INDUCTION HEATING APPARATUS FOR MINIMIZING VIBRATION AND NOISE

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FOREIGN PATENTS OR APPLICATIONS

1,157,711 7/1969 United Kingdom............. 219/10.49

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ABSTRACT

In an induction heating apparatus for induction heating a heated element by forming an alternating magnetic field, n groups (n ≥ 2) of magnetic circuits comprising said heated element are formed. The magnetic circuits are progressively excited by an excitation current having a phase difference in the range of

\[
\frac{180}{n} \times 0.8 \text{ to } \frac{180}{n} \times 1.2 \text{ degrees,}
\]

so that alternating components of the electromagnetic force applied to the heated element are decreased or removed and whereby the vibration and noise of the heated element is concomitantly decreased. The present invention finds particular use with respect to an induction heating cooking apparatus run by standard line frequency current.

18 Claims, 40 Drawing Figures
FIG. 15

STATIC ELECTROMAGNETIC FORCE $F$ (MN)

THICKNESS OF PLATE (mm)
FIG. 16

CALORIFIC VALUE

THICKNESS OF PLATE (mm)
INDUCTION HEATING APPARATUS FOR MINIMIZING VIBRATION AND NOISE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an induction heating apparatus, and more particularly, to the magnetic and excitation current circuit structures of an induction heating apparatus excited by a current of the standard line frequency.

2. Description of the Prior Art

An induction heating apparatus of the prior art heats a heated element by feeding an excitation current of the standard line frequency or the like to an exciter which forms an alternating magnetic field. The heated element receives a high alternating electromagnetic force of twice the excitation current frequency, whereby the heated element will be severely vibrated and excessive noise will be caused. The noise is quite severe, so much so that the practical application of such apparatus has been rather unsuccessful.

SUMMARY OF THE INVENTION

It is therefore a primary object of the present invention to provide an induction heating apparatus wherein vibration of the heated element and the noise generated thereby are minimized.

Another object of the present invention is to provide an induction heating apparatus for heating a heated element, such as a cooking pot, wherein the electromagnetic force vibrating in the vertical direction is reduced to substantially zero, especially with respect to an induction heating apparatus excited by a current of the standard line frequency, whereby the vibration of the heated element and the noise caused by such vibration are minimized.

The foregoing and other objects are attained in accordance with one aspect of the present invention through the provision of an induction heating apparatus having an exciter for induction heating a heated element by forming an alternating magnetic field under the excitation of the commercial or standard line frequency, wherein n groups (n ≥ 2) of substantially equivalent magnetic circuits which comprises the exciter and the heated element are formed. The magnetic circuits are excited progressively by an excitation current having a phase difference in the range between

\[
\frac{180}{n} \times 0.8 \quad \text{to} \quad \frac{180}{n} \times 1.2 \quad \text{degrees},
\]

whereby the alternating component of the electromagnetic force applied to the heated element is decreased or removed and the vibration and noise of the heated element will therefore be minimized.

In another embodiment of the induction heating apparatus according to this invention, the n groups of magnetic circuits are divided and each magnetic circuit is excited to form an opposing direction of magnetic field whereby the resultant rotating field will be decreased or removed as a whole so as to decrease or remove the rotating force applied to the heated element.

In an embodiment having two groups of magnetic circuits according to this invention, to provide an effective manner of excitation, the distance between the heated element and the exciter and the material of the heated element are controlled so as to excite one mag-
FIG. 33 is a perspective view of one embodiment of an iron core used for the exciter; FIGS. 34, 35 and 36 are perspective views of relay iron, magnetic pole and magnetic pole piece of the iron core used in this invention; and FIGS. 37 to 40 are perspective views of other embodiments of the iron core.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The induction heating apparatus of the present invention will be illustrated with respect to cooking apparatus since the invention is quite effective when applied to a cooking apparatus, although it is understood that other uses are possible.

Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to FIGS. 1 to 9 thereof, one embodiment of the induction heating cooking apparatus according to this invention is illustrated, wherein a metallic heated element (cooking pot) typically comprises an iron cooking pot having a copper or aluminum plate bonded at the bottom. The cooking pot can be an iron cooking pot or copper cooking pot, however it is preferable to use a cooking pot having a plied plate when it is excited by the standard line low frequency current, because of high heat efficiency and low vibration and noise.

The body of the apparatus (range table) has a cover plate covering the outer box. An exciter and a phase shift condenser Cn, seen in FIG. 4, are placed in the body. A control switch, a plug and a line are also provided. The cover plate supports the cooking pot thereon and protects exciter while maintaining a good appearance of the cooking apparatus. A stainless steel plate or a reinforced glass plate, for example, having a high mechanical and thermal strength can be used as the cover plate. As seen in FIG. 4, the exciter comprises an iron core 50 of a yoke 60, four magnetic poles 71 and 73 passing through the magnetic poles 71 and 73 and the cooking pot 10 form the magnetic circuit A. The yoke 60, a pair of the magnetic poles 72 and 74 and the cooking pot 10 form the other magnetic circuit B. The foregoing two magnetic circuits A and B are obviously equivalent to a single magnetic circuit having the same magnetic structure and the same resistance.

FIG. 8 illustrates in a sectional view the conditions of the magnetic flux passing through the magnetic circuits A and B. The alternating magnetic flux of one of the magnetic circuit A or B forms the magnetic circuit A or B passing from the magnetic pole 71 and 72 through the copper plate 12 of the bottom of the cooking pot, and the iron cooking pot 11, and the copper plate 12 to the other magnetic pole 73 or 74, as shown by the dotted line. An eddy current is induced on the bottom of the cooking pot (mainly on the copper plate 12) by the alternating magnetic flux of one of the magnetic circuit A or B, so that heating results by a Joule loss depending upon the resistance of the copper plate.

FIG. 9 illustrates the condition of the eddy current J formed on the bottom of the cooking pot by the alternating magnetic flux and/or magnetic field. The electromagnetic force between the exciter 40 and the cooking pot 10 will now be considered with respect to excitation by one magnetic circuit without the other magnetic circuit B. The electromagnetic force is composed of two components. One component is a force on the boundary surface of the magnetic part of the cooking pot, and is a force attracting the cooking pot 10 to the iron core 50. The other component is the Lorenz force between the eddy current J passing on the bottom of the cooking pot and the exciting current passing through the excitation windings 81-84. The eddy current has a phase difference of about 180° from that of the exciting current. Accordingly, the Lorenz force will be a force lifting up the cooking pot 10 (a repulsive force).

FIGS. 10 to 14 illustrate various conditions of the electromagnetic force applied to the cooking pot 10. In each FIG., the horizontal axis represents time (in the same scale) and the vertical axis represents current, the magnetic flux, or the electromagnetic force.

In FIG. 10, J represents an attracting current. In FIG. 11, Fc represents a magnetic flux and F represents an attractive force.

In FIG. 12, J represents an eddy current and F represents a repulsive force. The attractive force Fc is proportional to the square of the magnetic flux F and is changed in time at a frequency of twice the exciting current frequency. The repulsive force F is proportional to the product of the exciting current I and the eddy current J, and is changed in time at a frequency of twice the exciting current frequency, the same as that of the attractive force Fc. The total electromagnetic force Fc applied to the cooking pot 10 is a combination of the attractive force Fc and the repulsive force F. The frequency change of the electromagnetic force Fc is in a form which superimposes the static force with the alternating electromagnetic force and has a frequency of twice the current frequency.

Due to the aforementioned alternating electromagnetic force, the cooking pot 10 will be vibrated vertically and the noise originated thereby causes a disadvantageous phenomenon in a cooking apparatus. According to experiments, the vibration acceleration produced thereby is higher than 1 G and the noise is higher
than 70 horn and accordingly, such an arrangement could not be practically utilized. However, in accordance with this invention, the alternating electromagnetic force is theoretically zero, and only a constant static electromagnetic force is applied to the cooking pot so that no vibration or no noise will be cause. In practical application, an induction heating cooking apparatus having negligible vibration and noise can be obtained.

The solution to the problem will be now illustrated with reference again to the embodiments of FIGS. 1-9, wherein the exciting current $I_1$ is directly fed from the power source to the excitation windings 81 and 83 of one excitation circuit 80A by turning on the switch 22. The exciting current $I_1$ can be represented as

$$I_1 = I_m \sin \omega t.$$

The electric current $I_2 = I_m \sin (wt + \pi/2)$, whose phase is shifted 90° in advance by condenser $C_p$, is supplied to the excitation windings 82 and 84 of the other excitation circuit 80B. Since the exciting current of the excitation circuits 80A and 80B have a phase difference of about 90°, the magnetic fluxes $\Phi_a$ and $\Phi_b$ have a phase difference of about 90° between each other.

FIG. 14 illustrates the electromagnetic force in the foregoing case. The alternating electromagnetic force applied to the cooking pot 10 by the alternating magnetic flux has a frequency of twice the magnetic flux frequency. Accordingly, a phase difference of about 180° exists between the electromagnetic forces $F_a$ and $F_b$ applied to the cooking pot 10 by the excitation circuits 80A and 80B. Since the magnetic resistances of the magnetic circuits A and B are the same, the absolute values of the magnetic fluxes $\Phi_a$ and $\Phi_b$ are the same.

Accordingly, the absolute values of the electromagnetic force $F_a$ and $F_b$ will be the same.

The total force applied to the cooking pot 10 will now be considered. The alternating electromagnetic force based on the two excitation circuits 80A and 80B are cancelled, so that only the static force $F$ (which is not changed in time) remains, as shown in FIG. 14. In accordance with the above phenomenon, the electromagnetic force for vertically vibrating the cooking pot will theoretically be zero in the induction heating cooking apparatus according to this invention. Accordingly, the vibration of the cooking pot and the noise due to the vibration will be remarkably decreased. According to our experiments, the vibration acceleration will be less than 0.1 G and the noise is less than 40 horn if the techniques of the present invention are utilized.

FIG. 15 illustrates the static electromagnetic force $F$ of a practical induction heating apparatus equipped with an iron cooking pot (permeability $\mu_r = 5,000$), a copper cooking pot and a copper-iron plated plate cooking pot. In FIG. 15, the vertical axis represents the static electromagnetic force $F$ per AT (ampere turn) of the exciting current; the curves a, b, and c respectively represent the cases of the iron cooking pot, the copper cooking pot and the copper-iron plated plate cooking pot; and the horizontal axis represents the total thickness of the bottom of the iron cooking pot, the copper cooking pot or the thickness of the copper plate of the copper iron plated plate cooking pot, in the respective cases. The thickness of the iron plate of the copper-iron plated plate is 2 mm; however, the electromagnetic force will not be affected when the thickness of the iron plate is higher than about 1 mm.

From FIG. 15, the following facts can be observed:

1. The electromagnetic force applied to the iron cooking pot is a relatively high attractive force;
2. the electromagnetic force applied to the copper cooking pot is a repulsive force which is smaller than about one order when compared to that of the iron cooking pot; and
3. in the copper-iron plated plate cooking pot, the attractive force rapidly decreases depending upon the increase in the thickness of the copper plate, so that the electromagnetic force approaches zero, and a repulsive force will result by increasing the thickness further.

With respect to curve c (the copper-iron plated plate cooking pot), in the range of the thickness of the copper plate $d$ wherein

$$0 < d < 1.5,$$

the electromagnetic force will be an attractive force, which is lower than the attractive force of the iron cooking pot (curve a). In the range

$$1.3 < d < 1.5,$$

the electromagnetic force is lower than the gravitational force applied to the cooking pot. In the range

$$1.5 < d < 1.7,$$

the electromagnetic force will be a low repulsive force, which is of a lower magnitude than gravity, so that the cooking pot will remain on the plate.

Accordingly, with respect to the electromagnetic force, the static electromagnetic force $F$ is seen to be advantageously small in the range of the thickness of the copper plate $d$ wherein

$$0 < d < 1.7.$$

especially wherein

$$1.3 < d < 1.7.$$

The average electromagnetic force rapidly decreases in proportion to the thickness of the copper plate, because the attractive force applied to the iron part is rapidly decreased while the repulsive force mainly applied to the copper part is slowly increased. The vibration and noise caused by the static electromagnetic force $F$ is theoretically zero. However, in practice it is quite difficult to form two accurately equivalent magnetic circuits A and B. Accordingly, a small alternating current component generally remains. In such a case, when the static electromagnetic force is small, the alternating current component is small so that the vibration and noise will be decreased.

FIG. 16 illustrates the calorific value per AT (ampere turn) of the exciting current when the iron cooking pot, the copper cooking pot, or the copper-iron cooking pot is used. In FIG. 16, the horizontal axis is the same as that of FIG. 15, and the curves a, b and c are respectively for the iron cooking pot, the copper cooking pot and the copper-iron cooking pot. From the results of FIG. 16, it is clearly understood that the use of the copper-iron cooking pot is quite effective, because of the increase in the calorific value over the other two cases.

FIGS. 15 and 16 show characteristic data of specific structures, and similar characteristic data can be obtained when other practical structures are employed.
For example, when an aluminum plate is used instead of the copper plate of the copper-iron cooking pot, the electromagnetic force will be decreased. The electromagnetic force applied to the cooking pot becomes smaller than the gravitational force on the cooking pot in the range of aluminum plate thickness of 2.1–2.7 mm; the electromagnetic force is zero at a plate thickness of 2.4 mm. Similar phenomenon occurs when other conductive materials are used, and can be applied, for example, for a cooking pot prepared by bonding a ferromagnetic plate to non-magnetic plate having a higher conductive coefficient than that of the ferromagnetic plate.

The attractive force and the repulsive force applied to the cooking pot have been illustrated above. However, in such embodiments, the magnetic field formed by the exciter causes a rotating field so that a rotating force will be applied to the cooking pot. However, rotation of the cooking pot can be prevented by the following methods.

One of such methods is to retain a suitable attractive force without decreasing the static magnetic force F applied to the cooking pot, whereby the rotation of the cooking pot will be prevented by the remaining attractive force. Moreover, the cooking pot will not slip when the range table becomes inclined.

Another method is to prevent the rotation of the cooking pot by means of a mechanical structure. For example, as shown in the embodiments in FIGS. 17 to 19, three projections 13 are formed at the bottom of the cooking pot and corresponding three concave receptacles 31 are formed on the cover plate 30 of the range table 20 in a fitting relationship to each other. The rotation of the cooking pot can be prevented in such a manner so that the static electromagnetic force F will be zero and the vibration and noise will be quite small.

FIG. 20 is a schematic view of another embodiment of the exciter according to this invention, wherein the exciter comprises six magnetic poles 71–76 of the iron core 50. The windings 81–86 are respectively wound on each of the six magnetic poles 71–76. In the embodiment, the magnetic circuits formed by the iron core 50 and the cooking pot 10 are divided into three equivalent magnetic circuits A, B, and C. As shown in FIG. 21, each pair of windings 81 and 84, 82 and 85, and 83 and 86 are respectively connected to form each of the excitation circuits 80A, 80B, and 80C. Alternating currents having a phase difference of 60°, such as I_m sin wt, I_m sin (wt + \(\frac{\pi}{3}\) t), and I_m sin (wt + \(\frac{2\pi}{3}\) t), are respectively supplied to the corresponding excitation circuits to excite them. In the aforementioned induction heating cooking apparatus, the alternating electromagnetic force applied to the cooking pot will be approximately zero. This follows from a reconsideration of FIG. 13 which shows the change in time of the electromagnetic force applied to the cooking pot 10 by the three magnetic circuits A, B, and C. The electromagnetic force of the three magnetic circuits each have a phase shift of 120°. When they are combined, the alternating electromagnetic forces are cancelled so as to be zero, and only the static electromagnetic force remains.

FIG. 22 is a schematic view of another embodiment of the exciter having eight magnetic poles. Eight excitation windings 81–88 wound respectively on the eight magnetic poles 71–78 are divided into two groups 81, 83, 85 and 87; and 82, 84, 86 and 88 so as to form two excitation circuits 80A and 80B as shown in FIG. 23. Alternating currents having a phase shift of about 90°, such as I_m sin wt and I_m cos wt, are respectively supplied to the excitation circuits 80A and 80B. The relative directions of the magnetic flux are shown as \(\Phi A\) and \(\Phi B\) in FIG. 22. It is clear from the description above that the same effect occurs in the present embodiment as in the embodiment of FIG. 20.

Examples of an exciter having 4, 6 or 8 magnetic poles have been illustrated. Thus, the same effect can be achieved by an exciter having many magnetic poles by dividing the magnetic circuit into two or three groups of equivalent magnetic circuits formed by the magnetic poles and the cooking pot, and by providing a phase difference of 90° or 60° between the currents exciting each of the magnetic circuits. Accordingly, in an induction heating cooking apparatus forming magnetic circuits between an iron core and a cooking pot, it is possible to obtain a zero component of electromagnetic force for vertically vibrating the cooking pot by dividing the magnetic circuits into n equivalent magnetic circuits having the same structure and same magnetic resistances by providing a phase difference of \(180^\circ/n\) between the alternating currents exciting the divided magnetic circuits.

In practice, it is not always necessary to obtain a zero alternating electromagnetic force, but it is possible for the vibrating acceleration to be made lower than 1 G, which is lower than the weight of the cooking pot. Under such latitude, an allowance of about ±20% of phase difference deviation can be considered. According to our experiments, the vibrating acceleration was lower than 1 G with a calorific value of 1 kW when the phase difference was deviated 20%.

In the foregoing embodiments, the excitation current forms rotating fields to the cooking pot so as to form an electromagnetic force which rotates the cooking pot on a horizontal force. The following embodiment is for overcoming the disadvantage of such rotation. FIG. 24 is a schematic view of another embodiment of the improved exciter according to this invention. The structure of this embodiment is same as the embodiment of FIG. 22, except in the connection of the windings. FIG. 25 illustrates a connection of the excitation circuit which prevents a rotating field, wherein an alternating current source is connected between an initial end of the winding 81 and an initial end of the winding 87 and, for example, an excitation current having I_1 = I_m sin wt is applied. On the other hand, an alternating current source having a phase shift of about 90° is connected between an initial end of the winding 82 and an initial end of the winding 88 and, for example, an excitation current having I_2 = I_m cos wt is applied. In such an induction heating cooking apparatus, a rotating magnetic field applied to the cooking pot by the excitation current will not be formed. Moreover, an electromagnetic force for vertically vibrating the cooking pot will not be formed. This is because that when the magnetic field is shifted progressively to the windings 81-88-87-86, the magnetic field will simultaneously be shifted to the opposite direction of the windings 82-83-84-85, and taken as a whole, they will not form a rotating force. FIG. 26 illustrates the other connection of the other excitation circuit for the same purpose. In the induction heating cooking apparatus, both of the rotating forces are cancelled by each other.
FIGS. 27 to 30 illustrate another embodiment of the phase shift excitation according to this invention, wherein an excitation circuit 80A for one magnetic circuit A and an excitation circuit 80B for the other magnetic circuit B are equivalent to each other. The condensers \(C_a\) and \(C_b\) are respectively connected in series to the excitation circuits 80A and 80B, the condensers \(C_a\) and \(C_b\) are respectively connected in parallel to the excitation circuits 80A and 80B, and the reactor \(L_a\) is connected in series to the excitation circuit 80A. The reference \(V\) represents the electrode voltage, and \(I_a\) and \(I_b\) respectively represent the current fed to the excitation circuits 80A and 80B. The phase of the current \(I_a\) fed to the excitation circuit 80A lags the voltage from the power source voltage \(V\) by 45°. In the embodiment of FIG. 27, this can be attained by selecting the distance between the iron core surface and the bottom of the cooking pot, and the material of the cooking pot. In such a case, the resistive component of the excitation circuit 80A is equal to the reactance component thereof. When the resistive component of the excitation circuit 80A is higher than the reactance component thereof, a reactor \(L_a\) is connected in series as shown in FIG. 28 to attain the same result. The phase of the current \(I_b\) fed to the excitation circuit 80B lags the power source voltage \(V\) by 45°. A similar function can be attained by the embodiments shown in FIG. 30.

The induction heating cooking apparatus has an alternating electromagnetic force of zero and a power factor of 1 so that the power source equipment can be simplified. FIG. 31 shows a power vector diagram for illustrating the characteristics of the exciters having a phase difference angle other than 45° between the terminal voltage and current of the excitation circuits of FIGS. 27 to 30. In FIG. 31, the vertical axis represents the effective power component and the horizontal axis represents the ineffective power component, and the reference \(P_a\) and \(P_b\) respectively represent the effective power fed to the excitation circuits 80A and 80B. In order for the alternating electromagnetic power to be zero, the effective power \(P_a\) should be equal to \(P_b\). The references \(Q_a\) and \(Q_b\) respectively represent the ineffective power fed to the excitation circuits 80A and 80B and the references \(T_a\) and \(T_b\) respectively represent the complex power of the excitation circuits. In order for the alternating electromagnetic force applied to the cooking pot to be zero, the phase shift between the electric currents \(I_a\) and \(I_b\) must be 90°. Accordingly, the phase difference between the complex powers \(T_a\) and \(T_b\) must be 90°. The reference \(Q_a\) represents the ineffective power of the condenser \(C_a\) connected in series to the excitation circuit 80B so as to be 90° of the phase difference between the complex powers \(T_a\) and \(T_b\).

As is clear from the FIGURES, when the phase difference between the terminal voltage and current is not 45° in the excitation circuits 80A and 80B, the complex power \(T_a + T_b\) fed from the power source to all excitation circuits has an ineffective power component and accordingly the power factor will be less than 1.

FIG. 32 shows a power vector diagram according to this invention. In the embodiment of FIGS. 27 to 30, the electric current \(I_a\) fed to the excitation circuit 80A has a phase difference of 45° lagging the terminal voltage. On the other hand, in the excitation circuit 80B, the electric current \(I_b\) fed to the excitation circuit has a phase difference of 45° leading the power voltage, due to the presence of the condenser \(C_b\). Accordingly, the following relations result whereby the complex power \(T = T_a + T_b\) fed from the power source to all of the excitation circuits has no ineffective power component.

\[
P_a = \begin{bmatrix} P_a \cr Q_a \cr T_a \end{bmatrix} = \begin{bmatrix} T_a \cr T_a \cr T_a \end{bmatrix}
\]

Accordingly, the power factor will be 1 and the required capacity of the power source can be minimized.

As in the embodiment of FIG. 27, when the resistive component of the excitation circuit is equal to the reactance component by selecting the space between the iron core surface and the bottom of the cooking pot, and the material of the cooking pot, the additional part required for the circuit of this invention is only one condenser. This provides various advantages in that the apparatus can be compact, the power source equipment can be simplified, and the cost of manufacture can be decreased.

Herefore, the induction heating cooking apparatus excited by commercial standard line frequency current has been considered impossible to use in practice, because of the vibration and noise of the cooking pot. In accordance with the invention, this trouble has been overcome to provide a practical cooking apparatus. The induction heating cooking apparatus using commercial frequency current need not be equipped with any frequency converter, so that it can be manufactured with low cost. Accordingly, the economical effect of this invention is outstanding.

The practical structure of the iron core used in the apparatus will now be illustrated. FIG. 33 illustrates one embodiment of the iron core having four magnetic poles.

The iron core 50 has a ring-type winding iron core prepared by winding a ferrosilicon plate in a coil shape and by forming a winding holder by cutting grooves as shown in the drawing. The windings 81 to 84 are wound on the grooves 51. The direction of the plies of the ferrosilicon plate is arranged so as to oppose the passage of the eddy current, so that the iron core loss can be minimized. The core of FIG. 33 is advantageously formed from one piece.

Iron cores formed by an assembly of a separately prepared yoke, magnetic poles and if necessary a magnetic pole piece, will now be illustrated.

FIG. 34 illustrates various types, wherein the reference numeral

- \(60a\) designates an annular yoke made of ferrite;
- \(60b\) designates an annular yoke made of ferrite;
- \(60c\) designates a square plate yoke made of ferrite;
- \(60d\) designates a square ring yoke made of ferrite;
- \(60e\) designates a yoke of cross-shape made of plied ferrosilicon plate; and
- \(60f\) designates a yoke of cross-shape made of ferrite.

FIG. 35 illustrates various magnetic poles wherein the reference numeral

- \(70a\) designates a sector magnetic pole of plied steel plate;
- \(70b\) designates a sector magnetic pole of ferrite;
- \(70c\) designates a square magnetic pole of plied steel plate;
- \(70d\) designates a square magnetic pole of ferrite; and
70e designates a cylindrical magnetic pole of ferrite. FIG. 36 illustrates various magnetic pole pieces wherein the reference numeral 90α designates a sector magnetic pole piece of ferrite; 90β designates a square magnetic pole piece of ferrite; and 90γ designates a cylindrical magnetic pole piece of ferrite.

As stated above, various iron cores can be formed by assembling various yokes, magnetic poles and magnetic pole pieces. For example, FIG. 37 shows one embodiment of an assembly comprising the annular yoke 60α of FIG. 34, sector magnetic pole 70α of FIG. 35 and the magnetic pole piece 90α of FIG. 36, which are bonded together.

FIG. 38 shows another iron core assembly comprising the annular yoke 60α of FIG. 34, and the sector magnetic pole of ferrite 70β of FIG. 35.

FIG. 39 shows still another assembly comprising the annular yoke 60α of FIG. 34, and the cylindrical magnetic pole of ferrite 70ε of FIG. 35. FIG. 40 shows another assembly comprising the yoke of cross-plied plate 70δ of FIG. 35, and the reference numeral 100 designates a non-magnetic part having a high resistivity which is placed on one side of the magnetic pole 70δ to seal the magnetic flux passing through the surface to decrease the iron core loss.

The above mentioned embodiments are very suitable for utilization in the induction heating apparatus according to this invention because of their suitable magnetic characteristics, material, weight, ease of production and the like.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. Induction heating appliance comprising: an exciter for induction heating a heated element, said exciter comprising, a first magnetic pole having a first excitation winding disposed adjacent to said element, a second magnetic pole having a second excitation winding disposed adjacent to said element, a third magnetic pole having a third excitation winding disposed adjacent to said element, a fourth magnetic pole having a fourth excitation winding disposed adjacent to said element, means connecting said first excitation winding to said third excitation winding to form a first circuit, means connecting said second excitation winding to said fourth excitation winding to form a second circuit, means connecting a first low frequency current to said first circuit, means connecting a second low frequency current which is substantially 90° out of phase with said first current to said second circuit, whereby a magnetic force generated by said first circuit is equal and opposite to a magnetic force generated by said second circuit in order to minimize vibration and noise.

2. Induction heating appliance in accordance with claim 1 wherein said second current is 90° plus or minus 18° out of phase with said first current.

3. Induction heating appliance in accordance with claim 1 wherein said element comprises a cooking pot.

4. Induction heating appliance in accordance with claim 3 wherein the bottom of said cooking pot is planar.

5. Induction heating appliance in accordance with claim 1 wherein said first and third poles are diagonally disposed relative to each other and said second and fourth poles are diagonally disposed relative to each other.

6. Induction heating appliance in accordance with claim 1 wherein the top surfaces of said first, second, third and fourth poles are coplanar.

7. Induction heating appliance in accordance with claim 1 further including a cover plate covering said first, second, third and fourth windings.

8. Induction heating appliance in accordance with claim 8 wherein said cover plate is comprised of stainless steel.

9. Induction heating appliance comprising: an exciter for induction heating a heated element, said exciter comprising, a first magnetic pole having a first excitation winding disposed adjacent to said element, a second magnetic pole having a second excitation winding disposed adjacent to said element, a third magnetic pole having a third excitation winding disposed adjacent to said element, a fourth magnetic pole having a fourth excitation winding disposed adjacent to said element, a fifth magnetic pole having a fifth excitation winding disposed adjacent to said element, a sixth magnetic pole having a sixth excitation winding disposed adjacent to said element, means connecting said first excitation winding to said fourth excitation winding to form a first circuit, means connecting said second excitation winding to said fifth excitation winding to form a second circuit, means connecting said third excitation winding to said sixth excitation winding to form a third circuit, means connecting a first low frequency current to said first circuit, means connecting a second low frequency current substantially 60° out of phase with said first current to said second circuit, means connecting a third low frequency current which is substantially 60° out of phase with said second current and which is substantially 120° out of phase with said first current to said third circuit, whereby the combination of a magnetic force generated by said first circuit and a magnetic force generated by said second circuit and a magnetic force generated by said third circuit minimizes vibration and noise.

10. Induction appliance in accordance with claim 10 wherein said second circuit is 60° plus or minus 12° out of phase with said first current and said third current is 60° plus or minus 12° out of phase with said second current.
12. Induction heating appliance in accordance with claim 10 wherein said element comprises a cooking pot.

13. Induction heating appliance in accordance with claim 12 wherein the bottom of said cooking pot is planar.

14. Induction heating appliance in accordance with claim 10 wherein said first, second, third, fourth, fifth and sixth poles are disposed on the same side of said element and each pole is equally spaced from adjacent poles.

15. Induction heating appliance in accordance with claim 10 wherein said first and fourth poles are diagonally disposed relative to each other, said third, second and fifth poles are diagonally disposed relative to each other and said third and sixth poles are diagonally disposed relative to each other.

16. Induction heating appliance in accordance with claim 10 wherein the top surfaces of said first, second, third, fourth, fifth and sixth poles are coplanar.

17. Induction heating appliance in accordance with claim 10 further including a cover plate covering said first, second, third, fourth, fifth and sixth windings.

18. Induction heating appliance in accordance with claim 17 wherein said cover plate is comprised of stainless steel.

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