Innovation, Sciences et Développement économique Canada
Office de la Propriété Intellectuelle du Canada

Innovation, Science and Economic Development Canada
Canadian Intellectual Property Office

CA 3224896 A1 2022/12/29

(21) 3 224 896

# (12) DEMANDE DE BREVET CANADIEN CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2022/06/17
(87) Date publication PCT/PCT Publication Date: 2022/12/29
(85) Entrée phase nationale/National Entry: 2023/12/20
(86) N° demande PCT/PCT Application No.: CA 2022/050980
(87) N° publication PCT/PCT Publication No.: 2022/266748
(30) Priorité/Priority: 2021/06/24 (US63/214,695)

(51) Cl.Int./Int.Cl. *G01K 3/14* (2006.01), *G01K 15/00* (2006.01), *H01F 27/02* (2006.01), *H05K 5/02* (2006.01)

(71) Demandeur/Applicant:
IFD TECHNOLOGIES INC., CA

(72) Inventeurs/Inventors:
CHISHOLM, JOHN PAUL, CA;
LANDECKER, JAMES THOMAS ISAAC, CA;
LIN, YEN-YOU, CA;
PAULGAARD, MICHAEL STEPHEN, CA;
SCHNEIDER, MATHIEU GARRET, CA;
SIEBERT-TIMMER, AUDREY JOY CORRINE, CA;
...

(74) Agent: OYEN WIGGS GREEN & MUTALA LLP

(54) Titre : APPAREIL ET PROCEDE DE DETECTION NON INVASIVE DE LA TEMPERATURE INTERNE D'UN FLUIDE CONTENU DANS UN BOITIER

(54) Title: APPARATUS AND METHOD FOR NON-INVASIVELY SENSING INTERNAL TEMPERATURE OF A FLUID CONTAINED IN A HOUSING

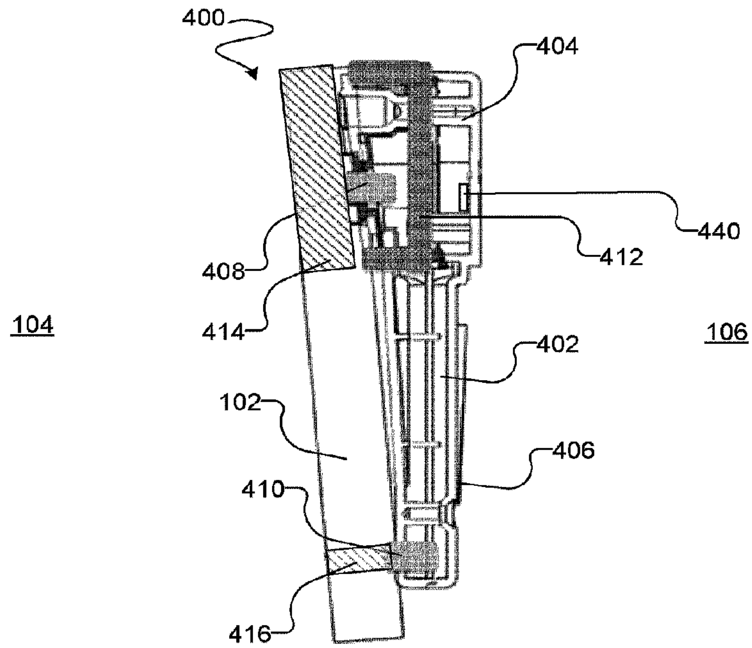



FIG. 5A

(57) Abrégé/Abstract:
Apparatus and methods for non-invasively determining a temperature of a fluid inside a housing are provided. First and second temperature sensors are positioned so that there is a temperature differential between the first and second temperature sensors. A difference between the temperature of the first and second temperature sensors can be used to estimate the temperature of the fluid inside the housing and/or a zero heat flow methodology can be used to determine the temperature of the fluid inside the housing.

(72) **Inventeurs(suite)/Inventors(continued)**: SILGARDO, ADRIAN BERNARD, CA; TUEY, AMANDA MAHN HAH, CA; TULINE, BENJAMIN DONALD CORMAC, CA; VAN HORN, JEREMY MICHAEL, CA; ZUIDERVEEN, THOMAS JACOB, CA

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
**29 December 2022 (29.12.2022)**

WIPO | PCT

(10) **International Publication Number**
**WO 2022/266748 A1**

(51) **International Patent Classification:**
*G01K 3/14* (2006.01) *H01F 27/02* (2006.01)
*G01K 15/00* (2006.01) *H05K 5/02* (2006.01)

(21) **International Application Number:** PCT/CA2022/050980

(22) **International Filing Date:** 17 June 2022 (17.06.2022)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**
63/214,695 24 June 2021 (24.06.2021) US

(71) **Applicant: IFD TECHNOLOGIES INC.** [CA/CA]; 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA).

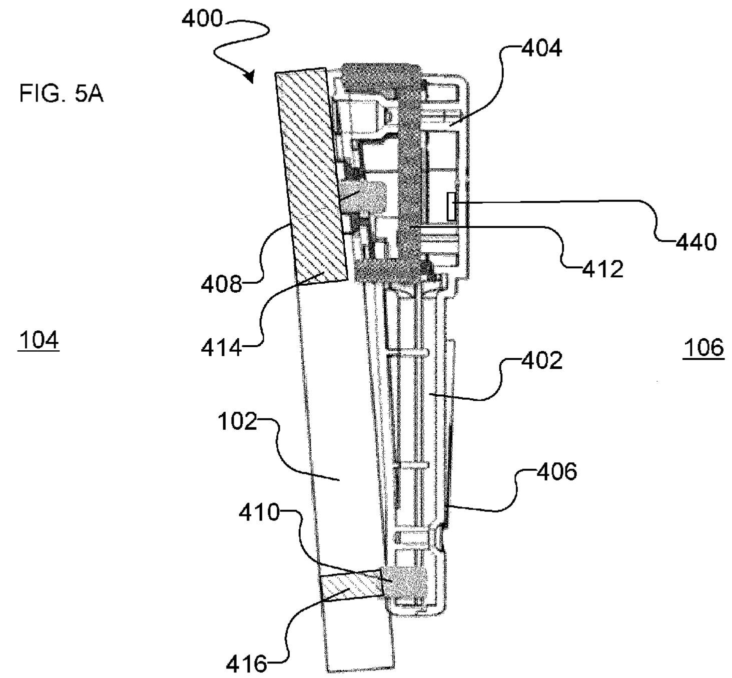
(72) **Inventors: SCHNEIDER, Mathieu Garret**; c/o 8505 Eastlake Drive, Burnaby, British Columbia V5A 4T7 (CA). **TULINE, Benjamin Donald Cormac**; c/o 8505 Eastlake Drive, Burnaby, British Columbia V5A 4T7 (CA). **PAULGAARD, Michael Stephen**; c/o 8505 Eastlake Drive, Burnaby, British Columbia V5A 4T7 (CA). **LANDECKER, James Thomas Isaac**; c/o 8505 Eastlake Drive, Burnaby, British Columbia V5A 4T7 (CA). **SILGARDO, Adrian Bernard**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA). **VAN HORN, Jeremy Michael**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA). **CHISHOLM, John Paul**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA). **SIEBERT-TIMMER, Audrey Joy Corrine**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA). **LIN, Yen-you**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA). **ZUIDERVEEN, Thomas Jacob**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA). **TUEY, Amanda Mahn Hah**; c/o 59 West 6th Avenue, Vancouver, British Columbia V5Y 1K2 (CA).

(74) **Agent: MARLES, Jennifer A.** et al.; 480 - 601 West Cordova Street, Vancouver, British Columbia V6B 1G1 (CA).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,

(54) **Title:** APPARATUS AND METHOD FOR NON-INVASIVELY SENSING INTERNAL TEMPERATURE OF A FLUID CONTAINED IN A HOUSING

FIG. 5A




(57) **Abstract:** Apparatus and methods for non-invasively determining a temperature of a fluid inside a housing are provided. First and second temperature sensors are positioned so that there is a temperature differential between the first and second temperature sensors. A difference between the temperature of the first and second temperature sensors can be used to estimate the temperature of the fluid inside the housing and/or a zero heat flow methodology can be used to determine the temperature of the fluid inside the housing.

WO 2022/266748 A1

*[Continued on next page]*

CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

**(84) Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

# APPARATUS AND METHOD FOR NON-INVASIVELY SENSING INTERNAL TEMPERATURE OF A FLUID CONTAINED IN A HOUSING

## Cross-Reference to Related Applications

**[0001]** This application claims priority to, and the benefit of, United States provisional patent application No. 63/214695 filed 24 June 2021, the entirety of which is incorporated by reference herein for all purposes.

## Technical Field

**[0002]** Some embodiments relate to an apparatus for measuring temperature. Some embodiments relate to an apparatus for non-invasively determining and/or estimating a temperature of a fluid contained within a housing. Some embodiments relate to methods for measuring temperature. Some embodiments relate to methods for non-invasively determining and/or estimating a temperature of a fluid contained within a housing.

## Background

**[0003]** Electrical equipment is a common feature of modern society. Electrical power distribution grids use a variety of electrical equipment, such as transformers, capacitors, reactors and voltage regulators. Electrical equipment such as transformers frequently contains components enclosed within a housing, the housing being filled with a dielectric fluid such as mineral oil, natural or synthetic ester fluids, or silicon oil in order to maintain a stable operating temperature for the electrical equipment, and to prevent or rapidly quench any electric discharges.

**[0004]** Maintaining the operating temperature of the electrical equipment, as reflected by the temperature of the dielectric fluid contained within the housing of the electrical equipment, within a desirable range is important. The life expectancy of electrical equipment such as transformers may be decreased as the operating temperature of the piece of electrical equipment is increased. For example, for some electrical equipment such as transformers, the life expectancy of the equipment may be reduced by as much as onehalf for every approximately 5°C to 10°C increase in continuous operating temperature that the equipment experiences.

**[0005]** If a piece of electrical equipment is regularly or consistently operating at an elevated temperature, the piece of electrical equipment may fail prematurely (i.e. before the predicted lifespan of the electrical equipment has elapsed). It can be prudent to replace such a piece of electrical equipment with a piece of electrical equipment having a larger load capacity if it is regularly or consistently operating at a temperature higher than the desired operating temperature.

**[0006]** As an example, transformer loss-of-life is a function of both time and temperature, so the longer that a transformer is operating at an over-loaded temperature, the more the expected lifetime of the transformer is reduced. A brief over-load will not have a significant impact on the expected lifetime unless it is at very extreme temperatures; however, frequent over-loading will have a significant impact on the expected lifetime of the transformer. Therefore, if a transformer is slightly over-loaded, utilities will monitor further to determine if this is a regular occurrence or a chance event. If they find it to be a regular occurrence, they may replace the transformer with a larger version designed to handle higher loads. If the transformer is heavily over-loaded, it is a sign that a significant loss-of-life may have already occurred, and that the transformer is likely somewhat over-loaded on a regular basis.

**[0007]** Some utilities have developed practices for optimizing the lifetime of their equipment and the effort required to maintain it. Such practices may involve categorizing over-loaded equipment based on its operating temperature relative to a reference temperature and performing different actions based on such categorization. For example, if a transformer is designed to operate at a reference temperature of 90°C, a transformer may be categorized as ‘over-loaded’ if it is operating at 110°C and ‘extremely over-loaded’ if it is operating at 120°C. A piece of equipment that is ‘over-loaded’ may be monitored more closely for a period of time, while equipment that is ‘extremely over-loaded’ may be replaced immediately.

**[0008]** There is a need to provide apparatus capable of sensing and communicating changes in temperature within electrical equipment to assist in determining if the electrical equipment is operating in an ‘over-loaded’ or ‘extremely over-loaded’ state. The more rapidly such over-temperature situations can be detected and the relevant power authority notified, the sooner the situation can be addressed, thereby preventing a premature or catastrophic failure of the electrical equipment.

**[0009]** There is also a need to provide an apparatus capable of non-invasively and accurately sensing and communicating changes in temperature within electrical equipment. US 9395252 to Frounfelker et al. teaches a system and method for estimating a temperature of a fluid contained in an electrical device without direct thermal communication with the fluid. The method includes measuring a temperature of an exterior wall of a housing of the electrical device, measuring an ambient temperature around the housing, and estimating a temperature of the fluid within the housing using the measured wall temperature and the measured ambient temperature. The method can also purportedly adjust the estimated fluid temperature for ambient humidity conditions.

**[0010]** The foregoing examples of the related art and limitations related thereto are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the drawings.

## Summary

**[0011]** The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tools and methods which are meant to be exemplary and illustrative, not limiting in scope. In various embodiments, one or more of the above-described problems have been reduced or eliminated, while other embodiments are directed to other improvements.

**[0012]** One aspect provides apparatus for non-invasively estimating a temperature inside a housing. The apparatus has an environmentally shielding portion shaped and configured to shield at least a portion of the housing from prevailing environmental conditions, a first temperature sensing element disposed within the environmentally shielding portion and located to be positionable proximate to the housing when the apparatus is in use, a second temperature sensing element spaced apart from the environmentally shielding portion, the second temperature sensing element located to be positionable proximate to the housing when the apparatus is in use. In some aspects, the second temperature sensing element is largely exposed to prevailing environmental conditions, or is more exposed to prevailing environmental conditions than the first temperature sensing element. In some aspects, the

apparatus has a cartridge portion shaped and configured for insertion into a cartridge housing extending inside the housing, the cartridge portion containing the second temperature sensing element. In some aspects, the apparatus has a sensor for determining if the cartridge portion has been inserted into the cartridge housing.

**[0013]** One aspect provides a method of using an apparatus as described above, the method having steps of: determining if the cartridge portion has been inserted into the cartridge housing; if it is determined that the cartridge portion has been inserted into the cartridge housing, using a third thermal sensing element to directly measure the temperature of the fluid contained within the housing; or if it is determined that the cartridge portion has not been inserted in the cartridge housing, using the first and second thermal sensing elements to estimate the temperature of the fluid contained within the housing.

**[0014]** One aspect provides a method of estimating a temperature of fluid contained within a housing, the method having the steps of: measuring a first temperature at a first external location on the housing, the first external location being sheltered from environmental conditions; measuring a second temperature at a second external location on the housing, the second external location being exposed to environmental conditions or being more exposed to environmental conditions than the first external location; and correlating a difference between the first temperature and the second temperature to estimate the temperature of the fluid contained within the housing.

**[0015]** One aspect provides an apparatus for estimating a temperature of fluid contained within a housing, the apparatus having a first thermal sensing element, a second thermal sensing element, a heating element positioned outwardly of both the first and second thermal sensing elements, and thermal insulation differentially positioned relative to the first and second thermal sensing elements.

**[0016]** One aspect provides a method of estimating a temperature of fluid contained within a housing, the method having the steps of: (i) measuring a first temperature at a first location proximate the housing; (ii) measuring a second temperature at a second location, a temperature differential being initially present between the first and second locations; (iii) if the first temperature is different than the second temperature, activating a heating element positioned outwardly of both the first and second locations; (iv) repeating steps (i) through (iii) until it is determined that the first and second temperatures are the same; and (v) determining the temperature of the fluid contained within the housing to be the same as the first and second temperatures.

**[0017]** One aspect provides an apparatus for estimating a temperature of fluid contained within a housing, the apparatus having a first thermal sensing element, a second thermal sensing element; and thermal insulation positioned to be located between the housing and the second thermal sensing element when the apparatus is in use.

**[0018]** One aspect provides a method of estimating a temperature of fluid contained within a housing, the method having the steps of: measuring a first temperature at a first location on the housing; measuring a second temperature at a second location, thermal insulation being positioned between the housing and the second location; and estimating the temperature of the fluid contained within the housing based on the relationship between the first temperature and the second temperature.

**[0019]** In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following detailed descriptions.

## Brief Description of the Drawings

**[0020]** Exemplary embodiments are illustrated in referenced figures of the drawings. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

**[0021]** FIG. 1 shows an exemplary embodiment of a piece of electrical equipment, namely a transformer.

**[0022]** FIG. 2A shows a second exemplary embodiment of a piece of electrical equipment, namely a transformer, with an internal recess formed therein. FIG. 2B is a cross-sectional view thereof taken along line 2B—2B.

**[0023]** FIG. 3A shows a sectional view of an exemplary embodiment of a temperature sensor that can be used to estimate the temperature of fluid within a housing using a zero heat flow methodology. FIG. 3B shows a sectional view of a second exemplary embodiment of a temperature sensor that can be used to estimate the temperature of fluid within a housing using a zero heat flow methodology.

**[0024]** FIG. 4 shows an exemplary embodiment of a method of estimating the temperature of fluid within a housing using a zero heat flow methodology.

**[0025]** FIG. 5A shows a sectional view, FIG. 5B shows an enlarged sectional view and FIG. 5C shows a partial perspective view of an exemplary embodiment of a temperature sensor that can be used to estimate the temperature of fluid within a housing using a temperature differential or Delta T method.

**[0026]** FIG. 6 shows an exemplary embodiment of a method of estimating the temperature of fluid within a housing using a temperature differential or Delta T methodology.

**[0027]** FIG. 7 shows an example embodiment of determining whether a temperature sensor has been installed to directly measure or to estimate a temperature of a fluid contained within a housing.

**[0028]** FIG. 8 shows an example embodiment of a method of estimating the temperature of fluid within a housing using a temperature differential or Delta T methodology incorporating a compensation factor for the ambient environmental temperature.

**[0029]** FIG. 9 shows an example embodiment of a temperature sensor that can be used to estimate a temperature of a fluid contained within a housing using a modified zero heat flow methodology.

**[0030]** FIG. 10 shows an example embodiment of a method of estimating the temperature of fluid within a housing using a hybrid zero heat flow and temperature differential or Delta T methodology.

**[0031]** FIG. 11 shows an example embodiment of a temperature sensor having a wired connection.

**[0032]** FIG. 12 shows an example test demonstrating the correlation between the estimated internal temperature versus the measured temperature of a housing.

## Description

**[0033]** Throughout the following description specific details are set forth in order to provide a more thorough understanding to persons skilled in the art. However, well known elements may not have been shown or described in detail to avoid unnecessarily obscuring the disclosure. Accordingly, the description and drawings are to be regarded in an illustrative, rather than a restrictive, sense.

**[0034]** As used herein, “environmental conditions” can include any external environmental parameter that may affect an internal temperature of a fluid contained within a housing or any combination of such parameters. Examples of environmental conditions include the prevailing environmental temperature, humidity, wind conditions, precipitation, solar radiation, and the like, including any combination of such conditions. For example, the housing and any fluid contained within a housing may be subject to greater cooling effects due to a combination of cold and wind, as compared with the cooling effects that might be experienced with only cold or only wind per se.

**[0035]** As used herein, “external” means the outer surface of a housing and “internal” means the inner surface or interior portion of the housing. “Outward” means in a direction away from the internal portion of the housing.

**[0036]** As used herein, the term “adjacent” or “proximate” can mean directly contacting, or can mean in close enough contact through any interposing elements or space that for example a temperature sensor can still measure an approximation of the temperature of the surface to which it is “adjacent” or “proximate”.

**[0037]** With reference to FIG. 1, an exemplary piece of electrical equipment being a transformer **100** is illustrated. Transformer **100** has a tank or housing **102** that encloses a fluid **104** within its interior. Fluid **104** is fluidly separated by housing **102** from an external environment **106** surrounding housing **102**. That is, fluid **104** is sealed within housing **102** so that it is largely not permitted to escape housing **102**. In some cases, fluid **104** can be hazardous to the environment (for example fluid **104** may be a recognized greenhouse gas or may have deleterious or harmful effects on various organisms), so that it is important to keep fluid **104** largely contained within housing **102** although some fluid **104** might be vented if the pressure within transformer **100** builds above a certain level and activates any pressure relief valve associated with transformer **100**. In some embodiments depending on the design and regulations applicable to a particular transformer **100**, housing **102** may be open to the external environment to a limited extent to allow for pressure equalization, for example via an aspiration tube. In some embodiments, the aspiration tube can be plugged with mineral wool or other substance that allows air to pass but that restricts the passage of fluid **104** therethrough.

**[0038]** Fluid **104** can be any suitable electrically insulating or dielectric fluid suitable for use in electrical equipment, including mineral oil, natural or synthetic ester fluids, silicon oil, or gases such as $SF_6$, or the like.

**[0039]** Housing **102** can be any suitable tank or housing for a piece of electrical equipment such as a transformer like transformer **100**. In some embodiments, housing **102** is made from carbon steel, stainless steel, or any other suitable material. Different styles of housings **102** for different transformers **100** can vary in a number of different design aspects, for example the thickness of the housing, the material from which the housing is made, the thermal conductivity of the material from which the housing is made, the type and thickness of the protective coating provided on the housing (e.g. paint), the size and dimensions of the housing (e.g. volume, height, length, width, diameter, and so on), the shape of the housing (e.g. round or rectangular), the fluid circulation pattern of fluid within the housing, and the like.

**[0040]** In the illustrated embodiment, a first portion of housing **102**, illustrated schematically as **108**, is shielded from the impact of environmental conditions, while a second portion of housing **102**, illustrated schematically as **110**, is exposed to the impact of environmental conditions.

**[0041]** With reference to FIG. 2A and FIG. 2B, an alternative embodiment of a transformer **200** with a housing **202** having an inlet **250** containing a cartridge housing **252** therein is illustrated. Transformer **200** is otherwise similar to transformer **100**, and like elements have been illustrated with like reference numerals incremented by **100** and are not further described again including fluid **204**, external atmosphere **206**, shielded portion **208** and exposed portion **210** of housing **202**. In the illustrated embodiment, cartridge housing **252** is placed in sealed engagement with housing **202** about inlet **250**, to prevent the escape of fluid **204** from the interior space of housing **202**. The fluid level **212** of fluid **204** is shown by a dashed line in FIG. 2B, and this can be referred to as the top oil level.

**[0042]** With reference to FIG. 3A, an example embodiment of a temperature sensor **300** that can be used to determine the temperature of fluid **104** or **204** within transformer **100** or **200** using the zero-heat-flow method described below is provided. The zero-heat-flow method uses two temperature sensing elements to determine the heat flux or heat flow through housing **102** or **202** and compensates for that heat loss using an actively powered heater.

**[0043]** Temperature sensor **300** has a body **302** that is shaped and configured to be mountable to the housing of an electrical device, e.g. housing **102**. Temperature sensor **300** is provided with first and second temperature sensing elements **304** and **306** which are spaced apart from one another and separated by a layer of thermal insulation **308**. Because first temperature sensing element **304** is exposed more directly to the housing **102** while temperature sensing element **306** is thermally shielded from the heat exiting housing **102** by thermal insulation **308**, that is because thermal insulation **308** is differentially positioned relative to the first and second thermal sensing elements when temperature sensor **300** is in use, a temperature differential is produced between first and second temperature sensing elements **304**, **306** when temperature sensor **300** is in use.

**[0044]** Any suitable temperature sensor can be used for first and second temperature sensing elements **304**, **306**, for example a thermocouple, resistive thermal device (RTD) sensor, thermistor, semiconductor-based integrated circuit, or the like. Any suitable material can be used to provide thermal insulation **308**, for example foam, entrapped air, materials forming part of or components of temperature sensor **300**, or the like. The insulation value provided by thermal insulation **308** should remain constant throughout the use of temperature sensor **300**, so that calibration of temperature sensor **300** as described below can be used to determine the temperature of fluid **104** or **204** within housing **102** or **202** as described herein. E.g. the components that form part of thermal insulation **308** should not be removed or modified in a manner that might change the insulation value provided by thermal insulation **308**.

**[0045]** A heating element **310** is provided outwardly of second temperature sensing element **306**. Temperature sensor **300** is configured so that first temperature sensing element **304** can be placed in or close to thermal contact with housing **102**. Thermal insulation **308** is positioned outwardly of first temperature sensing element **304**, so that heat moving outwardly along the path of heat flow (illustrated by arrow **312**) must pass through thermal insulation **308** to reach second temperature sensing element **306**, which is positioned outwardly on body **302** from thermal insulation **308**. Finally, any heat passing through second temperature sensing element **306** along the path of heat flow **312** will reach heating element **310**. As a result of this configuration, there will be a difference in the temperature measured by each of first temperature sensing element **304** and second temperature sensing element **306**, which reflects a portion of the temperature gradient from the fluid **104** to the external environment **106**.

**[0046]** The surface area of housing **102** that is covered by temperature sensor **300** should be sufficiently large that a significant amount of heat is not lost along paths of travel other than the path of heat flow **312**—that is, if the surface area of housing **102** that is covered by temperature sensor **300** is too small, then heat will move not only along the path of heat flow **312**, but also in directions orthogonal thereto, meaning that the temperature measured by second temperature sensing element **306** may be lower than would be the case if heat flowed only along path of heat flow **312**. Likewise, the surface area that is covered by thermal insulation **308** and heating element **310** should be sufficiently large to ensure that a significant amount of heat is not lost along paths of travel other than the path of heat flow **312**.

**[0047]** In use, heat is applied to the system using heating element **310** until there is no temperature gradient between the first and second heat sensing elements **304**, **306**. Such situation implies that heat has stopped flowing along the path of heat flow **312**, so that all of the first and second temperature sensing elements **304**, **306** and thermal insulation **308** are at the same temperature, as is the fluid **104** inside housing **102**. At this stage, the reading of temperature sensors **304**, **306** will correspond to the temperature of fluid **104**.

**[0048]** Alternative configurations can be used to determine the temperature of fluid **104** or **204** within transformer **100** or **200** using a zero-heat-flow method, so long as the temperatures initially measured by first and second temperature sensing elements **304**, **306** are different due to differing degrees of insulation interposing each of first and second temperature sensing elements **304**, **306** and either housing **102** or heating element **310** (i.e. so that a temperature differential is established between first and second temperature sensing elements **304**, **306**, which may be because thermal insulation **308** is differentially positioned relative to first and second temperature sensing elements **304**, **306**).

**[0049]** For example, with reference to FIG. 3B, an alternative embodiment of a temperature sensor **300’** in which first and second temperature sensing elements **304’**, **306’** are laterally spaced apart from one another is illustrated. In the illustrated embodiment, first temperature sensing element **304'** is proximate to housing **102'** of the transformer within body **302'** but without any significant insulating material interposing first temperature sensing element **304'** and housing **102'**, so that the temperature measured by first temperature sensing element **304'** is reflective of or approximates more closely the temperature of housing **102'**. Second temperature sensing element **306'** is spaced apart from housing **102'** by thermal insulation **308'**, so that a temperature differential is established between first temperature sensing element **304'** and second temperature sensing element **306'** by reason of the differential positioning of thermal insulation **308'** (i.e. first temperature sensing element **304'** will be more affected by changes in the in the temperature of internal fluid **104** than will second temperature sensing element **306'**). As for thermal insulation **308**, any suitable material can be used to provide thermal insulation **308'**, for example foam, entrapped air, materials forming part of or components of temperature sensor **300'**, or the like.

**[0050]** While in the illustrated embodiment second temperature sensing element **306'** is illustrated as being positioned farther outwardly from housing **102'** than first temperature sensing element **304'**, in alternative embodiments the first and second temperature sensing elements could be positioned the same distance outwardly from housing **102'**, or the second temperature sensing element **306'** could actually be positioned closer to housing **102'**, so long as the thermal insulation value of the material between second temperature sensing element **306'** and housing **102'** is greater than the amount of thermal insulation value of the material positioned between first temperature sensing element **304'** and housing **102'**, to provide a temperature differential between the first and second temperature sensing elements **304'**, **306'**.

**[0051]** Likewise in the illustrated embodiment, while thermal insulation **308'** has been illustrated as being positioned between second temperature sensing element **306'** and housing **102'** to provide the differential positioning of thermal insulation **308'** relative to first and second temperature sensing elements **304'**, **306'**, in alternative embodiments the temperature differential between first and second temperature sensing elements **304'**, **306'** could be produced by positioning thermal insulation **308'** instead between first temperature sensor **304'** and heating element **310'**.

**[0052]** Further alternative embodiments could be developed that produce a temperature differential between sensing elements **304'** and **306'** when heat is flowing by positioning thermal insulation in different orientations around the sensors to provide the differential positioning, for instance by shielding first temperature sensing element **304'** from lateral heat flow to a greater extent than second temperature sensing element **306'**.

**[0053]** In the case of temperature sensor **300'**, heat flows out of housing **102'** and past first temperature sensing element **304'** along a first path of heat flow **312A**, while heat flows out of housing **102'**, past thermal insulation **308'**, and then past second temperature sensing element **306'** along a second path of heat flow **312B**. Again, the difference in temperature measured by each of first temperature sensing element **304'** and second temperature sensing element **306'** is reflective of a portion of the temperature gradient from fluid **104** to external environment **106**, and can likewise be used in conjunction with the application of heat from heating element **310'** until there is no temperature gradient between the first and second heat sensing elements **304'**, **306'**. Upon reaching such situation, this implies that heat has stopped flowing along both path of heat flow **312A** and path of heat flow **312B** so that all of first and second temperature sensing elements **304'**, **306'** and thermal insulation **308'** are at the same temperature, as is fluid **104** inside housing **102'**. Again, at this point, the reading of temperature sensors **304'**, **306'** corresponds to the temperature of fluid **104**.

**[0054]** In further alternative embodiments, the shape and configuration of heating element **310** or **310'** could be varied. For example in some embodiments, heating element **310** or **310'** could be circular or oval in shape optionally with an aperture through the centre thereof (e.g. provided with a doughnut shape), to minimize the amount of heat that passes laterally away from path of heat flow **312** (or **312A/312B**). In other embodiments, both of the first and second temperature sensing elements could be spaced apart at the same or approximately the same distances from the housing, but with thermal insulation positioned only between the second temperature sensing element and the housing (i.e. not between the first temperature sensing element and the housing) or thermal insulation positioned only between the first temperature sensing element and the heating element (i.e. not between the second temperature sensing element and the heating element) to provide a temperature differential between the two temperature sensing elements.

**[0055]** Temperature sensor **300** or **300'** can be used in a method **3000** illustrated in FIG. 4 for estimating the temperature of fluid within a housing using a zero heat flow methodology. Initially at **3002**, heat flows from fluid **104** outwardly through housing **102** towards the external environment **106** along path of heat flow **312** (or **312A/312B**) Because of the presence of thermal insulation **308** or **308'**, the amount of heat reaching second temperature sensing element **306** or **306'** will be less than the amount of heat reaching first temperature sensing element **304** or **304'**, and the temperature $T_2$ measured by second temperature sensing element **306** or **306'** will be lower than the temperature $T_1$ measured by first temperature sensing element **304** or **304'**.

**[0056]** At **3004**, if it is determined that $T_1$ is greater than $T_2$, heating element **308** will be activated to supply heat at **3006**. Steps **3004** and **3006** will be repeated until it is determined at step **3004** that $T_1$ is the same as $T_2$. At that point, it will be concluded at step **3008** that the temperature of fluid **104** inside housing **102** is the same as both that $T_1$ and $T_2$. In the event that it is determined at step **3004** that $T_2$ is greater than $T_1$, heating element **308** can stop applying heat and step **3004** can be repeated until such time as it is determined at step **3004** that $T_1$ is again greater than $T_2$ (at which point step **3006** can be repeated) or until such time as it is determined at step **3004** that $T_1$ is equal to $T_2$, at which point it can be concluded at step **3008** that the temperature of fluid **104** inside housing **102** is the same as both that $T_1$ and $T_2$.

**[0057]** With reference to FIGs. 5A, 5B and 5C, an example embodiment of a temperature sensor **400** that can be used to estimate the temperature of fluid **104** within housing **102** using a temperature differential or Delta T method is shown. Sensor **400** has a body **402** which has a first portion or head **404** and a second portion stem **406**. In the illustrated embodiment, head **404** is positioned vertically above stem **406**, although it will be appreciated that the relative positions of these components could be varied depending on the orientation of sensor **400**.

**[0058]** Sensor **400** has a first or head temperature sensing element **408** positioned in head **404** so that head temperature sensing element **408** can be placed in thermal contact with housing **102** when sensor **400** is in an installed configuration, as shown in FIG. 5A. Sensor **400** also has a second or stem temperature sensing element **410**, which is positioned within stem **406** so that stem temperature sensing element **410** can be placed in thermal contact with housing **102** when sensor **400** is in the installed configuration. Any suitable temperature sensor can be used for first and second temperature sensing elements **408**, **410**, for example a thermocouple, resistive thermal device (RTD) sensor, thermistor, semiconductor-based integrated circuit, or the like.

**[0059]** A thermally insulating and environmentally shielding barrier, shown schematically as **412** in FIG. 5A, is provided in head **404**, to protect head temperature sensing element **408** and the corresponding shielded portion **414** of housing **102** to which head **404** is affixed from the external environment when sensor **400** is in the installed configuration. Thus, head temperature sensing element **408** and the corresponding shielded portion **414** of housing **102** to which head **404** is affixed are protected from the external environment when sensor **400** is in the installed configuration.

**[0060]** In contrast, no such thermally insulating or environmentally shielding barrier is provided on stem **406**. Further, the surface area of stem **406** that contacts housing **102** is relatively small, so that the portion **416** of housing **102** that is contacted by stem temperature sensing element **410** is relatively exposed to the external environment.

**[0061]** With further reference to FIGs. 5B and 5C, one example embodiment of a thermally insulating and environmentally shielding barrier that is a physical barrier is shown in more detail. In the illustrated embodiment, head temperature sensing element **408** is circumferentially surrounded by an inner circumferential gasket **420**. The outer periphery of the portion of head **404** that contacts housing **102** is likewise circumferentially surrounded by an outer circumferential gasket **421**. The inner and outer circumferential gaskets **420**, **421** can help to prevent or minimize the effect of certain environmental conditions such as wind, rain and solar radiation by physically preventing and/or reducing the ingress of such environmental elements to head temperature sensing element **408** and portion **414** of housing **102** to which head **404** is affixed. This minimizes the effect of such environmental elements on the temperature of portion **414** of housing **102** and minimizes the effect of such environmental elements on head temperature sensing element **408**.

**[0062]** The inner and outer circumferential gaskets **420**, **421** do not need to achieve a 100% sealing effect against the outer surface of housing **102** to achieve such minimization. The material of body **402** of head **404** and the components contained therein (e.g. entrained air **430**, circuit board **432**, internal gasket **422**, and the like) alone make it difficult for wind, rain and solar radiation to access the portion **414** of the external surface of housing **102** to which head **404** is affixed. Addition of inner and/or outer circumferential gaskets can enhance the blocking of such environmental elements that is provided by head **404**, although in some embodiments either or both of the inner and/or outer circumferential gaskets could be removed. Head **404** should be designed to cover a sufficient amount of surface area **414** to shield a sufficiently large surface area of housing **102** to ensure that head temperature sensing element **408** is sensing a shielded temperature. Thus, heat flow laterally through the wall of housing **102** from shielded portion **414** should be sufficiently low to allow the shielded temperature to be properly determined.

**[0063]** Head temperature sensing element **408** is also thermally shielded from the external environment. In the illustrated embodiment, the material of body **402** of head **404** and the components contained therein (e.g. entrained air **430**, circuit board **432**, inner gasket **422**, the walls of body **402**, inner and outer circumferential gaskets **420** and **421**, and the like) make it difficult for wind, rain and solar radiation to access the portion **414** of the external surface of housing **102** to which head **404** is affixed, and also collectively act as thermal insulation to thermally shield head temperature sensing element **408** from the external environment. This collectively shields head temperature sensing element **408** and shielded portion **414** of housing **102** against the impact of ambient temperature and environmental conditions.

**[0064]** In contrast to head temperature sensing element **408**, stem temperature sensing element **410** is not shielded from the external environment, and any shielding provided by stem **406** is minimized, for example by stem **406** having a relatively narrow width and small size compared to head **404**.

**[0065]** With reference to FIG. 6, a method **4000** of estimating the internal temperature of fluid **104** using a temperature differential or Delta T methodology is illustrated. Sensor **400** can be used to carry out some embodiments of method **4000**. At **4002** head temperature sensing element **408** measures the temperature $\mathbf{T_3}$ of shielded portion **414** of housing **102**. At **4004**, stem temperature sensing element **410** measures the temperature $\mathbf{T_4}$ of exposed portion **416** of housing **102**.

**[0066]** Because $\mathbf{T_3}$ is measured on the shielded portion **414** and $\mathbf{T_4}$ is measured on the exposed portion **416**, the temperatures will differ from one another. The difference between the temperatures or Delta T is a function of parameters such as the temperature of fluid **104** and the impact of external environment **106** on the cooling of transformer **100**. The head temperature sensing element **408** and stem temperature sensing element **410** can be calibrated using reference transformers operating with a known temperature of fluid **104**. Using the known reference measurements, the correlation between $\mathbf{T_3}$ and $\mathbf{T_4}$ can be used to derive a relationship between these two measurements and the internal temperature of fluid **104**, so that the difference between **T**$_3$ and **T**$_4$ can be used in the field at step **4006** to predict the temperature of fluid **104**.

**[0067]** In some embodiments, internal oil temperature is estimated using a transfer function, which can take a number of mathematical forms, such as power, linear, etc. If a power equation is used, it could look like the following Equation **(1)**:

$$T_{Oil} = A(T_S - T_E)^{-B} \tag{1}$$

Where

- $T_{Oil}$ is the estimated oil temperature
- $T_S$ is the shielded tank temperature
- $T_E$ is the exposed tank temperature
- A and B are empirically derived coefficients

If a linear function is used, it could take the following form of Equation **(2)**:

$$T_{Oil} = A + BT_S + CT_E \tag{2}$$

Where

- $T_{Oil}$ is the estimated oil temperature
- $T_S$ is the shielded tank temperature
- $T_E$ is the exposed tank temperature
- A, B and C are empirically derived coefficients

**[0068]** The foregoing equations for estimating the internal oil temperature are exemplary only. The person skilled in the art would be able to determine alternative transfer equations using forms other than power or linear which would produce similarly effective results given the same inputs of $T_S$ and $T_E$ (corresponding to **T**$_3$ and **T**$_4$ described above).

**[0069]** In some embodiments, stem **406** of temperature sensor **400** is shaped and configured to be insertable into cartridge housing **252**. In such embodiments, when transformer **200** is equipped with cartridge housing **252**, temperature sensor **400** can be inserted therein. In such configuration, stem temperature sensing element **410** is positioned inside the interior of housing **202** during use, and is able to directly or nearly directly measure the temperature of fluid **204** within the interior space of housing **202**. Thus, a measurement of the actual temperature of fluid **204** within housing **202** can be made.

**[0070]** In one example embodiment, temperature sensor **400** can be used in a method of developing calibration coefficients that can be used to estimate the internal temperature of fluid within transformers like transformer **100** that do not contain any aperture or orifice through which an internal temperature can be determined. For example, the calibration of a particular transformer **100** with respect to the difference between $T_3$ and $T_4$ measured by head temperature sensing element **408** and stem temperature sensing element **410** when sensor **400** is mounted externally on transformer **102** or **202** may depend on various parameters associated with transformer **100** or housing **102**, including the thickness of the walls of housing **102**, the paint coating applied, the type of metal from which housing **102** is made, and the like. Calibration should be conducted separately for each transformer **100** for which these parameters are varied, but calibration carried out on one transformer **100** having a particular set of these parameters (i.e. on one particular style of transformer) will be valid across other transformers **100** that share the same set of parameters. The same principles can be applied to develop calibration coefficients for determining an internal temperature of fluid contained in other pieces of electrical equipment or device.

**[0071]** Sensor **400** can be used to carry out such calibration by inserting the stem **406** of a first such sensor **400** into the cartridge housing **252** of a transformer **200**, and also mounting a second such sensor **400** externally on housing **202**. The transformer **200** can be subjected to a plurality of different temperature and environmental conditions to determine the respective different values of $T_3$ and $T_4$ measured by the head and stem temperature sensors **408**, **410** of the second sensor **400** at a plurality of different temperatures or under different environmental conditions, and comparing the values of $T_3$ and $T_4$ from the second sensor with the measured value of the temperature of fluid **204** inside housing **202** measured by the stem temperature sensing element **410** of the first such sensor acting as a third temperature sensor (or by in any other way directly measuring the internal temperature of fluid **204** inside housing **202**). Using the measured data, the coefficients of the equation used to model the internal temperature of the tank versus $T_3$ and $T_4$ could be determined.

**[0072]** In one example embodiment, temperature sensor **400** further includes an orientation sensor such as a gyroscope or contact sensor, schematically illustrated as sensor **440**.

Examples of sensors that can be used for sensor **440** include: a tilt switch to determine if sensor **400** is mounted vertically (indicating external mounting) or horizontally (indicating mounted inside cartridge housing **252**); a reed switch with magnet; logic rules based on the measured temperature, e.g. if the stem sensor is at a higher temperature than the head sensor, likely sensor **400** is installed in cartridge housing **252**, whereas a reverse temperature condition suggests external mounting; an accelerometer; a physical switch that is switched when sensor **400** is installed in a particular configuration; a light gate or other digital switch that is triggered in one mounting position but not the other; and so on.

**[0073]** Orientation sensor **440** can be used to determine if temperature sensor **400** has been mounted to the exterior of a housing, or if temperature sensor **400** has been inserted into cartridge housing **252**. If orientation sensor **440** determines that temperature sensor **400** has been inserted into cartridge housing **252**, then stem temperature sensing element **410** can be used to directly measure the internal temperature of the housing, and further can be used as the third sensor if carrying out calibration for a particular transformer **200**. If orientation sensor **440** determines that temperature sensor **400** has been mounted to the exterior of a housing, then temperature sensing elements **408** and **410** are used to make an estimate of the internal temperature of the fluid within the housing, e.g. by carrying out method **4000**.

**[0074]** For example, with reference to FIG. 7, method **700** can be used to determine how a temperature sensor like temperature sensor **400** has been installed and make a determination of a temperature of a fluid contained within a housing accordingly. At **702**, it is determined whether the stem **406** of temperature sensor **400** has been inserted into a cartridge housing within the electrical device. At **704**, if it is determined that the stem **406** of temperature sensor **400** has been inserted into the cartridge housing **252**, the temperature of the fluid contained within the housing is determined directly using stem temperature sensing element **410**. At **706**, if it is determined that the stem **406** of temperature sensor **400** has not been inserted into cartridge housing **252**, then thermal sensing elements **410** and **412** separated by thermal insulation **414** are used to make an estimate of the internal temperature of the fluid within the housing, e.g. by carrying out method **4000**.

**[0075]** In some embodiments, a method for estimating the temperature of fluid **104** using a temperature differential or Delta T methodology incorporating an additional compensation factor based on the ambient environmental temperature is provided. An example of such method **5000** is illustrated in FIG. 8. Method **5000** can be carried out using any suitable apparatus for determining the temperature of housing **102** at a shielded location **108** and at an exposed location **110** (e.g. temperature sensor **400**), as well as any suitable apparatus for determining ambient environmental temperature, e.g. a thermocouple, resistive thermal device (RTD) sensor, thermistor, semiconductor-based integrated circuit, or the like. The ambient temperature can be used as an additional variable in method **5000** to correlate the three measured temperatures to the temperature of fluid **104**, for example by including the ambient temperature in equations similar to Equations (1) and (2) and using known reference measurements as described above for the temperature differential or Delta T methodology described with reference to method **4000** to derive a correlation between $\mathbf{T_3}$, $\mathbf{T_4}$ and the ambient temperature, and the temperature of fluid **104**.

**[0076]** In method **5000**, at **5002**, the temperature of the shielded location **108** (corresponding to $\mathbf{T_3}$ described with reference to method **4000**) is determined. At **5004**, the temperature of the exposed region **110** (corresponding to $\mathbf{T_4}$ described with reference to method **4000**) is determined. At **5006**, ambient temperature is determined. At **5008**, the internal temperature of fluid **104** is estimated based on the measurements of $\mathbf{T_3}$, $\mathbf{T_4}$ and ambient environmental temperature.

**[0077]** With reference to FIG. 9, an example embodiment of a temperature sensor **600** that can be used to estimate the internal temperature of fluid **104** using a hybrid zero heat flow temperature differential methodology is illustrated. Temperature sensor **600** has a body **602** and is configured to be mountable on the external surface of housing **102**. A first temperature sensing element **604** is positioned to be mountable adjacent the external surface of housing **102**, and then similar to temperature sensor **300**, a layer of thermal insulation **608** is positioned outwardly from first temperature sensing element **604**, and then a second temperature sensing element **606** is positioned outwardly from thermal insulation **608**. Heat thus flows outwardly from housing **102** along the path of heat flow represented by arrow **612**.

**[0078]** Temperature sensor **600** differs from temperature sensor **300** in that a heating element is omitted. Thus, rather than using applied heat from a heating element to use a zero heat flow methodology to calculate the internal temperature of fluid **104**, temperature sensor **600** uses the calibration of the temperature difference between first and second temperature sensing elements **604**, **606** under a series of known internal temperature conditions to develop an equation that can be used to model and predict the temperature of fluid **104** based on the temperature difference between first and second temperature sensing elements **604**, **606**.

**[0079]** In some embodiments, a method for estimating the temperature of fluid **104** using a hybrid zero heat flow and temperature differential or Delta T methodology is provided. In some embodiments, such method can incorporate an additional compensation factor based on the ambient environmental temperature, similar to method **5000**. An example of such method **6000** is illustrated in FIG. 10. Method **6000** can be carried out using temperature sensor **600**. In some embodiments, any suitable apparatus for determining ambient environmental temperature, e.g. a thermocouple, resistive thermal device (RTD) sensor, thermistor, semiconductor-based integrated circuit, or the like, can also be used if ambient temperature is to be used in estimating the internal temperature of fluid **104**.

**[0080]** At **6002**, the temperature of the first temperature sensing element **604** that is positioned closest to housing **102** $T_5$ is determined. At **6004**, the temperature of the second temperature sensing element **606** that is positioned farther from housing **102** $T_6$ is determined. At **6006**, ambient temperature is optionally determined. At **6008**, the internal temperature of fluid **104** is estimated based on the measurements of $T_5$ and $T_6$ based on previously derived coefficients for the piece of electrical equipment. In some embodiments, if ambient environmental temperature is measured at step **6006**, then at step **6008** the internal temperature of fluid **104** is estimated based on all of $T_5$, $T_6$ and the measured ambient temperature.

**[0081]** In some embodiments, temperature sensor **300** or **400** can be equipped with a light, illustrated schematically as **320/320'/420**, or other visual indicator that provides an indication that the external temperature of a housing has exceeded a temperature that is beyond a predetermined temperature threshold, e.g. a threshold beyond which it is not safe for a person to touch the external surface of the housing.

**[0082]** In some embodiments, as shown with respect to temperature sensor **800** illustrated in FIG. 11, any of the temperature sensors described herein can also be provided with a wired connection **806**, to allow connection for example to a digital sensor bus or other processor or communications module. Temperature sensor **800** has a head **802** and stem **804**. Wired connection **806** allows temperature sensor **800** to relay information about the temperature sensed to a controller or other processor. In alternative embodiments, a wireless communications module could allow temperature sensor **800** to relay information about the temperature sensed to a controller or other processor equipped with a parallel wireless communications module. In some such embodiments, wired connection **806** could be omitted.

**Examples**

**[0083]** Certain embodiments are further described with reference to the following examples, which are intended to be illustrative and not limiting in nature.

<u>Example 1.0 Comparing Estimated and Actual Internal Temperatures</u>

**[0084]** The inventors conducted a test using an embodiment of temperature sensor **400** to estimate the internal temperature of fluid within a housing using method **4000**. A control measurement of the actual internal temperature of the fluid within the housing was taken to assess the accuracy of the estimated temperature. Oil temperature and environmental conditions such as ambient temperature and wind speed could be independently controlled in the experimental apparatus. The environmental conditions including ambient temperature were changed at each of time $T_1$ and $T_2$, although the actual internal oil temperature does not change throughout the period that $T_1$ and $T_2$ are varied.

**[0085]** Results are shown in FIG. 12. The measured temperature (Actual Oil T) of the fluid within the housing represents the known temperature value. The temperature of the shielded portion of the housing of the tank (Shielded Sensor T) and the exposed portion of the housing of the tank (Exposed Sensor T) were measured, and were used to estimate the internal temperature of the fluid inside the housing (Estimated Oil T) using a transfer function as described above.

**[0086]** As can be seen, the estimated temperature closely tracks the measured temperature (independently obtained using a separate temperature sensor disposed within the housing), particularly after a steady state has been reached shortly after any change in environmental conditions (i.e. shortly after the ambient temperature was changed at each of $T_1$ and $T_2$). In contrast, neither the Shielded Sensor T nor the Exposed Sensor T are particularly close to the Actual Oil T, demonstrating the need for an alternative method of determining the internal oil temperature.

**[0087]** While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are consistent with the broadest interpretation of the specification as a whole.

CLAIMS:

1. Apparatus for non-invasively estimating a temperature inside a housing, the apparatus comprising:
an environmentally shielding portion shaped and configured to shield at least a portion of the housing from prevailing environmental conditions;
a first temperature sensing element disposed within the environmentally shielding portion and located to be positionable proximate to the housing when the apparatus is in use;
a second temperature sensing element spaced apart from the environmentally shielding portion, the second temperature sensing element located to be positionable proximate to the housing when the apparatus is in use.

2. Apparatus as defined in claim 1, wherein the second temperature sensing element is largely exposed to prevailing environmental conditions, or is more exposed to prevailing environmental conditions than the first temperature sensing element.

3. Apparatus as defined in any one of claims 1 or 2, wherein the first temperature sensing element and/or the second temperature sensing element is located to be positionable against the housing when the apparatus is in use.

4. Apparatus as defined in any one of claims 1 to 3, wherein the first temperature sensing element and/or the second temperature sensing element is located to be positionable adjacent to the housing when the apparatus is in use.

5. Apparatus as defined in any one of claims 1 to 4, further comprising a cartridge portion shaped and configured for insertion into a cartridge housing extending inside the housing, the cartridge portion comprising the second temperature sensing element.

6. Apparatus as defined in claim 5, further comprising a sensor for determining that the cartridge portion has been inserted into the cartridge housing.

7. A method of using an apparatus as defined in claim 6, the method comprising:
determining if the cartridge portion has been inserted into the cartridge housing;

if it is determined that the cartridge portion has been inserted into the cartridge housing, using a third thermal sensing element to directly measure the temperature of the fluid contained within the housing; or

if it is determined that the cartridge portion has not been inserted in the cartridge housing, using the first and second thermal sensing elements to estimate the temperature of the fluid contained within the housing.

8. A method as defined in claim 7, wherein the second temperature sensor and the third temperature sensor are the same temperature sensor.

9. A method of estimating a temperature of fluid contained within a housing, the method comprising:

measuring a first temperature at a first external location on the housing, the first external location being sheltered from environmental conditions;

measuring a second temperature at a second external location on the housing, the second external location being exposed to environmental conditions or being more exposed to environmental conditions than the first external location; and

correlating a difference between the first temperature and the second temperature to estimate the temperature of the fluid contained within the housing.

10. An apparatus for estimating a temperature of fluid contained within a housing, the apparatus comprising:

a first thermal sensing element;

a second thermal sensing element;

a heating element positioned outwardly of both the first and second thermal sensing elements; and

thermal insulation differentially positioned relative to the first and second thermal sensing elements.

11. An apparatus as defined in claim 10, wherein the thermal insulation that is differentially positioned relative to the first and second thermal sensing elements comprises thermal insulation interposing either (i) the housing and the second thermal sensing element or (ii) the first thermal sensing element and the heating element.

12. An apparatus as defined in claim 11, wherein the thermal insulation interposes the both the housing and the second thermal sensing element and first and the second thermal sensing elements, but the thermal insulation is not positioned between the housing and the first thermal sensing element.

13. An apparatus as defined in any one of claims 10 or 11, wherein the first thermal sensing element is laterally spaced apart from the second thermal sensing element.

14. An apparatus as defined in claim 13, wherein the first and second thermal sensing elements are spaced apart from the housing by the same distance when the apparatus is in use.

15. A method of estimating a temperature of fluid contained within a housing, the method comprising:
(i) measuring a first temperature at a first location proximate the housing;
(ii) measuring a second temperature at a second location, a temperature differential being initially present between the first and second locations;
(iii) if the first temperature is different than the second temperature, activating a heating element positioned outwardly of both the first and second locations;
(iv) repeating steps (i) through (iii) until it is determined that the first and second temperatures are the same; and
(v) determining the temperature of the fluid contained within the housing to be the same as the first and second temperatures.

16. A method as defined in claim 15, wherein the temperature differential between the first and second locations is provided by thermal insulation positioned between either (i) the housing and the second location or (ii) the heating element and the first location.

17. A method as defined in claim 16, wherein the thermal insulation interposes the first and second locations.

18. An apparatus for estimating a temperature of fluid contained within a housing, the apparatus comprising:
a first thermal sensing element;

a second thermal sensing element; and
thermal insulation positioned to be located between the housing and the second thermal sensing element when the apparatus is in use.

19. An apparatus as defined in claim 18, wherein the thermal insulation interposes the first and second thermal sensing elements.

20. A method of estimating a temperature of fluid contained within a housing, the method comprising:
measuring a first temperature at a first location on the housing;
measuring a second temperature at a second location, thermal insulation being positioned between the housing and the second location; and
estimating the temperature of the fluid contained within the housing based on the relationship between the first temperature and the second temperature.

21. A method as defined in claim 20, wherein the thermal insulation interposes the first and second locations.

22. An apparatus as defined in any one of claims 1 to 6, 10 to 14 or 18 to 19, further comprising a sensor for measuring ambient temperature of the environment outside the housing.

23. A method as defined in any one of claims 7 to 9, 15 to 17 or 20 to 21, the method further comprising:
measuring an ambient temperature of the environment outside the housing; and
using the measured ambient temperature as an additional parameter to estimate the temperature of the fluid contained within the housing based on the relationship between the first temperature and the second temperature.

24. An apparatus as defined in any one of claims 1 to 6, 10 to 14, 18 to 19 or 22, further comprising a visual indicator for providing an indication that an external temperature of the housing exceeds a predetermined threshold.

25. A method of using an apparatus as defined in any one of claims 1 to 6, 10 to 14, 18 to 19, 22 or 24 to develop a calibration coefficient for a particular style of housing, the method comprising:

measuring an internal temperature of a first housing representative of the particular style of housing;

measuring the temperature recorded by each of the first and second temperature sensing elements to provide first and second temperatures; and

deriving a mathematical relationship between the first and second temperatures to yield the calibration coefficient.

26. The apparatus as defined in any one of claims 1 to 6, 10 to 14, 18 to 19, 22 or 24, wherein the housing comprises a housing of a piece of electrical equipment, wherein the piece of electrical equipment optionally comprises a transformer.

27. The method as defined in any one of claims 7 to 9, 15 to 17, 20 to 21, 23 or 25, wherein the housing comprises a housing of a piece of electrical equipment, wherein the piece of electrical equipment optionally comprises a transformer.

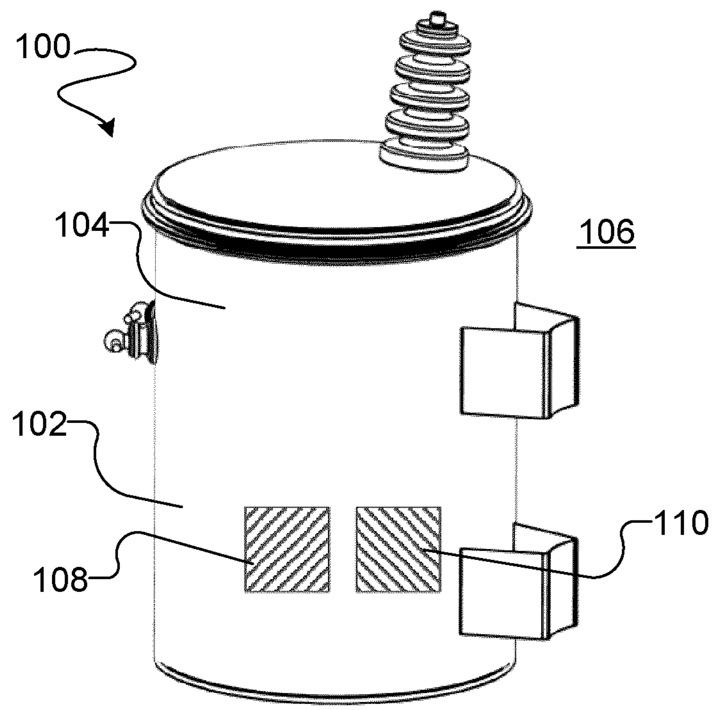



FIG. 1

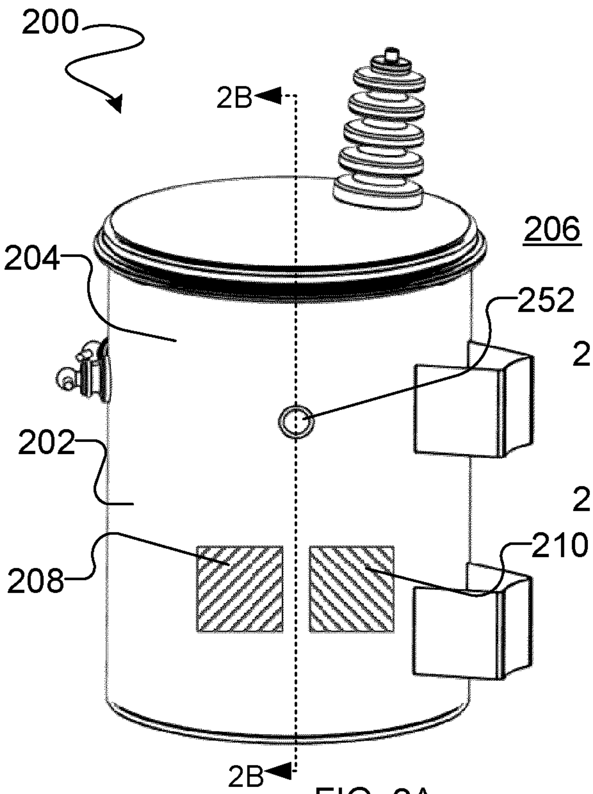



FIG. 2A

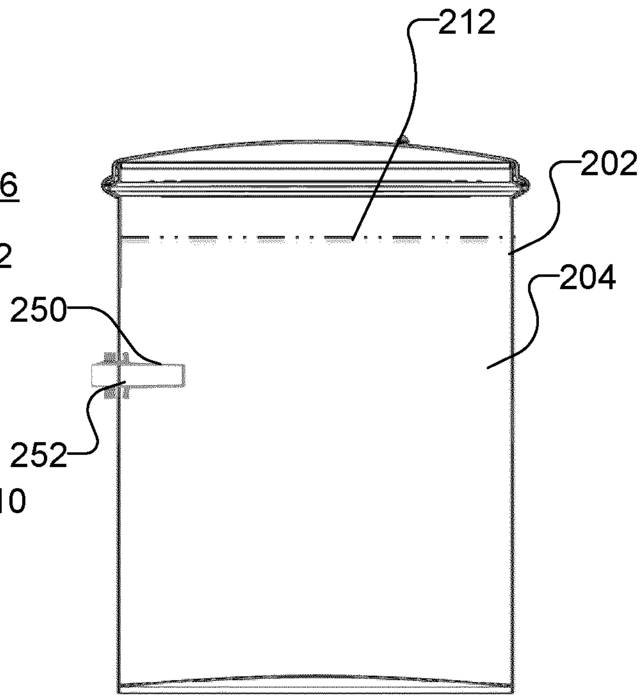



FIG. 2B

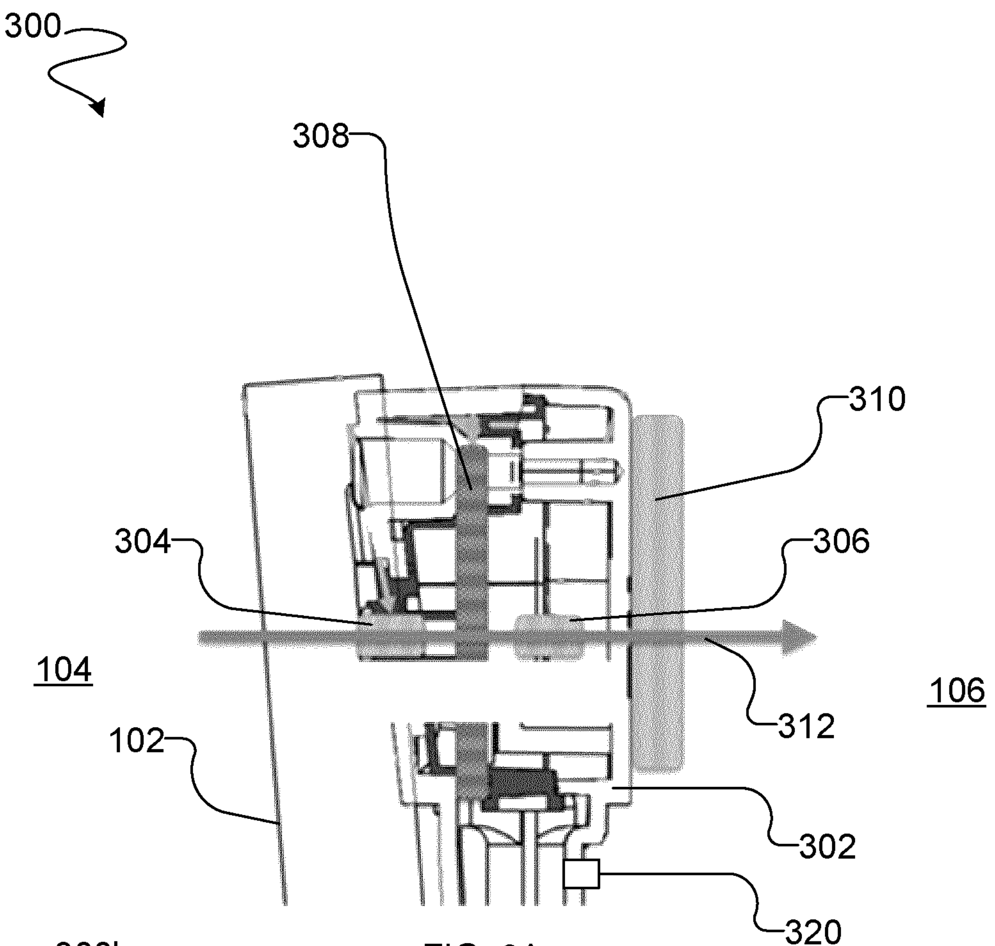

300
308
310
304
306
104
106
312
102
302
320

FIG. 3A

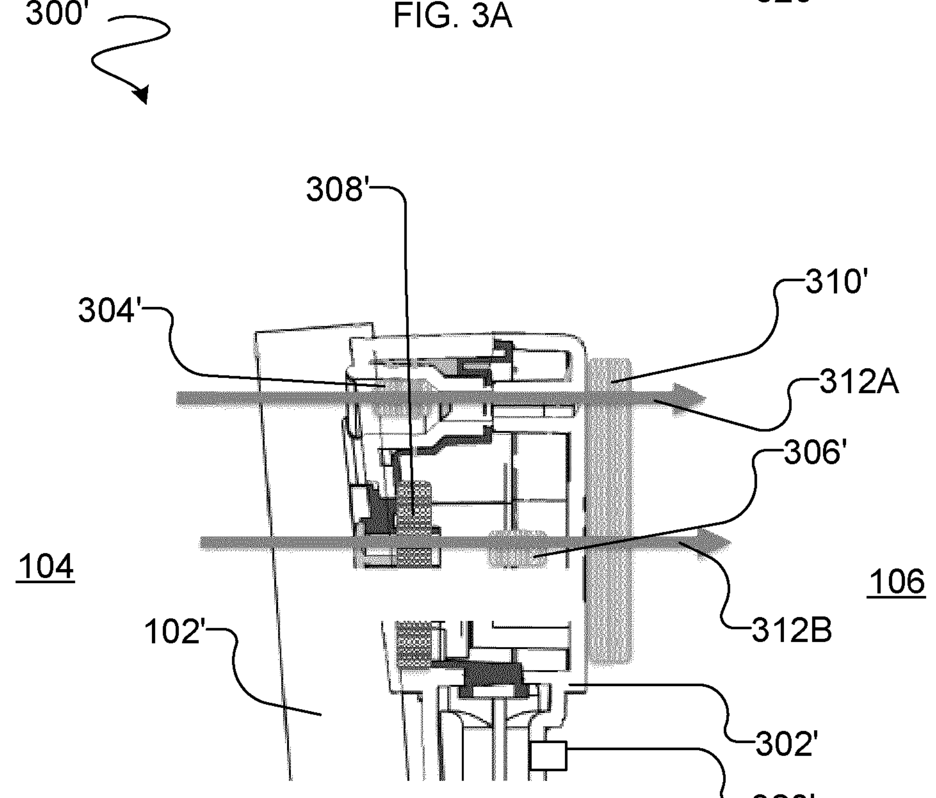

300'
308'
310'
304'
312A
306'
104
106
312B
102'
302'
320'

FIG. 3B

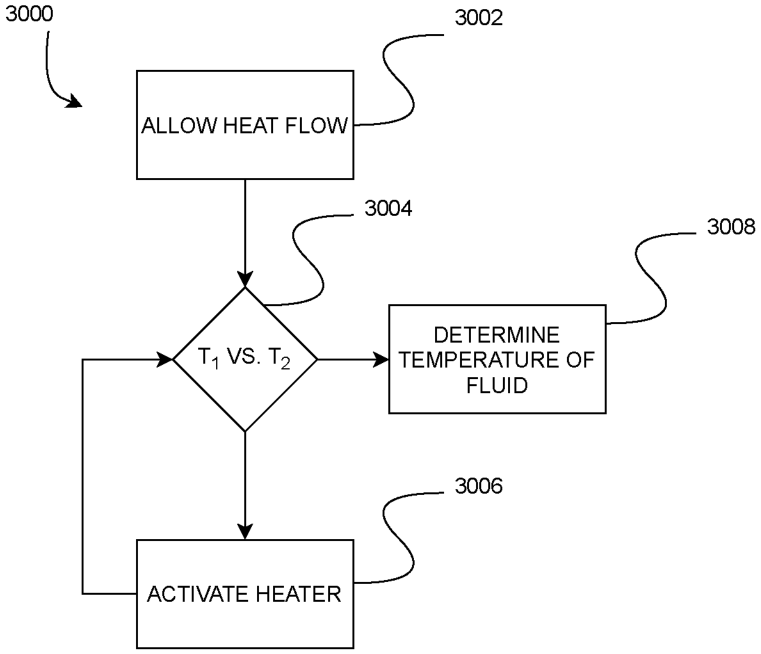

3000
3002
ALLOW HEAT FLOW
3004
3008
T1 VS. T2
DETERMINE TEMPERATURE OF FLUID
3006
ACTIVATE HEATER

FIG. 4

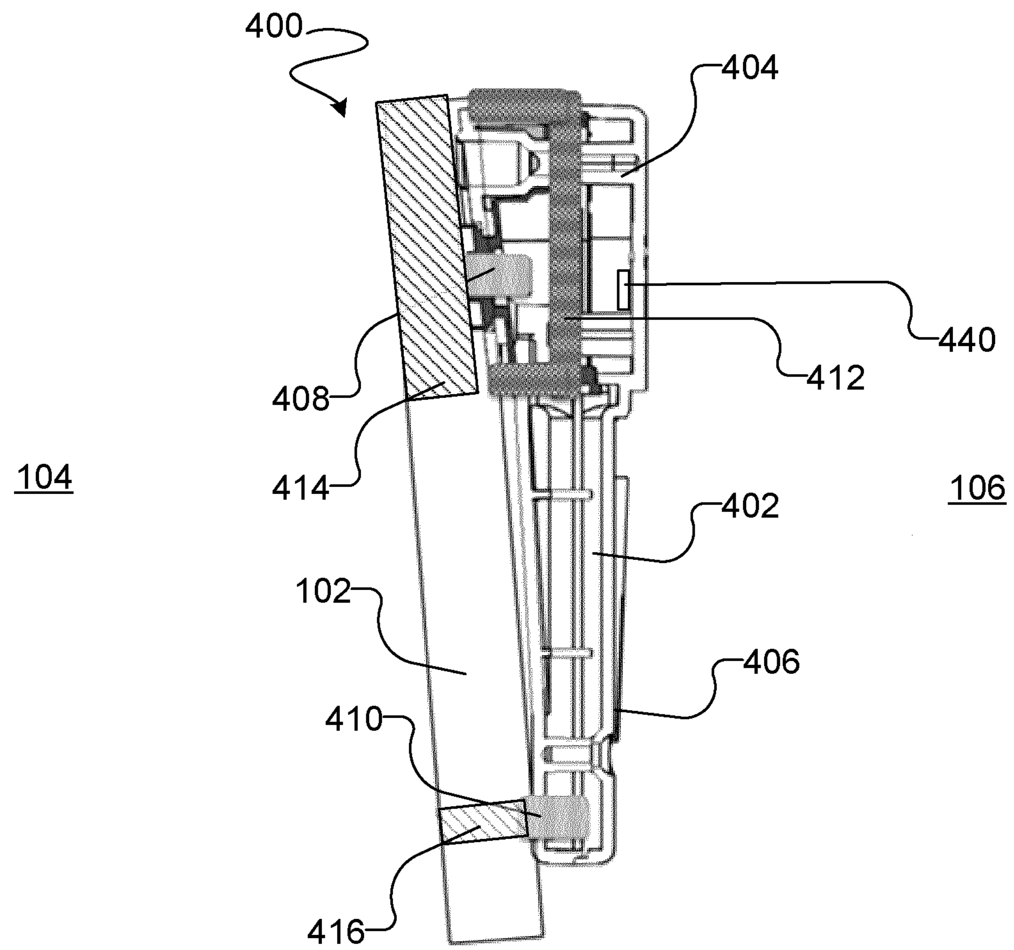



FIG. 5A

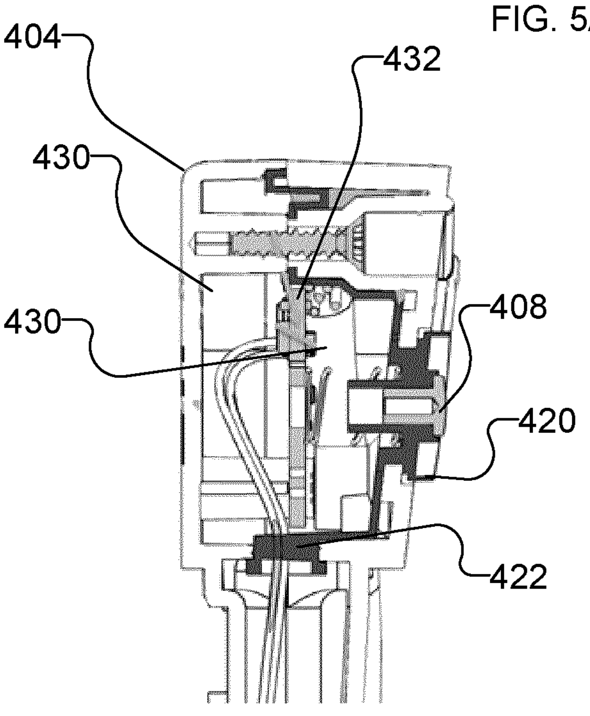



FIG. 5B

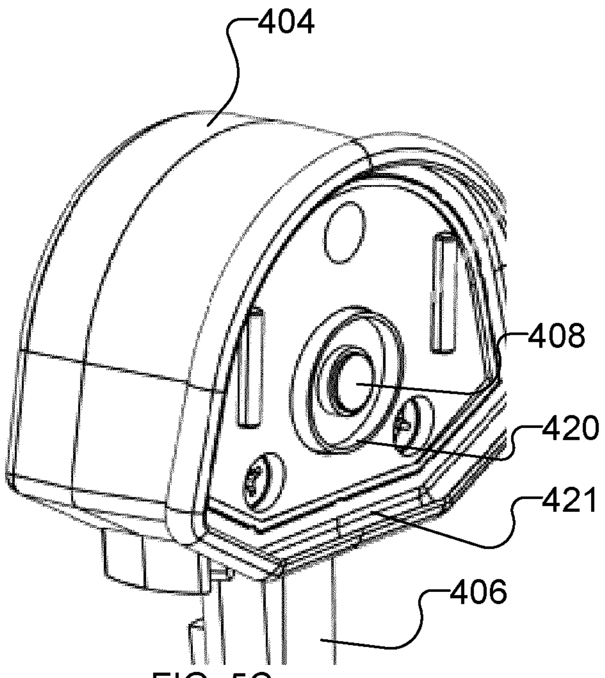



FIG. 5C

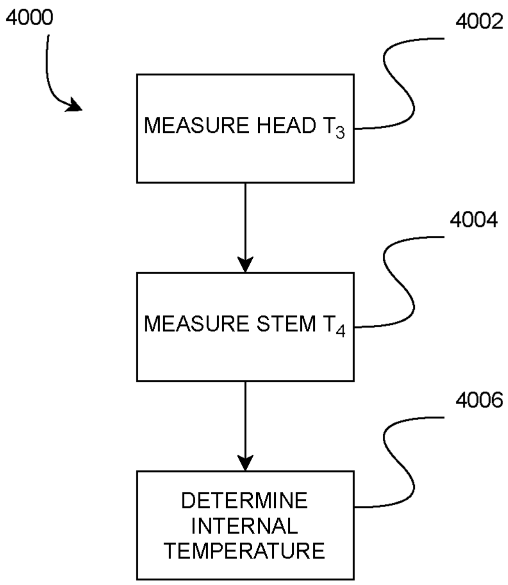

4000
4002
MEASURE HEAD $T_3$
4004
MEASURE STEM $T_4$
4006
DETERMINE INTERNAL TEMPERATURE

FIG. 6

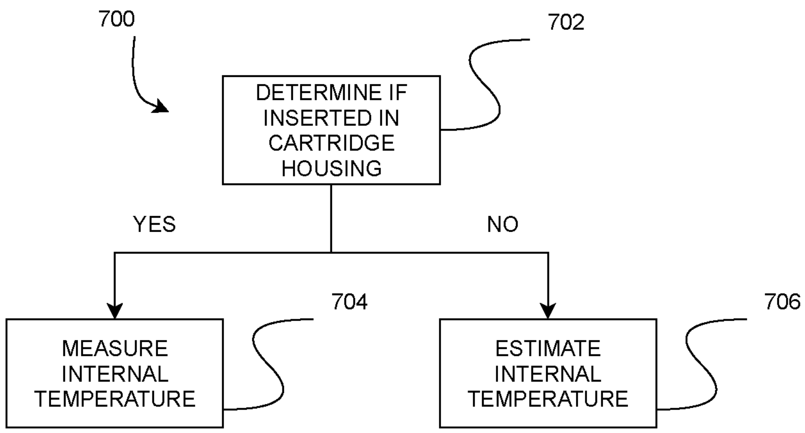

700
702
DETERMINE IF INSERTED IN CARTRIDGE HOUSING
YES
NO
704
706
MEASURE INTERNAL TEMPERATURE
ESTIMATE INTERNAL TEMPERATURE

FIG. 7

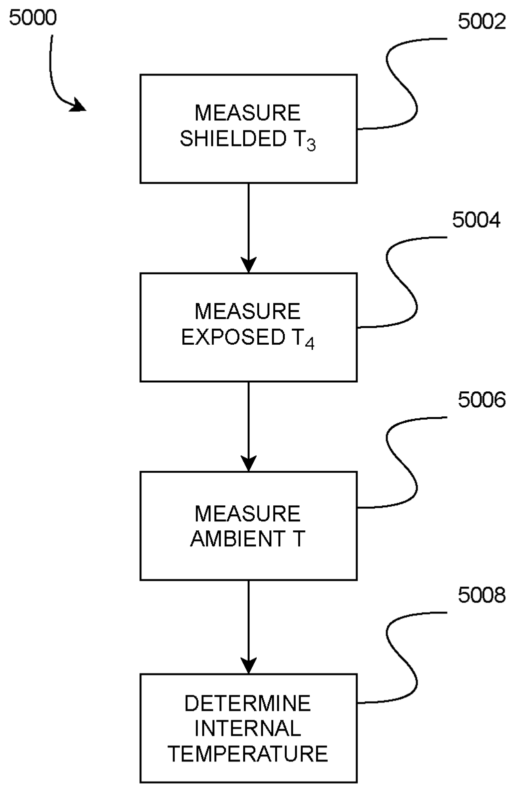

5000
5002
MEASURE SHIELDED $T_3$
5004
MEASURE EXPOSED $T_4$
5006
MEASURE AMBIENT T
5008
DETERMINE INTERNAL TEMPERATURE

FIG. 8

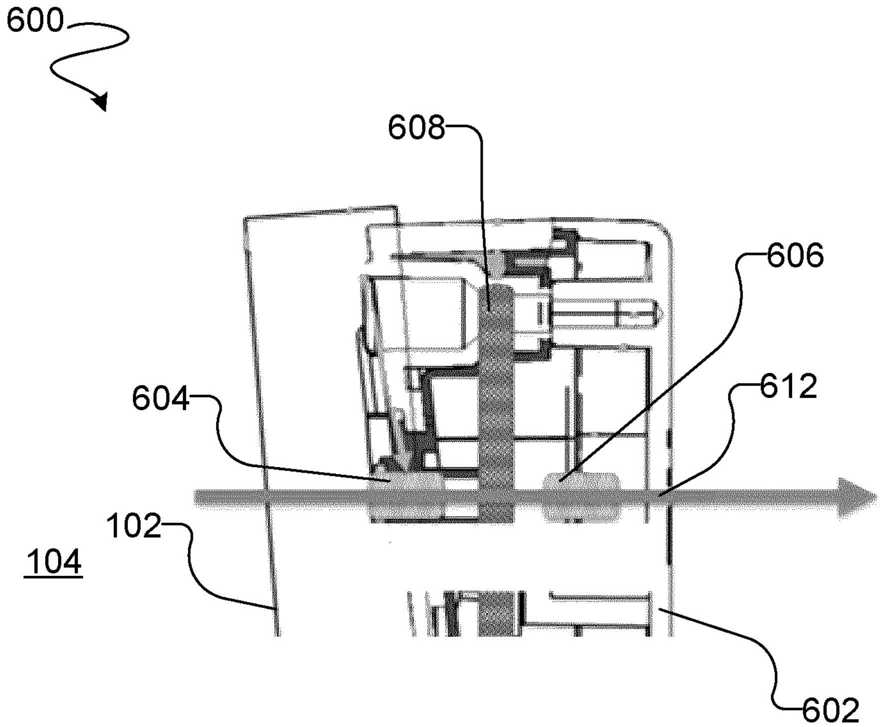



FIG. 9

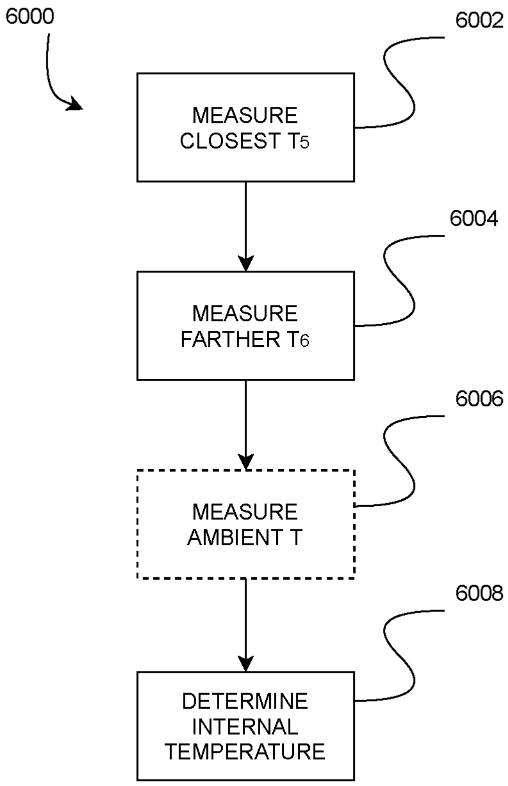

6000
6002
MEASURE CLOSEST T5
6004
MEASURE FARTHER T6
6006
MEASURE AMBIENT T
6008
DETERMINE INTERNAL TEMPERATURE

FIG. 10

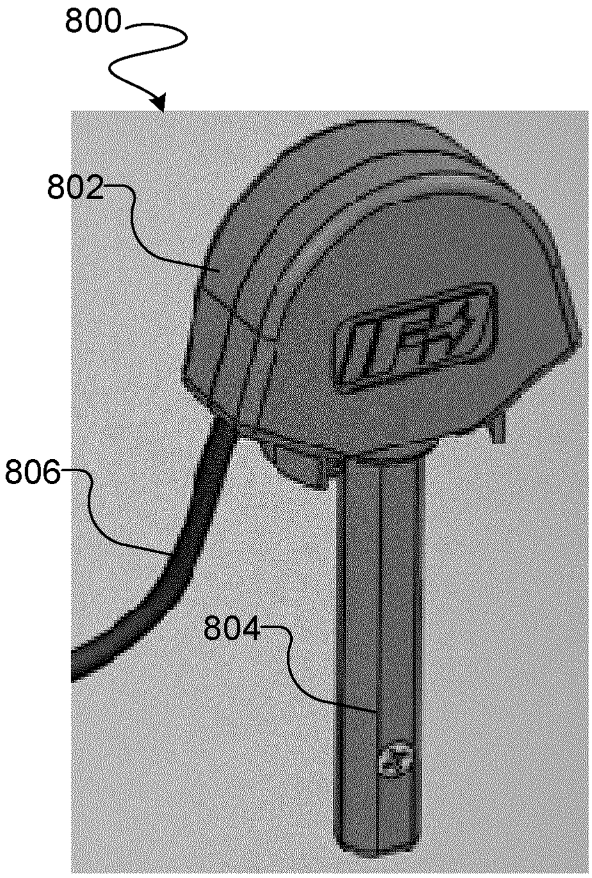



FIG. 11

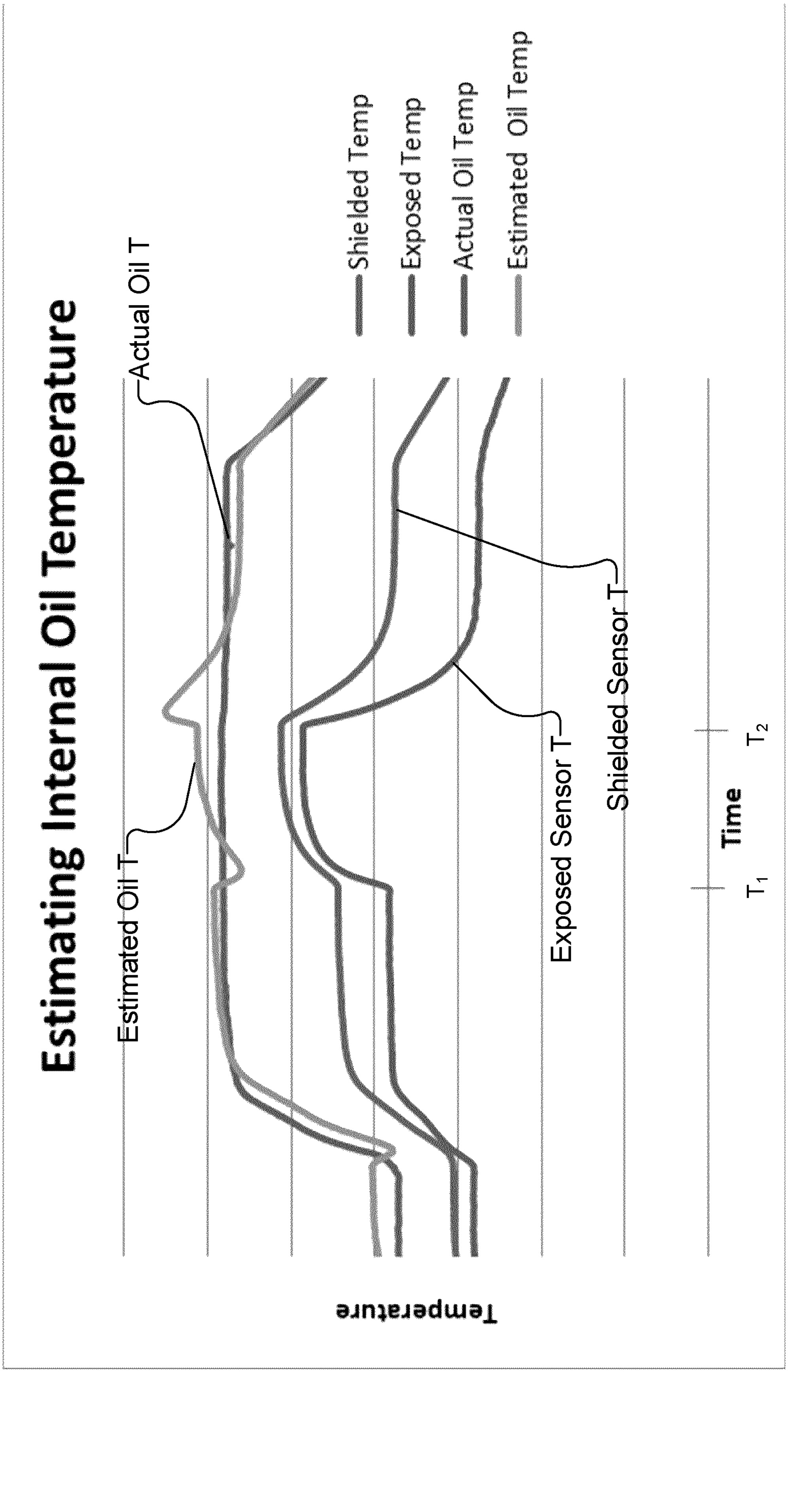

Estimating Internal Oil Temperature
Actual Oil T
Estimated Oil T
Exposed Sensor T
Shielded Sensor T
Shielded Temp
Exposed Temp
Actual Oil Temp
Estimated Oil Temp
Temperature
Time
$T_1$
$T_2$

FIG. 12

FIG. 5A