



(51) International Patent Classification:
H01M 8/04 (2006.01)

(21) International Application Number:
PCT/US2008/011513

(22) International Filing Date:
6 October 2008 (06.10.2008)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (for all designated States except US): **UTC POWER CORPORATION** [US/US]; 195 Governor's Highway, South Windsor, CT 06074 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **SPADACCINI, Richard, Jonathan** [US/US]; UTC Power Corporation, 195 Governor's Highway, South Windsor, CT 06074 (US). **HARRINGTON, Michael, D.** [US/US]; UTC Power Corporation, 195 Governor's Highway, South Windsor, CT 06074 (US).

(74) Agents: **KOENCK, Alan, M.** et al.; Kinney & Lange, P.A., Kinney & Lange Building, 312 South Third Street, Minneapolis, MN 55415-1002 (US).

(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, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Published:

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

(54) Title: SYSTEM AND METHOD FOR SENSING SUBSTACK VOLTAGES

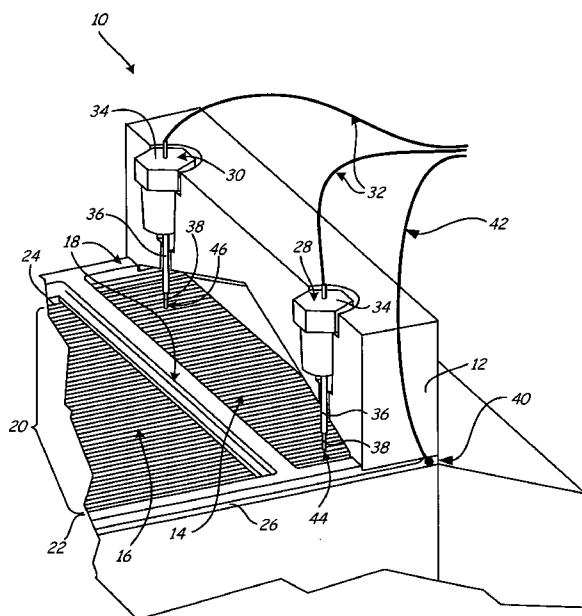


FIG. 1

(57) Abstract: Substack voltages in a cell stack assembly (10) are sensed using sensor elements (28, 30) positioned in contact with fluid in a fluid manifold (12) at locations (44, 46) between anode end (22) and cathode end (24) of stack (20). The fluid has an electrical potential varying from anode end (22) to cathode end (24) as a function of the electrical potential across stack (20) such that a voltage measured between sensor elements (28, 30) and/or between one of sensor elements (28, 30) and reference sensor element (40) indicates a substack voltage measurement for stack (20).

SYSTEM AND METHOD FOR SENSING SUBSTACK VOLTAGES

BACKGROUND

The present disclosure relates in general to the monitoring of voltages in fuel cell power plants, and more particularly, to a system and method of sensing and monitoring
5 substack voltages in electrochemical cell stack assemblies.

Fuel cell power plants are well known for converting chemical energy into usable electrical power. Fuel cell power plants usually comprise multiple fuel cells arranged in a repeating fashion to form a cell stack assembly ("CSA"), including internal ports or external manifolds connecting coolant fluid and reactant gas flow passages or channels.
10 Each individual fuel cell in a CSA typically includes a proton exchange membrane ("PEM") sandwiched between an anode electrode and a cathode electrode to form a membrane electrode assembly ("MEA"). On either side of the MEA are electrically conductive bipolar plates in electrical communication with the MEA that comprise reactant flow fields for supplying a reactant fuel (e.g. hydrogen) to the anode, and a
15 reactant oxidant (e.g. oxygen or air) to the cathode. The hydrogen electrochemically reacts with a catalyst layer disposed on the anode side of the PEM to produce positively charged hydrogen protons and negatively charged electrons. The anode side of the PEM only allows the hydrogen protons to transfer through the membrane to the cathode side, forcing the electrons to follow an external path through a circuit to power a load before
20 being conducted to the cathode. When the hydrogen protons and electrons eventually come together at a catalyst layer disposed on the cathode side of the PEM, they combine with the oxidant to produce water and thermal energy.

Each fuel cell produces a relatively small voltage, for example, around one volt, and the stacking of multiple fuel cells in electrical series increases the overall voltage
25 produced by the stack incrementally by each fuel cell added from the anode to the cathode end of the stack. For example, a CSA comprising 50 fuel cells may produce around 50 volts under normal operating conditions, whereas a CSA comprising 25 fuel cells will produce around 25 volts. However, individual fuel cells or groups of cells do not always operate efficiently or properly, for reasons including corrosion of catalysts
30 and obstruction of reactant and coolant channels. One method for determining the health of a CSA is by monitoring the individual voltages of the fuel cells (herein referred to as "substack voltages"). For example, in a CSA comprising multiple fuel cells each normally producing one volt, a substack voltage measurement of less than five volts taken at the fifth fuel cell with reference to the anode may indicate a problem with the

health of fuel cells one through five, such as insufficient reactant flow, overheating, or otherwise.

Typical substack voltage monitoring techniques involve placing a sensor in contact with a fuel cell bipolar plate and another sensor in contact with a reference. The reference may be, for example, a ground reference such as a pressure plate, or can be another fuel cell bipolar plate spaced apart from the first. For a CSA utilizing internal manifolds and ports for coolants, a portion of the bipolar plate is normally exposed on an exterior surface of the stack, making it easy to contact with a sensor. However, for a CSA using all external coolant manifolds, the bipolar plates and other conductive fuel cell components are normally obstructed by the manifold assembly. For such a system, wire is typically routed underneath an air manifold seal and into an air flow field to a sensor in mechanical contact with a bipolar plate. However, this mechanical connection is prone to failure under common physical stresses such as rapid heating and cooling of the stack, in addition to vibration experienced in automotive applications. If the sensor breaks off of the bipolar plate, it can lead to loss of substack voltage data in addition to the inconvenience of having to remove the entire manifold assembly in order to repair the broken wire or sensor. Additionally, running wire under an external manifold seal provides a potential leak path for reactants.

SUMMARY

The present disclosure relates to a system and method for sensing substack voltage measurements in an electrochemical cell stack assembly using sensor elements positioned in contact with fluid in the cell stack assembly. The fluid has an electrical potential that varies from the anode to cathode end of the stack as a function of each individual cell in the stack.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an embodiment of the present disclosure, including a cross section of an external coolant exit manifold.

FIG. 2 is a cross sectional view of a cell stack assembly, including an embodiment of the present disclosure.

DETAILED DESCRIPTION

Described herein is a system and method for sensing substack voltages using sensor elements positioned to contact fluid within a CSA external manifold. This invention is predicated in part on the discovery that fluid present in an operating CSA has an electrical potential that varies from an anode end to a cathode end of the stack as a

function of each individual cell in the stack. Thus, the electrical potential at a given cell can be measured in fluid that is in electrical communication with the fuel cell. Sensors in contact with fluid are not in direct mechanical connection with a rigid fuel cell component such as a bipolar plate, and thus possess the advantage of being less prone to
5 mechanical failure over time in response to normal operating stresses such as physical vibration and sudden temperature swings.

FIG. 1 is a perspective view of CSA 10, showing a cross section of external fluid manifold 12, including fluid manifold space 14, air manifold space 16, manifold seal 18, and fuel cell stack 20 comprising individual fuel cells arranged in series from anode end
10 22 to cathode end 24, the stack sandwiched between pressure plates 26 (both plates shown in FIG. 2). Due to the arrangement of the fuel cells in series, the electrical potential from anode end 22 to cathode end 24 of stack 20 will increase as a function of each individual cell.

Stack 20 connected to an external load normally forms an electrically closed
15 circuit that is insulated from other components of CSA 10, such as fluid manifold 12, in order to prevent short circuiting. However, it was discovered that fluid, including water or glycol-based coolants, in an operating CSA 10 carries a current and has an electrical potential measurable using the system and method of the present disclosure, even in parts of CSA 10 insulated from stack 20, such as in fluid manifold space 14. This
20 phenomenon can be explained by the electrically conductive elements that comprise the stack 16 components, including the fluid channels (not shown), combined with the ionic content of fluid in communication with stack 16. Because the ionic content for fluid will be minimal, electrical current in the fluid will face a high resistance and will likewise be minimal, preventing stack 16 from short circuiting. The electrical potential present in the
25 fluid will be a function of location to the nearest fuel cell within stack 16, and using the system and method of the present disclosure, can be utilized to provide a substack voltage measurement.

FIG. 1 shows an embodiment of the present disclosure for measuring substack voltages. Sensor element 28 and sensor element 30 comprise wire lead 32 extending
30 through cap fitting 34, through electrically insulative sheath 36, and ending in exposed wire electrode portion 38. Each cap fitting 34 penetrates external fluid manifold 12 and is preferably sealed so as to prevent leakage of fluid into the external environment. Additionally, reference sensor element 40 may also be used, comprising a wire lead 42 operably connected with any location on pressure plate 26, in which case pressure plate

26 will act as an electrode due to its electrically conductive nature and electrical continuity with stack 16 components. To measure substack voltages, exposed wire electrodes 38 are positioned to contact fluid (now shown) in fluid manifold space 14 at location 44 and location 46 near a fuel cell but not in actual contact with any fuel cell components, such as a bipolar plate. It may be appreciated that for each sensor element, any location can be chosen based on which substack voltage is to be measured, and that any number of sensor elements may be utilized. While fluid is present in manifold space 14 during operation of stack 20 to produce electrical power, an electrical potential can be measured between any two sensor elements to indicate a substack voltage measurement. This may be done, for example, by attaching a voltmeter or substack voltage monitor to wire leads 32, 42.

Reference sensor element 40 on pressure plate 26 at anode end 22 may be used to indicate zero volts relative to sensor element 28 or sensor element 30. For example, if location 44 of sensor element 28 is nearest the fifth fuel cell in stack 20 proceeding from anode end 22 to cathode end 24, a substack voltage measurement relative to reference sensor element 40 can be indicated for the fifth cell (e.g., five volts for a healthy stack 20 producing one volt per cell). Similarly, if location 46 for sensor element 30 is nearest the thirty-fifth cell in stack 20, a substack voltage measurement relative to reference sensor element 40 can be indicated for the thirty-fifth cell (e.g., thirty-five volts for a healthy stack 20 producing one volt per cell). Alternatively, sensor element 28 may be used as a zero volt reference in relation to sensor element 30 for providing a positive substack voltage measurement at a fuel cell closest to location 46. It may be appreciated that other sensor elements could be used that differ in construction from the specific sensor elements depicted in FIG. 1, for example, a simple wire lead and electrode used for standard commercially available multimeters or a printed circuit board with pins penetrating the manifold and making contact with coolant.

FIG. 2 is a cross sectional view of a CSA 10A having an external coolant manifold 48 containing coolant 50, fuel cell stack 52 comprising fuel cells 1, 2, 3, 4, 5, 6, 7, and 8, anode pressure plate 54, cathode pressure plate 56, and sensor element 58, 60, 62, 64, 66 and 68. Sensor elements 60, 62, 64, and 66 are shown penetrating the external coolant manifold wall, and may comprise a simple insulated wire with exposed electrode portion for contacting the coolant near a particular fuel cell, or could comprise the structure described with reference to FIG. 1. Coolant 50 may partially or completely fill external coolant manifold 48, which can be a coolant inlet or coolant exit manifold, and

will have an electrical potential that increases from anode pressure plate 54 to cathode pressure plate 56 as a function of each fuel cell 1, 2, 3, 4, 5, 6, 7, and 8 along the stack 52. For fuel cell assemblies that do not always have coolant 50 present in a coolant exit manifold, the system and method of the present disclosure can be practiced in a coolant inlet manifold to ensure continual contact of sensor elements 58, 60, 62, 64, 66 and 68 with coolant 50 and uninterrupted substack voltage readings during operation of CSA 10A. Fuel cell stack 52 is shown having eight fuel cells and only six sensor elements for the sake of simplicity, however, a stack 52 having any number of fuel cells and sensor elements may be used with the system and method of the present disclosure. For sensor element 60, 62, 64, and 66, the electrode for each sensor element is shown in contact with coolant 50 near fuel cell 2, 4, 5, and 7, respectively.

FIG. 2 further shows an embodiment of the present disclosure for measuring substack voltages using substack voltage monitor 70 having voltage input board 72 comprising voltmeter 72A, 72B, 72C, 72D, and 72E. Each voltmeter is connected to wires – voltmeter 72A to wires 74 and 76, voltmeter 72B to wires 78 and 80, voltmeter 72C to wires 82 and 84, voltmeter 72D to wires 86 and 88, voltmeter 72E to wires 90 and 92 – and each wire is further connected to a sensor element – wire 74 to sensor element 58, wires 76 and 78 to sensor element 60, wires 80 and 82 to sensor element 62, wires 84 and 86 to sensor element 64, wires 88 and 90 to sensor element 66, and wire 92 to sensor element 68. Thus, each voltmeter is configured to receive an analog electrical potential signal from a pair of sensor elements, at least one sensor of each pair positioned in contact with coolant 50 near a cell to indicate a substack voltage measurement.

For example, in stack 52 having fuel cells 1, 2, 3, 4, 5, 6, 7, and 8 each producing around one volt of electrical potential under normal operating conditions, voltmeter 72A will receive a substack voltage measurement of two volts between sensor element 60 nearest fuel cell 2 and sensor element 58 positioned on anode pressure plate 54. Voltmeter 72B will produce a substack voltage measurement of two volts between sensor element 62 nearest fuel cell 4 and sensor element 60 nearest fuel cell 2. Voltmeter 72C will produce a substack voltage measurement of one volt between sensor element 64 nearest fuel cell 5 and sensor element 62 nearest fuel cell 4. Voltmeter 72D will produce a substack voltage measurement of two volts between sensor element 66 positioned nearest fuel cell 7 and sensor element 64 nearest fuel cell 5. Lastly, voltmeter 72E will produce a substack voltage measurement of one volt between sensor element 68 positioned on cathode pressure plate 56 and sensor element 66 positioned nearest fuel

cell 7. Thus, in a healthy CSA 10A comprising eight fuel cells in stack 52, the sum of substack voltage measurements should equal a total value of eight volts representing the electrical potential from anode pressure plate 54 to cathode pressure plate 56 (i.e., anode terminal to cathode terminal) of stack 52. The number and particular distribution of sensor elements may vary depending on how many substack voltages measurements are necessary to properly indicate the health of a CSA.

Voltage input board 72 of substack voltage monitor 70 may comprise a standard analog-to-digital board, such as available from National Instruments, and takes each analog electrical potential signal received by each voltmeter 72A, 72B, 72C, 72D, and 72E and converts it to a digital signal. The digital signals may then be fed to a digital device, enabling appropriate processing of substack voltage measurement data and monitoring of CSA 10A health. For example, digital substack voltage measurement data could be sent to a controller 94 for automated processing of the data and response to irregular readings, including but not limited to shutting the fuel cell power plant down, increasing or decreasing reactant flow through CSA 10A, and increasing or decreasing coolant 50 flow. Controller 94 may further comprise a readout device, such as an LCD screen, for viewing by an operator of CSA 10A. Furthermore, in a situation where no signal data is being received by controller 94, an insufficient level of coolant 50 in CSA 10A could be indicated as described in related application entitled, "Voltage-Based Fluid Sensor for a Fuel Cell Stack Assembly," owned by the same applicant, which is incorporated by reference. Thus, the system and method of the present disclosure may be used for the dual purpose of monitoring both substack voltage measurements as well as indicating proper coolant 50 levels in a CSA.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

CLAIMS:

1. A substack voltage monitoring system for a fuel cell power plant, the system comprising:
 - an electrochemical cell stack assembly comprising stacked fuel cells located between an anode end and cathode end of the cell stack assembly;
 - a first sensor element positioned to contact a fluid in the cell stack assembly at a location between the anode end and cathode end, the fluid having electrical potential that varies from the anode end to the cathode end as a function of each individual fuel cell in the stack;
 - a second sensor element spaced from the first sensor element and in electrical communication with the first sensor element; and
 - a voltage sensor coupled to the first sensor element and the second sensor element for sensing electrical potential between the first sensor element and the second sensor element and providing an output indicating a substack voltage measurement.
2. The substack voltage monitoring system of claim 1, wherein the cell stack assembly further comprises an external fluid manifold, and wherein the first sensor element is positioned in the external fluid manifold to contact the fluid.
3. The substack voltage monitoring system of claim 2, wherein the cell stack assembly further comprises a pressure plate, and wherein the second sensor element is positioned to contact the pressure plate.
4. The substack voltage monitoring system of claim 3, wherein the pressure plate is an anode pressure plate.
5. The substack voltage monitoring system of claim 3, wherein the pressure plate is a cathode pressure plate.
6. The substack voltage monitoring system of claim 2, wherein the second sensor element is also positioned in the external fluid manifold to contact the fluid.
7. The substack voltage monitoring system of claim 1, wherein each of the first sensor element and second sensor element comprises an electrode.
8. The substack voltage monitoring system of claim 1, wherein the fluid is a coolant.
9. The substack voltage monitoring system of claim 1, wherein the output is sent to a controller.

10. A substack voltage monitoring system for a fuel cell power plant, the system comprising:
- an electrochemical cell stack assembly comprising a plurality of stacked fuel cells, the cell stack assembly having an anode end and a cathode end, with electrical potential increasing across the stack as a function of each fuel cell from the anode end to the cathode end;
 - a first electrode spaced from a second electrode, at least one of the electrodes positioned to contact a fluid in the cell stack assembly, the fluid having an electrical potential corresponding to the increase of electrical potential across the stack; and
 - a voltage sensor coupled to the first electrode and the second electrode for sensing the electrical potential in the fluid between the first electrode and the second electrode and providing an output indicating a measured substack voltage less than a total voltage produced by the stack.
11. The substack voltage monitoring system of claim 10, wherein the cell stack assembly further comprises an external fluid manifold, and wherein the first electrode is positioned in the external fluid manifold.
12. The substack voltage monitoring system of claim 11, wherein the cell stack assembly further comprises a pressure plate, and wherein the second electrode is positioned to contact the pressure plate.
13. The substack voltage monitoring system of claim 12, wherein the pressure plate is an anode pressure plate.
14. The substack voltage monitoring system of claim 12, wherein the pressure plate is a cathode pressure plate.
15. The substack voltage monitoring system of claim 10, wherein the fluid is a coolant.
16. The substack voltage monitoring system of claim 10, wherein the output is sent to a controller.
17. A method for monitoring substack voltages in a fuel cell power plant, comprising:
- operating an electrochemical cell stack assembly comprising stacked fuel cells located between an anode end and a cathode end of the cell stack assembly;

positioning a first sensor element to contact fluid in the cell stack assembly at a location between the anode end and the cathode end, the fluid having electrical potential that varies from the anode end to the cathode end as a function of each individual fuel cell in the stack;

positioning a second sensor element spaced from the first sensor element, the second sensor element in electrical communication with the first sensor element; and

sensing the electrical potential of the first sensor element and second sensor element to produce a substack voltage measurement.

18. The method of claim 17, wherein the cell stack assembly further comprises an external fluid manifold, and wherein the first sensor element is positioned in the external fluid manifold to contact the fluid.

19. The method of claim 18, wherein the cell stack assembly further comprises a pressure plate, and wherein the second sensor element is positioned to contact the pressure plate

20. The method of claim 18, wherein the second sensor element is also positioned in the external fluid manifold to contact the fluid.

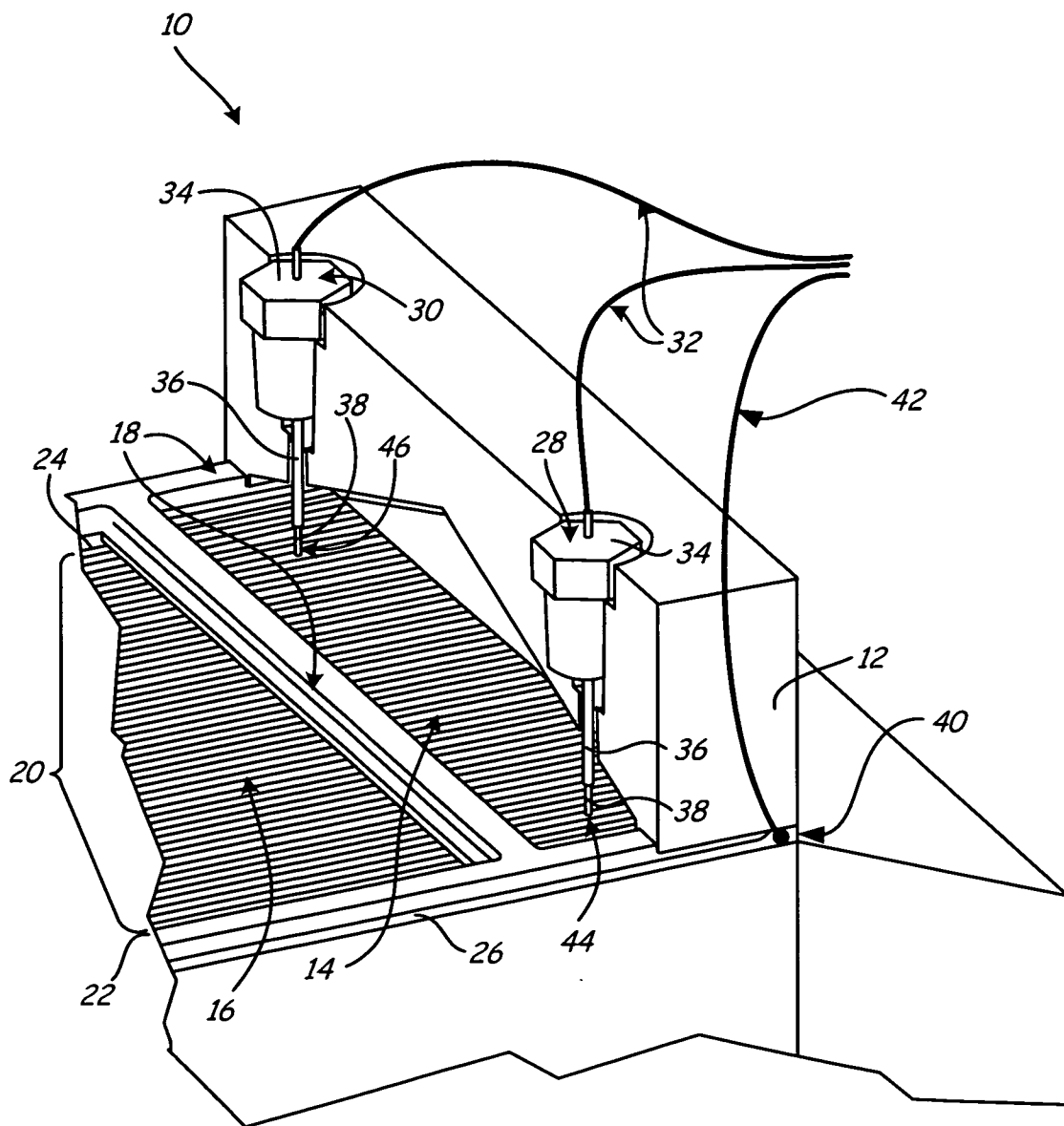
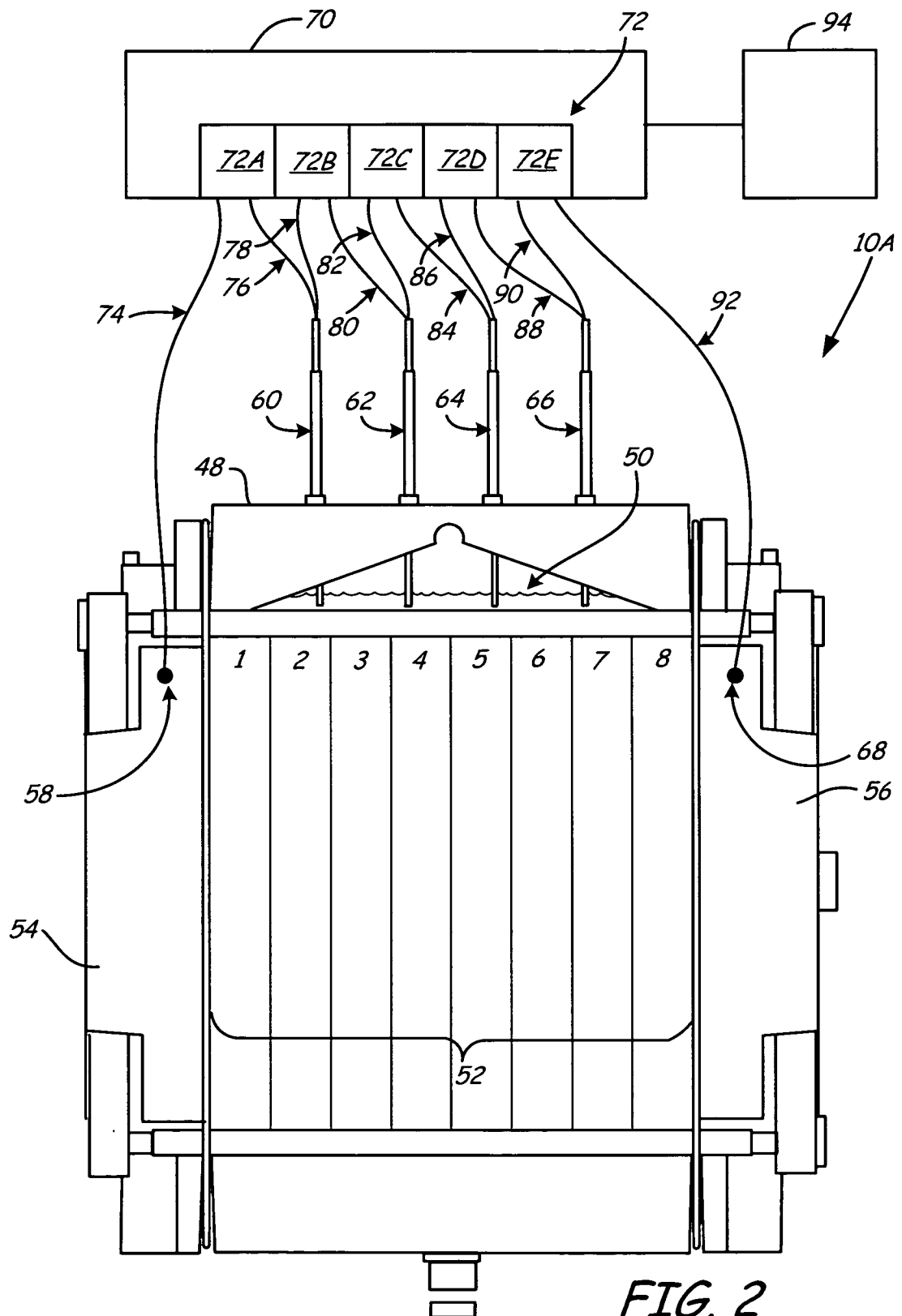


FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/011513**A. CLASSIFICATION OF SUBJECT MATTER****H01M 8/04(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 9: H01M, H02N, G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS(KIPO internal) and keywords "fuel cell, fluid detection, sensor, wire, conductive coolant, manifold, controller, voltage detection, voltage sensor, and similar terms"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007-0134527 A1 (Desouza et al.) 14 June 2007 See abstract, p. 4-6, Figures 1-8, and claims 1-21	1, 7, 10, 17
A	WO 2003-081762 A1 (SRI INTERNATIONAL) 02 October 2003 1-20 A See abstract, p.42, 52, and Figures 3A-3B and claims 1-35	1-20
A	US 2007-0154755 A1 (Wardrop) 05 July 2007 1-20 A See abstract, Figures 1-2, and claims 1-46	1-20
A	US 2008-0120046 A1 (TUNG et al.) 22 May 2008 1-20 A See abstract, Figure 4, and claims 1-32	1-20

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

30 APRIL 2009 (30.04.2009)

Date of mailing of the international search report

01 MAY 2009 (01.05.2009)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
Government Complex-Daejeon, 139 Seonsa-ro, Seo-
gu, Daejeon 302-701, Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

KIM, Kyong Min

Telephone No. 82-42-481-8173



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2008/011513

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007-0134527 A1	14.06.2007	NONE	
WO 2003-081762 A1	02.10.2003	AU 2003-223231 A1 AU 2003-225913 A1 EP 1481467 A1 EP 1512215 A1 JP 2005-522162 T JP 2005-527178 T US 2003-006669 A1 US 2004-008853 A1 US 2006-158065 A1 US 2007-164641 A1 US 2007-222344 A1 US 6891317 B2 US 7064472 B2 WO 0310-7523A1	31.12.2003 08.10.2003 01.12.2004 09.03.2005 21.07.2005 08.09.2005 09.01.2003 15.01.2004 20.07.2006 19.07.2007 27.09.2007 10.05.2005 20.06.2006 24.12.2003
US 2007-0154755 A1	05.07.2007	EP 1974412 A1 WO 2007-078976 A1	01.10.2008 12.07.2007
US 2008-0120046 A1	22.05.2008	NONE	