils 72 to a point of deliver (not shown), it being understood, however, that if desired the shell may be cooled in any controlled manner either while passing through the tube 73 or after delivery therefrom. The various air cylinders 32, 46b, 58 and 66 may be independently operated by suitable controls of well known character to skilled persons or may be operatively inter-related to provide a substantially automatic system by any of the well known schemes for sequential operation of hydraulic cylinders. It will be appreciated that all of the air cylinders, which of course may be hydraulic cylinders if desired, are of the double-acting type.

A suitable frame 74 is provided for supporting the groups of necessary capacitors 75 required in accordance with the electrical schematic of Figure 1.

As illustrated in Figure 1, I may provide a temperature indicating device such as an ammeter 76 placed in series with a high frequency coil 77. The ammeter may be shunted in accordance with known practice and may be calibrated to indicate the temperature as a function of current. In this way a very accurate temperature indication can be obtained.

The following table lists the frequency size relationship for optimum efficiency of various materials heated at various frequencies. Reasonable results can be obtained with sizes smaller than those indicated down to about 75% of the minimum sizes listed.

Table

Frequency	Material	Minimum size, inches, for optimum frequency		
		Dia. round	Square	Tube wall Thickness
60	Steel Below Curie Point.	2 $\frac{1}{4}$	1 $\frac{1}{2}$	$\frac{3}{4}$
55	Steel Above Curie Point.	10 $\frac{1}{4}$	7 $\frac{1}{2}$	3 $\frac{3}{4}$
60	Aluminum	2 $\frac{3}{4}$	2	1
60	Brass	3 $\frac{3}{4}$	2 $\frac{5}{8}$	1 $\frac{1}{2}$
1,080	Steel Below Curie Point.	.625	.375	.187
1,080	Steel Above Curie Point.	2 $\frac{1}{2}$	1 $\frac{3}{4}$	$\frac{7}{8}$
60	Aluminum	.68	.48	.24
1,080	Brass	.89	.63	.31
3,000	Steel Below Curie Point.	.812	.22	.11
3,000	Steel Above Curie Point.	1 $\frac{1}{2}$	1 $\frac{1}{4}$	$\frac{1}{2}$
3,000	Aluminum	.405	.29	.145
3,000	Brass	.526	.372	.186
9,600	Steel Below Curie Point.	.174	.123	.062
9,600	Steel Above Curie Point.	.83	.585	.292
9,600	Aluminum	.226	.16	.08
9,600	Brass	.284	.20	.10
400,000	Steel Below Curie Point.	.029	.021	.01
70	Steel Above Curie Point.	.128	.091	.045
400,000	Aluminum	.035	.025	.012
400,000	Brass	.045	.032	.016

The particular relation between frequency,

permeability, and specific resistance is obtained from the following formula developed by Steinmiz (see Industrial High Frequency Power by May, Chapman and Hall, pages 167 and 169).

$$A = \sqrt{\frac{r \cdot f}{2W^2 P \epsilon}}$$

where

A=depth (in cms.) to accommodate the total magnetic flux if it were uniformly distributed at the same density as exists at the surface.

r=resistivity of the charge, in electromagnetic units (resistivity of a 1 cm. cube in ohms) $\times 10^9 = r \times 10^9$.

W= $2\pi \times$ frequency in cycles per second.

f=frequency.

Pe=effective permeability of the charge=ratio of

Total magnetic flux actually existing
Flux produced by same ampere turns in air

It will be apparent that the particular frequency for a predetermined desired depth of penetration is related to and is a function of the effective permeability of the material and the resistivity.

In the heating of specially shaped objects such as hollow shells, a particular heat pattern may be desired in the shell base rather than a uniform heat pattern. In such instance, the high frequency induction heating part of the apparatus may operate at a higher frequency giving lesser penetration. In the case where one is heat treating a shell, the shell wall determines the desired depth of penetration and, accordingly, a higher frequency may be employed of the order of ten thousand cycles per second. If a frequency of materially greater penetration were employed there would be a substantial overlap of heating affects in the base of the shell outside a centre region thereof. Accordingly, the centre region can be heated to a different degree than the outer regions not only by selecting the frequency of the high frequency induction heating coils but by controlling the duration of heating in the low frequency induction coils. In this way, a controllable heat pattern can be accomplished wherein the outer skin is always heated to the same or a greater temperature than the core of the material in a solid metal object. The technique lends itself particularly to the heat treatment of various shaped castings wherein the heat pattern of the heat treating can be controlled in a specified way before quenching or controlled cooling by any other well known technique in the tempering and hardening arts.

It will be apparent that the present multiple frequency induction heating apparatus, in affording a control over the heat pattern, enables a substantially uniform heating of an article to be accomplished by an induction heating technique.

It is intended that the present disclosure should not be construed in any limiting sense other than that indicated by the scope of the following claims.

What I claim as my invention is:

1. Apparatus for heat treating a shell case comprising in combination: a stationary horizontally disposed induction heating coil including means for energizing same; means for passing a shell case through said coil; a swingable induction heating coil having an exit end and supported in coaxial alignment with said stationary coil; means swingably supporting said

swingable coil for swinging movement between said coaxial position and a downward substantially vertical position thereof; cooling means disposed below said swingable coil including a support; and means for guiding a shell case to said support as said case falls from the exit end of said swingable coil upon moving the latter to substantially the vertical position.

2. Apparatus as claimed in claim 1 in which said guide means is in the form of a curved plate spaced adjacent the path of movement of the exit end of said swingable coil during swinging movement thereof.

3. Apparatus as claimed in claim 1 and an inclined guideway rising from adjacent said support to a point exterior of said cooling means; means swinging said support and a shell case thereon to a position substantially placing said shell case on said inclined guideway; and means for moving said placed shell case from said support and along said inclined guideway exterior of said cooling means.

4. Apparatus as claimed in claim 1 and an inclined guideway rising from adjacent said support to a point exterior of said cooling means; means swinging said support and a shell case thereon to a position substantially placing said shell case on said inclined guideway; means for moving said placed shell case from said support and along said inclined guideway exterior of said cooling means; means for supporting said shell case on said guideway exterior of said cooling means; and a further induction heating coil including energizing means therefor disposed coaxially with said inclined guideway and forming a continuation thereof beyond said cooling means.

5. Apparatus as claimed in claim 1 and an inclined guideway rising from adjacent said support to a point exterior of said cooling means; means swinging said support and a shell case thereon to a position substantially placing said shell case on said inclined guideway; a swingable arm disposed in said cooling means having bifurcated arms on the free end thereof adapted upon swinging movement of said arm to engage and move said placed shell case from said support and upwardly along said inclined guideway to a position exterior of said cooling means.

6. Apparatus as claimed in claim 1 in which said guide means is in the form of a curved plate spaced adjacent the path of movement of the exit end of said swingable coil during swinging movement thereof; an inclined guideway rising from adjacent said support to a point exterior of said cooling means; means swinging said support and a shell case thereon to a position substantially placing said shell case on said inclined guideway; and means for moving said placed shell case from said support and along said inclined guideway exterior of said cooling means.

7. Apparatus as claimed in claim 1 in which said guide means is in the form of a curved plate spaced adjacent the path of movement of the exit end of said swingable coil during swinging movement thereof; and inclined guideway rising from adjacent said support to a point exterior of said cooling means; means swinging said support and a shell case thereon to a position substantially placing said shell case on said inclined guideway; means for moving said placed shell case from said support and along said inclined guideway exterior of said cooling means; means for supporting said shell case on said guideway

exterior of said cooling means; and a further induction heating coil including energizing means therefor disposed coaxially with said inclined guideway and forming a continuation thereof beyond said cooling means.

8. Apparatus as claimed in claim 1 in which said guide means is in the form of a curved plate spaced adjacent the path of movement of the exit end of said swingable coil during swinging movement thereof; an inclined guideway rising from adjacent said support to a point exterior of said cooling means; means swinging said support and a shell case thereon to a position substantially placing said shell case on said inclined guideway; a swingable arm disposed in said cooling means having bifurcated arms on the free end thereof adapted upon swinging

movement of said arm to engage and move said placed shell case from said support and upwardly along said inclined guideway to a position exterior of said cooling means.

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