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(54) POWER CONTROL FOR HAIR IRON HAVING CERAMIC HEATERS

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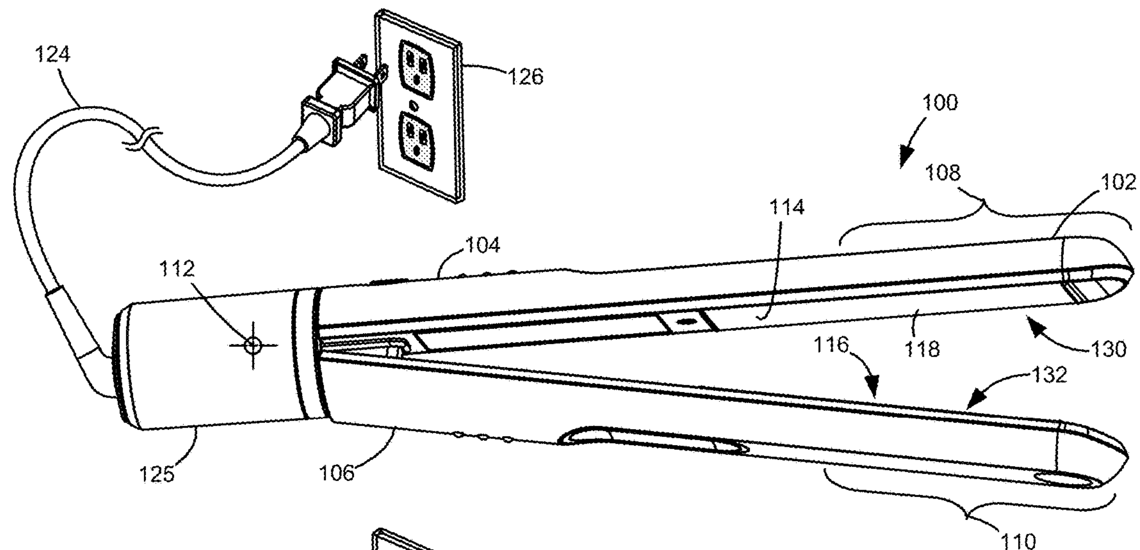
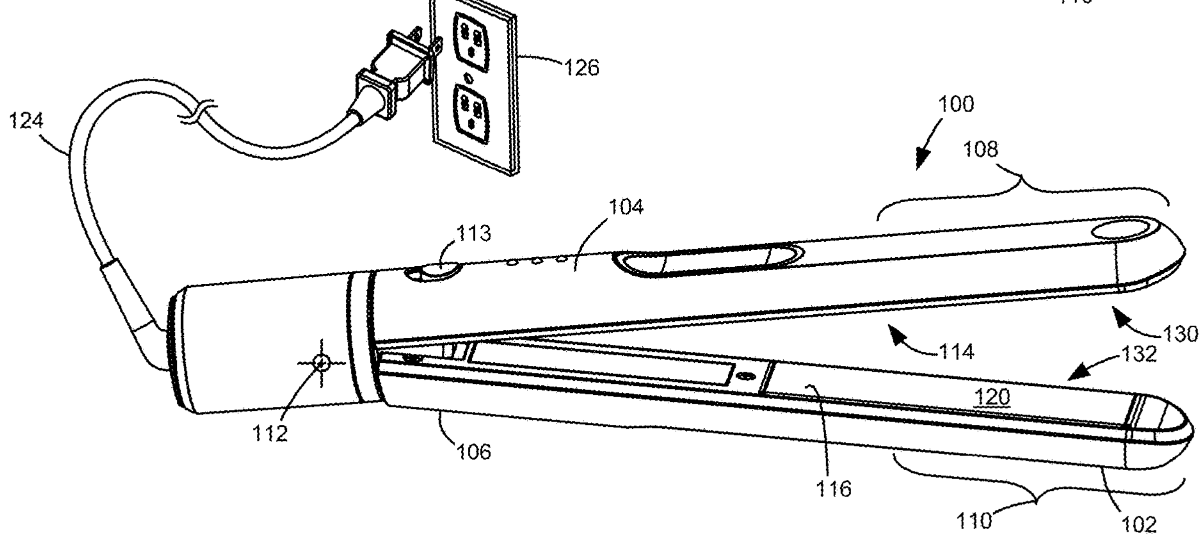
(57) ABSTRACT

A hair iron includes two longitudinally extending arms each having a ceramic heater. Users place hair between the heaters during use. A controller coordinates heating conditions of the heaters. If a line voltage supplied to the hair iron is a high voltage, the controller is configured to alternate heating between the heaters whereby only heating of one heater occurs at one time. To reduce flicker and harmonics, the controller supplies heating current so that one heater remains off for consecutive half-cycles of alternating current while the other heater is powered on variously. The controller then switches the heating. The hair iron further includes a line voltage detector to detect whether a line voltage supplied through a cord to the hair iron is either low voltage or high voltage. During such time, the controller limits heating power to the two heaters.





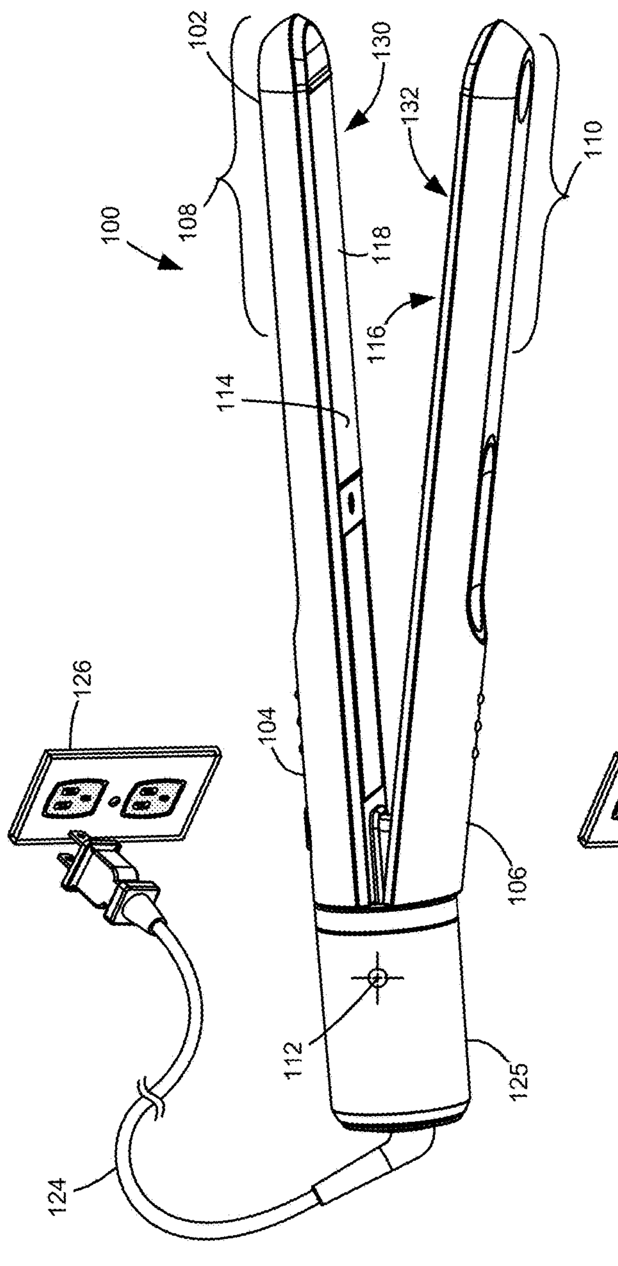

100
102
104
106
108
110
112
114
116
118
124
125
126
130
132

FIG. 1A

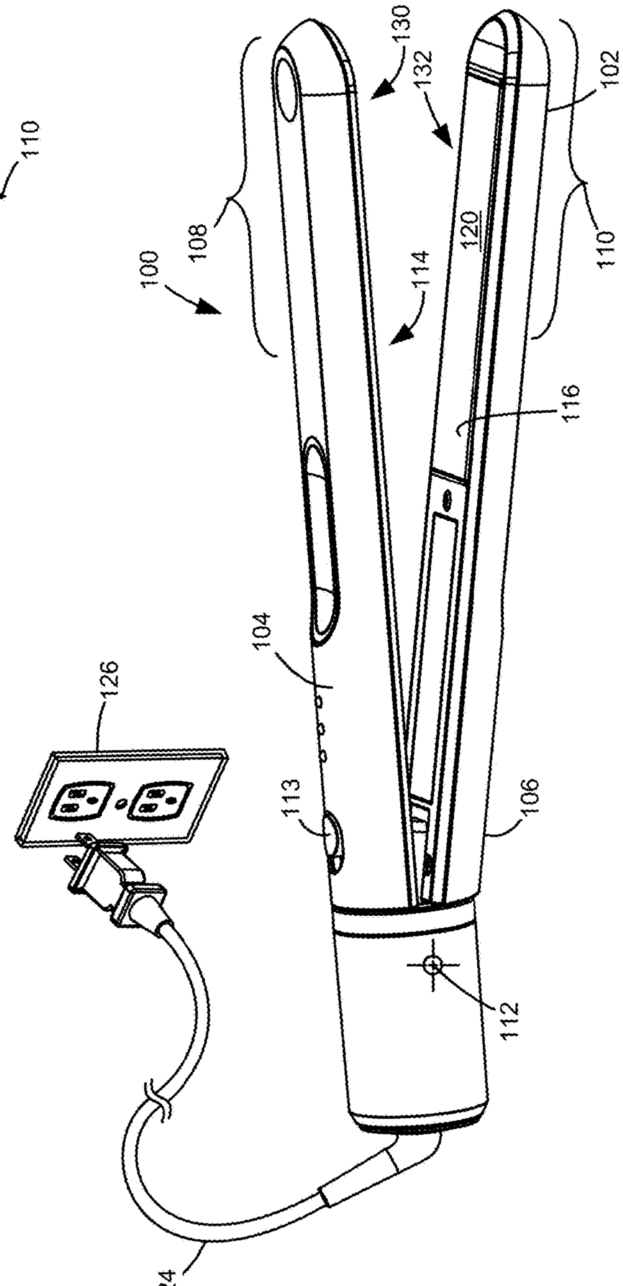

100
102
104
106
108
110
112
113
114
116
120
124
126
130
132

FIG. 1B

FIG. 2A

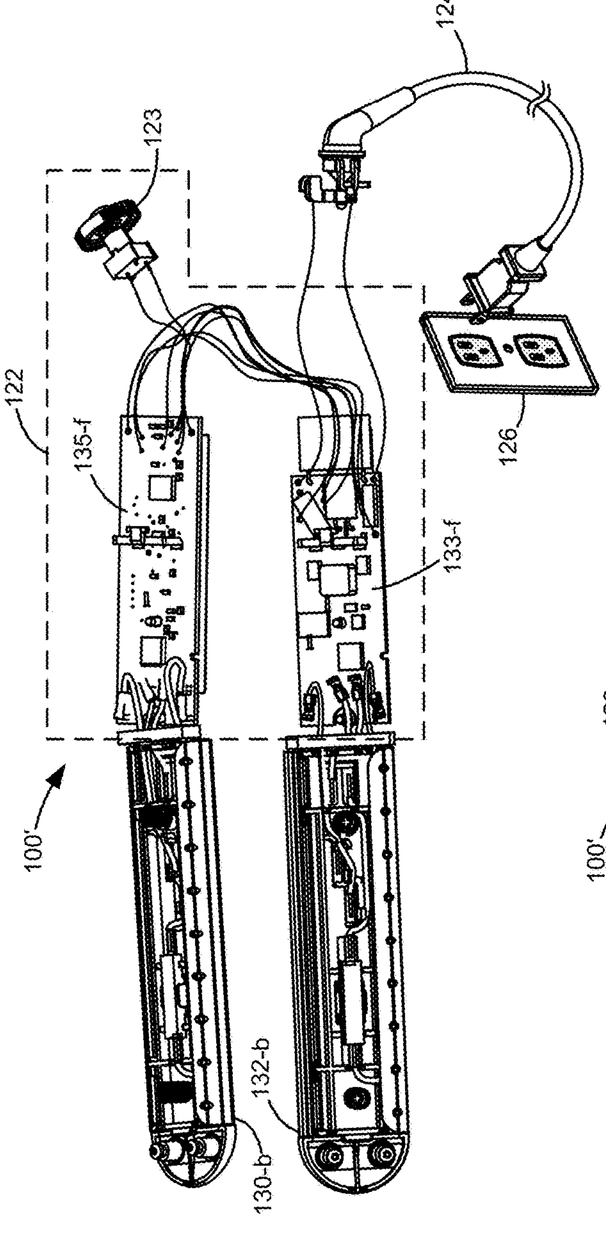
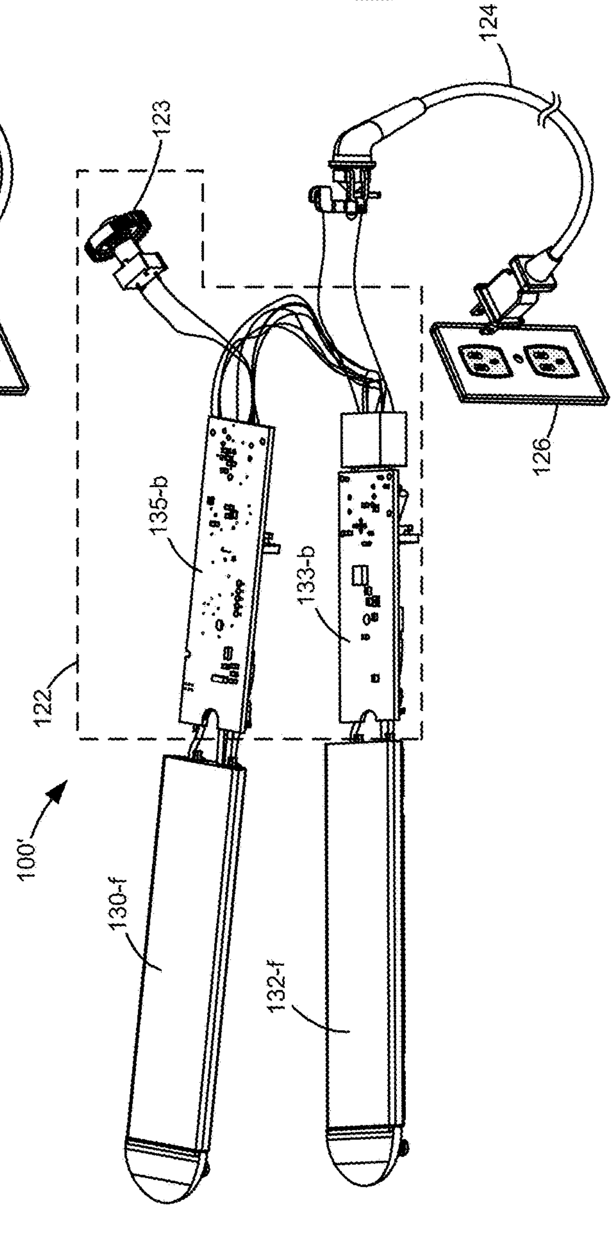

123
124
122
135-f
133-f
126
100'
132-b
130-b

FIG. 2B


123
124
135-b
133-b
122
126
100'
130-f
132-f

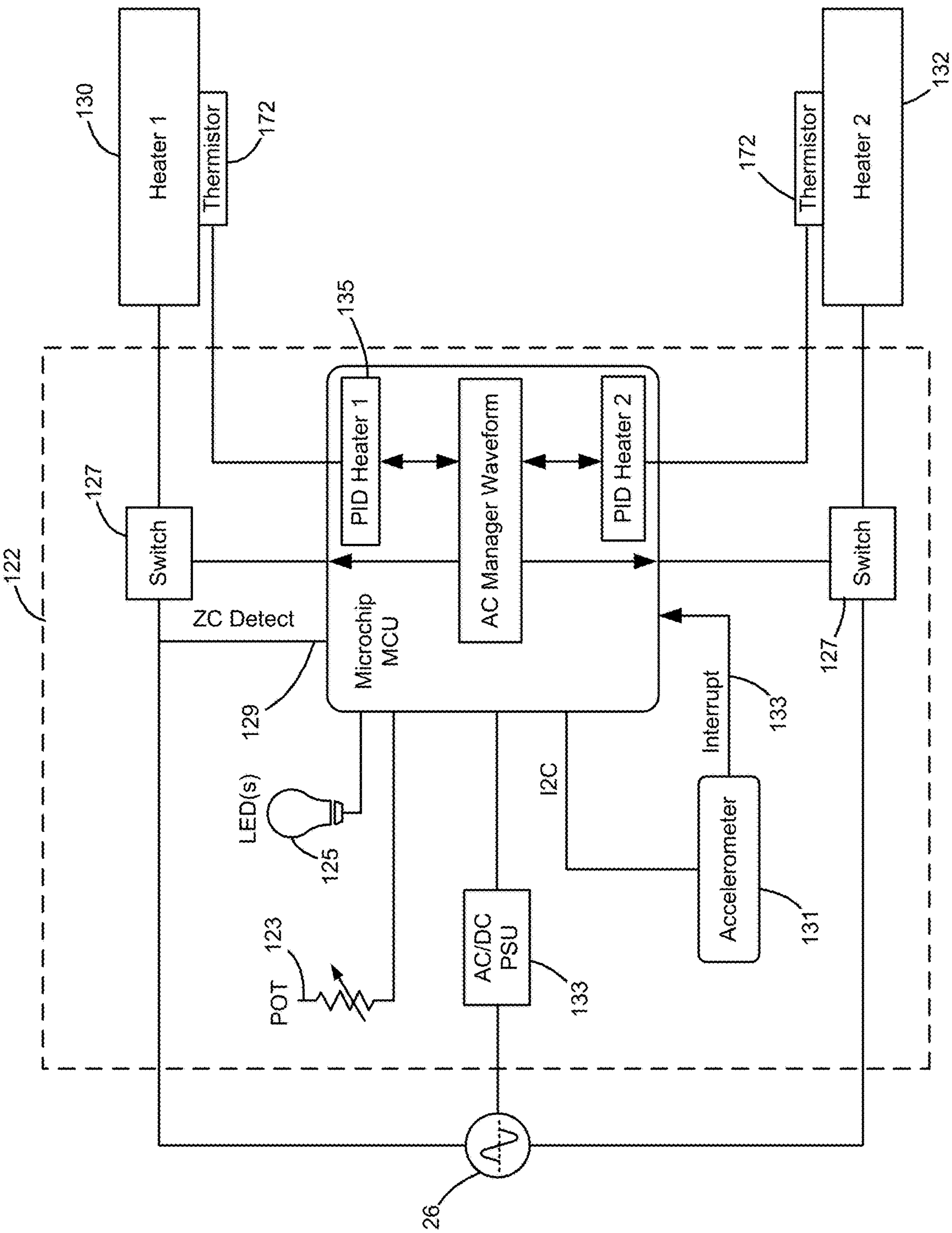

Heater 1
130
Thermistor
172
Heater 2
132
Thermistor
172
135
PID Heater 1
AC Manager Waveform
PID Heater 2
122
Switch
127
Switch
127
ZC Detect
Microchip MCU
129
Interrupt
133
I2C
LED(s)
125
POT
123
AC/DC PSU
133
Accelerometer
131
126

FIG. 3

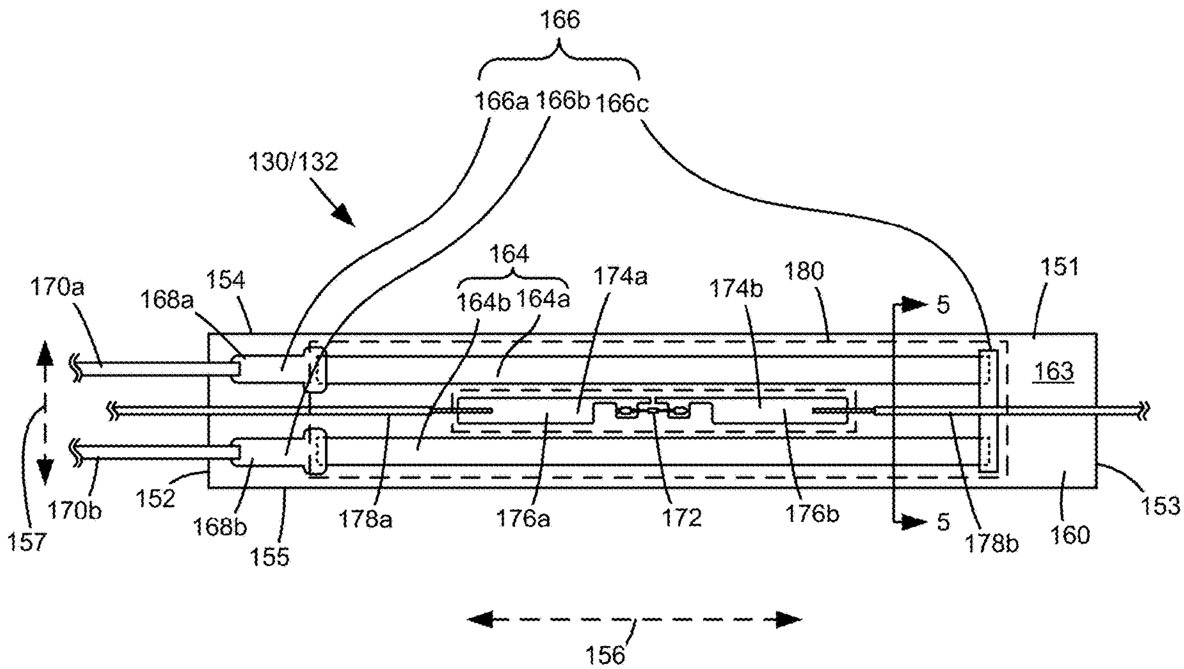

166
166a 166b 166c
130/132
164
164b 164a
174a
174b
180
151
170a
168a
154
5
163
157
170b
152
168b
155
178a
176a
172
176b
178b
160
153
156

FIG. 4A

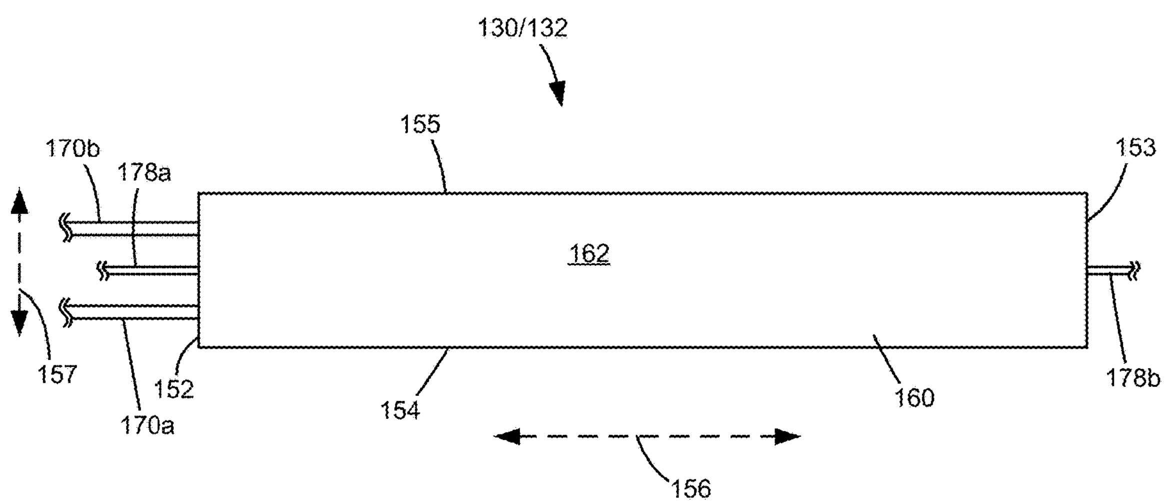

130/132
155
170b
178a
153
162
157
152
170a
154
160
178b
156

FIG. 4B

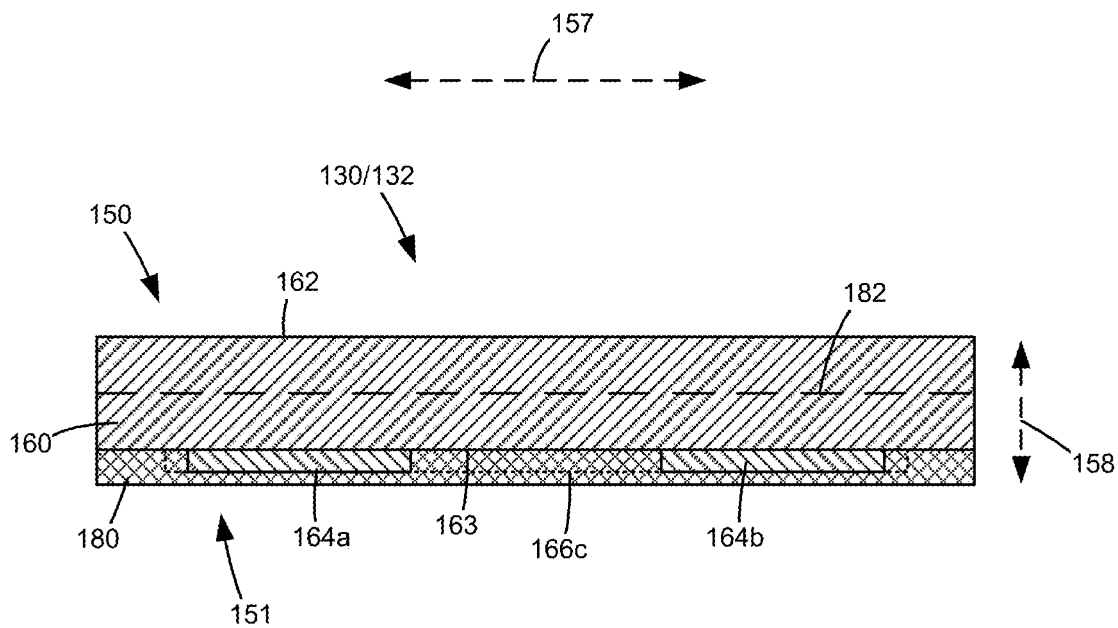


FIG. 5

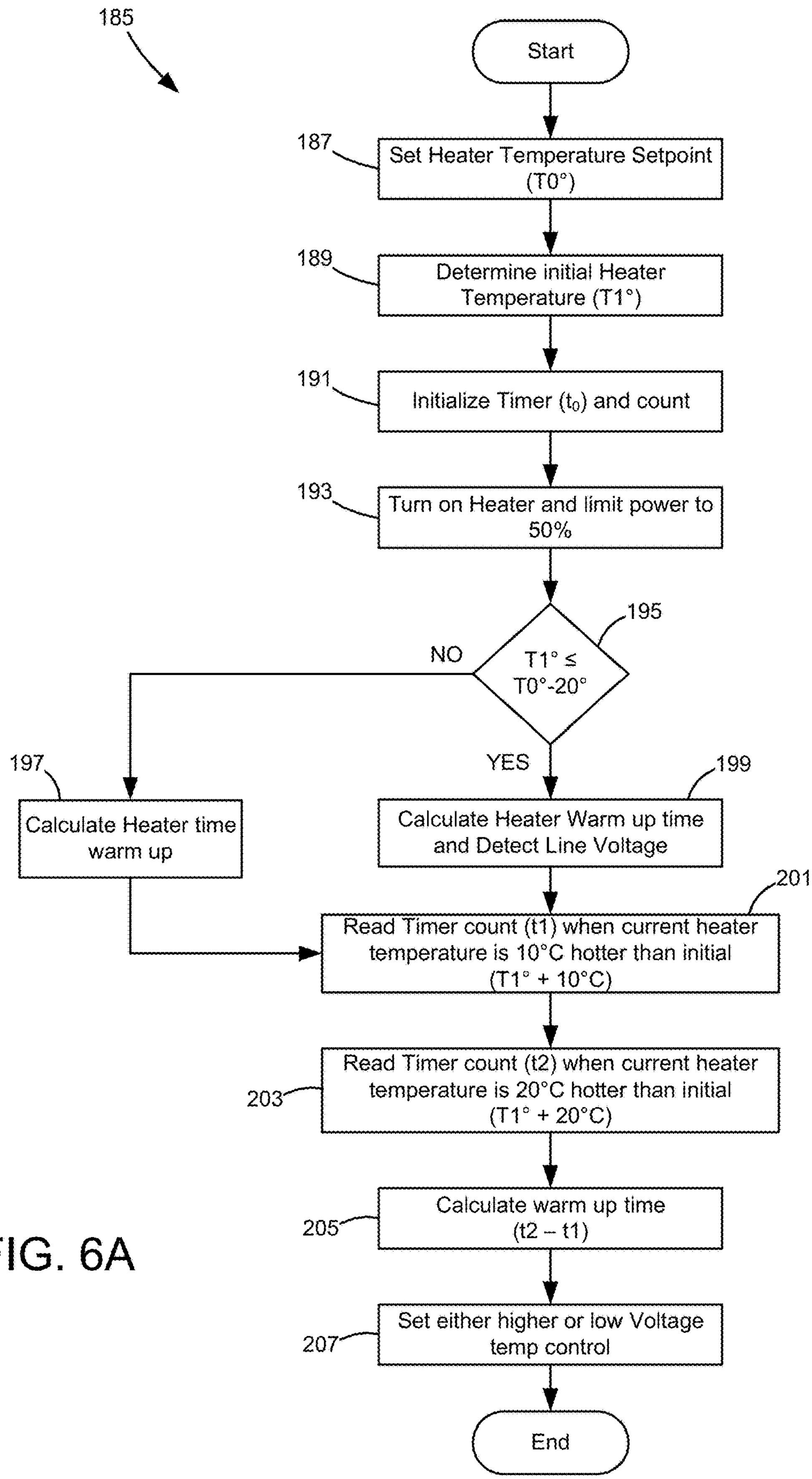

185
Start
187
Set Heater Temperature Setpoint (T0°)
189
Determine initial Heater Temperature (T1°)
191
Initialize Timer (t_0) and count
193
Turn on Heater and limit power to 50%
195
T1° ≤ T0°-20°
NO
YES
197
Calculate Heater time warm up
199
Calculate Heater Warm up time and Detect Line Voltage
201
Read Timer count (t1) when current heater temperature is 10°C hotter than initial (T1° + 10°C)
203
Read Timer count (t2) when current heater temperature is 20°C hotter than initial (T1° + 20°C)
205
Calculate warm up time (t2 – t1)
207
Set either higher or low Voltage temp control
End

FIG. 6A

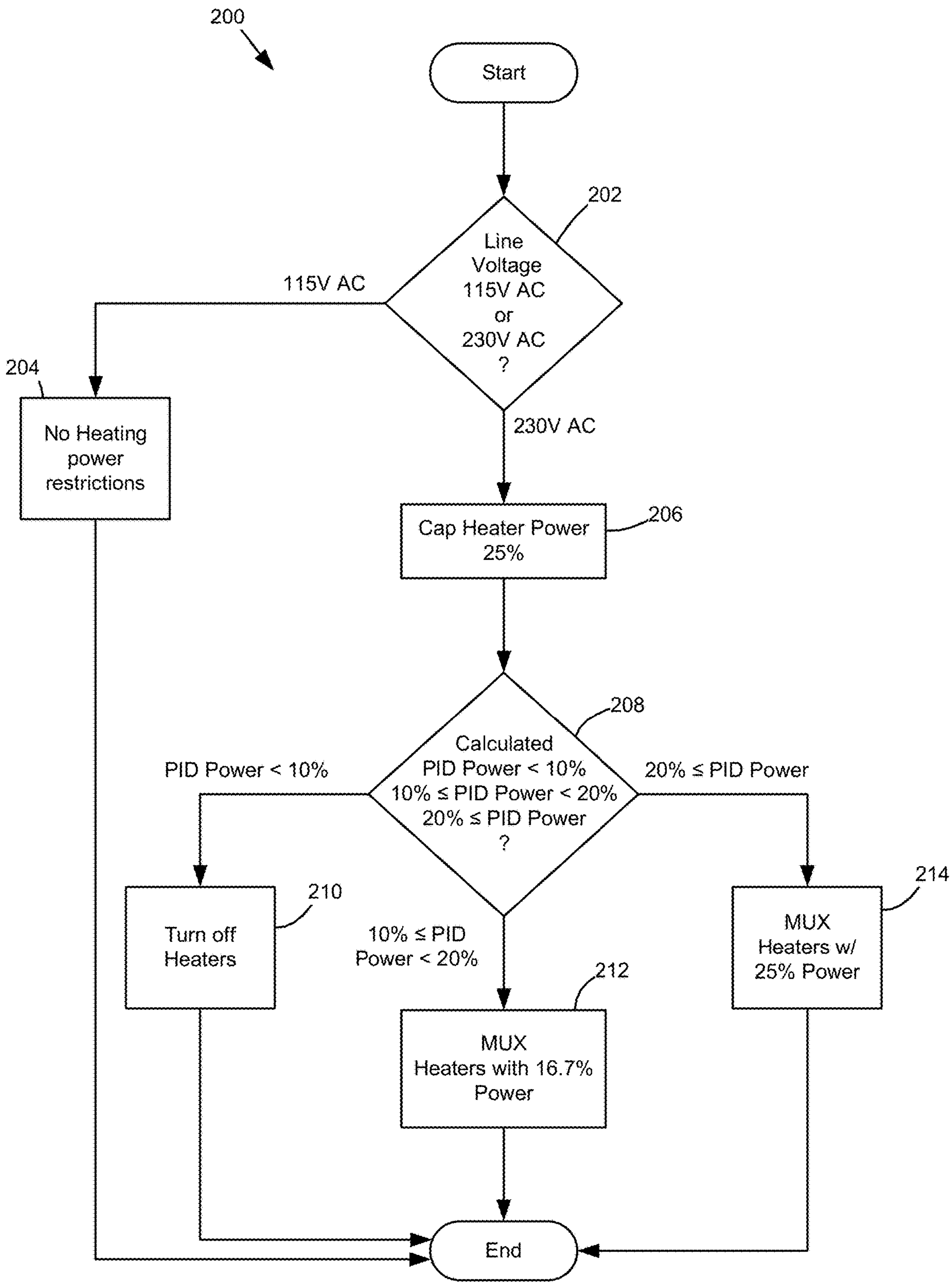

200
Start
202
Line Voltage 115V AC or 230V AC ?
115V AC
204
No Heating power restrictions
230V AC
Cap Heater Power 25%
206
208
Calculated PID Power < 10% 10% ≤ PID Power < 20% 20% ≤ PID Power ?
PID Power < 10%
20% ≤ PID Power
210
Turn off Heaters
10% ≤ PID Power < 20%
212
MUX Heaters with 16.7% Power
214
MUX Heaters w/ 25% Power
End

FIG. 6B

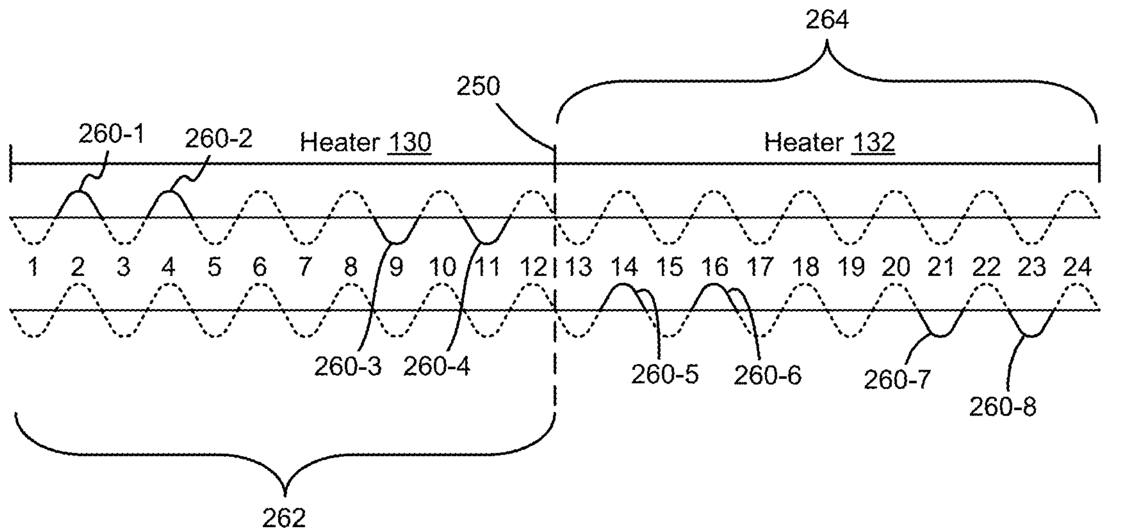

264
250
260-1
260-2
Heater 130
Heater 132
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
260-3
260-4
260-5
260-6
260-7
260-8
262

FIG. 7A

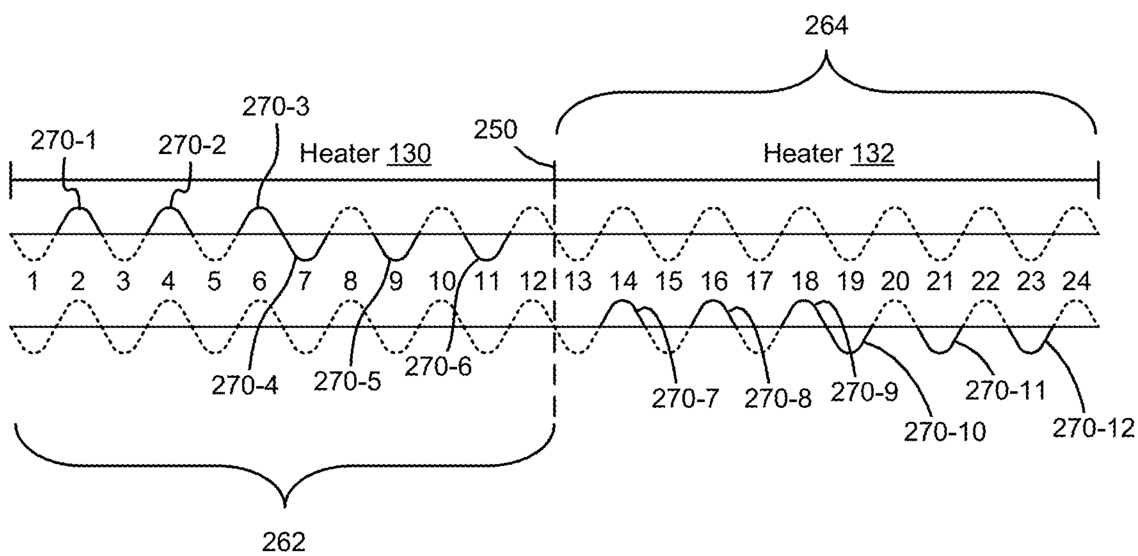

264
270-3
270-1
270-2
250
Heater 130
Heater 132
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
270-4
270-5
270-6
270-7
270-8
270-9
270-10
270-11
270-12
262

FIG. 7B

300

301 320

Power Level (%)	Half-Cycle 1	Half-Cycle 2	Half-Cycle 3	Half-Cycle 4	Half-Cycle 5	Half-Cycle 6	Half-Cycle 7	Half-Cycle 8	DC Offset
Polarity:	Pos	Neg	Pos	Neg	Pos	Neg	Pos	Neg	
0	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	0
12.5	ON (302)	OFF	OFF	OFF	OFF	OFF	OFF	OFF	1 (306)
25	ON	ON	OFF	OFF	OFF	OFF	OFF	OFF	0
37.5	ON	ON	ON	OFF	OFF	OFF	OFF	OFF	1 (308)
50	ON (304)	ON (304)	ON (304)	ON (304)	OFF	OFF	OFF	OFF	0
62.5	ON	ON	ON	ON	ON	OFF	OFF	OFF	1 (310)
75	ON	ON	ON	ON	ON	ON	OFF	OFF	0
87.5	ON	ON	ON	ON	ON	ON	ON	OFF	1 (312)
100	ON	ON	ON	ON	ON	ON	ON	ON	0

FIG. 8

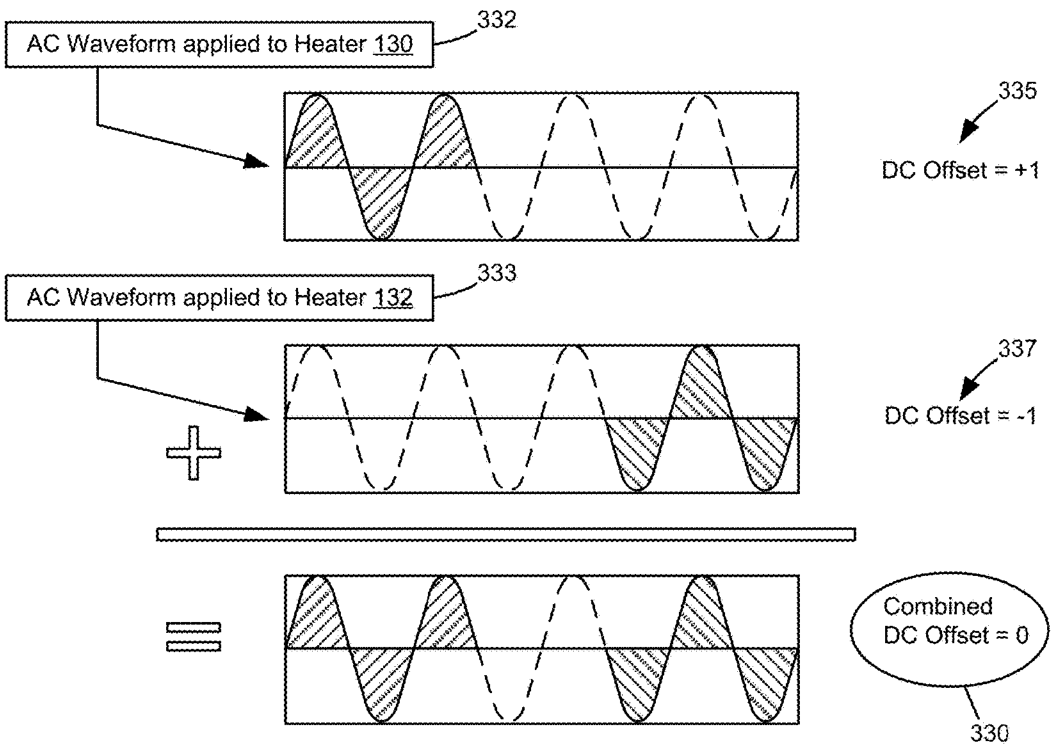

AC Waveform applied to Heater 130
332
335
DC Offset = +1
AC Waveform applied to Heater 132
333
337
DC Offset = -1
Combined
DC Offset = 0
330

FIG. 9A

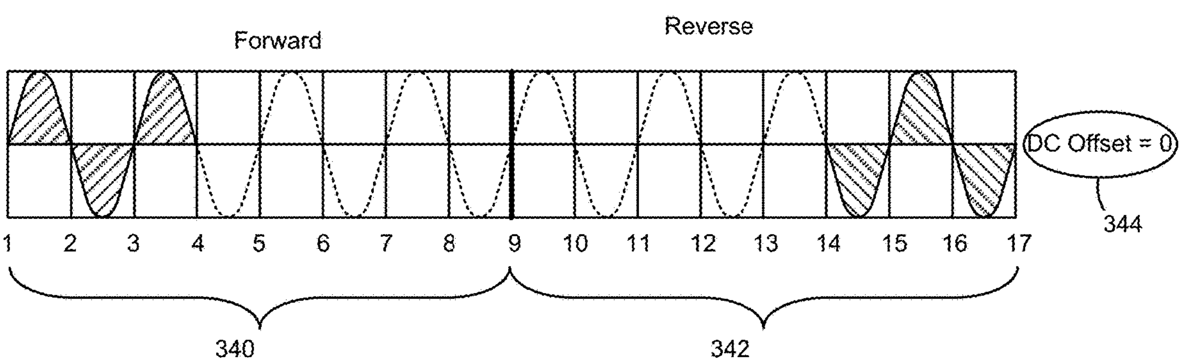

Forward
Reverse
DC Offset = 0
344
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
340
342

FIG. 9B

POWER CONTROL FOR HAIR IRON HAVING CERAMIC HEATERS

BACKGROUND

1. Field of the Invention

[0001] The present disclosure relates to alternating current (AC) power control systems. More particularly it relates to power control methods and apparatus for controlling the AC power delivered to a hair iron having ceramic heaters.

2. Description of Related Art

[0002] Many conventional hair irons, such as flat irons, straightening irons, curling irons, crimping irons, etc., suffer from heat lag, which results in lengthy times to heat irons for use and cool them afterwards. During these times, users often set their irons on countertops or the like which creates a safety risk, especially to children, who may accidentally contact them while hot. Additional safety risks also arise when users accidentally leave irons powered on when not in use. The inventors recognize a need for hair irons having faster heating and cooling, which tends to improve safety.

[0003] Hair irons draw power from an electrical power grid to operate, i.e., alternating current (AC) line power. In various geographies, countries supply power at a relatively low voltage, e.g., 115 VAC, or high voltage, e.g., 230 VAC. Manufacturers design their irons to operate at one voltage or the other, but not both. When traveling between countries, users regularly carry with them voltage-conversion devices to appropriately change the voltage of the line power to match that of their hair iron. At either low or high voltage, however, irons can draw power in such a manner that they generate power harmonics and voltage flicker. In most locations, regulatory bodies set strict certification requirements that dictate (un)acceptable amounts of flicker, harmonics, current symmetry, radiation, conduction, and the like to reduce undesirable health effects on users and/or disruption to sensitive electronic/electrical equipment. As a result, manufacturers are continuingly challenged to meet requirements while not compromising temperature control performance and safety. The inventors further recognize a need for hair irons that users can conveniently use anywhere without requiring voltage converters, while also complying with flicker and harmonics requirements, such as those set by the International Electrotechnical Commission (IEC).

SUMMARY

[0004] The foregoing and other problems are solved by a hair iron having two longitudinally extending arms each with a ceramic heater. Users place hair between the heaters to heat the hair and style it. A controller coordinates heating of the heaters. If a line voltage supplied to the hair iron is a high voltage, the controller is configured to alternate heating between the heaters whereby only heating of one heater occurs at one time. To reduce flicker and harmonics, the controller supplies heating current so that one heater remains off for consecutive half-cycles of alternating current while the other heater is powered on variously. The controller then switches the heating to the other heater. The hair iron further includes a line voltage detector to detect whether a line voltage supplied through a cord to the hair iron is either low voltage or high voltage. During such time, the controller limits heating power to the two heaters. One or more thermistors provide temperature feedback to the controller.

[0005] In other embodiments, a hair iron includes a first arm and a second arm movable relative to each other between an open position and a closed position. A distal segment of the first arm is spaced from a distal segment of the second arm in the open position. The distal segment of the first arm is positioned in close proximity to the distal segment of the second arm in the closed position. A contact surface is positioned on an exterior, such as an exterior of the distal segment, of the first arm for contacting hair during use. The first arm includes a heater having a ceramic substrate and an electrically resistive trace on the ceramic substrate, e.g., on an exterior face of the ceramic substrate. The electrically resistive trace is composed of an electrical resistor material. In some embodiments, the electrically resistive trace includes the electrical resistor material thick film printed on the exterior face of the ceramic substrate after firing of the ceramic substrate. The heater is positioned to supply heat generated by applying an electric current to the electrically resistive trace to the contact surface. Embodiments further include those wherein the heater includes one or more glass layers on the exterior face of the ceramic substrate that cover the electrically resistive trace for electrically insulating the electrically resistive trace.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The foregoing summary, as well as the following detailed description, is better understood when read in conjunction with the appended drawings. However, the invention is not limited to the specific methods and components disclosed herein. Like numerals represent like features in the drawings. In the views:

[0007] FIGS. **1**A and **1**B show a representative hair iron having power control for ceramic heaters;

[0008] FIGS. **2**A and **2**B are views similar to FIGS. **1**A and **1**B having covers removed to reveal electronic components;

[0009] FIG. **3** is a diagrammatic schematic view of a power control system of a hair iron;

[0010] FIGS. **4**A and **4**B are plan views of an inner face and an outer face, respectively, of a ceramic heater for use in a hair iron;

[0011] FIG. **5** is a cross-sectional view of the heater shown in FIGS. **4**A and **4**B taken along line **5**-**5** in FIG. **4**A;

[0012] FIGS. **6**A and **6**B show methods of detecting AC line voltage and operating a hair iron therefrom;

[0013] FIGS. **7**A and **7**B show example waveforms illustrating changes in the half-cycles of AC line voltage and power control therefor;

[0014] FIG. **8** shows a Table for applying AC half-cycles of power to heaters of a hair iron to achieve desired temperature responses; and

[0015] FIGS. **9**A and **9**B show further AC waveforms illustrating changes in the half-cycles of AC line voltage and power control therefor to have no DC offset applied to the heaters.

DETAILED DESCRIPTION

[0016] It is to be understood that while the preferred embodiments herein incorporate AC power delivery for a hair iron, the principles and concepts can be utilized in many other applications. Applications that are especially well adapted for using the features of the invention include other small appliances where AC power is to be delivered to the appliance at different AC voltages and likely to cause flicker and the generation of harmonic energy. The features of the invention can be utilized with AC power systems having frequencies and voltages different from that used in the United States.

[0017] Referring now to the drawings and particularly to FIGS. **1**A and **1**B, a hair iron **100** is shown according to an example embodiment. Hair iron **100** includes an appliance such as a flat iron, straightening iron, curling iron, crimping iron, or other similar device that applies heat and pressure to hair in order to change the structure or appearance of the hair. Hair iron **100** has a housing **102** that forms the overall support structure of hair iron **100**. The housing **102** may be composed of, for example, a plastic that is thermally insulative and electrically insulative and that possesses relatively high heat resistivity and dimensional stability and low thermal mass. Example plastics include polybutylene terephthalate (PBT) plastics, polycarbonate/acrylonitrile butadiene styrene (PC/ABS) plastics, polyethylene terephthalate (PET) plastics, including glass-filled versions of each. In addition to forming the overall support structure of hair iron **100**, the housing **102** also provides electrical insulation and thermal insulation in order to provide a safe surface for the user to contact and hold during operation of hair iron **100**.

[0018] Hair iron **100** further includes a pair of longitudinally extending arms **104**, **106** that are movable between an open and closed position. Distal segments **108**, **110** of arms **104**, **106** are spaced apart from each other in the open position and are in contact, or close proximity with one another in the closed position. The arms clamshell or are pivotable relative to each other about a pivot axis **112** between the open position and the closed positions. Hair iron **100** may include a bias member (not shown), such as one or more springs, that biases one or both of arms **104**, **106** toward the open position such that user actuation is required to overcome the bias applied to arms **104**, **106** to bring arms **104**, **106** together to the closed position. A lock **113** is provided to secure the arms in the closed position upon user manipulation.

[0019] Hair iron **100** includes a heater positioned on an inner side **114**, **116** of one or both of arms **104**, **106**. Inner sides **114**, **116** of arms **104**, **106** include the portions of arms **104**, **106** that face each other when arms **104**, **106** are in the open and closed positions. In the example embodiment illustrated, each arm **104**, **106** includes a respective heater **130**, **132** opposed to one another on or within the arm **104**, **106**. Heaters **130**, **132** supply heat to respective contact surfaces **118**, **120** on arms **104**, **106**. Each contact surface **118**, **120** is positioned on inner side **114**, **116** of distal segment **108**, **110** of the corresponding arm **104**, **106**. Contact surfaces **118**, **120** may be formed directly by a surface of each heater **130**, **132** or formed by a material covering each heater **130**, **132**, such as a shield or sleeve. Contact surfaces **118**, **120** are positioned to directly contact and transfer heat to hair upon a user positioning hair between arms **104**, **106** during use. Contact surfaces **118**, **120** are positioned to mate against one another in a relatively flat orientation when arms **104**, **106** are in the closed position in order to maximize the surface area available for contacting hair.

[0020] With reference to FIGS. **2**A and **2**B, hair iron **100'** (as seen in partial disassembled form) includes control circuitry **122** configured to control the power, thus the temperature, of each heater **130**, **132**. The control circuitry **122** in this design is bifurcated in the two arms of the hair iron, including a printed circuit board **133**, **135** having a front (-f) and back (-b) sides. The PCB boards **133**, **135** respectively relate to electrical circuit components for a power supply unit (PSU) and a microchip unit (MCU) that coordinate to selectively apply electrical current to the heaters **130**, **132** (shown schematically in FIG. **3**). The hair iron **100** further includes a power cord **124** for connecting hair iron **100** to an external line power or voltage source **126** to power the control circuitry **122** and heaters **130**, **132**. Amongst different geographies, the line power **126** is typically 115 VAC or 230 VAC. Regulating this power will be described below in relation to FIGS. **7**A and **7**B.

[0021] With reference to FIG. **3**, the regulation of line power **126** to the heaters **130**, **132**, includes control circuitry **122**. A potentiometer **123** receives input from a user by twisting a handle **125** (FIG. **1**A) of hair iron **100**. The settings are varied, but twists of the handle generally relate to the hair iron **100** being off or powered on with high, medium, or low heat to the heaters **130**, **132**. A corresponding light emitting diode (LED) **125** indicates to the user whether or not the hair iron **100** is powered on or off. Other settings are possible. One or more triacs or switches **127** connect the heaters **130**, **132** to line power **126** under control of the MCU **135**. The MCU turns on the triacs **127** when the AC voltage of the line power is at or near a zero-crossing (ZC) as provided on a zero-crossing detection circuit supplied at **129** to the MCU. An accelerometer **131** detects manipulation of the hair iron **100** and the MCU will stop heating of the heaters **130**, **132** regardless of the potentiometer **123** setting if the MCU does not receive any interrupts **133** per a given period of time, say every 60 seconds. In this way, the controller knows that a user is manipulating the hair iron for use and not merely setting it aside. The thermistors **172** gather current temperature readings of the heaters **130**, **132** that the MCU uses to control the set-points, temperature increases, temperature decreases, and the like, of the heaters. The thermistors provided input to the MCU per a given period of time, such as per every 1 msec. Line voltage varies per geography, e.g., 115 VAC or 230 VAC, and such is detected by the PSU **133** and supplied to the MCU for controlling the power to the heaters based thereon as described below in FIGS. **7**A and **7**B.

[0022] In FIGS. **4**A and **4**B, heaters **130** or **132** are detailed to show them as removed from their housing. They may or may not be identical to one another. FIG. **4**A shows inner face **151** of heater **130**/**132**, and FIG. **4**B shows outer face **150** of heater **130**/**132**. In the embodiment illustrated, outer face **150** and inner face **151** are bordered by four sides or edges **152**, **153**, **154**, **155** each having a smaller surface area than outer face **150** and inner face **151**. In this embodiment, heater **130**/**132** includes a longitudinal dimension **156** that extends from edge **152** to edge **153** and a lateral dimension **157** that extends from edge **154** to edge **155**. Heater **130**/**132** also includes an overall thickness **158** (FIG. **5**) measured from outer face **150** to inner face **151**.

[0023] Heater **130**/**132** includes one or more layers of a ceramic substrate **160**, such as aluminum oxide (e.g., commercially available 96% aluminum oxide ceramic). Where heater **130**/**132** includes a single layer of ceramic substrate **160**, a thickness of ceramic substrate **160** may range from, for example, 0.5 mm to 1.5 mm, such as 1.0 mm. Where heater **130** includes multiple layers of ceramic substrate **160**, each layer may have a thickness ranging from, for example, 0.5 mm to 1.0 mm, such as 0.635 mm. In some embodiments, a length of ceramic substrate along longitudinal dimension **156** may range from, for example, 80 mm to 120 mm. In some embodiments, a width of ceramic substrate **160** along lateral dimension **157** may range from, for example, 15 mm to 24 mm, such as 17 mm or 22.2 mm. Ceramic substrate **160** includes an outer face **162** that is oriented toward outer face **150** of heater **130/132** and an inner face **163** that is oriented toward inner face **151** of heater **130/132**. Outer face **162** and inner face **163** of ceramic substrate **160** are positioned on exterior portions of ceramic substrate **160** such that if more than one layer of ceramic substrate **160** is used, outer face **162** and inner face **163** are positioned on opposed external faces of the ceramic substrate **160** rather than on interior or intermediate layers of ceramic substrate **160**.

[0024] In the example embodiment illustrated, outer face **150** of heater **130/132** is formed by outer face **162** of ceramic substrate **160** as shown in FIG. **4**B. In this embodiment, inner face **163** of ceramic substrate **160** includes a series of one or more electrically resistive traces **164** and electrically conductive traces **166** positioned thereon. Resistive traces **164** include a suitable electrical resistor material such as, for example, silver palladium (e.g., blended 70/30 silver palladium). Conductive traces **166** include a suitable electrical conductor material such as, for example, silver platinum. In the embodiment illustrated, resistive traces **164** and conductive traces **166** are applied to ceramic substrate **160** by way of thick film printing. For example, resistive traces **164** may include a resistor paste having a thickness of 10-13 microns when applied to ceramic substrate **160**, and conductive traces **166** may include a conductor paste having a thickness of 9-15 microns when applied to ceramic substrate **160**. Resistive traces **164** form the heating element of heater **130** and conductive traces **166** provide electrical connections to and between resistive traces **164** in order to supply an electrical current to each resistive trace **164** to generate heat.

[0025] In the example embodiment illustrated, heater **130/132** includes a pair of resistive traces **164***a*, **164***b* that extend substantially parallel to each other (and substantially parallel to edges **154**, **155**) along longitudinal dimension **156** of heater **130**. Heater **130** also includes a pair of conductive traces **166***a*, **166***b* that each form a respective terminal **168***a*, **168***b* of heater **130**. Cables or wires **170***a*, **170***b* are connected to terminals **168***a*, **168***b* in order to electrically connect resistive traces **164** and conductive traces **166** to, for example, control circuitry **122** and voltage source **126** in order to selectively close the circuit formed by resistive traces **164** and conductive traces **166** to generate heat. Conductive trace **166***a* directly contacts resistive trace **164***a*, and conductive trace **166***b* directly contacts resistive trace **164***b*. Conductive traces **166***a*, **166***b* are both positioned adjacent to edge **152** in the example embodiment illustrated, but conductive traces **166***a*, **166***b* may be positioned in other suitable locations on ceramic substrate **160** as desired. In this embodiment, heater **130/132** includes a third conductive trace **166***c* that electrically connects resistive trace **164***a* to resistive trace **164***b*. Portions of resistive traces **164***a*, **164***b* obscured beneath conductive traces **166***a*, **166***b*, **166***c* in FIG. **4**A are shown in dotted line. In this embodiment, current input to heater **130/132** at, for example, terminal **168***a* by way of conductive trace **166***a* passes through, in order, resistive trace **164***a*, conductive trace **166***c*, resistive trace **164***b*, and conductive trace **164***b* where it is output from heater **130** at terminal **168***b*. Current input to heater **130** at terminal **168***b* travels in reverse along the same path.

[0026] In some embodiments, heater **130/132** includes a thermistor **172** positioned in close proximity to a surface of heater **130/132** in order to provide feedback regarding the current temperature of heater **130/132** to control circuitry **122**. In some embodiments, thermistor **172** is positioned on inner face **163** of ceramic substrate **160**. In the example embodiment illustrated, thermistor **172** is welded directly to inner face **163** of ceramic substrate **160**. In this embodiment, heater **130/132** also includes a pair of conductive traces **174***a*, **174***b* that are each electrically connected to a respective terminal of thermistor **172** and that each form a respective terminal **176***a*, **176***b*. Cables or wires **178***a*, **178***b* are connected to terminals **176***a*, **176***b* in order to electrically connect thermistor **172** to, for example, control circuitry **122** in order to provide closed loop control of heater **130**. In the embodiment illustrated, thermistor **172** is positioned at a central location of inner face **163** of ceramic substrate **160**, between resistive traces **164***a*, **164***b* and midway from edge **152** to edge **153**. In this embodiment, conductive traces **174***a*, **174***b* are also positioned between resistive traces **164***a*, **164***b* with conductive trace **174***a* positioned toward edge **152** from thermistor **172** and conductive trace **174***b* positioned toward edge **153** from thermistor **172**. However, thermistor **172** and its corresponding conductive traces **174***a*, **174***b* may be positioned in other suitable locations on ceramic substrate **160** so long as they do not interfere with the positioning of resistive traces **164** and conductive traces **166**.

[0027] FIG. **5** is a cross-sectional view of heater **130/132** taken along line **5-5** in FIG. **4**A. With reference to FIGS. **4**A, **4**B and **5**, in the embodiment illustrated, heater **130/132** includes one or more layers of printed glass **180** on inner face **163** of ceramic substrate **160**. In the embodiment illustrated, glass **180** covers resistive traces **164***a*, **164***b*, conductive trace **166***c*, and portions of conductive traces **166***a*, **166***b* in order to electrically insulate such features to prevent electric shock or arcing. The borders of glass layer **180** are shown in dashed line in FIG. **4**A. In this embodiment, glass **180** does not cover thermistor **172** or conductive traces **174***a*, **174***b* because the relatively low voltage applied to such features presents a lower risk of electric shock or arcing. An overall thickness of glass **180** may range from, for example, 70-80 microns. FIG. **5** shows glass **180** covering resistive traces **164***a*, **164***b* and adjacent portions of ceramic substrate **160** such that glass **180** forms the majority of inner face **151** of heater **130/132**. Outer face **162** of ceramic substrate **160** is shown forming outer face **150** of heater **130/132** as discussed above. Conductive trace **166***c*, which is obscured from view in FIG. **5** by portions of glass **180**, is shown in dotted line. FIG. **5** depicts a single layer of ceramic substrate **160**. However, ceramic substrate **160** may include multiple layers as depicted by dashed line **182** in FIG. **5**.

[0028] Heater **130/132** may be constructed by way of thick film printing. For example, in one embodiment, resistive traces **164** are printed on fired (not green state) ceramic substrate **160**, which includes selectively applying a paste containing resistor material to ceramic substrate **160** through a patterned mesh screen with a squeegee or the like. The printed resistor is then allowed to settle on ceramic substrate

160 at room temperature. The ceramic substrate **160** having the printed resistor is then heated at, for example, approximately 140-160 degrees Celsius for a total of approximately 30 minutes, including approximately 10-15 minutes at peak temperature and the remaining time ramping up to and down from the peak temperature, in order to dry the resistor paste and to temporarily fix resistive traces **164** in position. The ceramic substrate **160** having temporary resistive traces **164** is then heated at, for example, approximately 850 degrees Celsius for a total of approximately one hour, including approximately 10 minutes at peak temperature and the remaining time ramping up to and down from the peak temperature, in order to permanently fix resistive traces **164** in position. Conductive traces **166** and **174***a*, **174***b* are then printed on ceramic substrate **160**, which includes selectively applying a paste containing conductor material in the same manner as the resistor material. The ceramic substrate **160** having the printed resistor and conductor is then allowed to settle, dried and fired in the same manner as discussed above with respect to resistive traces **164** in order to permanently fix conductive traces **166** and **174***a*, **174***b* in position. Glass layer(s) **180** are then printed in substantially the same manner as the resistors and conductors, including allowing the glass layer(s) **180** to settle as well as drying and firing the glass layer(s) **180**. In one embodiment, glass layer(s) **180** are fired at a peak temperature of approximately 810 degrees Celsius, slightly lower than the resistors and conductors. Thermistor **172** is then mounted to ceramic substrate **160** in a finishing operation with the terminals of thermistor **172** directly welded to conductive traces **174***a*, **174***b*.

[0029] Thick film printing resistive traces **164** and conductive traces **166** on fired ceramic substrate **160** provides more uniform resistive and conductive traces in comparison with conventional ceramic heaters, which include resistive and conductive traces printed on green state ceramic. The improved uniformity of resistive traces **164** and conductive traces **166** provides more uniform heating across contact surface **118** as well as more predictable heating of heater **130**.

[0030] Preferably, heaters **130/132** are produced in an array for cost efficiency. Heaters are separated into individual heaters **130/132** after the construction of all heaters is completed, including firing of all components and any applicable finishing operations. In some embodiments, individual heaters are separated from the array by way of fiber laser scribing. Fiber laser scribing tends to provide a more uniform singulation surface having fewer microcracks along the separated edge in comparison with conventional carbon dioxide laser scribing.

[0031] It will be appreciated that the example embodiments illustrated and discussed above are not exhaustive and that the heater of the present disclosure may include resistive and conductive traces in many different geometries, including resistive traces on the outer face and/or the inner face of the heater, as desired. Other components (e.g., a thermistor) may be positioned on either the outer face or the inner face of the heater as desired.

[0032] The present disclosure does, however, provide a ceramic heater having a low thermal mass in comparison with the heaters of conventional hair irons. In particular, thick film printed resistive traces on an exterior face (outer or inner) of the ceramic substrate provides reduced thermal mass in comparison with resistive traces positioned internally between multiple sheets of ceramic. The use of a thin film, thermally conductive sleeve, such as a polyimide sleeve) also provides reduced thermal mass in comparison with metal holders, guides, etc. The low thermal mass of the ceramic heater of the present disclosure allows the heater, in some embodiments, to heat to an effective temperature for use in a matter of seconds (e.g., less than 5 seconds), significantly faster than conventional hair irons. The low thermal mass of the ceramic heater of the present disclosure also allows the heater, in some embodiments, to cool to a safe temperature after use in a matter of seconds (e.g., less than 5 seconds), again, significantly faster than conventional hair irons.

[0033] Further, embodiments of the hair iron of the present disclosure operate at a more precise and more uniform temperature than conventional hair irons because of the closed loop temperature control provided by the thermistor in combination with the relatively uniform thick film printed resistive and conductive traces. The low thermal mass of the ceramic heater and improved temperature control permit greater energy efficiency in comparison with conventional hair irons. The rapid warmup and cooldown times of the ceramic heater of the present disclosure also provide increased safety by reducing the amount of time the hair iron is hot but unused. The improved temperature control and temperature uniformity further increase safety by reducing the occurrence of overheating. The improved temperature control and temperature uniformity also improve the performance of the hair iron of the present disclosure.

[0034] Referring now to FIG. **6**A, a method **185** is provided for determining the AC line voltage. At **187**, both the heaters (**130**, **132**) are set to operate at a given setpoint temperature (T0°) well underneath their operating temperature. If the operating temperature is 200° C., for example, then a representative setpoint temperature is about 150° C. At **189**, the thermistors (**172**) read the initial or current temperatures (T1°) of the heaters and at **191** a corresponding timer is initialized (t0) and begins its count. At the same time, at **193**, current is allowed to heat the heaters to begin heating up to their setpoint temperatures, but in a manner whereby only 50% of the power is turned on. This also occurs in a manner whereby the controller only allows half-cycles of the AC line voltage to heat the heaters, say five out of ten half-cycles, or 50%. In this way, the controller keeps the heaters from overheating and prevents cracking. At **195**, the controller determines whether the current temperature T1° is less than or equal to the setpoint temperature T0° less 20° C. (i.e., is T1°≤T0°−20° C.?). If so, the warmup time (WUT) of each heater is calculated at **199**. If not, the current temperature of the heater is already much closer to the setpoint temperature and so the line voltage that powers the hair iron is calculated in addition to calculating the warmup time of the heaters at **197**. At **201**, the controller continues monitoring of the temperature of the heaters and a time or timer count (t1) is determined when the current temperature is ten degrees more than initially read (i.e., T1°+10° C.). Similarly, the controller monitors the temperature of the heaters at **203** and the time or timer count (t2) is noted when the current temperature is twenty degrees more than initially read (i.e., T1°+20° C.). Then, at **205**, the warmup time (WUT) of a given heater is the time or timer count difference between t2 and t1 (i.e., t2−t1).

[0035] Once known, the controller operates the heaters under a scheme of either low or high voltage control at **207**. Intuitively, if the line voltage corresponds to a low power source, such as 115 VAC, the time to heat the heaters from their setpoint will be slower than if the line voltage corresponds to a high-power source, such as 230 VAC, and vice versa. It is expected that low voltage control occurs for AC line voltages between 90-140 VAC and high voltage control occurs above that. In a further embodiment, if the warmup time t2−t1 is less than or equal to 255 msec (t2−t1≤255 milliseconds), a line voltage bit is set to "1" for high voltage temperature control. Conversely, if the warmup time t2−t1 is greater than 334 msec (t2−t1>334 milliseconds), the line voltage bit is set to 0 for low voltage temperature control. The below Table shows this pictorially.

Heater	Current	Measured WUT	
Power limit	Voltage Bit	WUT > 334 msec	WUT < 255 msec
50%	0\LV	Take No Action	Reset voltage bit to 1
50%	1\HV	Reset voltage bit to 0	Take No Action

[0036] After finishing line voltage detection **185**, the AC manager of the controller will immediately switch from line voltage detection to actual control of the temperature of the heaters **130**, **132**. Based on the temperature difference of the measured heater temperature by the thermistor and the setpoint temperature, the PID (proportional-integral-derivative) controller will calculate a temperature response to the current temperature to set the required heating power for each heater. The controller will adjust PID gains in a manner to minimize warm up time, reduce ramp up temperature overshoot, and achieve tight steady state temperature control. In general, however, if the current heater temperature is more than 30° C. lower than the setpoint temperature, ramping up PID gains will be used. Otherwise, steady state PID gains will be selected.

[0037] Referring now to FIG. **6**B, an example method **200** for controlling power delivered to the heaters **130**, **132** is illustrated. In it, a determination **202** of the line voltage corresponds to either low power, such as 115 VAC, or high power, such as 230 VAC. If the voltage is low power, there exists no special power restrictions **204** on the heaters **130**, **132** and flicker does not represent a sizable concern. If high power exists, on the other hand at **206**, the heating power to the heaters is capped at 25% capacity. Once there, the PID output power or temperature response is determined. If the PID output power is less than 10% at **208**, meaning the current temperature is relatively close to the desired temperature of the heaters, then the heaters are turned off at **210**. If the PID output power at **208** is equal to or more than 10%, but less than 20%, the heaters **130**, **132** are multiplexed (MUX) together in a manner at **212** whereby their heater power turned on for four of twenty-four half-cycles of AC power, or 4/24=16.7% (FIG. **7**A, described below). If the PID output power at **208** is greater than or equal to 20%, the heaters **130**, **132** are multiplexed together in a manner at **214** whereby their heater power is turned on for six of twenty-four half-cycles of AC power, or 6/24=25% (FIG. **7**B, described below).

[0038] With reference to FIGS. **7**A and **7**B, when situations dictate that the heaters **130**, **132** become multiplexed, neither heater is powered on at the same time as the other heater and powering on and off occurs at zero-crossings of the AC waveform to reduce flicker and harmonic components. In either situation, the waveform of the AC line voltage is divided into 24 half-cycles of AC power (numbered 1-24). A first twelve of the 24 half-cycles are reserved for one heater while the last twelve cycles are reserved for the other heater. Line **250** demarks the first and last twelve cycles from one another. Thereafter, in a repeating pattern, current becomes applied to the first heater **130** during the first twelve cycles while current is next applied to the opposite heater **132** during the next twelve cycles, or vice versa. As seen, solid lines **260**-*x*, **270**-*y* represent the application of current to the heaters thereby powering them on, whereas the dashed lines correspond to no application of current to the heaters. Thus, heater **132** is off at **264** during the second twelve half-cycles of AC power when heater **130** is powered on at during the first twelve half-cycles of AC power. Conversely, heater **130** is off at **262** during the first twelve half-cycles of AC power when heater **132** is powered on at during the second twelve half-cycles of AC power. That either heater in FIG. **7**A is only powered on for four of the twenty-four half-cycles of AC power (**260-1**, **260-2**, **260-3**, **260-4** corresponding to heater **130** and **260-5**, **260-6**, **260-7**, **260-8** corresponding to heater **132**), only 16.7% power levels of the heaters are achieved in the hair iron, or 4/24=16.7%. Similarly, in FIG. **7**B, that either heater is only powered on for six half-cycles of the twenty-four half-cycles of AC power (**270-1**, **270-2**, **270-3**, **270-4**, **270-5**, **270-6** corresponding to heater **130** and **270-7**, **270-8**, **270-9**, **270-10**, **270-11**, **270-12** corresponding to heater **132**), only 25% power levels of the heaters are achieved in the hair iron, or 6/24=25%. Of course, other percentages of power levels are possible, as are different half-cycles of AC power.

[0039] As examples, with reference back to FIG. **3**, artisans will note that the heaters **130**, **132** are two independent heating elements of equal resistance and each has a current temperature feedback mechanism by way of the thermistor **172** to the controller **135**. During use, the controller activates the switch **127** to control AC power delivery to the heaters. Using the AC zero-crossing feedback **129**, the power delivery is synchronized precisely with the zero-crossings of the AC mains voltage waveform. This establishes the minimum unit of power delivery as a single half-cycle of the AC waveform. The controller modulates the current of each heater to achieve a desired temperature. This action is moderated by a temperature control loop (e.g. PID) running on the controller. That is, the control loop calculates a desired temperature response by way of a power level in units of percent, where 100% is equal to rated wattage of the heater. The fundamental period of heater power delivery in the following embodiments is eight half-cycles.

[0040] With reference to the table **300** of FIG. **8**, the controller will cause the switch to connect heaters to the AC line voltage for an integer number of half-cycles within this period. To achieve a power level percent (%) of 12.5% (e.g., 1/8×100%), for example, one AC half-cycle **302** of one-thru-eight total half-cycles **301** of power is turned on to heat the heater. Similarly, to achieve a power level percent of 50%, four AC half-cycles **304** of one-thru-eight total half-cycles **301** of power are turned on to the heat the heater (e.g., 4/8×100%). Similarly, too, all power level percentages of the heaters is read from the table **300**, e.g., power level percentages 0%, 12.5%, 25%, 37.5%, 50%, 62.5%, 75%, 87.5%, and 100%. However, depending on the exact number and placement of ON half-cycles in the one-thru-eight half-cycle period (e.g., the "pattern"), there arises a DC offset in the resultant current waveform. Namely, if there exists an odd number 1, 3, 5, and 7 of AC half-cycles of power turned ON in the one-thru-eight AC half-cycles of power, corresponding to power level percentages 12.5%, 37.5%, 62.5%, and 87.5%, respectively, a DC offset **306**, **308**, **310**, and **312** results, respectively. Conversely, if the number of positive-polarity half-cycles equals the number of negative-polarity half-cycles, or there exists zero or an even number 0, 2, 4, 6, and 8, of AC half-cycles of power turned ON in the one-thru-eight AC half-cycles of power, corresponding to power level percentages 0%, 25%, 50%, 75%, and 100%, respectively, a DC offset does not exist. Stated mathematically, the DC offset **320** for a given pattern can be quantified by taking the difference between positive-polarity and negative-polarity ON half-cycles, or DC Offset=Number of positive AC half-cycles−Number of negative AC half-cycles. Importantly, the inventors observe that when the total length of the pattern is an even number of AC half-cycles, if the pattern is reversed the pattern sequence will yield a new pattern whose DC offset is equal in magnitude yet opposite in sign. This is because positive half-cycles will be replaced by negative half-cycles and vice versa. In turn, three Cases 1, 2, and 3 arise whereby the PID controllers calculate a desired temperature response for its given heater whereby the power level percent to be applied to the heaters has both power level percentages with a DC offset of 1 (Case 1); has both power level percentages with a DC offset of 0 (Case 2); and has one power level percent for one heater with a DC offset of 1 and one power level percent for the other heater with a DC offset of 0 (Case 3).

[0041] For Case 1, with further reference to FIG. **9**A, if a desired temperature response calculated by the PID controller for the heaters **130**, **132** is both a power level percent having a DC offset, such as power level 37.5%, where there exists three ON AC half-cycles of power, the controller switches the AC half-cycles of power to the heaters **130**, **132** in a manner that results in a combined DC offset of 330 of zero. That is, there exists a first **332** AC half-cycle of power of 37.5% applied to the heater **130** that is a reversed pattern of a second **333** AC half-cycle of power of 37.5% applied to the heater **132**. As the former has a DC offset **335** of +1, while the latter has a DC offset **337** of −1, there exists zero DC offset **330** applied to the combined, both heaters **130**, **132**. This leverages the fact that the resistances of the heaters **130**, **132** are equal to one another and therefor the current amplitude to both heaters is equal.

[0042] For Case 2, if a given a desired temperature response calculated by the PID controller for the heaters **130**, **132** is both a power level percent having no DC offset, or zero DC current, a trivial case exists and the controller merely switches the AC half-cycles of power to the heaters **130**, **132** according to the table **300**.

[0043] For Case 3, the situation exists whereby a desired temperature response calculated by the PID controller for the heaters **130**, **132** has both a DC offset for one of the heaters **130** or **132**, but not both of the heaters **130** and **132**. If summing together the two AC waveforms cannot result in a combined DC offset of zero, such as at **330** (FIG. **9**A), FIG. **9**B teaches the extension of the total pattern period of AC half-cycles to sixteen (16) AC half-cycles, instead of eight. In turn, the first eight AC half-cycles **340**, the AC waveform pattern applied to one of the heaters is provided in the forward direction and the second eight AC half-cycles **342** is provided to the other or opposite heater is in the reverse direction, or vice versa. Since the forward and reverse of a given pattern have equal and opposite DC offsets, the complete waveform has zero DC bias **344** over the sixteen half-cycle period. Of course, these three cases could be changed to more or fewer AC half-cycles of power.

[0044] Advantages should be now readily apparent to those skilled in the art. Among them, the hair iron herein: 1) can be conveniently used anywhere in the world without needing a voltage converter; 2) successfully meets IEC flicker and harmonic requirements, while many competitive products cannot; and 3) delivers thermal performance that readies itself in as few as five seconds, with fast cooling times.

[0045] The foregoing description illustrates various aspects of the present disclosure. It is not intended to be exhaustive. Rather, it is chosen to illustrate the principles of the present disclosure and its practical application to enable one of ordinary skill in the art to utilize the present disclosure, including its various modifications that naturally follow. All modifications and variations are contemplated within the scope of the present disclosure as determined by the appended claims. Relatively apparent modifications include combining one or more features of various embodiments with features of other embodiments.

1. A hair iron, comprising:

two longitudinally extending arms each having a heater corresponding to an opposite heater on an opposite arm of the two longitudinally extending arms, wherein during use hair becomes placed between said heater and opposite heater to heat the hair, said heater and opposite heater being a ceramic heater and each having a setpoint temperature for low and high voltage line voltage conditions;

at least one temperature sensor to sense a temperature of said heater and opposite heater;

an electrical cord to connect said heater and opposite heater to a line voltage during use;

a controller in communication with the temperature sensor and said heater and opposite heater; and

a line voltage detector between the cord and the controller, an output of the line voltage detector being supplied to the controller,

wherein the controller is configured to limit heating power to said heater and opposite heater to about fifty percent or less before the line voltage detector detects the line voltage.

2. The hair iron of claim **1**, further wherein the controller is configured to read from the at least one temperature sensor a current temperature of said heater and opposite heater and initializing a timer to time zero t0.

3. The hair iron of claim **2**, further wherein the controller is configured to calculate a warmup time for said heater and opposite heater, the warmup time corresponding to a second time t2 less a first time t1, wherein the second time t2 corresponds to a second time when a second read temperature from the at least one temperature sensor is the current temperature plus 20° C. and the first time t1 corresponds to a first time when a first read temperature from the at least one temperature sensor is the current temperature plus 10° C.

4. The hair iron of claim **3**, wherein if the warm up time is less than a first predetermined time, the controller is further configured to initiate a high voltage control routine of said heater and opposite heater.

5. The hair iron of claim **4**, wherein the first predetermined time is about 255 msec.

6. The hair iron of claim **3**, wherein if the warm up time is greater than a second predetermined time, the controller is further configured to initiate a low voltage control routine of said heater and opposite heater.

7. The hair iron of claim **6**, wherein the second predetermined time is about 344 msec.

8. A hair iron, comprising:

two longitudinally extending arms each having a heater corresponding to an opposite heater on an opposite arm of the two longitudinally extending arms, wherein during use hair becomes placed between said heater and opposite heater to heat the hair, said heater and opposite heater being a ceramic heater;

a line voltage detector to detect whether a line voltage supplied through a cord is either of a low voltage or high voltage; and

a controller to coordinate heating of said heater and opposite heater, wherein if said high voltage exists, the controller being configured to alternate heating between said heater and opposite heater and heating only one of said heater and opposite heater at any time.

9. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a first twelve of said half-cycles of power, the controller prevents said opposite heater from receiving heating current.

10. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a first twelve of said half-cycles of power, the controller allows said heater to receive heating current for only four of said half-cycles of power.

11. The hair iron of claim **10**, wherein said four of said half-cycles of power include two positive and two negative said half-cycles of power.

12. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a second twelve of said half-cycles of power, the controller prevents said heater from receiving heating current.

13. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a second twelve of said half-cycles of power, the controller allows said opposite heater to receive heating current for only four of said half-cycles of power.

14. The hair iron of claim **13**, wherein said four of said half-cycles of power include two positive and two negative said half-cycles of power.

15. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a first twelve of said half-cycles of power, the controller allows said heater to receive heating current for only six of said half-cycles of power.

16. The hair iron of claim **15**, wherein said six of said half-cycles of power include three positive and three negative said half-cycles of power.

17. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a second twelve of said half-cycles of power, the controller allows said opposite heater to receive heating current for only six of said half-cycles of power.

18. The hair iron of claim **17**, wherein said six of said half-cycles of power include three positive and three negative said half-cycles of power.

19. The hair iron of claim **8**, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, wherein during a second twelve of said half-cycles of power, the controller prevents said heater from receiving heating current.

20. A hair iron, comprising:

two longitudinally extending arms each having a heater corresponding to an opposite heater on an opposite arm of the two longitudinally extending arms, wherein during use hair becomes placed between said heater and opposite heater to heat the hair, said heater and opposite heater being a ceramic heater; and

a controller to coordinate heating of said heater and opposite heater, wherein if a high voltage is supplied to the hair iron, the controller is configured to alternate heating between said heater and opposite heater and heating only one of said heater and opposite heater at any time, wherein the high voltage includes an alternating current sinusoidal waveform, the waveform having consecutive half-cycles of power, the controller said heating said only one of said heater and opposite heater at 16.7% or 25% of a consecutive twelve of said half-cycles of power.

* * * * *