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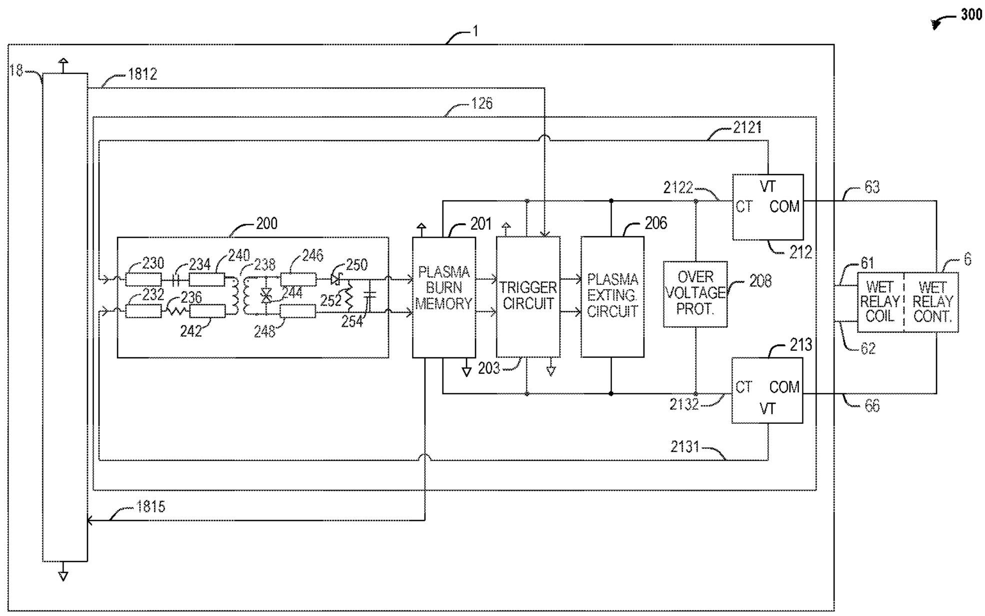

FIG. 3

(57) Abstract: A power contact electrode plasma therapy circuit includes a pair of terminals adapted to be connected to a set of switchable contact electrodes of a power contact. A plasma ignition detector is configured to detect an electrical parameter over the switchable contact electrodes indicative of the formation of plasma between the switchable contact electrodes and output a plasma ignition signal based on the electrical parameter as detected. A plasma burn memory is configured to receive and store the plasma ignition signal. A controller circuit is configured to receive from the plasma burn memory the plasma ignition signal, start a time based on receipt of the plasma ignition signal, and upon the timer meeting a time requirement, output a plasma extinguish command. A plasma extinguishing circuit, configured to bypass the pair of terminals upon receiving the trigger signal to extinguish the plasma between the switchable contact electrodes.

WO 2021/050830 A1

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POWER CONTACT ELECTRODE SURFACE PLASMA THERAPY

PRIORITY

[0001] This application claims the benefit of priority to U.S. Provisional Application Serial No. 62/898,780, filed September 11, 2019, U.S. Provisional Application Serial No. 62/898,783, filed September 11, 2019, U.S. Provisional Application Serial No. 62/898,787, filed September 11, 2019, U.S. Provisional Application Serial No. 62/898,795, filed September 11, 2019, and U.S. Provisional Application Serial No. 62/898,798, filed September 11, 2019, with the contents of all of the above-listed applications being incorporated herein by reference in their entireties.

TECHNICAL FIELD

[0002] The present application relates generally to electrical contact health assessment apparatus and techniques, including electrical contacts connected in parallel or in series with each other.

BACKGROUND

[0003] Product designers, technicians, and engineers are trained to accept manufacturer specifications when selecting electromechanical relays and contactors. None of these specifications, however, indicate the serious impact of electrical contact arcing on the life expectancy of the relay or the contactor. This is especially true in high-power (e.g., over two (2) Amperes) applications.

[0004] Electrical current contact arcing may have a deleterious effect on electrical contact surfaces, such as relays and certain switches. Arcing may degrade and ultimately destroy the contact surface over time and may result in premature component failure, lower quality performance, and relatively frequent preventative maintenance needs. Additionally, arcing in relays, switches, and the like may result in the generation of electromagnetic interference (EMI) emissions. Electrical current contact arcing may occur both in alternating current (AC) power and in direct current (DC) power across the fields of consumer, commercial, industrial, automotive, and military applications. Electrical current contact arcing can result in atomic recombination of the power contact electrodes, molecular disassociation, evaporation and condensation, explosion and expulsion of material, forging and welding of the power contact electrodes, fretting and fritting of the power contact electrodes, heating and cooling, liquefication and solidification of material, and sputtering and deposition processes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views.

[0006] The drawings illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

[0007] FIG. 1 is a diagram of a system including a power contact health assessor, according to some embodiments.

[0008] FIG. 2 is a block diagram of an example power contact health assessor, according to some embodiments.

[0009] FIG. 3 is a block diagram of an example power contact health assessor, according to some embodiments.

[0010] FIG. 4 depicts a logarithmic scale graph of average power contact stick duration for power contact health assessment, according to some embodiments.

DETAILED DESCRIPTION

[0011] It should be understood at the outset that although an illustrative implementation of one or more embodiments is provided below, the disclosed systems, methods, and/or apparatuses described with respect to FIGS. 1-4 may be implemented using any number of techniques, whether currently known or not yet in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, including the exemplary designs and implementations illustrated and described herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

[0012] In the following description, reference is made to the accompanying drawings that form a part hereof, and in which are shown, by way of illustration, specific embodiments which may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the inventive subject matter, and it is to be understood that other embodiments may be utilized, and that structural, logical, and electrical changes may be made without departing from the scope of the present disclosure. The following description of example embodiments is, therefore, not to be taken in a limiting sense, and the scope of the present disclosure is defined by the appended claims.

[0013] As used herein, the term “dry contact” (e.g., as used in connection with an interlock such as a relay or contactor) refers to a contact that is only carrying load current when closed. Such contact may not switch the load and may not make or break under load current. As used herein, the term “wet contact” (e.g., as used in connection with an interlock such as a relay or contactor) refers to a contact carrying load current when closed as well as switching load current during the make and break transitions.

[0014] Examples of power contact electrode surface plasma therapy and components utilized therein and in conjunction with power contact electrode surface plasma therapy are disclosed herein. Examples are presented without limitation and it is to be recognized and understood that the embodiments disclosed are illustrative and that the circuit and system designs described herein may be implemented with any suitable specific components to allow for the circuit and system designs to be utilized in a variety of desired circumstances. Thus, while specific components are disclosed, it is to be recognized and understood that alternative components may be utilized as appropriate.

[0015] It has been recognized that through the use of arc suppressors that the health of electrical contacts vis-à-vis the capacity of the contacts to open and close and without failing, e.g., by failing to open or close or by being in a conductive state when a non-conductive state or vice versa, may be identified. In particular, the buildup of debris on the contact, e.g., through the ignition and burning of non-suppressed arcs, may ultimately degrade the electrical contact and result in the failure of the electrical contact. By measuring various parameters, including an arc resistance, the status of the contact may be determined. In the event of such parameters reaching a certain threshold, it may be determined that the electrical contact performance has degraded to the point where the failure of the contact is probable and relatively imminent.

[0016] It has further been recognized that by timing the operation of the arc suppressor to certain conditions in the electrical contact that certain phases of the ignition of the arc may contribute to removing debris from the electrical contact. In particular, it has been recognized that the ignition of plasma, referred to as the metallic plasma phase, actually tends to remove debris from the contact, while the burning of the arc when the arc transitions to a gaseous plasma phase degrade the contact and deposits more debris on the electrical contact than may have been removed through the ignition of the metallic plasma phase. Thus, by allowing the metallic plasma phase to burn and then suppressing the arc before or upon transition to the gaseous plasma phase, some debris may be removed from the contact without adding additional debris through the burning of the gaseous plasma. If the process is repeated then degradation of the electrical contact may be halted or reversed and the electrical contact may be affirmatively cleaned.

[0017] As used herein, the term "stick duration" refers to the time difference between coil activation/deactivation (e.g., a relay coil of a relay contact) and power contact activation/deactivation. In some aspects, the discussed power contact health assessment operations may be structured so that such operations may be configured and executed in microcontrollers and microprocessors without the need for an external/computation apparatus or method. In various examples, the power contact health assessment operations do not rely on extensive mathematical and/or calculus operations. In some aspects, the dry contactor may be optional for power contact health assessment. The dry contactor may be utilized if high dielectric isolation and extremely low leakage currents are desired.

[0018] Arc suppressor is an optional element for the power contact health assessor. In some aspects, the disclosed power contact health assessor may incorporate an arc suppression circuit (also referred to as an arc suppressor) coupled to the wet contact, to protect the wet contact from arcing during the make and break transitions and to reduce deleterious effects from contact arcing. The arc suppressor incorporated with the power contact health assessor discussed herein may include an arc suppressor as disclosed in the following issued U.S. Patents – U.S. Patent No. 8,619,395 and U.S. Patent No. 9,423,442, both of which are incorporated herein by reference in their entirety. A power contact arc suppressor extends the electrical life of a power contact under any rated load into the mechanical life expectancy range. Even though the figures depict a power contact health assessor 1 with an internal arc suppressor, the disclosure is not limited in this regard and the power contact health assessor 1 may also use an external arc suppressor or no arc suppressor.

[0019] When a power contact can no longer break the electrode micro weld in time, the contact is considered failed. Anecdotally, the power relay industry considers a contactor or relay contact failed if the contact stick duration (CSD) exceeds one (1) second. The inevitable end-of-life (EoL) event for any relay and contactor is a failure. Power contact EoL may be understood as the moment when a relay/contactor fails either electrically or mechanically. Power relays and contactors power contacts either fail closed, open, or somewhere in between. Published power contact release times in relay and contactor datasheets are not the same as the power contact stick duration. The relay industry considers contacts with a current-carrying capability of 2A or greater, power contacts. Contacts with a current-carrying capability of less than 2A may not be considered power contacts. Conventional techniques to determine power contact condition may involve measuring power contact resistance. Such measurements, however, are performed ex-situ, using complex and expensive equipment to perform measurements.

[0020] Power contact electrode surface degradation/decay is associated with ever-increasing power contact stick durations. Techniques disclosed herein may be used to perform power contact health assessment for a power contact using in-situ, real-time, stand-alone operation by, e.g., monitoring contact stick durations providing a contact health assessment based on the measured stick duration. In-situ may be understood to involve operating in an actual, real-life, application while operating under normal or abnormal conditions. Real-time may be understood to involve performance data that is actual and available at the time of measurement. For example, real-time contact separation detection may be performed using real-time voltage measurements of the power contact voltage. Stand-alone-operation requires no additional connections, devices, or manipulations other than those outlined in the present disclosure (e.g., the main power connection, a relay coil driver connection, and an auxiliary power source connection).

[0021] FIG. 1 is a diagram of a system including a power contact health assessor, according to some embodiments. Referring to FIG. 1, the system may include a power contact health assessor 1 coupled to an auxiliary power source 2, a relay coil driver 3, a main power source 4, a dry relay 5, a wet relay 6, a main power load 7, and a data communication interface 19.

[0022] The dry relay 5 may include a dry relay coil coupled to dry relay contacts, and the wet relay 6 may include a wet relay coil coupled to wet relay contacts. The dry relay 5 may be coupled to the main power source 4 via the power contact health assessor 1. The dry relay 5 may be coupled in series with the wet relay 6, and the wet relay 6 may be coupled to the main power load 7 via the power contact health assessor 1. Additionally, the wet relay 6 may be protected by an arc suppressor coupled across the wet relay contacts of the wet relay 6 (e.g., as illustrated in FIGs. 2 and 3). Without an arc suppressor connected, the wet contactor or relay 6 contacts may become damaged or degraded and the dry contactor or relay 5 contacts may remain in excellent condition during normal operation of the power contact health assessor 1, which may result in the device clearing a fault condition in the case where the wet relay contacts have failed.

[0023] The main power source 4 may be an AC power source or a DC power source. Sources four AC power may include generators, alternators, transformers, and the like. Source four AC power may be sinusoidal, non-sinusoidal, or phase-controlled. An AC power source may be utilized on a power grid (e.g., utility power, power stations, transmission lines, etc.) as well as off the grid, such as for rail power. Sources for DC power may include various types of power storage, such as batteries, solar cells, fuel cells, capacitor banks, and thermopiles, dynamos, and power supplies. DC power types may include direct, pulsating, variable, and alternating (which may include superimposed AC, full-wave rectification, and half-wave rectification). DC power may be associated with self-propelled applications, i.e., articles that drive, fly, swim, crawl, dive, internal, dig, cut, etc. Even though FIG. 1 illustrates the main power source 4 as externally provided, the disclosure is not limited in this regard and the main power source may be provided internally, e.g., a battery or another power source. Additionally, the main power source 4 may be a single-phase or a multi-phase power source.

[0024] Even though FIG. 1 illustrates the power contact health assessor 1 coupled to a dry relay 5 and a wet relay 6 that include a relay coil and relay contacts, the disclosure is not limited in this regard and other types of interlock arrangements may be used as well, such as switches, contactors, or other types of interlocks. In some aspects, a contactor may be a specific, heavy-duty, high current, embodiment of a relay. Additionally, the power contact health assessor 1 may be used to generate an EoL prediction for a single power contact (one of the contacts of relays 5 and 6) or multiple power contacts (contacts for both relays 5 and 6).

[0025] The dry and wet contacts associated with the dry and wet relays in FIG. 1 may each include a pair of contacts, such as electrodes. In some aspects, the main power load 7 may be a general-purpose load, such as consumer lighting, computing devices, data transfer switches, etc. In some aspects, the main power load 7 may be a resistive load, such as a resistor, heater, electroplating device, etc.

In some aspects, the main power load 7 may be a capacitive load, such as a capacitor, capacitor bank, power supply, etc. In some aspects, the main power load 7 may be an inductive load, such as an inductor, transformer, solenoid, etc. In some aspects, the main power load 7 may be a motor load, such as a motor, compressor, fan, etc. In some aspects, the main power load 7 may be a tungsten load, such as a tungsten lamp, infrared heater, industrial light, etc. In some aspects, the main power load 7 may be a ballast load, such as a fluorescent light, a neon light, a light-emitting diode (LED), etc. In some aspects, the main power load 7 may be a pilot duty load, such as a traffic light, signal beacon, control circuit, etc.

[0026] The auxiliary power source 2 is an external power source that provides power to the wet and dry relay coils (of the wet relay 6 and the dry relay 5, respectively) according to the power contact health assessor 1. The first auxiliary power source node 21 may be configured as a first coil power termination input (e.g., to the auxiliary power termination and protection circuit 12 in FIG. 2). The second auxiliary power source node 22 may be configured as the second coil power termination input. The auxiliary power source 2 may be a single-phase or a multi-phase power source. Additionally, the coil power source 2 may be an AC power type or a DC power type.

[0027] The relay coil driver 3 is the external relay coil signal source which provides information about the energization status for the wet relay 6 coil and the dry relay 5 coil according to the control of the power contact health assessor 1. In this regard, the relay coil driver 3 is configured to provide a control signal. The first relay coil driver node 31 is a first coil driver termination input (e.g., to relay coil termination and protection circuit 14 in FIG. 2). The second relay coil driver node 32 may be configured as the second coil driver termination input. The relay coil driver 3 may be a single-phase or a multi-phase power source. Additionally, the relay coil driver 3 may be an AC power type or a DC power type.

[0028] The data communication interface 19 is an optional element that is coupled to the power contact health assessor 1 via one or more communication links 182. The data communication interface 19 may be coupled to external memory and may be used for, e.g., storing and retrieving data.

[0029] Data communication may not be required for the full functional operation of the power contact health assessor 1. In some aspects, the data communication interface 19 can include one or more of the following elements: a digital signal isolator, an internal transmit data (TxD) termination, an internal receive data (RxD) termination, an external receive data (Ext RxD) termination, and an external transmit data (Ext TxD) termination.

[0030] Data signal filtering, transient, over-voltage, over-current, and wire termination are not shown in the example data communication interface 19 in FIG. 1 and FIG. 2. In some aspects, the data communications interface 19 can be configured as an interface between the power contact health assessor 1 and one or more of the following: a Bluetooth controller, an Ethernet controller, a General Purpose Data Interface, a Human-Machine-Interface, an SPI bus interface, a UART interface, a USB controller, and a Wi-Fi controller.

[0031] The dry relay 5 may include two sections - a dry relay coil and dry relay contacts. As mentioned above, “dry” refers to the specific mode of operation of the contacts in this relay which makes or breaks the current connection between the contacts while not carrying current.

[0032] The first dry relay node 51 is the first dry relay 5 coil input from the power contact health assessor 1. The second dry relay node 52 is the second dry relay 5 coil input from the power contact health assessor 1. The third dry relay node 53 is the first dry relay contact connection with the main power source 4. The fourth dry relay node 56 is the second dry relay contact connection (e.g., with the wet relay 6). The dry relay 5 may be configured to operate with a single-phase or a multi-phase power source. Additionally, the dry relay 5 may be an AC power type or a DC power type.

[0033] The wet relay 6 may include two sections - a wet relay coil and wet relay contacts. As mentioned above, “wet” refers to the specific mode of operation of the contacts in this relay which makes or breaks the current connection between the contacts while carrying current.

[0034] The first wet relay node 61 is the first wet relay 6 coil input from the power contact health assessor 1. The second wet relay node 62 is the second wet relay 6 coil input from the power contact health assessor 1. The third wet relay node 63 is the first wet relay contact connection (e.g., with the dry relay). The fourth wet relay node 66 is the second wet relay contact connection (e.g., with the current sensor 127). The wet relay 6 may be configured to operate with a single-phase or a multi-phase power source. Additionally, the wet relay 6 may be an AC power type or a DC power type. The first wet relay node 61 and the second wet relay node 62 or third wet relay node 63 and the fourth wet relay node 66 form a pair of terminals which are coupled to the pair of contact electrodes of the wet relay 6 power contact.

[0035] In some aspects, the power contact health assessor 1 is configured to support both the normally open (NO) contacts (also referred to as Form A contacts) and the normally closed (NC) contacts (also referred to as Form B contacts). In some aspects, the power contact health assessor 1 measures, records, and analyzes the time difference between coil activation (or deactivation) and power contact activation (or deactivation). In this regard, by monitoring and measuring contact stick durations (e.g., for multiple contact cycles), the gradual power contact electrode surface degradation/decay/decay may be detected and the estimated EoL may be predicted in absolute or relative terms for the power contact. For example, the power contact EoL prediction may be expressed in percent of cycles left to EoL, numbers of cycles, etc. For the purposes of this disclosure, a cycle may be understood to be an opening and closing of the contact, or vice versa, with the number of cycles being the number of times the contact has open and closed or closed and opened.

[0036] In some aspects, the power contact health assessor 1 contains elements of a wet/dry power contact sequencer. In some aspects, the power contact health assessor 1 contains elements of a power contact fault clearing device. In some aspects, the power contact health assessor 1 contains elements of a power contact End-of-Life predictor. In some aspects, the power contact health assessor 1 contains elements of a power contact electrode surface plasma therapy device. In some aspects, the power contact health assessor 1 contains elements of an arc suppressor (the arc suppressor may be an optional element of the power contact health assessor 1).

[0037] The discussed specific power contact health assessor operations may be based on instructions located either in internal or external microcontroller/processor memory. In some aspects, wet/dry power contact sequencing operations may operate in support of the power contact health assessor 1. In some aspects, power contact fault clearing operations may operate in support of the power contact health assessor 1. In some aspects, power contact End-of-Life predictor operations may operate in support of the power contact health assessor 1. In some aspects, power contact electrode surface plasma therapy operation may operate in support of the power contact health assessor 1. The power contact health assessment operations discussed herein may be performed in-situ and in real-time, while the contact is performing under regular or abnormal operating conditions. In some aspects, contact maintenance schedules may be based on the actual health conditions of under power operating contacts, as determined one or more of the techniques discussed herein.

[0038] Power contact electrodes may be micro-welded during the make and especially during the make bounce phase of the current-carrying contact cycle. See U.S. Patent No. 9,423,442, FIGs. 8A-8H and FIGs. 9A-9L for the phases of arc generation. Micro welds between contact electrodes are desired for they provide the low contact resistance required for power current conducting. Contact stick duration analysis in the power contact health assessor 1 is a measure of contact performance degradation due to adverse contact conditions due to erosion in the form of and contact electrode surface decomposition. The contact stick duration is the difference between the moment the relay coil driver power de-activates and the power contact separates.

[0039] In some aspects, stick duration is defined as a time of contact opening minus a time of coil de-activation. Stick durations may be measured in milliseconds for conventional electrical contacts, though it is to be recognized and understood that faster or slower durations may be applicable depending on the electrical contact in question. Contact stick duration may be an indication of contact conditions health (contact stick durations getting longer over time are indications of decaying contact health). A relatively long contact stick duration is an indication of poor contact health. When contact sticking becomes permanent, then the contact has failed. Contact stick durations over one (1) second are generally considered a contact failure in the relay industry. In some aspects, stop time to arc minus the start time of the coil signal transition is equivalent to the contact stick duration.

[0040] In some aspects, separation of contact detection allows for a predictable timing reference in order to determine the time difference between coil deactivation Form A and the opening of the contact. This time difference is greatly influenced by the duration of contact sticking due to normal contact micro-welding. Even if the break of the micro weld takes more than one second, the contact may still prove to be functional albeit passed normal expectations. Once the micro weld cannot be broken anymore by the force of the contactor mechanism which is designed to open the contact or break the micro weld, the contact may be considered failed. In some aspects, contact sticking is the time difference between the coil activation signal to break the contact and the actual contact separation. In this regard, contact sticking may an indication of contact failure and not necessarily an increase in contact resistance.

[0041] The power contact health assessor discussed herein may be associated with the following features and benefits: AC or DC coil power and contact operation; authenticity and license control mechanisms; auto detect functions; auto generate service and maintenance calls; auto mode settings; automatic fault detection; automatic power failure coil signal bypass; assessing power contact electrode surface decomposition degree; assessing power contact electrode surface decay; assessing power contact electrode surface decay acceleration; assessing power contact electrode surface decay deceleration; assessing power contact electrode surface decomposition degree; assessing power contact electrode surface health condition; assessing power contact electrode surface performance level; bar graph indicator; behavior pattern learning resulting in out-of-pattern detection and indication; cell phone application; code verification chip; conducting real time power contact health diagnosis; conducting in-situ power contact health diagnosis; diagnosing power contact health symptoms; EMC compliance; enabling off-site troubleshooting; enabling faster cycle times; enabling lower duty cycles; enabling heavy duty operation with lighter duty contactors or relays; enabling high dielectric operation; enabling high power operation; enabling low leakage operation; enabling relays to replace contactors; external and internal contactors or relays; hybrid power relays, contactors and circuit breakers; intelligent hybrid-power-switching controllers; internet appliances; local and remote data access; local and remote firmware upgrades; local and remote register access; local and remote system diagnostics; local and remote troubleshooting; maximizing power contact life; maximizing equipment life; maximizing productivity; minimizing planned maintenance schedules; minimizing unplanned service calls; minimizing down times; minimizing production outages; mode control selection; multi-phase configuration; on-site or off-site troubleshooting; operating mode indication; power indication; processor status indication color codes; single-phase configuration; supporting high dielectric isolation between power source and power load; supporting low leakage current between power source and power load; and trigger automatic service calls.

[0042] In some aspects, the power contact health assessor 1 may use the following data communication interfaces: access control, Bluetooth interface, communication interfaces and protocols, encrypted data transmissions, an Ethernet interface, LAN/WAN connectivity, SPI bus interface, UART, a universal data interface, a USB interface, and a Wi-Fi interface.

[0043] In some aspects, the power contact health assessor 1 may use the following power contact parameters and interfaces: power contact arc current, power contact arc duration, power contact arc type, power contact arc voltage, power contact break bounce parameters, power contact break bounce duration, power contact current, power contact cycle counts, power contact cycle duration, power contact cycle frequency, power contact cycle times, power contact duty cycle, power contact energy, power contact fault and failure alerts and alarms, power contact fault and failure code clearing, power contact fault and failure detection, power contact fault and failure flash codes, power contact fault and failure history and statistics, power contact fault and failure alert, power contact fault and failure parameters, power contact health, power contact history, power contact hours-of-service, power contact make bounce parameters, power contact make bounce duration, power contact on duration, power contact off duration, power contact power, power contact resistance, power contact stick duration (PCSD), power contact average stick duration (PCASD), power contact peak stick duration (PCPSD), power contact stick duration crest factor (PCSDCF), power contact stick parameters, power contact parameter history, power contact parameter statistics, power contact statistics, power contact status, power contact voltage, and power contact voltage crest factor.

[0044] The power contact health assessor 1 or may be associated with the following results and the following beneficial outcomes: reducing or eliminating preventive maintenance program requirements; reducing or eliminating scheduled service calls; reducing or eliminating prophylactic contact, relay, or contactor replacements; and power contact life degradation/decay detection. Data communication interfacing may be optional for the discussed health assessor.

[0045] In comparison, conventional techniques are based on ex-situ analysis of power contact resistance increase as an indication of power contact decay and a metric for impending power contact failure prediction. Such conventional techniques are not based on in-situ health assessment, not based on mathematical analysis, and not taking into account the instant of power contact separation.

[0046] FIG. 2 is a block diagram of an example power contact health assessor 1 with an arc suppressor 126, in an example embodiment. The power contact health assessor 1 comprises an auxiliary power termination and protection circuit 12, a relay coil termination and protection circuit 14, a logic power supply 15, a coil signal converter 16, mode control switches 17, a controller (also referred to as microcontroller or microprocessor) 18, a data communication interface 19, a status indicator 110, a code control chip 120, a voltage sensor 123, an overcurrent protection circuit 124, a voltage sensor 125, an arc suppressor 126 (e.g., with a contact separation detector), a current sensor 127, a dry coil power switch 111, a dry coil current sensor 113, a wet coil power switch 112, and a wet coil current sensor 114.

[0047] The auxiliary power termination and protection circuit 12 is configured to provide external wire termination and protection to all elements of the power contact health assessor 1. The first auxiliary power termination and protection circuit 12 node 121 is the first logic power supply 15 input, the first coil power switch 111 input, and the first coil power switch 112 input. The second auxiliary power termination and protection circuit 12 node 122 is the second logic power supply 15 input, the second coil power switch 111 input, and the second coil power switch 112 input.

[0048] In some aspects, the auxiliary power termination and protection circuit 12 includes one or more of the following elements: a first relay coil driver terminal, a second relay coil driver terminal, an overvoltage protection, an overcurrent protection, a reverse polarity protection, optional transient and noise filtering, optional current sensor, and optional voltage sensor.

[0049] The relay coil termination and protection circuit 14 provides external wire termination and protection to all elements of the power contact health assessor 1. The first coil termination and protection circuit 14 node 141 is the first coil signal converter circuit 16 input. The second coil termination and protection circuit 14 node 142 is the second coil signal converter 16 input.

[0050] In some aspects, the relay coil termination and protection circuit 14 includes one or more of the following elements: a first relay coil driver terminal, a second relay coil driver terminal, an overvoltage protection, an overcurrent protection, a reverse polarity protection, optional transient and noise filtering, a current sensor (optional), and a voltage sensor (optional).

[0051] The logic power supply 15 is configured to provide logic level voltage to some or all digital logic elements of the power contact health assessor 1. The first logic power supply output 151 is the positive power supply terminal indicated by the positive power schematic symbol in FIG. 2. The second logic power supply output 152 is the negative power supply terminal indicated by the ground reference symbol in FIG. 2.

[0052] In some aspects, the logic power supply 15 includes one or more of the following elements: an AC-to-DC converter, input noise filtering, and transient protection, input bulk energy storage, output bulk energy storage, output noise filtering, a DC-to-DC converter (alternative), an external power converter (alternative), a dielectric isolation (internal or external), an overvoltage protection (internal or external), an overcurrent protection (internal or external), product safety certifications (internal or external), and electromagnetic compatibility certifications (internal or external).

[0053] The coil signal converter circuit 16 converts a signal indicative of the energization status of the wet and dry coils from the relay coil driver 3 into a logic level type signal communicated to the controller circuit 18 via node 187 for further processing.

[0054] In some aspects, the coil signal converter 16 is comprised of one or more of the following elements: current limiting elements, dielectric isolation, signal indication, signal rectification, optional signal filtering, optional signal shaping, and optional transient and noise filtering.

[0055] The mode control switches 17 allow manual selection of specific modes of operation for the power contact health assessor 1. In some aspects, the mode control switches 17 include one or more of the following elements: push buttons for hard resets, clearings or acknowledgments, DIP switches for setting specific modes of operation, and (alternatively in place of pushbuttons) keypad or keyboard switches.

[0056] The controller circuit 18 comprises suitable circuitry, logic, interfaces, and/or code and is configured to control the operation of the power contact health assessor 1 through, e.g., software/firmware-based operations, routines, and programs. The first controller node 181 is the status indicator 110 connection. The second controller node 182 is the data communication interface 19 connection. The third controller node 183 is the dry coil power switch 111 connection. The fourth controller node 184 is the wet coil power switch 112 connection. The fifth controller node 185 is the dry coil current sensor 113 connection. The sixth controller node 186 is the wet coil current sensor 114 connection. The seventh controller node 187 is the coil signal converter circuit 16 connection. The eight controller node 188 is the code control chip 120 connection. The ninth controller node 189 is the mode control switches 17 connection. The tenth controller node 1810 is the overcurrent voltage sensor 123 connection. The eleventh controller node 1811 is the voltage sensor 125 connection. The twelfth controller node 1812 is the arc suppressor 126 lock connection. The thirteenth controller node 1813 is the first current sensor 127 connection. The fourteenth controller node 1814 is the second current sensor 127 connection.

[0057] In some aspects, controller circuit 18 may be configured to control one or more of the following operations associated with the power contact health assessor 1: algorithm management; authenticity code control management; auto-detect operations; auto-detect functions; automatic normally closed or normally open contact form detection; auto mode settings; coil cycle (Off, Make, On, Break, Off) timing, history, and statistics; coil delay management; history management; power contact sequencing; coil driver signal chatter history and statistics; data management (e.g., monitoring, detecting, recording, logging, indicating, and processing); data value registers for present, last, past, maximum, minimum, mean, average, standard deviation values, etc.; date and time formatting, logging, and recording; embedded microcontroller with clock generation, power on reset, and watchdog timer; error, fault, and failure management; factory default value recovery management; firmware upgrade management; flash code generation; fault indication clearing; fault register reset; hard reset; interrupt management; license code control management; power-on management; power-up sequencing; power hold-over management; power turn-on management; reading from inputs, memory, or registers; register address organization; register data factory default values; register data value addresses; register map organization; soft reset management; SPI bus link management; statistics management; system access management; system diagnostics management; UART communications link management; wet/dry relay coil management; and writing to memory, outputs, and registers.

[0058] The status indicator 110 provides audible, visual, or other user alerting methods through operational, health, fault, code indication via specific colors or flash patterns. In some aspects, the status indicator 110 may provide one or more of the following types of indications: bar graphs, graphic display, LEDs, a coil driver fault indication, a coil state indication, a dry coil fault indication, a mode of operation indication, a processor health indication, and wet coil fault indication.

[0059] The dry coil power switch 111 connects the externally provided coil power to the dry relay coil 5 via nodes 51 and 52 based on the signal output from controller circuit 18 via command output node 183. In some aspects, the dry coil power switch 111 includes one or more of the following elements: solid-state relays, current limiting elements, and optional electromechanical relays.

[0060] The wet coil power switch 112 connects the externally provided coil power to the wet relay coil 6 via nodes 61 and 62 based on the signal output from controller circuit 18 via command output node 184. In some aspects, the wet coil power switch 112 includes one or more of the following elements: solid-state relays, current limiting elements, and optional electromechanical relays.

[0061] The dry coil current sensor 113 is configured to sense the value and/or the absence or presence of the dry relay coil 5 current. In some aspects, the dry coil current sensor 113 includes one or more of the following elements: solid-state relays, a reverse polarity protection element, optoisolators, optocouplers, Reed relays and/or Hall effect sensors (optional), SSR AC or DC input (alternative), and SSR AC or DC output (alternative).

[0062] The wet coil current sensor 114 is configured to sense the value and/or the absence or presence of the dry relay coil 6 current. In some aspects, the wet coil current sensor 114 includes one or more of the following elements: solid-state relays, a reverse polarity protection element, optoisolators, optocouplers, Reed relays and/or Hall effect sensors (optional), SSR AC or DC input (alternative), and SSR AC or DC output (alternative).

[0063] The code control chip 120 is an optional element of the power contact health assessor 1, and it is not required for the fully functional operation of the device. In some aspects, the code control chip 120 may be configured to include application or customer-specific code with encrypted or non-encrypted data security. In some aspects, the code control chip 120 function may be implemented externally via the data communication interface 19. In some aspects, the code control chip 120 may be configured to store the following information: access control code and data, alert control code and data, authentication control code and data, encryption control code and data, chip control code and data, license control code and data, validation control code and data, and/or checksum control code and data. In some aspects, the code control chip 120 may be implemented as an internal component of controller circuit 18 or may be a separate circuit that is external to controller circuit 18 (e.g., as illustrated in FIG. 2).

[0064] The voltage sensor 123 is configured to monitor the condition of the overcurrent protection 124. In some aspects, the voltage sensor 123 includes one or more of the following elements: solid-state relays, a bridge rectifier, current limiters, resistors, capacitors, reverse polarity protection elements, optoisolators, optocouplers, Reed relays, and analog-to-digital converters (optional).

[0065] The overcurrent protection circuit 124 is configured to protect the power contact health assessor 1 from destruction in case of an overcurrent condition. In some aspects, the overcurrent protection circuit 124 includes one or more of the following elements: fusible elements, fusible printed circuit board traces, fuses, and circuit breakers.

[0066] The voltage sensor 125 is configured to monitor the voltage across the wet relay 6 contacts. In some aspects, the voltage sensor 125 includes one or more of the following elements: solid-state relays, a bridge rectifier, current limiters, resistors, capacitors, reverse polarity protection elements, and alternative or optional elements such as optoisolators, optocouplers, solid-state relays, Reed relays, and analog-to-digital converters. In some aspects, the voltage sensor 125 may be used for detecting contact separation of the contact electrodes of the wet relay 6. More specifically, the connection 1811 may be used by the controller circuit 18 to detect that a voltage between the contact electrodes of the wet relay 6 measured by the voltage sensor 125 is at a plasma ignition voltage level (or arc initiation voltage level) or above. The controller circuit 18 may determine there is contact separation of the contact electrodes of the wet relay 6 when such voltage levels are reached or exceeded. The determined time of contact separation may be used to determine contact stick duration, which may be used for the power contact health assessment.

[0067] The arc suppressor 126 is configured to provide arc suppression for the wet relay 6 contacts. The arc suppressor 126 may be either external to the power contact health assessor 1 or, alternatively, may be implemented as an integrated part of the power contact health assessor 1. The arc suppressor 126 may be configured to operate with a single-phase or a multi-phase power source. Additionally, the arc suppressor 8 may be an AC power type or a DC power type.

[0068] In some aspects, the arc suppressor 126 may be deployed for normal load conditions. In some aspects, the arc suppressor 126 may or may not be designed to suppress a contact fault arc in an overcurrent or contact overload condition.

[0069] The controller circuit 18 is configured to perform one or both of the following tasks: identify health of the wet contact 6; and clean the wet contact 6 with plasma therapy, both as disclosed in detail herein. The controller circuit 18 is optionally an electronically-configurable microcontroller or microprocessor or may be implemented as discrete analog components, e.g., op-amps and the like, which would be selected and arranged to output a trigger signal to the trigger circuit 203 upon a predetermined passage of time. By contrast, with the controller circuit 18 implemented as a microcontroller or microprocessor, the controller circuit 18 may include logic to allow the controller circuit 18 to calculate the health of the wet contact 6 and adapt the timing of the plasma therapy based on the characteristics of the wet contact 6.

[0070] In some aspects, the connection 1812 between the arc suppressor 126 lock and the controller circuit 18 may be used for enabling (unlocking) the arc suppressor (e.g., when the relay coil driver signal is active) or disabling (locking) the arc suppressor (e.g., when the relay coil driver signal is inactive).

[0071] In some aspects, the arc suppressor 126 may include a contact separation detector (not illustrated in FIG. 2) configured to detect a time instance when the wet relay 6 power contact electrodes separate as part of a contact cycle. A connection with the controller circuit 18 (e.g., 1812) may be used to communicate a contact separation indication of a time instance when the contact separation detector has detected contact separation within a contact cycle of the wet relay 6. The contact separation indication may be used by the controller circuit 18 to provide a power contact health assessment with regard to the condition of the contact electrodes of the wet relay 6.

[0072] In some aspects, the arc suppressor 126 may be a single-phase or a multi-phase arc suppressor. Additionally, the arc suppressor may be an AC power type or a DC power type.

[0073] The current sensor 127 is configured to monitors the current through the wet relay 6 contacts. In some aspects, the current sensor 126 includes one or more of the following elements: solid-state relays, a bridge rectifier, current limiters, resistors, capacitors, reverse polarity protection elements, and alternative or optional elements such as optoisolators, optocouplers, Reed relays, and analog-to-digital converters.

[0074] In some aspects, the controller circuit 18 status indicator output pin (SIO) pin 181 transmits the logic state to the status indicators 110. SIO is the logic label state when the status indicator output is high, and /SIO is the logic label state when the status indicator output is low.

[0075] In some aspects, the controller circuit 18 data communication interface connection (TXD/RXD) 182 transmits the data logic state to the data communications interface 19. RXD is the logic label state identifying the receive data communications mark, and /RXD is the logic label state identifying the receive data communications space. TXD is the logic label state identifying the transmit data communications mark, and /TXD is the logic label state identifying the transmit data communications space.

[0076] In some aspects, the controller circuit 18 dry coil output (DCO) pin 183 transmits the logic state to the dry coil power switch 111. DCO is the logic label state when the dry coil output is energized, and /DCO is the logic label state when the dry coil output is de-energized.

[0077] In some aspects, the controller circuit 18 wet coil output pin (WCO) 184 transmits the logic state to the wet coil power switch 112. WCO is the logic state when the wet coil output is energized, and /WCO is the logic state when the wet coil output is de-energized.

[0078] In some aspects, the controller circuit 18 dry coil input pin (DCI) 185 receives the logic state of the dry coil current sensor 113. DCI is the logic state when the dry coil current is absent, and /DCI is the logic state when the dry coil current is present.

[0079] In some aspects, the controller circuit 18 wet coil input pin (WCI) 186 receives the logic state of the wet coil current sensor 114. WCI is the logic label state when the wet coil current is absent, and /WCI is the logic label state when the wet coil current is present.

[0080] In some aspects, the controller circuit 18 coil driver input pin (CDI) 187 receives the logic state of the coil signal converter 16. CDI is the logic state of the de-energized coil driver. /CDI is the logic state of the energized coil driver.

[0081] In some aspects, the controller circuit 18 code control connection (CCC) 188 receives and transmits the logic state of the code control chip 120. CCR is the logic label state identifying the receive data logic high, and /CCR is the logic label state identifying the receive data logic low. CCT is the logic label state identifying the transmit data logic high, and /CCT is the logic label state identifying the transmit data logic low.

[0082] In some aspects, the controller circuit 18 mode control switch input pin (S) 189 receives the logic state from the mode control switches 17. S represents the mode control switch open logic state, and /S represents the mode control switch closed logic state.

[0083] In some aspects, the controller circuit 18 connection 1810 receives the logic state from the overcurrent protection (OCP) voltage sensor 123. OCPVS is the logic label state when the OCP is not fused open, and /OCPVS is the logic label state when the OCP is fused open.

[0084] In some aspects, the controller circuit 18 connection 1811 receives the logic state from the wet contact voltage sensor (VS) 125. WCVS is the logic label state when the VS is transmitting logic high, and /WCVS is the logic label state when the VS is transmitting logic low.

[0085] In some aspects, the controller circuit 18 connection 1812 transmits the logic state to the arc suppressor 126 lock. ASL is the logic label state when the arc suppression is locked, and /ASL is the logic label state when the arc suppression is unlocked.

[0086] In some aspects, the controller circuit 18 connections 1813 and 1814 receive the logic state from the contact current sensor 127. CCS is the logic label state when the contact current is absent, and /CCS is the logic label state when the contact current is present.

[0087] In some aspects, the controller circuit 18 may configure one or more timers (e.g., in connection with detecting a fault condition and sequencing the deactivation of the wet and dry contacts). Example timer labels and definitions of different timers that may be configured by controller circuit 18 include one or more of the following timers.

[0088] In some aspects, the coil driver input delay timer delays the processing for the logic state of the coil driver input signal. COIL_DRIVER_INPUT_DELAY_TIMER is the label when the timer is running.

[0089] In some aspects, the switch debounce timer delays the processing for the logic state of the switch input signal. SWITCH_DEBOUNCE_TIMER is the label when the timer is running.

[0090] In some aspects, the receive data timer delays the processing for the logic state of the receive data input signal. RECEIVE_DATA_DELAY_TIMER is the label when the timer is running.

[0091] In some aspects, the transmit data timer delays the processing for the logic state of the transmit data output signal. TRANSMIT_DATA_DELAY_TIMER is the label when the timer is running.

[0092] In some aspects, the wet coil output timer delays the processing for the logic state of the wet coil output signal. WET_COIL_OUTPUT_DELAY_TIMER is the label when the timer is running.

[0093] In some aspects, the wet current input timer delays the processing for the logic state of the wet current input signal. WET_CURRENT_INPUT_DELAY_TIMER is the label when the timer is running.

[0094] In some aspects, the dry coil output timer delays the processing for the logic state of the dry coil output signal. DRY_COIL_OUTPUT_DELAY_TIMER is the label when the timer is running.

[0095] In some aspects, the dry current input timer delays the processing for the logic state of the dry current input signal. DRY_CURRENT_INPUT_DELAY_TIMER is the label when the timer is running.

[0096] In some aspects, the signal indicator output delay timer delays the processing for the logic state of the signal indicator output. SIGNAL_INDICATOR_OUTPUT_DELAY_TIMER is the label when the timer is running.

[0097] FIG. 3 is a block diagram of a system including an example power contact health assessor 1, according to some embodiments. The power contact health assessor of FIG. 3 may be a stand-alone power contact health assessor 1 or may exist as a specific implementation of the example of the power contact health assessor 1 illustrated and described in FIG. 2. Thus, principles disclosed with respect to the power contact health assessor 1 as illustrated in FIG. 3 apply as well to the power contact health assessor 1 of FIG. 2. Moreover, the arc suppressor 126 of FIG. 3 may be implemented as the arc suppressor 126 of FIG. 2.

[0098] The power contact health assessor 1 includes an arc suppressor 126 coupled to a controller circuit 18. The arc suppressor 126 includes voltage and current sensors 212, 213, in an example kelvin terminals. The voltage and current sensors 212, 213 output a detected voltage at terminals 2121, 2131, respectively, and a detected current at terminals 2122, 2132, respectively. The voltage terminals 2121, 2131 are coupled to a plasma ignition detector 200 of the arc suppressor 126. The plasma ignition detector is configured to detect an electrical parameter over the switchable contact electrodes of the wet relay 6 indicative of the formation of plasma between the switchable contact electrodes and output a plasma ignition signal based on the electrical parameter as detected. The current terminals 2122, 2132 are coupled to a plasma burn memory 201 of the arc suppressor. The plasma burn memory 201 is configured to receive and store a plasma ignition signal.

[0099] The arc suppressor further includes a trigger circuit 203 coupled to the plasma burn memory 201, a plasma extinguishing circuit 206 coupled to the trigger circuit, and an overvoltage protector 208 coupled between the current terminals 2122, 2132. The output of the plasma burn memory 201 is coupled to the input of the controller circuit 18 and the output of the controller circuit 18 is coupled to the trigger circuit 203. Thus, as will be disclosed in detail herein, the controller circuit 18 is configured to receive the indication of the plasma burn from the plasma burn memory 201 and, based on the existence of the plasma burn and the desired duration of the plasma burn for the purposes of cleaning the wet contact 6, output a command to the trigger circuit 203 to extinguish the plasma burn.

[00100] The plasma ignition detector 200 includes a transmission line 230 coupled to the voltage output 2121 of the voltage and current sensor 212 and a transmission line 232 coupled to the voltage output 2131 of the voltage and current sensor 213. The transmission line 230 is coupled to capacitor 234 and the transmission line 232 is coupled to resistor 236. The capacitor 234 is coupled to transformer 238 by way of transmission line 240 and the resistor 236 is coupled to the transformer 238 by way of transmission line 242. A Zener diode 244 is coupled across the transformer 238 and the terminals of the Zener diode 244 are each coupled to a transmission line 246, 248. The transmission line 246 is coupled to a diode 250, and a resistor 252 is coupled between the diode 250 and the transmission line 248. A capacitor 254 is coupled in parallel with the resistor 252 and across the plasma burn memory 201. Consequently, the plasma burn detector 200 takes as input the voltage across the wet contact 6, as detected by the voltage and current sensors 212, 213, and outputs a binary signal indicative of the voltage having met a threshold condition indicative of the start of the plasma burn.

[00101] The plasma burn memory 201 includes or is comprised of a circuit component that is set to retain a particular voltage until the component is starved for current. In that way, the plasma burn memory 201 may receive the plasma ignition signal from the plasma ignition detector 200 and hold that signal for as long as current is provided by the relay 6. In an example, the plasma burn memory 201 includes or is comprised of a thyristor, a semiconductor controller rectifier (SCR), or any triggerable latching switch.

[00102] The controller circuit 18 receives the output from the plasma burn memory 201 at terminal 1815. While not depicted, the controller circuit 18 may also be configured to receive some or all of the additional inputs shown for the controller circuit 18 in FIG. 2, including voltage and current output, and output logically controlled outputs for the health of the wet contact 6 and plasma therapy, as disclosed herein. However, where the controller circuit 18 is implemented as non-programmable components, the controller circuit 18 may simply receive the signal from the plasma burn memory 201, implement a timer or counter, and then output a logical signal at the terminal 1812 to the trigger circuit 203. It is, however, emphasized that the controller circuit 18 may operate according to all of the functionality of the controller circuit 18 disclosed with respect to FIG. 2. The controller circuit is configured to receive from the plasma burn memory 201 the plasma ignition signal, based on receipt of the plasma ignition signal, start a timer, and upon the timer meeting a time requirement, output a plasma extinguish command. Where the controller circuit 18 is not a microcontroller or microprocessor and thus is not configured with logic, registers of the type described above, and so forth, the controller circuit 18 may be designed to output the plasma extinguish command based on a predetermined time, e.g., five (5) microseconds.

[00103] The trigger circuit 203 is configured to receive the plasma extinguish command from the controller circuit 18 and output a trigger signal based on the plasma extinguish command to end the plasma therapy of the wet contact 6. The plasma extinguishing circuit 206 plasma extinguishing circuit is configured to bypass the pair of terminals upon receiving the trigger signal to extinguish the plasma between the switchable contact electrodes. The plasma extinguishing circuit 206 may be any suitable switchable shunt, including any of the embodiments of the contact bypass circuit shown in FIGs. 6A-6F of U.S. Patent No. 9,423,442, which has been incorporated by reference herein.

[00104] Plasma therapy of the wet contact 6 may be based on timing between the detection of the opening of the wet contact 6 and the time until the plasma created between the contact electrodes of the wet contact 6 transitions from the metallic plasma phase to the gaseous plasma phase, at which point the plasma ceases to clean the wet contact 6 and starts to degrade the wet contact 6. In an example in which the controller circuit 18 is a microcontroller or microprocessor, referring to FIGs. 2 and 3, when the wet contact 6 opens the voltage induced across the plasma ignition detector 200 eventually causes the plasma burn memory 201 to register the start of the metallic phase and the output to the controller circuit 18 a signal of the beginning of the plasma burn by way of terminal 1815. The controller circuit 18 then receives a voltage output from the voltage sensor 125 and a current output from the current sensor 114 and divides the voltage by the current to obtain an arc resistance at the commencement of the plasma phase, i.e., during the metallic plasma phase.

[00105] The transition from the metallic plasma phase to the gaseous plasma phase is marked by a significant increase in arc resistance. The controller circuit 18 continues to calculate the arc resistance until the arc resistance has increased by a predetermined multiple K, at which point the plasma has transitioned to the gaseous phase. The controller circuit 18 commands the arc suppressor 126, and specifically the trigger circuit 203, to extinguish the plasma by opening the plasma ignition circuit 206.

[00106] The predetermined multiple K may be empirically determined for a given wet contact 6. Thus, for instance, a relatively small wet contact 6 may have a K value of 2 while a relatively large wet contact 6 may have a K value of up to, e.g., 20 or more. The controller circuit 18 may be programmed with the K value that corresponds to the characteristics of the wet contact 6 with which the controller circuit 18 is being used, e.g., via the mode control switch 17.

[00107] Alternatively, the controller circuit 18 may iteratively determine the K value based on changes in the health of the wet contact 6. For instance, the K value may start at 2. If the power contact stick duration, as disclosed herein, progressively gets longer then controller circuit 18 may increase the K value in order to clean the wet contact 6 longer. If the power contact stick duration decreases then the K value may be maintained until the power contact stick duration has decreased to a desired amount, at which point the K value may be increased or maintained until the power contact stick duration stays steady. If the power contact stick duration growth accelerates then the K value may be decreased until the power contact stick duration growth decelerates and then decreases to a predetermined desired duration. Overall, the controller circuit 18 may track changes in the power contact stick duration and adjust the K value until the arc is allowed to burn sufficiently long that the metallic plasma phase is neither too short nor so that the arc burns long enough to transition into the gaseous plasma phase.

[00108] In alternative examples where the controller circuit 18 is a hardwired controller and does not include programmable logic, the controller circuit 18 may be hardwired to base the timing on a predetermined duration, e.g., as measured in microseconds. In an example, the duration from the receipt of the signal from the plasma burn memory 201 at terminal 1815 to the signal to the trigger circuit by way of terminal 1812 may be five (5) microseconds. Configurations of the controller circuit 18 for relatively larger wet contacts 6 may have increased durations, e.g., up to fifty (50) microseconds.

[00109] The health of the wet contact 6 may be determined on the basis of power contact stick duration. Power contact stick duration, its growth, and its change of growth as a function of the number of contact cycles within a series of consecutive observation windows and their mathematical analysis are surrogates for the electrode surface degradation/decay and are the basis for power contact health assessment. As mentioned above, the power contact stick duration is the time difference between a coil activation signal to break the power contact and the actual power contact separation, e.g., the time at which the plasma burn memory 201 outputs the plasma ignition signal to the controller circuit 18. The command for the coil activation may be mirrored or otherwise run through the controller circuit 18 to provide the time of the command to the controller circuit 18 for calculating the power contact stick duration.

[00110] In some aspects, the power contact stick duration (CSD) reports the precise moment of contact separation. This is the very moment the contact breaks the micro weld and the two contact electrodes start to move away from each other. Without an arc suppressor, even though the contact is separated, and the electrodes are moving away from each other, due to the maintained arc between the two electrodes, current is still flowing across the contact and through the power load. The power CSD provides a higher degree of prediction accuracy compared to using the moment where the current stops flowing between the separating power contact electrodes when the maintained arc terminates.

[00111] In some aspects, analysis of power contact stick duration over time, as the contact keeps on power cycling through its operational life, allows for the power contact health assessment by the health assessor 1. For example, increasing power contact stick durations, as the number of contact cycles increases, is an indication of deteriorating power contact health (e.g., surface electrode degradation/decay).

[00112] A certain power contact stick duration is considered by the relay industry as a failure and a permanently welded contact is a failed power contact. When a power contact gets older, the power contact stick duration becomes longer. When the spring force becomes weaker over time then the power contact stick durations become longer. When the current is higher and the micro weld gets

stronger, the power contact stick durations become longer. In some aspects, mathematical analysis of power contact stick duration as a function of power contact cycles allows for power contact health assessment. The mathematical analysis compares the power contact stick duration increase between two fixed, non-overlapping sampling windows. Power contact stick duration increase is also an indication of power contact decay and a surrogate for impending power contact failure prediction.

[00113] In some aspects, contact sticking (e.g., for normally open NO (Form A) contacts) may be measured as the coil de-energizing event starts the duration timer and the contact load current break arc (or the moment of contact separation) stops the timer.

[00114] A contactor is a specific, usually heavy-duty, high current, embodiment of a relay. Experimental evidence while investigating power contact electrode surface erosion has shown that the contact stick duration may be used as a surrogate for the power contact health. Further investigation has shown that the power contact stick duration becomes longer and longer as the total number of contact cycles in a power application. The contact stick duration is made worst over time due to the increased and compounded power contact electrode surface erosion in the form of asperities, craters, and pits. In this regard, while the power contact stick duration increases, the power contact health decreases.

[00115] Yet further investigation has shown that the contact stick duration and contact health relationship is neither linear nor following a natural exponential decay law but an exponential decay law in the form of A(N) = A(ref) * B^N, where A(ref) is the first reference stick duration from a new condition power contact of a relay or contactor, A(N) is the stick duration after N contact cycles, B is the stick duration growth factor, and N is the number of contact cycles.

[00116] In aspects when A(ref) = 40ms, the initial reference power contact stick duration A(N) = 1000ms, the industry-accepted maximum power contact stick duration N = 10,000,000 cycles (may be considered as a typical "maximum power contact electrical life expectancy"). Therefore, B = 321.87 x 10E-9. This value is an extremely low stick duration growth rate and may not agree with actual experienced maximum power contact electrical life while operating at rated power loads. Some relay and contactor manufacturers publish load-dependent maximum electrical contact life tables in their datasheets.

[00117] Due to inconsistencies and confusion relating to power contact electrical life expectancies, the techniques discussed herein may be used for a power contact health assessor capable of measuring stick durations, calculating, quantitatively and qualitatively assessing the actual health conditions of contacts in power relays and contactors. In some aspects, power contact health assessments may be based on the ratio of power contact average stick durations between two or more windows-of-observation (WoO).

[00118] FIG. 4 depicts a logarithmic scale graph 400 of average power contact stick duration for power contact health assessment, according to some embodiments. While specific timing is disclosed with respect to the graph 400, it is to be recognized and understood that the timings are for example only and those specific timings may vary based on the standards for what constitutes a failed power contact for the wet contact 6 being used. Thus, for instance, if the wet contact 6 is relatively sensitive then the timing may be shortened and if the wet contact 6 does not need to be as sensitive then the timing may be lengthened.

[00119] In some aspects, the windows-of-observation may be established as follows (and in reference to graph 400 in FIG. 4). After resetting the power contact health assessor or clearing stick duration register, a first window-of-observation (WoO1) 402 may be set-up. The first window-of-observation starts with the first power contact stick duration measurement and ends for example after the 100th stick duration measurement (e.g., N1 = 100 contact cycles). The power contact average stick duration for WoO1 402 is 31.25ms.

[00120] Subsequent windows-of-observation may be configured based on the first window and the average stick duration of the first window. The second window-of-observation WoO2 404 starts with the one hundred and first measurement. The WoO2 404 may be configured to end when the power contact average stick duration is, e.g., twice (or another multiple) the value of the first window-of-observation average stick duration. WoO2 404 ends when the average stick duration for that window reaches 2 x 31.25ms = 62.5ms (at contact cycle N2, where N2 may be different from N1).

[00121] The third window-of-observation (WoO3) 406 starts after the Wo02 404, e.g., after the N2 contact cycles. The WoO3 406 ends when the power contact average stick duration is, e.g., twice (or another multiple) the value of the Wo02 404 average stick duration. WoO3 406 ends when the average stick duration for that window reaches 2 x 62.5ms = 125ms

[00122] The fourth window-of-observation (WoO4) 408 starts after Wo03 406, e.g., after the N3 contact cycles. The WoO4 408 ends when the power contact average stick duration is, e.g., twice (or another multiple) the value of the Wo04 406 average stick duration. WoO4 408 ends when the average stick duration for that window reaches 2 x 125ms = 250ms

[00123] The fifth window-of-observation (WoO5) 410 starts after the Wo04 408, e.g., after the N4 contact cycles. The WoO5 410 ends when the power contact average stick duration is, e.g., twice (or another multiple) the value of the Wo04 408 average stick duration. WoO5 410 ends when the average stick duration for that window reaches 2 x 250ms = 500ms

[00124] The sixth window-of-observation (WoO6) 412 starts after the Wo05 412, e.g., after the N5 contact cycles. The WoO6 412 ends when the power contact average stick duration is, e.g., twice (or another multiple) the value of the Wo05 410 average stick duration. WoO6 412 ends when the average stick duration for that window reaches 2 x 500ms = 1000ms.

[00125] In some aspects, the last window-of-observation (or observation window) is configured so that the average stick duration for that window equals a pre-defined stick duration threshold value (e.g., 1000ms which is considered an industry limit indicating a contact has failed). Each of the obtained/configured observation windows can be associated with a corresponding health assessment characteristic indicative of the health of the contact electrodes when a contact stick duration for the electrodes falls within the corresponding window. For example, if a contact stick duration is measured at any given moment as 100ms, a health assessment of "average" may be output as 100ms falls within observation window WoO3. In some aspects, percentage indications may be used for the health assessment or a bar indicator to provide the power contact health assessment for each of the configured observation windows.

[00126] In some aspects, power contact stick duration (PCSD) may be measured for each and every contact break instant as follows: Contact Open Time minus the Coil De-energization Time. In some aspects, the contact open time may not be the same as the load current turn-off time. The load current turns off after the arc is extinguished. Arc burn durations may be up to about one-half power cycle. Furthermore, the arc may re-ignite and keep burning in the following power half cycle. The contact open time is the time when the power contact break arc ignites.

[00127] In some aspects, power contact peak stick duration (PCPSD) may be measured and used for power contact health assessment. PCPSD may be measured and recorded as the maximum power contact stick duration (PCSDmax) within the specific time window-of-observation (or PCPSD = PCSDmax).

[00128] In some aspects, power contact average stick duration (PCASD) may be measured and used for power contact health assessment. PCASD may be calculated for one or more specific windows-of-observation. PCASD may equal the sum of all stick durations within a defined window of time divided by the number of contact cycles within the specific window-of-observation.

[00129] In some aspects, the power contact stick duration crest factor (PCSDCF) may be measured and used for power contact health assessment. PCSDCF may be calculated for one or more specific time windows of observation. PCSTCF may equal the peak stick duration divided by the average stick duration within the specific window-of-observation.

[00130] In some aspects, power contact health assessment may be displayed and reported quantitatively in absolute values or relative values, such as absolute quantitatively power contact health conditions including power contact peak stick durations between 0 and 1000ms.

[00131] In some aspects, power contact stick duration crest factors may be calculated as follows for the observation windows in FIG. 3 and used for power contact health assessment: PCSDCF between 128 and 32 for the 0 to 31.25ms average stick time window-of-observation respectively ("mint/new condition failure"); PCSDCF between 32 and 16 for the 31.25 to 62.5ms average stick time window-of-observation respectively ("good condition failure"); PCSDCF between 16 and 8 for the 62.5 to 125ms average stick time window-of-observation respectively ("average condition failure"); PCSDCF between 8 and 4 for the 125 to 250ms average stick time window-of-observation respectively ("poor condition failure"); PCSDCF between 4 and 2 for the 250 to 500ms average stick time window-of-observation respectively ("replace condition failure"); and PCSDCF between 2 and 1 for the 500 to 1000ms average stick time window-of-observation respectively ("failed condition failure").

[00132] In some aspects, the following quantitative power contact health assessment may be provided: power contact health condition from 100% to 97% (new); power contact health condition from 97% to 94% (new); power contact health condition from 94% to 87.5% (average); power contact health condition from 87.5% to 75% (poor); power contact health condition from 75% to 50% (replace); and power contact health condition from 50% to 0% (failed).

[00133] In some aspects, power contact health assessment may be displayed and reported qualitatively, as follows: "new" for power contact average stick durations (PCASD) from 0 to 31.25ms; "good" for power contact average stick durations (PCASD) from 31.25 and 62.5ms; "average" for power contact average stick durations (PCASD) from 62.5 to 125ms; "poor" for power contact average stick durations (PCASD) from 125 to 250ms; "replace" for power contact average stick durations (PCASD) from 250 to 500ms; and "failed" for power contact average stick durations (PCASD) from 500 to 1000ms.

[00134] In some aspects, the power contact health assessor 1 registers may be located internally or externally to the controller circuit 18. For example, the code control chip 120 can be configured to store the power contact health assessor 1 registers that are described hereinbelow.

[00135] In some aspects, address and data may be written into or read back from the registers through a communication interface using either UART, SPI, or any other processor communication method.

[00136] In some aspects, the registers may contain data for the following operations: calculating may be understood to involve performing mathematical operations; controlling may be understood to involve processing input data to produce desired output data; detecting may be understood to involve noticing or otherwise detecting a change in the steady-state; indicating may be understood to involve issuing notifications to the users; logging may be understood to involve associating dates, times, and events; measuring may be understood to involve acquiring data values about physical parameters; monitoring may be understood to involve observing the steady states for changes; processing may be understood to involve performing controller or processor-tasks for one or more events; and recording may be understood to involve writing and storing events of interest into mapped registers.

[00137] In some aspects, the power contact health assessor 1 registers may contain data arrays, data bits, data bytes, data matrixes, data pointers, data ranges, and data values.

[00138] In some aspects, the power contact health assessor 1 registers may store control data, default data, functional data, historical data, operational data, and statistical data. In some aspects, the power contact health assessor 1 registers may include authentication information, encryption information, processing information, production information, security information, and verification information. In some aspects, the power contact health assessor 1 registers may be used in connection with external control, external data processing, factory use, future use, internal control, internal data processing, and user tasks.

[00139] In some aspects, reading a specific register byte, bytes, or bits may reset the value to zero (0).

[00140] Techniques disclosed herein relate to the design and configuration of a power contact health assessor (e.g., the power contact health assessor 1 of FIGs. 1-3) to provide an indication of the condition (or health) of the contact electrodes of the power contact. The health assessment determination can be performed based on the contact stick duration or other characteristics derived based on the contact stick duration. More specifically, different windows of observation (WoO) may be configured where each window is associated with a specific contact health condition (e.g., new, good, average, poor, replace, failed). To configure the WoO, a first observation window is configured by measuring the contact stick duration for a pre-defined number of contact cycles of a power contact within the window. An average stick duration is determined based on the measured stick durations and the number of cycles within the window. An average stick duration for each subsequent window is derived using the contact stick duration of the prior window. For example, the average stick duration of the second window is twice the average stick duration of the first observation window. The average stick duration of the third observation window is twice the average stick duration of the second observation window, and so forth. The last observation window is determined when the average stick duration reaches a maximum (pre-configured) threshold value (e.g., when the average stick duration reaches 1000 ms, which is the industry standard for a failed contact). After the observation windows with corresponding average stick durations are configured, each window can be associated with a health assessment characteristic (e.g., as illustrated in FIG. 4, six observation windows may be configured for a total of 6 possible health assessment characteristics). During operation of the power contact, contact stick durations may be periodically measured and referenced against the configured observation windows to determine in which window the measured stick duration fits, and then determine the corresponding health assessment characteristic of the current state of the contact associated with the measured contact stick duration.

[00141] <u>Additional Examples</u>

[00142] The description of the various embodiments is merely exemplary and, thus, variations that do not depart from the gist of the examples and detailed description herein are intended to be within the scope of the present disclosure. Such variations are not to be regarded as a departure from the spirit and scope of the present disclosure.

[00143] In Example 1 an electrical circuit includes a pair of terminals adapted to be connected to a set of switchable contact electrodes of a power contact, a plasma ignition detector operatively coupled to the pair of terminals, the plasma ignition detector configured to detect an electrical parameter over the switchable contact electrodes indicative of the formation of plasma between the switchable contact electrodes and output a plasma ignition signal based on the electrical parameter as detected, a plasma burn memory, configured to receive and store the plasma ignition signal, a controller circuit, operatively coupled to the plasma burn memory, configured to receive from the plasma burn memory the plasma ignition signal, based on receipt of the plasma ignition signal, start a timer, and upon the timer meeting a time requirement, output a plasma extinguish command, a trigger circuit, operatively coupled to the controller circuit, configured to receive the plasma extinguish command and output a trigger signal based on the plasma extinguish command, and a plasma extinguishing circuit, configured to bypass the pair of terminals upon receiving the trigger signal to extinguish the plasma between the switchable contact electrodes.

[00144] In Example 2, the electrical circuit of Example 1 optionally further includes that the time requirement is based on a time for the plasma to transition from a metallic plasma to a gaseous plasma.

[00145] In Example 3, the electrical circuit of any one or more of Examples 1 and 2 optionally further includes that the time requirement is based, at least in part, on an arc resistance over the pair of terminals.

[00146] In Example 4, the electrical circuit of any one or more of Examples 1-3 optionally further includes a voltage sensor and a current sensor each operatively coupled to the pair of terminals and to the controller circuit and wherein the

controller circuit is further configured to determine the arc resistance by dividing a voltage as detected by voltage sensor across the pair of terminals by a current detected by the current sensor across the pair of terminals.

[00147] In Example 5, the electrical circuit of any one or more of Examples 1-4 optionally further includes that the time requirement is based, at least in part, on the arc resistance increasing by a predetermined multiple K after the controller circuit receives the plasma ignition signal.

[00148] In Example 6, the electrical circuit of any one or more of Examples 1-5 optionally further includes that the predetermined multiple K is based on a physical characteristic of the switchable contact electrodes.

[00149] In Example 7, the electrical circuit of any one or more of Examples 1-6 optionally further includes that the predetermined multiple K is from 2 to 20.

[00150] In Example 8, the electrical circuit of any one or more of Examples 1-7 optionally further includes that the controller circuit is further configured to determine a change in contact stick duration of the switchable contact electrodes and adjust the predetermined multiple K based on the stick duration.

[00151] In Example 9, the electrical circuit of any one or more of Examples 1-8 optionally further includes that the controller circuit is further configured to increase the predetermined multiple K in response to an increase in the stick duration.

[00152] In Example 10, the electrical circuit of any one or more of Examples 1-9 optionally further includes that the time requirement is five (5) microseconds.

[00153] In Example 11 a method of cleaning switchable contact electrodes of a power contact includes coupling a pair of terminals to a set of switchable contact electrodes of a power contact. operatively coupling an arc suppressor across the pair of terminals, the arc suppressor comprising a plasma ignition detector operatively coupled to the pair of terminals, the plasma ignition detector configured to detect an electrical parameter over the switchable contact electrodes indicative of the formation of plasma between the switchable contact electrodes and output a plasma ignition signal based on the electrical parameter as detected, a plasma burn memory, configured to receive and store the plasma ignition signal, a trigger circuit, configured to receive a plasma extinguish command and output a trigger signal based on the plasma extinguish command, and a plasma extinguishing circuit, configured to bypass the pair of terminals upon receiving the trigger signal to extinguish the plasma between the switchable contact electrodes, and coupling a controller circuit to the plasma burn memory and the trigger circuit, the controller circuit configured to receive from the plasma burn memory the plasma ignition signal, based on receipt of the plasma ignition signal, start a timer, and upon the timer meeting a time requirement, output a plasma extinguish command.

[00154] In Example 12, the method of Example 11 optionally further includes that the time requirement is based on a time for the plasma to transition from a metallic plasma to a gaseous plasma.

[00155] In Example 13, the method of any one or more of Examples 11 and 12 optionally further includes that the time requirement is based, at least in part, on an arc resistance over the pair of terminals.

[00156] In Example 14, the method of any one or more of Examples 11-13 optionally further includes coupling each of a voltage sensor and a current sensor to the pair of terminals and to the controller circuit and wherein the controller circuit is further configured to determine the arc resistance by dividing a voltage as detected by voltage sensor across the pair of terminals by a current detected by the current sensor across the pair of terminals.

[00157] In Example 15, the method of any one or more of Examples 11-14 optionally further includes that the time requirement is based, at least in part, on the arc resistance increasing by a predetermined multiple K after the controller circuit receives the plasma ignition signal.

[00158] In Example 16, the method of any one or more of Examples 11-15 optionally further includes that the predetermined multiple K is based on a physical characteristic of the switchable contact electrodes.

[00159] In Example 17, the method of any one or more of Examples 11-16 optionally further includes that the predetermined multiple K is from 2 to 20.

[00160] In Example 18, the method of any one or more of Examples 11-17 optionally further includes that the controller circuit is further configured to determine a change in contact stick duration of the switchable contact electrodes and adjust the predetermined multiple K based on the stick duration.

[00161] In Example 19, the method of any one or more of Examples 11-18 optionally further includes that the controller circuit is further configured to increase the predetermined multiple K in response to an increase in the stick duration.

[00162] In Example 20, the method of any one or more of Examples 11-19 optionally further includes that the time requirement is five (5) microseconds.

[00163] In Example 21, a method includes using the electrical circuit of any one or more of Examples 1-10.

[00164] In Example 22, a non-transitory computer readable medium includes instructions which, when implemented by a controller circuit, cause the controller circuit to perform operations of any one or more of Examples 1-21.

[00165] The above-detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments. These embodiments are also referred to herein as "examples." Such examples may include elements in addition to those shown and described. However, the present inventor also contemplates examples in which only those elements shown and described are provided.

[00166] All publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) should be considered supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

[00167] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other

instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[00168] In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or integrated with other systems, modules, techniques, or methods without departing from the scope of the present disclosure. Other items shown or discussed as coupled or directly coupled or communicating with each other may be indirectly coupled or communicating through some interface, device, or intermediate component whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and could be made without departing from the scope disclosed herein.

[00169] The above description is intended to be, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with each other. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is provided to comply with 37 C.F.R. §1.72(b), to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the above Detailed Description, various features may be grouped together to streamline the disclosure. This should not be interpreted as intending that an unclaimed disclosed feature is essential to any claim. Rather, the inventive subject matter may lie in less than all features of a particular disclosed embodiment. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. An electrical circuit, comprising:

a pair of terminals adapted to be connected to a set of switchable contact electrodes of a power contact;

a plasma ignition detector operatively coupled to the pair of terminals, the plasma ignition detector configured to detect an electrical parameter over the switchable contact electrodes indicative of the formation of plasma between the switchable contact electrodes and output a plasma ignition signal based on the electrical parameter as detected;

a plasma burn memory, configured to receive and store the plasma ignition signal;

a controller circuit, operatively coupled to the plasma burn memory, configured to:

receive from the plasma burn memory the plasma ignition signal;

based on receipt of the plasma ignition signal, start a timer; and

upon the timer meeting a time requirement, output a plasma extinguish command;

a trigger circuit, operatively coupled to the controller circuit, configured to receive the plasma extinguish command and output a trigger signal based on the plasma extinguish command; and

a plasma extinguishing circuit, configured to bypass the pair of terminals upon receiving the trigger signal to extinguish the plasma between the switchable contact electrodes.

2. The electrical circuit of claim 1, wherein the time requirement is based on a time for the plasma to transition from a metallic plasma to a gaseous plasma.

3. The electrical circuit of claim 2, wherein the time requirement is based, at least in part, on an arc resistance over the pair of terminals.

4. The electrical circuit of claim 3, further comprising a voltage sensor and a current sensor each operatively coupled to the pair of terminals and to the controller circuit and wherein the controller circuit is further configured to determine the arc resistance by dividing a voltage as detected by voltage sensor across the pair of terminals by a current detected by the current sensor across the pair of terminals.

5. The electrical circuit of claim 4, wherein the time requirement is based, at least in part, on the arc resistance increasing by a predetermined multiple K after the controller circuit receives the plasma ignition signal.

6. The electrical circuit of claim 5, wherein the predetermined multiple K is based on a physical characteristic of the switchable contact electrodes.

7. The electrical circuit of claim 6, wherein the predetermined multiple K is from 2 to 20.

8. The electrical circuit of claim 7, wherein the controller circuit is further configured to determine a change in contact stick duration of the switchable contact electrodes and adjust the predetermined multiple K based on the stick duration.

9. The electrical circuit of claim 8, wherein the controller circuit is further configured to increase the predetermined multiple K in response to an increase in the stick duration.

10. The electrical circuit of claim 1, wherein the time requirement is five (5) microseconds.

11. A method of cleaning switchable contact electrodes of a power contact, comprising:

coupling a pair of terminals to a set of switchable contact electrodes of a power contact;

operatively coupling an arc suppressor across the pair of terminals, the arc suppressor comprising:

a plasma ignition detector operatively coupled to the pair of terminals, the plasma ignition detector configured to detect an electrical parameter over the switchable contact electrodes indicative of the formation of plasma between the switchable contact electrodes and output a plasma ignition signal based on the electrical parameter as detected;

a plasma burn memory, configured to receive and store the plasma ignition signal;

a trigger circuit, configured to receive a plasma extinguish command and output a trigger signal based on the plasma extinguish command; and

a plasma extinguishing circuit, configured to bypass the pair of terminals upon receiving the trigger signal to extinguish the plasma between the switchable contact electrodes; and

coupling a controller circuit to the plasma burn memory and the trigger circuit, the controller circuit configured to:

receive from the plasma burn memory the plasma ignition signal;

based on receipt of the plasma ignition signal, start a timer; and

upon the timer meeting a time requirement, output the plasma extinguish command.

12. The method of claim 11, wherein the time requirement is based on a time for the plasma to transition from a metallic plasma to a gaseous plasma.

13. The method of claim 12, wherein the time requirement is based, at least in part, on an arc resistance over the pair of terminals.

14. The method of claim 13, further comprising coupling a voltage sensor and a current sensor each operatively coupled to the pair of terminals and to the controller circuit and wherein the controller circuit is further configured to determine the arc resistance by dividing a voltage as detected by voltage sensor across the pair of terminals by a current detected by the current sensor across the pair of terminals.

15. The method of claim 14, wherein the time requirement is based, at least in part, on the arc resistance increasing by a predetermined multiple K after the controller circuit receives the plasma ignition signal.

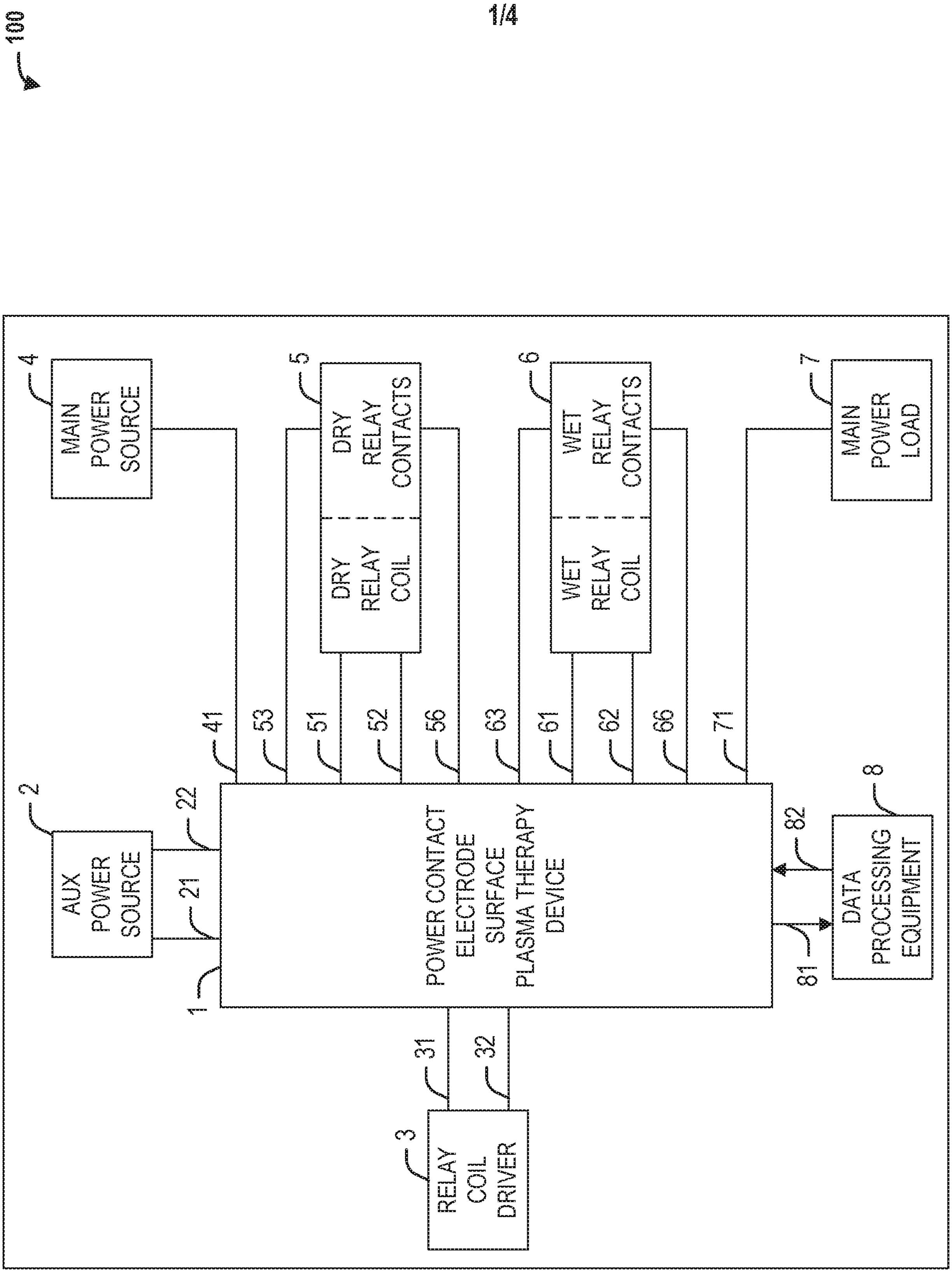
16. The method of claim 15, wherein the predetermined multiple K is based on a physical characteristic of the switchable contact electrodes.

17. The method of claim 16, wherein the predetermined multiple K is from 2 to 20.

18. The method of claim 17, wherein the controller circuit is further configured to determine a change in contact stick duration of the switchable contact electrodes and adjust the predetermined multiple K based on the stick duration.

19. The method of claim 18, wherein the controller circuit is further configured to increase the predetermined multiple K in response to an increase in the stick duration.

20. The method of claim 11, wherein the time requirement is five (5) microseconds.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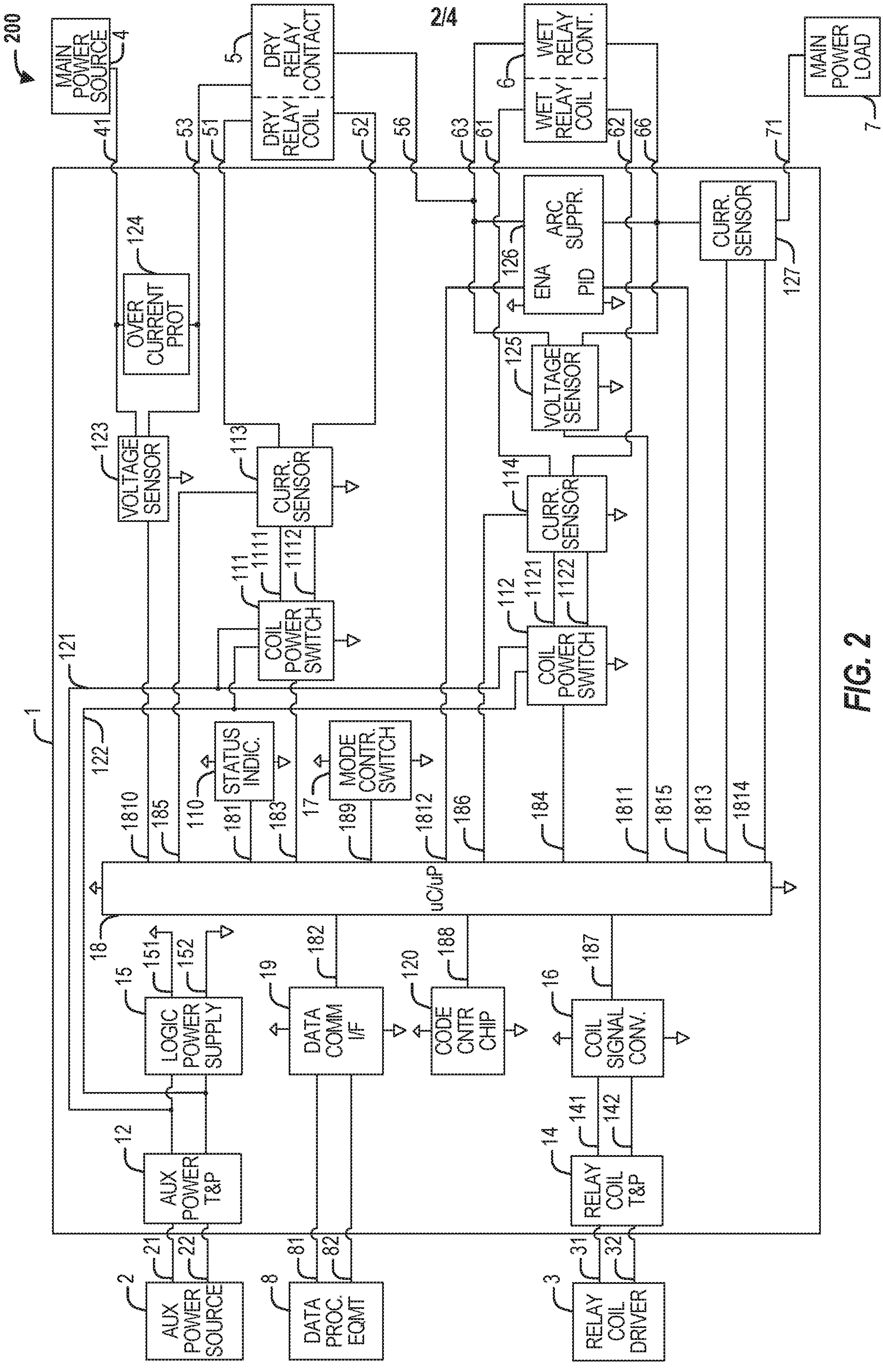
4
DRY RELAY CONTACTS
DRY RELAY COIL
5
WET RELAY CONTACTS
WET RELAY COIL
6
MAIN POWER LOAD
7
AUX POWER SOURCE
2
21
22
41
53
51
52
56
63
61
62
66
71
POWER CONTACT ELECTRODE SURFACE PLASMA THERAPY DEVICE
1
81
82
DATA PROCESSING EQUIPMENT
8
31
32
RELAY COIL DRIVER
3

FIG. 1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DRY RELAY CONTACT
5
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41
53
51
52
56
63
61
62
66
71
OVER CURRENT PROT
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ARC SUPPR.
ENA
PID
126
CURR. SENSOR
127
VOLTAGE SENSOR
125
VOLTAGE SENSOR
123
CURR. SENSOR
113
CURR. SENSOR
114
COIL POWER SWITCH
111
1111
1112
COIL POWER SWITCH
112
1121
1122
121
122
1
STATUS INDIC.
110
MODE CONTR. SWITCH
17
1810
185
181
183
189
1812
186
184
1811
1815
1813
1814
uC/uP
18
LOGIC POWER SUPPLY
15
151
152
DATA COMM I/F
19
182
CODE CNTR CHIP
120
188
COIL SIGNAL CONV.
16
187
AUX POWER T&P
12
RELAY COIL T&P
14
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DATA PROC. EQMT
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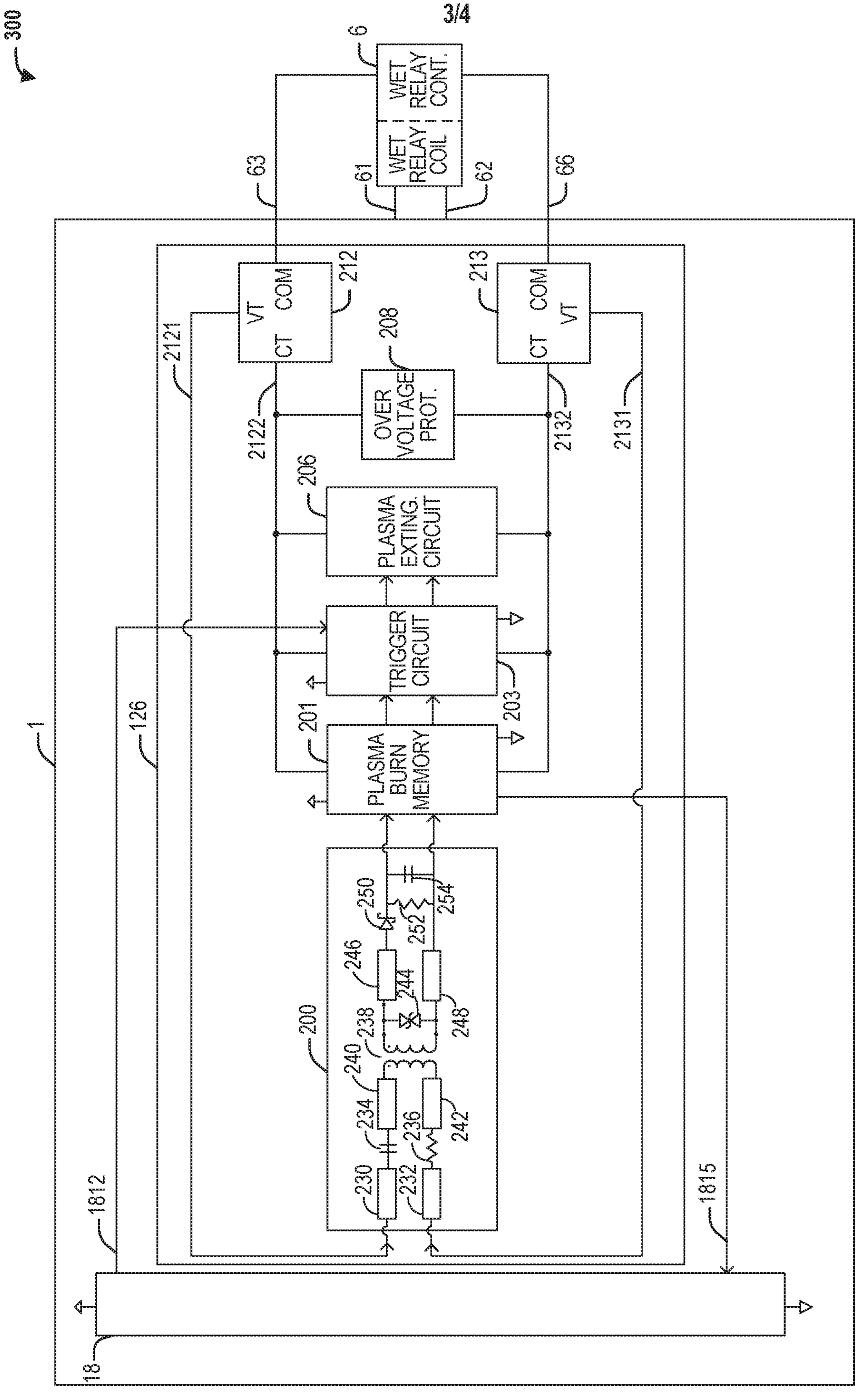
81
82
RELAY COIL DRIVER
3
31
32

FIG. 2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CT
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2132
2131
OVER VOLTAGE PROT.
208
PLASMA EXTING. CIRCUIT
206
TRIGGER CIRCUIT
203
PLASMA BURN MEMORY
201
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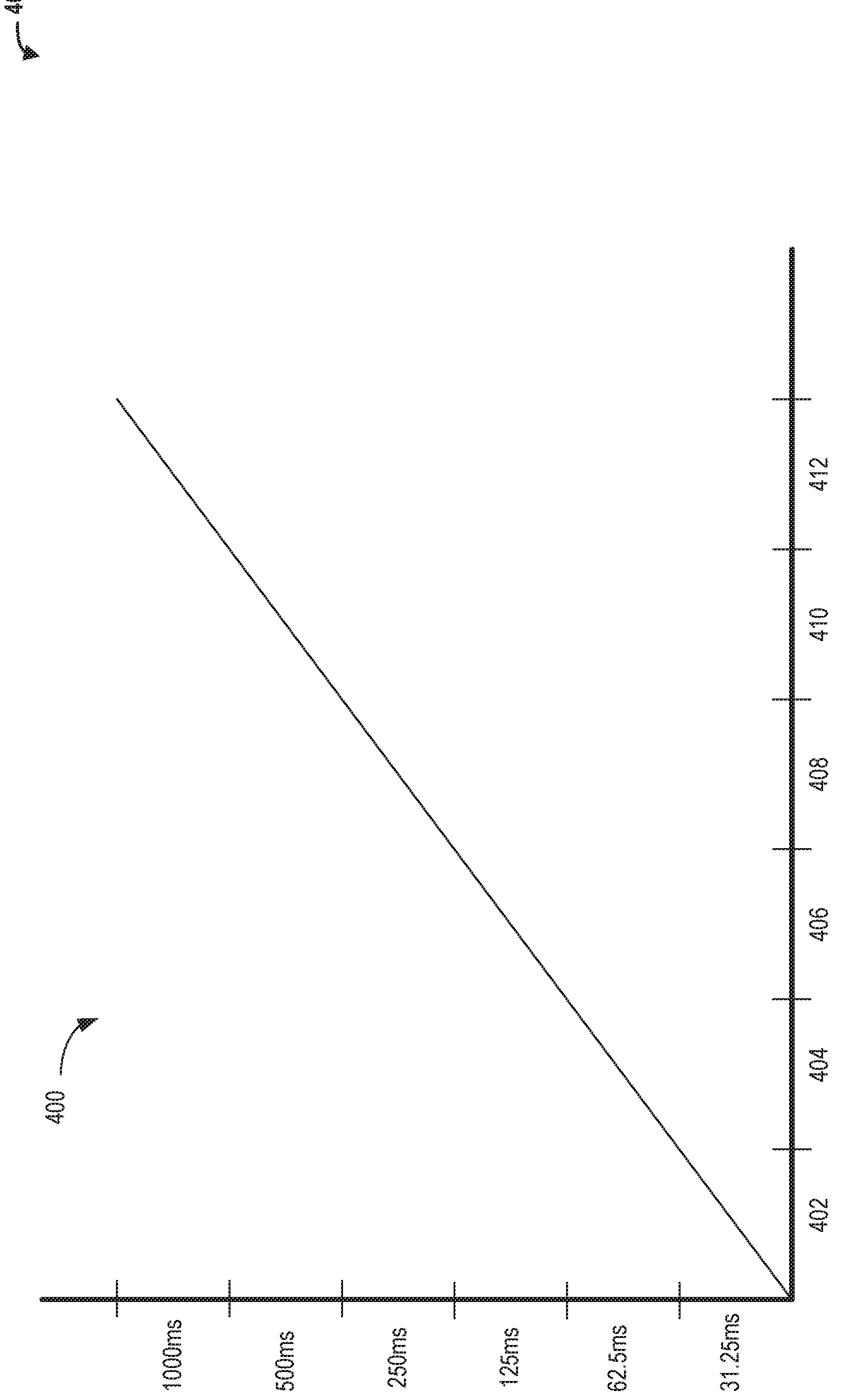
1815
18

FIG. 3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500ms
250ms
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31.25ms
402
404
406
408
410
412

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2020/050336

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01H47/002 H01H9/54 H01H1/60
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)
H01H

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.
A	DE 44 27 006 A1 (SIEMENS AG [DE]) 1 February 1996 (1996-02-01) page 3, lines 27-35; figure 2	1-20
A	US 2002/118495 A1 (BECKERT JAMES J [US] ET AL) 29 August 2002 (2002-08-29) paragraphs [0039], [0078], [0104]; figures	1-20
A	DE 197 11 622 C1 (FRAUNHOFER GES FORSCHUNG [DE]) 23 July 1998 (1998-07-23) the whole document	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"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
14 December 2020	18/12/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Ramírez Fueyo, M

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2020/050336

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
DE 4427006	A1	01-02-1996	DE	4427006	A1	01-02-1996
			EP	0694937	A2	31-01-1996
			ES	2145185	T3	01-07-2000
US 2002118495	A1	29-08-2002	NONE			
DE 19711622	C1	23-07-1998	DE	19711622	C1	23-07-1998
			EP	0866480	A2	23-09-1998