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(54) **TEMPERATURE SELF-REGULATING FOOD DELIVERY SYSTEM**

Publication Classification

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(52) **U.S. Cl.** **219/622; 219/670**

(57) **ABSTRACT**

Temperature self-regulating food delivery systems are provided having a magnetic induction heater (32, 126) and an associated food container (76, 124) equipped with an essentially permanent ferromagnetic heating element (82, 100, 128). The heater (32, 126) and heating elements (82, 100, 128) are designed so as to heat the element (82, 100, 128) to a user-selected regulation temperature when the elements (82, 100, 128) are coupled with the heater's magnetic field, and to maintain the temperature in the vicinity of the regulation temperature indefinitely temperature regulation is a heating achieved by periodically determining at least two parameters of the heaters resonant circuits related to the amplitude of the resonant current passing therethrough during heating and responsively altering the field strength of the magnetic field. Preferably, the value of the resonant circuit amplitude and the rate of change of the amplitude are determine.

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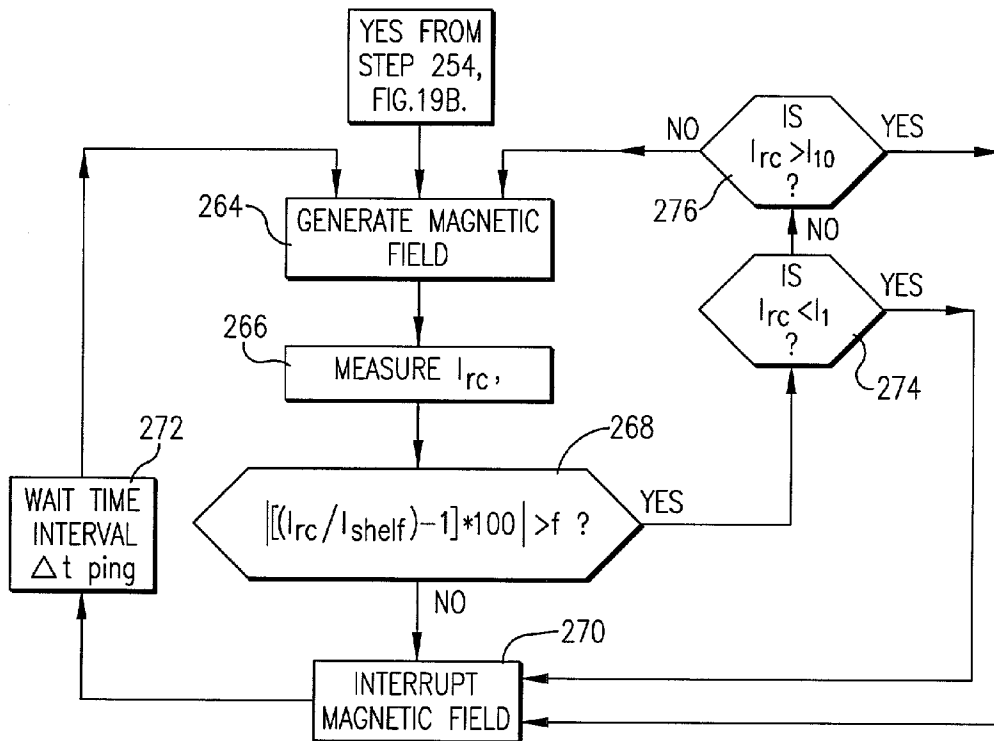
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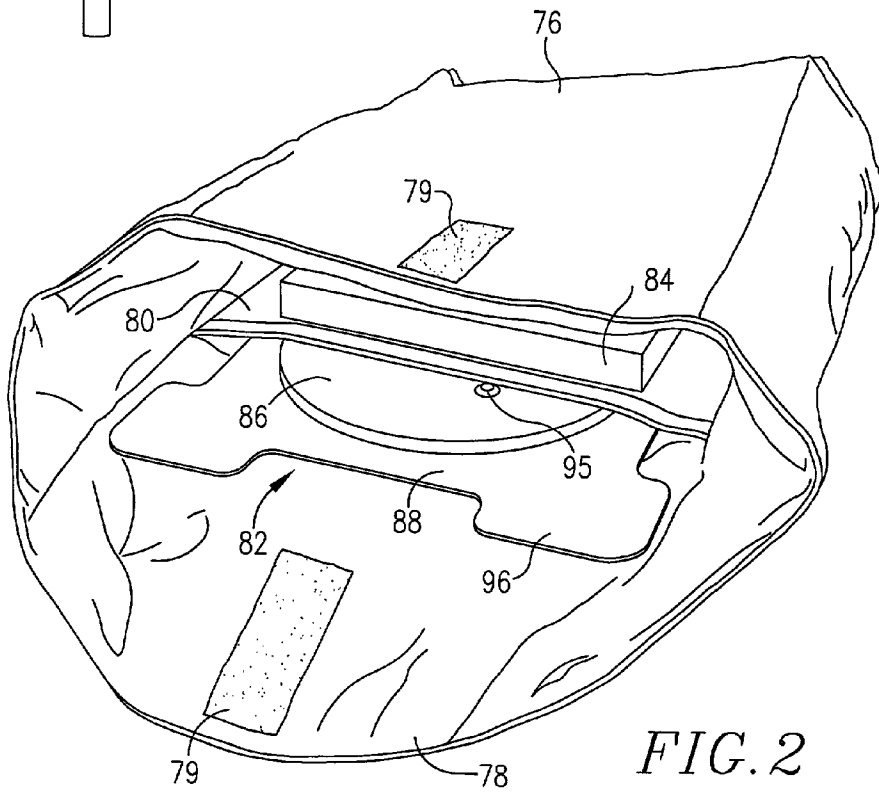
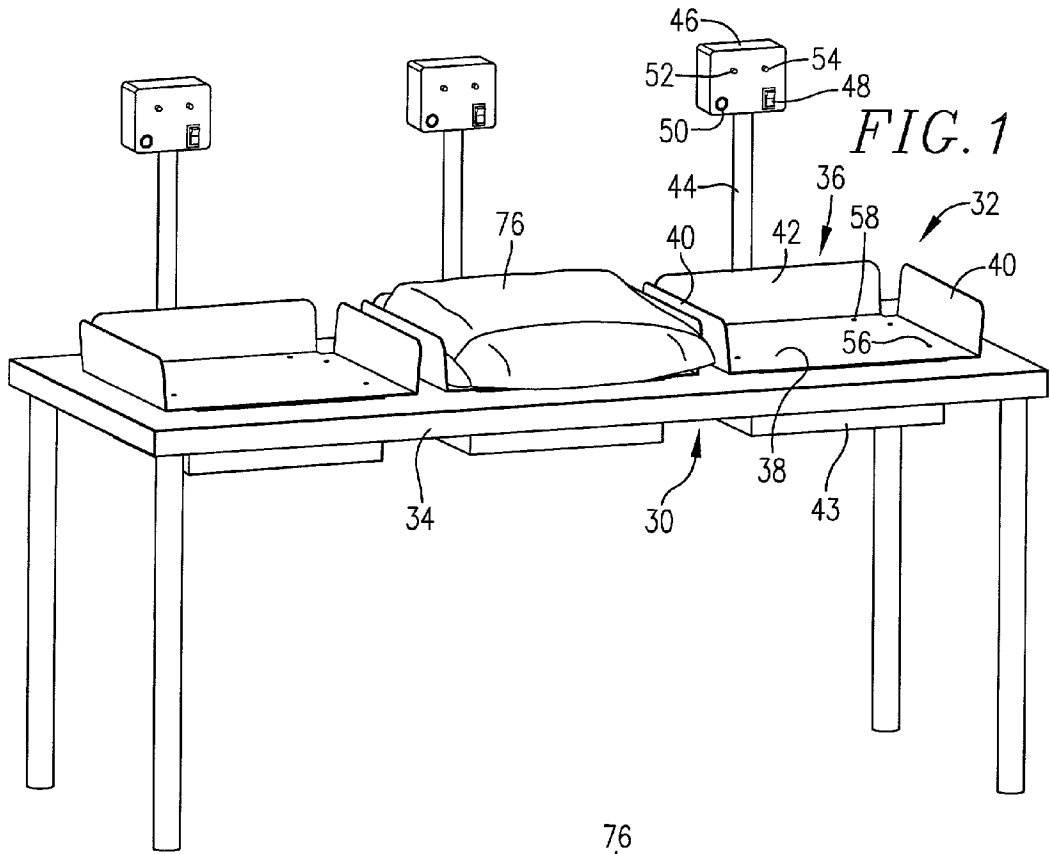
(21) Appl. No.: **10/046,885**

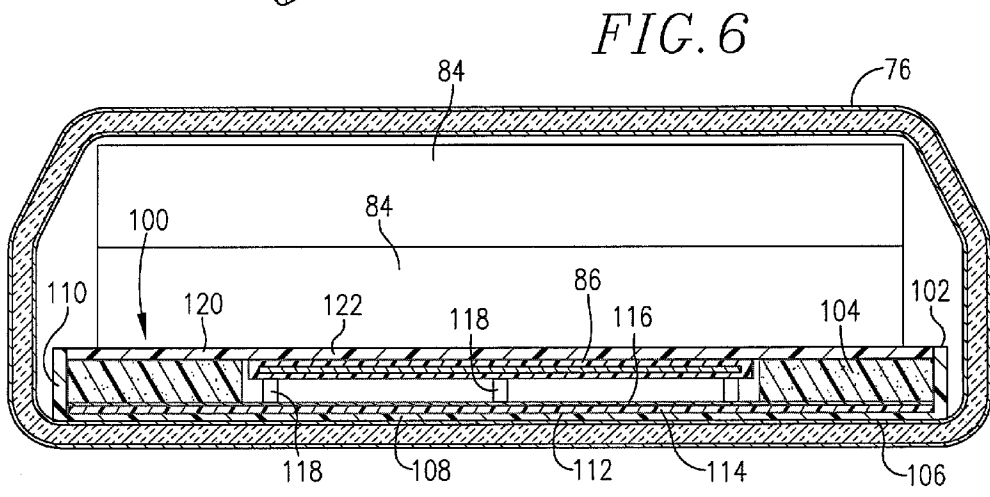
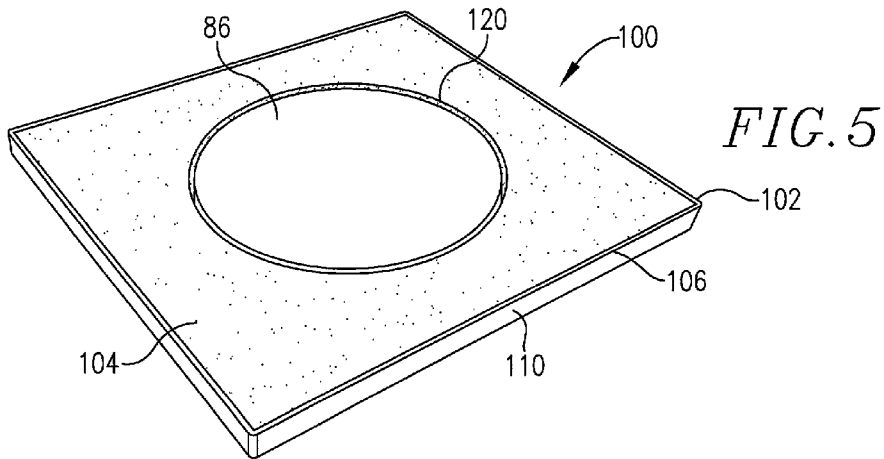
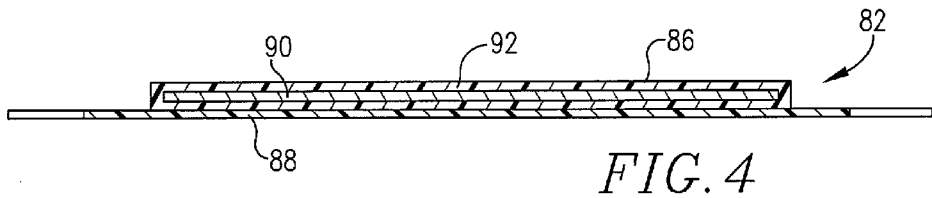
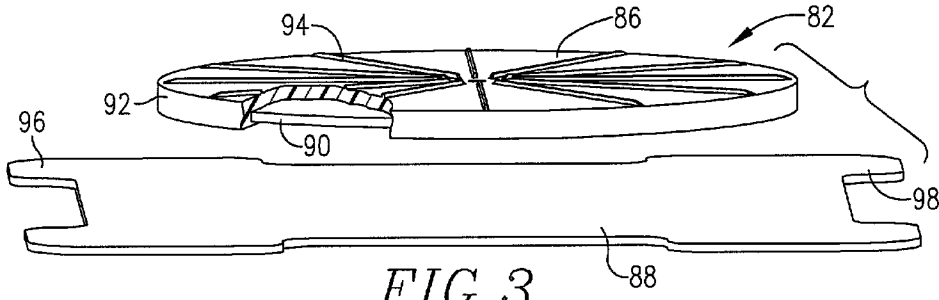
(22) Filed: **Jan. 15, 2002**

Related U.S. Application Data

(63) Continuation of application No. 09/826,782, filed on Apr. 5, 2001, which is a continuation of application No. 09/314,824, filed on May 19, 1999, now abandoned, which is a non-provisional of provisional application No. 60/086,033, filed on May 19, 1998.







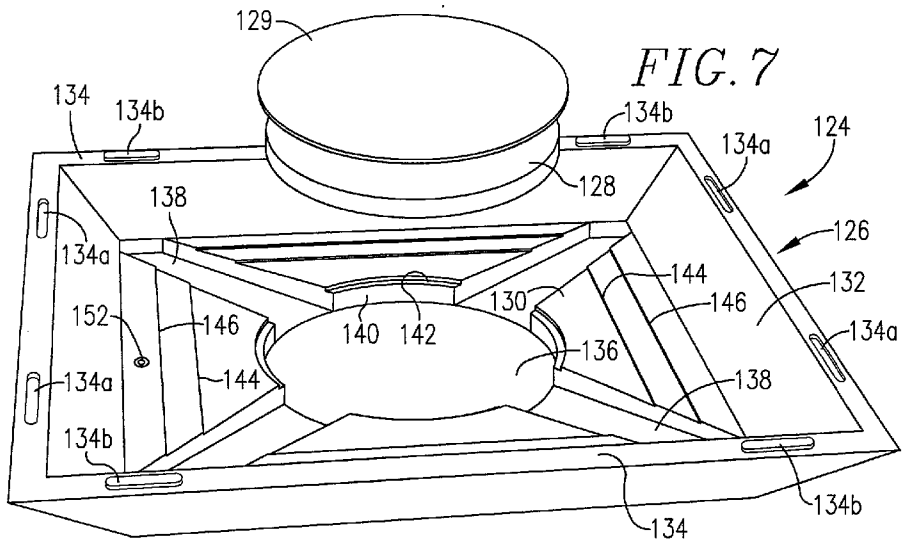


FIG. 7

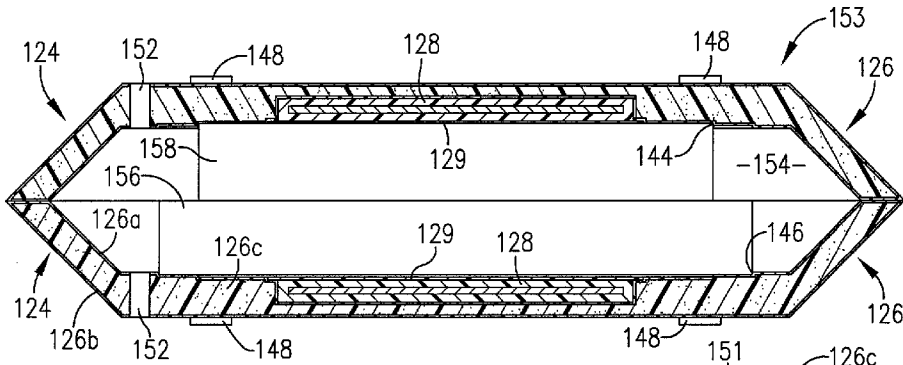


FIG. 8

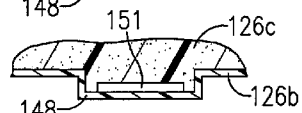


FIG. 8A

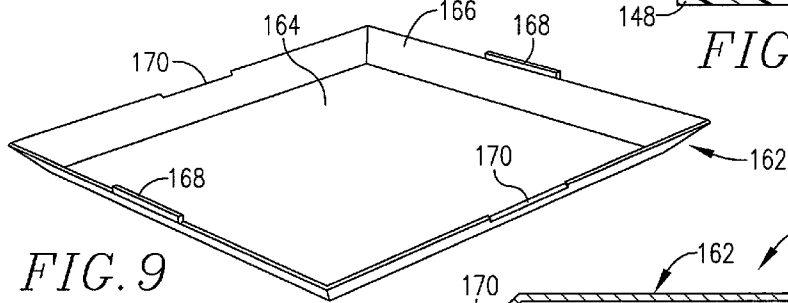


FIG. 9

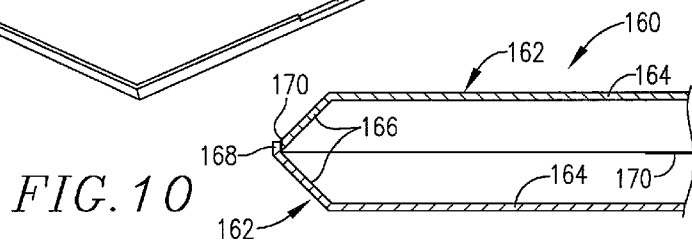
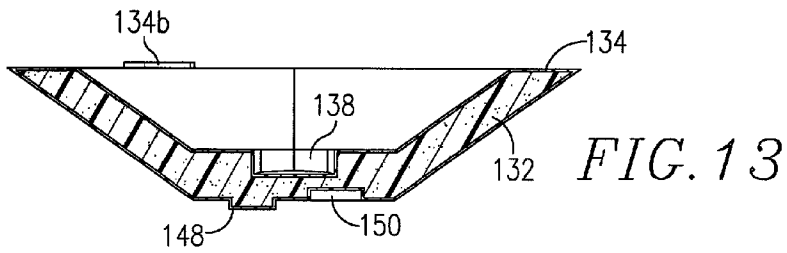
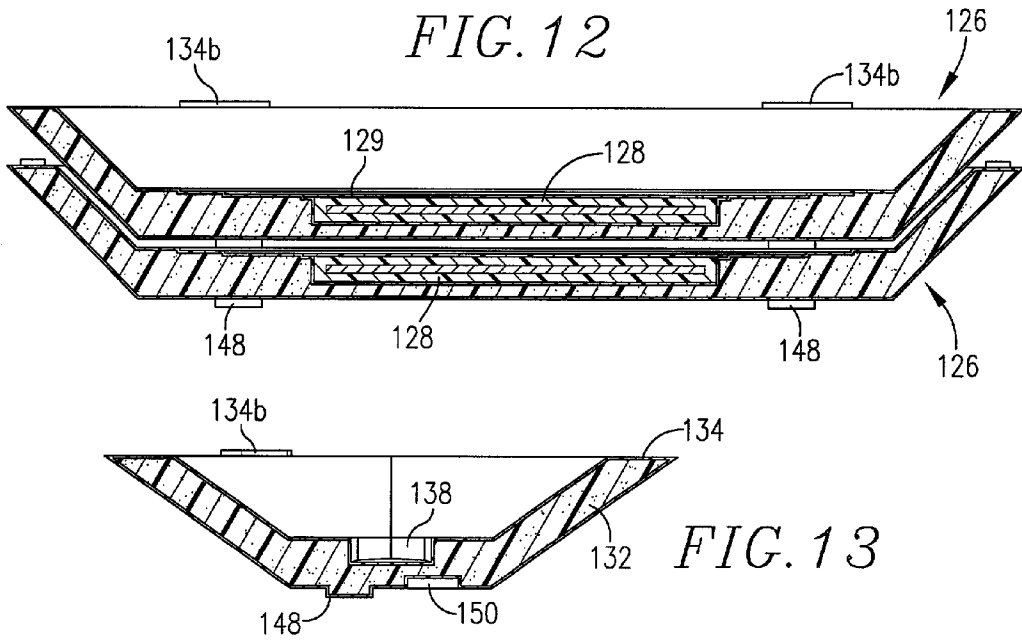
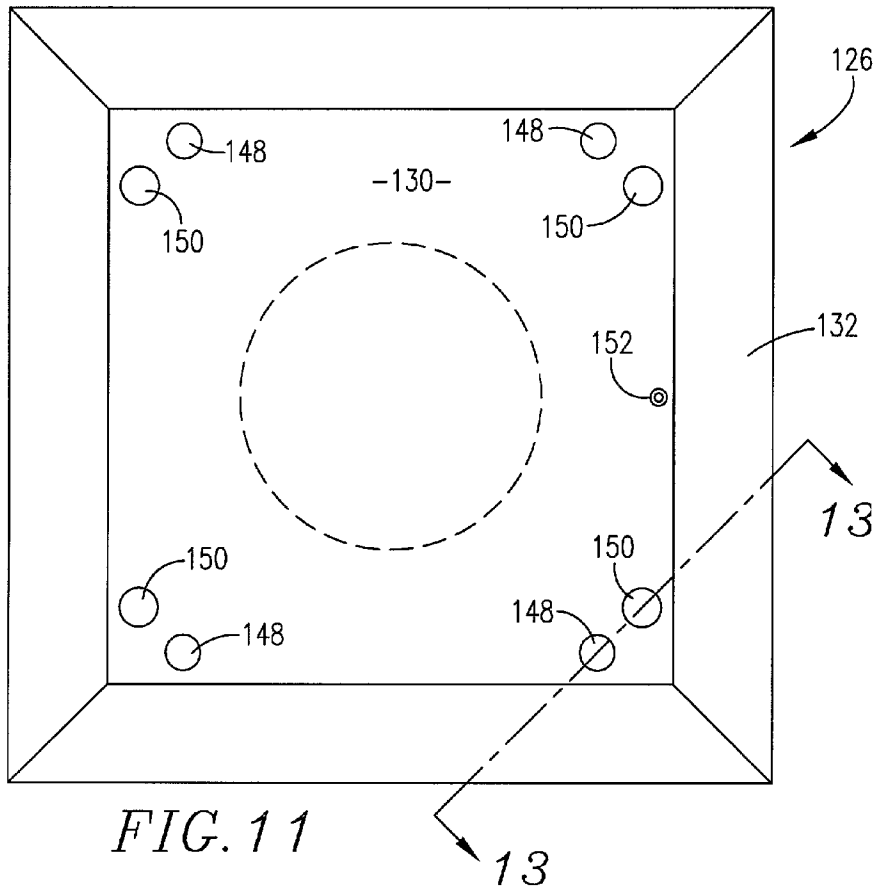


FIG. 10



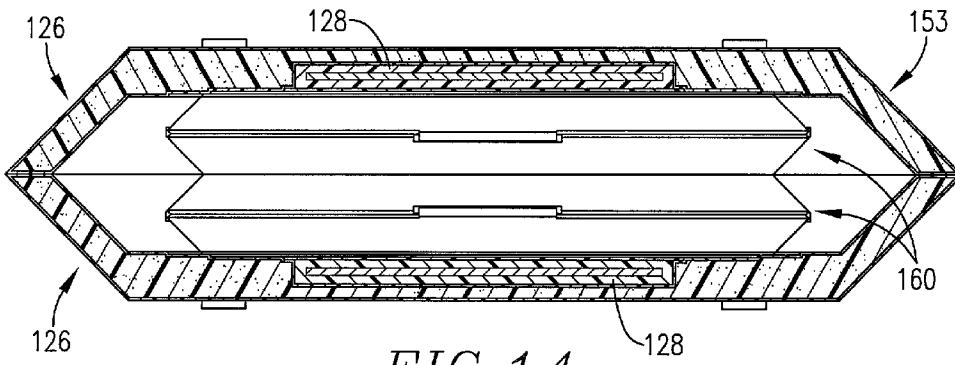


FIG. 14

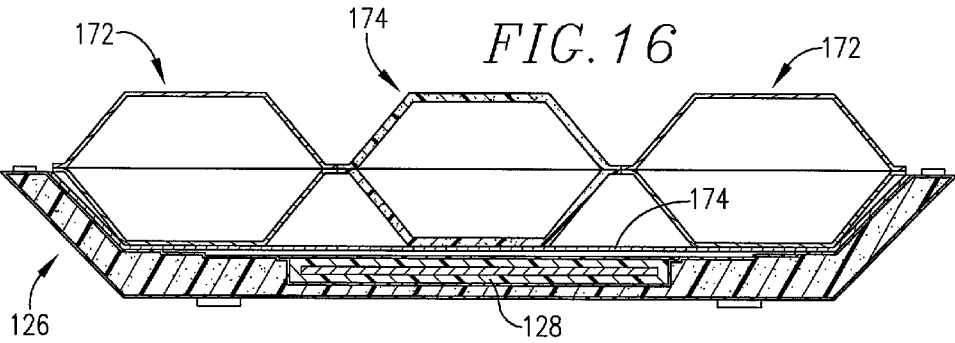
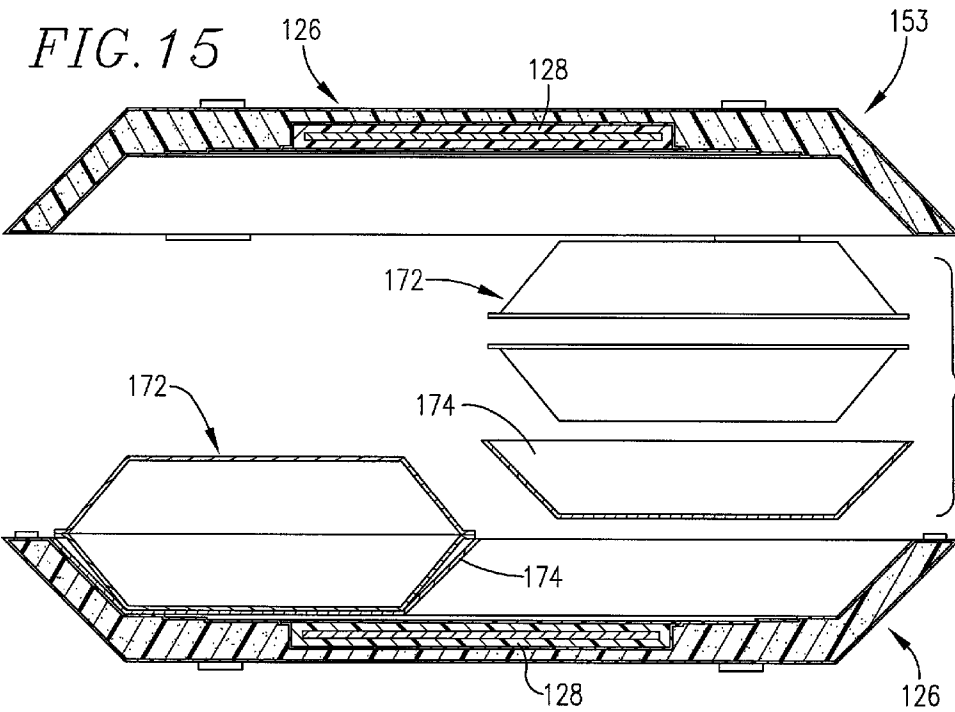
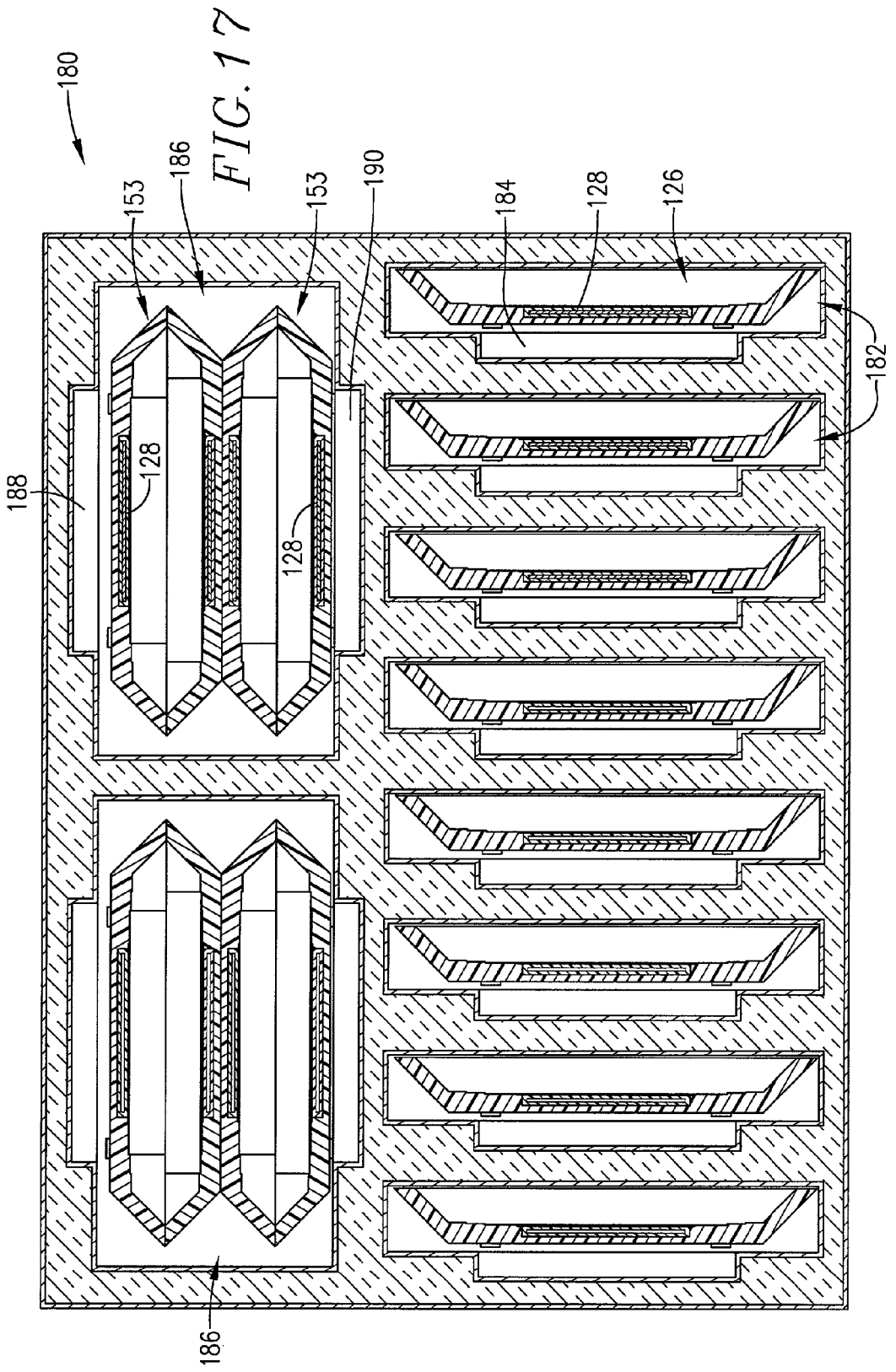


FIG. 16



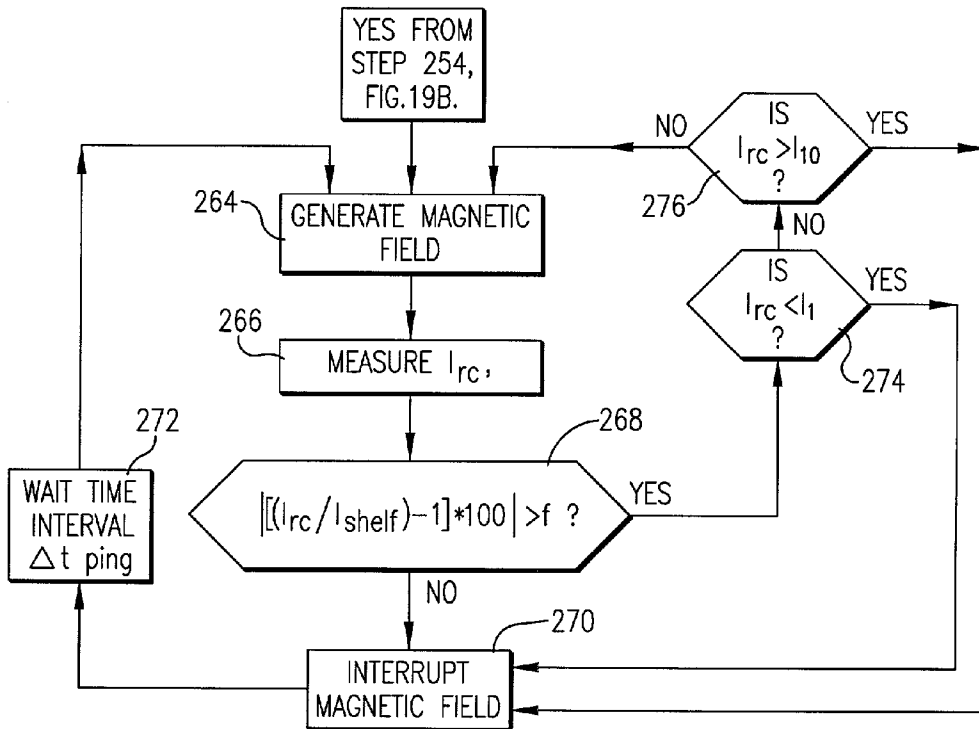
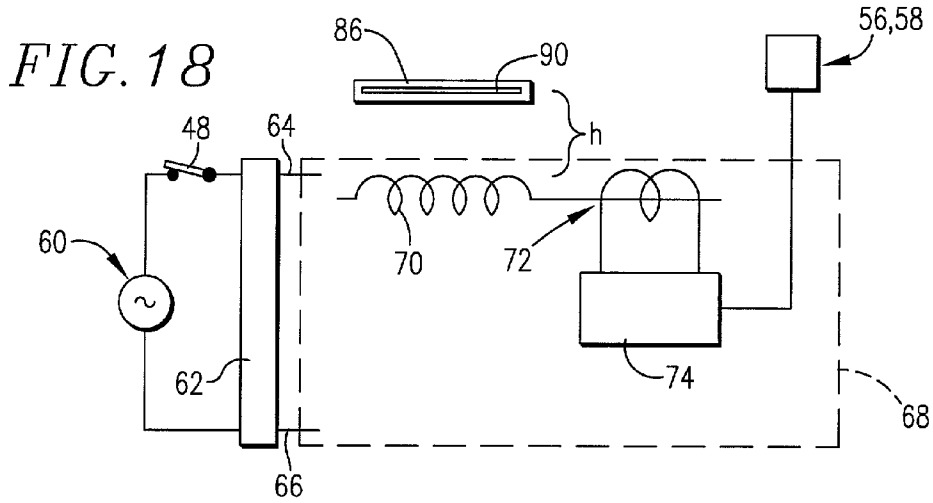


FIG. 20

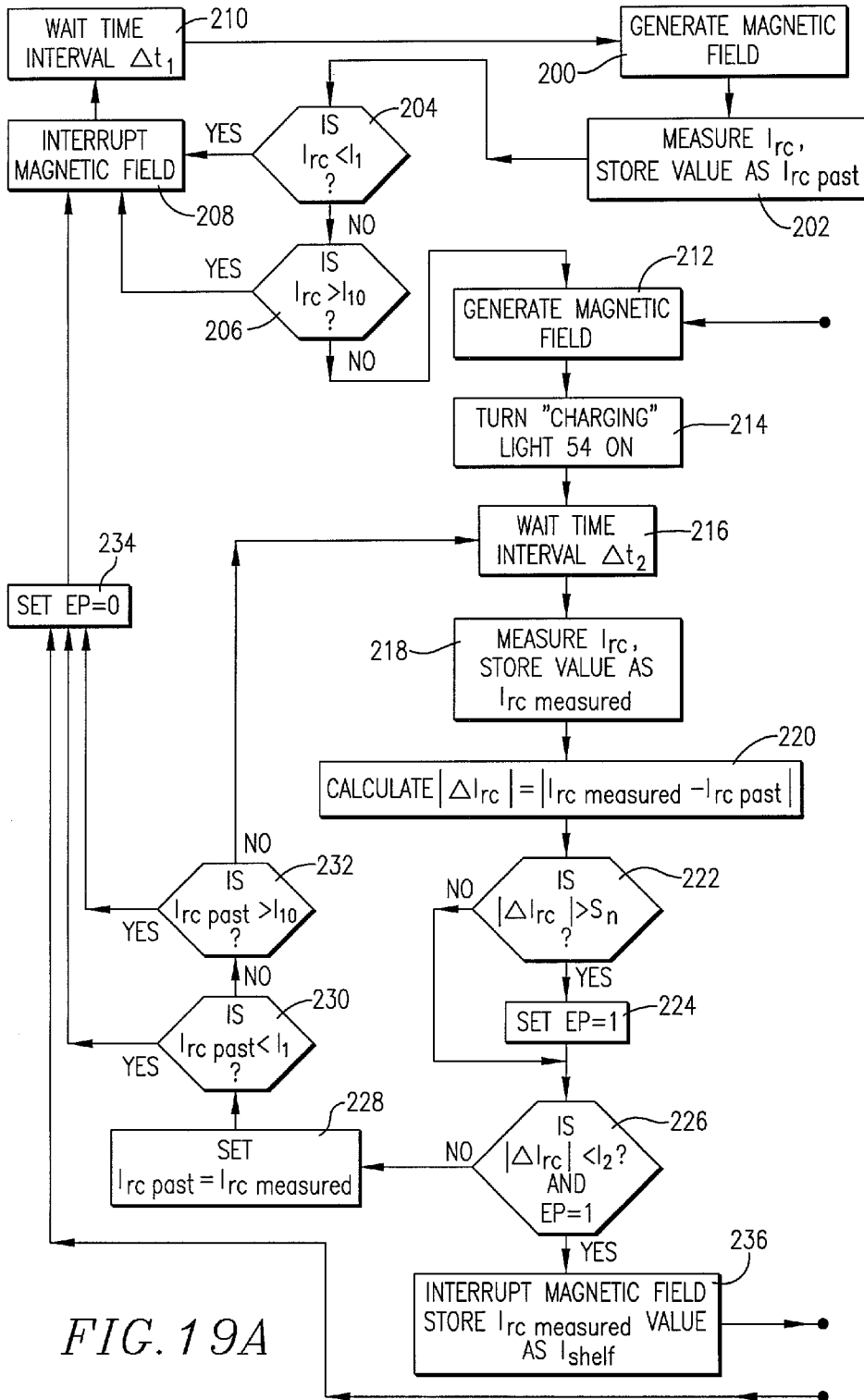


FIG. 19A

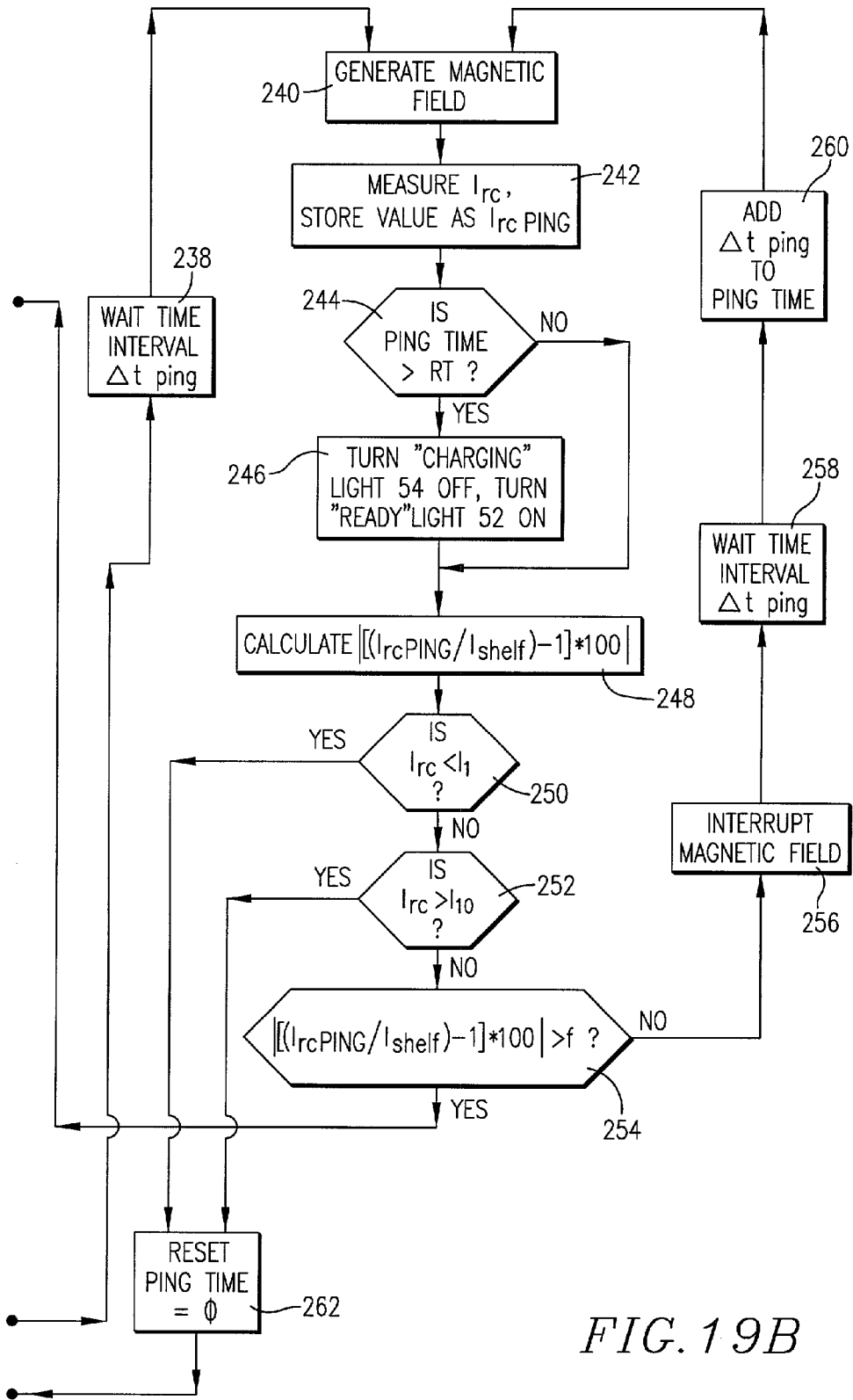


FIG. 19B

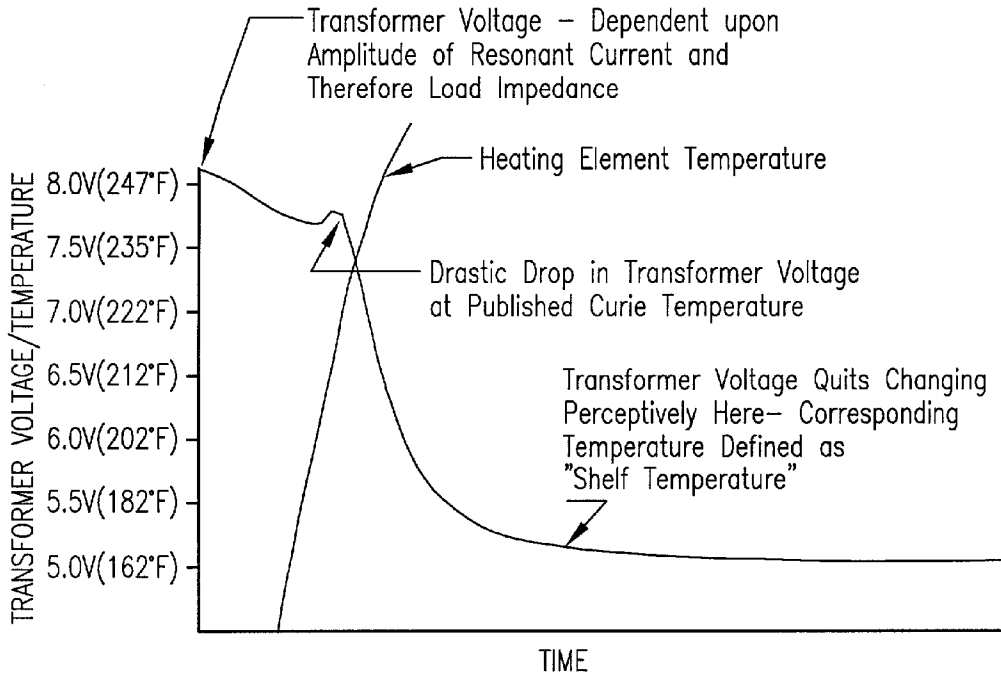
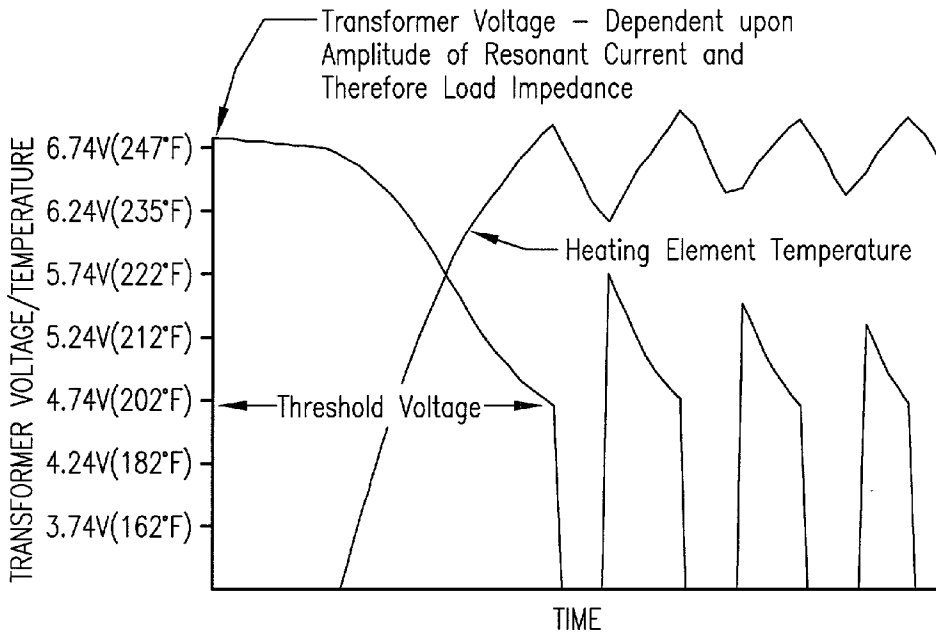


FIG. 21

FIG. 22



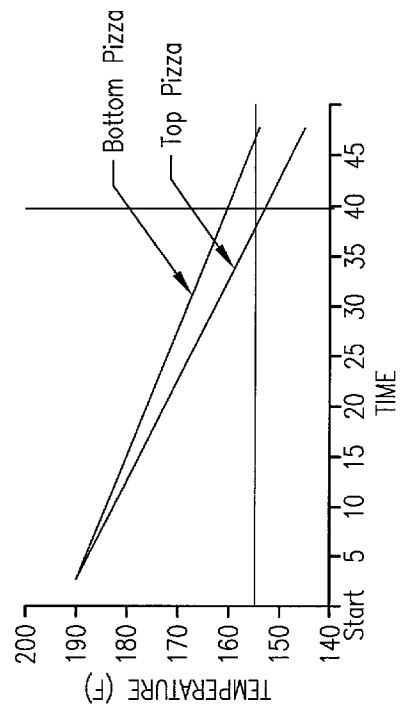
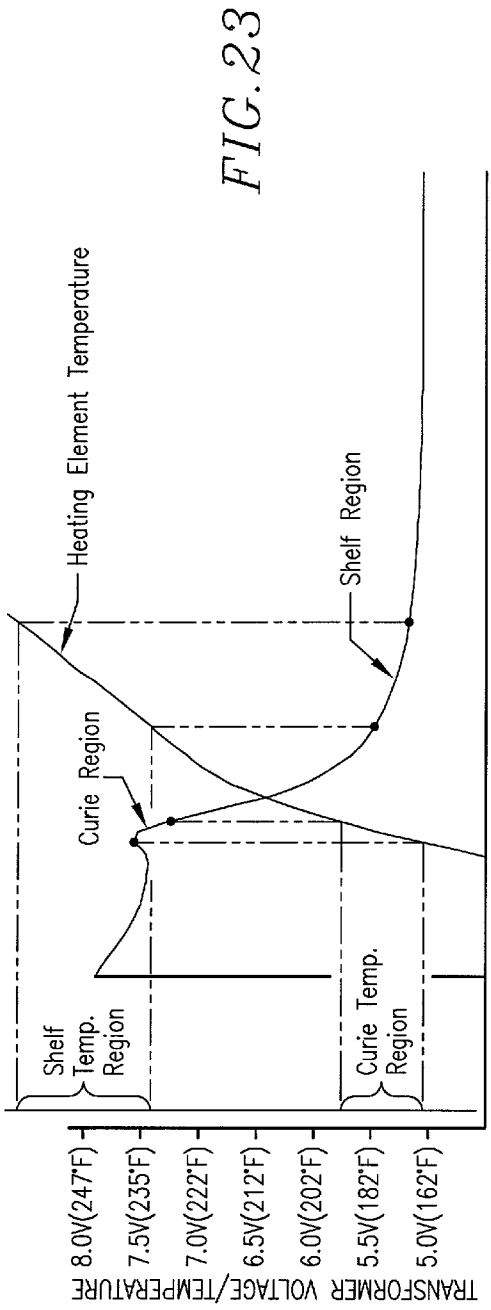


FIG. 25

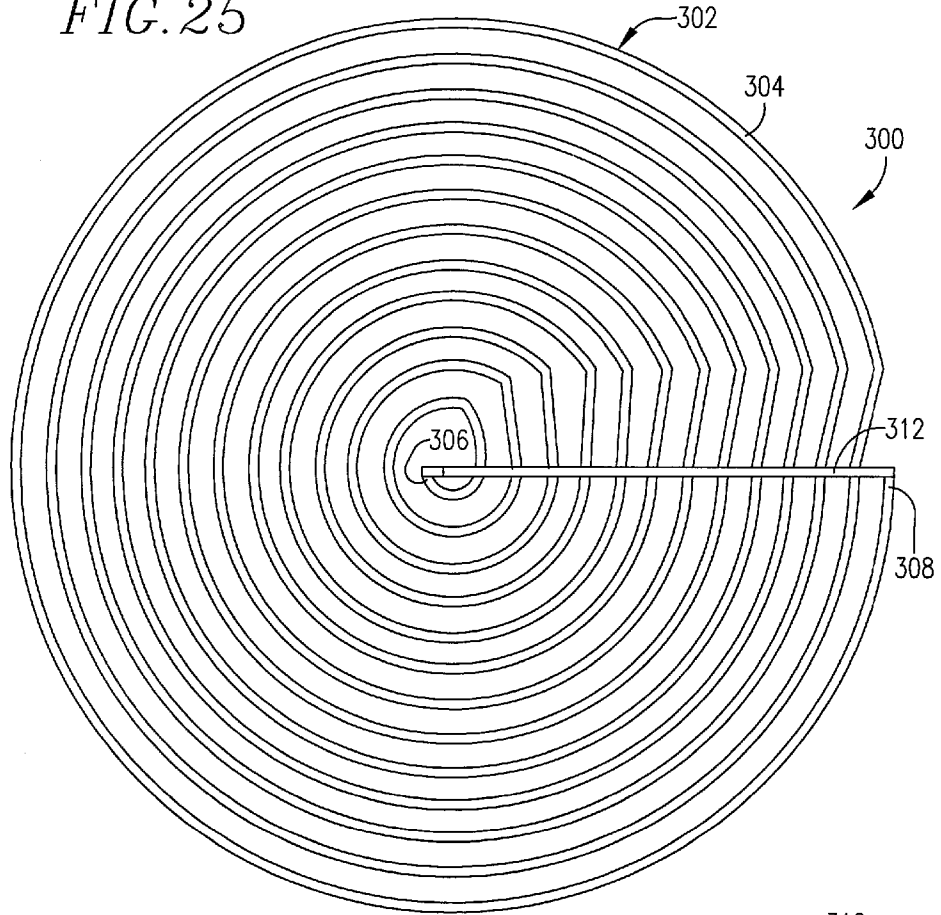


FIG. 27

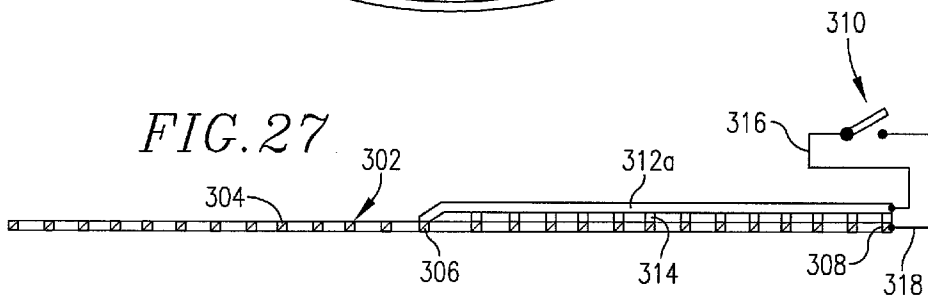
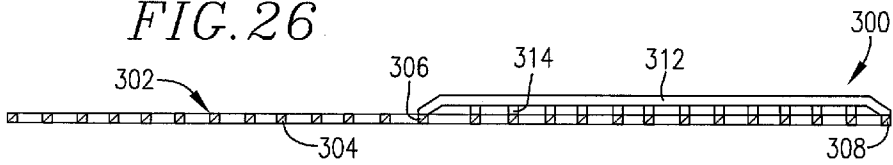


FIG. 26



TEMPERATURE SELF-REGULATING FOOD DELIVERY SYSTEM

RELATED APPLICATION

[0001] This application claims the benefit of provisional patent application No.60/086,033 filed May 19, 1998 and is a continuation of Ser. No. 09/314,824, filed May 19, 1999, which is a continuation of Ser. No. 09/826,782, filed Apr. 5, 2001.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention is broadly concerned with food delivery systems designed to maintain food at a selected temperature over relatively long periods of time. More particularly, the invention pertains to such food delivery systems which include a magnetically heatable thermal storage device within a food-holding container, wherein the storage device may be selectively heated within said container by an induction charging station. In preferred forms, the charging station indefinitely maintains the selectively heated portion of the thermal storage device at a user-selected regulation temperature by using contact-less feedback from said device.

[0004] 2. Description of Prior Art

[0005] The problems associated with the delivery of hot foods to consumers has in recent years taken on greater significance owing to the growth in convenience foods and those delivered directly to households. Although the rise in pizza deliveries is a prime example, other foods are now commonly delivered to the door, from simple hot sandwiches to complete meals.

[0006] For instance, most prior art pizza delivery systems consist simply of a partially insulated, non-sealing vinyl bag or sometimes a well-insulated nylon bag into which one or more cardboard boxes containing pizzas are placed so as to maintain the pizzas as warm as possible during delivery to the customer. Although the sauce layer of a freshly cooked pizza is typically over 200 F., the sauce layer upon delivery is often as low as 110 F., particularly where delivery times in excess of 30 minutes are experienced.

[0007] The problem of cold-delivered pizzas is only partly due to inefficient delivery bags and the like. In a typical pizza operation, once a pizza emerges from the oven it is removed and placed upon a cutting table to be sliced. The pizza is then placed in a cardboard box. Very commonly, two or more pizzas are to be delivered to the same address and multiple pizza bags full of pizzas are delivered to several different customers on the same delivery run. Under these circumstances, the boxed pizzas are placed under infrared heating lamps until all pizzas for a given run have been prepared, sliced and boxed. Due to the logistics involved in such operations, some pizzas can be almost cold before the delivery run even commences.

[0008] In 1998, Dominos Pizza introduced the Heat Wave™ pizza delivery system. This consists of an insulated nylon pizza bag, a wax-filled resistively heated plastic-coated thermal storage disk, and a rack charging system into which up to 20 thermal storage disks can be plugged so as to charge them with thermal energy. This system has several

drawbacks. The thermal storage disks are heavy, weighing in excess of three pounds. Thus, the delivery container is no longer lightweight once the disk is in place. Furthermore, the disk requires a substantial time to become fully charged with thermal energy, taking over two hours from room temperature and over thirty minutes after a typical delivery to be fully charged. Additionally, the thermal storage disks must be plugged into and out of the charging rack, thus requiring the operator to perform additional steps. Finally, to implement the rack charging system, a typical pizza parlor must be substantially modified in terms of its power supply network and floor space to accommodate the rack.

[0009] There is accordingly a need in the art for an improved food storage and delivery system which will permit the purveyor to maintain the food products at or near a desired temperature over sustained periods, while also allowing delivery under conditions to substantially maintain this temperature. An effective hot food storage and delivery system thus requires a lightweight delivery container, a fast-charging thermal storage device capable of storing and efficiently releasing large amounts of thermal energy, and easy to operate equipment not requiring skilled labor.

SUMMARY OF THE INVENTION

[0010] The present invention overcomes the problems outlined above and provides a food delivery system broadly including a food delivery container equipped with a thermal storage device with the latter being heated while in the container by a magnetic induction charging station. Thus in the case of a pizza system, a flexible insulated bag or hard-sided container is equipped with a thermal storage device designed to remain within the bag throughout its operation. This thermal storage device includes a heat pellet; the pellet has a ferromagnetic heating element which preferably is surrounded by synthetic resin heat retentive material. In order to charge the bag or container, it is simply placed upon a charging station including a magnetic induction coil having temperature maintenance control circuitry that requires no connection to the bag or container; this serves to quickly heat the heat retentive pellet and to maintain it at a user-selected temperature without overheating. When a food item is prepared, it is placed within the bag or container for delivery. Temperature maintenance during delivery is assured because of the very significant thermal energy stored in the heat retentive pellet.

[0011] The preferred system of the invention employs a magnetic induction charging station, having a magnetic induction cooktop which is capable of infusing a vast amount of thermal energy into coupled heat retentive pellets in a very short amount of time. For instance, for pizza applications, it has been found that approximately 150,000 joules of thermal energy must be added to a room temperature pellet, and that the pellet should be brought to a surface temperature of around 230 F. in less than about 4 minutes. The charging stations and heat retentive pellets of the invention can readily meet these demanding standards. Furthermore, the preferred charging station is capable of maintaining the pellet temperature indefinitely without any cords or other leads connecting the charging station and heating element, regardless of variations in thickness of the associated containers or other specific conditions of the containers. Finally, the charging stations of the invention are capable of charging a given heating element to the prede-

terminated regulation temperature notwithstanding the initial temperature of the element, which will be variable over the course of several delivery runs and returns to the food preparation location.

[0012] The thermal storage devices of the invention are lightweight and ruggedly constructed so as to endure heating/cooling cycles. The pellets are able to withstand very fast charges and can release approximately 75,000 joules of energy during a 30 minute delivery cycle to the container contents for temperature maintenance. A particular advantage of the thermal storage devices is that they are sized to fit within standard pizza bags without modification thereof.

[0013] As indicated, the systems and methods of the invention utilize magnetic induction as an energy transfer means in order to charge heat retentive pellets coupled in a magnetic field. Moreover, the invention employs the concept of interrupting the continuous production of a magnetic field at user-selected regulation temperatures in order to heat the heating elements to a temperature and to maintain that temperature over time. To this end, various types of feedback parameters related to the impedance of the load presented to the magnetic induction cooktop by the heating element may be used to determine whether and when to interrupt the cooktop's magnetic field.

[0014] For example, the feedback parameter may be the amplitude of the resonant current flowing through the work coil of the induction cooktop, or alternately the absolute value of the rate of change of the resonant current amplitude over time. Most preferably however, periodic amplitude measurements of the current flowing through the work coil are taken and this raw data is used by the cooktop's microprocessor to periodically compute the absolute value of the rate of change of the resonant current amplitude. The microprocessor employs an algorithm that uses both the absolute value of the rate of change of resonant current amplitude and the exact value of resonant current amplitude to determine whether and when to interrupt continuous production of the magnetic field.

[0015] Thus a preferred method of the invention involves heating a ferromagnetic heating element by magnetically coupling the element with the magnetic field of a magnetic field generator, the latter having an induction work coil and a resonant circuit that includes the work coil. The improvement of the invention comprises the steps of controlling the temperature of the element about a regulation temperature above the element's Curie temperature by periodically determining at least two parameters of the resonant circuit related to the amplitude of the resonant current passing therethrough during element heating; in response to the determining step, the field strength of the magnetic field is altered when at least one of the parameters is above or below a selected value correlated with the regulation temperature. The parameters are advantageously the amplitude of work coil current during inverter on times and the rate of change of this current amplitude.

[0016] Although the method of the invention contemplates any kind of field altering, generally the magnetic field is fully interrupted when a parameter is above or below a selected value. Furthermore, the regulation temperature is normally above the Curie temperature of the heating element and between this Curie temperature and a "shelf temperature" defined herein.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0017] FIG. 1 is a perspective view of a table equipped with three individual magnetic induction charging stations;

[0018] FIG. 2 is a perspective view illustrating an insulated pizza delivery bag having therein a magnetically heatable thermal storage device, with a boxed pizza in the bag adjacent the heat retentive pellet;

[0019] FIG. 3 is an exploded perspective view with parts broken away depicting one preferred style of magnetically heatable thermal storage device;

[0020] FIG. 4 is a vertical sectional view of the thermal storage device illustrated in FIG. 3;

[0021] FIG. 5 is a perspective view of another preferred type of thermal storage device with the top removed and adapted to be used within an insulated pizza bag or the like, wherein a heat retentive pellet is surrounded by insulative material;

[0022] FIG. 6 is a sectional view depicting the thermal storage device structure of FIG. 5 disposed within a flexible insulated bag along with two boxed pizzas;

[0023] FIG. 7 is an exploded perspective view of one half of a symmetric food delivery device, made up of a two synthetic resin, preformed rigid body half-containers each having a heat retentive pellet;

[0024] FIG. 8 is a vertical sectional view illustrating a pair of the preformed rigid body half-containers with pellets as illustrated in FIG. 7 in mating relationship to form a complete symmetric food delivery device, with a pair of boxed pizzas therein;

[0025] FIG. 8a is an enlarged fragmentary view illustrating a foot of one of the two preformed rigid body half-containers depicted in FIG. 8 and showing an RFID tag embedded in the foot;

[0026] FIG. 9 is a perspective view of a low-cost pizza half-box adapted to be used in conjunction with the food transfer devices of FIG. 8;

[0027] FIG. 10 is a fragmentary vertical sectional view illustrating a pair of the half-boxes of FIG. 9, shown in mating relationship to form a closed low-cost pizza box;

[0028] FIG. 11 is a plan view of the outside surface of the preformed rigid body half-container of FIG. 7;

[0029] FIG. 12 is a vertical sectional view illustrating a pair of the preformed rigid body half-containers with pellets of FIG. 7 in nested relationship, in further depicting the details of construction thereof;

[0030] FIG. 13 is a sectional view taken along line 13-13 of FIG. 11;

[0031] FIG. 14 is vertical sectional view illustrating a pair of the preformed rigid body half-containers with pellets of FIG. 7 in opposed, mating relationship to define a symmetric food transfer device, with a pair of the low-cost pizza boxes of FIGS. 9-10 situated within the closed cavity of the food transfer device;

[0032] FIG. 15 is an exploded view in partial vertical section showing a pair of the preformed rigid body half-

containers with pellets of FIG. 7, with liners and different types of inner food-holding containers between them;

[0033] FIG. 16 is vertical sectional view illustrating one of preformed rigid body half-containers with pellet of FIG. 7, shown with a preformed liner and with different types of inner food-holding containers therein;

[0034] FIG. 17 illustrates a multiple-bay holding and charging station for the preformed rigid body half-containers with pellets of FIG. 7 and for the symmetric food transfer devices of FIG. 8;

[0035] FIG. 18 is a schematic block-type diagram of circuitry typically forming a part of the charging stations of FIG. 1;

[0036] FIG. 19 (separated as FIGS. 19A and 19B owing to space considerations) is a flow chart describing one preferred temperature regulation method employed in the charging stations of the invention, wherein the regulation temperature is essentially equal to the shelf temperature of a ferromagnetic heat element;

[0037] FIG. 20 is a flow chart describing an improvement which may be employed with the FIGS. 19A and 19B method to allow temperature regulation at selected temperatures between the Curie and shelf temperatures of a ferromagnetic heating element;

[0038] FIG. 21 is a graph illustrating both the transformer voltage proportional to resonant circuit current amplitude of a commercial cooktop and corresponding temperature of a solid-sheet nickel/copper heating element heated thereon versus time;

[0039] FIG. 22 is a graph illustrating both the transformer voltage proportional to resonant circuit current amplitude of a commercial cooktop and corresponding temperature of a solid-sheet nickel/copper heating element heated thereon versus time wherein the magnetic field was interrupted to achieve temperature regulation;

[0040] FIG. 23 is a graph illustrating both the transformer voltage proportional to resonant circuit current amplitude of a commercial cooktop and corresponding temperature of a solid-sheet nickel/copper heating element heated thereon versus time whereon two regions of the transformer voltage corresponding to temperatures immediately about the known Curie temperature and temperatures immediately about the shelf temperature have been highlighted;

[0041] FIG. 24 is a graph illustrating the temperature decrease over time using two commercially available pizzas heated using the preferred system of the invention;

[0042] FIG. 25 is a plan view of another type of magnetic induction heatable device comprising a coil with a conductor interconnecting the ends of the coil;

[0043] FIG. 26 is a sectional view of the device of claim 25; and

[0044] FIG. 27 is a sectional view similar to that of FIG. 26, but showing another embodiment wherein a conductive assembly including a switch interconnects the ends of the coil.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0045] The present invention provides a food delivery system broadly comprising a food delivery container, a

thermal storage device intended to release thermal energy to the food within the delivery container and a means to infuse or charge the storage device with thermal energy so as to maintain the temperature of the food during transport. As explained above, one type of food item requiring temperature maintenance during delivery is pizza, and accordingly certain embodiments of the invention are specific to this problem. However, it should be understood that the invention is not limited to pizza temperature maintenance, but rather relates to any type of food delivery system for virtually all food items which require or may be rendered more palatable by temperature maintenance.

[0046] FIG. 1 illustrates a table 30 equipped with three laterally spaced apart magnetic induction charging stations 32. The top 34 of table 30 has three spaced openings therein, to accommodate the respective stations 32. Each of the latter are identical, and include an upright, open-front, polycarbonate locator/holder 36 equipped with a base plate 38, upstanding sidewalls 40, and back wall 42. Each such station 32 has a magnetic induction cooktop 43 directly below and connected with the base plate 38 of a locator/holder 36, as well as a flexible conduit 44 connecting the cooktop to a status indicator box 46. The box 46 has an on-off power switch 48, reset button 50, and a "ready" indicator light 52 and a "charging" indicator light 54. A pair of spaced apart photo sensors 56, 58 are positioned within base plate 38. Although not shown in FIG. 1, the indicator box 46 may also include a regulation temperature readout and input device allowing a user to select a desired regulation temperature within a given range.

[0047] Each cooktop 43 is preferably a CookTek Model CD-1800 magnetic induction cooktop having its standard ceramic top removed and connected to a locator/holder 36. The microprocessor of the cooktop is programmed so as to control the circuit in accordance with the preferred temperature control method of the invention as illustrated in the flow chart of FIGS. 19A and 19B described in more detail below. FIG. 18 depicts in block schematic form the circuitry of the cooktop 43. Thus, a commercial power supply 60 (preferably a standard 120V power outlet) is operably connected to an output switch 48. A full wave rectifier and filtering network 62 is coupled with the switch 48 and supplies a filtered, full wave rectified unidirectional excitation potential across bus lines 64, 66 for use by an oscillation and inverter circuit 68. The circuit 68 comprises primarily an induction coil 70, resonant capacitor(s), switching transistors, means for providing stable oscillation, sensing transformer coil 72 and microprocessor control circuit 74. As illustrated, photo sensors 56, 58 are operably connected as an input to circuit 74. The cooktop 43 is designed to produce an alternating magnetic field in the preferred range of 20-100 kHz. It will be understood that FIG. 18 represents a generalized description of well known magnetic induction cooktops, such as the CookTech Model CD-1800; however, a variety of other commercial available cooktops of this type can be used. Also, more detailed descriptions of magnetic induction cooktop circuitry can be found in U.S. Pat. Nos. 4,555,608 and 3,978,307, which are incorporated by reference herein.

[0048] In use, a ferromagnetic heating element 90 inside a heat retentive pellet 86 will be placed upon the cooktop adjacent work coil 70, and will be separated therefrom by a distance h. This distance h may vary depending upon the

construction of the particular food container and the design of the heat retentive pellet **86**.

[0049] Photo sensors **56, 58** are coupled with the micro-processor circuitry control **74** of the cooktop and serve as a sensor for determining when a food delivery container of this invention is located on cooktop **43**. When such a food delivery container is placed upon the cooktop **43**, the photo sensors **56, 58** will send an initiation signal to the micro-processor allowing it to initiate the heating operation. It will be understood that a variety of different sensors can be used in this context, so long as the sensors can discriminate between an appropriate food container/ferromagnetic heating element and another type of object which may be improperly or inadvertently placed upon the cooktop. The simplest such sensor would be a mechanical switch or several switches in series so placed on the base plate **38** so that only the proper food delivery containers would activate the switch or switches. Other switches such as proximity switches or light sensor switches (photosensors) could be substituted for press-type switches.

[0050] A more advanced locating sensor would make use of Radio Frequency Identification (RFID) technology. RFID is similar to barcode technology, but uses radio frequency instead of optical signals. An RFID system consists of two major components, a reader and a special tag or card. In the context of the present invention, the reader would be positioned adjacent the base plate **38** in lieu of or in addition to the photo sensors **56, 58**, whereas the corresponding tags would be associated with the food containers. The reader performs several functions, one of which is to produce a low level radio frequency magnetic field, usually at 125 kHz or 13.56 MHz, through a coil-type transmitting antenna. The corresponding RFID tags also contain a coil antenna and an integrated circuit. When the tag receives the magnetic field energy of the reader, it transmits programmed memory information in the IC to the reader, which then validates the signal, decodes the data, and transmits the data to an output device.

[0051] RFID technology has many advantages in the present invention. The RFID tag may be several inches away from the reader and still communicate with the reader. Furthermore, many RFID tags are read-write tags and many readers are readers-writers. The memory contents of the read-write tags may be changed at will by signals sent from the reader-writer. Thus, a reader (e.g., the OMR-705+ produced by Motorola) would have its output connected to the cooktop's microprocessor, and would have its antenna positioned beneath the base **38**. Each corresponding food container includes an RFID tag (e.g., Motorola's IT-254E). When a tag food container is placed upon the locator/holder **36**, the communication between the container tag and the cooktop reader generates an initiation signal permitting commencement of the heating cycle. Another type of object not including an RFID tag placed on the cooktop would not initiate any heating.

[0052] As depicted in **FIG. 1**, each of the locator/holders **36** is adapted to receive a flexible insulated pizza delivery bag **76**, in order to infuse thermal energy into a thermal storage device therein. Referring to **FIG. 2**, it will be seen that such a bag **76** has a closure flap **78** (closable by attaching mating Velcro strips **79** on the flap and bag) as well as an internal, non-insulated nylon pocket **80**. The pocket **80**

is designed to essentially permanently receive therein a thermal storage device broadly referred to by the numeral **82**, with one or more boxed pizzas **84** located atop pocket **80** and within the confines of the bag. Referring to **FIGS. 3 and 4**, the thermal storage device **82** is illustrated in more detail. The device **82** includes a circular, plate-like, heat retentive pellet **86** and a base **88**. The pellet **86** is preferably composed of an internal metallic magnetic induction heating element **90** surrounded by synthetic resin heat retentive material **92**.

[0053] As indicated previously, the bag **76** would be sized so that when placed upon the cooktop **43**, the photo sensors **56, 58** would sense its presence and send a heating cycle initiation signal to the cooktop's microprocessor. In the case of RFID technology, the bag **76** would include an RFID tag which would be read by a cooktop-mounted RFID reader.

[0054] The element **90** can have a wide variety of compositions, forms and shapes, but preferably is composed of a nickel/copper alloy whose nickel content is above about 70% by weight; the exact nickel percentage is dictated by the desired Curie temperature of the element **90**. As illustrated, the preferred element **90** is preferably a solid sheet of the selected nickel/copper alloy formed as a thin, circular disk typically having a thickness of about 0.035 inches. If desired, a plurality of holes may be drilled or punched through the disk to allow flow of heat retentive material during manufacture of the pellet.

[0055] The presently preferred element **90** for use in pizza temperature maintenance is a 0.036 inch thick solid sheet of 78% nickel/22% copper alloy with minimal trace element impurities. The sheet is cut into a 9.75 inch diameter disc. The disc has one center hole and five evenly spaced holes located along a 2.5 inch radius from the center.

[0056] The heat retentive material **92** is preferably a solid state phase change material formed of a mixture of polyethylene, structural additives, thermal conductivity additives, and antioxidants that has been radiation crosslinked after the entire pellet has been molded. In the form shown in **FIG. 2**, the upper surface of material **92** has molded elongated ribs **94**. Normally, at least about 70% by weight of the heat retentive material is selected from the family of polyethylene resins. Many factors well known in the prior art are used to choose the exact polyethylene resin used for a suitable thermal storage material: The density, percent crystallinity, melt index, molecular weight distribution, types of monomers making up the polyethylene molecules, catalyst used, processing method, processing additives blended into the resin, antioxidants blended into the resin packages, and others. Preferences such as "Radiation Chemistry of Macromolecules", Academic Press, NY, 1972 and journal articles such as "Crystalline Polymers as Heat Storage Materials in Passive Thermal Protection Systems", *Polymer Engineering and Science*, Vol. 15, No. 9, 1975, pp. 673-678 (incorporated by reference herein) may be consulted for guidance regarding particular heat retentive materials.

[0057] Since the exact temperature at which latent heat will be stored and later released is primarily a function of the polyethylene density, such density often becomes a primary design factor for choosing the optimum resin for a pellet of this invention. For instance, because the latent heat storage temperature for a pizza delivery application requires a latent heat storage temperature of approximately 230F, the types of resins capable of providing a phase change in this region are

usually low density polyethylenes and linear low density polyethylenes. For pizza delivery applications the preferred resins are: (1) a linear low density polyethylene resin designated as GA 564 from Equistar Chemicals, LP of Houston, Tex.; (2) a metallocene linear low density resin from Phillips Petroleum Company of Houston, Tex. designated as mPact D 139; and (3) a low density polyethylene resin designated as LDPE 640I from Dow Plastics of Midland, Mich. All three resins are FDA approved for food contact use.

[0058] Since various foods delivery applications of this invention may require a different latent heat storage temperatures, other polyethylene resins may be chosen for the corresponding pellets. The family of polyethylene resins have available latent heat storage temperatures ranging from between approximately 190 F. to approximately 290 F., corresponding to specific densities from approximately 0.915 to approximately 0.970. Furthermore, within each of these density ranges, many polyethylene resins that are FDA approved for food contact use may be found.

[0059] Prior to radiation crosslinking, the chosen resin may have antioxidants added thereto to deter oxidation of the heat retentive material during its life of periodic exposure to temperatures in excess of its crystalline melting temperature. Many antioxidants known in the prior art such as Hindered Phenols, Hindered Amine Light Stabilizers (HALS), phosphite antioxidants, and other may be used. Particularly, antioxidants such as Irganox[®] 1010 or Irganox[®] 1330 produced by Ciba Specialty Chemicals of Switzerland, Uvasil[®] 2000 LM produced by Great Lakes Chemical Corporation of West Lafayette, Ind., Ultrinox[®] 641 and Weston[®] 618 produced by GE Specialty Chemicals of Parkersburg, W.Va., and Doverphos[®] S-9228 produced by Dover Chemical Corp. of Dover, Ohio are preferred. Experimentation has shown that HALS provide the best balance of antioxidant protection and decreased crosslinking efficiency. Whatever the antioxidant used, care should be taken to ensure that the total level of each antioxidant used within the heat retentive material conforms with applicable standards for food contact use. Typically, this means antioxidant additions to resin ranging from 0.05% to 1.0% by weight. Furthermore, the cumulative total of antioxidant used must conform to such standards. These additional antioxidants are blended into the resin by means known in the art, such as by compounding.

[0060] Structural and/or thermal conductivity materials may also be added to the resin formulation. Particularly, chopped glass fiber, glass particles, and FDA approved carbon powders may be used. Chopped glass fiber at up to 30% by weight addition adds great structural strength to a heat retentive pellet that is heated above the melting point of the polyethylene resin. Chopped glass fiber, such as 415A CRATEC[®] Chopped Strands, is particularly formulated to optimize glass/polymer adhesion and may be added to the resin by means known in the art such as compounding.

[0061] Experimental resins incorporating carbon powder such as MPC Channel Black produced by Keystone Aniline Corporation of Chicago, Ill. and XPB-090 produced by Degussa Chemicals of Akron, Ohio as additives to LDPE and LLDPE resins demonstrate that they not only improve structural integrity of high temperatures and improve thermal conductivity of the mixture, but that they also reduce the oxidation rate of the polyethylene. A test sample composed

of 23% by weight Keystone MPC Channel Black and 77% by weight Equistar GA 564 resin with no additional additives, electron beam crosslinked to a total absorbed dose of 15 Mrad was found to show no signs of oxidation after 150 hours in a circulating air oven at 300 F. This performance was a substantial improvement over that of a identical sample composed of 100% Equistar GA 564 resin with no additional additives, identically crosslinked, and subjected to the same conditions.

[0062] Once the resin and any of the above-described additives are chosen and compounded, the mixture is preferably injection molded around the magnetic induction heating element via an insert molding technique. Other production methods known in the art such as compression molding may also be used.

[0063] After the pellet has been molded it is radiation crosslinked. Radiation crosslinking of polyethylenes and polyethylene-based composite materials is well known in the art. Companies such as E-BEAM Services, Inc. with plants in Cranbury, N.J., Plainview, N.Y., Lafayette, Ind., and Cincinnati, Ohio irradiate thousands of pounds of polyethylene annually with electron beams for use as high temperature wire and cable sheathing, shrink tape and tubing, among others. Furthermore, many companies also crosslink polyethylene with gamma radiation at treatment facilities across the nation. While electron beam crosslinking is the preferred crosslinking method for this invention, gamma radiation is also suitable. Both radiation methods produce no toxic byproducts within the pellet and radiation crosslinked polyethylene is FDA approved for food contact use.

[0064] Regardless of the source of radiation, the primary benefit of radiation crosslinking the heat retentive material **92** of the pellet of this invention is to ensure that it remains in the solid state when heated well above the melting temperature of the polyethylene. Thus, a magnetic induction heating element **90** encased in the preferred heat retentive material **92** may be quickly heated to a temperature well above the melting temperature of the non-crosslinked resin and remain there indefinitely, all the while storing both sensible and latent heat in a pellet that remains solid.

[0065] Tests have shown that a radiation doses between 10 Mrad and 20 Mrad, mixtures of 70% by weight or more of any of the above-mentioned resins combined with 30% by weight or less of glass and/or carbon powder fillers achieve enough gel percentage to be suitable solid-to-solid phase change heat retentive material for purposes of the invention. Furthermore, tests have shown that the latent heat per gram of the crosslinked resin is substantially retained. Thus, latent heat storage of from approximately 20 cal/g to approximately 50 cal/g may be achieved, depending upon the crystallinity of resin chosen. The addition of extra antioxidants to the resin/filler mixtures requires a higher total radiation dose to achieve the same gel percentage but does not affect the latent heat storage per gram of the resin itself.

[0066] In summary, a preferred heat retentive material **92** is radiation crosslinked, solid-to-solid phase change composite having at least about 70% by weight polyethylene content and from 0% up to about 30% by weight of additives such as antioxidants, thermal conductivity additives, structural additives, or other additives.

[0067] One preferred pellet for pizza temperature maintenance using flexible insulated pizza delivery bag **76** is

formed of a mixture of 70% by weight Equistar GA 564 LLDPE resin and 30% by weight chopped glass fiber, such as 415A CRATEC[®] Chopped Strands available from Owens Corning, that is injection molded around the element **90** using insert molding techniques to form a 10.0 inch diameter by 0.434 inch thick disk-shaped pellet weighing 1.8 pounds. Once molded, the pellet is electron crosslinked using a 2.0 MeV electron beam to achieve a total absorbed dose of 20 Mrad on each side of the pellet. It has been found in production that the magnetic induction heating element prevents adequate penetration of low energy electrons to evenly crosslink both sides of the pellet from a single side bombardment. The ribs **94** are used to provide a buffering air space between the pellets main surface area and any other object coming into contact with the pellet. Aluminum rivets **95** (see FIG. 2) are employed to connected the pellet **86** to base **88**.

[0068] For food delivery applications that do not require a pellet with latent heat storage ability, a non-toxic thermoplastic material with a high melting temperature and a high specific heat may also be used alone or in composite form with the additives described above, formed around a ferromagnetic core such as the element **90**. Suitable thermoplastic materials should have melting temperatures, and preferably continuous use temperatures, well above the desired regulation temperature of the pellet for a given food delivery application. For instance, for the pizza delivery application, the thermoplastic material should have a continuous use temperature above about 230 F. Furthermore, suitable thermoplastic materials should have high specific heats, preferably above 0.3 cal/g, so as to be able to store sufficient thermal energy to achieve the food delivery system goals.

[0069] Nylons, polyethylenes, polypropylenes, and thermoplastic polyesters are especially suitable. Furthermore, other engineering plastics known in the art may be used. The chosen materials should allow for either injection molding or compression molding of the pellet.

[0070] One preferred non-phase change pellet for pizza temperature maintenance within the flexible insulated pizza delivery bag **76** is formed of 30% glass filled nylon injection molded around the element **90** using insert molding techniques to form a 10.0 inch diameter by 0.434 inch thick disk-shaped pellet weighing 1.8 pounds. The ribs **94** are used to provide a buffering air space between the pellets main surface area and any other object coming into contact with the pellet. Aluminum rivets **95** (see FIG. 2) are employed to connected the pellet **86** to base **88**.

[0071] In summary, such non-phase change pellets are generally composites formed about a ferromagnetic core and having at least about 70% by weight thermoplastic resin and from 0% up to about 30% by weight of antioxidants, thermal conductivity additives, structural additives, or other additives that will remain solid throughout the heating/cooling cycle of the pellet.

[0072] Optionally, the heat retentive pellets of the invention may be encapsulated using a shell or coating which may act as a passive oxygen barrier so as to slow the oxidation rate of the crosslinked synthetic resin material, thus prolonging the useful life of the pellets. Many materials are known which may serve as an oxygen barrier. However, two specific coating materials and their associated deposition methods are preferred. First, the coating or shell may be

formed of diamond-like carbon (DLC) coating material. DLC is a highly ordered conformal carbon coating that is applied by plasma-enhanced chemical vapor deposition under vacuum under substrate temperatures less than 150 C., thus making it suitable for a thin encapsulating shell for the pellets hereof. Studies with plastic beer bottles have shown that DLC can improve the oxygen barrier properties of a plastic substrate by 500 to 1000%. Companies such as Diamonex, Inc. of Allentown, Pa. and other supply DLC coatings. Another preferred coating is parylene, which is a conformal pinhole-free protective polymere coating that is applied at the molecular level by a vacuum deposition process at ambient temperatures. Film coatings from 0.1 to 76 microns can easily be applied in a single operation. Parylene C has a low oxygen permeability and thus makes an excellent passive oxygen barrier. Specialty Coating Systems, Inc. of Indianapolis, Ind. applies parylene coatings. Other suitable encapsulating coatings can be used to act as moisture barriers as well as passive oxygen barriers.

[0073] The base **88** is a synthetic resin (phenolic, nylon, or other high temperature composite material) plate having bifurcated ends **96** and **98**. Any suitable material may be used in the fabrication of the base so long as it provides sufficient rigidity and support for the pellet **86**. The base **88** provides a flat rigid bottom to the pizza bag **76** and thus keeps the insulation in the bag from bunching up. It also functions to provide an insulting layer between the pellet **86** and the bottom panel of the pizza bag. However, the primary function of the base **88** is to locate the pellet **86** directly over the coil of one of the charging stations **32**.

[0074] FIGS. 5 and 6 illustrate another thermal storage device embodiment in accordance with the invention, namely thermal storage device **100**. Broadly, this embodiment includes a heat retentive pellet **86** having any of the above-described constructions housed within a casing structure **102** that includes thermal insulation **104**. In detail, it will be observed that the casing structure **102** includes a unitary, open top tray **106** having a bottom wall **108** and upstanding sidewalls **110**. A laminated base plate **112** is positioned on the bottom wall **108** and is adhered thereto by silicone adhesive. The plate **112** is formed of a synthetic resin corrugate sheet **114**, supporting a thin metallized film **116**; polyester, polypropylene, polyvinyl flouride, polyvinyl chloride, or other thin insulating film that has been coated with a thin layer of metal by vapor deposition, sputtering, or other coating methods known in the art. The sheet **114** functions to reduce conductive heat losses from the pellet to the tray bottom. A piece of low emissivity, metallized film **116** (e.g., NRC-2/500 from Metallized Products of Winchester, Mass.) is adhered by silicone adhesives to the sheet **114** and serves to reflect infrared radiation from the pellet away from the bottom of the box while not interfering with the magnetic field created during charging. Tests have shown that NRC-2/500 film reduces the peak temperature of the bottom wall over a normal 30 minute pizza delivery as well as aluminum foil yet does not prevent the pellet from being temperature regulated via the preferred method of this invention. A series of upright 0.5" diameter×0.25" thick nylon washers **118** are secured to the film **116** by adhesive and support the pellet **86**. Foam insulation **104** is situated within the confines of the tray **106** and has a central opening **120**; the insulation **104** is maintained in place by silicone adhesive. As best seen in FIG. 6, the pellet **86** is positioned atop the washers **118**, with the insulation **104** in surrounding

relationship thereto. A removable top 122 formed of nylon is snapped into place on the tray 106 such that it makes thermal contact with the pellet 86; this completes the assembly of thermal storage device 100. Again as seen in FIG. 6, the assembly 100 is sized to fit within bag 76, and is operable to support one or more boxed pizzas 84. If desired, mating Velcro patches on the bottom of the tray 106 and the interior of the pizza bag 76 may be used to hold the assembly 100 in place.

[0075] The preferred pellet 86 of this embodiment employs a heat retentive material is composed of a blend of a 23% by weight Keystone MPC Channel Black and 77% by weight Equistar GA 564 resin with no additional additives. Once molded, the pellet is electron crosslinked using a 2.0 MeV beam to achieve a total absorbed dose of 15 Mrad on each side of the pellet. It has been found in production that the magnetic induction heating element prevents adequate penetration of low energy electrons to evenly crosslink both sides of the pellet from a single side bombardment. Of course, other members of the family of latent heat composite materials previously disclosed may also be used in this context as well.

[0076] FIG. 8 illustrates a symmetric food delivery device 153 that consists of two identical assemblies 124 and which can be used for delivery of a wide variety of different food items using disposable internal containers. FIG. 7 illustrates an exploded perspective view of one such assembly 124. The assembly 124 includes a preformed, rigid, polypropylene-walled, foam-filled half-container 126 and a heat retentive pellet 128 held in place by a nylon cover 129. The preformed walls of the half-container 126 are formed by rigid polypropylene sheets 126a and 126b, with an insulating foam 126c therebetween. The half-container 126 includes a base 130 and a continuous, upwardly extending, obliquely oriented sidewall 132 presenting an uppermost, substantially flat surface 134 interrupted by elongated concavities 134a along two side surfaces and corresponding elongated projections 134b along the other two side surfaces. The inside wall of base 130, formed of rigid polypropylene sheet 126a, has a central circular depression 136 formed therein, as well as four radially outwardly extending channels 138 communicating with the depression 136. It will be observed that the depression 136 is defined by an upright surface 140 interrupted by the channels 136 and having an upper lip 142. Additionally, the inside wall of base 130 has a stepped or tiered configuration between the channels 138, in the form of parallel ridge sections 144, 146. As best seen in FIGS. 11 and 13, the outside wall of base 130, formed of rigid polypropylene sheet 126b, has projecting feet 148 (in the form of flat-top cylinders $\frac{1}{8}$ " in height and 1" in diameter) and corresponding depressions 150 ($\frac{1}{8}$ " in depth and $\frac{1}{2}$ " in diameter). Finally, the half-container 126 includes a valve stem 152 through the base 130 thereof.

[0077] The pellet 128 is preferably the same as that described in connection with the embodiments of FIGS. 5 and 6, except that the mass of synthetic resin material used in fabricating this pellet may be less. This reduction in material is possible because two pellets are used in each completed symmetric food delivery device, as will be described. Of course, other types of heat retentive materials previously described can be used in this context as well. In

any case, the pellet 128 is secured within the central depression 136, with the pellet cover 129 engaging the half-container lip 142.

[0078] FIG. 8a illustrates a half-container 126 equipped with an RFID tag 151 in the base thereof, in this instance the tag 151 is embedded within a foot 148.

[0079] In use, a pair of identical assemblies 124 are placed in face-to-face relationship to form a completed symmetric food delivery device 153 presenting an enclosed cavity 154, as seen in FIG. 8. To this end, the half-containers 126 are rotated so that the concavities 134a of the bottom half-container mate with the projections 134b of the upper half-container. If desired, one of the valves 152 may be employed for withdrawing a small amount of air from the cavity 154 so as to insure a tight vacuum-assisted fit between the half-containers 126. When the symmetric food delivery device 153 reaches its final destination, a valve 152 is manipulated to relieve the low magnitude vacuum within the container to thus permit the container halves to be separated.

[0080] FIG. 8 depicts a situation wherein two different sized pizza boxes 156, 158 are housed within the cavity 154 of the completed symmetric food delivery device 153. It will be seen that the ridges 144 and 146 form tiered surfaces which accommodate the different box sizes. That is, the outer ridges 146 of the lower half-container 126 are sized to accept the larger pizza box 156 whereas the inner ridges 144 of the upper half-container 126 accept the smaller pizza box 158. At the same time, the channels 138 assure that heated convection air travels radially outwardly from the pellet 128 to flow around and maintain the temperature of the pizza within the boxes 156, 158.

[0081] The completed symmetric food delivery device 153 may also accept a low-cost pizza box depicted in FIGS. 9 and 10. Specifically, the box 160 is formed of two half boxes 162. Each half box 162 (which may be constructed of standard cardboard, synthetic resin or molded pulp) presents a bottom wall 164, with a continuous, upstanding, oblique sidewall 166. The upper margins of the four sides of sidewall 166 have alternating tabs 168 and slots 170 so as to permit interconnection of the half boxes 162 as shown in FIG. 10. The use of boxes 160 within a container 153 is depicted in FIG. 14, where it will be seen that a pair of such boxes are oriented in stacked relationship with the bottom box 160 in close contact with the pellet 128 of the lower container half 126, whereas the upper box 160 is in close thermal contact with the pellet 128 of the corresponding upper container half 126.

[0082] One principal advantage of the symmetric food delivery device is that it may be used to deliver a variety of different foods packaged within novel disposable containers. As depicted in FIG. 15, a preformed synthetic resin sandwich-type container 172 can be seated within an open top liner 174 within the confines of the symmetric food delivery device 153. The liner 174 and the halves of container 172 are illustrated in exploded relation in the righthand portion of FIG. 15. In FIG. 16, the liner 174 is illustrated within the lower container half 126, and three separate food containers, made up of two containers 172 for hot foods and a central insulated container 178 for cold foods, is seated within the liner 174.

[0083] Another principal advantage of the symmetric food delivery device is that its half-containers 126 are fully

nestable for ease of storage. As shown in FIG. 12, a pair of half-containers are in nested relationship with the feet 148 of the upper container half 126 engaging the inner surface of the base of the next lower container half. Thus, the feet 148 assure that the nested container halves may be readily separated.

[0084] Moreover, the location of the feet 140 and depressions 150 assists in the stable stacking of a plurality of symmetric food delivery devices 153. The feet 148 of an upper symmetric food delivery device 153 may be seated within the somewhat larger diameter depressions 150 formed in the upper surface of the next lower symmetric food delivery device 153, so as to form a more stable stack.

[0085] It will also be appreciated that the hard sided half-containers 126 may be charged with thermal energy via a magnetic induction charger of the type illustrated in FIG. 1. However, as shown in FIG. 17, a multiple-station charging/holding device 180 is preferably employed for the half containers 126 and the fully assembled symmetric food delivery devices 153. The device 180 is in the form of an insulated cabinet presenting a series of open lower vertical charging stations 182 for respective half containers 126. Each of the stations 182 includes a magnetic induction cooktop 184 identical to that shown in FIG. 1 without the attached locator/holder 36. It will further be observed that each station 182 is sized to snugly receive a half container 126 so as to assure that the pellet 128 thereof is closely adjacent the induction coil of the assembly 184. As will be appreciated, the respective half containers 126 can be situated within corresponding stations 182 for charging thereof as will be described, until the half containers are ready for use. If the half containers are then used to form completed containers 153 containing pizza boxes or the like, these completed and filled containers 153 can be stored and maintained at temperature in the upper horizontal holding stations 186. Again, each of these stations includes a pair of opposed, upper and lower magnetic induction charging assemblies 188, 190, and are sized to receive a pair of superposed containers 153. In this orientation, the lower pellet 128 of lower container 153 is closely adjacent the assembly 190, whereas the upper pellet 128 of the upper container 153 is proximal to upper charging assembly 188. This permits the user to extract two container halves 126 from the lower stations 182, to fill one of these with a food product and to use the other to close the filled half-container. The completed containers are then inserted into an upper station 186.

[0086] FIGS. 25-27 depict another type of magnetic induction heating element in accordance with the invention. In particular, an induction heatable device 300 is illustrated in FIGS. 25 and 26 which is made up of a spiral coil 302, comprising a single continuous strand 304 of flat metal with an inner end 306 and an outer end 308. The shape of the spiral 302 may be circular, square, elliptical, or any other shape as long as it is one continuous strand. By itself, the strand 304 is an open circuit. To work as an induction heating element, the spiral strand's circuit path must be closed. This must be accomplished permanently as shown in FIGS. 25 and 26, or with a switch 310 as shown in FIG. 27. Referring first to a permanent connection, a cross-element 312 may be permanently connected as shown in FIGS. 25 and 26 and may be formed of the same metal as the spiral strand or simply from a metal such as copper or aluminum.

The element 312 is adhered to the spiral strand at all points except ends 306, 308 with a thermally conductive but electrically insulative adhesive 314 such as a ceramic adhesive from Aremco Products, Inc. or a high-temperature epoxy. The thickness of this adhesive layer is exaggerated in FIG. 26, and in reality need only be thick enough to electrically isolate cross element 312 from each point of contact with spiral 302. The two ends of the element 312 are directly connected to the inner and outer coil ends 306, 308 to complete the electrical circuit. These connections can be made by soldering, welding, twisting, or any other means by which permanent electrical contact can be achieved.

[0087] The embodiment of FIG. 27 makes use of a coil 302 made up of a continuous strand 304 presenting inner and outer ends 306, 308; moreover, a cross element 312a is provided which extends across the coil 302 and is electrically separated therefrom by insulative adhesive 314. Thus, this embodiment is identical with that of FIGS. 25-26, except for the use of switch 310. Specifically, a pair of electrical conductors 316 and 318 are respectively attached to the outer end of element 312a and to outer coil end 308. The switch 310 is disposed between and electrically connected to the conductors 316, 318. When switch 310 is open, an open circuit exists and thus no induced current can flow along the entire length of spiral 302, and when the switch 310 is closed, the coil circuit is closed, thereby permitting induced current flow. The switch 310 may be an electromechanical switch or an electronic switch with associated programming. The latter alternative allows for electronically programmed cooking systems.

[0088] It will be appreciated that even if the FIG. 27 coil is open by virtue of the switch 310 being open, and the coil is forcefully exposed to the changing magnetic flux of a magnetic induction heating device, very little joule heating due to induced eddy current flow in the heating element occurs, because all induced eddy currents are confined to the size of the spiral strip's width. Thus, the FIG. 27 embodiment has the ability to stop the induced joule heating of the spiral heating element at any time with the flip of a switch.

[0089] Either of the spiral heating elements described above may be used with a commercially available magnetic induction heating device that employs a "no load" or "abnormal load" condition detecting system described previously. These heating devices typically do not detect or sense the impedance of an external load, but rather the influence of the impedance upon the performance of the heater circuit is reflected in a parameter that is directly sensed. The exact parameter sensed by various commercial "no-load" detection systems may differ, e.g., some sense the amount of current flowing through the induction coil, some sense the voltage drop across a particular resistor in the detector circuit, and some detect a variation in oscillation frequency.

[0090] Thus, an overall heating assembly making use of the heating elements illustrated in FIGS. 25-27 include a magnetic induction heater including a heater circuit having a magnetic field generator, a detector operable to detect a heater circuit parameter related to the impedance presented to the heater by an induction heatable device, and control circuitry capable of altering the magnitude of the magnetic field generated by the generator in response to detection of the parameter. The heating assembly further has an induction heatable device 300 including a continuous coil 302 formed

of electrically conductive material with a pair of terminal coil ends **306, 308**. A conductive assembly is operably connected between the ends **306, 308** to complete a coil circuit including the coil **302**. The conductive assembly may be simply the element **312** (FIGS. 25 and 26), or may additionally comprise a selectively operable switch component **310** and associated conductive elements **316, 318**. The switch **312** is switchable between a closed coil circuit mode and an open coil circuit mode.

[0091] In use, the coil **302** experiences a magnetically induced flow of current therethrough when the induction heatable device is placed adjacent the heater and the heater generator is operating and the switch **310** is in its circuit-make, coil circuit mode (here when the switch is closed). In such a situation, the heatable device presents a circuit-make, coil circuit impedance to the heater. Of course, when the induction heatable device and heater are cooperable so that, when the switch **310** is moved between the circuit-make and circuit-break configurations, the switch it in its circuit-break configuration (here, when the switch is open) a circuit-break impedance different than the circuit-make impedance is presented to the heater. The detector associated with the heater detects a change in the parameter and the control circuit operates to alter (typically by fully terminating) the magnitude of the magnetic field.

[0092] Operation

[0093] In order to understand the operation of the preferred apparatus of the invention, it is helpful to initially consider the disclosure of PCT Publication WO 98/05184, incorporated by reference herein. This disclosure describes two different temperature regulation techniques. Both methods utilize magnetic induction as the energy transfer means, a ferromagnetic heating element preferably composed of a nickel/copper alloy as the device whose temperature is regulated, and the concept of interrupting the continuous production of a magnetic field at a user-selective regulation temperature. However, each method uses a different feedback parameter related to the impedance of the load presented to the magnetic induction heater by the heating element to determine whether and when to interrupt magnetic field production.

[0094] The First Temperature Regulation Method of Publication WO 98/05184

[0095] The first technique involves regulation about an impedance threshold of a "no-load detector" forming a part of commercially available magnetic induction cooking device. In this method, a commercially available magnetic induction cooking device employing "abnormal load" or "no-load detection" circuitry, whose purpose is to prohibit continuous magnetic field production when the impedance of the load is improper, is used to temperature regulate a ferromagnetic heating element. FIG. 6A of Publication WO 98/05184 illustrates the operation of conventional "no-load detection" circuitry.

[0096] In many magnetic induction cooking devices the impedance that the external load presents to the resonant circuit is indirectly "detected" by measuring the amplitude of the resonant current flowing through the work coil. A variety of resonant circuit parameters may be used for such detection. Regardless of the exact circuit parameter measured, each commercially available "no-load" detection sys-

tem ultimately reacts to a threshold value of load impedance, which was referred to in Publication WO 98/05184 as Z_{detector} and which corresponds to a threshold value of resonant current amplitude, I_{detector} , below which the continuous magnetic field production is interrupted.

[0097] For this temperature regulation method to be successful, a ferromagnetic heating element magnetically coupled to the cooktop's work coil provides an impedance to the cooktop's resonant circuit that changes in a predictable, controlled fashion such that the amplitude of the resonant current, I_{rc} , consistently moves through the value of I_{detector} at the same temperature. Provided this occurs, the cooktop's no-load detector de-energizes the current flowing through its induction work coil, thereby eliminating continuous magnetic field production and thus interrupting the joule heating of the heating element at the heating element's "user-selected regulation temperature" corresponding to the value of I_{detector} .

[0098] FIG. 21 shows a desired I_{rc} vs. time (and temperature) relationship for a ferromagnetic heating element on a commercial induction cooktop employing this first temperature regulation method. FIG. 21 shows how the "user-selected regulation temperature" may be selected from any temperature within a range of temperatures from just above the published Curie temperature of the heating element up to a temperature defined as "the shelf temperature." The data graphed in FIG. 21 was obtained from a test conducted with a Sunpentown Model SR-1330 Induction Cooktop and a 5 inch square piece of 77% nickel/23% copper alloy sheet of 0.035 inch thickness. The sheet stock alloy square was placed upon the cooktop, centered over the work coil. The alloy square was prevented from warpage or movement throughout the test. A medium power setting was selected on the cooktop.

[0099] In order to properly comprehend the data graphed in FIG. 21, it is important to understand the basics of the Sunpentown SR-1330's no-load detection circuitry. Within this no-load detection circuit, a sensing transformer's primary has the SR-1330's resonant circuit current flowing through it. The transformer's secondary provides an induced EMF which results in current that, after rectification, is used by the no-load detector to determine if a proper load is in place upon the cooktop. The "transformer voltage", plotted in FIG. 21 is the voltage drop across a resistor, $R_{\text{no load}}$, through which this rectified secondary current flows. The "transformer voltage" is proportional to I_{rc} and thus is proportional to the load impedance of the 77% nickel/23% copper alloy square. This transformer voltage was measured, recorded, and plotted every second by a Hewlett Packard 34970A Data Acquisition/Switch Unit interfaced with an IBM 770 ThinkPad™ computer running Hewlett Packard Benchlink™ Data Logger Software. Furthermore, an average temperature of the alloy square's surface was measured and recorded every second and plotted on the same graph. For this test the I_{detector} value of the SR-1330's no-load detector was lowered to a value corresponding to a voltage drop across $R_{\text{no load}}$ of 3.0 Volts, such that the continuous magnetic field was not interrupted through the test.

[0100] Again referring to FIG. 21, the transformer voltage is approximately 8.2 volts while the nickel/copper heating element remains below approximately 225 F. This temperature is within experimental error of the published Curie

temperature of an alloy of 77% nickel/23% copper with minimal trace elements. Thus, the temperature for which this first drastic drop in I_{rc} occurs is hereafter referred to as the "published Curie temperature."

[0101] As the temperature of the alloy square increased above the published Curie temperature, the transformer voltage decreased drastically down to a value of 5.1 V, at which time the transformer voltage remained essentially constant even as the alloy square's temperature continued to rise. The heating element's temperature at which the transformer voltage (and hence I_{rc}) remained essentially constant (determined as the temperature beyond the published Curie temperature at which the absolute value of the rate of change of transformer voltage first became less than one tenth the maximum rate of change value) is referred to herein as the "shelf temperature." Under these test conditions the shelf temperature of the 77% nickel/23% copper alloy square of thickness 0.035" is 290 F. By adjusting the value of detector (which may be done by adjusting a potentiometer accessible to the user) the user of the induction cooktop may select as the regulation temperature for the alloy square of this example any single temperature within the range of temperatures between 225 F and 290 F.

[0102] The I_{rc} vs. time (and temperature) curve for sheet stock heating elements of other nickel/copper alloys (different nickel percentages) under the same test conditions are almost identical in shape. Each curve shows the drastic drop in transformer voltage for all alloy temperatures beyond the shelf temperature.

[0103] FIG. 22 shows the I_{rc} v. time relationship as well as the I_{rc} vs. temperature relationship for a solid sheet alloy square that was actually temperature regulated via the first method of Publication WO 98/05184. A 5-inch 77% Nickel/23% copper alloy square was placed upon the same Sunpentown SR-1330 cooktop used to gather the data of FIG. 21. The same data gathering apparatus was used to record the transformer voltage and average temperature of the alloy square. In this case the alloy square was raised ¼ inch above the cooktop (whereas in FIG. 21 test the square was directly on the cooktop surface). As can be seen, the transformer voltage drops continuously until the average temperature of the square reaches approximately 247 F. At this point, the transformer voltage drops to 4.74 volts, the voltage setting corresponding to $I_{detector}$. At this point, the no-load detector interrupts the continuous magnetic field production. The alloy square cools. Within four seconds the transformer voltage rises to approximately 5.74 volts, at which time the magnetic field was again produced continuously. The alloy square's temperature rose again. As the alloy square's temperature rose, the transformer voltage decreased again to the level corresponding to $I_{detector}$ and the continuous magnetic field production was interrupted. This process can be continued indefinitely. With a more significant heating load, the "on time" of the magnetic field would decrease dramatically.

[0104] FIG. 22 shows that the alloy disc regulated continuously at a temperature of 242 ± 5 F. when the voltage setting corresponding to $I_{detector}$ was set to 4.74 volts. If detector had been set to correspond to 5.24 volts, the regulation temperature would have been approximately 235 ± 5 F. Furthermore, should the value of $I_{detector}$ been set to correspond to 5.74 volts, the regulation temperature would have been approximately 224 ± 5 F. Finally if the value

of detector had been set to correspond to 6.24 volts, the regulation temperature would have been approximately 210 ± 5 F. Thus, it can be seen that a variety of "user selected" regulation temperatures may be achieved with this temperature regulation method, by simply altering the value of $I_{detector}$.

[0105] Another means to vary the regulation temperature achieved by the first method of Publication WO 98/05184 is by altering the distance between the heating element and the induction cooktop's work coil. The effective load impedance that the heating element presents to the magnetic induction cooktop's work coil is dependent upon the distance between the heating element and the induction cooktop's work coil. Referring to FIG. 21, it can be seen that the transformer voltage corresponding to I_{rc} drops from a value of 8.2 volts to a low of 5.1 volts for the apparatus used in this test. For the same apparatus, an increase in the distance between the heating element and the work coil would decrease both the maximum (previously 8.2 volts) and a minimum (previously 5.1 volts) voltages. Conversely, a decrease in the distance would increase both the maximum and minimum voltages. In both cases (increased and decreased distances), the transformer voltage versus time curves (and thus the value of I_{rc} vs. time curves) are almost identical in shape.

[0106] Although this regulation method has many advantages, its main drawback is that the exact value of the load impedance is used as the magnetic field-controlling feedback parameter. Thus, all the factors that contribute to the exact value of the heating element's impedance (as presented to the resonant circuit) must be held substantially fixed for this method to give a reproducible regulation temperature from one test to another. In fact, the following main factors must be controlled so as to guarantee the exact same regulation temperature as expected trial after trial: (1) distance between heating element and work coil; (2) size of the heating element; (3) position of heating element over the work coil, and (4) line voltage.

[0107] The Second Temperature Regulation Method of Publication WO 98/05184

[0108] FIG. 6B Publication WO 98/05184 illustrates an alternate method of temperature regulation involving regulation about a specific rate of change of a circuit parameter that is proportional to the load impedance. This method virtually eliminates the dependence of the heating element's regulation temperature on the distance between the ferromagnetic heating element and the work coil. In this second method, two types of comparisons are made in determining whether to interrupt the continuous production of the magnetic field. The first comparison is similar to the comparison made in the Publication's first method. The measured impedance, $Z_{measured}$, as manifested by the amplitude of the resonant current during inverter on times, $I_{rc\ measured}$, is compared with a predetermined impedance level, Z_1 , corresponding to a predetermined value I_1 . If $I_{rc\ measured}$ is less than I_1 , the control circuitry will interrupt the magnetic field and will cause periodic measurements of the amplitude of the resonant circuit current during inverter on times. As long as $I_{rc\ measured}$ is greater than I_1 , a second comparison is made.

[0109] This second comparison is based on the absolute value of the change in impedance, $|\Delta Z|$, and therefore the absolute value of the change in resonant current

amplitude, $|\Delta I_{rc}|$, between the present and immediate past measured current values, $I_{rc \text{ measured}}$ and $I_{rc \text{ past}}$, respectively. As is shown in **FIG. 6B** of Publication WO 98/05184, after the second measurement of the resonant current amplitude, the field will be interrupted if $|\Delta I_{rc}|$ is greater than a second pre-selected value, I_2 . As long as $|\Delta I_{rc}|$ remains less than I_2 , $I_{rc \text{ measured}}$ will be re-measured, as shown in **FIG. 6B**. It is important to note that the second comparison can alternatively be used to interrupt the continuous production of the magnetic field if $|\Delta I_{rc}|$ is less than the second pre-selected value, I_2 . Thus for this alternative, as long as $|\Delta I_{rc}|$ remains greater than I_2 , $I_{rc \text{ measured}}$ will be re-measured, as shown in the flow diagram, **FIG. 6B**.

[0110] The second comparison effectively eliminates the dependence of the self-regulation temperature on the distance between the heating element and the magnetic induction heating coil because the absolute value of the rate of change of the impedance of the heating element between its room temperature impedance temperature and its shelf temperature impedance is independent of the exact impedance value at any temperature in between. In other words, referring to **FIG. 21**, it does not matter what the exact value of the transformer voltage is at the room temperature of the heating element: the shape of the transformer voltage vs. time curve stays essentially the same regardless of the distance between the heating element and the induction work coil. Therefore, by selecting a particular value of $|\Delta I_{rc}|$, namely I_2 , for a specific time interval, Δtime , during which the second comparison is made, a particular temperature (within a small temperature range), corresponding to that value $|I_{rc}/\{\text{time}\}$ becomes the self-regulation temperature, regardless of that temperature's corresponding value of $I_{rc \text{ measured}}$.

[0111] This second temperature regulation method not only virtually eliminates the dependence of the self-regulation temperature on the distance between the heating element and the magnetic induction coil, it also virtually eliminates the heating element regulation temperature's dependence upon the other factors that determine the amplitude of the resonant current when a heating element is magnetically coupled to the work coil: (1) size of the heating element; (2) horizontal position of heating element over the work coil; and (3) line voltage.

[0112] The term "virtually eliminates" is used because each of the above factors can still slightly influence the regulation temperature as follows. If the diameter of a flat disc heating element is much larger than the diameter of the flat pancake induction work coil, then the disc will temperature regulate when the disc's surface within the work coil diameter is much hotter than the outer disc surface. Also, as the disc is moved further away from the work coil, the inner diameter hot zone will change in size. Furthermore, if a disc heating element is not centered over the work coil, the portion of the disc directly over the work coil will temperature regulate at a hotter temperature than the portion not over the work coil. Finally, a wildly fluctuating line voltage can confuse the rate of change detector as described in this second method of Publication WO 98/05184, inasmuch as the value of each individual value of $I_{rc \text{ measured}}$ depends upon the line voltage amplitude. However, typically line voltage fluctuations only temporarily interrupt the magnetic field production prematurely while the heating element is yet below the user-selected regulation temperature. Once the

heating element is regulating about the user-selected regulation temperature, a typical line voltage fluctuation may cause the magnetic field to be produced when it should be interrupted, causing only a temporary overheating of the element. Of course, methods known in the art to eliminate or compensate for line voltage fluctuations can avoid this problem.

[0113] Despite the advantages of the second method over the first method of Publication WO 98/05184, further research and testing of prototype cooktops employing the second method and using nickel/copper alloy heating elements have shown that in many cases only two distinct temperature ranges provide enough resolution (i.e., show enough rate of change of the rate of change in the resonant circuit current—essentially $|d^2 I_{rc}/d(\text{time})^2|$) so as to temperature regulate precisely. Referring to **FIG. 23**, two regions of the transformer voltage vs. time curve are highlighted and their corresponding temperature regions are bracketed: (1) the region corresponding to temperatures immediately following the published Curie temperature, labeled the "Curie Region," and (2) the region corresponding to temperatures immediately about the self temperature, labeled the "Shelf Region." At other temperatures between the Curie Region and the Shelf Region for selected nickel/copper alloy heating elements, the second temperature regulation method of Publication WO 98/05184 does not allow precise temperature regulation.

[0114] The Preferred Temperature Regulation Method of the Invention

[0115] The preferred temperature regulation method of this invention combines elements of both methods of Publication WO 98/05184 in a new way. In summary, the preferred method indirectly detects the impedance of the external load presented by a ferromagnetic induction heating element to the resonant circuit of a magnetic induction heater, by measuring an appropriate feedback parameter related to such impedance and in a way to avoid the potential problems of the first and second temperature regulation methods described in Publication No. WO 98/05184. This is done by periodically measuring the amplitude of the resonant circuit current, I_{rc} , via a sensing transformer through whose primary flows the cooktop's work coil current.

[0116] At the outset it should be understood that only one magnetic induction cooktop circuit feedback parameter is measured and fed to the control circuit that determines when the magnetic field is to be produced and when it is to be interrupted: the amplitude of the resonant circuit current, I_{rc} . It is also to be understood the amplitude of the resonant current, I_{rc} is preferably determined by measuring the amplitude of current that has been induced in a detection circuit forming a part of the magnetic induction heater during heating operations. As illustrated in **FIG. 18**, a portion of the resonant circuit that includes the work or induction coil **70** is a primary with respect to the secondary sensing coil **72**; therefore, the impedance of the external load may be detected in this arrangement by measuring the amplitude of the rectified current induced in the coil **72** and its connected control circuit **74**. All logical operation conducted by the microprocessor control circuit **74** use this raw data.

[0117] The entire **FIGS. 19A and 19B** flow chart of 32 steps can be thought of as three interconnected logical loops. Logic loop #1 is called the "ready loop" and encompasses

steps **200-210**, inclusive, of the flow chart. Logic loop #1 performs a function very similar to the “no-load” detector previously described, i.e., it insures that only a load with the proper impedance, preferably a food container with a desired ferromagnetic heating element installed, will ever receive full power from the cooktop.

[**0118**] Full power to charge the pellet within the food container is provided in logic loop #2 (the “full charge” loop), encompassing steps **212-236**, inclusive. Logic loop #2 implements the rate of change of load impedance detection method similar to the second temperature regulation methods of PCT Publication No. WO 98/01584, and solves the potential problem of having the ferromagnetic heating element at variable distances from the work coil of the cooktop. The full charge loop charges the pellet with full power until its heating element’s temperature reaches the shelf temperature, at which time the full power magnetic field is interrupted and the cooktop controller moves to logic loop #3 (the “temperature holding” loop). The full charge loop #2 also insures that the magnetic field is not interrupted at or before the Curie temperature; as seen in **FIG. 21**, there is a region immediately adjacent the Curie temperature having a rate of change which could interrupt the magnetic field and terminate heating at a heating element temperature just below the Curie Temperature region. Such result is avoided because of the slope value S_n , i.e., when the absolute rate of change in I_{rc} , $|\Delta I_{rc}|$, is greater than this selected S_n , one is assured of being between the Curie temperature and the shelf temperature, and the counter is set to EP=1.

[**0119**] Logic loop #3 (steps **238-262** inclusive) maintains the pellet temperature near the shelf temperature and notifies the user that the pellet is fully charged. Logic loop #3 performs analogously to the first temperature regulation method of PCT Publication No. WO 98/10584, except that full power is not applied to the pellet within this loop. The cooktop functions within logic loop #3 until the user either removes the fully charged pellet, at which time the cooktop reverts to logic loop #1, or the pellet’s heating element temperature drops below a certain percentage of the shelf temperature, at which time the cooktop reverts to logic loop #2.

[**0120**] There are nine pre-programmed values used in the logic comparisons of the **FIGS. 19A and 19B** flow chart: (1) I_1 , the lower boundary for resonant current; (2) I_{10} , the upper boundary for resonant current; (3) Δt_1 , the time interval employed within logic loop #1; (4) Δt_2 , the time interval employed within logic loop #2; (5) S_n , the absolute value of a rate of change of resonant current between the Curie region and Shelf region; (6) RT, a time value chosen such that the pellet is considered charged if the cooktop remains in logic loop #3 for this amount of time; (7) f, the percentage change in resonant current from I_{shelf} that is allowed before forcing the cooktop to re-enter logic loop #2; (8) I_2 , the absolute value of the rate of change of resonant current that corresponds to the chosen regulation temperature; and (9) Δt_{PING} , the selected time interval employed in logic loop #3. These values are chosen in relation to the specific magnetic induction heating element chosen for a particular application, and vary so as to achieve the desired temperature maintenance for each respective pellet.

[**0121**] Furthermore, there are 7 memory sites whose values are set and reset at specified times throughout the

operation of the cooktop, as described by the **FIGS. 19A and 19B** flow chart. These values are: (1) $I_{rc\ measured}$, a snapshot value of resonant current amplitude; (2) $I_{rc\ past}$, another snapshot value of resonant current amplitude; (3) $|\Delta I_{rc}| = |I_{rc\ measured} - I_{rc\ past}|$, the absolute value of the rate of change of resonant current; (4) EP, a logical 1 or 0 used to enable magnetic field interruption by the rate of change detector of logic loop #2; (5) I_{shelf} , the amplitude of the resonant current corresponding to the pellet heating element’s shelf temperature; (6) $I_{rc\ PING}$, a snapshot value of the amplitude of resonant current measured within logic loop #3; and (7) PING TIME, the cumulative time that the cooktop has remained operating under logic loop #3 rules. In all cases, the I_{rc} values are averages obtained by measuring a plurality of successive values (e.g., 4), summing these values and dividing by the number of values measured.

[**0122**] Prior to applying power to the cooktop, all 9 pre-programmed values will exist within the cooktop’s microprocessor, whereas all 7 memory sites will be set to the value zero. Once power is applied and the container sensor signals the presence of a food container, the microprocessor moves to step **200** (**FIGS. 19A and 19B**). Here the magnetic field is generated in a low duty cycle mode, typically for one cycle every 60 available power cycles. If no suitable pellet is within the food container placed upon the charging station, the cooktop’s microprocessor logic flows from step **200-204**, to **208**, then **210**, and back again to step **200** after the interval Δt_1 . Should a foreign object be placed upon a cooktop operating in logic loop #1 such that the load impedance causes the resonant circuit to draw excessive current, the microprocessor logic would flow from steps **200-210**, and back again. This is because during step **206**, a determination is made as to whether I_{rc} is greater than I_{10} , the selected upper boundary for resonant current. If this condition is satisfied by a YES, an object other than the designed heating element has been placed upon the induction heater, and therefore to avoid overheating thereof, the circuit interrupts the magnetic field at step **208**. In either case, the cooktop remains in a low power pulsing mode, searching for a proper load. Once a food container having an appropriate ferromagnetic heating element pellet of this invention is placed upon the cooktop, the cooktop leaves logic loop #1 and enters logic loop #2.

[**0123**] At step **212**, full power is initiated. Full power is defined as production of a magnetic field for at least 50 and more preferably 59 or 60 of every 60 available power cycles. At step **214**, the charging light on the status indicator box **46** (**FIG. 1**) is illuminated. In step **216**, the microprocessor delays for a time equal to $\{t_2$ and then measures I_{rc} and stores this value as $I_{rc\ measured}$ in step **218**. Referring to **FIGS. 21 and 23**, it will be seen that at temperatures below the published Curie temperature, the resonant current amplitude changes very little. Therefore, by step **220** the value of $|\Delta I_{rc}| = |I_{rc\ measured} - I_{rc\ past}|$ will be very small. Thus, the answer to the question in step **222** will be NO, since the value of S_n is typically chosen to be at least two times the absolute value of the highest value of $|\Delta I_{rc}|$ for pellet temperatures below the published Curie temperature. Thus, EP will stay a logical 0 until the pellet’s heating element temperature passes the Curie region. This means that the answer to the question at step **226** will also remain a NO. The microprocessor then sets $I_{rc\ past}$ equal to $I_{rc\ measured}$ in step **228** and determines if $I_{rc\ past}$ is less than I_1 in step **230** and if $I_{rc\ past}$ is greater than I_{10} in step **232**. At this point, the

answers to steps 230 and 232 are NO, and thus, after a time interval of Δt_2 , the logic steps 218-232 will be repeated again, unless the food container is removed or altered. If this should occur, either step 230 or 232 would interrupt the magnetic field and send the control circuit back into logic loop #1.

[0124] The reason for the inclusion of the logic value EP in steps 222-226 is to prevent step 236 from interrupting full power charging and mistakenly sending the cooktop into the holding mode of logic loop #3 while the pellet is still in the region of temperatures prior to the Curie region. Thus, the pellet's heating element will continue to increase in temperature until it reaches a temperature near to the shelf temperature at which time the answer to question 222 will become a YES. Some time multiple of Δt_2 later, the pellet's heating element temperature will reach the shelf temperature where the value of $|\Delta I_{rc}|$ becomes less than I_2 . At the shelf temperature the answer to question 226 becomes a YES, production of the magnetic field is interrupted, and the value of $I_{rc\ measured}$ is stored in memory as I_{shelf} . At this time the control circuit moves to logic loop #3 beginning at step 238 in FIG. 19B.

[0125] Should a container/pellet that has come back from a delivery cycle with its heating element temperature above the published Curie temperature be placed upon the cooktop, the control circuit would proceed to step 236 as described above. However, the value EP would become a logical 1 via steps 222 and 224 and the answer to question 226 would become a YES much sooner. Thus, while the cooktop would still leave logic loop #2 for logic loop #3 with the pellet's heating element temperature at the shelf temperature, the time spent in logic loop #2 would be much less.

[0126] Although the pellet's heating element has reached the shelf temperature at step 236 of the control circuit flow chart, some of the synthetic resin heat retentive material encasing the heating element that makes up the bulk of the pellet may not have reached the shelf temperature. Thus, one need for logic loop #3 is to allow temperature equalization between the ferromagnetic core and the surrounding synthetic resin heat retentive material of the pellet prior to giving the user the "ready" light on the charging station's status indicator box. The other reason for logic loop #3 is to allow the heating element to maintain a regulation temperature in a small range about the shelf temperature for as long as the container/pellet remains on the charging station.

[0127] Logic loop #3 begins a time interval Δt_{PING} after the shelf temperature has been reached and a corresponding value of resonant current amplitude, I_{shelf} , has been stored in memory. Steps 240, 242, 248, 254, 256, and 258 constitute a modified version of the first temperature regulation method of Publication No. WO 98/01584: that is, the feedback information used to determine when to interrupt magnetic field production is based solely upon the load impedance itself at a given time, as reflected in the measured value I_{rc} . At step 240, the magnetic field is generated continuously at a low power level, typically for 4 out of every available 60 power cycles. At step 242, the measured value of I_{rc} is stored in memory as $I_{rc\ PING}$. Step 244 determines if the PING time is greater than R_c , which at this point is NO. Therefore, the microprocessor skips to step 248. Referring to FIG. 23, at this point the pellet's heating element will have cooled very little. Thus the value of $I_{rc\ PING}$ will be very close to the

value of I_{shelf} . Thus when step 248 calculates the percentage difference in $I_{rc\ PING}$ from the stored value of I_{shelf} , it will be a very small value, say for example 0.5%. At this point, the answers to steps 250 and 252 are both NO. Assuming that the value of f is chosen to be 5%, the answer to question 254 will be NO, and thus the magnetic field will be interrupted in step 256, and the microprocessor will wait a time interval Δt_{ping} in step 258 and add Δt_{ping} to the PING time in step 260.

[0128] At time intervals of Δt_{PING} , the sequence of steps 240, 242, 248, 254, 256 and 258 will be repeated until the temperature of the heating element drops enough so that its load impedance, and therefore the value of $I_{rc\ PING}$, rises enough such that the percentage difference of $I_{rc\ PING}$ from the stored value of I_{shelf} is more than the value f . At this time, the answer to question 254 will be YES and the control circuit will transition back to logic loop #2, the charging loop.

[0129] Within logic loop #3 are two other important functions. Steps 250 and 252 ensure that the magnetic field will be interrupted and the cooktop will revert to logic loop #1 that should the container/pellet be removed from the charging station or somehow altered. Steps 244, 246, 260 and 262 constitute a time counter that causes the "charging" light on the charging station's status indicator box to go off, while simultaneously causing the "ready" light to turn on after the charger has remained solely within logic loop #3 longer than a predetermined time interval RT.

[0130] Different pre-programmed values of I_2 , Δt_2 , Δt_{PING} , and f will alter both the exact regulation temperature and the Δ temperature about the regulation temperature that this preferred method of temperature regulation achieves. Slight alterations in the flow chart of FIGS. 19A and 19B can also provide temperature regulation methods with other features as well. For instance, should a logic loop #4 consisting of simply another modified version of logic loop #1 be added to the YES branch of step 254, the pellet would temperature regulate at a new temperature between the shelf temperature and the published Curie temperature despite the fact that its heating element first had been heated to the shelf temperature. FIG. 20 shows such a logic loop #4, consisting of steps 264-276. This loop #4 is very similar to loop #1.

[0131] One advantage of the temperature regulation method shown in FIG. 20 is a faster charging time to the intended regulation temperature of a pellet. This can be achieved since the heating element has a higher ultimate charging temperature, corresponding to I_{shelf} , than the regulation temperature, corresponding to the value of I_{rc} that satisfies the equation $[\{I_{rc}/I_{shelf}\}-1]\cdot 100\pi=f$. If the value chosen for parameter f is relatively larger, the regulation temperature moves closer to the Curie temperature; correspondingly, as the value of f is made relatively smaller, the regulation temperature moves closer to the shelf temperature.

[0132] Thus, slight modifications to the preferred regulation temperature of this invention as described in FIGS. 19A and 19B can achieve different shelf temperatures for the same heating element. It will thus be appreciated that a variety of analogous algorithms may be used for such modification.

[0133] The operation of the invention will be described with reference to the pizza bag 76 of FIG. 2 and the charging

station 32. However, it will be appreciated that this explanation is equally applicable to the other heating elements and containers previously described. In the first step, the switch 48 of a station 32 is turned ON and the user places the bag 76 containing the pellet 86 on the holder/locator 36 of the charging station 32. Such placement is initially sensed by the locating photo sensors 56,58 which sends an initiation signal to the microprocessor of the cooktop, allows heating to commence. The microprocessor then initiates the sequence of steps set forth in FIGS. 19A and 19B (assuming that the user desires to regulate the temperature about the shelf temperature of the element 86). In logic loop # 1, the presence of the pellet 86 on the charging station is confirmed. The microprocessor then proceeds to logic loop #2 where a magnetic field is generated in step 212 and the charging light 54 is turned on. This serves to initiate heating of the heating element 90 which continues until the regulation (shelf) temperature is achieved (step 236). The microprocessor then proceeds to logic loop #3 which serves to maintain the temperature of the pellet 86 near the shelf temperature and turns off charging light 54 and illuminates ready light 52. This of course notifies the user that pellet 86 within pizza bag 76 is fully charged and ready for use.

[0134] One or more pizzas are placed within the bag 76 as shown in FIG. 2, and the flap 78 is closed. The closed bag 76 is then removed from the charging station 32 and the pizza is delivered to the customer. During transit, the pellet 86 serves to substantially maintain the bag contents at the desired temperature. The pellet 86 and its heat retentive material 92 is capable of maintaining temperature over relatively long periods of time. For example, as illustrated in FIG. 24, two commercially available boxed pizzas at 190 F. were placed within a bag 76 having a fully charged pellet 86 (FIG. 3) therein. Over a period of 40 minutes, the bottom pizza decreased in temperature to about 160 F., whereas the top pizza decreased to a temperature of about 153 F. This is very effective temperature maintenance, particularly when it is considered that many delivery times are substantially less than 40 minutes.

[0135] As explained above, if a user desires to regulate the pellet at a temperature below the shelf temperature of the ferromagnetic heating element, this can readily be accomplished. One way of doing this is shown in FIG. 20, explained previously. In practice, regulation can be achieved at virtually any temperature between the Curie and shelf temperatures of the heating element.

[0136] The preferred indicator box 46 associated with each station 32 has a user-operated temperature input feature allowing a user to select any one of a number of regulation temperatures within the regulatable range of the heating element. The cooktop microprocessor also has in a look up table memory different values for the 9 initial program values described above (I_1 , I_{10} , Δt_1 , Δt_2 , S_n , RT , f , I_2 and Δt_{PING}) which correspond to each user selectable regulation temperature. If the range between the Curie and shelf temperatures of the associated heating element 90 is 230 F.-290 F., the user may select a regulation temperature of 250 F. The microprocessor then retrieves from memory the 9 initial program values corresponding to a 250 F. regulation temperature and uses these values in the temperature control sequence.

[0137] Where the bag 76 has an RFID tag and the station 32 includes an appropriate RFID reader, additional benefits

can be obtained. For example, this would permit use of different sizes or configurations of bags 76 on a given charging station 32. If a small bag were placed on the charging station, the RFID reader, sensing the small bag RFID tag code, would initiate a temperature control sequence appropriate for the small bag. Similarly, if a larger bag were placed on the charging station, the RFID reader would sense a different RFID tag and begin a temperature control sequence better suited to the larger bag. Of course, the microprocessor would have in look up table memory the 9 initial program values corresponding to each of these sequences.

[0138] Furthermore, use of RFID technology would allow a business owner to determine the number of delivery trips for each bag 76 and the duration of each such trip. The RFID tags associated with each bag could include timer and count circuitry which would be read by the reader on a continuing basis. This would give the owner detailed information about delivery performance not otherwise readily obtainable.

What is claimed is:

1. A heating assembly comprising:

a magnetic induction heater including a heater circuit having a magnetic field generator, a detector operable to detect a heater circuit parameter related to the impedance presented to the heater by an induction heatable device, and control circuitry capable of altering the magnitude of said magnetic field generated by said generator in response to said detection of said parameter; and

an induction heatable device including a continuous coil formed of electrically conductive material with a pair of terminal coil ends, and a conductive assembly operably connected between said terminal coil ends to complete a circuit, said conductive assembly comprising a selectively operable switch component switchable between a circuit-make configuration and a circuit-break configuration,

said coil experiencing a magnetically induced flow of current therethrough when said generator is operating, said switch is in the circuit-make configuration thereof, and said device is placed adjacent said heater to present a circuit-make impedance to the heater,

said coil experiencing a circuit-break impedance different than said circuit-make impedance when said switch is in said circuit-break configuration,

said device and heater cooperable so that, when said switch moves between the circuit-make and circuit-break configurations thereof, said detector detects a change in said parameter, and said control circuit operates to alter the magnitude of said magnetic field.

2. The heating assembly of claim 1, said parameter being the magnitude of current passing through said heater circuit, or the rate of change of said magnitude.

3. The heating assembly of claim 1, said conductive assembly including an electrically conductive wire element connected to each of said terminal coil ends, with said switch component connected between the ends of said wire elements remote from said terminal coil ends.

4. The heating assembly of claim 1, said switch component comprising an electronic switch.

5. The heating assembly of claim 1, said control circuitry operable to terminate the operation of said magnetic field generator.

6. The assembly of claim 5, said electronic switch being programmable.

7. The assembly of claim 1, said control circuitry operable to alternately terminate or maintain the operation of said magnetic field generator.

8. The assembly of claim 1, said coil formed at least in part of a ferromagnetic material.

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