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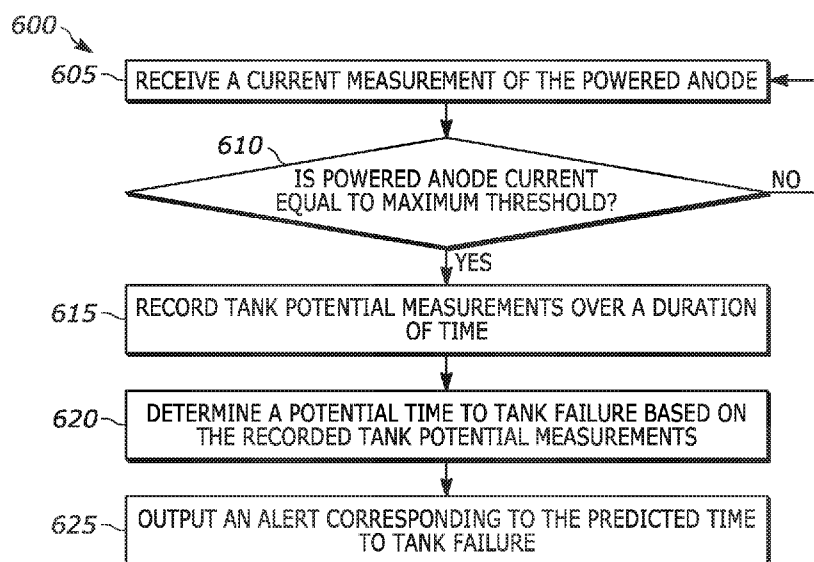


FIG. 6

(57) Abstract: A storage-type water heater including a tank configured to contain a fluid, a powered anode at least partially disposed in the fluid, and an electronic processor. The electronic processor is configured to receive a current measurement of the powered anode, determine whether the current measurement exceeds a maximum threshold, record, when the current measurement exceeds the maximum threshold, a plurality of tank potential measurements over a duration of time, determine, based on the recorded tank potential measurements, a predicted time to tank failure, and output an alert corresponding to the predicted time to tank failure.



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SYSTEM AND METHOD FOR PREDICTING TANK FAILURE OF A WATER HEATER

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority of US Provisional Patent Application No. 62/841,539 filed on May 1, 2019, the contents of which are incorporated herein by reference in its entirety for all purposes.

FIELD

[0002] Embodiments relate to water heaters.

SUMMARY

[0003] Powered anodes may be used to protect storage tanks of water heating systems from corrosion. In such systems, an anode may be constructed with a metal such as platinum or mixed metal oxide (MMO) coated titanium and extends into the water held in the water storage tank. A current may then be applied through the anode to prevent the exposed steel from oxidizing and corroding. In some such systems, the amount of current required to adequately protect the exposed steel is dependent upon, among other things, the quality and material of the tank lining, and the electrical conductivity of the water within the tank. In at least one system, the applied current may be adjusted as the internal lining of the tank corrodes.

[0004] As the tank lining erodes, the amount of current required to protect the exposed steel of the water storage tank increases. However, due to practical limitations, the amount of current applied through the anode may be less than a value necessary to protect the tank. This may result in the deterioration of the tank wall of the water storage tank. Although the powered anode is able to delay the failure of the water storage tank, eventually the metal will corrode and the water storage tank may begin to leak.

[0005] One embodiment provides a storage-type water heater including a tank configured to contain a fluid, a powered anode at least partially disposed in the fluid, and an electronic processor configured to receive a current measurement of the powered anode, determine whether the current measurement exceeds a maximum threshold, record, when the current measurement

exceeds the maximum threshold, a plurality of tank potential measurements over a duration of time, determine, based on the recorded tank potential measurements, a predicted time to tank failure, and output an alert corresponding to the predicted time to tank failure.

[0006] Other aspects of the application will become apparent by consideration of the detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a block diagram of a water heating system according to some embodiments.

[0008] FIG. 2 is a side view of an electrode capable of being used in the water heater of FIG. 1.

[0009] FIG. 3 is a block diagram of a control circuit of the water heater of FIG. 1 according to some embodiments.

[0010] FIG. 4 is a chart illustrating a control circuitry of the control circuit of FIG. 3 according to some embodiments.

[0011] FIG. 5 is a chart illustrating a tank potential and powered anode current characteristic of a water heater according to some embodiments.

[0012] FIG. 6 is a flowchart of a method of predicting tank failure of the water heater of FIG. 1 according to some embodiments.

[0013] FIG. 7 is a diagram 700 of recorded tank potential measurements of a water heater over time according to some embodiments.

[0014] FIG. 8A is a diagram illustrating a relationship between temperature setpoint and tank life according to some embodiments.

[0015] FIG. 8B is a diagram illustrating a relationship between differential temperature setpoint and tank life according to some embodiments.

[0016] FIG. 8C is a diagram illustrating a relationship between incoming water temperature and tank life according to some embodiments.

[0017] FIG. 8D is a diagram illustrating a relationship between duty cycle and tank life according to some embodiments.

[0018] FIG. 9A a diagram illustrating a relationship between lower duty cycle and tank potential according to some embodiments.

[0019] FIG. 9B a diagram illustrating a relationship between higher duty cycle and tank potential according to some embodiments.

DETAILED DESCRIPTION

[0020] Before any embodiments of the application are explained in detail, it is to be understood that the application is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The application is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

[0021] FIG. 1 is a block diagram of a water heating system 100 according to some embodiments of the application. Although illustrated as a water heater, in other embodiments, the system 100 may be another appliance such as, but not limited to, a furnace or other types of water heater (for example, an electric water heater). The water heating system 100 is configured to manipulate a temperature (for example, increase a temperature) of a fluid (for example, water). The water heating system 100 includes an enclosed water tank 15 configured to contain

the fluid, an exhaust assembly 20, a burner assembly 25, a control circuit 200, an upper temperature sensor 70, and a lower temperature sensor 75. Some components and functions of the water heating system 100, both illustrated and not shown, are commonly used and understood in the art. Accordingly, for sake of brevity, only the components of the water heater 10 that are for understanding the present application are described more fully herein.

[0022] The water heating system 100 further includes a shell 110 surrounding the tank 15, and foam insulation 115 filling an annular space between the water tank 15 and the shell 110. The tank 15 may be formed using ferrous metal and lined internally with a glass-like porcelain enamel to protect the metal from corrosion. In other embodiments, the tank 15 may be formed using other materials, such as plastic.

[0023] The burner assembly 25 is configured to provide heat to the fluid of the tank 15 via combustion performed by a burner. In the illustrated embodiment, the burner assembly 27 is positioned at the bottom of the tank 15. The burner assembly 27 is configured to receive combustion gas from a gas line and air from an air supply line. The air and gas are combined within the assembly 27 and are subsequently combusted by the burner. The burner assembly 27 includes additional components (for example, a fan/blower, thermocouple(s), control valves, etc.) for operation which, for sake of brevity, are not described here. The exhaust assembly 20 is configured to force the exhaust (resulting from the combustion performed by the burner assembly 25) outside of the system 100 via a blower (not shown).

[0024] The upper temperature sensor 70 is positioned in the upper portion of the water tank 15 to determine an upper temperature of the water stored in the upper portion of the water tank 15. The lower temperature sensor 75 is positioned in the lower portion of the water tank 15 to determine a lower temperature of the water in the lower portion of the water tank 15. In some embodiments, the upper temperature sensor 70 and the lower temperature sensor 75 may be coupled to an exterior or an interior surface of the water tank 15. Additionally, the upper temperature sensor 70 and the lower temperature sensor 75 may be thermistor type sensors, thermocouple type sensors, semiconductor-based sensors, resistance temperature detectors, and the like. The upper temperature sensor 70 and the lower temperature sensor 75 are coupled to the control circuit 200 (in particular, the electronic processor 160 of FIG. 2) to provide

temperature information (for example, the sensed upper temperature and the sensed lower temperature) to the control circuit 200. In some embodiments, the water tank 15 may include one or more additional temperature sensors located at various positions around the water tank 15. For example, the water tank 15 may be divided into three or more portions and a temperature sensor may be positioned in each portion. In some embodiments, the water heating system 100 may include one or more additional sensors configured to measure one or more characteristics (for example, temperature, pressure, voltage, etc.) of the water heating system 100.

[0025] The water heating system 100 includes an electrode assembly 165. The electrode assembly 165 (and control circuit 200) may be similar to those described in U.S. Patent No. 7,372,005 and U.S. Patent No. 8,068,727, both of whose entire contents are incorporated herein by reference. The electrode assembly 165 is attached to the water heating system 100 and extends into the tank 105 to provide corrosion protection to the tank. As mentioned above and described in more detail below, the electrode assembly 165 is used by a control circuit of the water heating system 100 to predict tank failure caused by corrosion of the inner lining of the tank 105. An example electrode assembly 165 capable of being used with the water heating system 100 is shown in FIG. 2. With reference to FIG. 2, the electrode assembly 165 includes an electrode wire 170 and a connector assembly 175. The electrode wire 170 comprises titanium and has a first portion 180 that is coated with a metal-oxide material and a second portion 185 that is not coated with the metal-oxide material. During manufacturing of the electrode assembly 165, a shield tube 190, comprising PEX or polysulfone, is placed over a portion of the electrode wire 170. The electrode wire 170 is then bent twice (for example, at two forty-five degree angles) to hold the shield tube 190 in place. A small portion 195 of the electrode wire 170 near the top of the tank is exposed to the tank for allowing hydrogen gas to exit the shield tube 190. In other constructions, the electrode assembly 165 does not include the shield tube 190. The connector assembly 175 includes a spud 196 having threads, which secure the electrode rod assembly to the top of the water tank 15 by mating with the threads of an opening 197 (not shown). Other connector assemblies known to those skilled in the art can be used to secure the electrode assembly 165 to the tank 105. The connector assembly 175 also includes a connector 198 for electrically connecting the electrode wire 170 to a control circuit (discussed below). Electrically connecting the electrode assembly 165 to the control circuit results in the electrode

assembly 165 becoming a powered anode. The electrode wire 170 is electrically isolated from the tank 105 to allow for a voltage potential to develop across the electrode wire 170 and the tank 105. Other electrode assembly designs can be used with the invention.

[0026] FIG. 3 is a block diagram of a control circuit 200 for the water heating system 100. The control circuit 200 may be mounted onto (and/or integrated into) the water heating system 100 (for example, on the surface of the tank 15). In some embodiments, the control circuit 200 is housed separate from the water heating system 100. As illustrated in FIG. 2, the control circuit 200 includes the electronic processor 160, a memory 204, and input/output devices 206. The control circuit 200 receives power from an AC source (not shown). In one embodiment, the AC power source provides 120VAC at a frequency of approximately 50Hz to approximately 60Hz. In another embodiment, the AC power source provides approximately 220VAC at a frequency of approximately 50Hz to approximately 60Hz. In some embodiments, the control circuit 200 also includes a power regulator 223 that converts the power from the AC power source to a nominal voltage (for example, a DC voltage), and provides the nominal voltage to the control circuit 200 (for example, the electronic processor 160, the input/output devices 206, and the like).

[0027] The memory 204 stores algorithms and/or programs used to control and process information from the components of the exhaust assembly 20, the burner assembly 25, and other components of the water heating system 100 and to receive and provide information to a user of the water heating system 100. The memory 207 may also store operational data of the water heating system 100 (for example, characteristics of the exhaust assembly 20 and/or burner assembly 25, historical data, usage patterns, and the like) to help control the water heating system 100.

[0028] The electronic processor 160 is coupled to the memory 204, the upper temperature sensor 70, the lower temperature sensor 75, and the input/output devices 206. The electronic processor 160 receives an upper temperature signal (for example, the upper temperature) from the upper temperature sensor 70 and a lower temperature signal (for example, the lower temperature) from the lower temperature sensor 75. In addition, the electronic processor 160 accesses the programs, algorithms, and/or thresholds stored in the memory 204 to control the water heating system 100 accordingly.

[0029] The input/output devices 206 includes one or more device configured to output information to the user regarding the operation of the water heating system 100 and also may receive input from the user. In some embodiments, the input/output devices 206 may include a user interface for the water heating system 100. The input/output devices 206 may include a combination of digital and analog input or output devices required to achieve level of control and monitoring for the water heating system 100. For example, the input/output devices 206 may include a touch screen, a speaker, buttons, and the like, to output information and/or receive user inputs regarding the operation of the water heating system 100 (for example, a temperature set point at which water is to be delivered from the water tank 15). The electronic processor 160 controls the input/output devices 206 to output information to the user in the form of, for example, graphics, alarm sounds, and/or other known output devices. The input/output devices 206 may be used to control and/or monitor the water heating system 100. For example, the input/output devices 206 may be operably coupled to the electronic processor 160 to control temperature settings of the water heating system 100. For example, using the input/output devices 206, a user may set one or more temperature set points for the water heating system 100.

[0030] The input/output devices 206 are configured to display conditions or data associated with the water heating system 100 in real-time or substantially real-time. For example, but not limited to, the input/output devices 206 may be configured to display measured electrical characteristics of one or more components of the water heating system 100, the temperature sensed by temperature sensors 150, 155, etc.

[0031] The input/output devices 206 may be mounted on the shell of the water heating system 100, remotely from the water heating system 100 in the same room (for example, on a wall), in another room in the building, or even outside of the building. The input/output devices 206 may provide an interface between the electronic processor 160 and the user interface that includes a 2-wire bus system, a 4-wire bus system, and/or a wireless signal. In some embodiments, the input/output devices 206 may also generate alarms regarding the operation of the water heating system 100. The input/output devices 206 may further include a transceiver, an antenna, and/or the like to wirelessly communicate with one or more networks (for example, to receive and/or store the field data described below).

[0032] In some embodiments, the input/output devices 206, the memory 204, and/or other components of the control circuit 200 are modular and separate from the electronic processor 160. In other words, some of the components of the control circuit 200 may be manufactured separately as add-on devices to be connected to the electronic processor 160. In some embodiments, the control circuit 200 may be communicatively coupled to an external device (for example, a wireless control panel, a smartphone, a laptop computer, and the like) through, for example, a remote network, a transceiver, and the like.

[0033] The control circuit 200 includes control circuitry 250 coupled to the electronic processor 160 for controlling and measuring characteristics of the electrode assembly 165. The additional control circuitry 250 may include one or more sensors for measured electric and/or thermal characteristics of the electrode assembly 165. For example, FIG. 4 illustrates the control circuitry 250 in accordance to some embodiments. The electronic processor 160 outputs a pulse-width-modulated (PWM) signal at P0.1. The PWM signal controls the voltage applied to the electrode wire 170. A one hundred percent duty cycle results in full voltage being applied to the electrode wire 170, a zero percent duty cycle results in no voltage being applied to the electrode wire 170, and a ratio between zero and one hundred percent will result in a corresponding ratio between zero and full voltage being applied to the electrode wire 170.

[0034] The PWM signal is applied to a low-pass filter and amplifier, which consists of resistors R2, R3, and R4; capacitor C3; and operational amplifier U3-C. The low-pass filter converts the PWM signal into an analog voltage proportional to the PWM signal. The analog voltage is provided to a buffer and current limiter, consisting of operational amplifier U3-D, resistors R12 and R19, and transistors Q1 and Q3. The buffer and current limiter provides a buffer between the processor 160 and the electrode assembly 165 and limits the current applied to the electrode wire 170 to prevent hydrogen buildup. Resistor R7, inductor L1, and capacitor C5 act as a filter to prevent transients and oscillations. The result of the filter is a voltage that is applied to the electrode assembly 165, which is electrically connected to CON1.

[0035] As discussed in further detail below, the drive voltage is periodically removed from the electrode assembly 165. The processor 160 deactivates the drive voltage by controlling the signal applied to a driver, which consists of resistor R5 and transistor Q2. More specifically,

pulling pin P0.3 of the processor 160 low results in the transistor Q1 turning OFF, which effectively removes the applied voltage from driving the electrode assembly 165. Accordingly, the processor 160, the low-pass filter and amplifier, the buffer and current limiter, the filter, and the driver act as a variable voltage supply that controllably applies a voltage to the electrode assembly 165, resulting in the powered anode. Other alternative circuit designs can also be used to controllably provide a voltage to the electrode assembly 165.

[0036] The input, or connection, CON2 provides a connection that allows for an electrode return current measurement. More specifically, resistor R15 provides a sense resistor that develops a signal having a relation to the current at the tank 105. Operational amplifier U3-B and resistors R13 and R14 provide an amplifier that provides an amplified signal to the processor 160 at pin P1.1. Accordingly, resistor R15 and the amplifier form a current sensor. However, other current sensors can be used in place of the sensor just described. Furthermore, in some constructions, a similar current sensor is configured to monitor the current at CON1 (i.e., at the anode).

[0037] With the removal of the voltage, the potential at the electrode 165 drops to a potential that is offset from, but proportional to, the open circuit or “natural potential” of the electrode 165 relative to the tank 105. A voltage proportional to the natural potential is applied to a filter consisting of resistor R6 and capacitor C4. The filtered signal is applied to operational amplifier U3-A, which acts as a voltage follower. The output of operational amplifier U3-A is applied to a voltage limiter (resistor R17 and zener diode D3) and a voltage divider (resistor R18 and R20). The output is a signal having a relation to the natural potential of the electrode assembly 165, which is applied to processor 160 at pin P1.0. Accordingly, the just-described filter, voltage follower, voltage limiter, and voltage divider form a voltage sensor. However, other voltage sensors can be used in place of the disclosed voltage sensor.

[0038] The control circuit 200 controls the voltage applied to the electrode wire 170 and, thereby, controls the current through the powered anode. As will be discussed below, the control circuit 200 also measures tank protection levels, adapts to changing water conductivity conditions, and adapts to electrode potential drift in high conductivity water. In addition, when the control circuit 200 for the electrode assembly 165 is combined or in communication with the

control circuit for the burner assembly 25, the resulting control circuit can take advantage of the interaction to provide additional control of the water heating system.

[0039] The electronic processor 160 is further configured to control the electrode assembly 165 to predict tank failure by controlling the voltage applied to the electrode wire 170 and, thereby, controls the current through the powered anode. The electronic processor 160, in particular (as described in U.S. Patent No. 7,372,005 and U.S. Patent No. 8,068,727), measures tank protection levels by disabling the voltage applied to the electrode assembly 165 for a predetermined amount of time, determines (measures) an electrode potential (voltage) via the control circuitry 250, reapplies the voltage supply to the electrode assembly 165. Based on the determined electrode potential, the electronic processor 160 increases or decreases the voltage applied to the electrode assembly 165. Increasing the applied voltage will result in an increase in the tank potential measured by the electrode and decreasing the applied voltage will decrease the tank potential measured by the electrode. Therefore, the control circuit 200 can adjust the open circuit potential of the electrode until it reaches the target potential described below. Furthermore, as the characteristics of the water heating system 100 change, the control circuit 200 can adjust the voltage applied to the electrode to have the open circuit potential of the electrode equal the target point potential.

[0040] The electronic processor 160 may then determine (measure) an electrode current via the control circuitry 250 (for example, via current measurement at CON2 as described above) and determines a conductivity state of the water of the tank 105 based on the applied current and voltage. For example, the conductivity state can be either a high conductivity for the water or a low conductivity for the water. The conductivity state is indicative of a degree of exposure of the metal of the water storage tank (for example, caused by corrosion within the tank 105 as described above). When the resultant is less than an empirically set value, then the electronic processor 160 determines the conductivity state is low and sets the target potential (mentioned above) to a first value; otherwise the electronic processor 160 sets the target potential to a second value indicating a high conductivity state. It should be understood that, in further embodiments, the electronic processor 160 may utilize other methods to determine the conductivity state of the water.

[0041] As the storage tank 105 ages, the internal porcelain enamel lining deteriorates and more of the ferrous metal is exposed to the water stored in the tank 105. As the amount of exposed metal surface area increases, the amplitude of the powered anode current must also be increased in order to adequately protect the exposed ferrous metal. However, the maximum amount of current that can be applied to the water heating system 100 may be limited. For example, electric current can cause the water to ionize which produces excessive hydrogen within the sealed tank and the hydronium produced by this reaction can give the heated water an unpleasant odor. Therefore, as the internal lining deteriorates, the water heater may reach a point where the powered anode is no longer able to adequately protect the exposed metal of the storage tank 105. The storage tank 105 may then eventually corrode.

[0042] The electronic processor 160 is configured to monitor the potential (voltage) of the electrode 165 relative to the tank 105 and to monitor the current at the tank 105 at the electrode 165. Utilizing data from these measurements, the processor 160 is able evaluate the protection provided by the powered anode. Thus, when the electronic processor 160 detects that the powered anode is no longer sufficient to protect the tank 105 from corrosion (for example, when the powered anode current exceeds a threshold indicative of a state of the storage tank 105 such as the amount of exposed metal inside the tank that renders the powered anode insufficient to protect against corrosion or threshold is indicative of a level of electric current that will cause an undesirable or dangerous condition in the water), the electronic processor 160 estimates a remaining time until failure of the storage tank 105.

[0043] FIG. 5 is a diagram 400 of the anode current and measured powered anode voltage (referred to herein as tank potential or voltage) characteristic over the time of service of the water heating system 100. As illustrated in diagram 400, after reaching the maximum anode current that can safely be applied to the water heating system 100, the tank potential may steadily reduce. Field data has shown that tank failure usually may not occur until the value (for example, the absolute value) of the tank potential has reduced to between approximately X and $X + 3$ volts. Field data has also shown that this level of reduction in value (for example, the absolute value) of the tank potential (approximately $X + 1$ volts) may take, on average, approximately more than a year and a half. Thus, using maximum current alone predicts failure by more than one year, which may be too early in certain circumstances. It may be more

desirable, and accurate, to implement a method that would predict a time to failure later in the time of service of the water heater, for example, more approximate to a year or less.

[0044] FIG. 6 is a flowchart illustrating a process, or method, 600 of predicting tank failure of the water heating system 100 according to one embodiment of the application. It should be understood that the order of the steps disclosed in method 600 could vary. Additional steps may also be added to the control sequence and not all of the steps may be required. The method 600 is described herein in terms of the control circuit 200 of the water heating system 100 (in particular, the electronic processor 160).

[0045] As shown in FIG. 6, initially, the electronic processor 160 receives a powered anode current measurement (step 605). In some embodiments, this is measured as the current at or through the powered anode. In some embodiments, this is measured as the current at the tank 105 provided from the powered anode. The electronic processor 160 determines, at block 610, whether the powered anode current measurement is approximately equal to (or exceeds) a maximum powered anode current threshold. The maximum powered anode current threshold corresponds to a maximum amount of current that can safely be applied to the water heating system 100 (for example, approximately Y mA). When the powered anode current is approximately equal to or exceeds the threshold, the electronic processor 160 records a plurality of tank potential measurements over a duration of time (block 615). After the duration of time, the electronic processor 160 determines a predicted time to tank failure (length of service) of the water heating system 100 based on the recorded tank potential measurements over time (block 620). For example, the electronic processor 160, as described in more detail below may determine a trendline based on the recorded tank potential measurements. The trendline may be a curve-fit trendline. For example, the electronic processor 160 determines the time to failure based on when the trendline is projected to fall below a predetermined tank potential threshold corresponding to a tank potential indicative of eminent tank failure (between Y to Y+3 volts as mentioned above in regard to FIG. 5) and collected estimated tank life from water tanks after reaching maximum current and the predetermined tank potential threshold data. Such water tanks may be similar to the water tank 15 to ensure a more accurate prediction. The electronic processor 160 then outputs an alert corresponding to the predicted time to tank failure (block 625). For example, the electronic processor 160 may display a graphic including the predicted

time to tank failure on a display for the operator of the water heating system 100. The electronic processor 160 may also be configured to take adaptive action based upon this information, such as, for example, initiating the draining of water from the storage tank or sending a signal to a repair specialist.

[0046] FIG. 7 is a diagram 700 of recorded tank potential measurements of a water heater (such as the water heating system 100) over time. Here, the maximum current is approximately the same over time while the tank potential (set point voltage) reduces over time. Tank potential measurements are recorded on from when the maximum current is reached (starting at approximately $X+4$ volts). Over a duration of time (here approximately 60 days of recording), as more tank potential measurements are recorded, a trendline 702 is calculated. A projection 704 of the trendline 702 may then be calculated from the trendline 702 to determine approximately when the tank potential will reach the predetermined tank potential threshold (here, $X + 1$ volts). As shown in diagram 700, the time to predicted failure is within 20 days.

[0047] In some embodiments, the electronic processor 160 is configured to display a warning to the user that the tank 105 is insufficiently protected when the maximum current has been reached. The processor 160 may further display an approximate length of service left on the water heating system 100 based on collected data from other water tanks that have failed due to tank degradation. For example, field test data shows, based on approximately 46 tanks, that tanks have approximately 393 days left before failure after reaching the maximum current.

[0048] In some embodiments, the electronic processor 160 is further configured to determine the predicted time to tank failure based on at least one other characteristic of the water heating system 100. For example, water heaters running at high duty cycle, high setpoint temperature, wide differential temperature setpoint, and low incoming water temperature may shorten tank life. In particular, these as well as other factors related to high temperature cycles directly affect the reliability of glass on the heat exchanger of the water heater. This information may be used by the processor 160 to adjust the slope of the trendline to improve accuracy of the predicted time to tank failure. Extreme temperature cycling increases glass degradation and thus increases the rate at which the tank potential falls. FIGS. 8A - 8D are each a diagram 800A - 800D

illustrating a relationship between temperature setpoint, differential temperature setpoint, incoming water temperature, and duty cycle and tank life respectively.

[0049] In addition to improving the estimate of the rate of tank potential degradation, the accuracy of the failure prediction may further be improved by evaluating factors over time that raise or increase the tank potential threshold at failure. Several factors may be utilized to adjust the tank potential up or down. For example, factors that may increase the potential of earlier tank failure (in other words, failure at a higher tank potential) include higher duty cycle, higher total dissolved solids (TDS) levels, higher tank temperature setpoint, and a more rapidly decreasing slope of the tank potential trendline (indicative of increased glass degradation). Another factor that may impact failure versus tank potential is the conductivity of the water. High conductivity waters are likely to reach maximum current sooner but survive longer at lower tank potentials (less than $X+1$ volts). FIGS. 9A and B are each a diagram 900A and 900B respectively illustrating how a high duty cycle affects the failure point of tank potential. In diagram 900A of FIG. 9A, a first water heater with a low duty cycle failed at a tank potential of $X-50$ volts after reaching the maximum powered anode current. In diagram 900B of FIG. 9B, a second water heater with a high duty cycle failed at X volts after reaching the maximum powered anode current. Factors that may lower the potential of earlier tank failure include, for example, lower duty cycle conditions.

[0050] In some embodiments, as an alternative or in addition to recording the tank potential measurements over a duration of time (block 615 of FIG. 6), when the powered anode current is approximately equal to or exceeds the threshold, the electronic processor 160 determines the estimated tank life by calculating a time adjustment factor. The time adjustment factor may be determined using similar characteristics as those described above.

[0051] Thus, this application describes, among other things, a method of predicting tank failure of a water heater.

CLAIMS

What is claimed is:

1. A storage-type water heater comprising:
a tank configured to contain a fluid;
a powered anode at least partially disposed in the fluid; and
an electronic processor configured to
 receive a current measurement of the powered anode,
 determine whether the current measurement exceeds a maximum threshold,
 record, when the current measurement exceeds the maximum threshold, a
plurality of tank potential measurements over a duration of time,
 determine, based on the recorded tank potential measurements, a predicted time to
tank failure, and
 output an alert corresponding to the predicted time to tank failure.
2. The water heater of claim 1, wherein the electronic processor is further configured to
determine the predicted time to tank failure based on at least one characteristic of the water
heater.
3. The water heater of claim 2, wherein the at least one characteristic affects a rate of
degradation of the metal, the lining, or both.
4. The water heater of claim 3, wherein the at least one characteristic includes at least one
selected from the group consisting of a tank temperature setpoint, a differential temperature
setpoint, an incoming water temperature, and a duty cycle of the water heater.
5. The water heater of claim 2, wherein the electronic processor is further configured to
determine the predicted time to tank failure based on a calculation of when a trendline of the
plurality of tank potential measurements is projected to fall below a tank potential threshold.

6. The water heater of claim 5, wherein the tank potential threshold is determined based on at least one selected from the group consisting of a duty cycle of the water heater, a tank temperature setpoint, a slope of the trendline, and a conductivity of water in the water storage tank.
7. The water heater of claim 5, wherein the tank potential threshold is adjusted based on at least one selected from a group consisting of a duty cycle, a total dissolved solids level, a tank temperature setpoint, a slope of the trendline, and a conductivity of water in the storage tank.
8. The water heater of claim 1, wherein the predicted time to tank failure is less than one year.
9. The water heater of claim 1, wherein the electronic processor determines the predicted time to tank failure based on a trendline of the recorded tank potential measurements.
10. A storage-type water heater comprising:
 - a tank configured to contain a fluid;
 - a powered anode at least partially disposed in the fluid; and
 - an electronic processor configured to
 - receive a current measurement of the powered anode,
 - determine whether the current measurement exceeds a maximum threshold,
 - determine, based on the maximum threshold and an adjustment factor, a predicted time to tank failure, and
 - output an alert corresponding to the predicted time to tank failure.
11. The water heater of claim 10, wherein the electronic processor is further configured to determine the adjustment factor based on at least one characteristic of the water heater.
12. The water heater of claim 11, wherein the at least one characteristic affects a rate of degradation of the metal, the lining, or both.

13. The water heater of claim 12, wherein the at least one characteristic includes at least one selected from the group consisting of a tank temperature setpoint, a differential temperature setpoint, an incoming water temperature, and a duty cycle of the water heater.
14. The water heater of claim 11, wherein the electronic processor is further configured to adjust the adjustment factor based on at least one selected from a group consisting of a duty cycle, a total dissolved solids level, a tank temperature setpoint, a slope of a trendline of a plurality of tank potential measurements, and a conductivity of water in the storage tank.
15. The water heater of claim 10, wherein the predicted time to tank failure is less than one year.

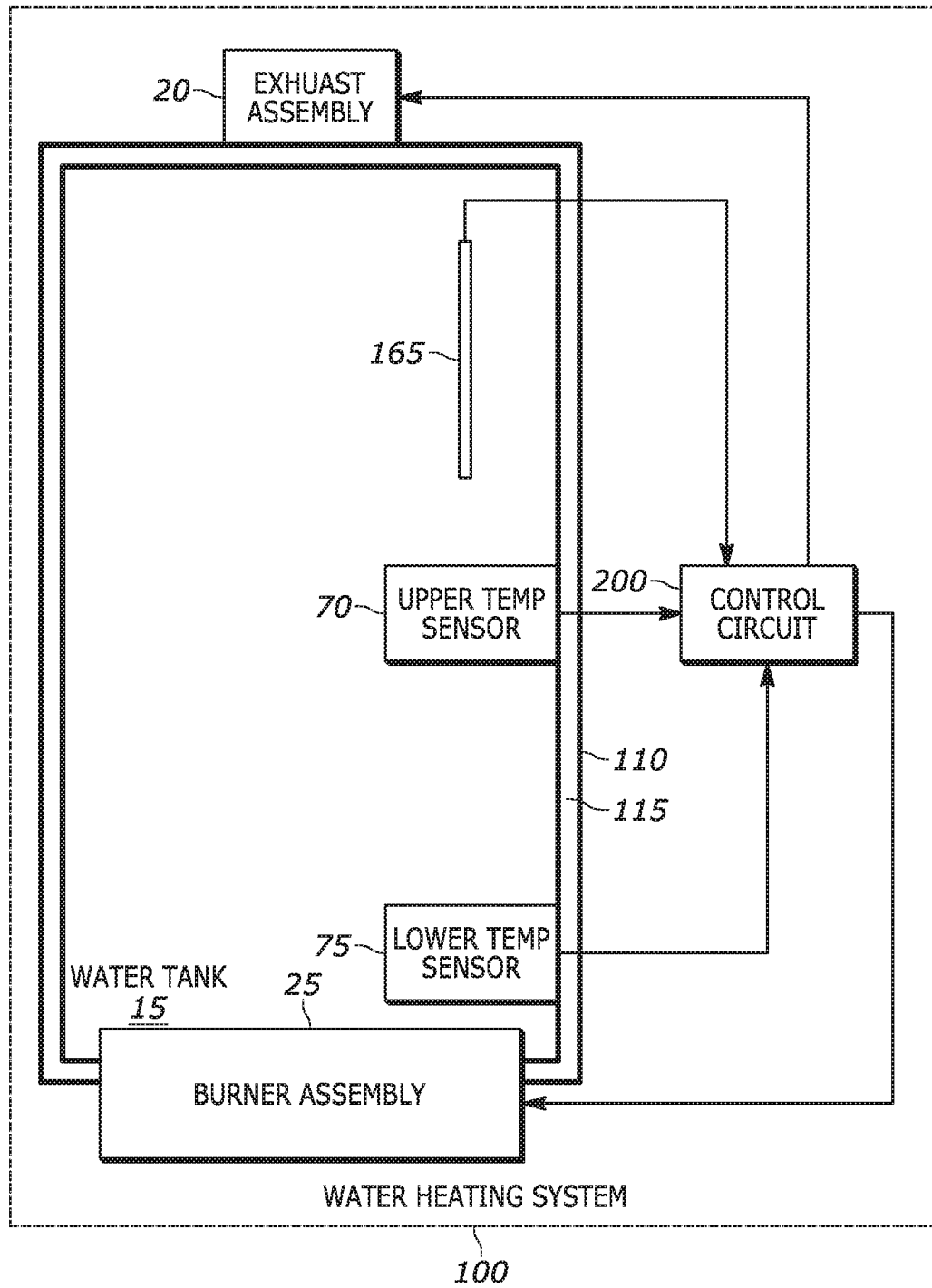
1/10

FIG. 1

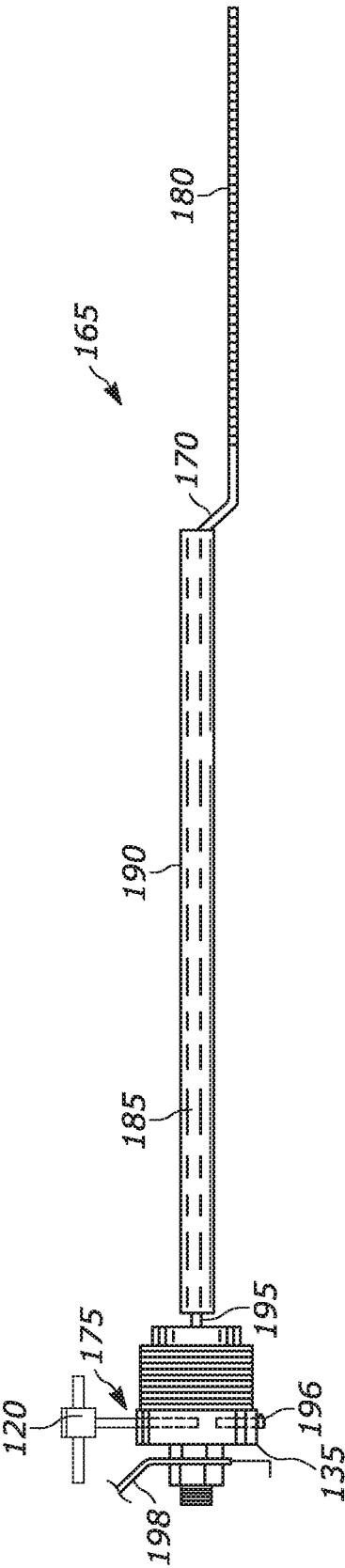


FIG. 2

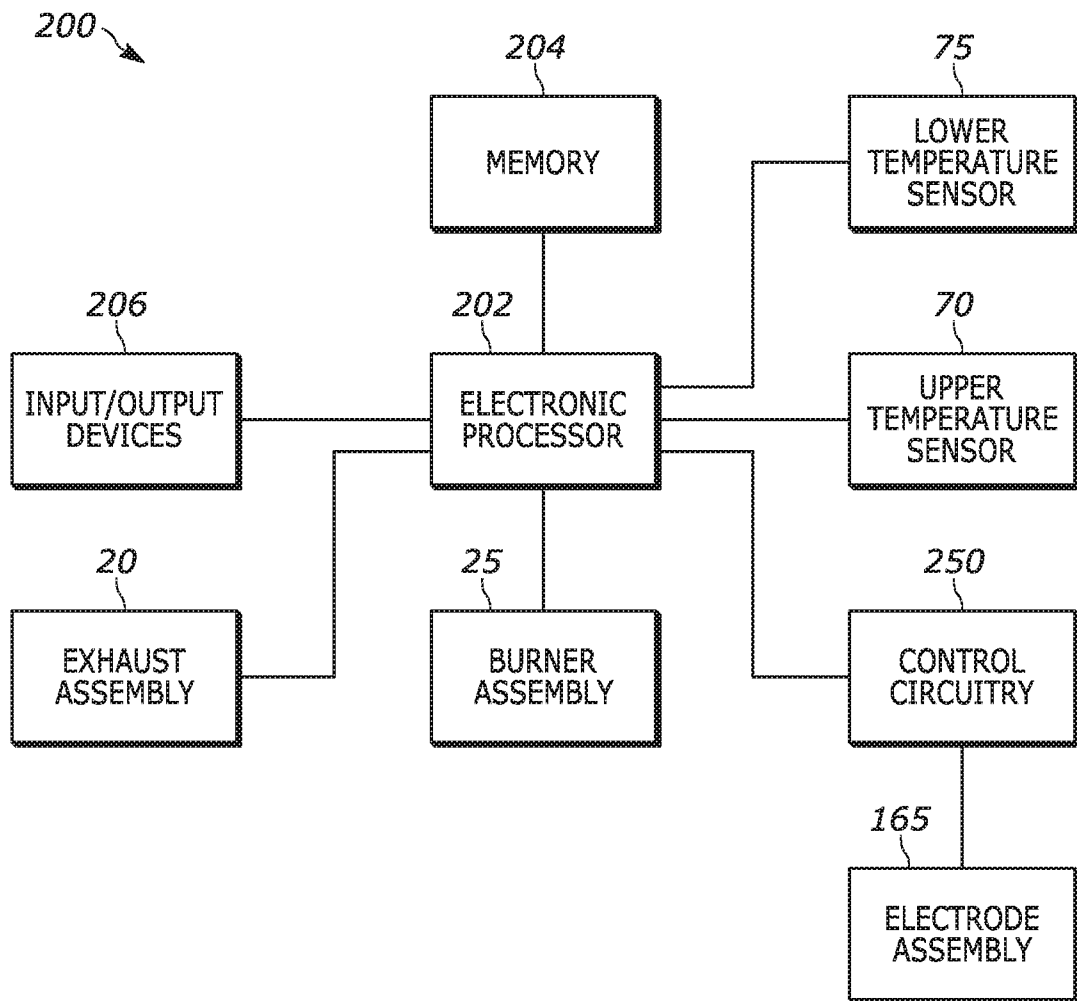
3/10

FIG. 3

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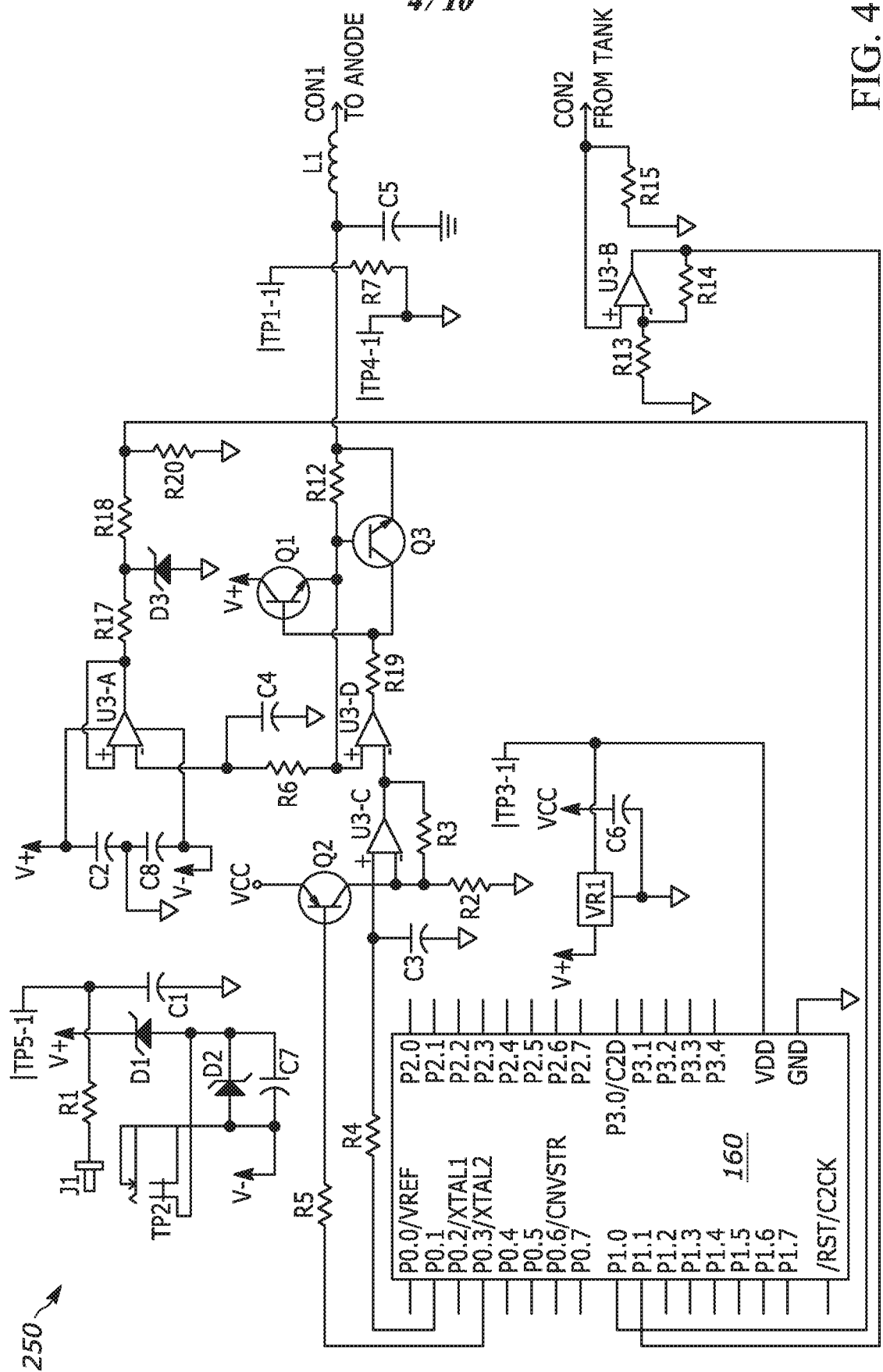
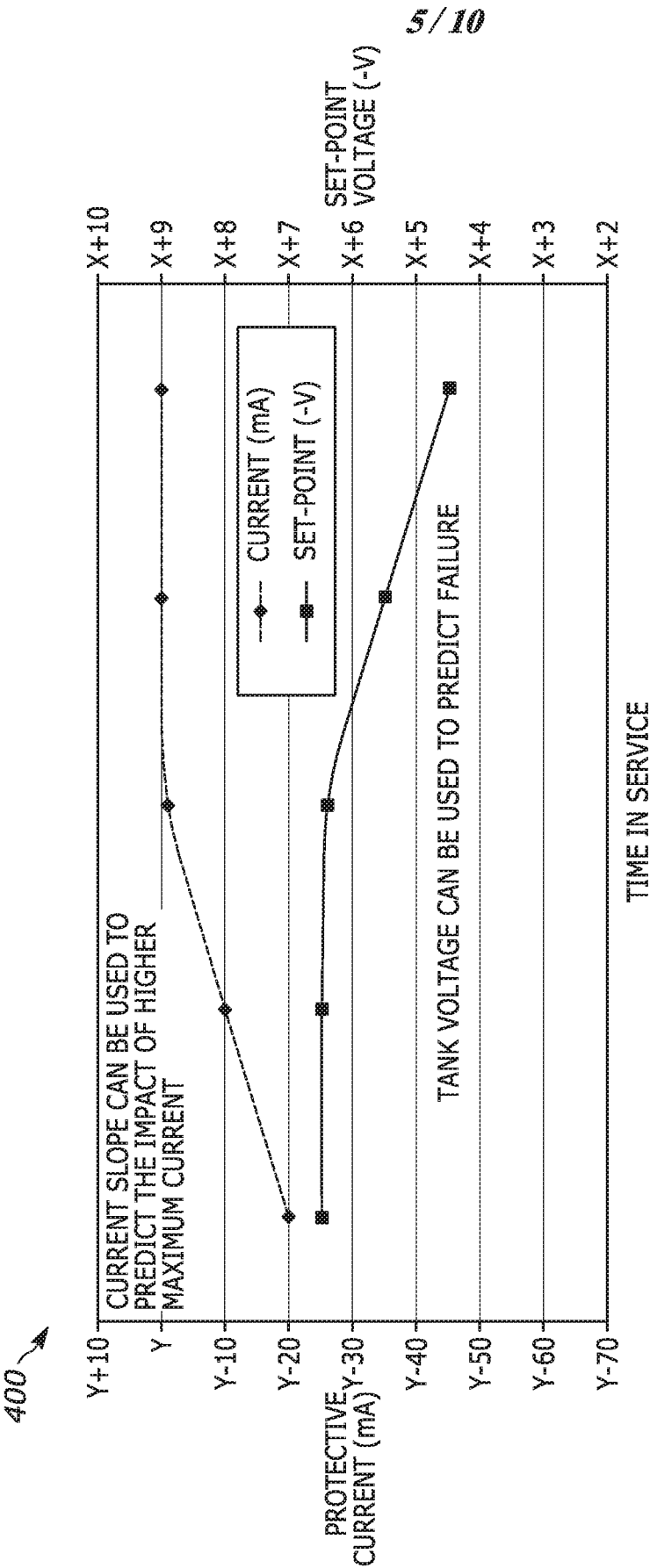


FIG. 4



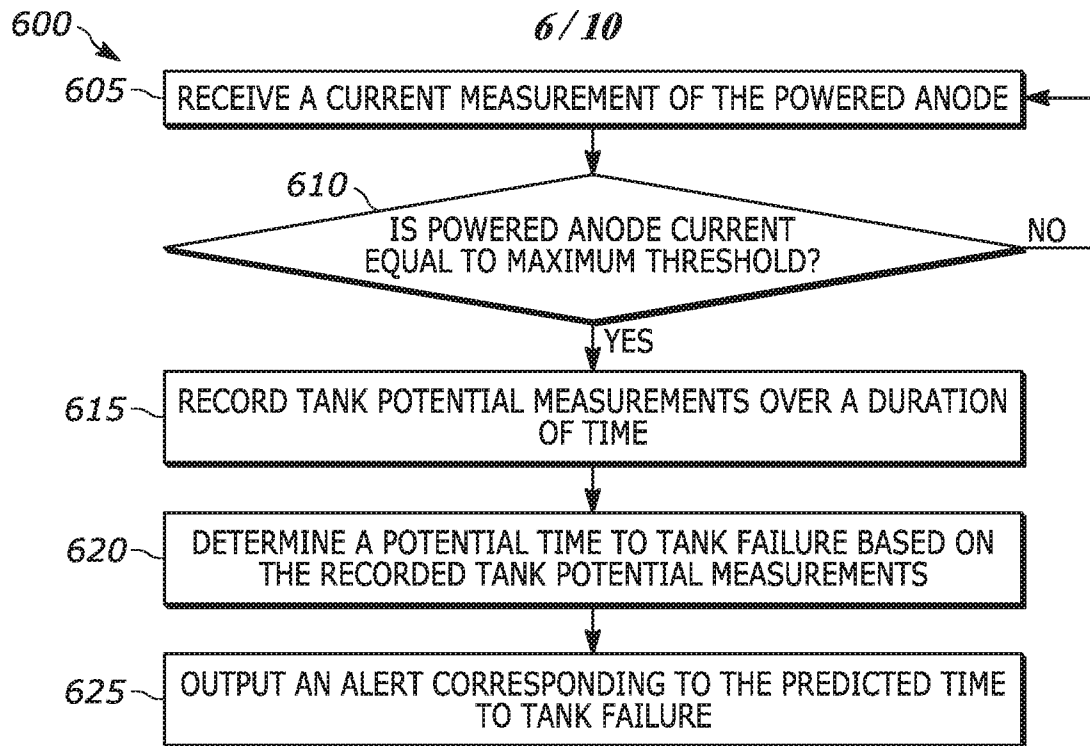


FIG. 6

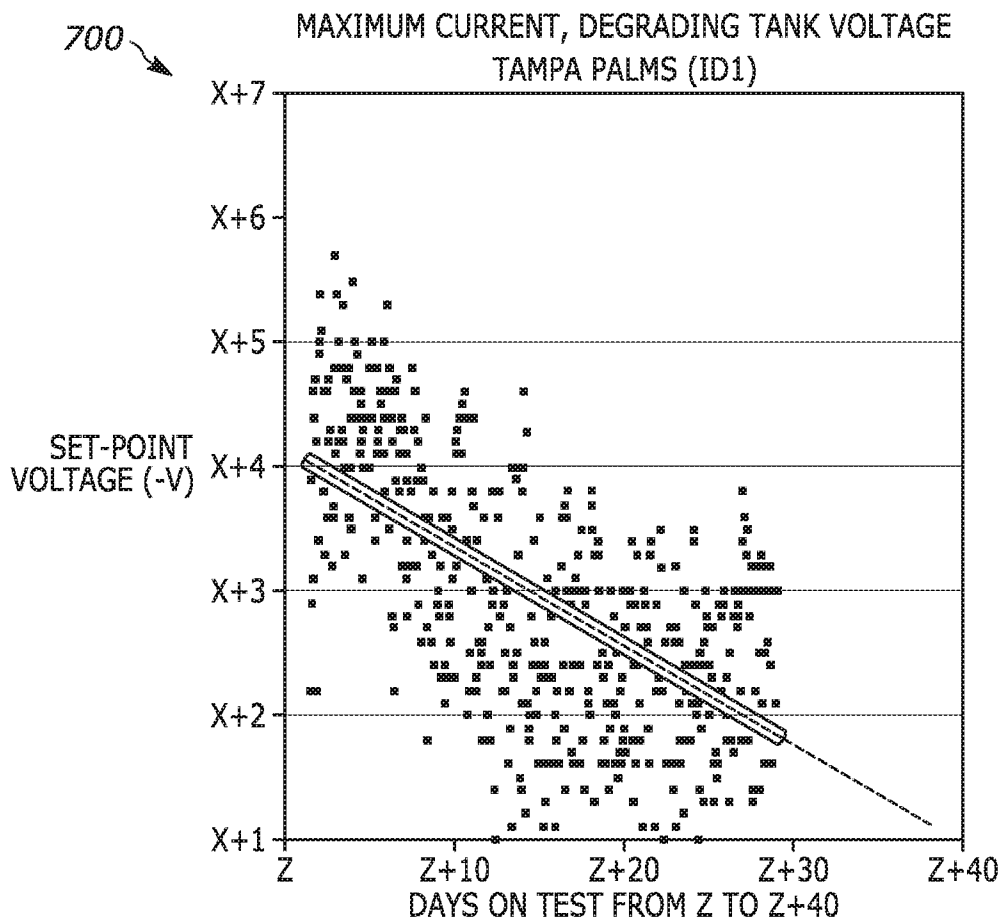


FIG. 7

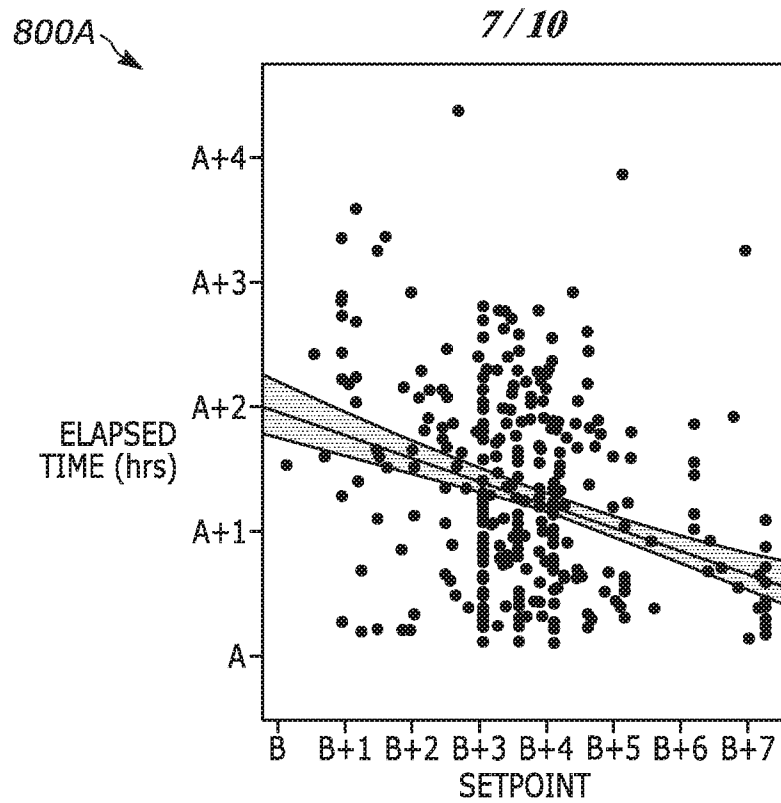


FIG. 8A

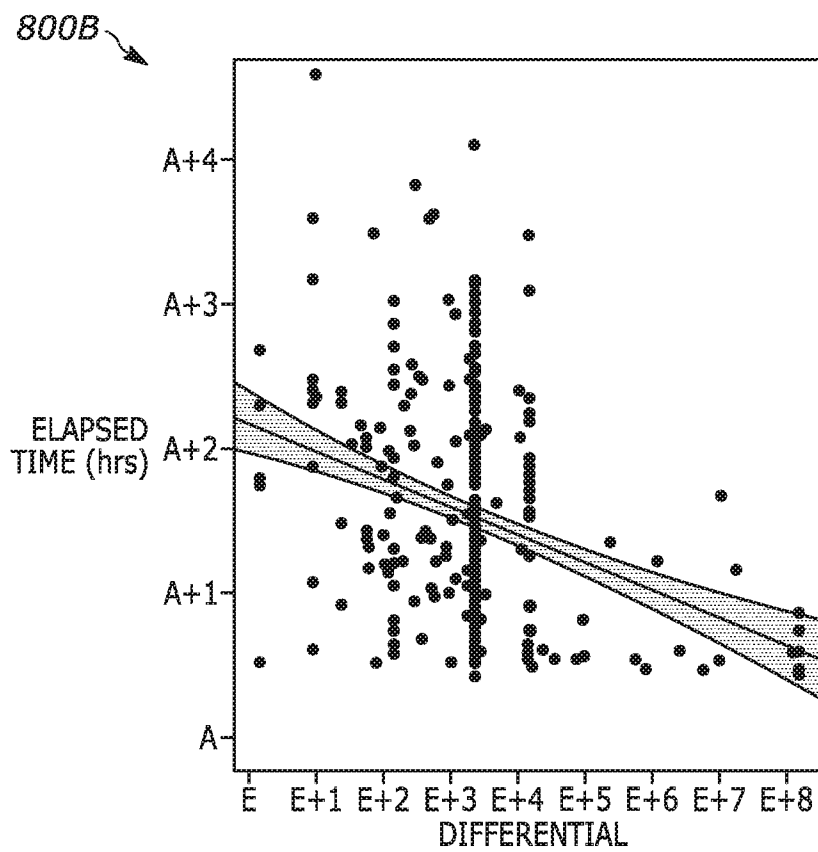


FIG. 8B

800C

8/10

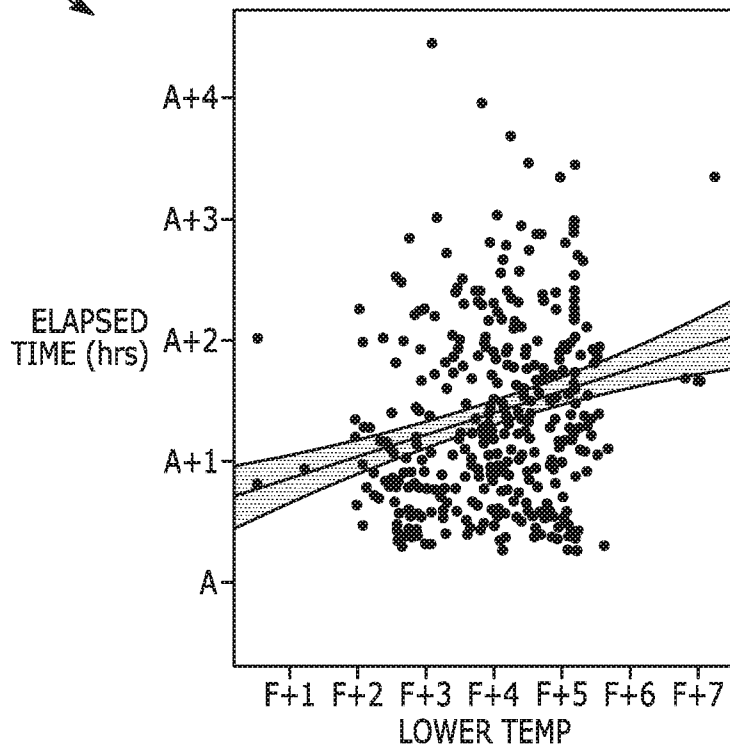


FIG. 8C

800D

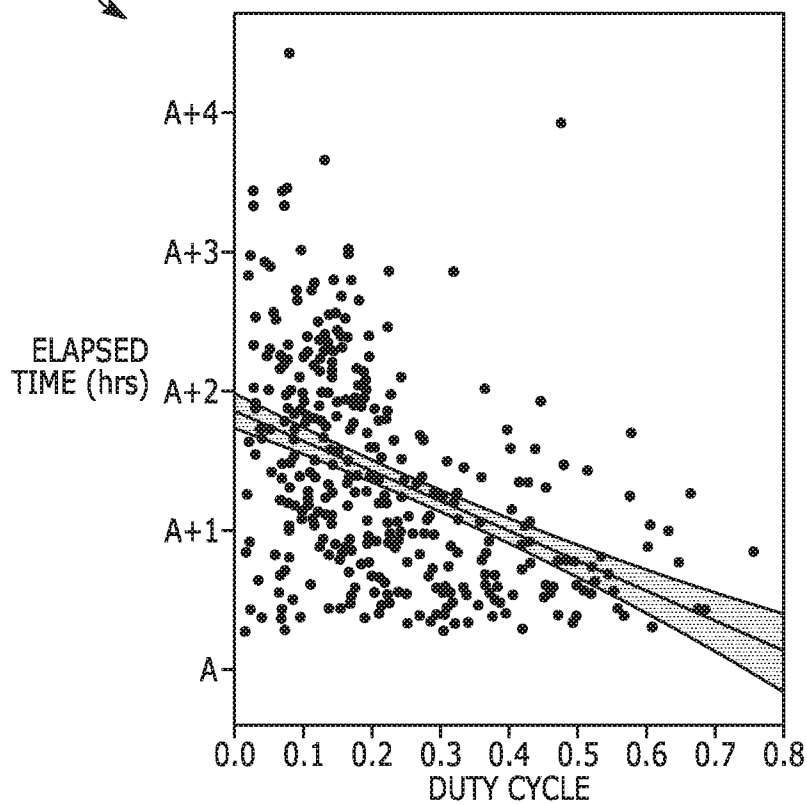


FIG. 8D

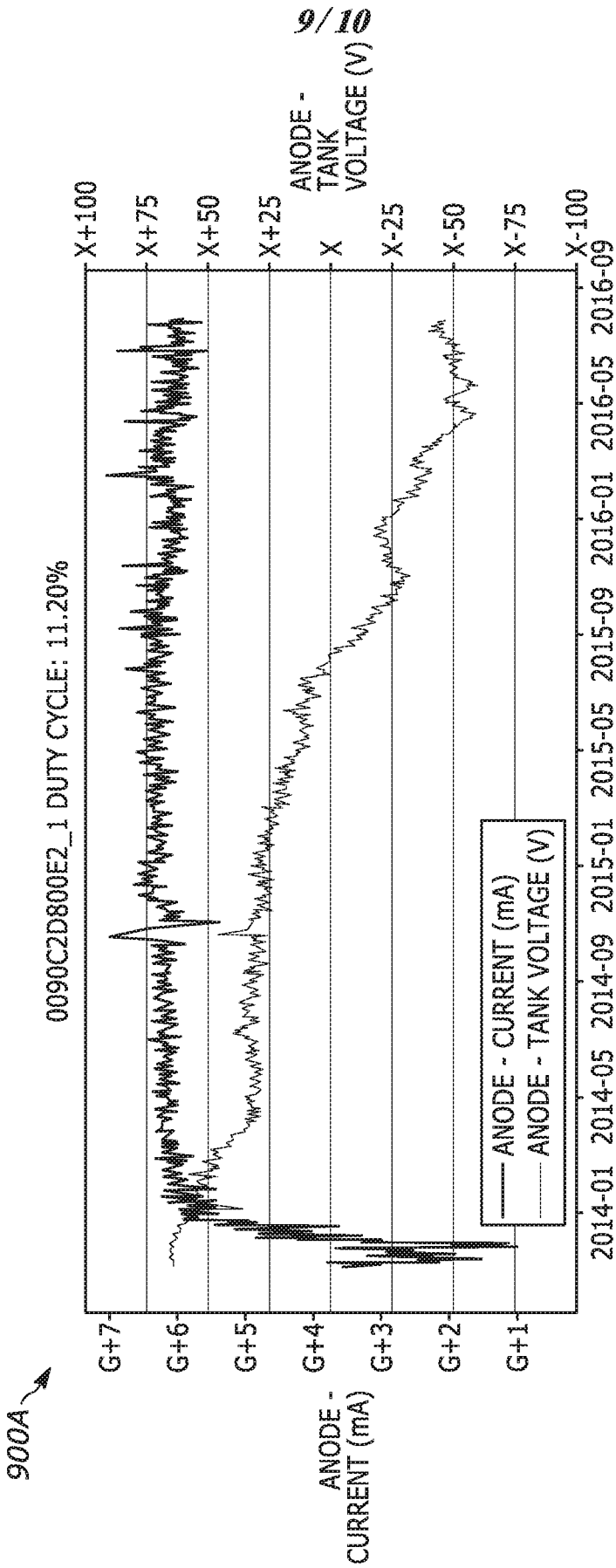


FIG. 9A

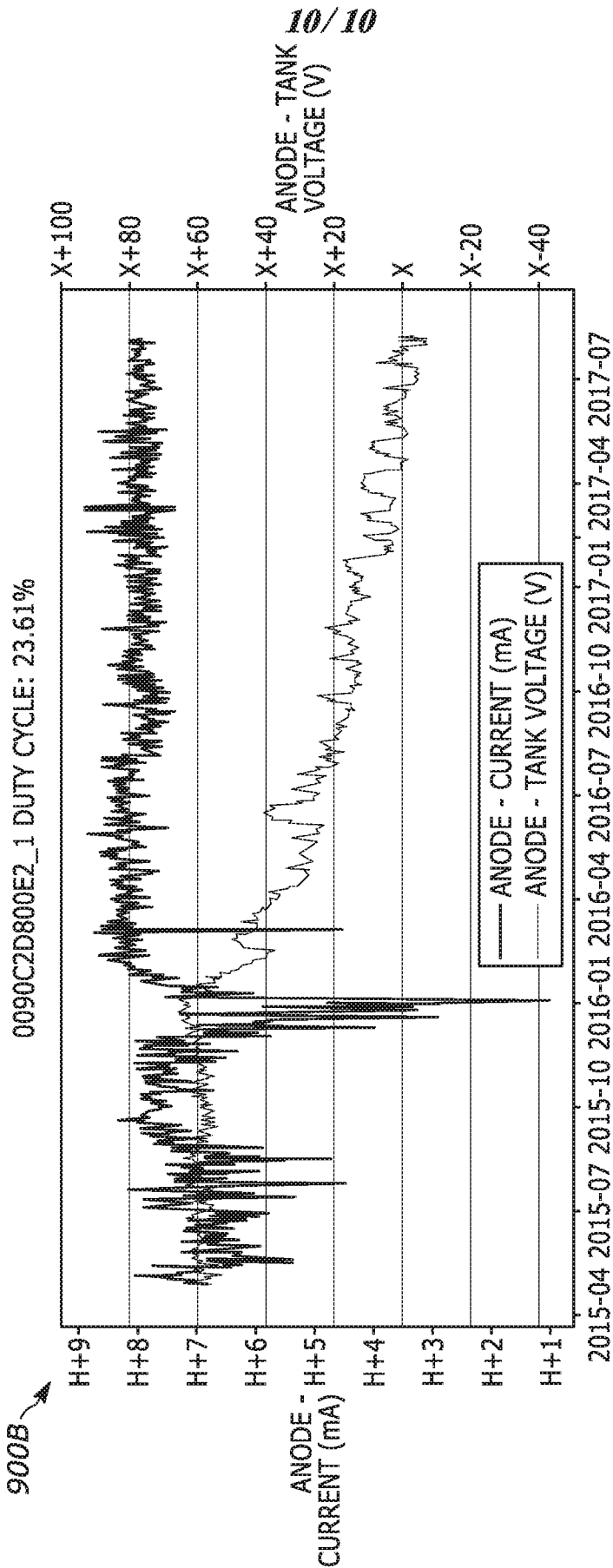


FIG. 9B

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2020/031065

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C23F 13/22; C23F 13/00; C23F 13/04; C23F 13/20; F24H 9/00; F24H 9/20 (2020.01)

CPC - C23F 13/22; C23F 13/005; C23F 13/04; F24H 9/0047; F24H 9/2007; F24H 9/2021 (2020.05)

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)

see Search History document

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

see Search History document

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

see Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0056644 A1 (PHILLIPS et al) 05 March 2009 (05.03.2009) entire document	10-12, 14, 15
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Y		1-9, 13
Y	WO 2008/110625 A1 (CAEN RFID SRL et al) 18 September 2008 (18.09.2008) entire document	1-9
Y	US 2018/0128514 A1 (A O SMITH CORPORATION) 10 May 2018 (10.05.2018) entire document	4, 13
A	US 4,972,066 A (HOULE et al) 20 November 1990 (20.11.1990) entire document	1-15
A	US 2018/0363149 A1 (DELTA SUBSEA LLC) 20 December 2018 (20.12.2018) entire document	1-15

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

* Special categories of cited documents:

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"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

07 July 2020

Date of mailing of the international search report

24 JUL 2020

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