(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 776 146 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
28.05.1997 Bulletin 1997/22

(51) Int. Cl.^{6}: **H05B 6/44**, H05B 6/10

(21) Application number: **96203552.3**

(22) Date of filing: **27.11.1991**

(84) Designated Contracting States:
CH DE GB LI

(30) Priority: **30.11.1990 US 621231**

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
92901510.5 / 0 583 242

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Remarks:
This application was filed on 16 - 12 - 1996 as a divisional application to the application mentioned under INID code 62.

(54) Induction dryer and magnetic separator

(57) Apparatus is described for heating compound material applied to can ends, which comprises:

an electrically nonconductive support structured to support the can ends while being transported in face-to-face relationship along the support;

an alternating current source;

an electrical conductor connected to the alternating current source and disposed in sufficient proximity to the support to produce an alternating magnetic field within the support; and

a transporting device which transports the can ends in face-to-face relationship along the support and through the alternating magnetic field to induce current flow in the can ends to induction heat the can ends and thereby heat the compound material applied to the can ends.

A method of drying compound material applied to can ends is also described.

Printed by Rank Xerox (UK) Business Services
2.14.3/3.4

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for heating or otherwise treating metal objects, and more particularly, to a method and apparatus for inductively heating or otherwise treating metal can lids or closures for drying, curing or other purposes, for maintaining a spacing between them, and for motivating them along a path.

2. Description of Related Art

Closures for metal beverage containers are generally of a circular shape with a flanged perimeter called a curl. The closures are usually made of aluminum or steel, and the curl is used in attaching the closure to a can body through a seaming operation. To aid the integrity of the seal thus formed between the can body and the closure, it is a common practice to apply a bead of sealant within the curl during manufacture of the closure. Different types of coatings are also selectively or generally applied to can closures for various other purposes as well, for example, to repair damaged coatings.

One problem which arises in this manufacturing operation is the curing or drying of such coatings. Recently there has been increased interest in the use of water-based sealants in the container industry, which may take up to ten days to dry to an acceptable state for application of the closure to a can body. This was not a severe problem for solvent-based coatings, because the volatile solvent quickly evaporates and is acceptably dry for application of the closure to a can body typically within 24 to 48 hours.

In the past, can closures were heated to aid the drying or curing process typically either by infrared radiation or convection heating. These systems, especially the convection heating systems, tended to be large, bulky and expensive to operate due to inefficient energy usage.

Metal can closures are typically conveyed into the heat-treating apparatus in either of two ways. They can be conveyed by a conveyor belt, in which case the closures lie flat on the belt with coating side up, or they can be stacked within a track or cage, in abutting face-to-face contact with each other. In the latter case the closures are pushed through the apparatus in a direction transverse to their faces. The latter arrangement is shown in U.S. Patent No. 4,333,246 to Sullivan.

In both orientations, the conveyance velocity and the length of the drying apparatus are chosen to ensure that a sufficient amount of the water in the coating has been driven out by the time each can closure emerges from the apparatus. A problem arises, however, if the production line should stop for some reason or somehow become blocked. In this case, the can closures in the heating apparatus would remain there longer than originally intended, thereby overheating them and potentially destroying them. No closed-loop mechanism has been provided for handling this situation. Furthermore, for IR systems and high-temperature convection systems, even if such a mechanism were provided it would be difficult to stop the heating process quickly enough to avoid damage. Lower temperature convection heating systems do exist which avoid the risk of overheating can lids simply because they never get hot enough to cause damage, but the lower temperatures undesirably also necessitate longer drying times and longer conveyance paths.

Another problem with some prior-art heaters for can closures occurs because of the speed with which the can closures are conveyed through the heating apparatus. Can closures are increasingly being produced at rates as high as approximately 1,600 per minute, requiring movement at a high rate of speed through the heater. Especially for conveyor belt conveyance systems, it is very easy for the can lids to fly off the belt when moving at that speed. To avoid this, prior-art heating apparatus typically included vacuum equipment or permanent magnets for adhering the closures tightly onto the belt. Such vacuum equipment can be expensive and bulky.

The heating of certain types of metal objects by high-frequency induction is known, but has heretofore not been applied to the manufacture of metal can closures. See, for example, U.S. Patent No. 4,339,645 to Miller; U.S. Patent No. 4,481,397 to Maurice; U.S. Patent No. 4,296,294 to Beckert; and U.S. Patent No. 4,849,598 to Nozaki. While some of the systems disclosed in these references may be usable for heating can closures, they are not optimal. In particular, for example, they may be very large and bulky, may require water cooling, and may be inefficient due to unnecessary wasting of flux energy. The coils in prior-art induction heating apparatus also typically must be shaped very carefully in order to ensure adequate energy transfer.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide can closure heating apparatus which overcomes some or all of the above disadvantages.

According to the invention, roughly stated, metal can closures are heated inductively by placing them in a high-frequency, oscillating magnetic field generated by an induction coil wrapped around a high-permeability, low-conductivity core. The core is shaped and oriented so that its two magnetically opposite poles direct magnetic flux in a concentrated manner from the coil along a path which passes through the can closures.

The can closures may be conveyed along a conveyance path which passes through the magnetic field, and can be oriented either flat on a conveyor belt or in stacked, face-to-face relationship with each other. If lying flat on a conveyor belt, and if the can closures include a ferromagnetic material, then the cores may concentrate the magnetic flux lines into the conveyance path from below the conveyor belt, thereby holding the closures on the belt magnetically in addition to heating them inductively. This avoids the necessity for the bulky vacuum system described above.

In another aspect of the invention, multiple cores can generate multiple oscillating magnetic fields at different longitudinal positions along the conveyance path, and/or at different radial positions around the conveyance path. The field generating apparatus can be readily modularized and therefore readily adapted to the changing needs of each particular production line.

In yet another aspect of the invention, closed-loop temperature control of the can closures is provided by apparatus which senses the temperature of the can lids and turns off the heating means if the temperature exceeds a predetermined threshold.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described with respect to particular embodiments thereof, and reference will be made to the drawings, in which

Fig. 1 is a side view of apparatus according to the invention.
Fig. 2 is a drawing illustrating certain magnetic flux lines generated in the apparatus of Fig. 1.
Fig. 3 is a top view of one of the cores shown in Fig. 1, together with one of the can closures of Fig. 1.
Fig. 4 is a front view of another embodiment of the invention.
Fig. 5 is a top view, taken along lines 5-5, of the apparatus of Fig. 4.
Figs. 6 and 7 are a side view and a cross-section, respectively, of another embodiment of the invention.
Figs. 8 and 9 illustrate motivational techniques according to the invention.
Figs. 10 and 11 are side views of apparatus according to the invention, illustrating respective aspects thereof.
Fig. 12 is a top view of a portion of apparatus according to the invention, for use with a conveyor belt such as that shown in Fig. 1.

DETAILED DESCRIPTION

In Fig. 1 there is shown inductive drying apparatus according to the invention. It comprises a series of E-shaped cores 10, 12 and 14 placed at different longitudinal positions along the length of a conveyance path 16. Each of the cores has a center parallel prong 20 and two outer parallel prongs 22 and 24. The cores are spaced from each other in the longitudinal direction by respective gaps 26 and 28, for reasons described below. Each of the parallel prongs 20, 22 and 24 of each of the E-shaped cores is directed toward the conveyance path 16.

A conveyor belt 40 is positioned above the cores 10, 12 and 14, and is moved continuously forward in the longitudinal direction of the conveyance path 16 due to the rotation of a motor and roller shown symbolically as 42. A series of metal can closures 50 lie flat on the conveyor belt 40 and are motivated forward along the conveyance path 16 by the movement of the conveyor belt 40. As can be seen in the drawing, the can closures 50 are resting on their curls 52 which extend downwards from the major surface of the closures. A bead of coating (not shown) to be dried may be placed in these curls prior to being placed on the conveyor belt 40.

The center prong of each of the E-shaped cores 10, 12 and 14 is wrapped with a respective coil 60, 62 and 64 of a wire 66. The opposite ends of wire 66 are connected to an AC current source 68. The coil 62 is wrapped in the opposite direction from coil 60, and the coil 64 is wrapped in the opposite direction from coil 62. The reasons for the different coil winding directions will become apparent.

Fig. 2 shows the magnetic flux paths which are generated by the coils 60, 62 and 64 in conjunction with the cores 10, 12 and 14, for one phase of the AC current source 68. When the AC current source 68 is in its positive half cycle, a magnetic field is induced in the coil 60 having a north pole at the free (top) end of the center prong of the core 10 and a south pole at the opposite end (bottom) of the coil. The cores 10, 12 and 14 are each of high-permeability, however, and therefore have the effect of containing the magnetic flux lines emanating from the bottom end of the coil 60 and carrying them around to the two outer parallel prongs 22 and 24 of the core 10.

Two flux circuits are thereby created. One extends from the north pole 20 across an air gap to the south pole 22, around the base of the core 10 and back to the north pole 20. The other extends from the north pole 20 across the other air gap of the E-shaped core to the south pole 24, around the base of the core 10 in the opposite direction, and back to the north pole 20. Because of the shape of the core 10, the magnetic flux lines which cross the gaps from the north pole 20 to the south pole 24 are both generally arcuate paths. And because of the orientation and position of the core 10, these arcuate paths pass through the conveyance path 16 and ultimately through each of the can closures 50 as they pass by. Accordingly, it can be said that the shape, orientation, and position of the core 10 is such as to, in essence, concentrate magnetic flux lines from the magnetic field generated by the coil 60, through the conveyance path 16. This feature of the invention greatly improves the coupling efficiency of energy from the AC current source 68 into the can closures 50, and does not require any particular accuracy in the winding or shaping of coil 60.

Additional efficiencies are obtained due to the aforementioned longitudinal gaps 26 and 28 between the cores 10, 12 and 12, 14. As previously mentioned, the coil 62 is wrapped around the center prong 20 of the E-shaped core 12 in a direction opposite to the winding of cores 10 and 14. Accordingly, whenever the outer prongs 22 and 24 of the E-shaped core 10 are magnetically south, the outer prongs 22 and 24 of the E-shaped core 12 will be north. The same is true with respect to the relationship between cores 12 and 14. Accordingly, in addition to the flux paths generated across the prongs of each individual core, an additional arcuate flux path is generated across the nearest adjacent outer prongs of each pair of adjacent cores.

The AC current source 68 oscillates on the order of 20 KHz, thereby causing the magnetic fields generated by the coils and cores to oscillate at the same frequency. This generates AC electrical currents also oscillating at the same frequency, in the metal can closures 50 as they move along the conveyance path 16. The figure of 20KHz is chosen as an optimum base frequency for an optimum depth of heating of the can closures. Because of skin effects, as is well known, lower frequencies will induce currents deeper into the can closure, whereas the currents induced at higher frequencies are more shallow. Optimally, the AC current source 68 is intelligent enough to vary the frequency by several kilohertz in each direction in order to optimize the energy transfer efficiency for can closures 50 of different available sizes, shapes, material content, and position relative to the cores 10, 12 and 14.

Fig. 3 shows a top view of one of the E-shaped cores 10, and one of the can closures 50 with which it is intended to operate. It can be seen that the width of the core 10, transverse to the conveyance path 16, is wider than the diameter of the can closure 50. In general, in order to ensure that all parts of the metal can closure 50 are heated, the core 10 should be at least as wide as the largest expected workpiece width.

The cores 10, 12 and 14, as previously stated, should be made of a material of high permeability in order to best contain the magnetic flux generated by the coils 60, 62 and 64. The cores should also have low electrical conductivity, in order to prevent loss of energy through the induction of currents within the core. Ferrite is a suitable material for these purposes. Similarly, the conveyor belt 40 should be made of a non-conductive material.

It can be seen that numerous variations on the embodiment shown in Figs. 1, 2 and 3 are possible. For example, though all three coils 60, 62 and 64 are shown as being series connected to the same AC current source 68, some or all of them could be powered by separate current sources instead. As another example, the cores could be oriented differently, though still concentrating magnetic flux through the conveyance path 16. As yet another example, though each of the cores shown in Fig. 1 have windings wrapped only around their center parallel prongs 20, it will be apparent that additional windings in the opposite direction may be placed around the outer parallel prongs 22 and 24. Windings may also be placed around the base portions of the cores. Other shapes or cores are also feasible. For example, a U-shaped core would also work, as long as it is positioned and oriented to concentrate magnetic flux through the conveyance path 16.

The modularity of the construction of the inductive heating apparatus shown in Figs. 1-3 offers extensive flexibility with regard to the placement of cores. For example, it is easy to increase or decrease the length of the conveyance path along which the can and closures are heated simply by adding or removing cores. Such a need may arise due to, for example, changes in the speed of the production line, or changes in the water content of the coatings to be dried. As another example, in some situations it may be desirable to increase the temperature of the workpieces more slowly as they enter the heater apparatus and more quickly as they progress downstream. This may be accomplished simply by placing the upstream core or cores at a greater distance from the conveyance path 16 and the more downstream cores at a smaller distance from the conveyance path.

It will also be apparent that the invention is not limited to metal can closures, but can also be used with other, preferably but not necessarily flat, electrically conductive workpieces. Many other variations will be apparent.

Figure 12 is a top view of a different embodiment of apparatus according to the invention, in which the cores 10, 12 and 14 are omitted. The apparatus comprises a support 350 on which is mounted a plurality of spiral windings facing, and arranged sequentially along, the conveyance path 16. The conveyor belt 40 (Figure 1), on which the can lids 50 are carried, is not shown in Figure 12. The spirals 352 are interconnected in a polyphase manner, in particular, every third spiral being connected together. Three phases of the AC current source 68 (not shown in Figure 12) are connected respectively to the three phases A, B and C of the spirals. As with the embodiment of Figure 1, the embodiment of Figure 12 will generate high frequency oscillating eddy currents in the metal can closures 50 as they move along the conveyance path 16. The use of polyphase spirals as shown in Figure 12 is appropriate to provide motivational forces as explained in more detail below; a single phase arrangement is all that is necessary if motivation is provided by some other means, such as a moving conveyor belt.

Temperature Sensing

As mentioned previously, a problem with prior-art can-closure drying apparatus has been their tendency to overheat and damage or destroy can closures which are inside the heater when the production line becomes blocked or stops for some reason. Even if a means were to be provided to turn off the heater when the line stops, heating can nevertheless continue for an undesirably long period of time.

In accordance with an aspect of the invention, closed-loop temperature control is provided for the can lids 50. In particular, as shown in Fig. 1, a temperature sensor 80, which may be a conventional IR sensor, is provided adjacent the conveyance path 16 to sense the temperature of the closures 50. Should the temperature be higher than a predetermined temperature, the AC current source 68 is automatically turned off. This stops all current flow through the can closures, thereby almost immediately preventing the closures from becoming any hotter.

Temperature sensing can also be used as part of closed-loop temperature control for the ordinary operation of the inductive heater, even absent failures such as line stoppage. For example, it is known that a particular water-based sealant placed in the curl 52 has been sufficiently heated to reach 98% solids within 10 minutes when the closure 50 has reached a temperature of 150-220°F. A closed-loop temperature-sensing system can therefore be incorporated in an induction dryer which senses the temperature of the can closures individually and turns off the AC current source 68 when each closure reaches that threshold temperature. In this way closures of different size, thickness, position or orientation can be accommodated, even within a continuous stream of closures, without changing the construction of the induction drying portion of the production line.

Holding Means

The conveyor belt 40 of Fig. 1 typically moves very quickly, so as to dry on the order of 1,600 can closures per minute. At this velocity it is common for the closures to slide off the conveyor belt 40 unless they are held in place by some holding means. A holding means should be included also to counteract the magnetic repulsive forces created between the current in the windings and the induced current in the can closures.

As previously mentioned, can closures are usually made either of aluminum or steel. For aluminum can closures, a holding means may be constructed which draws air downward through the conveyor belt 40 through holes punched therein. Such a vacuum apparatus can be expensive and bulky, however, and it is desirable to avoid it if possible. Accordingly, for steel (or other ferromagnetic) can closures, the cores 10, 12 and 14 and coils 60, 62 and 64 themselves provide the holding means. That is, the cores are positioned and oriented such that, in addition to inducing appropriate currents in the closures 50, they also magnetically attract the closures toward the conveyor belt 40. The positioning and orientation of the cores 10, 12 and 14 should be such that this magnetic attraction more than counteracts the repulsive forces generated by the induced currents.

Alternative Embodiment

In Figs. 4 and 5 there is shown an alternative embodiment for the inductive drying apparatus according to the invention, which the can closures are stacked face-to-face and pushed through the heating apparatus in a direction transverse to the major surfaces of the closures.

Fig. 4 shows a front view of the apparatus, and Fig. 5 shows a projection taken along lines 5-5 shown in Fig. 4. One set of the cores, namely core 120 and the cores directly behind it, are omitted from Fig. 5 for purposes of clarity of illustration. In the apparatus, each of the can closures 100 in a stack rests end-wise on a pair of guide rods 102 and 104. Two more guide rods 106 and 108 are provided to help hold the closures in place. The four guide rods 102, 104, 106 and 108 together define a conveyance path 110 for the stack of closures 100. Though the closures 100 are shown spaced from each other in Fig. 5, this is only for the illustrative purpose of showing portions of the apparatus that would otherwise be blocked from view. In actuality, the can lids abut each other and, if their shape permits it, are nested with each other. In this way, the entire stack of lids may be pushed along the conveyance path 110 by force from only the rear end of the stack.

Located at three different radial positions around the conveyance path 110 are a plurality of E-shaped cores 120, 122 and 124. Each of the cores 120, 122 and 124 has a respective coil 126, 128 and 130 wrapped around its center prong in the manner described with respect to the apparatus of Fig. 1. The three cores 120, 122 and 124 are attached to a frame, not shown, which also rides on the guide rods 102, 104, 106 and 108. In this manner, the three cores 120, 122 and 124 form a relatively self-contained module (except for the AC current source) which can be disposed at any longitudinal position along the length of the conveyance path 110. These modules can also be added or removed from an induction heater as desired according to the changing needs of any particular production line. Additional modularity can be obtained by including a separate AC current source in each module.

As shown in Fig. 5, this particular induction drying apparatus includes three modules located at three successive longitudinal positions along the length of the conveyance path 110. In particular, the module immediately behind the module visible in Fig. 4 includes cores 132 and 134 wrapped with respective windings 136 and 138. A third core positioned at the same radial position as core 120 (Fig. 4) is omitted from Fig. 5 for the purposes of clarity of illustration. Similarly, a third module including cores 142 and 144, wrapped with respective coils 146 and 148, is located longitudinally behind cores 132 and 134 along the conveyance path 110. Again, a third core located at the same radial position as core 120 (Fig. 4) has been omitted from the drawing of Fig. 5.

The coils wrapping the center prongs of successive ones of the E-shaped cores along the longitudinal axis of the conveyance path 110 are wrapped in opposite directions, and the cores are spaced from each other for the same reasons as described above with respect to Fig. 2. Additionally, the guide rods 102, 104, 106 and 108 are made of a non-conductive material such as plastic or ceramic.

In operation, can closures are treated with selective coatings and typically pushed onto the rear end of the stack by a magnetic wheel or other means (not shown). The act of pushing each new can closure onto the rear of the stack effectively pushed the entire stack forward by the width of one can closure. Dried closures are removed from the front of the stack at the same rate.

As the closures pass through the AC magnetic fields generated by the various cores and coils shown in Figs. 4 and 5, high-frequency AC currents are generated in the closures, thereby heating them in much the same way as described above with respect to the apparatus of Fig. 1. Figs. 4 and 5 also illustrate an additional feature, namely that the cores can be shaped at the ends of the prongs similarly to the shape of the workpiece, in order to maximize the amount of flux which passes through the can lids. This feature is illustrated by the arcuate shape of the ends 150, 152 and 154 of the prongs of the E-shaped cores 120, 122 and 124, respectively.

As with the apparatus of Fig. 1, an AC current source 168 is included with the apparatus of Figs. 4 and 5 to cause the currents through the windings to oscillate at approximately 6-20KHz. Additionally, an IR temperature sensor 180 may be included for closed-loop temperature control to turn off the AC current source 168 if and when the temperature of the lids increases beyond a predetermined threshold. The remainder of the considerations and variations described above with respect to the apparatus of Fig. 1 also apply to the apparatus of Figs. 4 and 5.

Additional Embodiment

As can lids or other substantially plate-like objects are moved through a drying or curing apparatus, it is desireable to keep them separated from each other to permit air to access all parts of the workpiece. Sullivan U.S. Patent No. 4,333,246, mentioned above, describes one technique for separating a series of workpieces being pushed along a track in face-to-face relationship in a direction transverse to the major surfaces of the workpieces. In Sullivan, the workpieces are pushed through a curvilinear path defined by a constant width trackwork, allowed to pivot on the portions of the workpieces in proximity to the shorter radiuses whereby fan-like separation of the portions in proximity to the longer radius occurs. Sullivan uses this trackwork to partially separate can lids as heated air is directed toward the separated portions.

The Sullivan technique has a number of major disadvantages. First, though one portion of each of the workpieces is separated from the other workpieces, there is always another portion of the workpieces (the portions in proximity to the shorter radiuses) which are touching other workpieces. The pieces are only fanned, not truly separated. Thus, if the apparatus is being used to cure selectively applied coatings on can lids, for example, it can be used only where the selectively applied coating has been applied somewhere other than around the circumference where the lids are likely to touch each other. Additionally, the pressure on the portions of the lids which do touch each other, caused by the forces pushing the lids along the track, can soften and/or damage the metal of the lids or their coating. Moreover, the Sullivan apparatus can generate only limited separation between the fanned portions of the can lids, since greater separation requires tighter curves in the trackwork, which in turn requires greater force and stronger materials in the equipment which pushes the lids along the track. Nor can the technique be used for long conveyance paths, for the same reason, even if the curves are kept shallow. Still further, Sullivan's technique will not work well with can lids which have pull rings, since these can lids do not nest well and are likely to scratch each other if they touch.

It is well known that a plurality of magnetic objects free to move within a magnetic field, will spread out to share the entire available magnetic field equally. However, this technique has not heretofore been used in apparatus that heats metal beverage can lids, since in the past, expensive magnetic materials with very high curie temperatures would have been required.

Figure 6 shows a side view, partially cut away, of inductive heating apparatus which uses permanent magnets for maintaining a separation between steel (or other ferromagnetic) beverage container lids 100. Figure 7 shows a cross-section of the same apparatus. The can closures 100 rest end-wise on a pair of guide rods 202 and 204, and two more guide rods 206 and 208 are provided to help hold the closures in place. The four guide rods 202, 204, 206 and 208 together define a conveyance path 210 for the stack of closures 100. The guide rods 202, 204, 206 and 208 are oriented axially at different circumferencial positions along the inside surface of a guide tube 220. Both the guide rods and the guide tube are made of non-electrically-conductive material such as ceramic or teflon. The tube 220 preferably should also be thermally insulating, for reasons which will become apparent below. Guide rods 202, 204, 206 and 208 can be omitted in some embodiments, their function being replaced by the tube 220 itself.

Mounted on the outside surface of the guide tube 220 is inductive wiring 222 which is connected to an AC current source 68, such as that shown in Figure 1. The wiring 222 comprises four parallel regions of spirals 223, each region subtending a little less than one quarter arc on the circumference of the tube 220 and extending along substantially the entire length of the tube 220 within which heating is desired. Various well known techniques can be used to satisfy electronic switching requirements in the power supply and permit higher current carrying capacity in the wiring. The wiring 222 can also be provided as a series of axially adjacent wiring sections if desired for modularity or other purposes.

It should be noted that instead of spirals 223, the wiring 222 can be provided as a single, many-turn coil (not shown) wrapping the tube 220. The magnetic forces induced by this arrangement, however, tend to rotate the can lids about a diameter, making it difficult to keep their faces oriented transversely to the direction of the conveyance path. Also, such an arrangement tends to heat the permanent separator magnets, discussed below, undesirably.

The tube 220 has holes such as 224 at various positions along its length for ventilation of the can lids inside. Air can be circulated through these holes to provide for moisture scrubbing, cooling or otherwise treating. The spirals 223 are wound to avoid these holes 224. This affects the AC magnetic induction field inside the tube at that point, but the overall heating process is not significantly affected since the wiring still extends *substantially* the entire length of the tube 220 which is being used for inductive heating.

Located within the gaps between the four regions of spirals 223, and oriented longitudinally along the length of the tube 220, are a plurality of rail magnets 230. Only one of the rail magnets 230 is shown in Figure 6, for illustrative simplicity. The permanent magnets 230 are oriented to provide alternating magnetic north and south poles around the circumference of the tube 220. Four permanent magnets 230 are shown in Figure 7, but any number greater than 1 may be used. Also, the permanent magnets 230 may each run the length of the tube, or they may be provided in axially adjacent segments for modularity or other purposes.

The apparatus of Figures 6 and 7 further includes a vibrator 240 (shown only in Figure 6), which mechanically vibrates the permanent magnets 230 axially.

In operation, when a particular number of can lids 100 are inside the tube, they will try to equally share the magnetic fields generated by the permanent magnets 230 along the length of the tube. Friction is overcome by the mechanical vibrator 240, which vibrates the magnets 230, and therefore the magnetic fields generated by them, axially. The vibration frequency may be on the order of 60Hz, and the wavelength should be shorter than the spacing between the lids. Vibration can be achieved instead by other methods, such as by mounting the guide rods 202, 204, 206 and 208 on flexures and vibrating them axially, or by using the force oscillations inherent in the reversing field of the coil 222. Another alternative would be to wrap a coil (not shown) around the tube 220 to provide a more slowly oscillating magnetic field specifically for vibrating the can lids 100. Vibrations would also be effective if transverse to the direction of travel.

With the can lids inside the tube 220, and spaced apart by the magnetic fields generated by the permanent magnets 230, a high frequency AC current is provided to the wiring 222. A high frequency AC magnetic field is thereby generated in each of the can lids inside the tube 220, which generates eddy currents to heat and dry them.

It can be seen that though high temperatures are induced in the can lids 100 themselves, the wiring 222 remains cool. Water cooling of a few-turn induction coil is not necessary. Also, since high temperatures are generally restricted to the lids 100 themselves, and since the permanent magnets 230 are substantially outside the fields generated by the spirals 223, the permanent magnets 230 may be inexpensive ceramic magnets instead of expensive magnets made of a high-curie-temperature material. It should also be noted that though permanent magnets 230 are shown in Figures 6 and 7, AC or DC electromagnets may be used instead to accomplish spacing.

As long as no other forces are applied, the can lids 100 in the tube 220 will simply space out to share the field generated by the permanent magnets 230. A motivating force or motivating means further may be provided to move the lids longitudinally along the path of travel 210. One way to apply such a force would be to tilt the tube such that the entrance end is higher than the exit end. This method uses gravity to skew the distribution of can lids along the length of the tube, so that they are spaced more closely together as they move toward the exit. When the lids reach some maximum packing density at the exit, the magnetic fields generated by the permanent magnets 230 will no longer be strong enough to overcome the gravitational tendency of the lid which is closest to the exit to fall out of the tube. Accordingly, for a given number of can lids desired in the tube at once, and for given magnetic field strengths generated by the spacer magnets, a tilt angle can be determined at which whenever one lid is added at the entrance of the tube, another lid falls out the exit. Thus a continuous flow of lids through the induction dryer can be maintained.

The lids 100 can be motivated through the tube 220 also by other means, such as by mechanically removing a lid from the exit of the tube each time a new lid is added to the entrance. For example, Figure 8 shows an upstream conveyor belt 250 transporting can lids 100 to a magnetic upstacker 252, which periodically adds a new can lid 100 to the entrance of the tube 220. Each time such a new can lid is added, a magnetic downstacker 254 removes the can lid then at the exit of the tube 220, and places it on a downstream conveyor belt 256 for further processing. Each time one lid is added to the entrance and another lid is removed from the exit, the remainder of the lids inside the tube automatically readjust their longitudinal positions to equally share the magnetic field generated by the permanent magnets 230 (not shown in Figure 8). A rotating knife (not shown) may also be used instead of the downstacker 254 to remove individual can lids from the exit end of the tube 220.

Another method for motivating the can lids along the conveyance path 210 in the tube 220 is to cause them to move as if part of a linear induction motor. If the spirals 223 are connected in, for example, three phases, and three phases of the AC current source 68 are provided, then assuming the spirals are properly spaced, a given one of the can lids 100 will be repeatedly attracted to the next downstream spiral and repelled from the previous spiral as the phases of the current source 68 rotate. The spirals 223 can be connected with a displacement of any desired number of turns.

Alternatively, a motivating means can be provided by adding a separate polyphase motivating coil, wrapped around the tube 220, for motivating the lids 100 along the conveyance path inside the tube 220. A three-phase (A,B,C) motivating coil 260 is shown in Figure 9. The motivating coil 260 can operate at a lower frequency, for example 60Hz. A separate motivating coil is disadvantageous in that it requires additional wiring, but it is advantageous in that the functions of heating and motivating are kept inductively independent. Thus the can lids may be kept moving by a separate motivating coil such as 260 even through a portion of the tube 220 within which inductive heating is not desired. Such a feature is useful in repair coat dryers, for example, in which can lids may be moved through an inductive heating portion of the tube, followed by a hot air soak portion of the tube, followed by a cool down portion of the same tube. In such a system, one portion of the tube might be wound with motivating coil 260, and only the inductive heating portion of the tube provided with the induction wiring 222.

A motivating coil should not be used in the <u>same</u> portion of the tube 220 in which inductive heating will take place, since the magnetic fields generated by the inductive wiring may induce undesired currents in the motivating coil and vice versa.

Any of the above described motivation techniques can be aided, if desired, by strategic placement of the separator magnets 230. For example, in Figure 10, two of the permanent magnets 230 are shown slanting away from the tube 220 toward the exit end thereof. This reduces the separating magnetic field within the tube at the exit end, and thereby permits the lids to space themselves more densely toward the exit end of the tube. This technique for controlling the density of the lids 100 at various points along the length of the tube 220 may be used as desired for any purpose. For example, the technique might be useful if it in any way simplifies the process of removing can lids from the exit end of the tube.

The invention permits significant flexibility in the design of can lid processing equipment. For example, since the permanent magnets 230 (Figures 6 and 7) do not need to have a high curie temperature, they can be made of a flexible material. This permits the use of a curved tube 220, such as that shown in Figure 11. The tube 300 in Figure 11, though mainly horizontal; curves 90° at the entrance to form a vertical uptake. The entrance of the tube 300 is disposed directly above a conveyor belt 302, which carries the can lids 100 into position. The can lids are individually attracted into the tube 300 by permanent magnets 304 (only two of which are shown in Figure 11), which follow the curve of the tube 300. An inductive wiring such as 222 (Figures 6 and 7) may be provided on the tube 300, or on only a portion thereof as shown in Figure 11. This technique effectively obviates any necessity for an upstacker. A similar curve at the exit of the tube 300 can obviate any need for a downstacker.

Aluminum can lids and bodies, since they are not ferromagnetic, probably cannot be magnetically spaced by spacer magnets such as 230 (Figures 6 and 7). However, since they do conduct eddy currents induced in them by wiring on the outside of the tube 220, aluminum can lids nevertheless are subject to induction heating by the wiring 222. The motivational features of the invention also apply to aluminum workpieces, since the eddy currents induced in the workpieces generate a magnetic field oriented repulsively to the magnetic field generated by the wiring 222. Thus the workpiece and the wiring 222 form a repulsive linear motor, propelling the workpiece longitudinally along the inside of the tube 220. Moreover, whereas for ferromagnetic workpieces, the magnetic attraction of the workpieces to the spirals 223 may be so strong as to counteract the magnetic repulsive forces generated, this is not true with aluminum can lids. Thus, aluminum workpieces will be repelled inwardly from all sides of the tube with substantial uniformity, forcing it into the middle of the tube and thereby minimizing friction as the workpiece is propelled longitudinally. This minimizes the need for a vibrator such as 240. Aluminum workpieces can also be propelled by a polyphase linear propulsion motor formed with a polyphase winding such as that shown as 260 (Figure 9).

The invention has been described with respect to particular embodiments thereof, and numerous variations are possible within its scope.

Claims

1. A method of drying water-based sealant compound applied to electrically conductive can ends, comprising the steps of:

   providing can ends to an inlet of a dryer, the can ends already having the water-based sealant compound applied thereto;

   transporting the can ends through the dryer in face-to-face relationship along with an electrically nonconductive support structure; and

   during the transporting step, passing the can ends through an alternating magnetic field to induce current flow in the can ends to induction heat the can ends and thereby heat the compound applied to the can ends to remove water from the

   compound.

2. A method according to claim 1 wherein the electrically nonconductive support structure comprises an

electrically nonconductive tube.

3. A method according to claim 2 wherein the magnetic field is produced by an electrical conductor wrapped around the tube, and wherein the electrical conductor is connected to an alternating current source.

4. A method according to any preceding claim wherein the step of transporting the can ends through the dryer in face-to-face relationship comprises the step of transporting the can ends through the dryer in face-to-face contact.

5. A method according to any one of claims 1 to 3 further comprising, during the transporting step, the step of spacing the can ends apart magnetically.

6. A method according to claim 5 wherein the spacing step comprises the step of producing a magnetic field which is effective to cause the can ends to space apart to share the magnetic field.

7. Apparatus for heating compound material applied to can ends, comprising:

   an electrically nonconductive support structured to support the can ends while being transported in face-to-face relationship along the support,

   an alternating current source;

   an electrical conductor connected to the alternating current source and disposed in sufficient proximity to the support to produce an alternating magnetic field within the support; and

   a transporting device which transports the can ends in face-to-face relationship along the support and through the alternating magnetic field to induce current flow in the can ends to induction heat the can ends and thereby heat the compound material applied to the can ends.

8. Apparatus according to claim 7 wherein the electrically nonconductive support comprises an electrically nonconductive tube.

9. Apparatus according to claim 8 wherein the electrical conductor is wrapped around the tube.

10. Apparatus according to any one of claims 7 to 9 wherein said transporting device transports the can ends in face-to-face contact along the support.

11. Apparatus according to any one of claims 7 to 9 further comprising magnetic separating elements which space the can ends apart magnetically while the can ends are transported along the support.

12. Apparatus according to any one of claims 7 to 9 or 11 further comprising a magnet disposed to produce a magnetic field within the support which is effective to cause the can ends to space apart to share the magnetic field.

13. Apparatus according to any one of claims 7 to 9 wherein said transporting device comprises a means for transporting the can ends in face-to-face relationship along the support.

14. Apparatus according to claim 13 wherein said transporting means comprises a magnetic wheel which pushes the can ends in face-to-face relationship along the support.

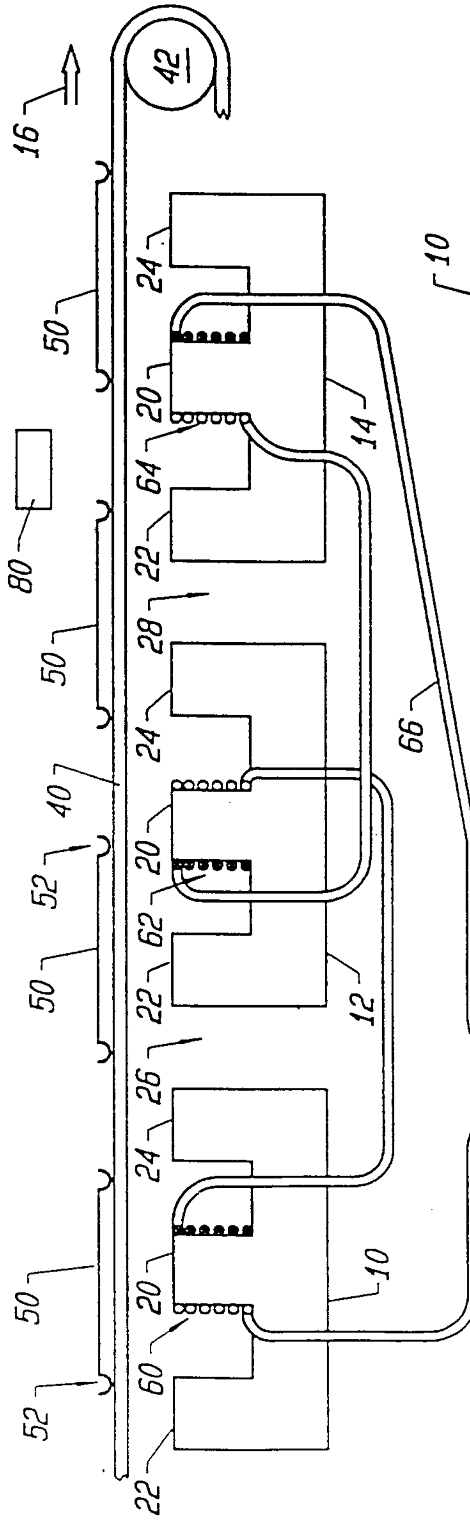


FIG. 1

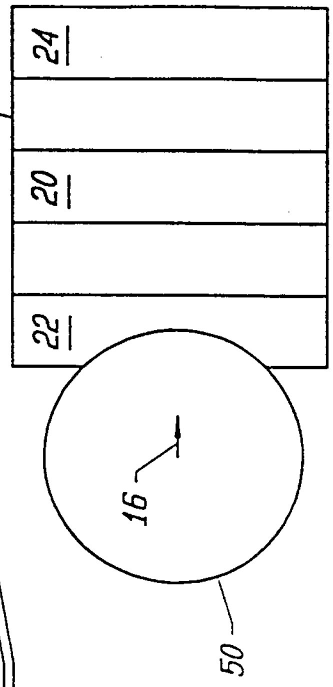


FIG. 3

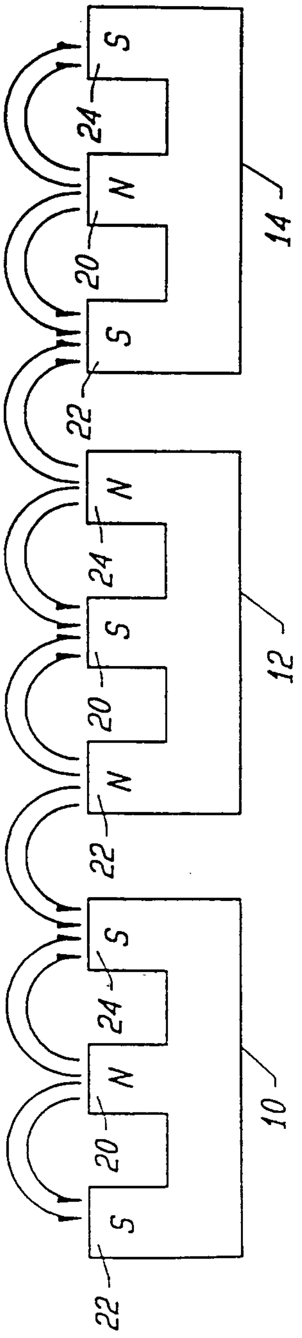


FIG. 2

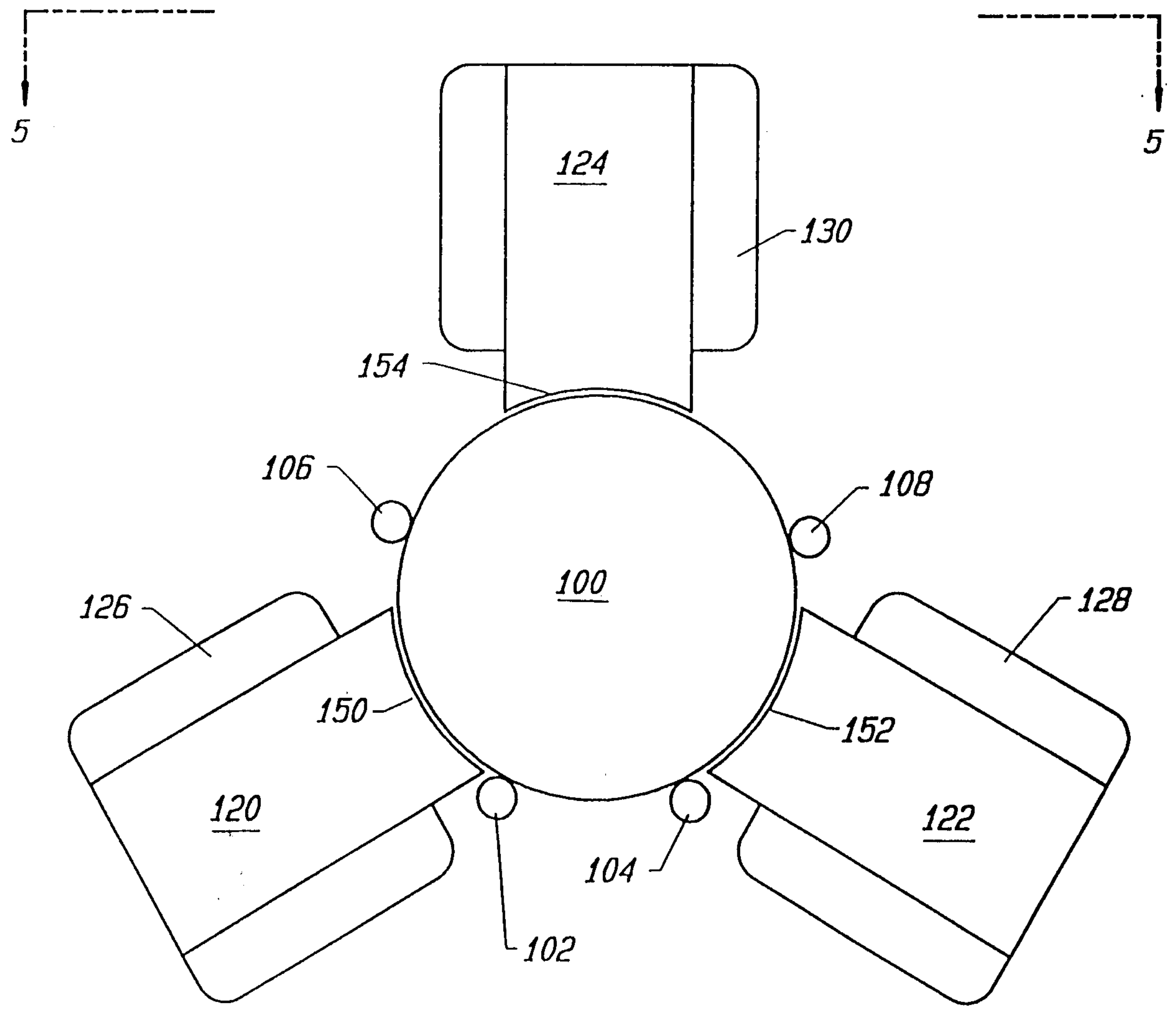
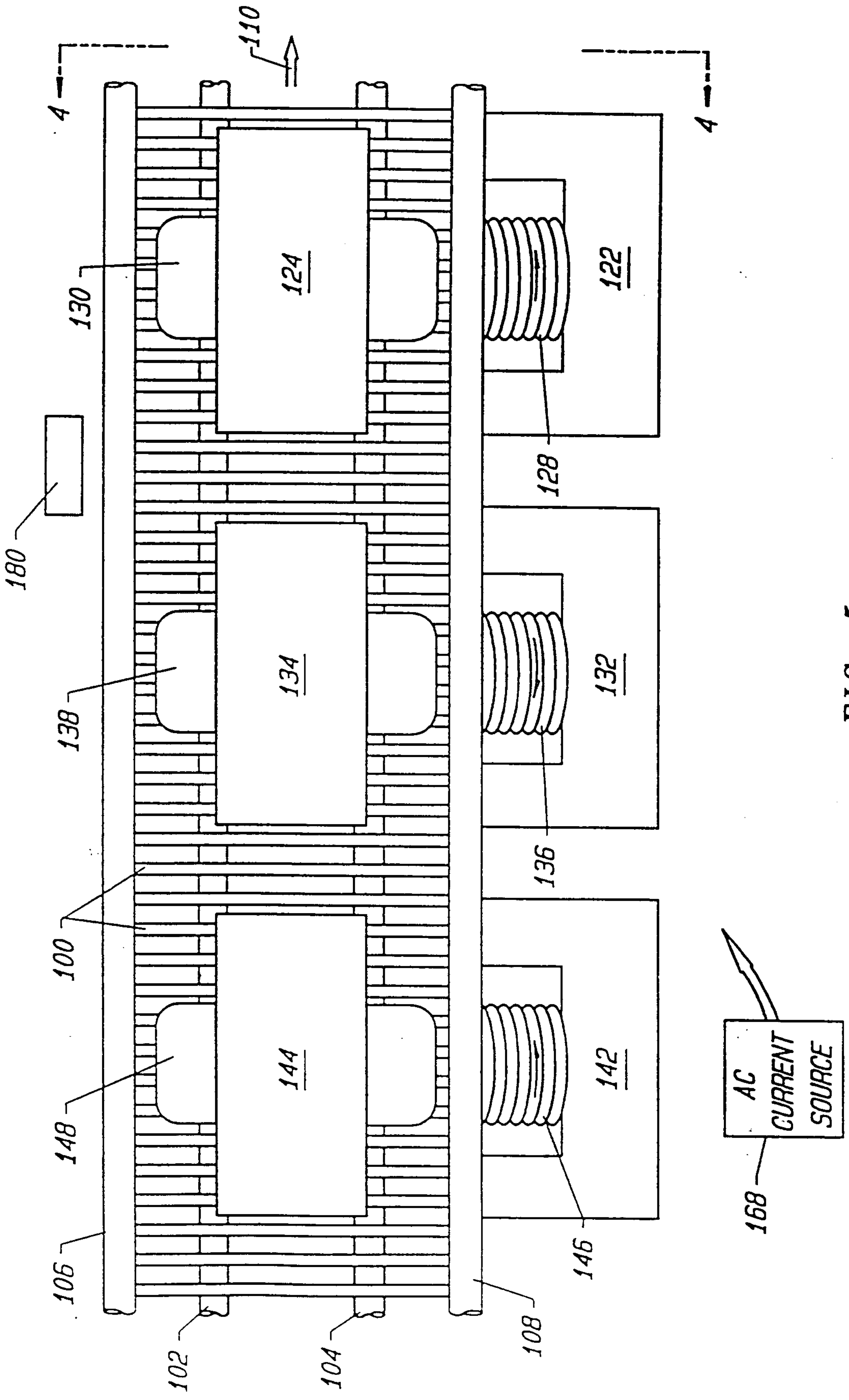


FIG. 4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122
130
128
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142
148
146
106
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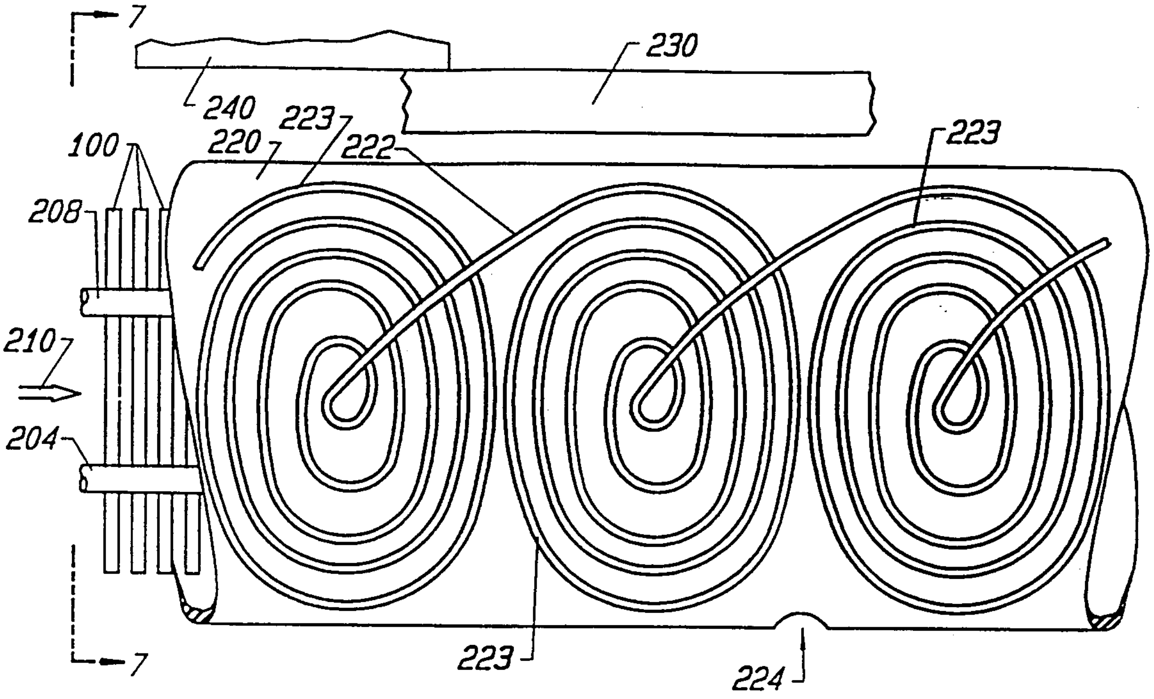
104
108
AC
CURRENT
SOURCE
168

FIG. 5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230
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223
222
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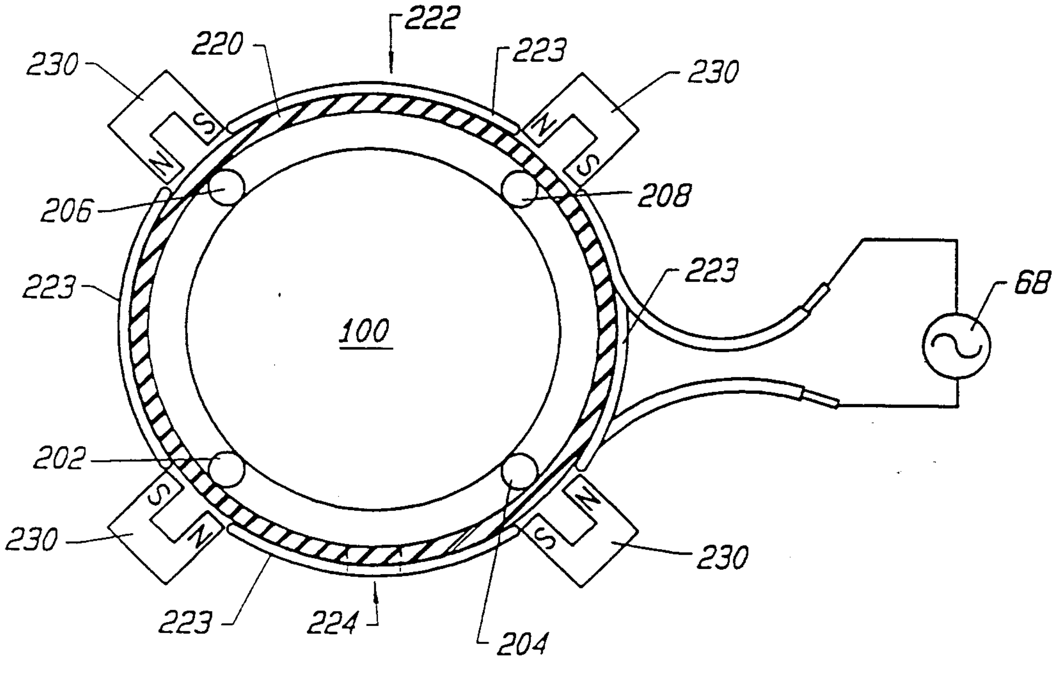
208
210
204
223
224
7

FIG. 6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220
223
230
230
S
N
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223
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202
S
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S
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230
223
224
204

FIG. 7

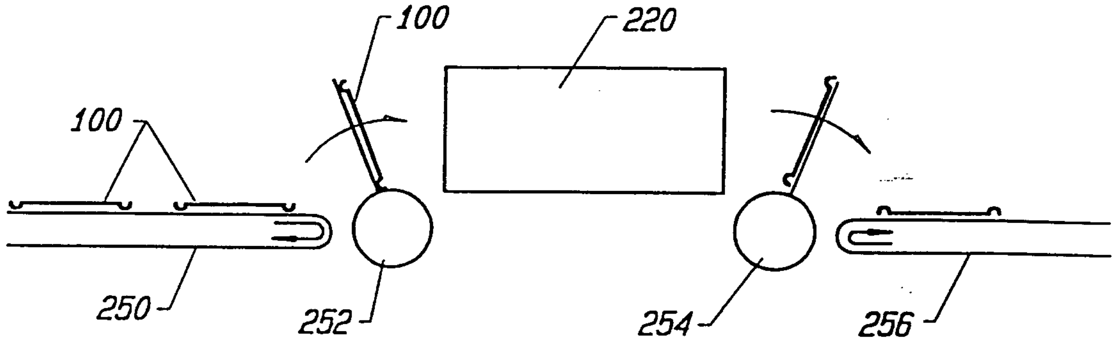

FIG. 8

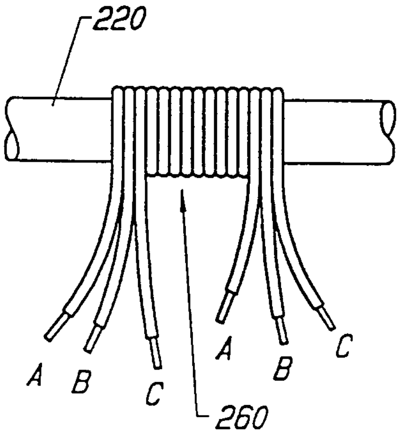

FIG. 9

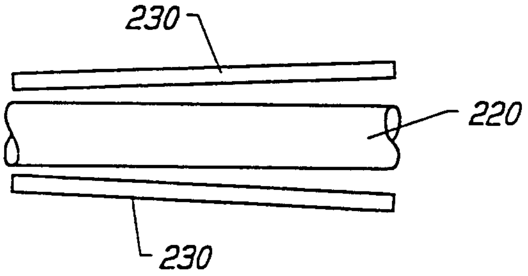

FIG. 10

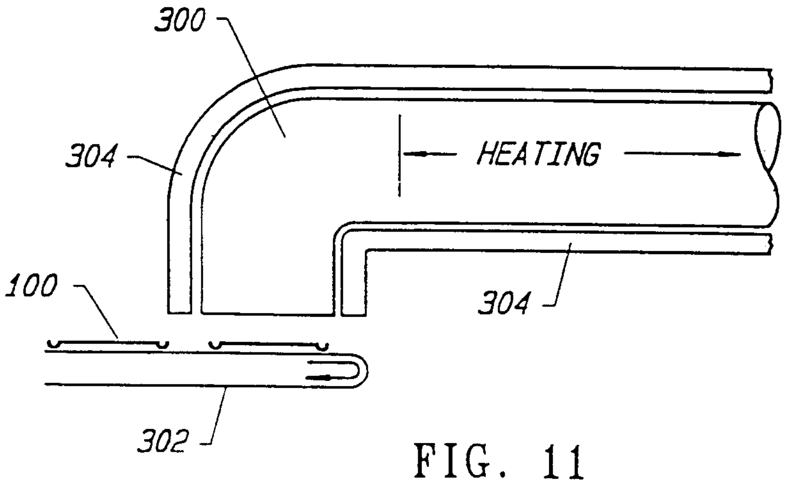

FIG. 11

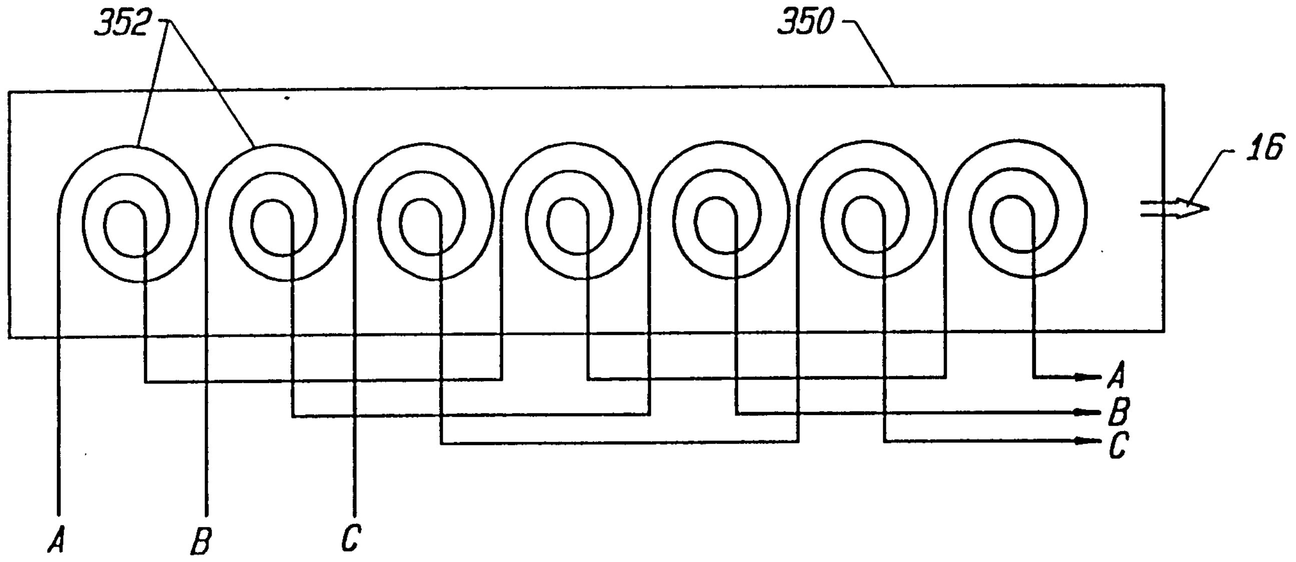

FIG. 12