Aug. 8, 1961 W. H. BUSSEY 2,995,642

INDUCTION HEATING APPARATUS

Filed June 4, 1959 2 Sheets-Sheet 1

Fig. 1

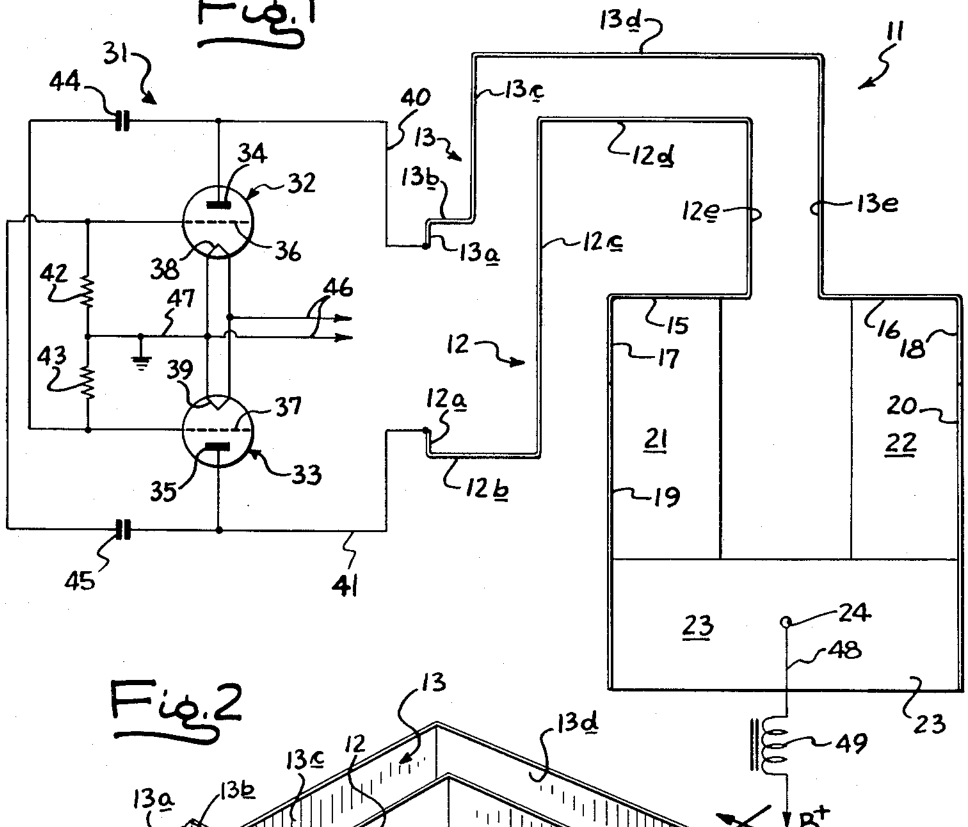
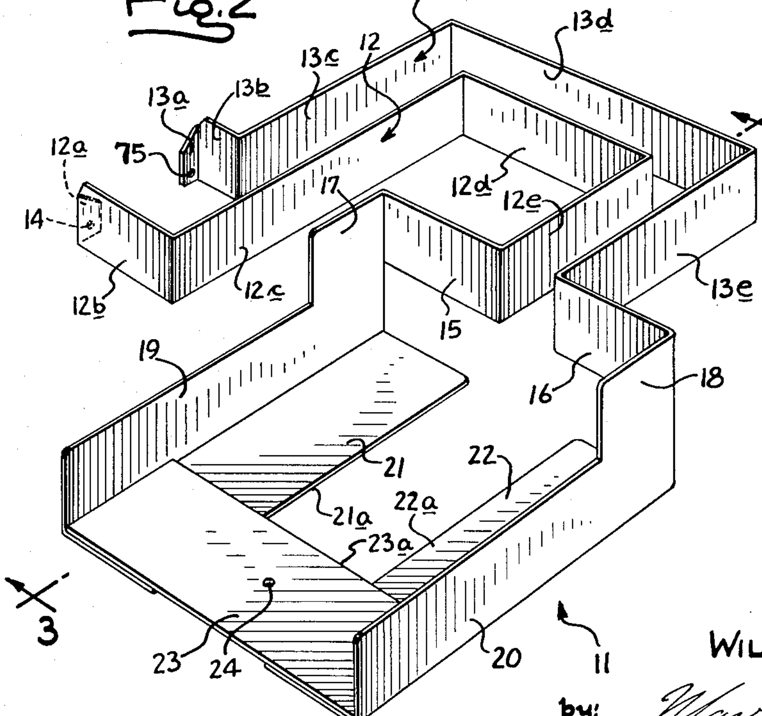


Fig. 2



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INDUCTION HEATING APPARATUS

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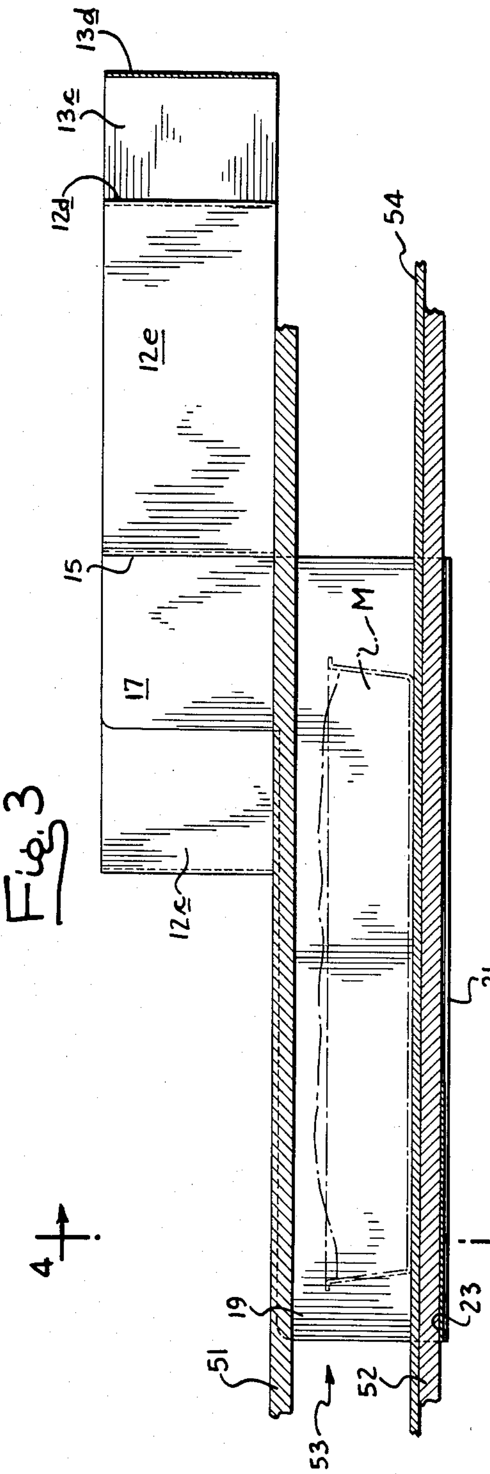

Fig. 3

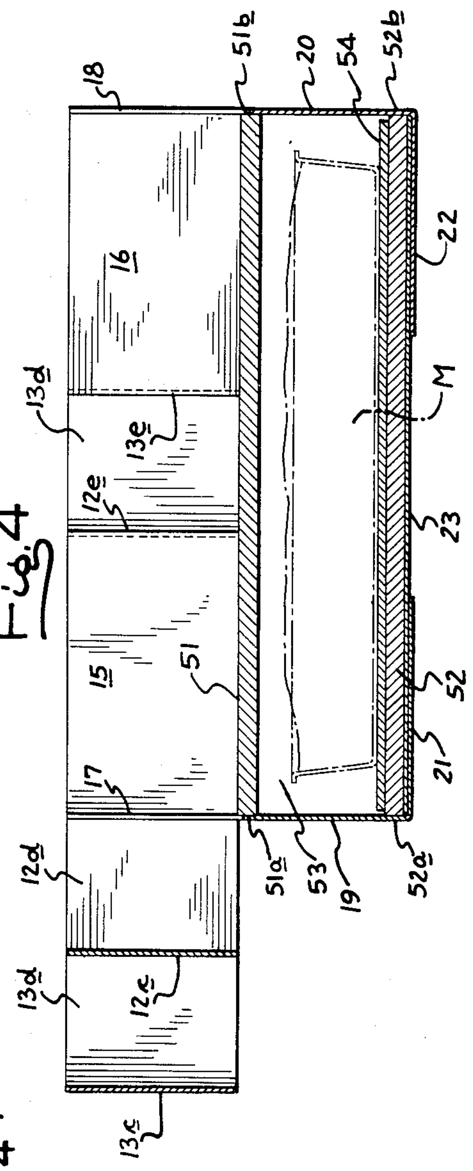

Fig. 4

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United States Patent Office

2,995,642

Patented Aug. 8, 1961

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2,995,642

INDUCTION HEATING APPARATUS

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Filed June 4, 1959, Ser. No. 818,122
5 Claims. (Cl. 219—10.69)

This invention relates to an induction heating apparatus and, more particularly, to a novel electronic heating coil in the form of a compact folded quarter-wave transmission line having a lumped inductance load termination for generating the magnetic flux.

Electronic heating by induction is well known in the prior art. A coil is supplied with high frequency alternating current by means of a conventional oscillator circuit. The alternating current flowing through the coil generates an alternating magnetic field in which the object to be heated is placed. The alternating magnetic field induces alternating currents in the object which, of course, must be somewhat conductive, and the induced currents flowing in the object produce the desired heating effect.

Such heating coils, as heretofore employed in the prior art, were usually of spiral or rectangular configuration and were connected directly to the oscillator circuit so as to constitute a conventional inductive load for the latter. This prior art arrangement, while satisfactory for some applications where the heating time and the initial cost of the apparatus were not of vital importance, is nevertheless inadequate for other applications where such factors are vital. For example, in automatic vending machines which dispense hot sandwiches, meals, and other foods, it is necessary that the merchandise be heated from the refrigerated temperature (at which it is stored to prevent spoilage) to the desired temperature within a very short time. Furthermore, the heating apparatus for an automatic vending machine cannot be too complex or expensive in order that the cost of the machine may not be prohibitive. For an oscillator circuit of a given power output, the rapidity with which an object can be inductively heated is dependent upon the efficiency with which the coil converts the oscillator power output into current-inducing magnetic flux. Heretofore, the available inexpensively constructed inductive heating arrangements were not efficiency enough to satisfy the requirements as to heating time, while those which did heat rapidly were prohibitively expensive.

The present invention solves these problems by a novel heating arrangement in the compact form of a folded quarter-wave transmission line having substantially uniformly distributed parameters therealong and a load termination in the form of a single conductive loop for generating the magnetic field in response to the current flow therethrough. Because the equivalent electrical length of the line is a quarter of the wave length of the alternating current supplied thereto by the oscillator circuit, the current will be a maximum at the termination of the line, whereby the magnetic field will also be a maximum to provide the ultimate induced current in the food or other product for a given power rating of the oscillator.

By the use of a heating arrangement comprising a compact folded transmission line, the present invention provides a higher "Q" than the prior art devices; that is, for a given oscillator circuit, less of the energy generated thereby is dissipated as a power loss.

Another novel feature of the present invention resides in the particular construction of the loop or single-turn coil constituting the load termination of the transmission line, whereby an optimum number of ampere-turns are so located with respect to the food or other product as to provide a field producing the maximum induced current in the food for any given oscillator output. This load termination loop comprises thin wide planar conductive elements formed of sheet copper and lying in a horizontal plane parallel to and closely adjacent the plane of the food or other product to be heated. The resultant upwardly extending electromagnetic field diverges outwardly as it rises through the food so that the diffused part of the field goes through the periphery of the food or other product and is not wasted.

The conductive elements are preferably provided with vertical flanges which dissipate heat by radiation and conduction. This, together with the heat dissipation provided by the large surface to volume ratio of the sheet-like conductive elements, eliminates the necessity of forced air cooling. The vertical flanges also serve the additional important functions of preventing the electromagnetic field from leaking horizontally below the plane of the food or other product and for rigidifying the coil structure.

Another novel feature of the present invention is the arrangement whereby the entire transmission line including the load termination constituting the flux generating loop or coil may be economically formed of one or a few integral metal sheet strips.

Other advantages and novel features of the present invention are inherent in the structure described and claimed below or will become apparent to those skilled in the art from the following detailed description in connection with the accompanying drawings wherein:

FIG. 1 is a schematic view showing a conventional push-pull oscillator circuit connected to the novel transmission line arrangement constituting the present invention;

FIG. 2 is a perspective view showing the transmission line with the flux generating single-loop coil constituting the load termination thereof;

FIG. 3 is a longitudinal sectional view taken substantially on line 3—3 in FIG. 2 and showing the single-loop coil in combination with insulating sheets and a conveyor belt for carrying a packaged meal through the field of the coil so as to illustrate how the invention may be employed in an automatic vending machine for vending hot packaged meals; and

FIG. 4 is a vertical transverse sectional view taken substantially on line 4—4 of FIG. 3.

Referring first to FIG. 2, reference numeral **11** indicates generally a quarter wave transmission line having a flux generating single-loop coil as the load termination thereof. Line **11** comprises a pair of longitudinal mutually-parallel planar conductive portions **12, 13** which lie in vertical planes and extend in a folded configuration in a horizontal plane. The line portions **12, 13** comprise input terminal portions **12*a*, 13*a*** having apertures at **14, 75**, respectively, for electrical connection to the plates of a push-pull oscillator circuit as will be described in more detail below. Terminal portions **12*a*, 13*a*** are formed integral with and extend perpendicular to line portions **12*b*, 13*b***, respectively, which are mutually spaced and parallel to each other. Line portions **12*c*, 13*c*** extend perpendicular to portions **12*b*, 13*b***, respectively, and lead to parallel line portions **12*d*, 13*d*** which extend perpendicular to portions **12*c*, 13*c***. Portions **12*d*, 13*d*** in turn lead to parallel line portions **12*e*, 13*e*** extending perpendicular thereto.

Formed integral with line portions **12*e*, 13*e*** are a pair of oppositely extending connecting portions **15, 16** each in turn formed integral with an edge of a respective upwardly extending portion **17, 18** of vertical flange portions **19, 20**. The latter extend along and are formed integral with the outer longitudinal edges of a pair of parallel longitudinal mutually-spaced planar conductive elements **21, 22** which lie in a common horizontal plane. A transverse planar conductive element **23** has its opposite ends secured to the respective ends of elements **21, 22** as by soldering. The transverse element **23** is provided with an aperture **24** for connection to the B+ plate supply voltage.

The entire transmission line **11** is preferably stamped or otherwise formed of sheet copper, and is silver plated in order to prevent the formation of copper oxide which would increase the resistivity of the line and thereby lower the "Q." Portions **12, 15, 17, 19** and **21** may be formed of a single integral sheet, as may also portions **13, 16, 18, 20** and **22**. If desired, the transverse portion **23** may be integral with the portions **21** and/or **22** so that the entire line **11** may be stamped or cut from a single integral sheet.

Referring now to FIG. 1, there is shown schematically a push-pull oscillator circuit indicated generally by the reference numeral **31** and comprising a pair of triode vacuum tubes **32, 33** having plates **34, 35**, grids **36, 37**, and directly heated cathodes **38, 39** respectively.

A lead **40** secured within aperture **75** connects plate **34** with portion **13** of the transmission line **11**, and a lead **41** similarly connects the other plate **35** with line portion **12**. Grids **36, 37** are respectively connected to grid leak resistors **42, 43** which have their other ends connected to ground. A capacitor **44** is connected between the plate **34** of one tube **32** and the grid **37** of the other tube **33**. In a similar manner, another capacitor **45** is connected between the plate **35** of the second tube **33** and the grid **36** of the first tube **32**.

The leads **46** extend from the cathodes **38, 39** to a conventional heater supply (not shown) for heating the cathodes **38, 39**. One side of the cathode heater supply may be grounded by the lead **47**. A lead **48** has one end secured within aperture **24** of transverse portion **23** and its opposite end is connected to a choke **49** which is in turn connected to the B+ plate supply voltage.

Referring now to FIGS. 3 and 4, the reference numerals **51, 52** indicate a pair of horizontal planar insulating sheets formed of boro-silicate glass and powdered mica such as manufactured by the General Electric Company under the trademark "Mycalex," or by Mykroy, Inc. under the trademark "Mykroy." Sheet members **51, 52** have respective longitudinal edges **51*a*, 52*a*** in abutment with or closely adjacent to vertical flange **19**, and their opposite longitudinal edges **51*b*, 52*b*** are similarlry disposed with respect to the other flange **20**. The lower sheet member **52** rests upon conductive elements **21, 22, 23**. The upper sheet member **51** is arranged a predetermined height above the lower sheet member **52** so as to form therebetween a channel or passageway **53** through which may pass the product to be heated by the apparatus, which may be, for example, a frozen packaged meal shown in dash-dot lines and indicated by the reference letter "M" and of a type suitable for dispensing by an automatic vending machine.

The meal package "M" may be in the form of a conventional container of plastic, paper or other non-conductive material and is refrigerated while in storage in the vending machine. However, it is to be understood that other types of products may be heated by the subject invention which is not limited in its application to food heating or to the vending machine field. In order to carry the meal package "M" through the channel **53**, there is provided a continuous conveyor belt **54** formed of cloth or polyethylene and which has a run portion riding along the upper surface of the lower sheet member **52**. Continuous belt **54** is entrained in the usual manner around a pair of pulleys (not shown) and travels in a direction from left to right as viewed in FIG. 3.

The oscillator circuit **31** generates a high-frequency alternating voltage, preferably in the range of about 20 to 55 megacycles, which is imposed across the input terminals **12*a*, 13*a*** of transmission line **11**. As previously noted the transmission line comprises line portions **12, 13** and a load termination or "end" of the line consisting of elements **21, 22, 23** and flange portions **19, 20**. This load termination is in effect an enlarged rectangular loop and may be considered as a one-turn coil. The line portions **12, 13** are so constructed and oriented as to have substantially uniformly distributed parameters of inductance, capacitance and resistance, insofar as may be practically attaintable in view of the folded construction, except at the input end where there is a lumped capacitance due to the effective anode capacitance of tubes **32, 33** and except at the load termination "end" of the line where the enlarged rectangular loop constitutes a lumped inductance.

The line **11** has an equivalent electrical length equal to one-quarter of the wave length of the oscillator frequency. As a result, the current at the electrical end of the line will be at a maximum for any given power rating of the oscillator circuit **31**. That is, the alternating current flowing through the rectangular loop formed by elements **19, 20, 21, 22, 23** will be at a maximum and hence the magnetic flux generated by the loop will also be at a maximum. At the same time, the alternating voltage in the loop will be at a minimum.

The transmission line arrangement of the present invention is superior to the conventional electronic heating coil in several respects. The line has a characteristically higher "Q" at the relatively high frequencies employed in electronic heating, and, as a result, less of the oscillator energy will be dissipated as a power loss. In addition, the construction of the rectangular loop forming the end of the line provides a maximum coupling of the generated flux to the food or other product to be heated. That is, a maximum number of ampere-turns are so located as to provide a field producing a maximum induced current in the food for a given oscillator output. Furthermore, the sheet metal construction of the line portions and rectangular loop provides for rapid heat dissipation by radiation and conduction due to the relatively large surface-volume ratio, and eliminates the necessity for expensive forced air cooling. The sheet metal construction is further advantageous in that it is economical to fabricate.

The field generated by the alternating current flowing through the rectangular loop extends vertically upward through the rectangular space formed by the inner edges **21*a*, 22*a*, 23*a*** of the respective horizontal conductive elements **21, 22, 23**. As the field extends upwardly, it also diverges outwardly whereby the diffused part or fringe of the field goes through the periphery of the food and is not wasted.

The vertical flanges **19, 20** prevent the field from leaking in a horizontal path below the food. That is, flanges **19, 20** tend to direct the field upwardly through the food so as to reduce the leakage flux. Flanges **19, 20** further function to dissipate heat by radiation and conduction and also increase the rigidity of the rectangular loop.

It is to be understood that the specific embodiment shown in the drawing and described above is merely illustrative of one of the many forms which the invention may take in practice and that many changes therein may be devised by those skilled in the art without departing from the scope of the invention as delineated in the appended claims which are to be construed as broadly as permitted by the prior art.

I claim:

1. An induction heating apparatus comprising an oscillator circuit, a transmission line having input terminals connected to said oscillator circuit and having a load termination comprising an induction coil for generating a magnetic field, and means for locating the object to be heated in the field of said coil, said coil comprising a plurality of relatively thin wide planar conductive elements connected to each other in end-to-end relation and lying substantially in a single plane, the flux lines of said coil field extending perpendicularly through said

plane, a pair of said conductive elements extending longitudinally parallel to each other and each having a vertical flange formed integral therewith along a respective outermost longitudinal edge thereof, said vertical flanges extending parallel to each other and forming a horizontal channel therebetween, said locating means comprising a conveyor belt having a portion extending horizontally through said channel and through said coil field.

2. An induction heating apparatus comprising an oscillator circuit, a transmission line having input terminals connected to said oscillator circuit and having a load termination comprising an induction coil for generating a magnetic field, and means for locating the object to be heated in the field of said coil, said coil comprising a pair of parallel longitudinal mutually spaced conductive elements lying in a horizontal plane, a third longitudinal planar conductive element lying substantially in said horizontal plane and extending transversely of said first recited pair of conductive elements, said third element having each of its ends in electrical contact with an end of a respective one of said first pair of elements, each of said first pair of elements having a vertical flange portion formed integral therewith along the longitudinal edge thereof farthest removed from the other of said pair of elements, said locating means comprising a conveyor belt having a run portion thereof extending longitudinally of said conductive elements between said flange portions thereof and in a second horizontal plane spaced parallel to and closely adjacent said first recited plane.

3. An induction heating apparatus comprising an oscillator circuit, a transmission line having input terminals connected to said oscillator circuit and having a load termination comprising an induction coil for generating a magnetic field, and means for locating the object to be heated in the field of said coil, said coil comprising a pair of parallel longitudinal mutually-spaced planar conductive elements lying in a horizontal plane, a third longitudinal planar conductive element lying substantially in said horizontal plane and extending transversely of said pair of conductive elements, said third conductive element having each of its ends in electrical contact with a first end of a respective one of said pair of elements, each of said pair of elements having a vertical flange portion formed integral therewith along its longitudinal edge farthest removed from the other element of said pair, each of said flange portions having a vertical extension thereof located adjacent the other end of its respective conductive element, said transmission line having vertical planar connecting portions in electrical contact with and extending transversely of said flange portions, said connecting portions having horizontal lower edges, said locating means comprising a conveyor belt extending longitudinally of said conductive elements between said flange portions thereof and in a second horizontal plane immediately above said first recited plane and spaced a predetermined distance below said horizontal edges of said connecting portions so as to permit the conveyed objects to pass below the latter.

4. An induction heating apparatus as recited in claim 3 wherein said line comprises a pair of longitudinal mutually-parallel portions lying vertically and extending in a folded configuration lying in a horizontal plane, each of said line portions being in electrical contact with a respective one of said connecting portions.

5. An induction heating apparatus as recited in claim 4 wherein each of said line portions together with its respective connecting portion, flange portion and conductive element constitutes an integral unitary sheet of conductive material.

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