US 20100046934A1

(19) **United States**
(12) **Patent Application Publication**
Johnson et al.
(10) **Pub. No.: US 2010/0046934 A1**
(43) **Pub. Date: Feb. 25, 2010**

(54) **HIGH THERMAL TRANSFER SPIRAL FLOW HEAT EXCHANGER**

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(21) Appl. No.: **12/194,399**

(22) Filed: **Aug. 19, 2008**

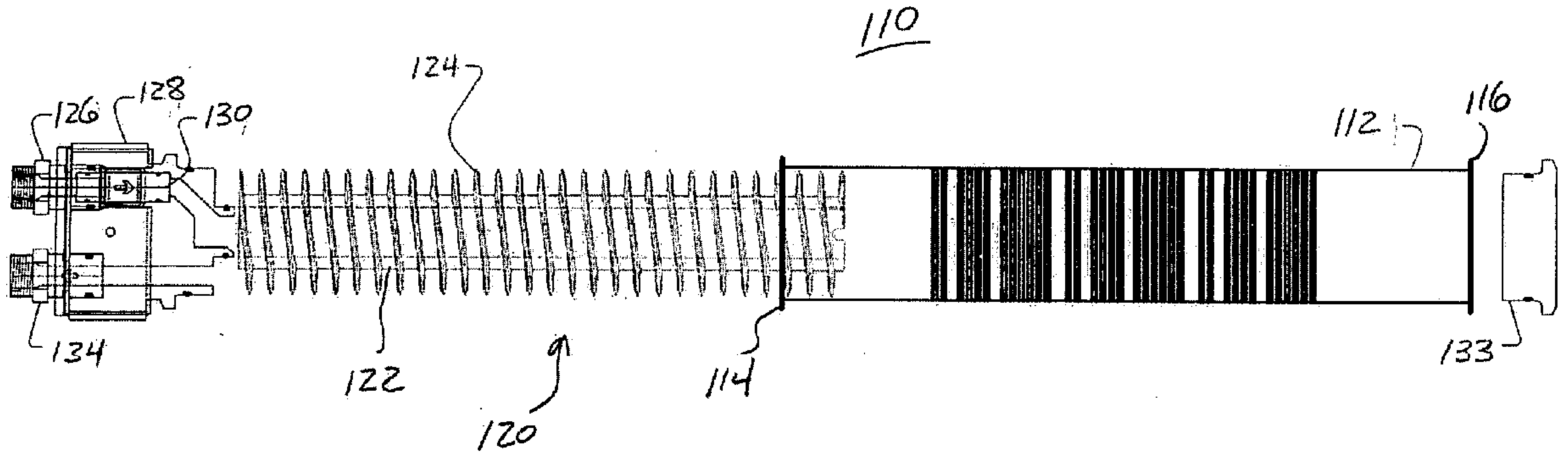
Publication Classification

(51) **Int. Cl.**
F24H 1/12 (2006.01)
F28F 1/20 (2006.01)

(52) **U.S. Cl.** **392/480**; 165/181

(57) **ABSTRACT**

A fluid heating system with a heat exchanger includes an elongated cylindrical tube with an inlet end and an opposed end. An array of film resistive elements is positioned on the outer surface of the cylindrical tube and extends circumferentially at least partially around the outer surface. A spiral channel guide is coaxially positioned within the cylindrical tube so as to force fluid flowing in the tube into a spiral path at least partially against an inner surface of the cylindrical tube. The spiral channel guide directs fluid flowing in the cylindrical tube so as to cause turbulence to occur in the flow and increase thermal transfer from the inner surface of the cylindrical tube to the fluid flowing in the tube.



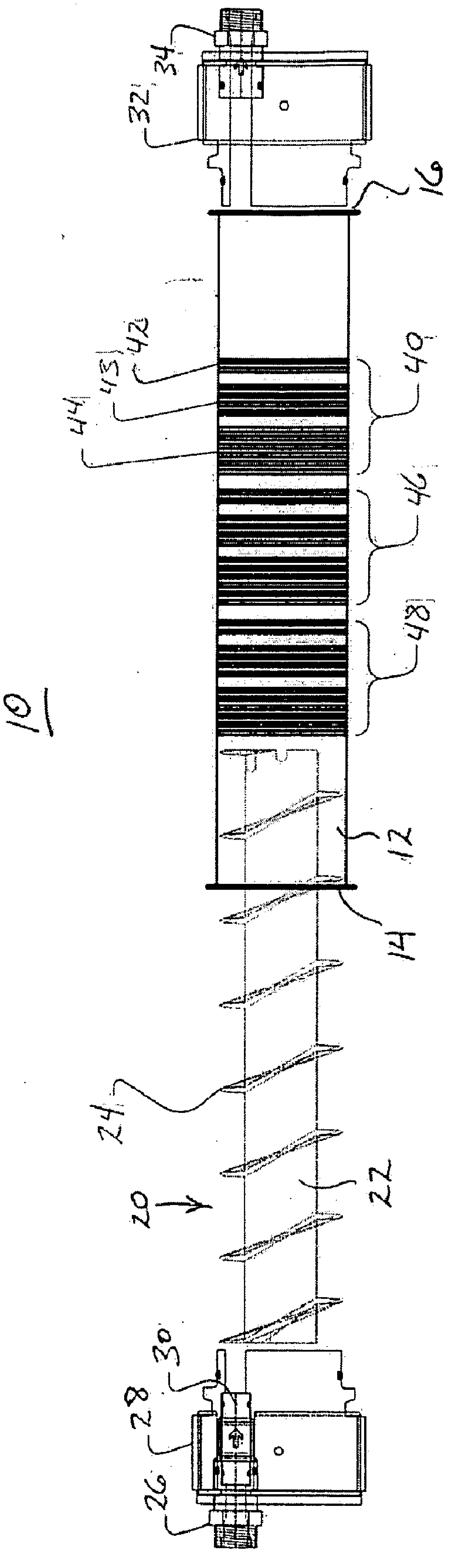


FIG. 1a

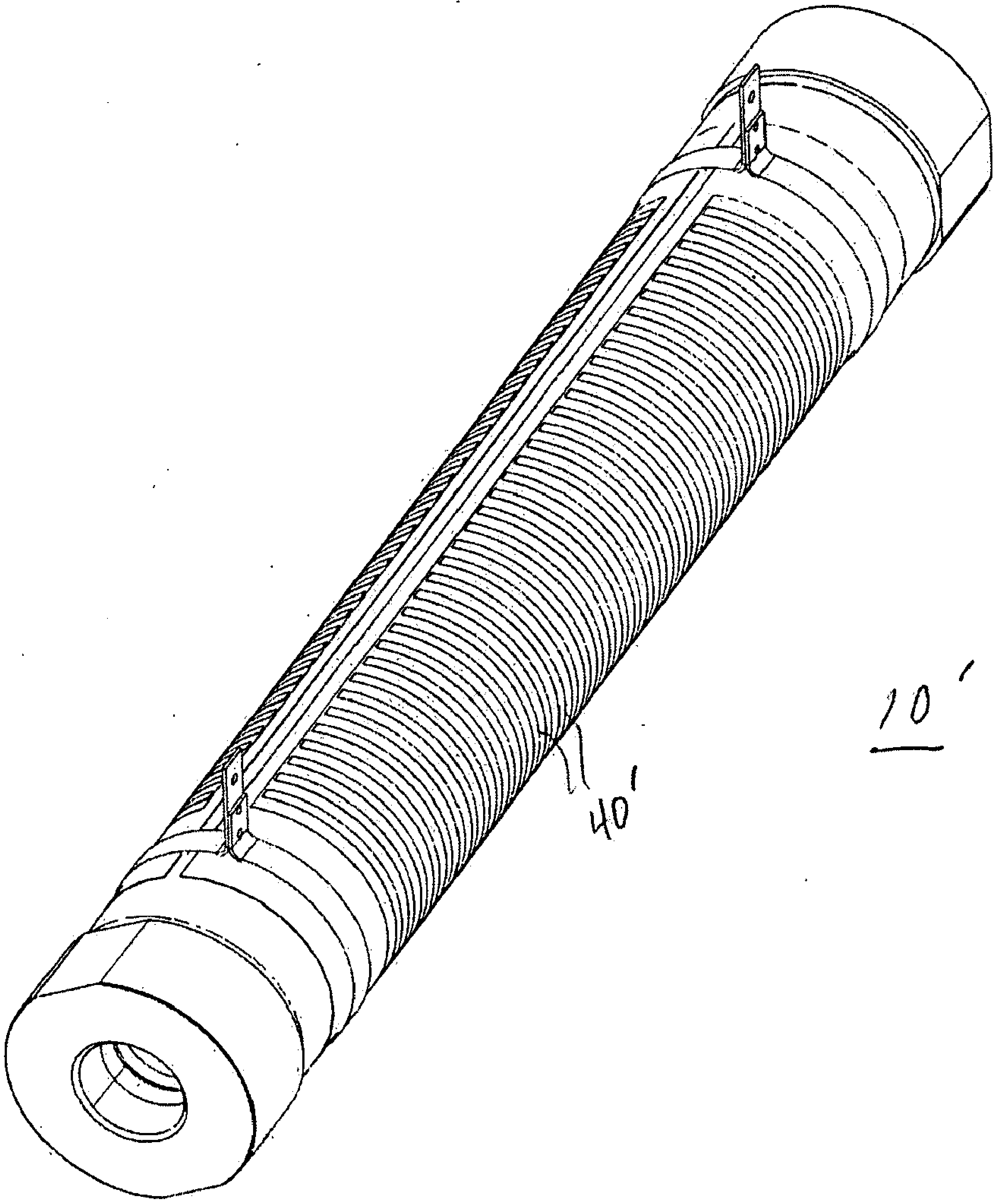


FIG. 1b

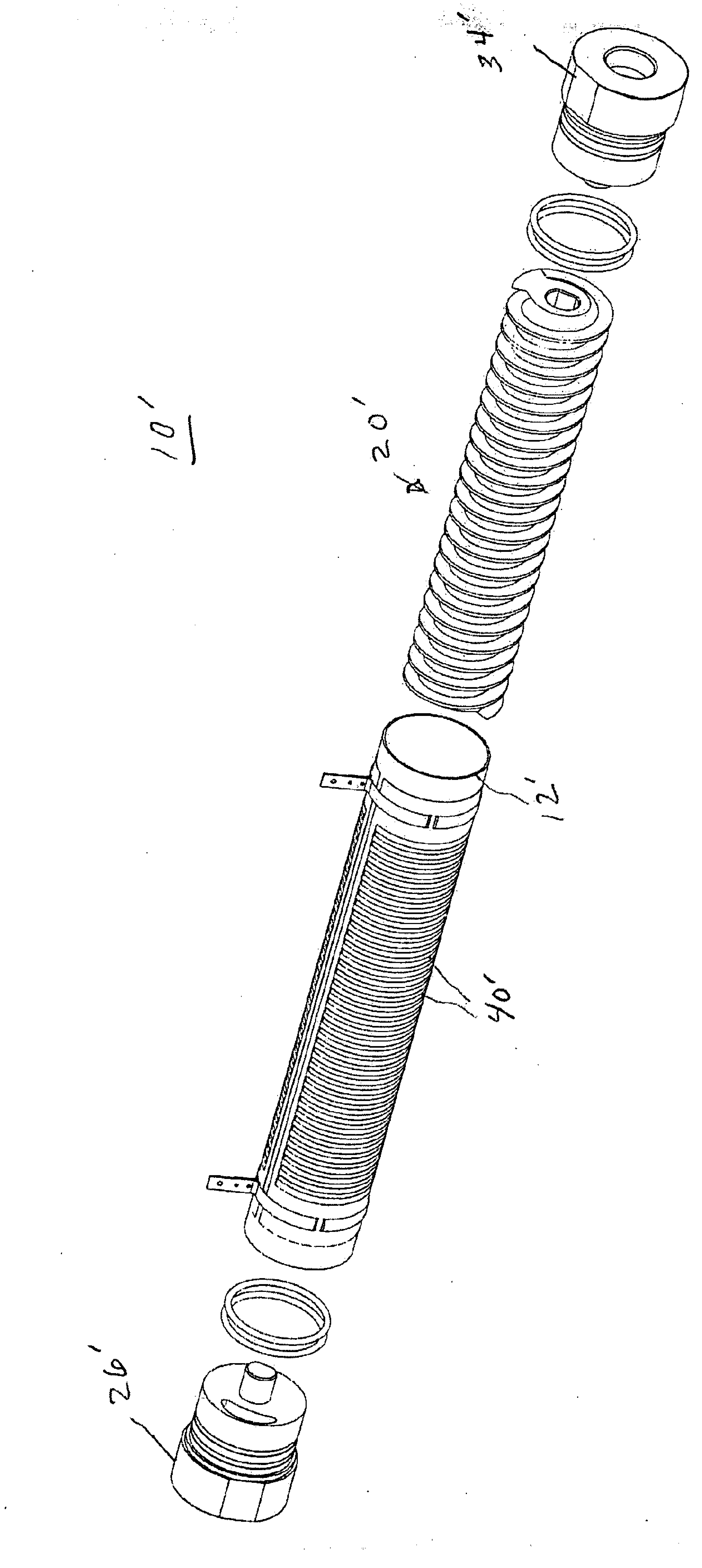


FIG. 1C

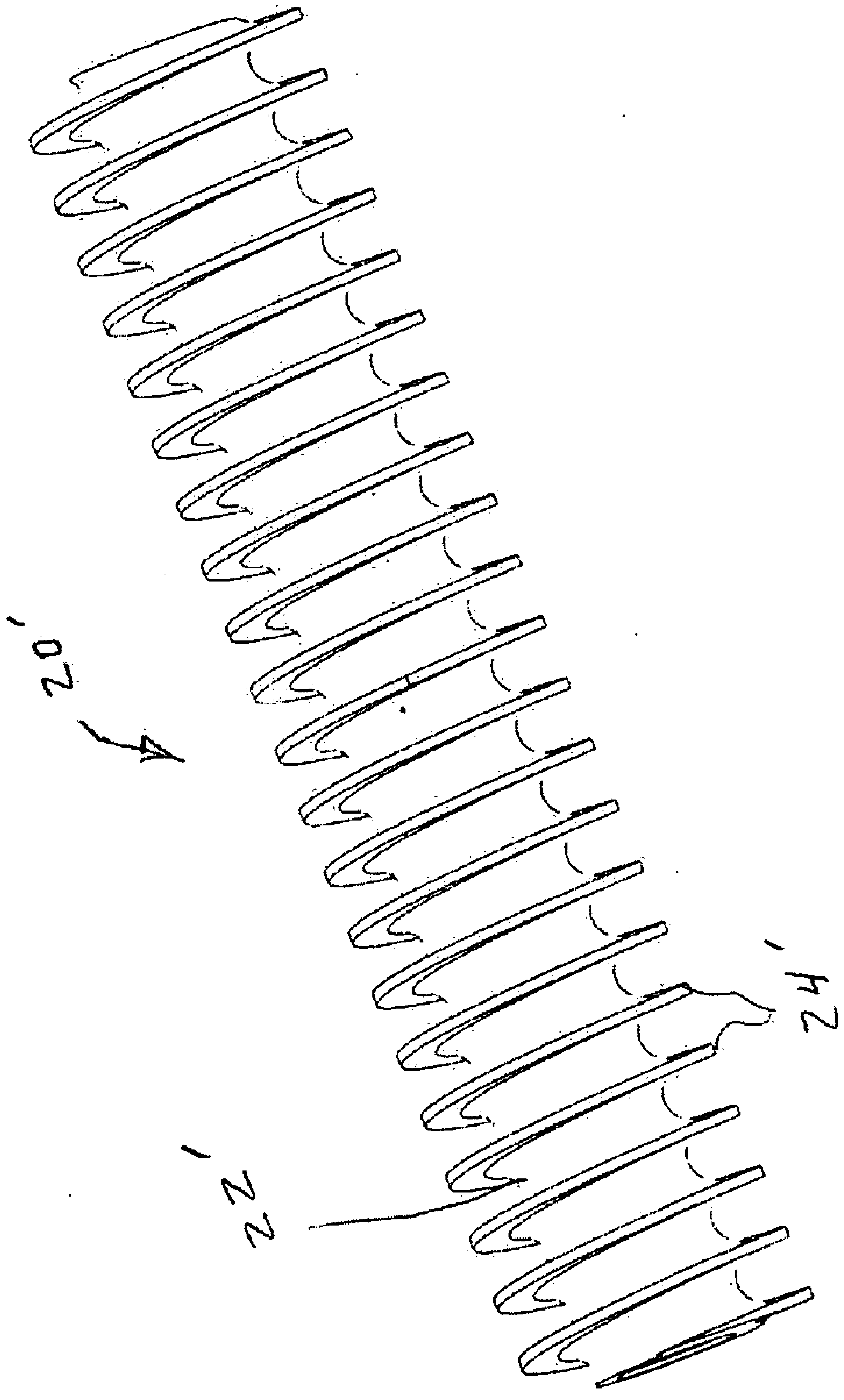


FIG. 1d

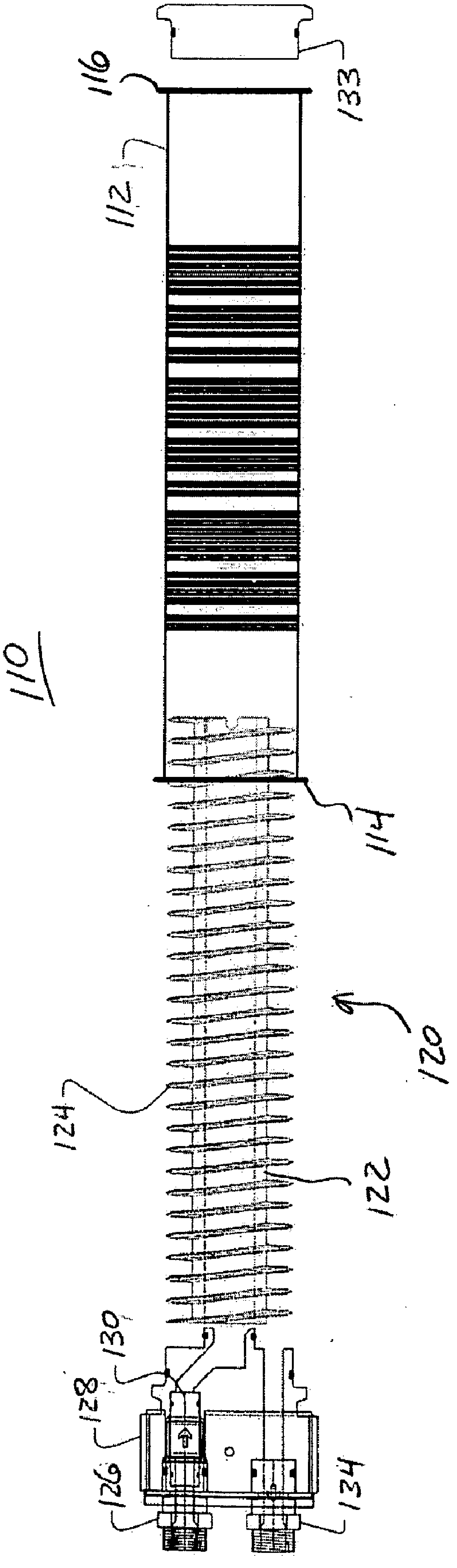


FIG. 2

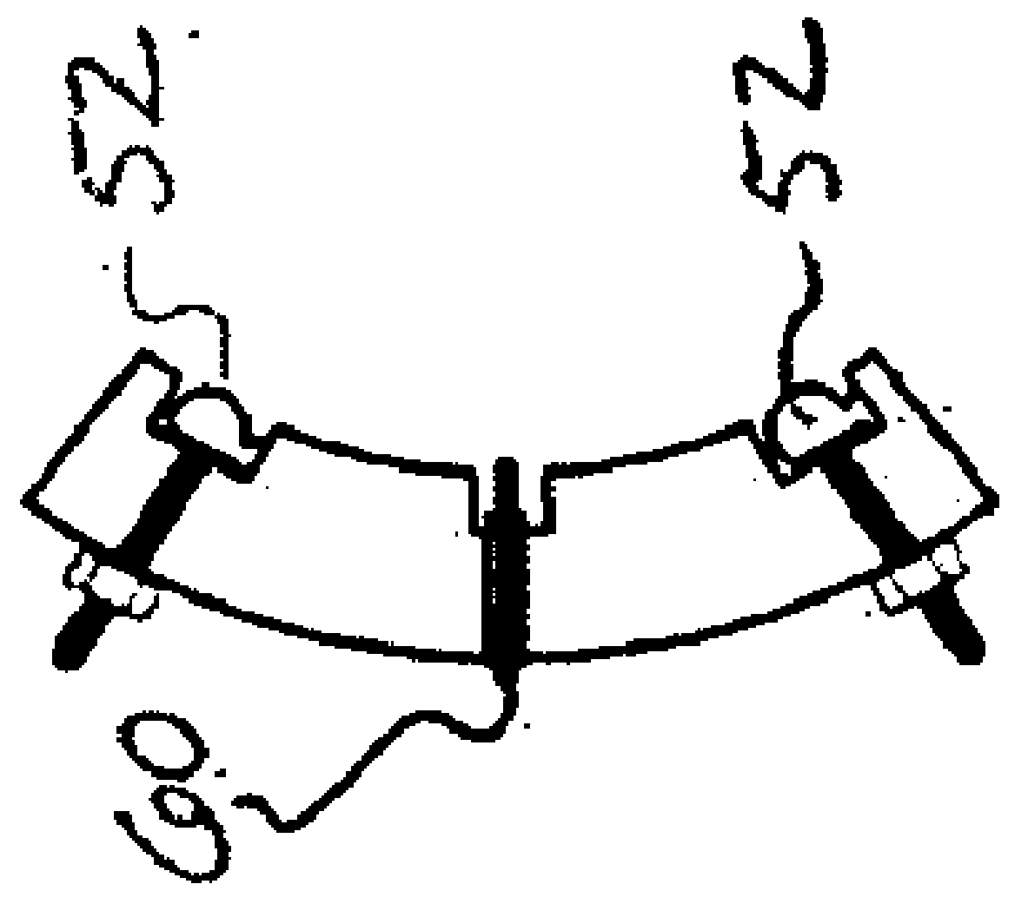


FIG. 5

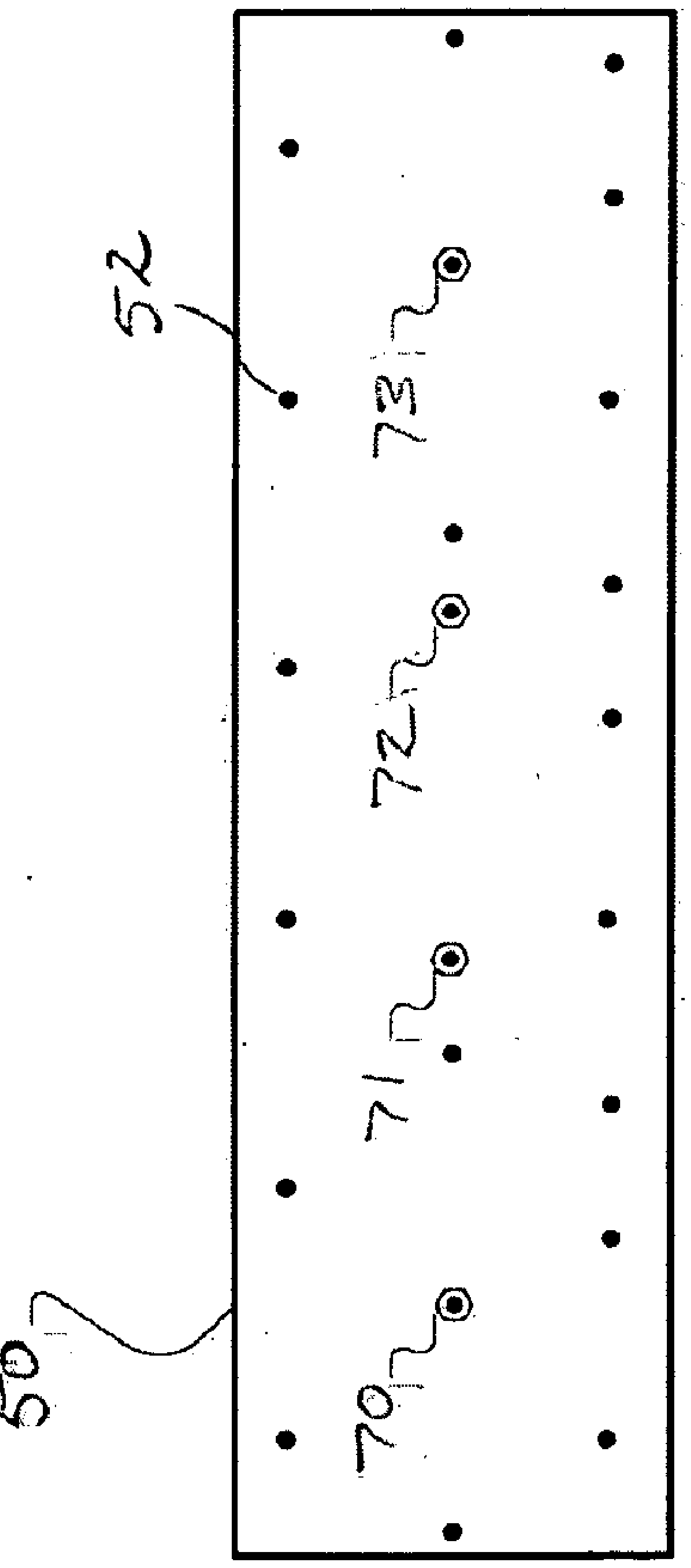


FIG. 4

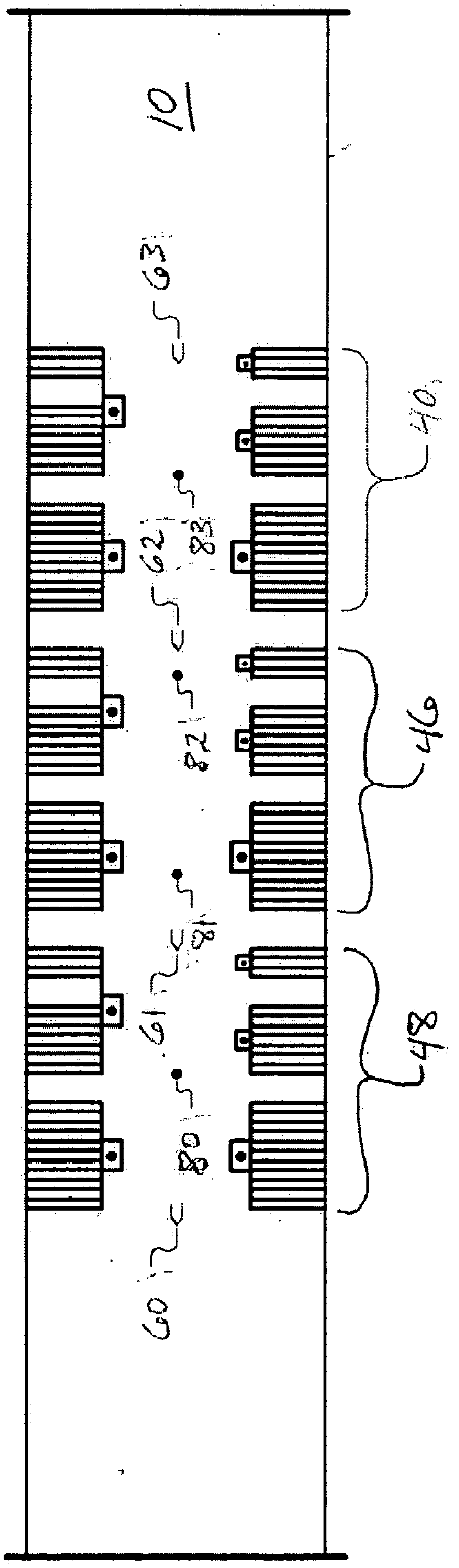


FIG. 3

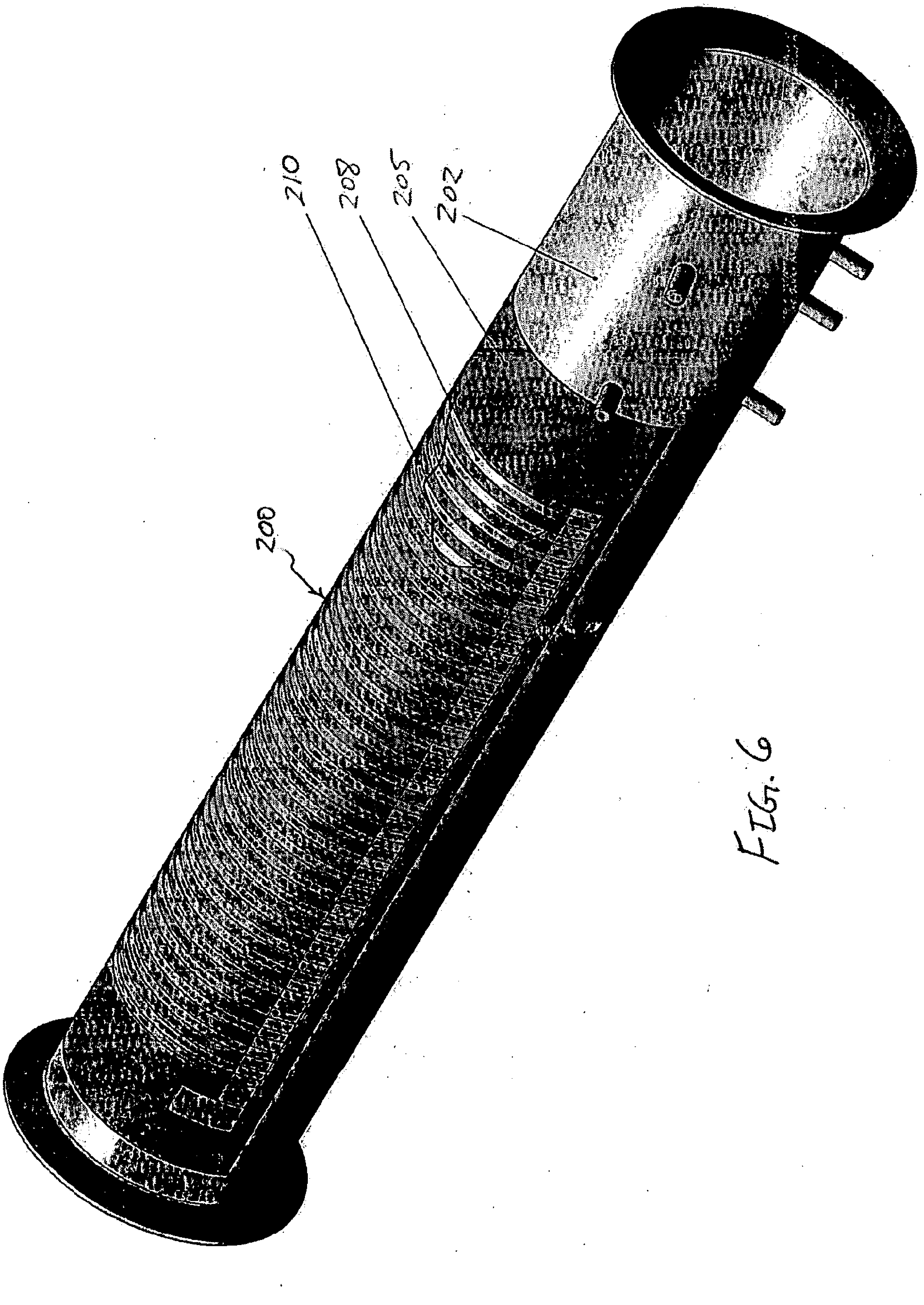


FIG. 6

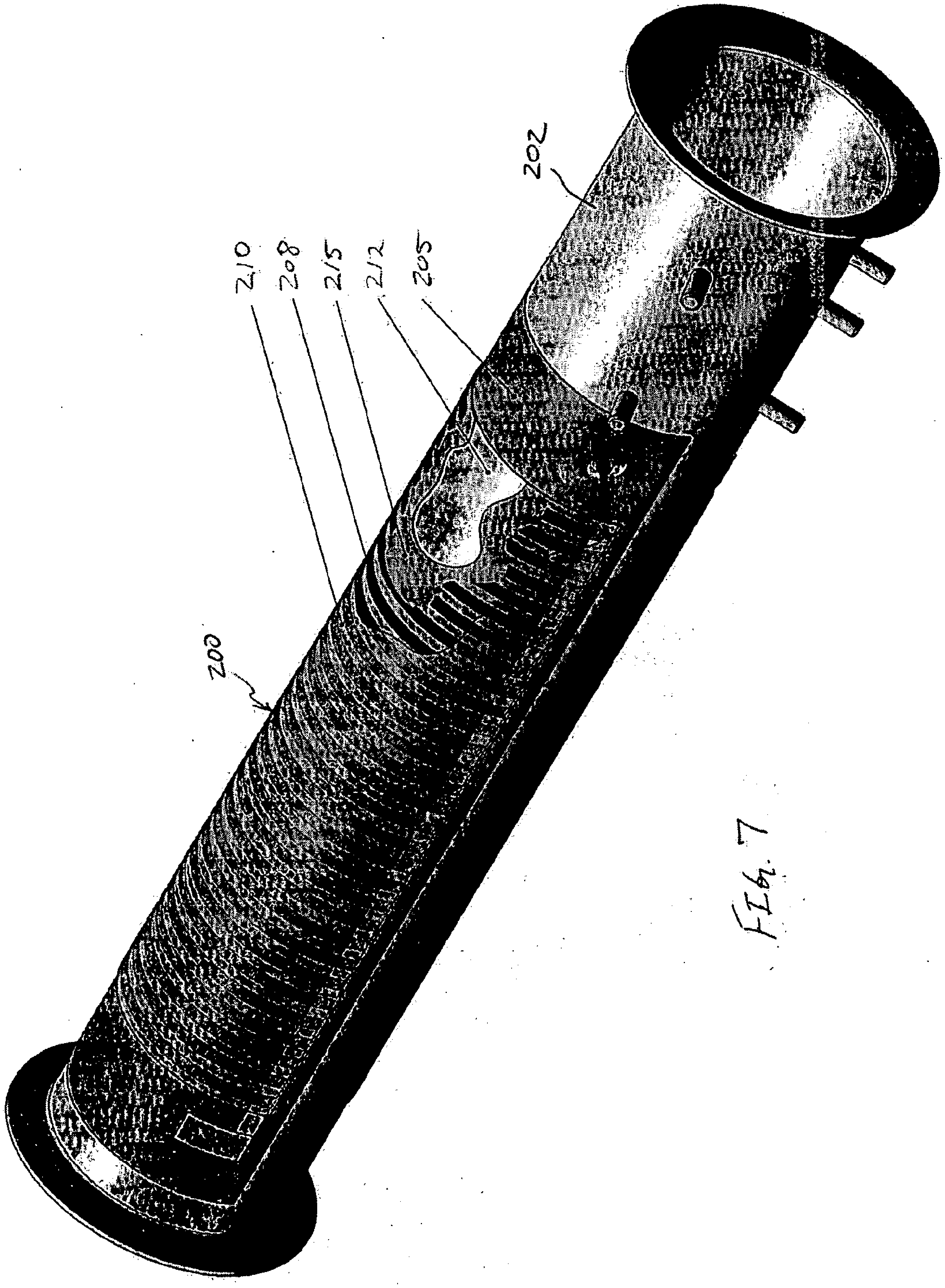


FIG. 7

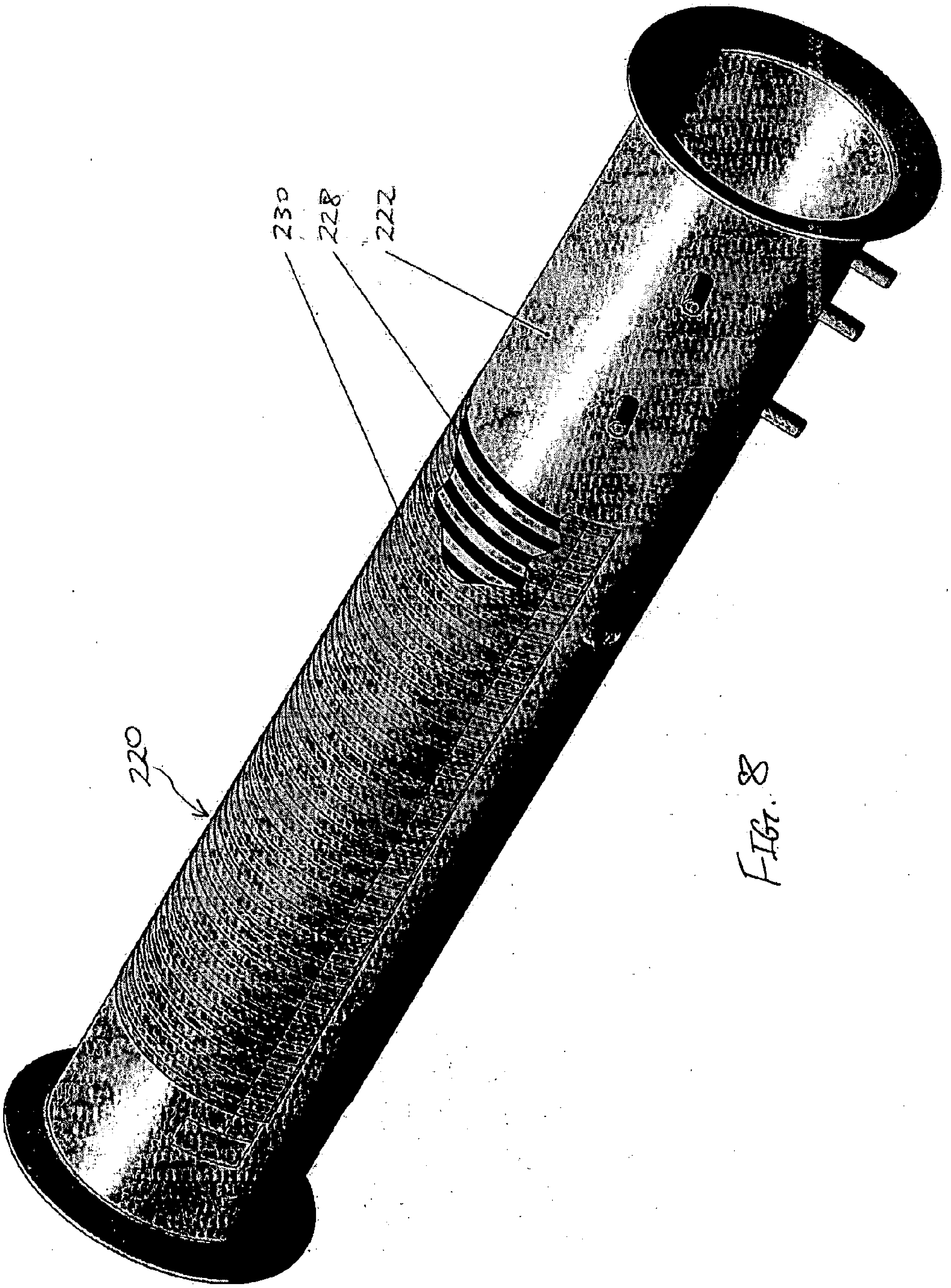


FIG. 8

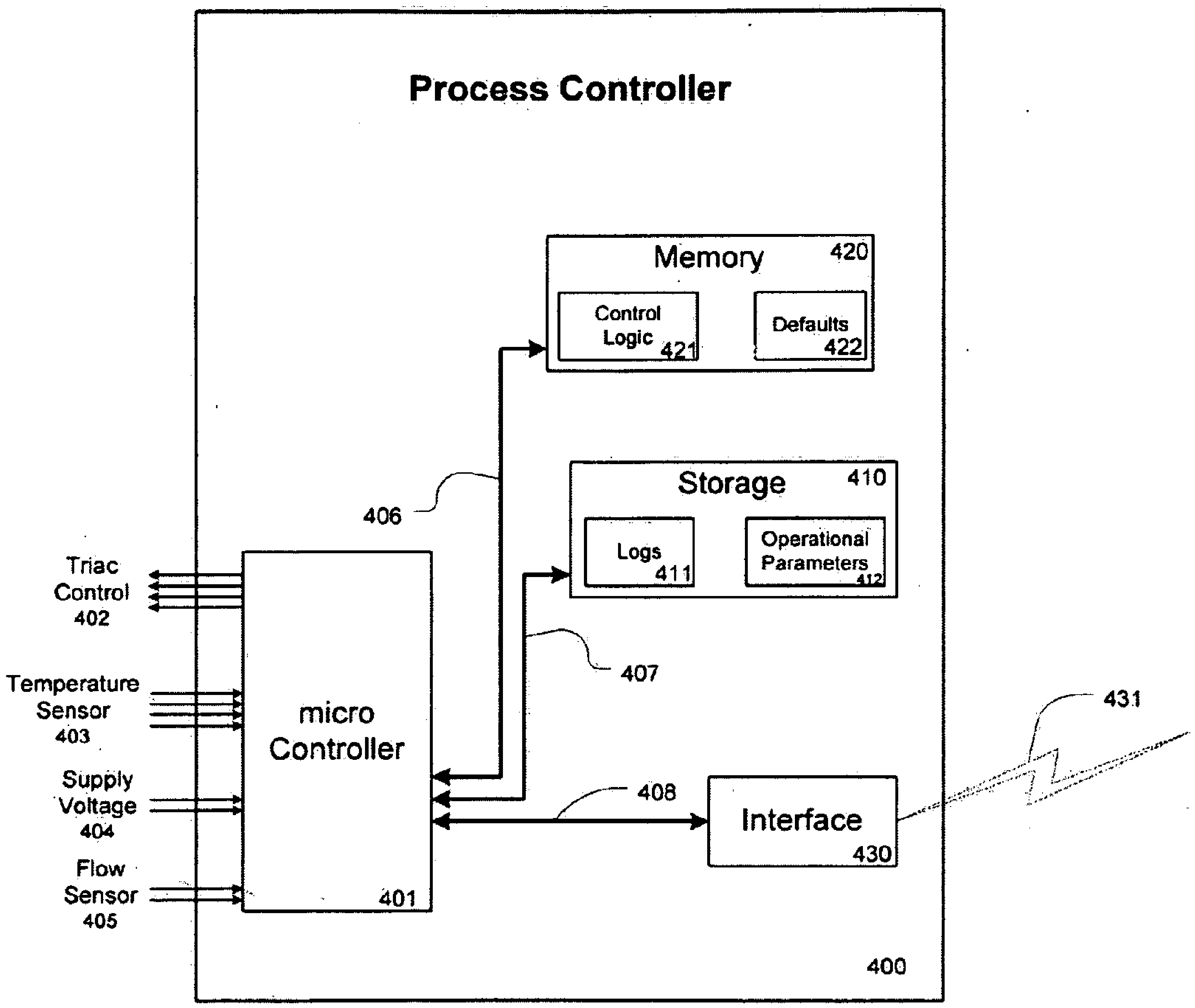

Process Controller
Memory
420
Control Logic
421
Defaults
422
Storage
410
Logs
411
Operational Parameters
412
406
407
408
431
Interface
430
micro Controller
401
Triac Control
402
Temperature Sensor
403
Supply Voltage
404
Flow Sensor
405
400

FIG. 9

HIGH THERMAL TRANSFER SPIRAL FLOW HEAT EXCHANGER

FIELD OF THE INVENTION

[0001] This invention relates to tankless fluid heaters and more specifically to fluid heaters employing resistive heating elements.

BACKGROUND OF THE INVENTION

[0002] There has been a drive to replace the conventional tank style water heater with something smaller, more energy efficient and with faster recovery. This has lead to the development of what is commonly called tankless water heaters. Sizes for these devices range from small point-of-use heaters designed to mount under sinks to whole house heaters that can deliver 5 gallons of water per minute or more. Smaller under sink heaters typically operate from electricity while the larger whole house heaters may operate from electricity or gas. Electric units are generally rated at 29 KW or less with efficiencies greater than 95% and gas units can achieve 175,000 Btu (51.2 KW) or more at 85% efficiency.

[0003] The need for tankless water heaters is on the rise. Increasing energy costs and the need to conserve water usage has prompted homeowners to replace large tank heaters with new compact tankless heaters. With their small size they can be located at optimum locations to minimize the distance from the water heater to the point of use. Further, only heating water when it is needed reduces the energy losses associated maintaining high storage temperatures in tank heaters. Studies have concluded as much as 50% of the energy used by conventional tank heaters can be lost to the surroundings.

[0004] Improvements in tankless heater design aimed at lower cost, smaller size and improved operation will allow more homeowners to conserve energy and scarce water resources.

[0005] Most electric tankless water heaters use immersion type heating elements. These are the same type of heating elements used for years in conventional tank heaters. The immersion elements are mounted so as to protrude into a small chamber or tube that is intended to have a continuous flow of water past each element.

[0006] Effective heating occurs when the liquid being heated can be in uniform contact with the heating surface. Immersion elements are typically round or oval tubes with a much smaller surface area than the chamber in which they are inserted. As the fluid flows through the heating chamber, only a limited amount of the fluid actually comes in contact with the heating element. It is possible to put deflectors on each element to stimulate turbulence in the chamber and maintain full contact with the element but the surface area is still limited and part of the element is exposed to low turbulence areas especially at higher flow rates. This situation causes the element to operate with a surface temperature much hotter than the water it is attempting to heat.

[0007] A characteristic of conventional immersion elements is when flow stops the residual energy stored in the element is dissipated into the surrounding water. Large temperature swings can occur during this event. For example, a typical tankless water heater with a 29 KW heating capacity will realize upwards of a 25° F. increase over the normal heating temperature when immediately going from a full flow of 3 gallons per minute to zero. For reference, the chamber in this example holds approximately 1.5 pints of water.

[0008] Depending on the type and concentration of the minerals in the water being heated, elements that operate hotter than the surrounding water will tend to build up mineral deposits on the element surface. This further reduces the thermal transfer and further increases deposits until element failure occurs. With proper design the deposits will break off the element due to thermal cycling but may collect in the heater then causing other problems.

[0009] Temperature control in tank type heaters is a simple matter. Most often a mechanical thermostat is attached to the outside of the vessel and turns the heating elements on and off to maintain the desired water temperature. Tankless heaters require a more sophisticated control mechanism that must react quickly to varying inlet temperatures and flow rates to provide a regulated output water temperature. In an effort to apply only the necessary energy to tankless water heaters the common approach has been to cycle the elements on and off quickly using triacs or other similar electrical control devices. Depending on the heater capacity one or more individual heating elements can be used. Generally, practical limitations exist as to the number of elements that can be used. Adding additional elements to the heater requires increasing the size of the heater chamber and increasing the manufacturing costs. By limiting the number of elements in the heater, each element produces a proportionately large amount of energy.

[0010] A triac is a common solid-state switch used for element control, which can be turned ON with a relatively small control current and which is capable of carrying the relatively large currents used in the heating elements. These devices can switch on any time during the power cycle and by their design will turn off when the applied voltage drops to zero. To reduce EMI (electromagnetic interference), triacs are generally turned on at the beginning of the power cycle. The resulting maximum control resolution is therefore ½ cycle of applied power or 8.33 msec in locations of 60 Hz power. A 28.8 KW heater with 4 elements would have an effective resolution of 60 watts. This would not be a problem except for the fact that the power step for this type of heater is 7.2 KW. Stepping the power in such dramatic increments leads to flickering lights and voltage surges.

[0011] The development of thick-film resistive (TFR) materials with high wattage per unit area has made it ever more difficult to transfer heat rapidly from a heat source. Applications such as fluid heat exchangers benefit from high power density to keep the size small and reduce cost but suffer if the transfer fluid cannot absorb the heat fast enough to prevent boiling or overheating.

[0012] A relatively new approach is to place thick-film resistive (TFR) material on a thermally conductive glass or ceramic insulator that is, in turn, fused to a stainless steel tube. U.S. Pat. No. 7,206,506, issued 17 Apr. 2007, describes some details of thick film use in a fluid heater, and is incorporated herein in its entirety by reference. In the use of TFR materials, according to the '506 patent, heat is conducted through a thermally conductive insulator, through a stainless steel tube and into a heat exchange fluid flowing through the tube. Advantages include lower thermal mass of the heater, reduced mineral deposit buildup due to temperature excursions and flexible element design.

[0013] Power density of the tankless fluid heater is still a limitation. Attempting to reduce the heater size and reduce cost drives the power density up and causes many of the same problems of the immersion heaters. A common solution includes increasing the flow rate in an attempt to absorb heat faster. Another is to increase the pipe diameter to decrease the power density. Both have problems. An increasing flow rate generally requires a larger pumping system or is not possible in fixed flow situations. Increasing the flow rate also leads to an increasing portion of the fluid flowing concentrated towards the center of the pipe. This can actually lead to a reduction in thermal transfer. A larger pipe reduces the power density but also reduces the proportion of fluid in contact with the inner wall of the heater tube.

[0014] With the innovation of TFR elements, lower cost and smaller point-of-use and whole house heaters have become more feasible. Still two major problems exist for these electric heaters. It is necessary to improve the thermal transfer from the heating element to the water to reduce the size and cost. Also, there is a need to improve the power control to reduce large load swings on the supply to the heater and, in turn, eliminate flickering lights and voltage fluctuations.

[0015] It would be highly advantageous, therefore, to remedy the foregoing and other deficiencies inherent in the prior art.

[0016] Accordingly, it is an object of the present invention to provide a high thermal transfer spiral flow heat exchanger in a fluid heating system.

[0017] It is another object of the present invention to provide a high thermal transfer spiral flow heat exchanger including heating elements that evidence no appreciable residual heat and no mineral deposit buildup.

[0018] It is another object of the present invention to provide a high thermal transfer spiral flow heat exchanger using thick-film resistive heating (TFR) elements having no appreciable thermal mass and, therefore, nowhere to store energy.

[0019] It is another object of the present invention to provide a high thermal transfer spiral flow heat exchanger configured to allow a single heat exchanger to economically be configured for a variety of heating application demands.

[0020] It is another object of the present invention to provide a fluid heating system including a high thermal transfer spiral flow heat exchanger and a process controller that provides localized monitoring of the electrical supply source in such a way as to provide overload protection to the supply circuit.

SUMMARY OF THE INVENTION

[0021] Briefly, to achieve the desired objects of the present invention in accordance with a preferred embodiment thereof there is provided a tankless fluid heating system with a heat exchanger including an elongated cylindrical tube with an inlet end and an opposed end. An array of film resistive elements is positioned on an outer surface of the cylindrical tube and extends circumferentially, at least partially, around the outer surface. A spiral channel guide is coaxially positioned within the cylindrical tube so as to force fluid flowing in the tube into a spiral path at least partially against an inner surface of the cylindrical tube. The spiral channel guide directs fluid flowing in the cylindrical tube so as to cause turbulence to occur in the flow and increase thermal transfer from the inner surface of the cylindrical tube to the fluid flowing in the tube.

[0022] To further achieve the desired objects of the present invention, in a specific embodiment of the present invention, a high thermal transfer cylindrical heat exchanger using film resistive heating elements, provides a system and method for heating fluids under a broad range of flow rates with no appreciable residual heat and no mineral deposit buildup. A characteristic of film resistive elements is the lack of residual energy upon the removal of power. They have no appreciable thermal mass, therefore nowhere to store energy. The present invention also takes advantage of film resistive materials on insulator technology with the ability to subdivide resistive elements into various sizes without significantly increasing the heater size.

[0023] In one embodiment of the present invention, a process controller receives signals from a flow sensor, placed in the inlet stream, and determines the fluid flow rate. Additionally, the process controller receives signals from a plurality of temperature sensors placed on the cylindrical heat exchanger. This information allows the process controller to calculate the amount of power necessary to raise the fluid temperature to the desired level.

[0024] In another embodiment, the process controller provides localized monitoring of the electrical supply source in such a way as to provide overload protection to the supply circuit. This monitoring is done on a cycle-by-cycle basis, thus providing a methodology of self-control that can prevent circuit, as well as, service overloads. This information is used to identify local overloading conditions that may result from the potentially high current demand associated with the calculated power referenced above. If the supply voltage goes below a predetermined or acceptable level, the process controller will limit the ability to heat the fluid rather than allow an overload condition due to the heaters demand.

[0025] Characteristics and flexibility of the spiral channel guide allows control of the fluid flow direction and turbulence within the heating chamber, maximizing thermal transfer from the heater tube to the fluid. In one embodiment of the spiral channel guide, the core is solid and the root dimension of the spiral is reduced, as well as having the pitch adjusted, to effectively provide any equivalent pipe size up to approximately two (2) inches from a three (3) inch diameter heat exchanger. This allows a single heat exchanger to economically be configured for heating application demands ranging from low flow (high delta T) to high flow (low delta T), and anything in between.

[0026] Other features and advantages of the present invention will become apparent to one skilled in the art upon examination of the following detailed description, when read in conjunction with the accompanying drawings. It is intended that all such features and advantages be included herein within the scope of the present invention and protected by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The foregoing and further and more specific objects and advantages of the invention will become readily apparent to those skilled in the art from the following detailed description of a preferred embodiment thereof, taken in conjunction with the drawings in which:

[0028] FIG. **1***a* is an exploded view of a spiral flow heat exchanger in a straight-thru configuration, in accordance with the present invention;

[0029] FIG. **1***b* is a perspective view of another embodiment of a spiral flow heat exchanger;

[0030] FIG. **1***c* is an exploded view of the spiral flow heat exchanger of FIG. **1***b;*

[0031] FIG. **1***d* is an enlarged side view of the internal component of the spiral flow heat exchanger of FIG. **1***c;*

[0032] FIG. **2** is an exploded view of a spiral flow heat exchanger in a loop-back configuration, in accordance with the present invention;

[0033] FIG. **3** is a top plan view of the spiral flow heat exchanger of FIG. **1** with electrical and temperature sensor connections;

[0034] FIG. **4** is a top plan view of a contact assembly formed to overlie the electrical and temperature sensor connections of FIG. **3**;

[0035] FIG. **5** is an end view of the contact assembly illustrated in FIG. **4**;

[0036] FIG. **6** is a perspective view of a film resistive heating element on a conductive outer tube;

[0037] FIG. **7** is a perspective view of a film resistive heating element on the conductive outer tube of FIG. **6** with a ground layer;

[0038] FIG. **8** is a perspective view of a film resistive heating element on a non-electrically conductive outer tube; and

[0039] FIG. **9** is a block diagram illustrating an embodiment of a process controller and communications system for the spiral flow heat exchanger.

DETAILED DESCRIPTION OF THE DRAWINGS

[0040] In general, the present invention relates to a system and method for heating fluids by using film resistive elements fused to the outside of a cylindrical tube. Film resistive heating elements include thin film and thick-film resistive (TFR) elements. Thin film resistive elements are typically formed electrostatically on a surface, or using a very fine spray, while TFR elements typically employ a printing technique. It will be understood that substantially any technique and method of forming a film of resistive material on the outer surface of a cylindrical tube, such as deposition techniques, plating, painting, silk screening, and the like, can be employed. A spiral channel guide is disposed within the tube and creates the equivalent of a coil of tubing within the walls of a compact cylinder. This 'coil effect' allows the fluid to remain in contact with the heat source for longer durations than would normally be possible with immersion type heating elements. This combination of a spiral channel and film heating elements allows for a controlled watt density per linear inch that is unachievable by any other current technology. While the embodiments disclosed are illustrated primarily for heating water, it will be understood that they could be used for heating virtually any fluid.

[0041] Turning now to FIG. **1***a*, an exploded view of a spiral flow heat exchanger, designated **10**, in a straight-thru flow configuration is illustrated. Heat exchanger **10** includes an elongated cylindrical outer tube **12** having an inlet end **14** and an opposed end, which in this embodiment is an outlet end **16**. An elongated spiral channel guide **20** is positioned coaxially within tube **12** and includes a cylindrically shaped core **22** with a spiral shaped, fluid diverter **24** positioned relative to the outer surface. While the preferred embodiment of diverter **24** is as a continuous spiral, it should be understood that it could be formed in separate segments if desired. It will be understood that fluid diverter **24** may be formed as an integral part of core **22** or formed separately and attached to the outer surface thereof by any convenient means or otherwise affixed in the desired orientation, for example by affixing it to the inner surface of tube **12**. Also, in this straight-thru flow configuration, core **22** is solid for extra rigidity but could be formed hollow, partially hollow, etc. for lighter weight. Also, for reasons that will become apparent presently, tube **12** is can be formed of electrically insulative material or has an outer electrically insulative surface. While cylindrical outer tube **12** is stainless steel in this embodiment, it will be understood that other materials of both an electrically conductive nature such as other metals, and a non-electrically conductive nature such as plastic, glass, quartz, ceramics, PVC and the like, can also be used. The film resistive elements on the electrically conductive materials and on the non-electrically conductive materials will be described presently.

[0042] The outer diameter of diverter **24** is substantially the same as the inner diameter of tube **12** so that when spiral channel guide **20** is properly positioned within tube **12** fluid flowing in inlet end **14** (the fluid being heated) is restricted to the spiral path defined by diverter **24**. An inlet piping connection **26**, inlet manifold **28**, and optional flow sensor **30** are attached to inlet end **14** of tube **12** to provide fluid to be heated. An outlet manifold **32** and outlet piping connection **34** are attached to outlet end **16** of tube **12** to receive heated fluid and deliver the heated fluid to a selected location.

[0043] Spiral channel guide **20** controls the effective size of the flow restriction placed upon the fluid being heated. A desired flow restriction is achieved by selecting a specific core **22** and/or a specific fluid diverter **24**. Depending upon the desired fluid flow rate, the root diameter and pitch of spiral channel guide **20** can be easily changed by the shape of diverter **24**. An example of a change in pitch of the spiral channel can be seen in a comparison of FIG. **1***a* and FIG. **2**. Also, the outer diameter of core **22** and the inner diameter of tube **12** can be selected during fabrication to provide a desired fluid flow. This varied fluid flow rate is accommodated not only by appropriate selection of spiral channel guide **20**, but also by sizing the inlet piping connection **26**, inlet manifold **28**, outlet manifold **32**, outlet piping connection **34**, and flow sensor **30** (if included). This embodiment provides a solution to high flow rate applications requiring an inline heater to minimize flow restriction.

[0044] As shown in FIGS. **1***a* and **3**, heat exchanger **10** includes an array **40** of film resistive element groups, including at least one, and preferably, a plurality of groups, herein shown and represented as groups **42**, **43**, and **44**, each containing a plurality of film resistive elements which in this preferred embodiment are TFR elements. As will be understood more fully from the following explanation, the number of groups in array **40** and the number of elements in each group can vary in accordance with the number of heating steps desired, the amount of total heat and the amount of heat per step. Also, in this embodiment, multiple arrays **46** and **48** of TFR element groups are included. While any number of arrays and array configurations might be included if desired and convenient, in this embodiment each array **40**, **46**, and **48** is similar with a similar number of groups and a similar number of elements in each similar group. Further, when multiple arrays are included similar groups might be energized simultaneously in all of the arrays or might be energized in some sequence to provide a large variety of heating steps. The specific configuration or embodiment illustrated in FIG. **1** shows a three (3) phase electrical supply to be balanced to within the value of the smallest TFR group **42**. Heat exchanger **10**, when connected to a residential electrical supply (for example) or other supply source, may be configured so that TFR element groups **46** and/or **48** are not present, thereby reducing the capacity of the heat exchanger.

[0045] One characteristic of the film resistive material, whether thick-film or thin film, is that it has no appreciable thermal mass and, therefore, nowhere to store energy. Conversely, because there is substantially no mass to heat-up or cool-down (no energy to store), heating and cooling is very fast. Thus, cycling from cool to a heating step is very fast (nearly instantaneous) and cycling from a heating step to not heating is very fast. Thus, the desired heat is present upon supplying power to the heating element or elements and the heat is removed almost instantaneously as power is removed. This feature greatly simplifies heating cycles and the amount of power required.

[0046] A spiral heat exchanger, designated **10'**, similar to the heat exchanger illustrated in FIG. **1***a* is illustrated in FIGS. **1***b* through **1***d*. Components similar to components in FIG. **1***a* are designated with similar numbers and a prime (') is added to indicate the different embodiment. In this embodiment an array **40'** of thick-film resistive (TFR) element groups, including at least one, and preferably, a plurality of groups, is distributed substantially equally along the length of elongated cylindrical outer tube **12'**.

[0047] Referring now to FIG. **2**, an exploded view of a spiral flow heat exchanger **110** in a loop-back configuration is illustrated. Generally, components similar to components in the embodiment illustrated in FIG. **1***a* are designated with similar numbers with a "1" added in front to indicate the different embodiment. Heat exchanger **110** includes an elongated cylindrical outer tube **112** having an inlet end **114** and an opposed end **116**. An elongated spiral channel guide **120** is positioned coaxially within tube **112** and includes a cylindrically shaped core **122** with a spiral shaped, fluid diverter **124** positioned relative to the outer surface. It will be understood that fluid diverter **124** may be formed as an integral part of core **122** or formed separately and affixed relative to the outer surface thereof by some convenient means.

[0048] In this loop-back configuration, core **122** of spiral channel guide **120** includes a hollow core **123**, to enable input feed flow therethrough. A reversing header **133** is positioned in opposed end **116**. Thus, any incoming fluid is directed to travel through the core to opposed end **116** of spiral channel guide **120**, reversed in direction by reversing header **133**, and returned via the spiral channel. Fluid to be heated enters through an inlet piping connection **126**, flowing through a flow sensor **130**, and is directed to the hollow core of spiral channel guide **120** by an inlet/outlet manifold **128**. The reversing header **133** is positioned in opposed end **116** and, fluid, upon encountering reversing header **133**, is redirected down the outside of the spiral channel guide **120** and forced into contact with the inside diameter of tube **112** before exiting via an outlet piping connection **134** through inlet/outlet manifold **128**. This embodiment is applicable to low flow rate applications requiring a large temperature differential between the inlet and the outlet. In this embodiment, for illustrative purposes, the pitch of spiral channel guide **120** is greatly decreased, i.e., more turns per foot of length. Thus, spiral channel guide **120**, as depicted in FIG. **2**, has an effective length equivalent to fifteen (15) feet of one half (½) inch copper, yet is only fourteen (14) inches long from inlet end **114** to opposed end **116**.

[0049] It is important to note that in either embodiment presented in FIG. **1***a* or FIG. **2**, the heat exchanger **10**/**110** has not been altered, i.e. remains a standard unit. The control strategy for turning the TFR elements on and off will change depending upon the application. However it is preferable for manufacturing convenience that the physical heat exchanger, remain constant. It will be understood that the heat exchanger can change in accordance with various applications and differing flow rates.

[0050] Turning now to FIGS. **3**, **4**, and **5**, an exploded view of a spiral flow heat exchanger **10**/**110** with electrical and temperature sensor connections is illustrated. For convenience, heat exchanger **10** and the associated array **40** of film resistive elements will be used in this example. The various film resistive elements of array **40**, in this alternate embodiment, are formed by deposition of a thick film conductor on the outer surface of tube **12**. It should be understood that a plurality of arrays, such as arrays **46** and **48**, may be present in addition to array **40** and, if present, they are formed similar to and generally simultaneous with the formation of array **40**. The formation may be performed using any of a wide variety of techniques or processes including, for example, silk screening, printing, spraying, dipping, etc. This same process allows for electrical traces, similar to printed circuit board traces, to be formed onto the heat exchanger **10**. Taking advantage of the ability to place electrical traces on the heat exchanger **10** at virtually any location allows for the utilization of a multi-conductor high pressure contact assembly **50**, to provide a quick assembly method that minimizes the physical stresses on the electrical connections at the heat exchanger **10**.

[0051] Here it should be noted that because the arrays (**40**, **46**, **48**) of film resistive elements are formed by depositing the thick-film resistive material using any of the above described processes, the parameters of each element (e.g. the thickness, width, etc.) can be easily adjusted to provide any desired heating characteristics. It will be understood, for example, that a thinner layer of TFR material over a greater surface area will increase the heating area. Also, operating current and voltage can be selected by adjusting thickness and width parameters.

[0052] Rather than utilizing an attachment method that involves pushing/pulling or bolting contacts together, preferably, a plurality of compressive contacts **52** are supported by and secured to the multi-conductor high pressure contact assembly **50**. Assembly **50** is an arcuately shaped section of a tube formed to fit over the ends and associated electrical contacts of arrays **40**, **46**, and **48** and provides external contacts to the arrays. In a preferred embodiment, the compressive contacts **52** are bolted to the multi-conductor high pressure contact assembly **50** (see FIG. **5**), providing a secure contact point for the high current conductors providing power to the TFR elements of array **40**, **46**, and **48** on the heat exchanger **10**. Electrical connection to a plurality of temperature sensors **60**-**63** are also supported by the multi-conductor high pressure contact assembly **50** and allows a plurality of nuts **70**-**73** to clamp the contact assembly **50**, via studs **80**-**83**, to the heat exchanger **10**, thus placing no mechanical strain on the thick film conductors deposited on the surface of tube **12**.

[0053] Referring now to FIGS. **6**-**8**, different embodiments of film resistive elements are illustrated. A film resistive heating element **200** on an outer tube **202** of an electrically conductive material, such as stainless steel, is illustrated in FIG. **6**. Since film resistive heating element **200** is formed on an electrically conductive substrate, an electrically insulative layer, such as dielectric layer **205** is formed on the outer surface of outer tube **202**. A resistive layer **208** is then formed on dielectric layer **205** as described previously. An additional electrically insulative layer, dielectric layer **210** is formed overlying resistive layer **208** to prevent any extraneous electrical contact with and to protect resistive layer **208**. As should be understood, the various layers and the material of outer tube **202** should have closely matching thermal coefficients of expansion.

[0054] With reference to FIG. **7**, an additional ground layer **212** can be formed as part of film resistive heating element **200**. In this instance, a ground layer **212** of a conductive material such as silver is formed on dielectric layer **205** and covered with another electrically insulative layer, dielectric layer **215**. Resistive layer **208** is then formed on dielectric layer **205** as described previously. The additional electrically insulative layer, dielectric layer **210**, is formed overlying resistive layer **208** to prevent any extraneous electrical contact with and to protect resistive layer **208**.

[0055] With reference specifically to FIG. **8**, a film resistive heating element **220** on an outer tube **222** of a non-electrically conductive material, such as plastic, PVC, glass, ceramic and the like, is illustrated. Since film resistive heating element **220** is formed on a non-electrically conductive substrate, an electrically insulating layer need not be provided on the outer surface of outer tube **222**. A resistive layer **228** can be formed directly on the outer surface of outer tube **222**. An electrically insulating layer, dielectric layer **230** can be formed overlying resistive layer **228** to prevent any extraneous electrical contact with and to protect resistive layer **228**. As should be understood, the various layers and the material of outer tube **222** should have closely matching thermal coefficients of expansion.

[0056] Turning now to FIG. 9, a block diagram of an embodiment of a process controller, designated at **400**, including a communications system is illustrated. The process controller **400** includes at least a micro-controller **401**, an interface **430** with a communication link **431**, a data storage device **410**, and a memory device **420**. Data storage device **410** includes at least the operational parameters **412** and logs **411**. Memory device **420** includes at least control logic **421** and default parameters **422**.

[0057] A flow sensor **405** is coupled to micro-controller **401** to supply flow signals. Flow sensor **405** may be, for example, flow sensor **30** of FIG. **1**, or any sensor positioned to sense a flow of fluid in the system. When micro-controller **401** receives a signal from flow sensor **405** indicating the presence of fluid flow, micro-controller **401** retrieves and executes control logic signals from control logic **421** in memory device **420**, via a connection **406**, to determine the flow rate. Micro controller **401** simultaneously monitors the supply voltage, designated **404**, and temperature sensors **403** (e.g. sensors **60**-**63** in FIG. **3**). Micro-controller **401** then retrieves and executes additional control logic signals from control logic **421**, via connection **406**, to determine the amount of power necessary to raise the fluid temperature, provided by the plurality of temperature sensors **403** (e.g. temperature sensors **60**-**63**), to a predetermined value. This calculated amount of power is then compared to the amount of power required by the plurality of TFR element arrays of groups (**42**/**43**/**44** and **46**/**48**, if included, from FIG. **1**) to determine how many of the TRF element groups to energize.

[0058] It should be noted that the process controller **400**, may enable the supply voltage to be connected to a three (3) phase source. Here, the calculated required power, is divided by three (3) to determine how much power is needed from each phase. The capacity of the plurality of TFR elements **42**/**43**/**44**, from FIG. **1**, needed to provide the calculated power is subtracted from the calculated power, with the remaining additional power to be supplied by a single TFR array of groups (**40**/**46**/**48** from FIG. **1**).

[0059] Alternatively, the process controller **400**, may enable the supply voltage **404** to be connected to a standard residential source. Here, the calculated power is supplied by one or more of the largest TFR elements (**44** or **43** from array **40** and/or **46**/**48**, if present, in FIG. **1**) needed to meet the power requirement, with the remaining power supplied from one or more of the smaller TFR elements (**42** or **43** from array **40** and/or **46**/**48**, if present, in FIG. **1**).

[0060] Still further, the process controller **400** may only receive a signal from flow sensor **405** to indicate the presence of flow rather than a flow rate. Here, micro-controller **401** will select the smallest TFR element **42** of array **40** (from FIG. **1**) to energize initially. Values received from temperature sensors **403** allow micro controller **401** to approximate a flow rate and determine subsequent TFR elements to energize, according to the electrical supply source.

[0061] The energizing of a TFR element is done by micro-controller **401** sending a signal to an electrical control device such as a triac(s) controlling the appropriate TFR elements of the appropriate TFR element group or groups. This signal is correlated to the zero crossing of the electrical supply source for the respective TFR element.

[0062] Still further, the process controller **400** may enable the supply voltage **404** to be compared to the nominal supply voltage for the electrical supply source. If the supply voltage **404** is below a defined range, a power offset is applied to the calculated power before determining the energization of TFR elements. This offset is adjusted on a cycle-by-cycle basis to minimize the chances of an electrical supply overload. This embodiment will cause the heat exchanger **10** or **110** to provide a fluid outlet temperature that is below the predetermined value and allow other loads to consume power as necessary.

[0063] Furthermore, process controller **400** may enable communication with a plurality of heat exchangers using a Power Management Controller (PMC), such as described in U.S. Pat. No. 6,806,446, incorporated herein by reference. Communications link **431** enables the communication. The PMC allows multiple heat exchangers, each having a unique identifier, to have an electrical supply source that would normally be overloaded if multiple loads were allowed to energize at the same time. Here, micro-controller **401** communicates over interface **430** and communications link **431**, via connection **408**, with the PMC prior to energizing any of the TFR elements. If sufficient power is available, the process controller **400** will energize the TFR elements necessary to meet the calculated demand. If sufficient power is not available, the process controller **400** will limit the element energization accordingly. If another heat exchanger were to require power, the PMC would allocate available resources, as configured. This verification of available power is done multiple times per second.

[0064] One skilled in the art will appreciate that the process controller **400** may be configured in an infinite number of operating modes to provide any desired degree of control and flexibility. Although the present invention has been described with respect to a tankless water heater, it is to be appreciated that the fluid heated by the spiral flow heat exchanger **10** or **110** can range from gases, such as air, to liquids, such as water. This same flexibility extends to the materials used to manufacture the spiral channel guide **24** and **124**, inlet/outlet manifolds **28**/**32** and **128**, and reversing header **133**, as well as tube **12** and **112**.

[0065] Thus, a high thermal transfer spiral flow heat exchanger is disclosed. Further, the high thermal transfer spiral flow heat exchanger is disclosed in conjunction with a fluid heating system. It should be understood that the high thermal transfer spiral flow heat exchanger can be used as a booster in any operating system, such as in an already installed and operating hot water heating system. Also, the high thermal transfer spiral flow heat exchanger can be used as a simple ON/OFF fluid heating system or the various disclosed flow and heat sensors can be incorporated in conjunction therewith. Further, the high thermal transfer spiral flow heat exchanger with sensors, etc. can be used as a whole house water heating system or for only portions thereof. Additionally, the high thermal transfer spiral flow heat exchanger can be used as a point-of-use fluid heater, and can be coupled in series or in parallel as desired for any of the uses herein.

[0066] The high thermal transfer spiral flow heat exchanger disclosed herein includes heating elements that evidence no appreciable residual heat and no mineral deposit buildup. Also, the high thermal transfer spiral flow heat exchanger uses thick-film resistive heating (TFR) elements having no appreciable thermal mass and, therefore, nowhere to store energy so that there is substantially no mass to heat-up or cool-down and cycle time can be made very accurate. Further, the high thermal transfer spiral flow heat exchanger is configured to allow a single (standard) heat exchanger to economically be configured for a variety of heating application demands. Also, a fluid heating system including a high thermal transfer spiral flow heat exchanger and a process controller provides localized monitoring of the electrical supply source in such a way as to provide overload protection to the supply circuit.

[0067] Various changes and modifications to the embodiments herein chosen for purposes of illustration will readily occur to those skilled in the art. To the extent that such modifications and variations do not depart from the spirit of the invention, they are intended to be included within the scope thereof, which is assessed only by a fair interpretation of the following claims.

Having fully described the invention in such clear and concise terms as to enable those skilled in the art to understand and practice the same, the invention claimed is:

1. A fluid heating system with a heat exchanger comprising:

an elongated cylindrical tube with an outer surface, an inner surface, an inlet end and an opposed end;

an array of film resistive elements positioned on the outer surface of the cylindrical tube and extending circumferentially at least partially around the outer surface; and

a spiral channel guide coaxially positioned within the cylindrical tube so as to force fluid flowing in the tube into a spiral path at least partially against the inner surface of the cylindrical tube.

2. A fluid heating system with a heat exchanger as claimed in claim **1** wherein the array of film resistive elements includes a plurality of separate groups of film resistive elements.

3. A fluid heating system with a heat exchanger as claimed in claim **1** wherein the array of film resistive elements includes a film conductor formed on the outer surface of the cylindrical tube with a predetermined depth and width.

4. A fluid heating system with a heat exchanger as claimed in claim **1** wherein the spiral channel guide includes a central elongated cylindrical core and a fluid diverter extending along an outer surface of the cylindrical core.

5. A fluid heating system with a heat exchanger as claimed in claim **4** wherein the fluid diverter is one of an integral part of the outer surface of the cylindrical core and an element affixed to the outer surface of the central core.

6. A fluid heating system with a heat exchanger as claimed in claim **4** wherein the fluid diverter has an outer diameter substantially the same as an inner diameter of the cylindrical tube.

7. A fluid heating system with a heat exchanger as claimed in claim **4** wherein the fluid diverter is in the form of a continuous spiral.

8. A fluid heating system with a heat exchanger as claimed in claim **1** further including one of an inlet manifold and an inlet/outlet manifold positioned in the inlet end of the cylindrical tube.

9. A fluid heating system with a heat exchanger as claimed in claim **8** further including one of an outlet manifold and a reversing header positioned in the outlet end of the cylindrical tube.

10. A fluid heating system with a heat exchanger as claimed in claim **1** further including a process controller unit connected to the array of film resistive elements and adapted to be connected to an electrical supply, the process controller unit for energizing the array of film resistive elements.

11. A fluid heating system with a heat exchanger comprising:

an elongated cylindrical tube with an outer surface, an inner surface, an inlet end and an opposed end;

an array of film resistive elements positioned on the outer surface of the cylindrical tube and extending circumferentially at least partially around the outer surface;

a spiral channel guide including a central elongated cylindrical core and a fluid diverter extending along an outer surface of the cylindrical core, the spiral channel guide coaxially positioned within the cylindrical tube so as to force fluid flowing in the tube into a spiral path at least partially against the inner surface of the tube; and

one of an inlet manifold and an inlet/outlet manifold positioned in the inlet end of the cylindrical tube to introduce fluid into the cylindrical tube and one of an outlet manifold and a reversing header positioned in the opposing end to one of conduct fluid from the cylindrical tube and reverse the flow of fluid within the cylindrical tube, respectively.

12. A fluid heating system with a heat exchanger as claimed in claim **11** wherein the fluid diverter is one of an integral part of the outer surface of the cylindrical core and an element affixed to the outer surface of the central core.

13. A fluid heating system with a heat exchanger as claimed in claim **11** wherein the fluid diverter has an outer diameter substantially the same as an inner diameter of the cylindrical tube.

14. A fluid heating system with a heat exchanger as claimed in claim **11** wherein the fluid diverter is in the form of a continuous spiral.

15. A fluid heating system with a heat exchanger as claimed in claim **11** further including a process controller unit connected to an electrical supply for energizing the array of film resistive elements.

17. A fluid heating system with a heat exchanger comprising:

an elongated cylindrical tube with an outer surface, an inner surface, an inlet end and an opposed end;

an array of film resistive elements positioned on the outer surface of the cylindrical tube and extending circumferentially at least partially around the outer surface;

a spiral channel guide including a central elongated cylindrical core and a fluid diverter extending along an outer surface of the cylindrical core, the spiral channel guide coaxially positioned within the cylindrical tube so as to force fluid flowing in the tube into a spiral path at least partially against the inner surface of the tube;

one of an inlet manifold and an inlet/outlet manifold positioned in the inlet end of the cylindrical tube to introduce fluid into the cylindrical tube and one of an outlet manifold and a reversing header positioned in the opposing end to one of conduct fluid from the cylindrical tube and reverse the flow of fluid within the cylindrical tube, respectively;

a plurality of temperature sensors positioned in the fluid flow within the cylindrical tube;

a flow sensor positioned adjacent the inlet end of the cylindrical tube; and

a process controller unit connected to receive a flow signal from the flow sensor and programmed to calculate a flow rate, the process controller unit further connected to receive temperature signals from the plurality of temperature sensors and further programmed to determine from the temperature signals the amount of power necessary to heat fluid from a source temperature adjacent the inlet end, at the calculated flow rate, to a specified temperature adjacent the outlet manifold and control energization of the film resistive elements to achieve the specified temperature.

18. A fluid heating system with a heat exchanger as claimed in claim **17** wherein the spiral channel guide directs fluid flowing in the cylindrical tube to cause turbulence to occur in the flow and increase thermal transfer from the inner surface of the cylindrical tube to the fluid flowing in the tube.

19. A fluid heating system with a heat exchanger as claimed in claim **17** wherein the array of film resistive elements includes a plurality of separate groups of film resistive elements, at least some of the separate groups including different numbers of film resistive elements.

20. A fluid heating system as claimed in claim **19** wherein an electrical supply is coupled to the process controller unit from a three (3) phase source and phase-to-phase loading is balanced to within the value of a smallest number of the different numbers of film resistive elements.

21. A fluid heating system as claimed in claim **20** wherein the process controller unit monitor includes means for coupling an electrical supply to the process controller unit and means for adjusting energization of the array of film resistive elements in response to the monitored voltage.

22. A fluid heating system as claimed in claim **20** further including a communication interface configured to provide access to a Power Management Controller.

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