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(54) **HEATER BUNDLE FOR ADAPTIVE CONTROL AND METHOD OF REDUCING CURRENT LEAKAGE**

HEIZERBÜNDEL ZUR ADAPTIVEN STEUERUNG UND VERFAHREN ZUR VERRINGERUNG VON LECKSTROM

COMMANDE ADAPTATIVE ET PROCÉDÉ DE RÉDUCTION DE FUITE DE COURANT PAR FAISCEAU DE CHAUFFAGE

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(56) References cited:
EP-A1- 3 033 954
EP-A2- 3 737 206
GB-A- 1 603 687
US-A- 3 970 822
US-A- 4 039 995
US-A- 5 552 998
US-A1- 2008 083 721
US-A1- 2009 001 778

EP 3 482 603 B1

Description

FIELD

[0001] The present disclosure relates to electric heaters, and more particularly to heaters for heating a fluid flow such as heat exchangers and the control thereof.

BACKGROUND

[0002] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

[0003] A fluid heater may be in the form of a cartridge heater, which has a rod configuration to heat fluid that flows along or past an exterior surface of the cartridge heater. The cartridge heater may be disposed inside a heat exchanger for heating the fluid flowing through the heat exchanger. If the cartridge heater is not properly sealed, moisture and fluid may enter the cartridge heater to contaminate the insulation material that electrically insulates a resistive heating element from the metal sheath of the cartridge heater, resulting in dielectric breakdown and consequently heater failure. The moisture can also cause short circuiting between power conductors and the outer metal sheath. The failure of the cartridge heater may cause costly downtime of the apparatus that uses the cartridge heater.

[0004] Further, during operation, some heaters may experience "current leakage," which is generally the flow of current through to a ground. The current leaks by way of insulation surrounding conductors in electrical heaters and this condition can cause a rise in voltage and overheating.

[0005] US4039995A discloses a heater system according to the preamble of claim 9.

SUMMARY

[0006] In one form of the present disclosure, a method of controlling a heating system is provided that comprises providing at least one heater assembly, the heater assembly comprising a plurality of heater units, each heater unit including a core body and defining at least one independently controlled heating zone. Power is supplied to each of the heater units through a plurality of power conductors electrically connected to each of the independently controlled heating zones in each of the heater units, and power supplied to each of the independently controlled heating zones is modulated, by switching the independently controlled heating zones such that a reduced number of independently controlled heating zones receives voltage at a time to reduce current leakage while allowing the independently controlled heating zones to provide a desired power distribution along the length of the heater assembly.

[0007] In another form, a heater system is provided that comprises one or more heater assemblies, each heater assembly comprising a plurality of heater units, each heater unit including a core body and defining at least one independently controlled heating zone, and a plurality of power conductors extending through holes defined in the core bodies and electrically connected to each of the independently controlled heating zones in each of the heater units. A power supply device including a controller is configured to modulate power to each of the independently controlled heating zones of the heater units through the power conductors by switching the independently controlled heating zones such that a reduced number of independently controlled heating zones receives the voltage at a time to reduce current leakage while allowing the independently controlled heating zones to provide a desired power distribution along the length of the heater assembly.

[0008] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0009] In order that the disclosure may be well understood, there will now be described various forms thereof, given by way of example, reference being made to the accompanying drawings, in which:

FIG. 1 is a perspective view of a heater bundle constructed in accordance with the teachings of the present disclosure;
FIG. 2 is a perspective view of a heater assembly of the heater bundle of FIG. 1;
FIG. 3 is a perspective view of a variant of a heater assembly of the heater bundle of FIG. 1;
FIG. 4 is a perspective view of the heater assembly of FIG. 3, wherein the outer sheath of the heater assembly is removed for clarity;
FIG. 5 is a perspective view of a core body of the heater assembly of FIG. 3;
FIG. 6 is a perspective view of a heat exchanger including the heater bundle of FIG. 1, wherein the heater bundle is partially disassembled from the heat exchanger to expose the heater bundle for illustration purposes; and
FIG. 7 is a block diagram of a method of operating a heater system including a heater bundle constructed in accordance with the teachings of the present disclosure.

[0010] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

DETAILED DESCRIPTION

[0011] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0012] Referring to FIG. 1, a heater system constructed in accordance with the teachings of the present disclosure is generally indicated by reference 10. The heater system 10 includes a heater bundle 12 and a power supply device 14 electrically connected to the heater bundle 12. The power supply device 14 includes a controller 15 for controlling power supply to the heater bundle 12. A "heater bundle", as used in the present disclosure, refers to a heater apparatus including two or more physically distinct heating devices that can be independently controlled. Therefore, when one of the heating devices in the heater bundle fails or degrades, the remaining heating devices in the heater bundle 12 can continue to operate.

[0013] In one form, the heater bundle 12 includes a mounting flange 16 and a plurality of heater assemblies 18 secured to the mounting flange 16. The mounting flange 16 includes a plurality of apertures 20 through which the heater assemblies 18 extend. Although the heater assemblies 18 are arranged to be parallel in this form, it should be understood that alternate positions/arrangements of the heater assemblies 18 are within the scope of the present disclosure.

[0014] As further shown, the mounting flange 16 includes a plurality of mounting holes 22. By using screws or bolts (not shown) through the mounting holes 22, the mounting flange 16 may be assembled to a wall of a vessel or a pipe (not shown) that carries a fluid to be heated. At least a portion of the heater assemblies 18 are be immersed in the fluid inside the vessel or pipe to heat the fluid in this form of the present disclosure.

[0015] Referring to FIG. 2, the heater assemblies 18 according to one form may be in the form of a cartridge heater 30. The cartridge heater 30 is a tube-shaped heater that generally includes a core body 32, a resistive heating wire 34 wrapped around the core body 32, a metal sheath 36 enclosing the core body 32 and the resistive heating wire 34 therein, and an insulating material 38 filling in the space in the metal sheath 36 to electrically insulate the resistive heating wire 34 from the metal sheath 36 and to thermally conduct the heat from the resistive heating wire 34 to the metal sheath 36. The core body 32 may be made of ceramic. The insulation material 38 may be compacted Magnesium Oxide (MgO). A plurality of power conductors 42 extend through the core body 32 along a longitudinal direction and are electrically connected to the resistive heating wires 34. The power conductors 42 also extend through an end piece 44 that seals the outer sheath 36. The power conductors 42 are connected to the external power supply device 14 (shown in FIG. 1) to supply power from the external power supply device 14 to the resistive heating wire 32. While FIG. 2 shows only two power conductors 42 extending through the end piece 44, more than two power conductors 42 can extend through the end piece 44. The power conductors 42 may be in the form of conductive pins. Various constructions and further structural and electrical details of cartridge heaters are set forth in greater detail in U.S. Patent Nos. 2,831,951 and 3,970,822. Therefore, it should be understood that the form illustrated herein is merely exemplary and should not be construed as limiting the scope of the present disclosure.

[0016] Alternatively, multiple resistive heating wires 34 and multiple pairs of power conductors 42 may be used to form multiple heating circuits that can be independently controlled to enhance reliability of the cartridge heater 30. Therefore, when one of the resistive heating wires 34 fails, the remaining resistive wires 34 may continue to generate heat without causing the entire cartridge heater 30 to fail and without causing costly machine downtime.

[0017] Referring to FIGS. 3 to 5, the heater assemblies 50 may be in the form of a cartridge heater having a configuration similar to that of FIG. 2 except for the number of core bodies and number of power conductors used. More specifically, the heater assemblies 50 each include a plurality of heater units 52, and an outer metal sheath 54 enclosing the plurality of heater units 52 therein, along with a plurality of power conductors 56. An insulating material (not shown in FIGS. 3 to 5) is provided between the plurality of heating units 52 and the outer metal sheath 54 to electrically insulate the heater units 52 from the outer metal sheath 54. The plurality of heater units 52 each include a core body 58 and a resistive heating element 60 surrounding the core body 58. The resistive heating element 60 of each heater unit 52 may define one or more heating circuits to define one or more heating zones 62.

[0018] In the present form, each heater unit 52 defines one heating zone 62 and the plurality of heater units 52 in each heater assembly 50 are aligned along a longitudinal direction X. Therefore, each heater assembly 50 defines a plurality of heating zones 62 aligned along the longitudinal direction X. The core body 58 of each heater unit 52 defines a plurality of through holes/apertures 64 to allow power conductors 56 to extend therethrough. The resistive heating elements 60 of the heater units 52 are connected to the power conductors 56, which, in turn, are connected to an external power supply device 14. The power conductors 56 supply the power from the power supply device 14 to the plurality of heater units 50. By properly connecting the power conductors 56 to the resistive heating elements 60, the resistive heating elements 60 of the plurality of heating units 52 can be independently controlled by the controller 15 of the power supply device 14. As such, failure of one resistive heating element 60 for a particular heating zone 62 will not affect the proper functioning of the remaining resistive heating elements 60 for the remaining heating zones 62. Further, the heater units 52 and the heater assemblies 50 may be interchangeable for ease of repair or assembly.

[0019] In the present form, six power conductors 56 are used for each heater assembly 50 to supply power to five independent electrical heating circuits on the five heater units 52. Alternatively, six power conductors 56 may be connected to the resistive heating elements 60 in a way to define three fully independent circuits on the five heater units 52. It is possible to have any number of power conductors 56 to form any number of independently controlled heating circuits and independently controlled heating zones 62. For example, seven power conductors 56 may be used to provide six heating zones 62. Eight power conductors 56 may be used to provide seven heating zones 62.

[0020] The power conductors 56 may include a plurality of power supply and power return conductors, a plurality of power return conductors and a single power supply conductor, or a plurality of power supply conductors and a single power return conductor. If the number of heater zones is *n,* the number of power supply and return conductors is *n +1*.

[0021] Alternatively, a higher number of electrically distinct heating zones 62 may be created through multiplexing, polarity sensitive switching and other circuit topologies by the controller 15 of the external power supply device 14. Use of multiplexing or various arrangements of thermal arrays to increase the number of heating zones within the cartridge heater 50 for a given number of power conductors (e.g. a cartridge heater with six power conductors for 15 or 30 zones.) is disclosed in U.S. Patent Nos. 9,123,755, 9,123,756, 9,177,840, 9,196,513, and their related applications.

[0022] With this structure, each heater assembly 50 includes a plurality of heating zones 62 that can be independently controlled to vary the power output or heat distribution along the length of the heater assembly 50. The heater bundle 12 includes a plurality of such heater assemblies 50. Therefore, the heater bundle 12 provides a plurality of heating zones 62 and a tailored heat distribution for heating the fluid that flows through the heater bundle 12 to be adapted for specific applications. The power supply device 14 can be configured to modulate power to each of the independently controlled heating zones 62.

[0023] For example, a heating assembly 50 may define an "m" heating zones, and the heater bundle may include "k" heating assemblies 50. Therefore, the heater bundle 12 may define $m \times k$ heating zones. The plurality of heating zones 62 in the heater bundle 12 can be individually and dynamically controlled in response to heating conditions and/or heating requirements, including but not limited to, the life and the reliability of the individual heater units 52, the sizes and costs of the heater units 52, local heater flux, characteristics and operation of the heater units 52, and the entire power output.

[0024] Each circuit is individually controlled at a desired temperature or a desired power level so that the distribution of temperature and/or power adapts to variations in system parameters (e.g. manufacturing variation/tolerances, changing environmental conditions, changing inlet flow conditions such as inlet temperature, inlet temperature distribution, flow velocity, velocity distribution, fluid composition, fluid heat capacity, etc.). More specifically, the heater units 52 may not generate the same heat output when operated under the same power level due to manufacturing variations as well as varied degrees of heater degradation over time. The heater units 52 may be independently controlled to adjust the heat output according to a desired heat distribution. The individual manufacturing tolerances of components of the heater system and assembly tolerances of the heater system are increased as a function of the modulated power of the power supply, or in other words, because of the high fidelity of heater control, manufacturing tolerance of individual components need not be as tight/narrow.

[0025] The heater units 52 may each include a temperature sensor (not shown) for measuring the temperature of the heater units 52. When a hot spot in the heater units 52 is detected, the power supply device 14 may reduce or turn off the power to the particular heater unit 52 on which the hot spot is detected to avoid overheating or failure of the particular heater unit 52. The power supply device 14 may modulate the power to the heater units 52 adjacent to the disabled heater unit 52 to compensate for the reduced heat output from the particular heater unit 52.

[0026] The power supply device 14 may include multi-zone algorithms to turn off or turn down the power level delivered to any particular zone, and to increase the power to the heating zones adjacent to the particular heating zone that is disabled and has a reduced heat output. By carefully modulating the power to each heating zone, the overall reliability of the system can be improved. By detecting the hot spot and controlling the power supply accordingly, the heater system 10 has improved safety.

[0027] The heater bundle 12 with the multiple independently controlled heating zones 62 can accomplish improved heating. For example, some circuits on the heater units 52 may be operated at a nominal (or "typical") duty cycle of less than 100% (or at an average power level that is a fraction of the power that would be produced by the heater with line voltage applied). The lower duty cycles allow for the use of resistive heating wires with a larger diameter, thereby improving reliability.

[0028] Normally, smaller zones would employ a finer wire size to achieve a given resistance. Variable power control allows a larger wire size to be used, and a lower resistance value can be accommodated, while protecting the heater from overloading with a duty cycle limit tied to the power dissipation capacity of the heater.

[0029] The use of a scaling factor may be tied to the capacity of the heater units 52 or the heating zone 62. The multiple heating zones 62 allow for more accurate determination and control of the heater bundle 12. The use of a specific scaling factor for a particular heating circuit/zone will allow for a more aggressive (i.e. higher) temperature (or power level) at almost all zones, which, in turn, lead to a smaller, less costly design for the heater bundle 12. Such a scaling factor and method is disclosed in U.S. Patent No. 7,257,464.

[0030] The sizes of the heating zones controlled by the individual circuits can be made equal or different to reduce the total number of zones needed to control the distribution of temperature or power to a desired accuracy.

[0031] Referring back to FIG. 1, the heater assemblies 18 are shown to be a single end heater, i.e., the conductive pin extends through only one longitudinal end of the heater assemblies 18. The heater assembly 18 may extend through the mounting flange 16 or a bulkhead (not shown) and sealed to the flange 16 or bulkhead. As such, the heater assemblies 18 can be individually removed and replaced without removing the mounting flange 16 from the vessel or tube.

[0032] Alternatively, the heater assembly 18 may be a "double ended" heater. In a double-ended heater, the metal sheath are bent into a hairpin shape and the power conductors pass through both longitudinal ends of the metal sheath so that both longitudinal ends of the metal sheath pass through and are sealed to the flange or bulkhead. In this structure, the flange or the bulkhead need to be removed from the housing or the vessel before the individual heater assembly 18 can be replaced.

[0033] Referring to FIG. 6, a heater bundle 12 is incorporated in a heat exchanger 70. The heat exchanger 70 includes a sealed housing 72 defining an internal chamber (not shown), a heater bundle 12 disposed within the internal chamber of the housing 72. The sealed housing 72 includes a fluid inlet 76 and a fluid outlet 78 through which fluid is directed into and out of the internal chamber of the sealed housing 72. The fluid is heated by the heater bundle 12 disposed in the sealed housing 72. The heater bundle 12 may be arranged for either cross-flow or for flow parallel to their length.

[0034] The heater bundle 12 is connected to an external power supply device 14 which may include a means to modulate power, such as a switching means or a variable transformer, to modulate the power supplied to an individual zone. The power modulation may be performed as a function of time or based on detected temperature of each heating zone.

[0035] The resistive heating wire may also function as a sensor using the resistance of the resistive wire to measure the temperature of the resistive wire and using the same power conductors to send temperature measurement information to the power supply device 14. A means of sensing temperature for each zone would allow the control of temperature along the length of each heater assembly 18 in the heater bundle 12 (down to the resolution of the individual zone). Therefore, the additional temperature sensing circuits and sensing means can be dispensed with, thereby reducing the manufacturing costs. Direct measurement of the heater circuit temperature is a distinct advantage when trying to maximize heat flux in a given circuit while maintaining a desired reliability level for the system because it eliminates or minimizes many of the measurement errors associated with using a separate sensor. The heating element temperature is the characteristic that has the strongest influence on heater reliability. Using a resistive element to function as both a heater and a sensor is disclosed in U.S. Patent No. 7,196,295.

[0036] Alternatively, the power conductors 56 may be made of dissimilar metals such that the power conductors 56 of dissimilar metals may create a thermocouple for measuring the temperature of the resistive heating elements. For example, at least one set of a power supply and a power return conductor may include different materials such that a junction is formed between the different materials and a resistive heating element of a heater unit and is used to determine temperature of one or more zones. Use of "integrated" and "highly thermally coupled" sensing, such as using different metals for the heater leads to generation of a thermocouple-like signal. The use of the integrated and coupled power conductors for temperature measurement is disclosed in U.S. Application No. 14/725,537.

[0037] The controller 15 for modulating the electrical power delivered to each zone may be a closed-loop automatic control system. The closed-loop automatic control system 15 receives the temperature feedback from each zone and automatically and dynamically controls the delivery of power to each zone, thereby automatically and dynamically controlling the power distribution and temperature along the length of each heater assembly 18 in the heater bundle 12 without continuous or frequent human monitoring and adjustment.

[0038] The heater units 52 as disclosed herein may also be calibrated using a variety of methods including but not limited to energizing and sampling each heater unit 52 to calculate its resistance. The calculated resistance can then be compared to a calibrated resistance to determine a resistance ratio, or a value to then determine actual heater unit temperatures. Exemplary methods are disclosed in U.S. Patent Nos. 5,280,422 and 5,552,998.

[0039] One form of calibration includes operating the heater system 10 in at least one mode of operation, controlling the heater system 10 to generate a desired temperature for at least one of the independently controlled heating zones 62, collecting and recording data for the at least one independently controlled heating zones 62 for the mode of operation, then accessing the recorded data to determine operating specifications for a heating system having a reduced number of independently controlled heating zones, and then using the heating system with the reduced number of independently controlled heating zones. The data may include, by way of example, power levels and/or temperature information, among other operational data from the heater system 10 having its data collected and recorded.

[0040] In a variation of the present disclosure, the heater system may include a single heater assembly 18, rather than a plurality of heater assemblies in a bundle 12. The single heater assembly 18 would comprise a plurality of heater units 52, each heater unit 52 defining at least one independently controlled heating zone. Similarly, power conductors 56 are electrically connected to each of the independently controlled heating zones 62 in each of the heater units 62, and the power supply device is configured to modulate power to each of the independently controlled heater zones 62 of the heater units through the power conductors 56.

[0041] Referring to FIG. 7, a method 100 of controlling a heater system includes providing a heater bundle comprising a plurality of heater assemblies in step 102. Each heater assembly includes a plurality of heater units. Each heater unit defines at least one independently controlled heating circuit (and consequently heating zone). The power to each of the heater units is supplied through power conductors electrically connected to each of the independently controlled heating zones in each of the heater units in step 104. The temperature within each of the zones is detected in step 106. The temperature may be determined using a change in resistance of a resistive heating element of at least one of the heater units. The zone temperature may be initially determined by measuring the zone resistance (or, by measurement of circuit voltage, if appropriate materials are used).

[0042] The temperature values may be digitalized. The signals may be communicated to a microprocessor. The measured (detected) temperature values may be compared to a target (desired) temperature for each zone in step 108. The power supplied to each of the heater units may be modulated based on the measured temperature to achieve the target temperatures in step 110.

[0043] Optionally, the method may further include using a scaling factor to adjust the modulating power. The scaling factor may be a function of a heating capacity of each heating zone. The controller 15 may include an algorithm, potentially including a scaling factor and/or a mathematical model of the dynamic behavior of the system (including knowledge of the update time of the system), to determine the amount of power to be provided (via duty cycle, phase angle firing, voltage modulation or similar techniques) to each zone until the next update. The desired power may be converted to a signal, which is sent to a switch or other power modulating device for controlling power output to the individual heating zones.

[0044] In the present form, when at least one heating zone is turned off due to an anomalous condition, the remaining zones continue to provide a desired wattage without failure. Power is modulated to a functional heating zone to provide a desired wattage when an anomalous condition is detected in at least one heating zone. When at least one heating zone is turned off based on the determined temperature, the remaining zones continue to provide a desired wattage. The power is modulated to each of the heating zones as a function of at least one of received signals, a model, and as a function of time.

[0045] For safety or process control reasons, typical heaters are generally operated to be below a maximum allowable temperature in order to prevent a particular location of the heater from exceeding a given temperature due to unwanted chemical or physical reactions at the particular location, such as combustion/fire/oxidation, coking boiling etc.). Therefore, this is normally accommodated by a conservative heater design (e.g., large heaters with low power density and much of their surface area loaded with a much lower heat flux than might otherwise be possible).

[0046] However, with the heater bundle of the present disclosure, it is possible to measure and limit the temperature of any location within the heater down to a resolution on the order of the size of the individual heating zones. A hot spot large enough to influence the temperature of an individual circuit can be detected.

[0047] Since the temperature of the individual heating zones can be automatically adjusted and consequently limited, the dynamic and automatic limitation of temperature in each zone will maintain this zone and all other zones to be operating at an optimum power/heat flux level without fear of exceeding the desired temperature limit in any zone. This brings an advantage in high-limit temperature measurement accuracy over the current practice of clamping a separate thermocouple to the sheath of one of the elements in a bundle. The reduced margin and the ability to modulate the power to individual zones can be selectively applied to the heating zones, selectively and individually, rather than applied to an entire heater assembly, thereby reducing the risk of exceeding a predetermined temperature limit.

[0048] The characteristics of the cartridge heater may vary with time. This time varying characteristic would otherwise require that the cartridge heater be designed for a single selected (worse-case) flow regime and therefore that the cartridge heater would operate at a sub-optimum state for other states of flow.

[0049] However, with dynamic control of the power distribution over the entire bundle down to a resolution of the core size due to the multiple heating units provided in the heater assembly, an optimized power distribution for various states of flow can be achieved, as opposed to only one power distribution corresponding to only one flow state in the typical cartridge heater. Therefore, the heater bundle of the present application allows for an increase in the total heat flux for all other states of flow.

[0050] Further, variable power control can increase heater design flexibility. The voltage can be de-coupled from resistance (to a great degree) in heater design and the heaters may be designed with the maximum wire diameter that can be fitted into the heater. It allows for increased capacity for power dissipation for a given heater size and level of reliability (or life of the heater) and allows for the size of the bundle to be decreased for a given overall power level. Power in this arrangement can be modulated by a variable duty cycle that is a part of the variable wattage controllers currently available or under development. The heater bundle can be protected by a programmable (or pre-programmed if desired) limit to the duty cycle for a given zone to prevent "overloading" the heater bundle.

[0051] In still another form of the present disclosure, a method and apparatus to reduce current leakage is provided. One method of controlling a heating system comprises providing at least one heater assembly, the heater assembly comprising a plurality of heater units, each heater unit defining at least one independently controlled heating zone as set forth above. Power is supplied to each of the heater units through power conductors electrically connected to each of the independently controlled heating zones in each of the heater units, and the power supplied is modulated to each of the independently controlled heating zones. In order to reduce current leakage, a voltage from the power supply is selectively supplied to each of the independently controlled heating zones such that a reduced number of independently controlled heating zones receives the voltage at a time. In one example, the voltage may be selectively supplied by a variable transformer.

[0052] The independently controlled zones can be switched in sequence thus limiting the number of zones (and the cross-sectional area of electrical insulation that is exposed to electrical potential). By limiting the number of zones (and the area) subjected to the electrical potential at any given time to a fraction of the total number of zones, we can reduce the current leakage by a similar fraction. For example, if the zones in a heater bundle are divided into four groups (not necessarily geometrically contiguous) and if each of these groups covered approximately 1/4 of the total area of the heater, and further, if the switching scheme is configured so that no more than one of the four zones is powered on at any given instant in time, then the overall leakage current from the heater can be reduced by a factor of 4 (to 25% of its original value).

[0053] In order to accomplish the selective supply of voltage, in one form a scaling factor is employed. The scaling factor may be employed according to the teachings of U.S. Patent No. 7,257,464. The scaling factor may be employed for at least one of adjusting the modulating power, determining a magnitude of the voltage to be selectively supplied, and determining a duration for which the voltage is selectively supplied.

[0054] Further, the scaling factor may be a function of operational characteristics of the heating system. For example, the scaling factor can be a function of power dissipation capacity of at least one independently controlled heating zone, a maximum allowable temperature of at least one independently controlled heating zone, an exposed heating area of at least one independently controlled heating zone, a thermal behavior model of the heating system, characteristics of an environmental system producing fluid flow being heated by the heater system, a fluid flow rate across the heater assembly, an area of at least one independently controlled heating zone, electrical insulation resistance of at least one independently controlled heating zone, an electrical current leakage of at least one independently controlled heating zone, a circuit resistance of at least one independently controlled heating zone, a zone circuit EMF of at least one independently controlled heating zone, and a dielectric constant of at least one independently controlled heating zone, among others.

[0055] In another form, the scaling factor is a power limiting function that limits a value that is one of wattage, magnitude of voltage selectively supplied, and duration for which the voltage is selectively supplied provided to each heating zone to multiple values less than that produced at a full line voltage through the use of a scaling function, the scaling function being a ratio between a desired value and the value full line voltage, wherein a power controller provides a scaled output by multiplying the percentage output by the scaling function.

[0056] The order and/or location of the independently controlled heating zones to which the voltage is sequentially supplied may be any of a variety depending on application requirements. For example, voltage may be sequentially supplied around a periphery or around edges of a heater first before being next supplied to other geometric areas of independently controlled heating zones. Further, the voltage may be sequentially supplied to different heating zones based on a change in resistance of each heating zone.

[0057] In another form, at least one heating zone is turned off based on an anomalous condition, while remaining zones continue to receive voltage selectively.

[0058] In still another form, a rate of succesively supplying the voltage to each of the heating zones is adjusted based on at least one operational characteristic of at least one heating zone. The operational characteristics may be, by way of example, resistance, temperature, and change in resistance over time of at least one heating zone, a fluid flow rate across the heater assembly, an area of an independently controlled heating zone, electrical insulation resistance of at least one independently controlled heating zone, an electrical current leakage of at least one independently controlled heating zone, a circuit resistance of at least one independently controlled heating zone, a zone circuit EMF of at least one independently controlled heating zone, a dielectric constant of at least one independently controlled heating zone, and characteristics of an environmental system producing fluid flow being heated by the heater system.

[0059] The methods according to this form of the present disclosure that reduces leakage current may also be applied to at least one heater assembly, the heater assembly comprising a plurality of heater units, each heater unit defining at least one independently controlled heating zone. The methods can be employed with any of the embodiments of heaters and heater systems disclosed herein while remaining within the scope of the present disclosure.

[0060] It should be noted that the disclosure is not limited to the embodiment described and illustrated as examples. A large variety of modifications have been described and more are part of the knowledge of the person skilled in the art. These and further modifications as well as any replacement by technical equivalents may be added to the description and figures, without leaving the scope of the protection of the disclosure and of the present patent.

Claims

1. A method of controlling a heating system (10) comprising:

   providing at least one heater assembly (18), the heater assembly comprising a plurality of heater units (52), each heater unit (52) including a core body (58) and defining at least one independently controlled heating zone (62);
   supplying power to each of the heater units (52) through a plurality of power conductors (56) extending through holes (64) defined in the core bodies (58) and electrically connected to each of the independently controlled heating zones (62) in each of the heater units (52); and
   modulating power supplied to each of the independently controlled heating zones (62), by switching the independently controlled heating zones (62) such that a reduced number of independently controlled heating zones (62) receives voltage at a time to reduce current leakage while allowing the independently controlled heating zones (62) to provide a desired power distribution along the length of the heater assembly (18).

2. The method according to Claim 1 further comprising using a scaling factor for determining a duration for which the voltage is selectively supplied.

3. The method according to Claim 2 further comprising using the scaling factor as a function of at least one of a power dissipation capacity of at least one independently controlled heating zone (62), a maximum allowable temperature of at least one independently controlled heating zone (62), an exposed heating area of at least one independently controlled heating zone (62), a thermal behavior model of the heating system, characteristics of an environmental system producing fluid flow being heated by the heater system, a fluid flow rate across the heater assembly, an area of at least one independently controlled heating zone (62), electrical insulation resistance of at least one independently controlled heating zone (62), an electrical current leakage of at least one independently controlled heating zone (62), a circuit resistance of at least one independently controlled heating zone (62), a zone circuit EMF of at least one independently controlled heating zone (62), and a dielectric constant of at least one independently controlled heating zone (62).

4. The method according to Claim 2, wherein the scaling factor is a power limiting function that limits a value that is one of wattage, magnitude of voltage selectively supplied, and duration for which the voltage is selectively supplied provided to each heating zone (62) to multiple values less than that produced at a full line voltage through the use of a scaling function, the scaling function being a ratio between a desired value and the value full line voltage, wherein a power controller provides a scaled output by multiplying the percentage output by the scaling function.

5. The method according to Claim 1, wherein the voltage is sequentially supplied to predetermined geometric areas of the independently controlled heating zones (62).

6. The method according to Claim 1, wherein at least one heating zone (62) is turned off based on an anomalous condition, while remaining zones continue to receive the voltage selectively.

7. The method according to Claim 1, wherein a rate of successively supplying the voltage to each of the heating zones (62) is adjusted based on an operational characteristic of at least one heating zone (62).

8. The method according to Claim 7, wherein the operational characteristic is one of resistance, temperature, and change in resistance over time of at least one heating zone (62), a fluid flow rate across the heater assembly, an area of an independently controlled heating zone (62), electrical insulation resistance of at least one independently controlled heating zone (62), an electrical current leakage of at least one independently controlled heating zone (62), a circuit resistance of at least one independently controlled heating zone, a zone circuit EMF of at least one independently controlled heating zone, a dielectric constant of at least one independently controlled heating zone (62), and characteristics of an environmental system producing fluid flow being heated by the heater system.

9. A heater system (10) comprising:

   one or more heater assemblies (18), each heater assembly (18) comprising a plurality of heater units (52), each heater unit (52) including a core body (58) and defining at least one independently controlled heating zone (62); and
   a plurality of power conductors (56) extending through holes (64) defined in the core bodies (58) and electrically connected to each of the independently controlled heating zones (62) in each of the heater units (52);

   characterised in that the heater system comprises a power supply device including a controller configured to modulate power to each of the independently controlled heating zones (62) of the heater units (52) through the power conductors (56) by switching the independently controlled heating zones such that a reduced number of independently controlled heating zones (62) receives voltage at a time to reduce leakage current while allowing the independently controlled heating zones (62) to provide a desired power distribution along the length of the heater assembly (18).

10. The heater system (10) according to Claim 9, wherein the voltage is selectively supplied via a variable transformer.

11. The heater system (10) according to Claim 9, wherein the plurality of power conductors includes at least one set of a power supply and a power return conductors (56) comprising different materials such that a junction is formed between the different materials and a resistive heating element of a heater unit (52) and is used to determine temperature of one or more heating zones (62).

12. The heater system (10) according to Claim 9, wherein the number of heater zones is *n*, and a number of power conductors (56) is *n +1.*

13. The heater system (10) according to Claim 9, wherein the power supply sequentially supplies the voltage to predetermined geometric areas of the independently controlled heating zones.

14. The method according to Claim 1 or the heater system (10) according to Claim 9, wherein the voltage is sequentially supplied, preferably by the power supply device, to different heating zones based on a change in resistance of each heating zone.

15. The heater system (10) according to Claim 9, wherein the power supply device turns off at least one heating zone (62) based on an anomalous condition, while remaining zones (62) continue to receive voltage selectively.

Patentansprüche

1. Verfahren zum Steuern eines Heizsystems (10), umfassend:

Bereitstellen mindestens einer Heizeranordnung (18), wobei die Heizeranordnung eine Vielzahl von Heizereinheiten (52) umfasst, wobei jede Heizereinheit (52) einen Kernkörper (58) beinhaltet, und mindestens eine unabhängig gesteuerte Heizzone (62) definiert;

Zuführen von Strom zu jeder der Heizereinheiten (52) durch eine Vielzahl von Stromleitern (56), die sich durch Löcher (64) hindurch erstrecken, die in den Kernkörpern (58) definiert sind, und elektrisch mit jeder der unabhängig gesteuerten Heizzonen (62) in jeder der Heizereinheiten (52) verbunden sind; und

Modulieren des jeder der unabhängig gesteuerten Heizzonen (62) zugeführten Stroms durch Schalten der unabhängig gesteuerten Heizzonen (62), sodass eine verringerte Anzahl an unabhängig gesteuerten Heizzonen (62) Spannung zu einer Zeit empfängt, um Leckstrom zu verringern, während es den unabhängig gesteuerten Heizzonen (62) erlaubt wird, eine gewünschte Stromverteilung entlang der Länge der Heizeranordnung (18) bereitzustellen.

2. Verfahren nach Anspruch 1, weiter umfassend das Verwenden eines Skalierungsfaktors zum Bestimmen einer Dauer, in der die Spannung selektiv zugeführt wird.

3. Verfahren nach Anspruch 2, weiter umfassend das Verwenden des Skalierungsfaktors in Abhängigkeit von mindestens einem von einer Verlustleistungskapazität von mindestens einer unabhängig gesteuerten Heizzone (62), von einer maximal zulässigen Temperatur von mindestens einer unabhängig gesteuerten Heizzone (62), von einem ausgesetzten Heizbereich von mindestens einer unabhängig gesteuerten Heizzone (62), von einem Wärmeverhaltensmodell des Heizsystems, von Eigenschaften eines Umgebungssystems, welches Fluidstrom erzeugt, der durch das Heizersystem erwärmt wird, von einer Fluidflussrate durch die Heizeranordnung hindurch, von einem Bereich von mindestens einer unabhängig gesteuerten Heizzone (62), von einem elektrischen Isolationswiderstand von mindestens einer unabhängig gesteuerten Heizzone (62), von einem elektrischen Leckstrom von mindestens einer unabhängig gesteuerten Heizzone (62), von einem Schaltungswiderstand von mindestens einer unabhängig gesteuerten Heizzone (62), von einer EMF-Zonenschaltung von mindestens einer unabhängig gesteuerten Heizzone (62), und von einer dielektrischen Konstanten von mindestens einer unabhängig gesteuerten Heizzone (62).

4. Verfahren nach Anspruch 2, wobei der Skalierungsfaktor eine Strombegrenzungsfunktion ist, die einen Wert begrenzt, der einer von Wattzahl, Größe einer selektiv zugeführten Spannung, und Dauer, in der die Spannung selektiv zugeführt, einer jeden Heizzone (62) bereitgestellt wird, auf mehrere Werte, geringer als jener, der auf einer vollen Netzspannung erzeugt wird, durch die Verwendung einer Skalierungsfunktion, wobei die Skalierungsfunktion ein

Verhältnis zwischen einem gewünschten Wert und dem Wert der vollen Netzspannung ist, wobei eine Stromsteuerung einen skalierten Ausgang durch Multiplizieren des prozentualen Ausgangs mit der Skalierungsfunktion bereitstellt.

5. Verfahren nach Anspruch 1, wobei die Spannung sequenziell vorbestimmten geometrischen Bereichen der unabhängig gesteuerten Heizzonen (62) zugeführt wird.

6. Verfahren nach Anspruch 1, wobei mindestens eine Heizzone (62) basierend auf einem anormalen Zustand abgeschaltet wird, während die verbleibenden Zonen die Spannung weiter selektiv empfangen.

7. Verfahren nach Anspruch 1, wobei eine Rate von sukzessivem Zuführen der Spannung zu jeder der Heizzonen (62) basierend auf einer betrieblichen Eigenschaft von mindestens einer Heizzone (62) angepasst wird.

8. Verfahren nach Anspruch 7, wobei die betriebliche Eigenschaft eine ist von Widerstand, Temperatur, und Änderung des Widerstands mit der Zeit von mindestens einer Heizzone (62), einer Fluidflussrate durch die Heizeranordnung, einem Bereich einer unabhängig gesteuerten Heizzone (62), elektrischem Isolationswiderstand von mindestens einer unabhängig gesteuerten Heizzone (62), einem elektrischen Leckstrom von mindestens einer unabhängig gesteuerten Heizzone (62), einem Schaltungswiderstand von mindestens einer unabhängig gesteuerten Heizzone, einer EMF-Zonenschaltung von mindestens einer unabhängig gesteuerten Heizzone, einer dielektrischen Konstante von mindestens einer unabhängig gesteuerten Heizzone (62), und Eigenschaften von einem Umgebungssystems, das den Fluidfluss erzeugt, der durch das Heizersystem erwärmt wird.

9. Heizersystem (10), umfassend:

eine oder mehrere Heizeranordnungen (18), wobei jede Heizeranordnung (18) eine Vielzahl von Heizereinheiten (52) umfasst, wobei jede Heizereinheit (52) einen Kernkörper (58) beinhaltet, und mindestens eine unabhängig gesteuerte Heizzone (62) definiert; und
eine Vielzahl von Stromleitern (56), die sich durch Löcher (64) hindurch erstrecken, die in den Kernkörpern (58) definiert sind, und elektrisch mit jeder der unabhängig gesteuerten Heizzonen (62) in jeder der Heizereinheiten (52) verbunden sind;
dadurch gekennzeichnet, dass das Heizersystem umfasst
eine Stromzuführungsvorrichtung, die eine Steuerung beinhaltet, die konfiguriert ist, um Strom zu jeder der unabhängig gesteuerten Heizzonen (62) der Heizereinheiten (52) durch die Stromleiter (56) hindurch durch Schalten der unabhängig gesteuerten Heizzonen zu modulieren, sodass eine verringerte Anzahl an unabhängig gesteuerten Heizzonen (62) Spannung zu einer Zeit empfängt, um Leckstrom zu verringern, während es den unabhängig gesteuerten Heizzonen (62) erlaubt wird, eine gewünschte Stromverteilung entlang der Länge der Heizeranordnung (18) bereitzustellen.

10. Heizersystem (10) nach Anspruch 9, wobei die Spannung selektiv über einen variablen Transformator zugeführt wird.

11. Heizersystem (10) nach Anspruch 9, wobei die Vielzahl von Stromleitern mindestens einen Satz an Stromzuführungs- und Stromrückführleitern (56) beinhaltet, die unterschiedliche Werkstoffe umfassen, sodass eine Anschlussstelle zwischen den unterschiedlichen Werkstoffen und einem Widerstandsheizelement einer Heizereinheit (52) gebildet wird, und verwendet wird, um die Temperatur von einer oder mehreren Heizzonen (62) zu bestimmen.

12. Heizersystem (10) nach Anspruch 9, wobei die Anzahl an Heizerzonen n ist, und eine Anzahl an Stromleitern (56) $n+1$ ist.

13. Heizersystem (10) nach Anspruch 9, wobei die Stromzuführung die Spannung sequenziell vorbestimmten geometrischen Bereichen der unabhängig gesteuerten Heizzonen zuführt.

14. Verfahren nach Anspruch 1, oder Heizersystem (10) nach Anspruch 9, wobei die Spannung sequenziell, vorzugsweise durch die Stromzuführungsvorrichtung, basierend auf einer Änderung des Widerstands verschiedener Heizzonen verschiedenen Heizzonen zugeführt wird.

15. Heizersystem (10) nach Anspruch 9, wobei die Stromzuführungsvorrichtung mindestens eine Heizzone (62) basierend auf einem anormalen Zustand abschaltet, während verbleibende Zonen (62) die Spannung weiter selektiv empfangen.

Revendications

1. Procédé de commande d'un système de chauffage (10) comprenant :

la fourniture d'au moins un ensemble chauffant (18), l'ensemble chauffant comprenant une pluralité d'unités chauffantes (52), chaque unité

chauffante (52) comportant un corps central (58) et définissant au moins une zone de chauffage (62) à commande indépendante ;
l'alimentation électrique de chacune des unités chauffantes (52) au moyen d'une pluralité de conducteurs d'alimentation électrique (56) s'étendant à travers des trous (64) définis dans les corps centraux (58) et connectés électriquement à chacune des zones de chauffage (62) à commande indépendante dans chacune des unités chauffantes (52) ; et
la modulation de la puissance fournie à chacune des zones de chauffage (62) à commande indépendante, en commutant les zones de chauffage (62) à commande indépendante de telle sorte qu'un nombre réduit de zones de chauffage (62) à commande indépendante reçoive une tension à un instant donné pour réduire le courant de fuite tout en permettant aux zones de chauffage (62) à commande indépendante de fournir une distribution de puissance souhaitée sur la longueur de l'ensemble chauffant (18).

2. Procédé selon la revendication 1, comprenant en outre l'utilisation d'un facteur d'échelle pour la détermination d'une durée pendant laquelle la tension est fournie sélectivement.

3. Procédé selon la revendication 2, comprenant en outre l'utilisation du facteur d'échelle en fonction d'au moins une capacité de dissipation de puissance d'au moins une zone de chauffage (62) à commande indépendante, une température maximale admissible d'au moins une zone de chauffage (62) à commande indépendante, une zone de chauffage exposée d'au moins une zone de chauffage (62) à commande indépendante, un modèle de comportement thermique du système de chauffage, des caractéristiques d'un système environnemental produisant un écoulement de fluide chauffé par le système de chauffage, un débit de fluide à travers l'ensemble chauffant, une zone d'au moins une zone de chauffage (62) à commande indépendante, une résistance d'isolation électrique d'au moins une zone de chauffage (62) à commande indépendante, un courant électrique de fuite d'au moins une zone de chauffage (62) à commande indépendante, une résistance de circuit d'au moins une zone de chauffage (62) à commande indépendante, une FEM de circuit de zone d'au moins une zone de chauffage (62) à commande indépendante, et une constante diélectrique d'au moins une zone de chauffage (62) à commande indépendante.

4. Procédé selon la revendication 2, dans lequel le facteur d'échelle est une fonction de limitation de puissance qui limite une valeur parmi la puissance en watts, l'amplitude de la tension fournie sélectivement et la durée pendant laquelle la tension est fournie sélectivement fournie à chaque zone de chauffage (62) à de multiples valeurs inférieures que celle produite à une tension de ligne complète à travers l'utilisation d'une fonction de mise à l'échelle, la fonction de mise à l'échelle étant un rapport entre une valeur souhaitée et la valeur de tension de ligne complète, dans lequel un contrôleur de puissance fournit une sortie mise à l'échelle en multipliant le pourcentage en sortie par la fonction de mise à l'échelle.

5. Procédé selon la revendication 1, dans lequel la tension est appliquée séquentiellement à des zones géométriques prédéterminées des zones de chauffage (62) à commande indépendante.

6. Procédé selon la revendication 1, dans lequel au moins une zone de chauffage (62) est éteinte sur la base d'une condition d'anomalie, alors que les zones restantes continuent de recevoir la tension de manière sélective.

7. Procédé selon la revendication 1, dans lequel la vitesse de fourniture successive de la tension à chacune des zones de chauffage (62) est ajustée sur la base d'une caractéristique opérationnelle d'au moins une zone de chauffage (62).

8. Procédé selon la revendication 7, dans lequel la caractéristique opérationnelle est l'une parmi la résistance, la température et le changement de résistance au cours du temps d'au moins une zone de chauffage (62), un débit de fluide à travers l'ensemble chauffant, une zone d'une zone de chauffage (62) à commande indépendante, une résistance d'isolation d'au moins une zone de chauffage (62) à commande indépendante, un courant électrique de fuite d'au moins une zone de chauffage (62) à commande indépendante, une résistance de circuit d'au moins une zone de chauffage (62) à commande indépendante, une FEM de circuit de zone d'au moins une zone de chauffage à commande indépendante, une constante diélectrique d'au moins une zone de chauffage (62) à commande indépendante, et des caractéristiques d'un système environnemental produisant un écoulement de fluide chauffé par le système de chauffage.

9. Système de chauffage (10) comprenant :

un ou plusieurs ensembles chauffants (18), chaque ensemble chauffant (18) comprenant une pluralité d'unités chauffantes (52), chaque unité chauffante (52) comportant un corps central (58) et définissant au moins une zone de chauffage (62) à commande indépendante ; et
une pluralité de conducteurs d'alimentation électrique (56) s'étendant à travers des trous (64) définis dans les corps centraux (58) et con-

nectés électriquement à chacune des zones de chauffage (62) à commande indépendante dans chacune des unités chauffantes (52) ;
caractérisé en ce que le système de chauffage comprend
un dispositif d'alimentation électrique comportant un contrôleur configuré pour moduler la puissance de chacune des zones de chauffage (62) à commande indépendante des unités chauffantes (52) au moyen des conducteurs d'alimentation électrique (56) en commutant les zones de chauffage à commande indépendante de telle sorte qu'un nombre réduit de zones de chauffage (62) à commande indépendante reçoive une tension à un instant donné pour réduire le courant de fuite tout en permettant aux zones de chauffage (62) à commande indépendante de fournir une distribution de puissance souhaitée sur la longueur de l'ensemble chauffant (18).

10. Système de chauffage (10) selon la revendication 9, dans lequel la tension est fournie sélectivement via un transformateur variable.

11. Système de chauffage (10) selon la revendication 9, dans lequel la pluralité de conducteurs d'alimentation électrique comporte au moins un ensemble d'un conducteur d'arrivée de puissance et d'un conducteur de retour de puissance (56) comprenant différents matériaux de telle sorte qu'une jonction est formée entre les différents matériaux et un élément chauffant résistif d'une unité chauffante (52) et est utilisée pour déterminer la température d'une ou plusieurs zones de chauffage (62).

12. Système de chauffage (10) selon la revendication 9, dans lequel le nombre de zones de chauffage est n, et le nombre de conducteurs d'alimentation électrique (56) est $n+1$.

13. Système de chauffage (10) selon la revendication 9, dans lequel l'alimentation électrique fournit séquentiellement la tension à des zones géométriques prédéterminées des zones de chauffage (62) à commande indépendante.

14. Procédé selon la revendication 1 ou système de chauffage (10) selon la revendication 9, dans lequel la tension est fournie séquentiellement, de préférence par le dispositif d'alimentation électrique, à différentes zones de chauffage sur la base d'un changement de résistance de chaque zone de chauffage.

15. Système de chauffage (10) selon la revendication 9, dans lequel le dispositif d'alimentation électrique éteint au moins une zone de chauffage (62) sur la base d'une condition d'anomalie, alors que les zones restantes (62) continuent de recevoir la tension de manière sélective.

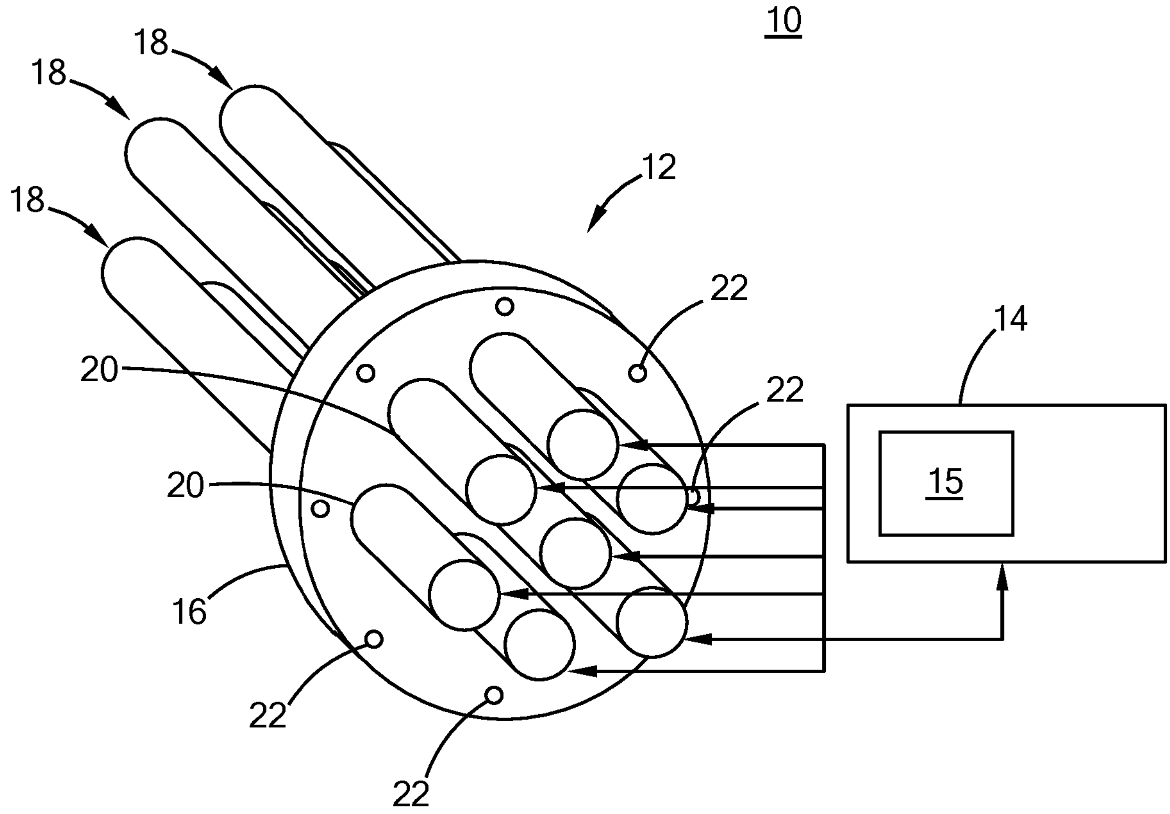

FIG. 1

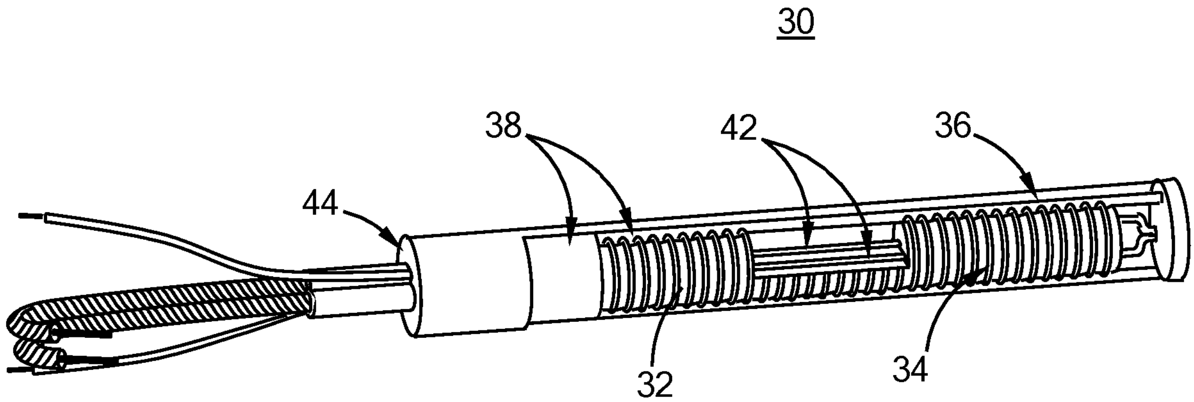

FIG. 2

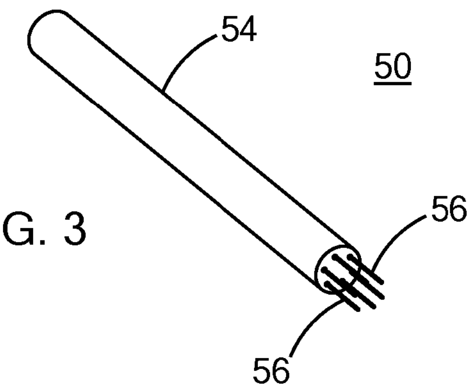

FIG. 3

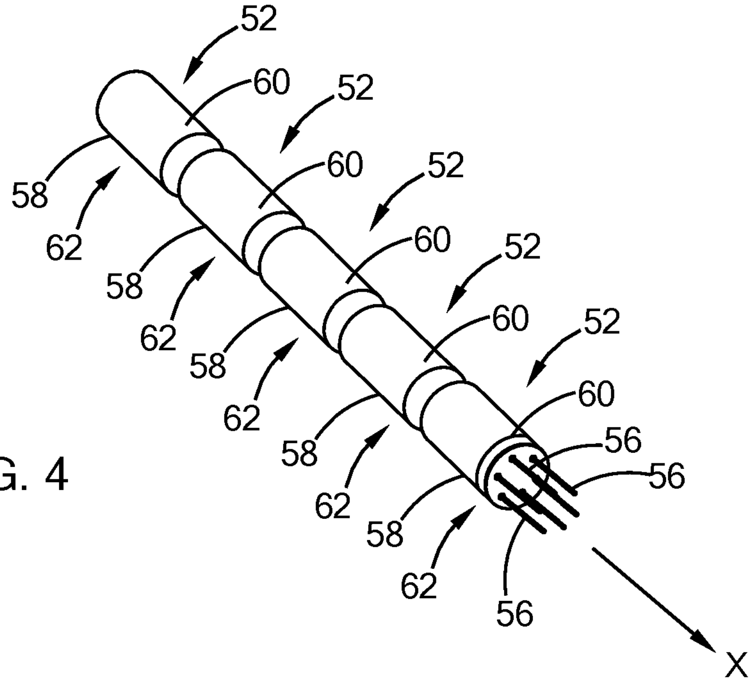

FIG. 4

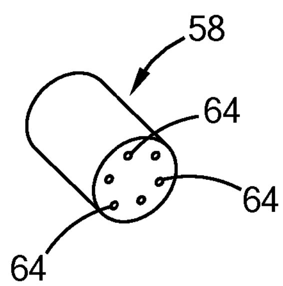

FIG. 5

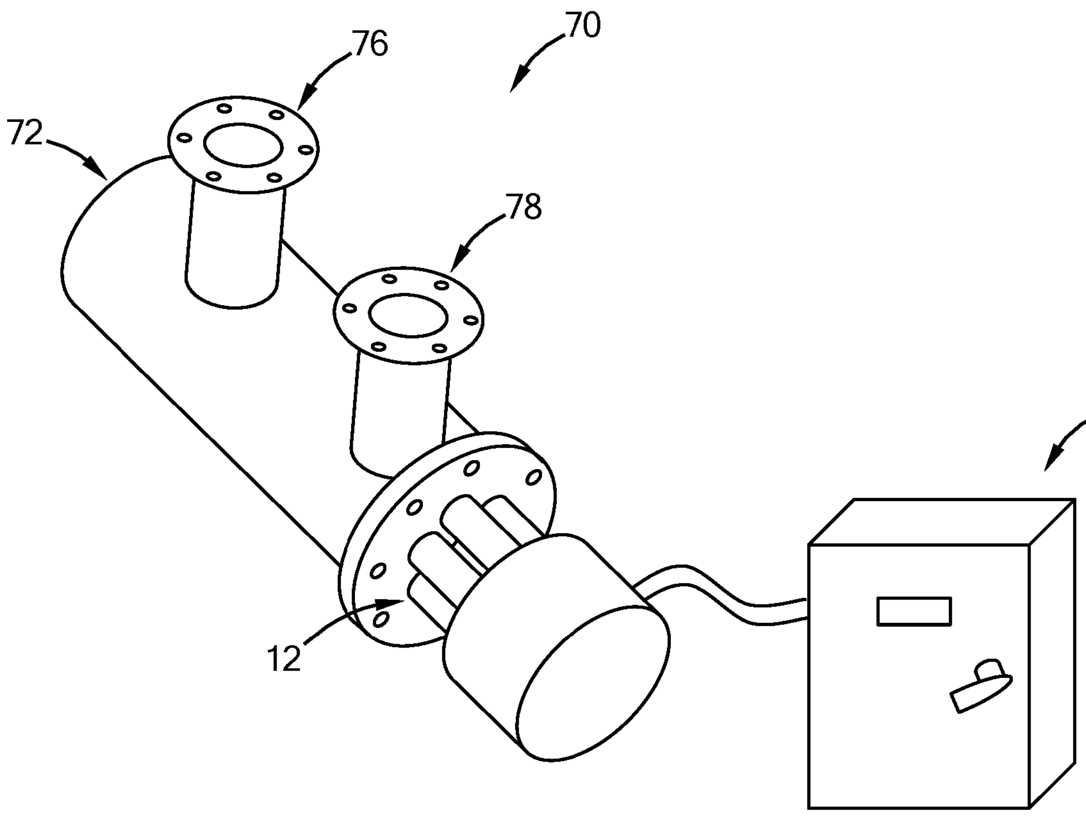

FIG. 6

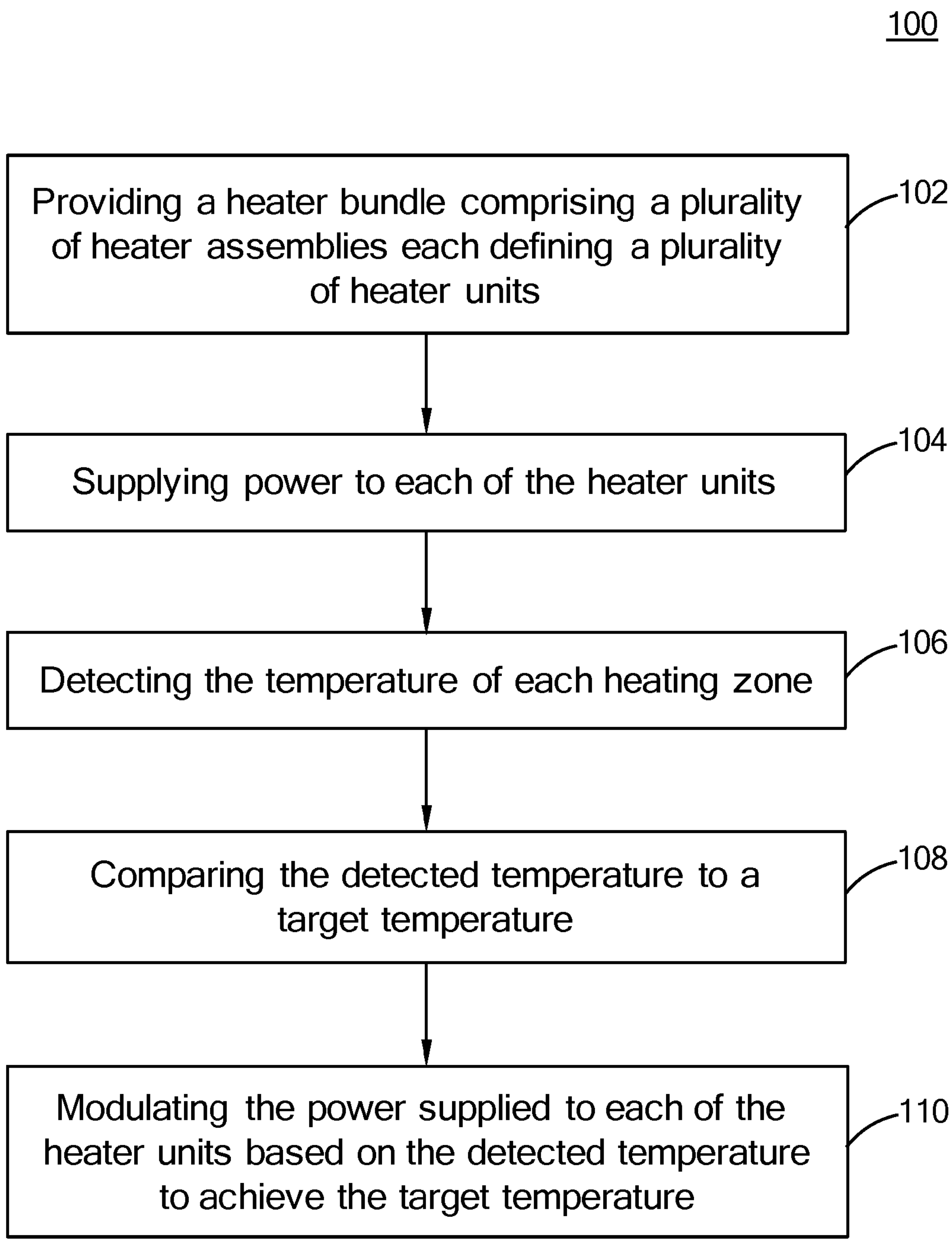
100
Providing a heater bundle comprising a plurality of heater assemblies each defining a plurality of heater units
102
Supplying power to each of the heater units
104
Detecting the temperature of each heating zone
106
Comparing the detected temperature to a target temperature
108
Modulating the power supplied to each of the heater units based on the detected temperature to achieve the target temperature
110

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 4039995 A **[0005]**
- US 2831951 A **[0015]**
- US 3970822 A **[0015]**
- US 9123755 B **[0021]**
- US 9123756 B **[0021]**
- US 9177840 B **[0021]**
- US 9196513 B **[0021]**
- US 7257464 B **[0029] [0053]**
- US 7196295 B **[0035]**
- US 725537 **[0036]**
- US 5280422 A **[0038]**
- US 5552998 A **[0038]**