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(54) Title: INTEGRATED DEVICE AND METHOD FOR ENHANCING HEATER LIFE AND PERFORMANCE

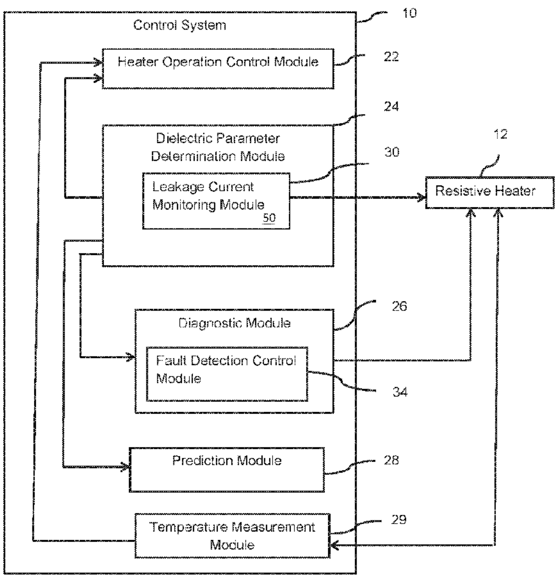

FIG. 1

(57) Abstract: A control system for controlling an operation of a resistive heater includes a dielectric parameter determination module for determining a dielectric parameter of the resistive heater when the resistive heater is in an active mode, and a diagnostic module for diagnosing performance of the resistive heater based on the dielectric parameter.

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INTEGRATED DEVICE AND METHOD FOR ENHANCING HEATER LIFE AND PERFORMANCE

FIELD

[0001] The present disclosure relates to resistive heating devices, and more particularly to control systems and methods for monitoring and controlling operation of the resistive heating devices.

BACKGROUND

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

[0003] Resistive heating devices, such as tubular heaters, are generally designed to have a predetermined life expectancy and maximum allowable temperature if operated under certain operating conditions. The performance and the life expectancy of the heating devices generally depend on the material properties of the constituent components of the heating devices. When one of the constituent components degrades over time to an unacceptable degree and fails, the entire heating device may fail to function properly. The maximum allowable temperature of the heating device depends on reliability of the constituent components. When one of the constituent components cannot withstand an elevated operating temperature and fail, the entire heating device may also fail.

[0004] In addition to the material properties and reliability of the constituent components of the heating device, the life expectancy and maximum allowable temperature of the heating devices are affected by operating conditions and operating modes. For example, the heating devices may have a relatively shorter life expectancy and relatively lower maximum allowable temperature if operated in vacuum environment with low partial pressure of oxygen, or in a rapid ramp-up and ramp-down speed. In view of the various factors that affect performance of the heating device, it is difficult to predict the life expectancy and maximum allowable temperature of the heating devices under a given operating condition.

SUMMARY

[0005] In one form of the present disclosure, a control system for controlling an operation of a resistive heater includes a dielectric parameter determination module for determining a dielectric parameter of the resistive heater when the resistive heater is in an active mode, and a diagnostic module for diagnosing performance of the resistive heater based on the dielectric parameter.

[0006] In another form, a method for controlling an operation of a resistive heater includes determining a dielectric parameter of the resistive heater when the resistive heater is in an active mode, and diagnosing performance of the resistive heater based on the dielectric parameter.

[0007] Further areas of applicability will become apparent from the description provided herein. It should be understood that the description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the present disclosure.

DRAWINGS

[0008] In order that the disclosure may be well understood, there will now be described various forms thereof, given by way of example, reference being made to the accompanying drawings, in which:

[0009] FIG. 1 is a block diagram of a control system for a resistive heater constructed in accordance with the teachings of the present disclosure; and

[0010] FIG. 2 is a schematic, cross-sectional view of the resistive heater of FIG. 1.

[0011] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

DETAILED DESCRIPTION

[0012] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0013] Referring to FIG. 1, a control system 10 for a resistive heater 12 is shown. The control system 10 is configured to monitor and diagnose performance of a resistive heater 12, detect a fault in the resistive heater 12, and predict the life expectancy of the resistive heater 12 under a given operating condition.

[0014] Referring to FIG. 2, the resistive heater 12 may be a tubular heater 12 and include a resistive element 14, a dielectric material 16 surrounding the resistive element 14, a metal sheath 18 surrounding the dielectric material 16, and a protective layer 20 surrounding the metal sheath 18. The resistive element 14 may be a resistive coil or wire and has high electric resistivity to generate heat. The metal sheath 18 has a generally tubular structure to enclose the resistive element 14 and the dielectric material 16 therein, and includes a heat-resistant metal, such as stainless steel, Inconel alloy or other high refractory metals. The protective layer 20 is disposed around the metal sheath 18 to provide further protection for the metal sheath 18 in a corrosive environment or to facilitate rapid heat radiation from the surface of the metal sheath 18 to the surrounding environment. The dielectric material 16 fills in a space defined by the metal sheath 18 and electrically insulates the resistive element 14 from the metal sheath 18. The dielectric material 16 has a predetermined dielectric strength, heat conductivity and may include magnesium oxide (MgO).

[0015] During the heater operation, the material properties of the dielectric material 16 may vary with an operating temperature during an operating period. Generally, the dielectric strength of the dielectric material 16 decreases as the operating temperature increases. When the tubular heater 12 is operated at an elevated temperature for a relatively long period of time, the dielectric strength of the dielectric material 16 may significantly decrease, resulting in a dielectric breakdown in the dielectric material 16. The dielectric breakdown causes a short circuit between the resistive element 14 and the metal sheath 18, resulting in a heater failure. Dielectric breakdown is a common cause of heater failure. The dielectric material 16 generally degrades faster than other constituent components of the resistive heater 12 and is the first to fail.

[0016] Therefore, the control system 10 according to the present disclosure is configured to monitor the material properties of the dielectric material 16, particularly a change in the dielectric property/strength of the dielectric material 16 when the heater 12 is in an active mode. The dielectric parameters being monitored may be used to diagnose performance of the heater 12, detect a fault in the heater 12, or predict a life expectancy of the heater 12 under a given operating condition. The dielectric parameters may also be used to provide a feedback to the control system 10 to optimize operation and control of the heater 12.

[0017] Referring back to FIG. 1, the control system 10 according to the teachings of the present disclosure includes a heater operation control module 22, a dielectric parameter determination module 24, a diagnostic module 26, and a prediction module 28. The control system 10 may further include a temperature measurement module 29 for monitoring and measuring a temperature of the heater 12.

[0018] The heater operation control module 22 controls the operation of the heater 12 based on input parameters, such as a desired operating temperature, a desired ramp-up/ramp-down speed, and/or a desired heating duration.

[0019] The dielectric parameter determination module 24 dynamically monitors and determines a dielectric parameter of the heater 12 when the heater 12 is in an active mode (i.e., when the heater is operating). The dielectric parameter as used herein refers to a parameter that can provide an indication of the dielectric property of the dielectric material 16 under the operating conditions. The dielectric property of the dielectric material 16 varies with an operating temperature and operating time, and may affect the proper functioning of the heater 12, if it decreases to an unacceptable degree.

[0020] In the one form, the dielectric parameter may be a change in a leakage current flowing through the dielectric material 16. The amount of the leakage current through the dielectric material 16 provides an indication of a change in the dielectric property, strength or integrity of the dielectric material 16. In one form, an integrated device 50 is used to measure leakage current or other current parameters. The integrated device 50 may be disposed within the heater 12 or on an exterior portion thereof and in electrical communication with the lead wires or power pins (not shown). In another form, the integrated device 50 may be integrated within the leakage current monitoring module 30 as described in greater detail below. The integrated device 50 may be, by way of example, a transducer capable of measuring current in micro or milliamp levels.

[0021] Therefore, the dielectric parameter determination module 24 may include a leakage current monitoring module 30 for monitoring and measuring a leakage current through the dielectric material 16, and determining a change in the leakage current. The leakage current monitoring module 30 measures and records the leakage current changes as a function of time and temperature. It is understood that any parameters other than the leakage current may be used without departing from the scope of the present disclosure as long as the parameters can provide information about the dielectric strength and dielectric property of the dielectric material 16.

[0022] The diagnostic module 26 receives the dielectric parameter from the dielectric parameter determination module 24 and diagnoses performance of the heater 12 based on the dielectric parameter, such as a change in the leakage current. For example, a heater may have a life expectancy of 90 days at an operating temperature of 900°C before the heater shows any sign of failure. The same heater may have a life expectancy of over 350 days at an operating temperature of 800°C without showing any sign of failure. Therefore, the diagnostic module 26 may periodically or regularly analyze the dielectric parameter or information about the leakage current received from the dielectric parameter determination module 24 based on a stored program to detect an abnormality in the heater.

[0023] The diagnosing module 26 may further include a fault detection control (FDC) module 34, which sets a threshold for a fault in the heater. During heater operation, a small amount of leakage current may flow through the dielectric material 16. As the resistive heater 12 continues to be operated at an elevated temperature for a prolonged period of time, the amount of leakage current may increase abruptly. When the amount of the leakage current reaches the threshold, the FDC module 34 may determine that a dielectric breakdown is forthcoming and generates a warning signal to alert the operator or generates an enable signal to turn on a switch to shut off power supply to the resistive heater 12.

[0024] Alternatively, the diagnostic module 26 may diagnose the performance of the resistive heater 12 based on an increase rate of the leakage current. When the leakage current increases at a rate faster than a threshold rate, the diagnostic module 26 may determine that the heater 12 is not operated in an optimum manner. A signal may be generated accordingly to provide such information to the operator.

[0025] The prediction module 28 receives the dielectric parameters from the dielectric parameter determination module 22, calculates a constant factor (K), and predicts a life expectancy of the heater 12 under the monitored operating conditions. The prediction module 28 may include pre-stored correlations among operating temperatures, dielectric parameters such as leakage current, and time. The dielectric parameter may be sent to the prediction module 28, which calculates a constant factor (K) based on the dielectric parameter. The prediction module 28 then calculates and predicts the life expectancy of the heater at a given temperature and time based on the constant factor (K). The prediction module 28 includes a mathematical formula or algorithm to dynamically predict the life expectancy of the heater at a given temperature and time.

[0026] Optionally, the dielectric parameter can also be sent to the heater operation control module 22 for a closed-loop feedback control. Based on the dielectric parameter as a feedback, the heater operation control module 22 may optimize control of the heater 12 by changing the operating temperature and/or ramp up/ramp down speed of the heater 12, in order to improve the heater performance and life expectancy.

[0027] It should be noted that the disclosure is not limited to the embodiment described and illustrated as examples. A large variety of modifications have been described and more are part of the knowledge of the person skilled in the art. These and further modifications as well as any replacement by technical equivalents may be added to the description and figures, without leaving the scope of the protection of the disclosure and of the present patent.

CLAIMS

What is claimed is:

1. A control system for controlling an operation of a resistive heater, the control system comprising:

a dielectric parameter determination module for determining a dielectric parameter of the resistive heater when the resistive heater is in an active mode; and

a diagnostic module for diagnosing performance of the resistive heater based on the dielectric parameter.

2. The control system according to Claim 1, wherein the dielectric parameter determination module further includes a monitoring module for monitoring a leakage current through a dielectric material of the heater.

3. The control system according to Claim 2, wherein the monitoring module determines a change in the leakage current.

4. The control system according to Claim 1, wherein the diagnostic module determines performance of the heater based on a comparison of the leakage current and a threshold leakage current.

5. The control system according to Claim 4, wherein the diagnostic module further includes a fault detection control module that generates a warning signal when the leakage current reaches the threshold leakage current.

6. The control system according to Claim 1, further comprising a prediction module for predicting a life expectancy of the resistive heater based on the dielectric parameter.

7. The control system according to Claim 6, wherein the prediction module includes correlations among the dielectric parameter, a life expectancy, and an operating temperature of the resistive heater.

8. The control system according to Claim 6, wherein the prediction module determines a constant factor (K) based on the dielectric parameter.

9. The control system according to Claim 1, further comprising a heater operation control module that operates the resistive heater based on the monitored dielectric parameter.

10. The control system according to Claim 1, wherein the dielectric parameter relates to a dielectric strength of the dielectric material.

11. A method for controlling a resistive heater, comprising:

determining a dielectric parameter of the resistive heater; and

diagnosing an operation of the resistive heater based on the dielectric parameter.

12. The method according to Claim 11, further comprising predicting a life expectancy of the resistive heater based on the dielectric parameter.

13. The method according to Claim 11, further comprising controlling the resistive heater based on the dielectric parameter.

14. The method according to Claim 11, further comprising establishing maximum limit margin for the heater failure.

15. The method according to Claim 11, further comprising providing dielectric parameter changes and correlation factor as a feedback for diagnostic and fault detection control (FDC).

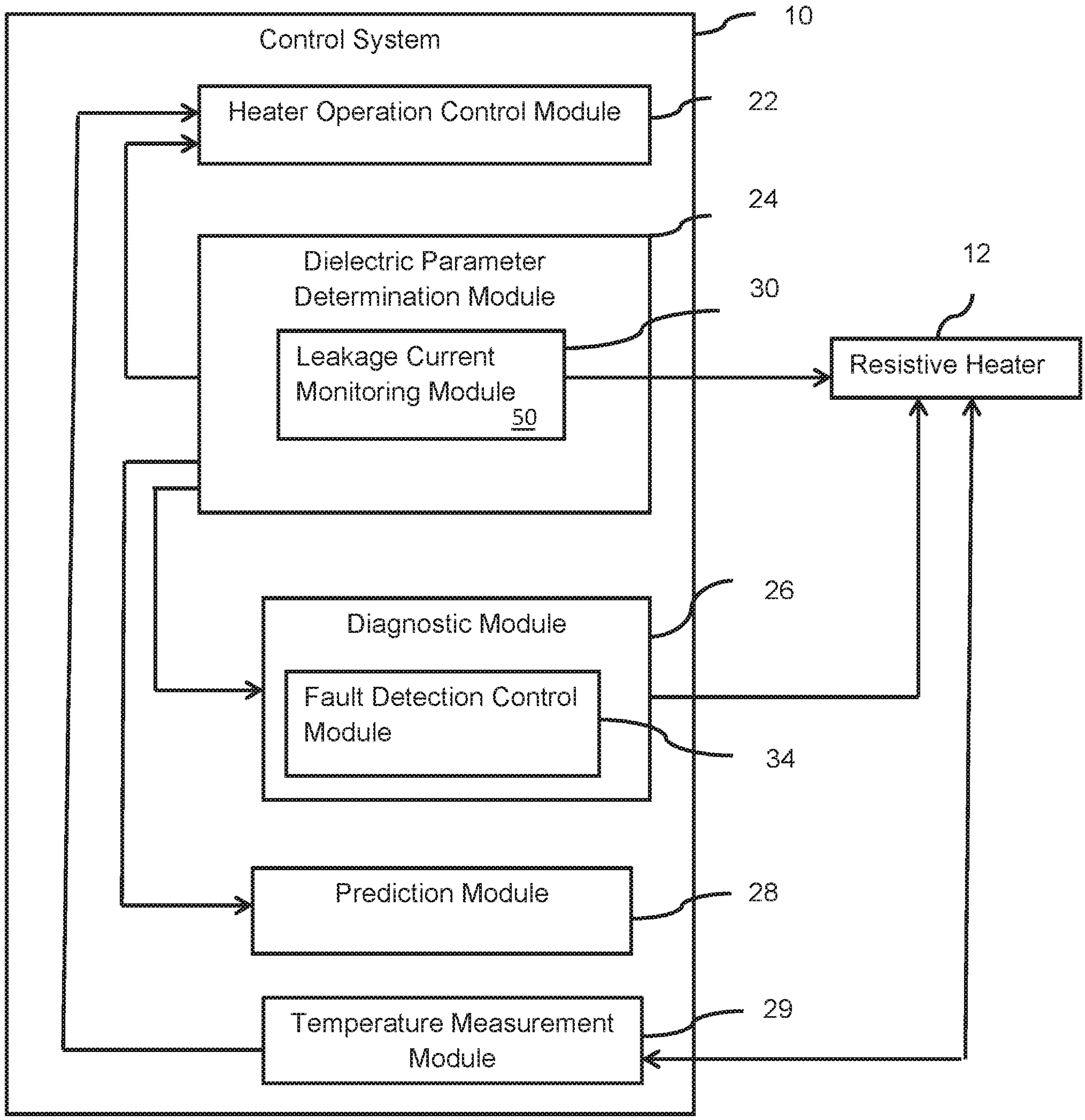
10
Control System
Heater Operation Control Module
22
24
Dielectric Parameter Determination Module
30
12
Leakage Current Monitoring Module
50
Resistive Heater
26
Diagnostic Module
Fault Detection Control Module
34
Prediction Module
28
29
Temperature Measurement Module

FIG. 1

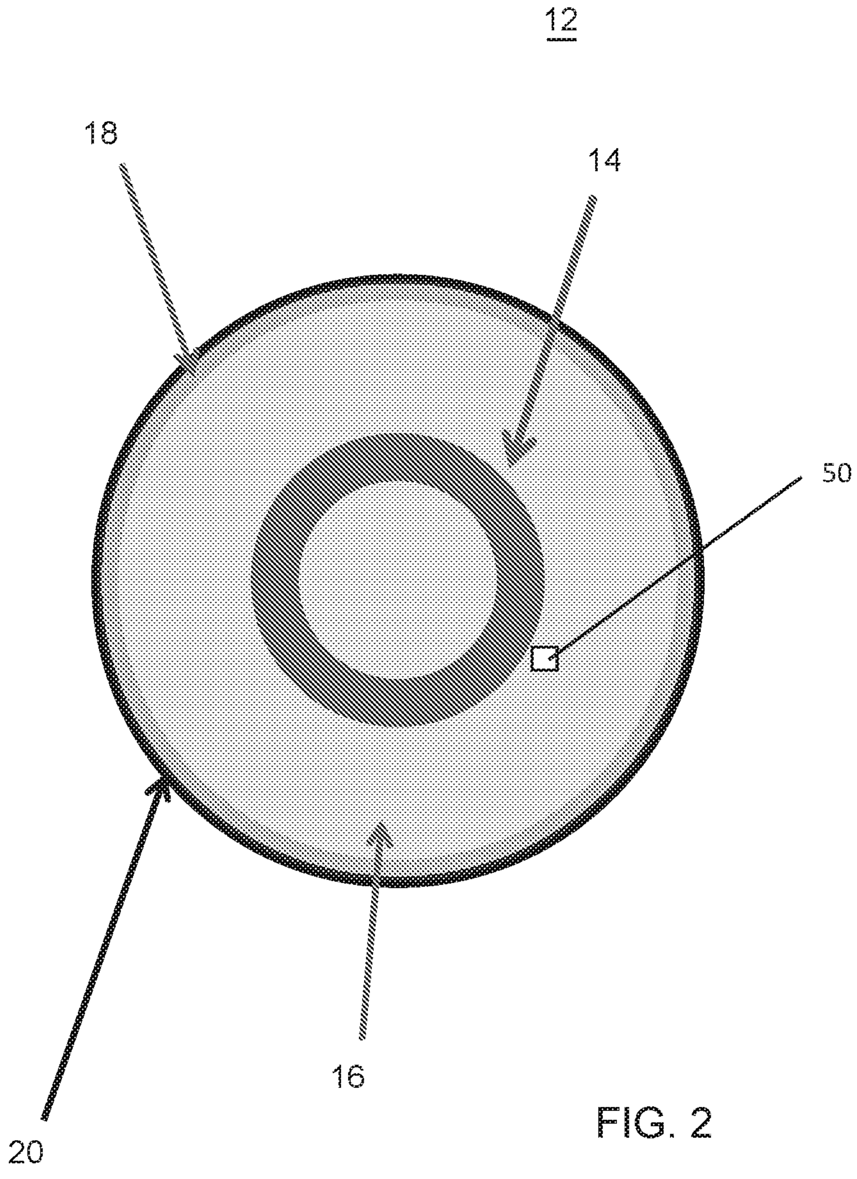

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/055131

A. CLASSIFICATION OF SUBJECT MATTER
INV. H05B1/02 H05B3/48
ADD.

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)
H05B

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2014/176585 A1 (WATLOW ELECTRIC MFG [US]) 30 October 2014 (2014-10-30) paragraph [0029] -----	1-3, 9-11,13 4-8,12, 14,15
X	WO 01/67818 A1 (FERRO TECH BV [NL]; KAASTRA SIMON [NL]) 13 September 2001 (2001-09-13) page 4, line 9 - line 12 page 5, line 18 - line 22 -----	1-5, 9-11, 13-15
X	WO 99/51064 A1 (AMERICAN ROLLER CO [US]) 7 October 1999 (1999-10-07) page 10, line 22 - line 26 -----	1-5, 9-11, 13-15

☐ 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 another 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	Date of mailing of the international search report
8 December 2016	20/12/2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2016/055131

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