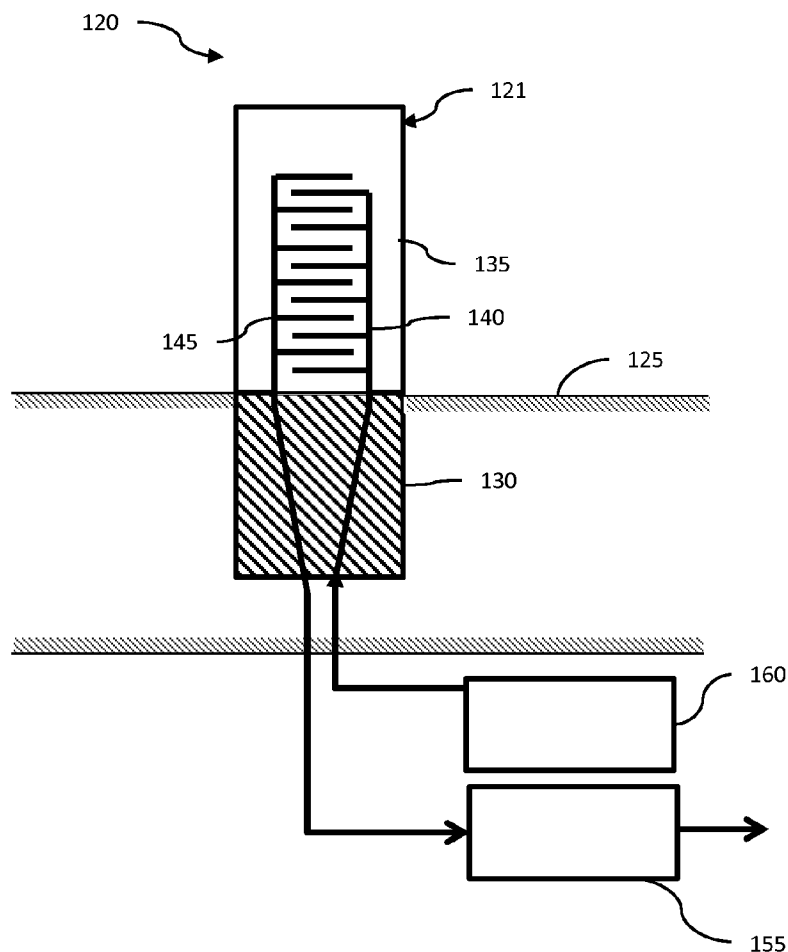


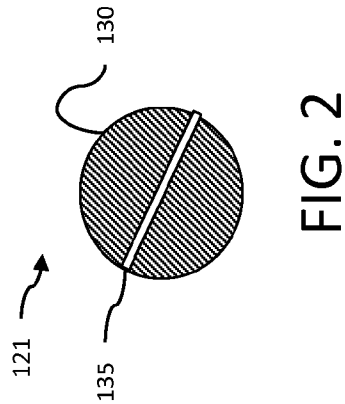
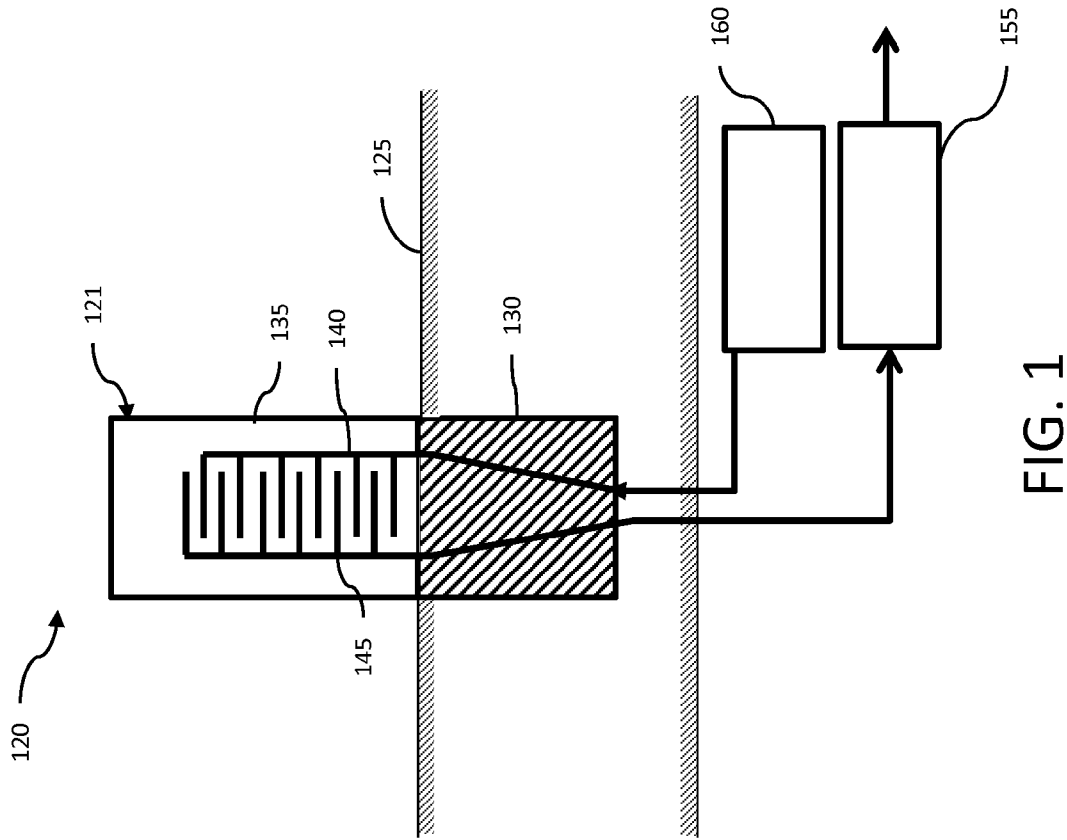


US 20140174474A1

(19) **United States**(12) **Patent Application Publication**
Ekanayake et al.(10) **Pub. No.: US 2014/0174474 A1**(43) **Pub. Date: Jun. 26, 2014**(54) **SYSTEMS AND METHODS FOR WASHING A
GAS TURBINE COMPRESSOR****Publication Classification**(71) Applicant: **General Electric Company,**
Schenectady, NY (US)(72) Inventors: **Sanji Ekanayake**, Mableton, GA (US);
Alston Ilford Scipio, Mableton, GA
(US); **Thomas Edward Wickert**,
Greenville, SC (US); **Douglas Frank**
Beadie, Greer, SC (US)(73) Assignee: **General Electric Company,**
Schenectady, NY (US)(21) Appl. No.: **13/947,319**(22) Filed: **Jul. 22, 2013****Related U.S. Application Data**(63) Continuation-in-part of application No. 13/721,718,
filed on Dec. 20, 2012.(51) **Int. Cl.**
F01D 25/00 (2006.01)
(52) **U.S. Cl.**
CPC **F01D 25/002** (2013.01)
USPC **134/18; 134/56 R**(57) **ABSTRACT**

A method is provided for washing a compressor in a gas turbine. The method includes establishing a compressor fouling set point and sensing a fouling level in the compressor with a sensor. The fouling level is communicated to a control subsystem that determines a wash initiation instruction based on the fouling level and the compressor fouling set point. The wash initiation instruction is executed by initiating a wash with a fluid. A system is also disclosed including a compressor, an on-line wash system coupled to the compressor, and a compressor fouling sensor that senses a compressor fouling level. A source of washing fluid is provided, and a control subsystem that initiates a wash with washing fluid from the source of washing fluid based on a compressor fouling level.





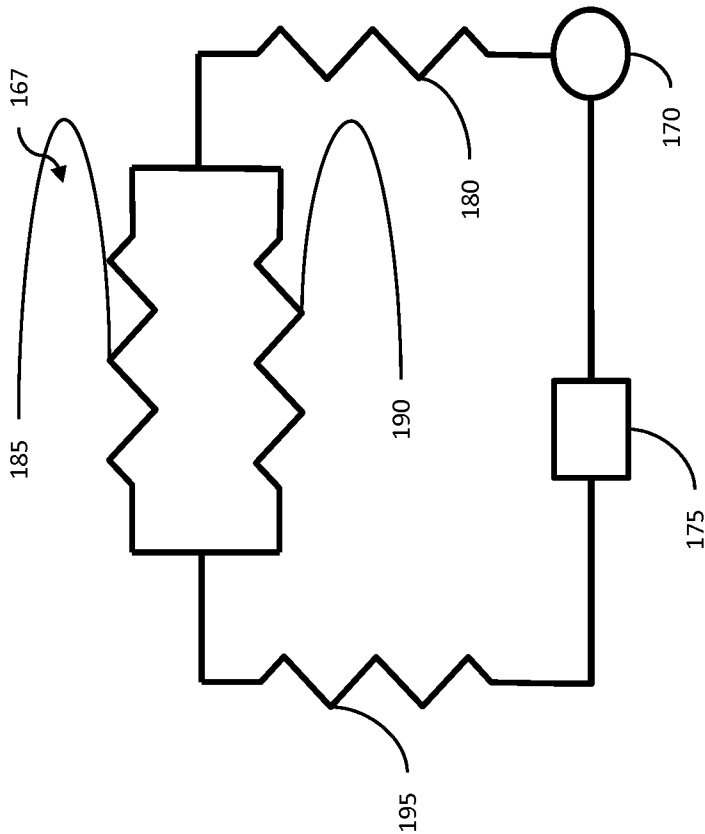


FIG. 3

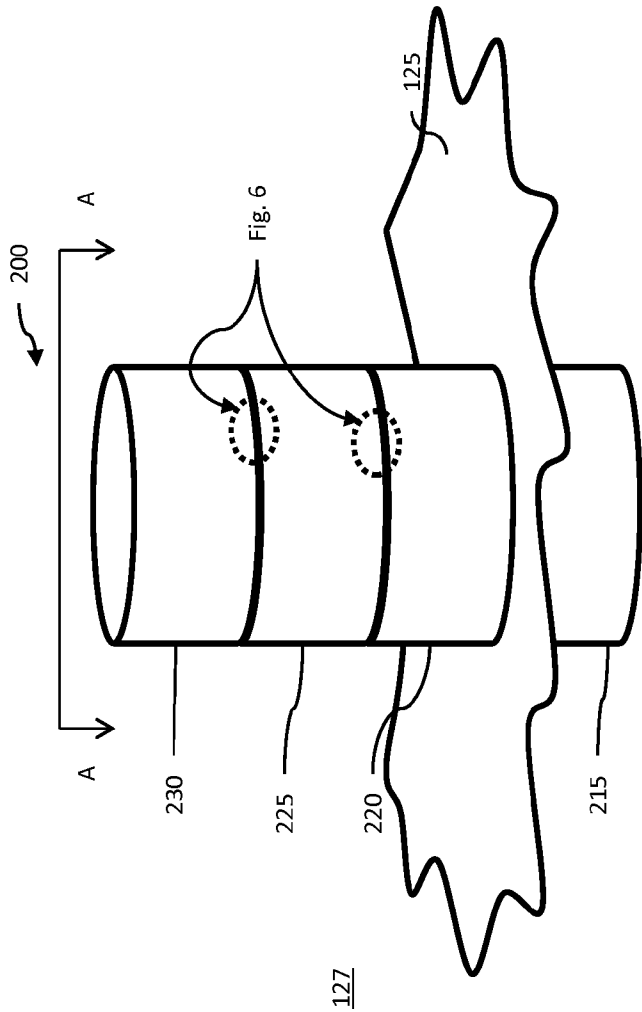


FIG. 4

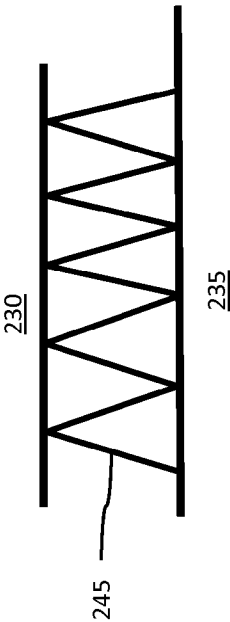


FIG. 5

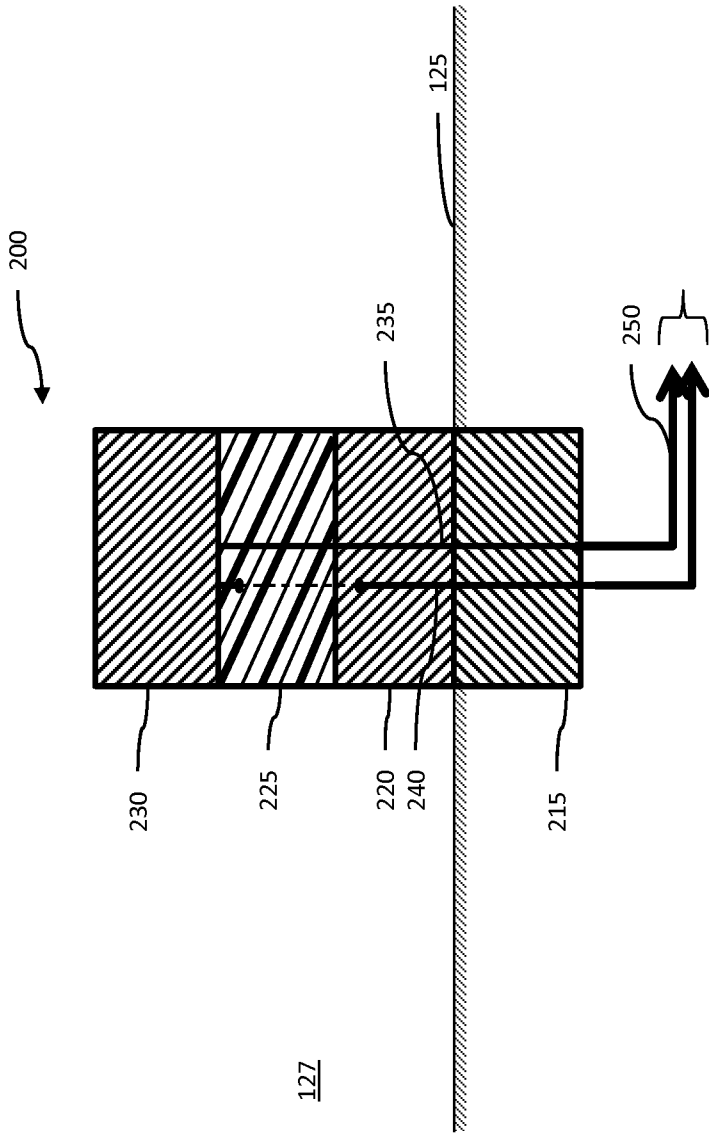
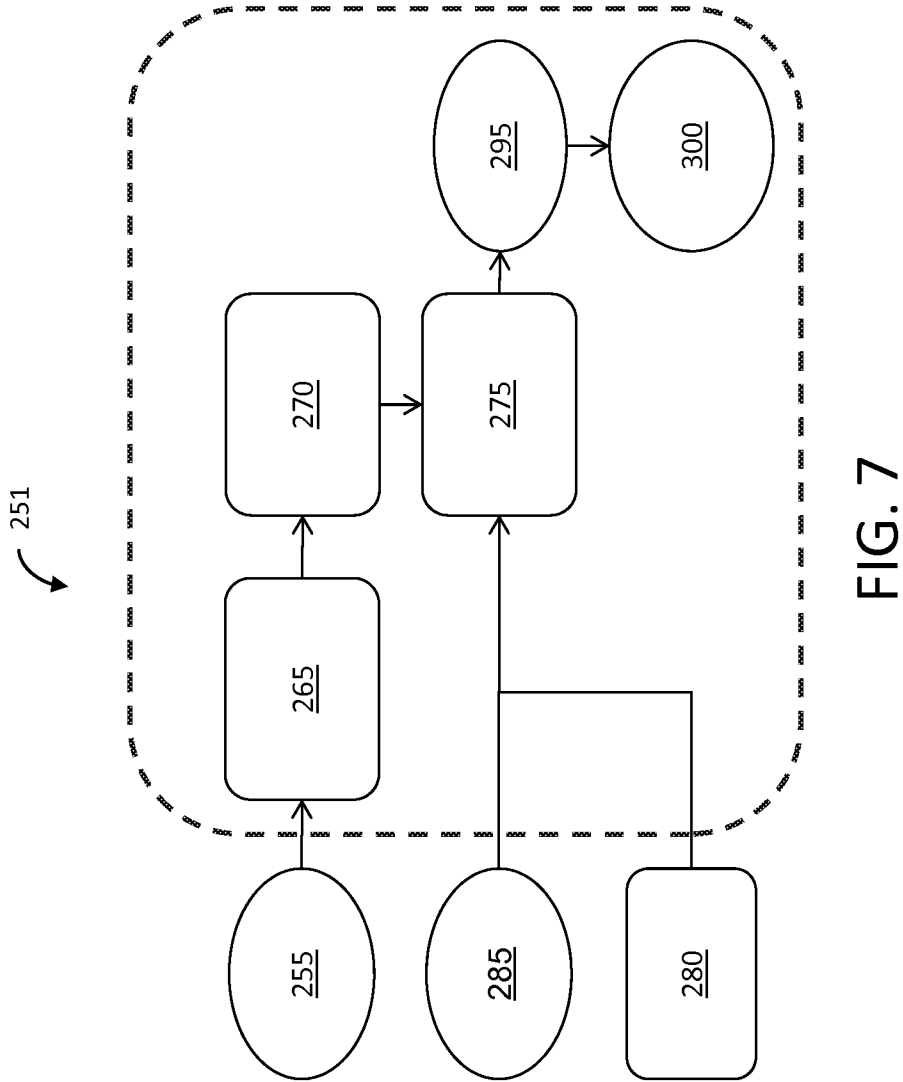


FIG. 6



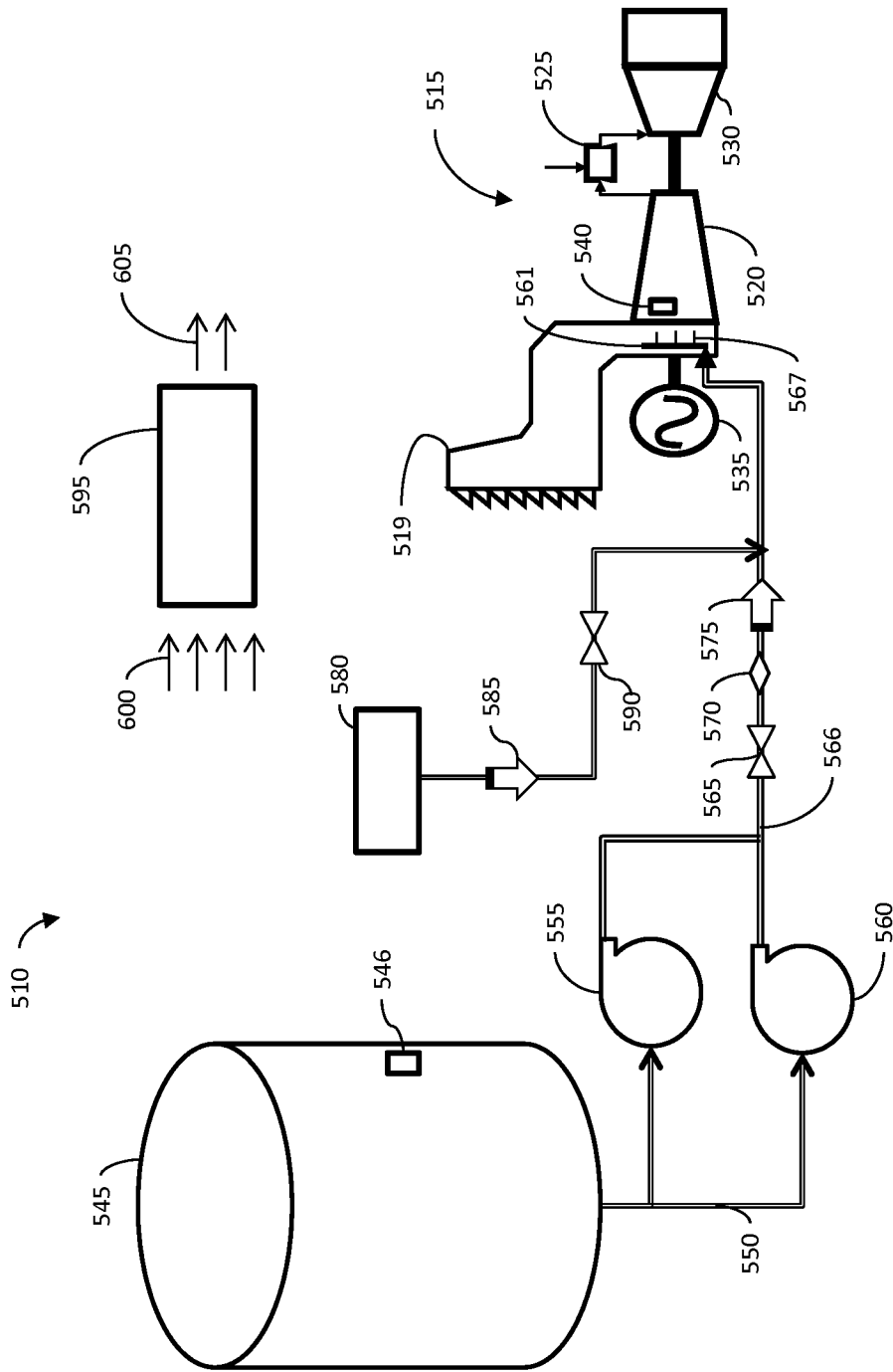


Fig. 8

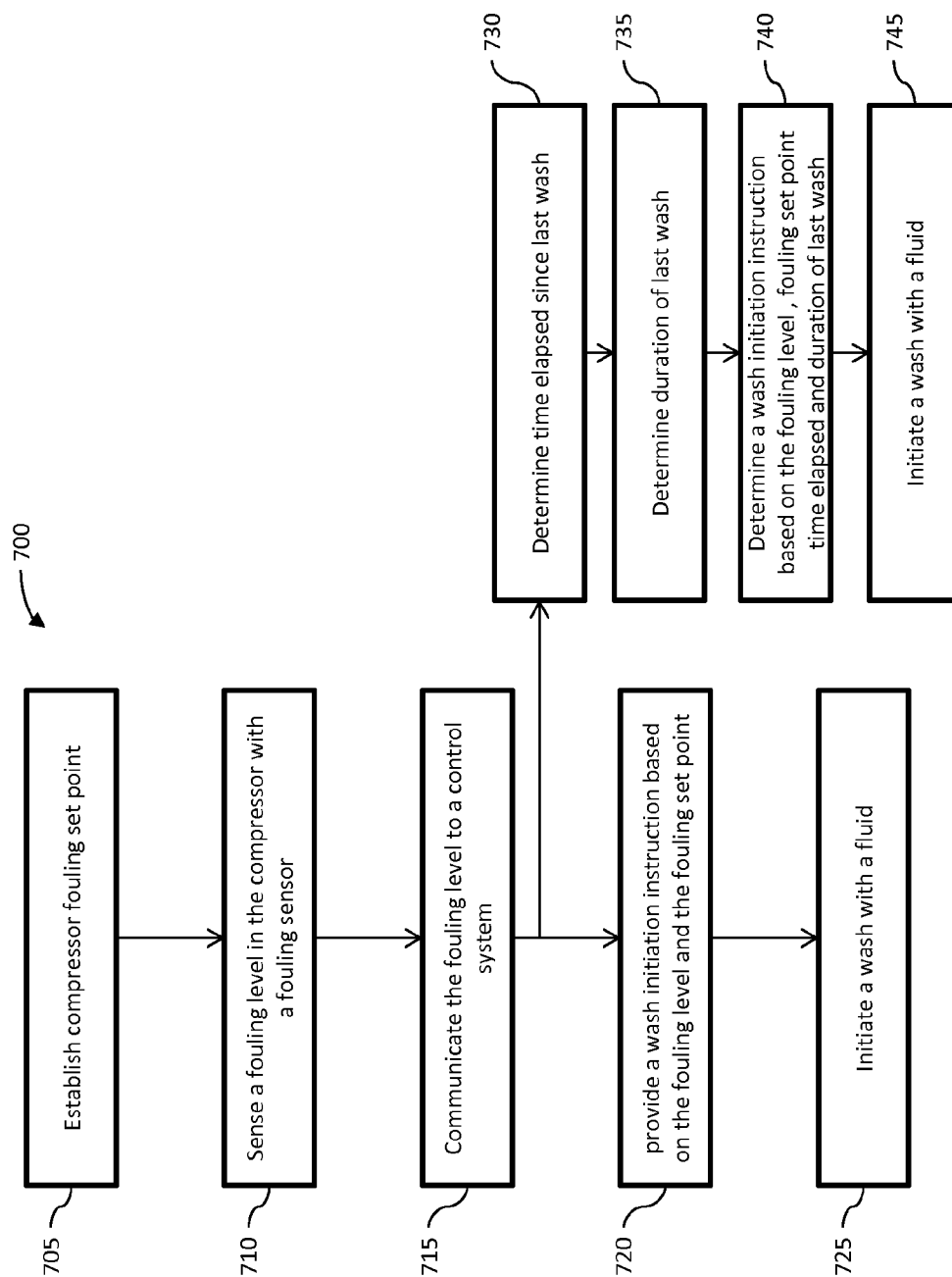


Fig. 9

SYSTEMS AND METHODS FOR WASHING A GAS TURBINE COMPRESSOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of commonly assigned U.S. application Ser. No. 13/721,718 filed Dec. 20, 2012.

TECHNICAL FIELD

[0002] The subject matter disclosed herein generally relates to gas turbine compressor washing and more particularly to systems and methods to trigger a wash of a gas turbine compressor.

BACKGROUND

[0003] Turbine systems, including gas turbines, generally include a compressor section, one or more combustors, and a turbine section. Typically, the compressor section pressurizes inlet air, which is then turned in a direction or reverse-flowed to the combustors, where it is used to cool the combustor and also to provide air for the combustion process. In a multi-combustor turbine, the combustors are generally located in an annular array about the turbine and a transition duct connects the outlet end of each combustor with the inlet end of the turbine section to deliver the hot products of the combustion process to the turbine.

[0004] Components of turbine systems are subject to performance loss and damage from fouling during operation. Fouling is a buildup of material on components of the compressor and is caused by the adherence of particles, oils and organic vapors to the airfoils and annulus surfaces. Particles that cause fouling are typically smaller than 2 to 10 nm. Fouling may lead to a modified aerodynamic profile which reduces the efficiency of the compressor. Fouling may also significantly impact the performance and heat-rate of the turbine system.

[0005] To maintain the compressor operating efficiently, industrial turbine system operators perform various maintenance actions, typically including online water washes, offline inspections, offline water washes, and filter maintenance. Fouling can be removed by offline inspections and offline water washing and slowed down by online water washing. Online water washing provides the advantage of cleaning the compressor without shutting down the turbine system. The online washing approach recovers turbine system efficiency when the operating schedule does not permit shut-down time so as to perform a more effective offline wash. Water nozzles of the system may be located in positions upstream or directly at the inlet to the compressor bellmouth casing. These nozzles create a spray mist of water droplets and when in operation, the spray mist is drawn through the bellmouth and into the compressor inlet by the negative pressure produced by the rotating compressor.

[0006] Understandably, disadvantages exist if these tasks are performed too frequently or infrequently. For example, excessive online washing can promote erosion while insufficient online washing results in increased buildup of fouling agents on the compressor blades. Inevitably, offline inspections must be performed, requiring turbine shutdown and dismantlement that incur downtime. Though offline inspections are very costly events, failing to timely perform these inspections can result in damage to the turbine, such as from

liberation of a compressor blade due to pitting corrosion. Consequently, turbine system operators rely on carefully scheduled offline inspections to monitor compressor performance, and perform repairs to avert destructive events.

BRIEF DESCRIPTION OF THE INVENTION

[0007] The systems and methods of the disclosure improve the efficacy of the gas turbine compressor on-line wash, thereby improving the performance degradation rate over time and reducing the need for frequent compressor off-line water washes.

[0008] In accordance with one exemplary non-limiting embodiment, the invention relates to a method for washing a compressor in a gas turbine. The method includes the establishment of a compressor fouling set point and the sensing of a fouling level in the compressor with a sensor. The fouling level is communicated to a control subsystem where a wash initiation instruction is determined based on the fouling level and the compressor fouling set point. The method includes initiating a wash with a fluid upon determination of the wash initiation instruction.

[0009] In another embodiment, a system having a compressor and an on-line wash system coupled to the compressor is provided. The system includes a compressor fouling sensor that senses a compressor fouling level and a source of washing fluid. The system also includes a control subsystem that initiates a wash with washing fluid from the source of washing fluid based on a compressor fouling level.

[0010] In another embodiment, a method for servicing a gas turbine having a compressor is provided. The method includes establishing a fouling level set point; sensing a fouling level in the compressor with a fouling sensor; and washing the compressor if the fouling level exceeds the fouling level set point.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of certain aspects of the invention.

[0012] FIG. 1 is a schematic illustration of an embodiment of a fouling sensor.

[0013] FIG. 2 is a top view of an embodiment of the fouling sensor.

[0014] FIG. 3 is an equivalent circuit diagram of the fouling sensor.

[0015] FIG. 4 is an alternate embodiment of a fouling sensor.

[0016] FIG. 5 is a detailed view of the area labeled FIG. 5 from FIG. 4.

[0017] FIG. 6 is a cross section of the alternate embodiment of a fouling sensor taken along line A-A in FIG. 5.

[0018] FIG. 7 is a schematic diagram of an embodiment fouling measurement system.

[0019] FIG. 8 is a schematic illustration of an embodiment of a compressor wash system.

[0020] FIG. 9 is a flow diagram of an embodiment of a method for washing a compressor.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Illustrated in FIGS. 1 and 2 is an embodiment of a fouling measurement system 120. The fouling measurement system 120 includes a conductivity/resistance sensor 121 attached to the compressor casing 125. Conductivity/resistance sensor 121 is inexpensive and is of a type used in many common systems. Conductivity/resistance sensor 121 includes an attachment component 130 adapted to be connected to the compressor casing 125. The attachment component 130 also supports a flat nonconductive substrate 135 having a first electrode 140 and a second electrode 145. As illustrated in FIG. 1, the first electrode 140 and the second electrode 145 are spaced apart and are connected only through the flat nonconductive substrate 135. The first electrode 140 and the second electrode 145 are connected to signal wires 150 which in turn are connected to a reader 155 and an alternating current source 160.

[0022] Illustrated in FIG. 3 is the equivalent measurement circuit 167 for the conductivity/resistance sensor 121. The equivalent measurement circuit 167 includes a power supply 170 and a detector 175. The circuit includes a signal wiring resistance 180 (R_1), a substrate resistance 185 (R_{2a}), and a surface resistance 190 (R_{2b}). The surface resistance 190 decreases with increased fouling. The total resistance 195 (R_T) may be calculated as follows:

$$R_T = R_1 + R_2,$$

where

$$R_2 = R_{2a} R_{2b} / (R_{2a} + R_{2b})$$

[0023] The fouling measurement system 120 may be disposed in the air flow stream at the compressor inlet mouth 127 of the compressor assembly 102 and/or in between compressor stages. Over time particles that cause fouling are deposited on the flat nonconductive substrate 135 thereby lowering the surface resistance 190 (R_{2b}). The change in the total resistance 195 (R_T) is therefore a function of the degree of fouling in the compressor assembly 102. The electrical conductivity of the flat nonconductive substrate 135 and the particles deposited on the flat nonconductive substrate 135 is measured by measuring the voltage drop produced across the flat nonconductive substrate 135. The voltage drop is measured between the first electrode 140 and the second electrode 145 by passing an electrical current from the circuit portion through the flat nonconductive substrate 135 and the particles deposited on the flat nonconductive substrate 135.

[0024] Illustrated in FIGS. 4, 5 and 6 is a cylindrical sensor 200 that may be attached to the compressor casing 125. FIG. 4 is a perspective view of the cylindrical sensor 200 with a partial cut away the compressor casing 125. FIG. 6 is a cross section of the cylindrical sensor 200 taken along the line A-A in FIG. 4. The cylindrical sensor 200 is disposed in the compressor inlet mouth 127. The cylindrical sensor 200 includes an attachment component 215, a lower cap 220, a high resistance surface conductor 225, and an end cap 230. Disposed inside the cylindrical sensor 200 are a first electrode 235, and a second electrode 240. The interface between the end cap 230 and the high resistance surface conductor 225 may be an extended interface 245 to improve sensitivity to surface fouling (illustrated in FIG. 5). This increased sensitivity is accomplished by increasing the relative areas between the first electrode 235 and the second electrode 240 exposed to fouling buildup on the high resistance surface conductor 225. The

first electrode 235 and the second electrode 240 are connected to signal wires 250. The equivalent circuit of the cylindrical sensor 200 is the same as the equivalent circuit of the conductivity/resistance sensor 121 and the degree of fouling can be correlated to a decrease in the resistance measured across the high resistance surface conductor 225.

[0025] In operation, the cylindrical sensor 200 and the conductivity/resistance sensor 121 may be disposed in the compressor inlet mouth 127 or any latter stages. In the case of conductivity/resistance sensor 121, a current is provided across the flat nonconductive substrate 135 between the first electrode 140 and the second electrode 145. The resistance is measured by reader 165. Resistance or conductivity may be measured by determining the value of the current that must be passes through the cylindrical sensor 200 and the conductivity/resistance sensor 121 to maintain a predetermined value of voltage drop through the sensor. Over time, particles are deposited on the flat nonconductive substrate 135 which result in a decrease in resistance between the first electrode 140, and second electrode 145. The decrease in resistance is correlated to a degree of fouling. In the case of cylindrical sensor 200, a current is provided across the high resistance surface conductor 225 between the first electrode 235 and the second electrode 240. As particles adhere to the high resistance surface conductor 225, the overall resistance of the circuit is decreased.

[0026] FIG. 7 is a schematic diagram of a fouling measurement system 251. The fouling measurement system 251 includes one or more conductivity sensor(s) 255. The conductivity sensor(s) 255 provides a signal to a measured resistance module 265 and converts the signal to an output that can be processed by a processing module 270. The processing module 270 utilizes model based controls and Kalman filters to process measured resistance and provide an input to a characterization module 275. The model-based controls are derived from a model of a fouling measurement system 251. One approach to modeling is using a numerical process known as system identification. System identification involves acquiring data from a system and then numerically analyzing stimulus and response data to estimate the parameters of the system. The processing module 270 may utilize parameter identification techniques such as Kalman filtering, tracking filtering, regression mapping, neural mapping, inverse modeling techniques, or a combination thereof, to identify shifts in the data. The filtering may be performed by a modified Kalman filter, an extended Kalman filter, or other filtering algorithm, or alternatively, the filtering may be performed by or other forms of square (n-inputs, n-outputs) or non-square (n-input, m-outputs) regulators. The characterization module 275 characterizes fouling as a function of measured changes in conductivity or resistance. The characterization module 275 may receive a calibration input 280 that correlates resistance to the degree of fouling. Calibration may be made at a production facility or in the field. The characterization module 275 may also receive as input the time since last offline water wash 285. The output from characterization module 275 may be provided to a display module 295 such as a graphical user interface. An output 300 of the display module 295 may be a recommendation or triggering of a compressor wash.

[0027] The fouling measurement system 251 may be integrated into a larger control system such as a conventional General Electric Speedtronic™ Mark VI™ Turbine system Control System. The SpeedTronic™ controller monitors

various sensors and other instruments associated with a turbine system. In addition to controlling certain turbine functions, such as fuel flow rate, the SpeedTronic™ controller generates data from its turbine sensors and presents that data for display to the turbine operator. The data may be displayed using software that generates data charts and other data presentations, such as the General Electric Cimplicity™ HMI software product.

[0028] The Speedtronic™ control system is a computer system that includes microprocessors that execute programs to control the operation of the turbine system using sensor inputs and instructions from human operators. The control system includes logic units, such as sample and hold, summation and difference units that may be implemented in software or by hardware logic circuits. The commands generated by the control system processors cause actuators on the turbine system to, for example, adjust the fuel control system that supplies fuel to the combustion chamber, set the inlet guide vanes to the compressor, and adjust other control settings on the turbine system.

[0029] The controller may include computer processors and data storage that convert the sensor readings to data using various algorithms executed by the processors. The data generated by the algorithms are indicative of various operating conditions of the turbine system. The data may be presented on operator displays, such as a computer work station, that is electronically coupled to the operator display. The display and/or controller may generate data displays and data printouts using software, such as the General Electric Cimplicity™ data monitoring and control software application.

[0030] Illustrated in FIG. 8 is an embodiment of a compressor wash system 510 for use with a gas turbine 515. The gas turbine 515 includes an air inlet system 519, a compressor 520, a combustor 525, and a turbine 530. The gas turbine 515 may be used to drive an electrical or mechanical load such as generator 535. The compressor 520 may be provided with a compressor fouling sensor 540. The compressor fouling sensor 540 may be a conductivity/resistance sensor 121 (shown in FIG. 1), or a cylindrical sensor 200 (shown in FIG. 4). The compressor wash system 510 may include a storage tank 545 that contains a washing fluid. The washing fluid may be a solvent such as alcohol or a mixture of deionized water and alcohol. Preferably the alcohol is methanol or ethanol. In one embodiment, the mixture of alcohol and deionized water is a 50-50 mix of deionized water and alcohol. The storage tank 545 may be provided with a level sensor 546 and is coupled through a conduit 550 to a redundant pair of supply pumps 555 and 560. The supply pumps 555 and 560 are connected to an on-line wash system 561 through a washing fluid modulating valve 565 disposed in washing fluid conduit 566. The on-line wash system 561 includes a plurality of nozzles 567 that direct washing fluid to the compressor 520. A pressure sensor 570 and a flow sensor 575 may be disposed on the washing fluid conduit 566 to provide the data necessary to control the flow of washing fluid to the on-line wash system 561. The compressor wash system 510 may also include a source of deionized water 580 coupled to a water conduit 581 which may be coupled to washing fluid conduit 566 through a deionized water modulating valve 585. A flow sensor 590 may be disposed on the water conduit 581.

[0031] The compressor wash system 510 also includes a control subsystem 595. The control subsystem 595 receives inputs 600 such as the time elapsed since the last wash; the duration of the last wash; the level of fouling of the compres-

sor 520; the level of the storage tank 545; the flow rate through the supply pumps 555; the status of the supply pumps 555; the flow rate of the solvent to the compressor 520; and the flow rate of deionized water, among others. Inputs 600 to the control subsystem 595 may include a calculated percent lower explosive level (LEL) for the solvent mixture in the compressor 520. This value may be used as a permissive preventing the wash if the composition of solvent mixture exceeds the LEL. Thus, a wash instruction or a wash may be interrupted if the composition of the solvent mixture exceeds the LEL. Another input to the control system may be a change to the compressor discharge temperature (CTD) that may also serve as a permissive in the actuation of the wash if the CTD exceeds a predetermined threshold. The control subsystem 595 provides outputs 605 such as instructions to the washing fluid modulating valve 565, deionized water modulating valve 585, and instructions to the supply pumps 555 and 560, among others. The control system may be a self-contained control system or may be integrated into the aforementioned SpeedTronic™ controller.

[0032] The compressor wash system 510 provides the ability to avoid unnecessary on-line washes of the compressor 520 by coupling the triggering of an on-line wash to a measured degree of fouling of the compressor 520. A predetermined threshold of fouling may be established, and the on-line wash may be triggered when the measured degree of fouling exceeds the predetermined level. Additionally other parameters such as the time elapsed since the last wash, the duration of the last wash, and the blend ratio of water to solvent may be taken into account in determining the length of the wash as well as the blend ratio of water to solvent used in the wash. Initiation of wash may be subject to permissives such as the LEL of the washing fluid, and changes to the CTD.

[0033] Illustrated in FIG. 9 is a method 700 for washing a compressor 520 of a gas turbine 515.

[0034] In step 705, the method 700 establishes a predetermined compressor fouling set point.

[0035] In step 710, the method 700 periodically monitors the fouling level in the compressor 520 using a compressor fouling sensor 540.

[0036] In step 715 values representative of the fouling level are periodically provided to the control subsystem 595.

[0037] In step 720 the control subsystem 595 provides a wash initiation instruction when the fouling set point is reached.

[0038] In step 725, the method 700 initiates a wash with a fluid. The fluid may be a solvent such as methyl or ethyl alcohol which may be mixed with deionized water at a predetermined ratio.

[0039] Although in step 710 the monitoring of the fouling level is described as being periodic, is also contemplated that the monitoring may be continuous. Similarly, values representative of the fouling level may be provided continuously to the control subsystem 595. Additionally, the wash initiation may be automatic.

[0040] In another embodiment, the method 700 may include a step 730 in which the elapsed time since last wash is determined

[0041] The method 700 may also include a step 735 in which the duration of the last wash is determined

[0042] In step 740, the method 700 may determine a wash initiation instruction based on the fouling level, the fouling set point, the time elapsed since the last wash, and the duration of the last wash.

[0043] In step 745, the method 700 may initiate a wash with a fluid. The fluid may be a blend of deionized water and a solvent at a predetermined blend ratio. The wash may be subject to a permissive based on the LEL of the wash fluid. For example, the wash may be interrupted (wash initiation is prevented, or current wash is stopped) if the wash fluid composition exceeds the LEL. Additionally, the wash initiation may be subject to a permissive based on the change of CTD, for example if the CTD is below a threshold level. For example, the wash may be interrupted (wash initiation is prevented, or current wash is stopped) if the CTD is below a threshold level.

[0044] In yet another embodiment, the method 700 may determine the duration of the last wash and the blend ratio of water to solvent of the last wash. The method 700 may then determine the duration and blend ratio of the wash and initiate a wash based on the duration of the last wash and the blend ratio of the last wash.

[0045] Where the definition of terms departs from the commonly used meaning of the term, applicant intends to utilize the definitions provided below, unless specifically indicated.

[0046] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. Where the definition of terms departs from the commonly used meaning of the term, applicant intends to utilize the definitions provided herein, unless specifically indicated. The singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be understood that, although the terms first, second, etc. may be used to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. The term “and/or” includes any, and all, combinations of one or more of the associated listed items. The phrases “coupled to” and “coupled with” contemplate direct or indirect coupling.

[0047] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements.

What is claimed:

1. A method for washing a compressor in a gas turbine, the method comprising:

establishing a compressor fouling set point;
sensing a fouling level in the compressor with a sensor;
communicating the fouling level to a control subsystem;
determining a wash initiation instruction based on the fouling level and the compressor fouling set point; and
initiating a wash with a fluid.

2. The method of claim 1, wherein sensing a fouling level comprises sensing a fouling level with a conductivity resistance sensor.

3. The method of claim 1, further comprising:
determining a time elapsed since a last wash; and
determining a duration of the last wash; and
wherein determining a wash initiation instruction comprises determining a wash initiation instruction based on

the fouling level, the compressor fouling set point, the time elapsed since the last wash and the duration of the last wash.

4. The method of claim 1, wherein initiating a wash comprises initiating a wash with a blend of water and a solvent at a predetermined blend ratio.

5. The method of claim 4, further comprising calculating a wash duration and a wash blend ratio based on a duration of a last wash and the predetermined blend ratio of the last wash.

6. The method of claim 4, wherein the solvent is an alcohol.

7. The method of claim 6, further comprising interrupting the wash if the predetermined blend ratio is above a lower explosive level.

8. The method of claim 1, further comprising interrupting the wash if a compressor temperature discharge is below a predetermined threshold.

9. A system comprising:

a compressor;
an on-line wash system coupled to the compressor;
a compressor fouling sensor that senses a compressor fouling level;
a source of washing fluid; and
a control subsystem that initiates a wash with washing fluid from the source of washing fluid based on a compressor fouling level.

10. The system of claim 9, wherein the source of washing fluid comprises:

a source of water;
a source of solvent; and
a mixing subsystem adapted to mix water from the source of water with solvent from the source of solvent.

11. The system of claim 10, wherein the mixing subsystem is adapted to mix the water and solvent in a proportion based on the compressor fouling level.

12. The system of claim 10 wherein the mixing subsystem is adapted to mix the water and solvent in a proportion based on a duration of a last wash.

13. The system of claim 10, wherein the mixing subsystem is adapted to mix the water and solvent in a proportion based on a time elapsed since a last wash.

14. The system of claim 10, wherein the mixing subsystem comprises:

a pump for the solvent;
a modulating valve; and
a flow sensor.

15. The system of claim 9, further comprising a combustion system and a turbine.

16. The system of claim 15, further comprising a load coupled to the turbine; an air inlet system coupled to the compressor; and a distributed control system.

17. A method for servicing a gas turbine having a compressor; the method comprising:

establishing a fouling level set point;
sensing a fouling level in the compressor with a fouling sensor; and

washing the compressor if the fouling level exceeds the fouling level set point.

18. The method of claim 17, further comprising:

determining a time elapsed since a last wash;
determining a duration of the last wash; and
determining a duration of a wash based on the time elapsed since the last wash and the duration of the last wash.

19. The method of claim **17**, wherein washing the compressor comprises washing the compressor with a blend of water and solvent.

20. The method of claim **19**, further comprising:
determining a blend ratio of water and solvent used for a last wash; and
wherein washing the compressor with a blend of water and solvent comprises washing the compressor with a blend of water and solvent at a blend ratio of water and solvent based on the blend ratio of water and solvent used for the last wash.

* * * * *