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[Continued on next page]

(54) Title: HIGH RELIABILITY ESP GAUGE TESTING

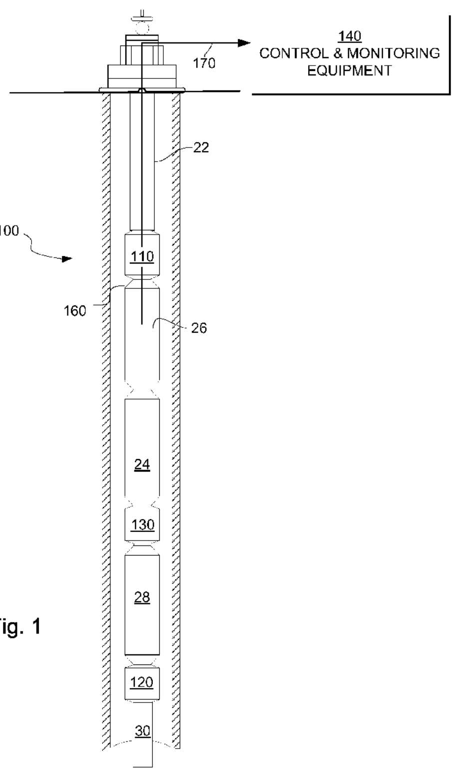

Fig. 1

(57) Abstract: Systems, apparatus and methods for testing quality and reliability of gauges used in electric submersible pump (ESP) implementations utilize a testing control device for controlling gauge testing according to predetermined test profiles. The test profiles may define test parameters and testing sequences that are appropriate for evaluating the quality, reliability and robustness for a particular gauge. The testing control device may provide instructions for facilitating and controlling test environments for ESP gauge testing. Test profiles may provide parameters and test conditions for shock tests, including transport, operational and vertical drop tests, cold storage tests, random vibration tests, temperature or thermal pressure-temperature envelope tests, and highly accelerated life tests (HALT), and combinations thereof. Gauge testing may include gauges for detecting the motor resistance temperature of motors used in ESP implementations.

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HIGH RELIABILITY ESP GAUGE TESTING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present document is based on and claims priority to U.S. Provisional Patent Application Serial No: 61/833,926 filed June 12, 2013, the subject matter of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Oil well completions may employ electric submersible pumps (ESP's) to inject fluid. In typical ESP applications, a number of gauges may be employed to monitor operational and environmental parameters such as pressure, temperature and flow in the ESP system. Down hole conditions may include high pressure and high temperature (HPHT) and otherwise harsh environments. Such conditions are especially prevalent in sub-sea applications for ESP's.

[0003] Efficient and cost-effective operation of any ESP application vitally depends upon the reliability and robustness of the gauges employed in that application. Gauge failure or inaccuracy may lead to excessive operational costs, which can exceed millions of dollars. While an ESP can be operated "blind" (without full operation of one or more gauges), such operation increases the risk of ESP string failure and the requirement for intervention, which, in the case of subsea ESP deployments, can be extremely costly. Typically, before deployment of equipment to a subsea application, gauges may be tested in an onshore environment.

SUMMARY

[0004] Aspects of high reliability ESP gauge testing disclosed herein provide systems, apparatus and methods that address the aforementioned problems and shortcomings in the prior art. The systems, apparatus and methods may utilize a testing control device for controlling gauge testing according to predetermined test profiles and which may send instructions to a test bed or test environment. The test profiles may define test parameters and testing sequences that are appropriate for evaluating the quality, reliability and robustness for a particular gauge. The testing control device may provide instructions for facilitating and controlling test environments for ESP gauge testing.

[0005] Methods may include developing and storing test profiles, determining an ESP gauge to be tested, retrieving a selected profile based on the type of ESP gauge, conducting at least one test associated with the selected profile, and evaluating the quality and reliability of the ESP gauge based on the conducted test.

[0006] Test profiles according to an aspect of high reliability ESP gauge testing may provide parameters and test conditions for shock tests, including transport, operational and vertical drop tests, cold storage tests, random vibration tests, temperature or thermal pressure-temperature envelope tests, and highly accelerated life tests (HALT), and combinations thereof. Gauge testing may

include gauges for detecting the motor resistance temperature of motors used in ESP implementations.

[0007] Test methodologies, sequences and profiles according to an aspect of high reliability ESP gauge testing may be customized based on specific past environments and experience of the particular gauge, such as transportation vibration or temperature variations occurring during transport or storage. Aspects of high reliability ESP gauge testing may also be customized based on the particular HPHT application or mission profile for which a particular gauge is to be used, including temperature variations likely to be experienced by the gauge during an ESP shutdown, the frequency of ESP shutdowns or any anticipated HPHT condition. Moreover, additional design, test or error margins and noise factors may be the basis for customizing test methodologies, sequences and/or profiles according to aspects of high reliability ESP gauge testing.

[0008] Aspects of high reliability ESP gauge testing may further include developing a testing profile according to an overall qualification strategy, which includes sequences for testing electrical or mechanical subassemblies of a particular gauge. A test sequence for testing the complete tool, in addition to testing the subassemblies, may also be performed for evaluating the reliability of gauges for ESP's.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Certain embodiments of high reliability ESP gauge testing will hereafter be described with reference to the accompanying drawings, in which like reference numerals denote like elements, and:

[00010] Figure 1 is a front elevation view of an ESP implementation showing diverse uses and configurations for down hole monitoring gauges;

[00011] Figure 2 is a schematic view of a gauge testing control device according to an aspect of high reliability ESP gauge testing;

[00012] Figure 3 is a schematic view of a testing environment or test bed according to an aspect of high reliability ESP gauge testing;

[00013] Figure 4 is a high level flow diagram for a gauge testing process supported by a testing control device according to an aspect of high reliability ESP gauge testing;

[00014] Figures 5A, 5B and 5C are respective flow diagrams for a gauge electronic subassembly test, mechanical subassembly test and complete tool test according to an aspect of high reliability ESP gauge testing;

[00015] Figure 6 is a schematic diagram of a vertical drop test equipment suitable for supporting a vertical drop test according to an aspect of high reliability ESP gauge testing;

[00016] Figure 7 is a graph illustrating temperature changes according to a cold storage test profile according to an aspect of high reliability ESP gauge testing;

[00017] Figure 8 is graph illustrating a random vibration test profile according to an aspect of high reliability ESP gauge testing;

[00018] Figure 9 is a graph illustrating a temperature cycling test profile according to an aspect of high reliability ESP gauge testing;

[00019] Figure 10 is a pressure-temperature envelope test profile according to an aspect of high reliability ESP gauge testing;

[00020] Figures 11A and 11B illustrate a Highly Accelerated Life Test (HALT) profile according to an aspect of high reliability ESP gauge testing;

[00021] Figure 12 illustrates a motor winding resistance temperature detector (RTD) qualification process according to an aspect of high reliability ESP gauge testing; and

[00022] Figure 13 illustrates a pressure-temperature envelope test profile for a motor RTD qualification test according to an aspect of high reliability ESP gauge testing.

DETAILED DESCRIPTION

[00023] In the following description, numerous details are set forth to provide an understanding of the present invention. However, it will be understood by those of ordinary skill in the art that the present invention may be practiced without these details and that numerous variations or modifications from the described aspects may be possible.

[00024] Referring generally to Fig. 1, which is a front elevation view of an ESP implementation showing diverse uses and configurations for down hole monitoring gauges, a typical ESP installation 100 may include one or more pumps 28 which are driven by a motor 26. A pressure compensating section or compensator 24 may be disposed in the ESP string below the motor 26. An intake gauge 120 may monitor flow from an intake shroud 30. A discharge gauge 130 may monitor fluid discharging from the compensator 24. A base gauge 110 for monitoring upstream parameters may be disposed above the motor 26.

[00025] Intake gauge 120 and discharge gauge 130 may be in electrical and data communication with base gauge 110 via control lines, as is known in the art. A thermal couple wire 160 may form a thermal communication link between the windings of motor assembly 26 and base gauge 110 to provide information regarding motor resistance temperature, as will be described. Base gauge 110 may also communicate data and/or signals via a control line 170 which may extend through a connector housing 22 and communicates with control and monitoring equipment 140, which is typically located on the surface. The aforementioned configuration of ESP installation components is generally well known in the art.

[00026] As will be appreciated, different gauges can perform different tasks, or may perform similar tasks at different locations in an ESP string. It is therefore important for each gauge to generate reliable output and to be robust in its ability to do so regardless of the physical conditions of the down hole environment, such as high pressure and temperature. Unreliable gauges not only generate inaccurate

output, but may also skew the interpretation of data that is output by other gauges on the ESP string. Thus, the testing and verification of gauge accuracy, reliability and robustness prior to deployment of the gauge in an ESP string is of vital importance.

[00027] According to an aspect of high reliability ESP gauge testing, testing of gauge reliability and quality may be conducted according to a testing methodology, which establishes a sequence of tests or test points and provides for the testing of gauges according to specific test profiles for evaluating the degree of reliability for a particular gauge and particular application. An example methodology, sequence of tests, and/or test profiles can be customized based on: 1) specific past experience (e.g., transportation vibration, historical cold temperature exposure or other conditions experienced prior to installation of the gauge); 2) a high pressure high temperature (HPHT) application mission profile associated with an expected deployment conditions for an ESP gauge (e.g., temperature variation expected due to ESP shutdown, shutdown frequency, or a known HPHT condition); 3) additional design considerations, test margins and noise factors.

[00028] An example test system and methodology may adopt an overall qualification strategy, and includes techniques and test sequences for testing each electrical subassembly and each mechanical subassembly of a monitoring gauge, and thereby provides a complete testing tool or testing system for evaluating the reliability of ESP gauges.

[00029] Figure 2 illustrates a testing control device 200 according to an aspect of high reliability ESP gauge testing. A computing hardware and software environment suitable for implementing a testing control device and gauge testing system according to an aspect of high reliability ESP gauge testing may include one or more processors or processing units 210 as well as one or more memory components 206, one ore more input/output devices 208, and a data bus (not shown), which provides for communication between processors 210, memory 206 and various other components of testing control device 200. The data bus may be characterized by any of several types of known bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. Data bus may be a wired or wireless bus.

[00030] Local data storage 230 provides for the storage of data. Memory components 206 may include volatile media, such as random access memory (RAM) and/or non-volatile media (such as read only memory (ROM), flash memory, etc. Local data storage 230 can include fixed media (e.g. RAM, ROM, a fixed hard drive, solid state drive, etc.) as well as removable media (e.g., a flash memory drive, a removable hard drive, optical disks, magnetic disks, and so forth).

[00031] One or more input/output devices 208 may allow a user to input commands and information to testing control device 200, and may also allow information to be presented to the user and/or other components or devices.

Examples of input devices include a keyboard, a mouse, a microphone, a scanner and so forth. Examples of output devices include a display device, such as a monitor or projector, speakers, a printer, a network card and so forth.

[00032] A user interface device may also communicate via user interface (UI) controller 240, which may connect with the UI device either directly or through the data bus. A network interface 250 may communicate with external hardware and software, as well as gauge testing and monitoring environment 270, which may include various testing equipment or test beds that are not necessarily co-located with one another, upon which the testing according to the test profiles 222 and test sequences 220 stored in memory may be performed.

[00033] Media drive /interface 260 accepts media 265, such as flash drives, optical disks, removable hard drives, software products, etc. Logic, computing instructions, or a software program comprising elements of the gauge testing system may reside on removable storage media 265 that is readable by the media drive 260.

[00034] Various techniques and modules of the gauge testing system may be described herein in the general context of software or program modules, or components. It will be understood and recognized that the techniques and modules may be implemented in pure computing hardware as well as software or a combination of both. Software generally includes routines, programs, objects, components, data structures, and so forth that perform particular tasks or implement particular data types. An implementation of these modules and/or techniques may be stored on or transmitted across some form of tangible computer readable media. Computer readable media can be any available data storage medium or media that is tangible and that can be accessed by a computing device. Computer-readable media thus may comprise computer storage media.

[00035] Computer storage media include volatile and non-volatile, removable and non-removable tangible media implemented for storage of information such as computer readable instructions, data structures, program modules, or other data. Computer storage media include, but are not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other tangible medium which can be used to store the desired information, and which can be accessed by a computer.

[00036] In accordance with an aspect of high reliability ESP gauge testing, one or more test profiles 222 may be stored in memory 206. Test profiles are pre-configured data and instructions for performing tests on particular ESP gauges and based on particular applications or mission objectives. Profiles 222 may include test sequences to be performed in an automated fashion, or may include instructions for operators to perform on test equipment. The testing control device 200 may be implemented to monitor and analyze gauge data and control or intervene to help provide improved operation, high reliability, and high availability to gauges and their associated ESP strings. It will be understood that the hardware environment and associated system is only one example of a testing control device according to an aspect of high reliability ESP gauge testing and is not intended to suggest any limitation as to scope of use or functionality or architecture. Neither should testing control device 200 be interpreted as having any dependency or requirement relating to any one or a combination of components illustrated in the example device 200.

[00037] Figure 3 illustrates a testing environment or test bed 300 according to an aspect of high reliability ESP gauge testing. It will be recognized that components of the test bed or test environment need not be at a single geographic location or test facility, but may extend across different testing facilities and physical locations. Testing environment 300 may be utilized to implement the test profiles of testing control device 200 through appropriate communication and data links.

[00038] Test bed 300 may include a number of controls for the ambient environment 310, including a temperature control 312, pressure control 314 and humidity control 316. Test bed 300 may also include vibration and shock controls 320, which may include a vertical shock test fixture 322 and vibration controls 324 for subjecting the device under test to shock forces and vibrations of varying frequency. A gauge monitoring device 330 may monitor gauge performance and accuracy during testing.

[00039] Figure 4 illustrates a high level process 400 for testing an ESP gauge according to aspects of high reliability ESP gauge testing. The process 400 may be performed by hardware and software elements of the testing control device 200 described above. At 402, a test profile is designed for a particular gauge and gauge application for evaluating the quality and reliability of the gauge. The test profile may be then stored in memory 206 (Figure 1) of testing control device 200 (Figure 1). Step 404 may involve the application of the test profile to the ESP gauge testing in a sequence of tests, which may be performed in test bed 300 (Figure 3) or across a number of test beds or testing environments according to the profile. At 406, the quality and reliability of the gauge is evaluated based on the results of the sequence of tests performed according to a selected test profile.

[00040] An example test sequence according to an aspect of high reliability ESP gauge testing may include simulation of worst-case scenarios for a particular ESP gauge. Test profiles and the rationale for them are described with regard to test cases below.

[00041] An example test profile may include:

1. Shock Test
2. Vertical Drop Test
3. Cold Storage Test
4. Random Vibration Test
5. Temperature Cycle Test
6. Pressure-Temperature (PT) Envelope Test
7. Highly Accelerated Life Test (HALT)
8. Motor Resistance Temperature Qualification

9. High Temperature Accelerated Life Test

[00042] Profiles may also specify an application acceleration model to be used, such as a Coffin-Manson model for temperature cycling, or an Arrhenius model for a high temperature life test.

[00043] Test strategies may involve testing of subassemblies, including electrical subassemblies as well as mechanical subassemblies of an ESP gauge. Table A below describes test methods or strategies for various types of components, which may constitute mechanical or electrical subassemblies of an ESP gauge or an ESP string.

Table A

Component	Test Method/Strategy
Surface Unit	Accelerated Testing
Electrical Connector/Penetrator	Environmental Robustness Test
Twisted Pair Cable	Environmental Robustness Test
Mechanical Seal	Pressure/Temperature Test, Environmental Robustness Test
Mechanical Body	Design Margin/Modeling and Pressure Test
Multi-chip Module (MCM)	High Temperature Accelerated Life Testing
Sensors	Drift Test, Environmental Robustness Test

[00044] Referring to Figures 5A, 5B and 5C, example test profiles may include test sequences for electronic and mechanical subassemblies of an ESP gauge, in addition to test sequences for the completely assembled gauge. As will be recognized, testing of subassemblies may occur as part of a manufacturing process, or may occur when the subassembly is fully assembled in the ESP gauge.

[00045] Figure 5A illustrates a process 500 for an electronic subassembly test according to an aspect of high reliability ESP gauge testing. The process is initiated at 502. At 504, a high temperature life test may be performed. At 506, a highly accelerated life test (HALT) may be performed on the electronic subassembly. Further testing may involve thermal analysis at 508, shock test (room temperature) at 510, elevated or "hot" shock test at 512, thermal cycle testing at 514, vibration testing (transmissibility and transport) at 516 and a humidity test at 518. This subassembly test sequence may be developed for each particular gauge and expected operating environment. The process terminates at 520.

[00046] Figure 5B illustrates a process 530 for a mechanical subassembly test according to an aspect of high reliability ESP gauge testing. The process is initiated at 532. An optional chemical compatibility test may be performed at 534. Further tests may include a vibration/transmissibility test at 536, a shock test at 538, a pressure/temperature envelope test at 540, a load test at 542 and a bending test at 544. The process terminates at 546.

[00047] Figure 5C illustrates a process for testing of the complete tool (gauge). The process is initiated at 552. A high temperature life test may be performed at 554. Additional tests are performed on the complete tool, including a cold storage test at 556, vertical drop test at 558, shock test at 560, hot shock test at 562, vibration test at 564 and pressure/temperature envelope test at 566. Field tests may be performed at 570 and robustness tests, which may include statistical methods such as those utilizing a Taguchi DOE Matrix, may be performed at 572.

[00048] Details regarding the various tests that may be performed to verify the quality, reliability and robustness of an ESP gauge will be described. Test profiles, which may be stored and retrieved by testing control device 200 (Figure 2) will also be described in conjunction with the corresponding test apparatus or test environment.

Shock Test (Transport)

[00049] According to an aspect of high reliability ESP gauge testing, low-cost shock or impact detectors may be provided on or in packaging or shipping containers for ESP gauges or may be provided on the ESP gauge itself. For example, such shock detectors may include products sold under the name SHOCKWATCH® by a company of the same name in Dallas, Texas. (www.shockwatch.com). Shock testing sequences in testing profiles, according to aspects of high reliability ESP gauge testing, may include the acquisition of data from shock detectors associated with the transportation of an ESP gauge. Shock detectors, in the form of low cost adhesive detectors provided on a shipping container may indicate whether or not the container and ESP gauge, or subassembly thereof, experienced a shock force in excess of a predetermined threshold.

[00050] For example, a test profile may include a requirement that the shock detectors having thresholds of a predetermined force are not activated or set off during any time while an ESP gauge is in transit.

Shock Test (Operational)

[00051] Test profiles according to aspects of high reliability ESP gauge testing may provide for limiting the shock of an ESP to 10g maximum during operation. The operation threshold is typically lower than the transportation threshold as damage to the ESP is more likely when experiencing smaller shocks under operation.

[00052] A testing profile according to aspects of high reliability ESP gauge testing may include a 50g shock force administered at 2 ms, over a total of 100 shocks per axis. That is a total of 400 shocks, with 100 administered each across the positive and negative x-axis and the positive and negative y-axis of a frame of reference associated with the ESP gauge to be tested. Shock tests may be administered at room temperature, as well as at an elevated temperature, such as 311 degrees F across a predetermined sample size.

Shock Test (Vertical Shock)

[00053] Testing sequences may also include a vertical shock test. The vertical shock test may simulate axial shock to the ESP gauge during transportation or installation. An apparatus for performing a vertical shock test is shown in Figure

6. A test profile according to the invention may include 5 drops from a six inch height, on a steel and/or concrete surface. A sample size of three ESP gauges may be used to ensure that results are consistent across a manufactured sample.

[00054] As will be recognized, with regard to the tests described herein, the number of shock tests, number of samples, drop height and environmental conditions can be modified, depending on the mission profile associated with a particular ESP gauge.

Cold Storage Test

[00055] A cold storage test may be included in the test profiles according to aspects of high reliability ESP gauge testing. Referring to Figure 7, a cold storage test may include reducing the ambient temperature of the ESP gauge under test to an expected low temperature at a wellhead, such as 40 °F. A gauge functional check may be performed prior to installation. The cold storage test may also factor in expected minimum transportation temperatures. An profile may include holding the ambient temperature at -35 ° C for a dwell period of 48 hours, with a transition rate of temperature less than 5 ° C per minute. The test profile may also include a power-on cycle for the ESP gauge under test, whereby the gauge is powered on and off for 5 cycles at the end of the dwell period. A sample size of three test ESP gauges may be used for more dependable test results. As will be recognized, the temperature, test duration, dwell time, power cycle number and sample size may be varied according to a particular mission profile or other parameters or environment associated with the ESP gauge under test.

Random Vibration Test

[00056] A random vibration test may be employed as a test sequence in test profiles according to aspects of high reliability ESP gauge testing. Random vibration tests may simulate vibration that occurs during transportation of an ESP gauge. Figure 8 illustrates a random vibration test characteristic. Vibration frequency of a range between 5Hz to 450 Hz may be used with a 3.72Grms value. The ESP gauge may be power on and monitored during the vibration. A sample size of three maybe used for dependable results.

Thermal Cycling Fatigue Test

[00057] According to aspects of high reliability ESP gauge testing, test profiles may incorporate thermal cycling fatigue tests testing the effects of thermal cycle fatigue on an ESP gauge. Reference is made to Standards Document JEP122G titled "Failure Mechanisms and Models for Semiconductor Devices," the subject matter of which is incorporated herein by reference in its entirety. An acceleration factor for fatigue testing may be calculated as follows:

$$A_f = \left(\frac{\Delta T_t}{\Delta T_u}\right)^m$$

Where A_f is the acceleration factor; ΔT_t is the thermal cycle temperature change in the test environment; ΔT_u is the thermal cycle temperature change in the use environment; and m is a constant, typical value for a given failure mechanism or derived from empirical data.

[00058] Figure 9 illustrates a thermal cycling test. According to a test profile, a temperature cycle range (Tmin to Tmax in Figure 9) of -35C to 155C, 300 cycles and a 5 degree C per minute transition rate, 15-minute dwell time may be used. An acceleration factor may be derived according to a known Coffin-Manson model as described in standards document Jedec JEP122G, where the factor m equals a constant according to a failure mode described in the Jedec specification.

Pressure Temperature Envelope Test

[00059] Figure 10 shows an example pressure-temperature envelope test that may be used in testing profiles according to aspects of high reliability ESP gauge testing. Operational pressure may vary from atmospheric pressure up to 23kpsi, with a rate change of 200 psi per minute or more. A testing profile may, according to aspects of high reliability ESP gauge testing may include a temperature range (envelope) of ambient temperature up to operating temperature, plus a predetermined temperature margin, and a pressure range of atmospheric pressure up to operating pressure plus a predetermined pressure margin and a rate change of pressure of 500 psi/min, for example. A sample size of a predetermined number of gauges may be used for testing to increase dependability of the test results.

Highly Accelerated Life Test (HALT)

[00060] Figures 11A and 11B illustrate a Highly Accelerated Life Test (HALT). Such testing is useful for determining operating and destruction limits when ESP gauges are exposed to hot or cold thermal stress, rapid thermal transitions (50 C/min), vibration (6-degree of freedom random vibration), and thermal cycling and vibration combined. HALT enables quick identification of system weak points. The purpose of HALT is to determine the operating and destruct limits of a design - why those limitations exist and what is required to increase those margins. HALT, therefore, stresses products beyond their design specifications. HALT provides improved ESP gauge design, increased ESP gauge robustness and minimizes the possibility of costly gauge failure or low performance in an ESP deployment.

Motor Resistance Temperature Detector (RTD) Qualification

[00061] One type of gauge that may be used in an ESP implementation is a Motor Resistance Temperature Detector (RTD), which is typically used to measure/detect the temperature of motor windings in ESP pump motors (26, Figure1). An qualification test process for a motor RTD is illustrated in Figure 12. The process is initiated at 1202. A beginning sample of five test gauges may be used. Preliminary tests are performed on all five beginning samples at 1204, as well as metrology evaluation at 1206. A high temperature aging test may be performed at 1208 on all five samples. Upon passing the high temperature aging test, three of the five samples may be further tested using a shock test at 1212, pressure/temperature envelope test at 1214, and a helium leak test at 1216. The process is concluded at 1218. As will be recognized, the above-described sequences may proceed in a different order, such as the helium leak test 1216 or pressure/temperature envelope test 1214 being done prior to the high temperature aging test 1208.

[00062] Table B below sets forth a hot shock test for a motor resistance temperature detector (RTD) qualification. Four different orientations are assumed by the gauge, and 100 shocks at shock levels of 50G for 2.0 ms are applied to the test gauge at each orientation.

Table B

Orientation (Degrees)	Shock Level(g)	Shock Quantity	Duration (ms)
0	50	100	2.0
90	50	100	2.0
180	50	100	2.0
270	50	100	2.0

[00063] Figure 13 illustrates a pressure-temperature cycle at ambient temperature according to an aspect of high reliability ESP gauge testing. A pressure-temperature (P/T) envelope test profile sequence of the motor RTD qualification may include:

A) At ambient temperature:

1) increase pressure in device under test (DUT) from ambient to 30000 psi at 500 psi/minute;

2) dwell at 30000 psi for 45 minutes;

3) decrease from 30000 psi to 2000 psi at 500 psi/minute;

4) dwell at 2000 psi pressure for 45 minutes.

The temperature may the be increased to 255 °C (+/- 5°C) at 2° C/minute and allowed to stabilize, then at the elevated, stabilized temperature of 255 °C:

B) At elevated temperature of 255 °C:

1) increase pressure in DUT from 2000 to 30000 psi at 500 psi/minute;

2) dwell at 30000 psi pressure for 5 minutes on each cycle.

3) decrease from 30000 psi pressure to 5000 psi at 500 psi/minute;

4) dwell at 5000 psi for 5 minutes;

5) increase pressure from 5000 to 30000 psi at 500 psi/minute;

6) repeat 3) to 5) until 5 cycles are completed in total

7) at the end of the fifth cycle, simultaneously decrease temperature and pressure to ambient. A maximum temperature transition rate of 3 °C/minute may be implemented to ensure undesirable levels of thermal stresses do not develop.

Accelerated Temperature Life Test

[00064] An example accelerated temperature life test can be used to estimate electronics life expectancy at a stress level that is expected to be seen in operation - up to the temperature rating. The test sequence may comprise subjecting the electronics sub-assembly or the complete tool (gauge) to high temperature burn-in and testing until failure. The product may be powered on during the test. An Arrhenius model may be used to analyze the life versus stress relationship. Two or three different temperatures may be used to calculate the correct activation energy (which caused failure) used in the Arrhenius model. Life data analysis techniques may be used to calculate life expectancy at a stress level (operational condition) below test stress levels.

[00065] Although the preceding description has been set forth herein with reference to particular means, materials and embodiments, it is not intended to be limited to the particulars disclosed herein; rather, it extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. While some aspects and embodiments of the present invention have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this invention. Accordingly, such modifications are intended to be included within the scope of this invention, which is defined in the claims that follow. The specific test parameters and ranges set forth herein are intended as examples, and not as limits on the scope of high reliability ESP gauge testing disclosed herein.

CLAIMS

What is claimed is:

1. A testing control device for supporting testing of an ESP gauge comprising:

a non-transitory, computer-readable medium for storing data and instructions;

at least one test profile stored in the non-transitory computer-readable medium and defining test parameters and sequences for an ESP gauge;

a processor for executing the instructions stored in the non-transitory computer-readable medium, the instructions, when executed, causing the testing control device to:

receive information representing an ESP gauge;

retrieve the at least one test profile based on the information representing the ESP gauge;

send instructions representing operation of test equipment according to the test parameters and sequences corresponding to the retrieved test profile.

2. The testing control device of claim 1, wherein the at least one test profile includes information for at least one test selected from the group consisting of: a shock test, a vertical drop test, a cold storage test, a random vibration test; a temperature cycle test; a pressure temperature envelope test; a highly accelerated

life test; a motor resistance test device qualification test, and a high temperature accelerated life test.

3. The testing control device of claim 1, wherein the at least one test profile includes test parameters and sequences for testing subassemblies of an ESP gauge.

4. The testing control device of claim 3, wherein the at least one profile includes test parameters and sequences for testing an electrical subassembly, a mechanical subassembly and the complete gauge.

5. The testing control device of claim 1, further comprising a test bed for performing tests on an ESP gauge.

6. The testing control device of claim 5, wherein the test bed includes a facility for conducting shock tests, vibration tests and thermal cycling tests on an ESP gauge.

7. The testing control device of claim 5, wherein the test bed includes controls for ambient environment, including temperature, pressure and humidity, vibration controls and shock controls.

8. The testing control device of claim 1, wherein the at least one test profile includes test parameters and sequences for testing a motor resistance temperature detector associated with an electric submersible pump installation.

9. The testing control device of claim 1, wherein the at least one test profile includes test parameters and sequences for a shock test.

10. A method for testing an ESP gauge comprising:

developing at least one test profile for evaluating the quality and reliability of a corresponding ESP gauge;

storing the at least one test profile;

determining an ESP gauge to be tested;

retrieving a selected one of the at least one test profile based on the determined ESP gauge;

conducting at least one test associated with the selected test profile; and

evaluating the quality and reliability of the ESP gauge based on the conducted test.

11. The method of claim 10, wherein the at least one test profile includes parameters and sequences for at least one test selected from the group consisting of: a shock test, a vertical drop test, a cold storage test, a random vibration test; a temperature cycle test; a pressure temperature envelope test; a highly accelerated

life test; a motor resistance test device qualification test, and a high temperature accelerated life test.

12. A method of claim 10, further comprising testing subassemblies of an ESP gauge according to the selected test profile.

13. The method of claim 10, wherein conducting at least one test comprises utilizing a test bed having ambient environment controls for temperature, pressure and humidity.

14. The method of claim 13, wherein the test bed includes a facility for conducting shock tests, vibration tests and thermal cycling tests on an ESP gauge.

15. The method of claim 10, wherein conducting at least one test comprises testing a motor resistance temperature detector associated with an electric submersible pump installation.

16. A system for testing an ESP gauge comprising:

a testing control device for storing and retrieving at least one test profile including parameters and sequences for an testing an ESP gauge;

a test environment in communication with the testing control device for performing tests on the ESP gauge;

a gauge monitoring device for monitoring the quality and reliability of the ESP gauge as tests are performed thereon.

17. The system of claim 16, wherein the testing control device stores test profiles for at least one test selected from the group consisting of: a shock test, a vertical drop test, a cold storage test, a random vibration test; a temperature cycle test; a pressure temperature envelope test; a highly accelerated life test; a motor resistance test device qualification test, and a high temperature accelerated life test.

18. The system of claim 16, wherein the test bed includes a facility for conducting shock tests, vibration tests and thermal cycling tests on an ESP gauge.

19. The system of claim 16, wherein the test bed includes controls for ambient environment, including temperature, pressure and humidity, vibration controls and shock controls.

20. The system of claim 16, wherein the at least one test profile includes test parameters and sequences for testing a motor resistance temperature detector associated with an electric submersible pump installation.

21. The method of claim 10, wherein conducting at least one test comprises conducting a cold storage test.

22. The method of claim 10, wherein conducting at least one test comprises conducting a random vibration test to simulate transport of an ESP gauge.

23. The method of claim 10, wherein conducting at least one test comprises conducting a pressure-temperature envelope test.

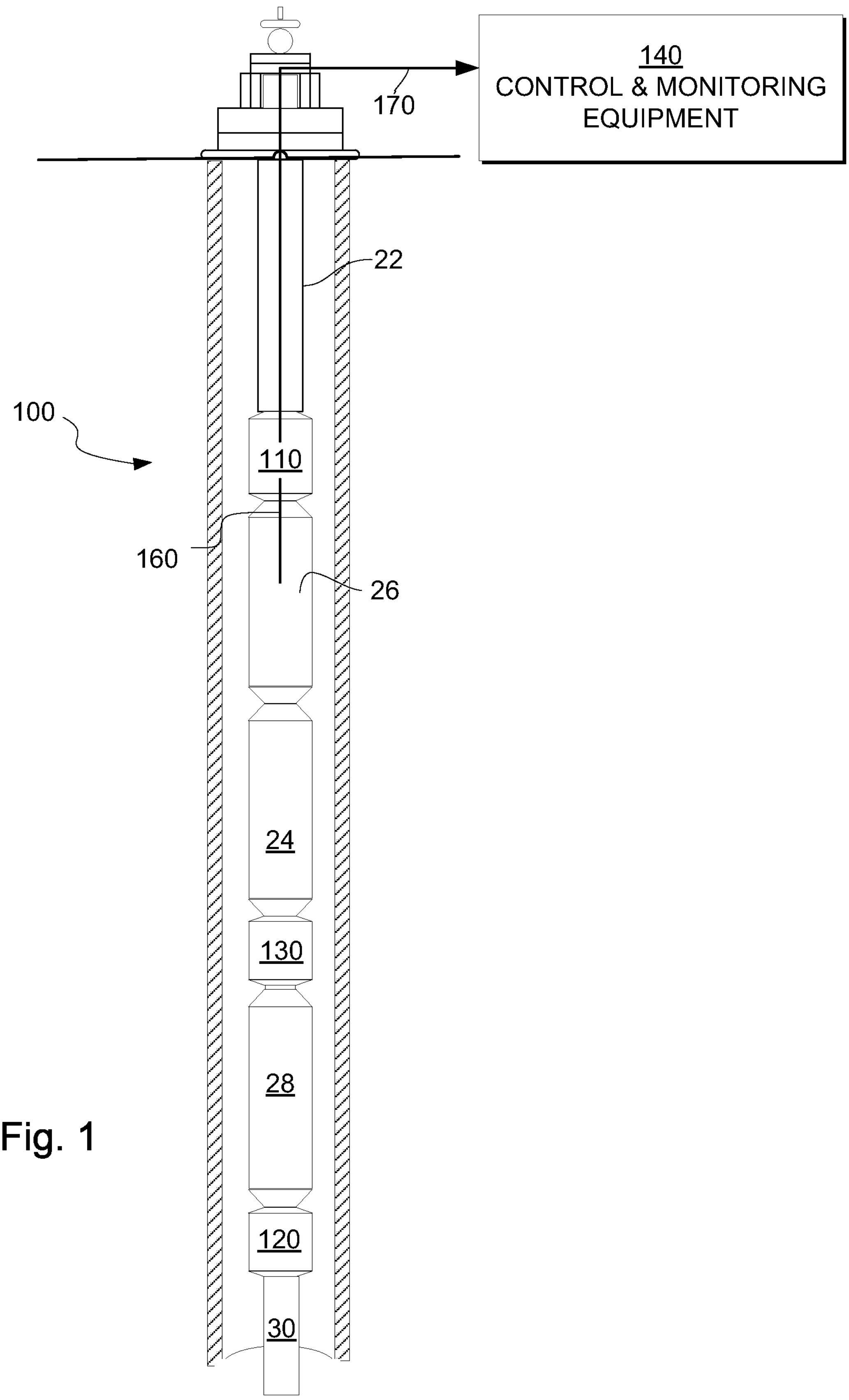

140
CONTROL & MONITORING EQUIPMENT
170
22
100
110
160
26
24
130
28
120
30

Fig. 1

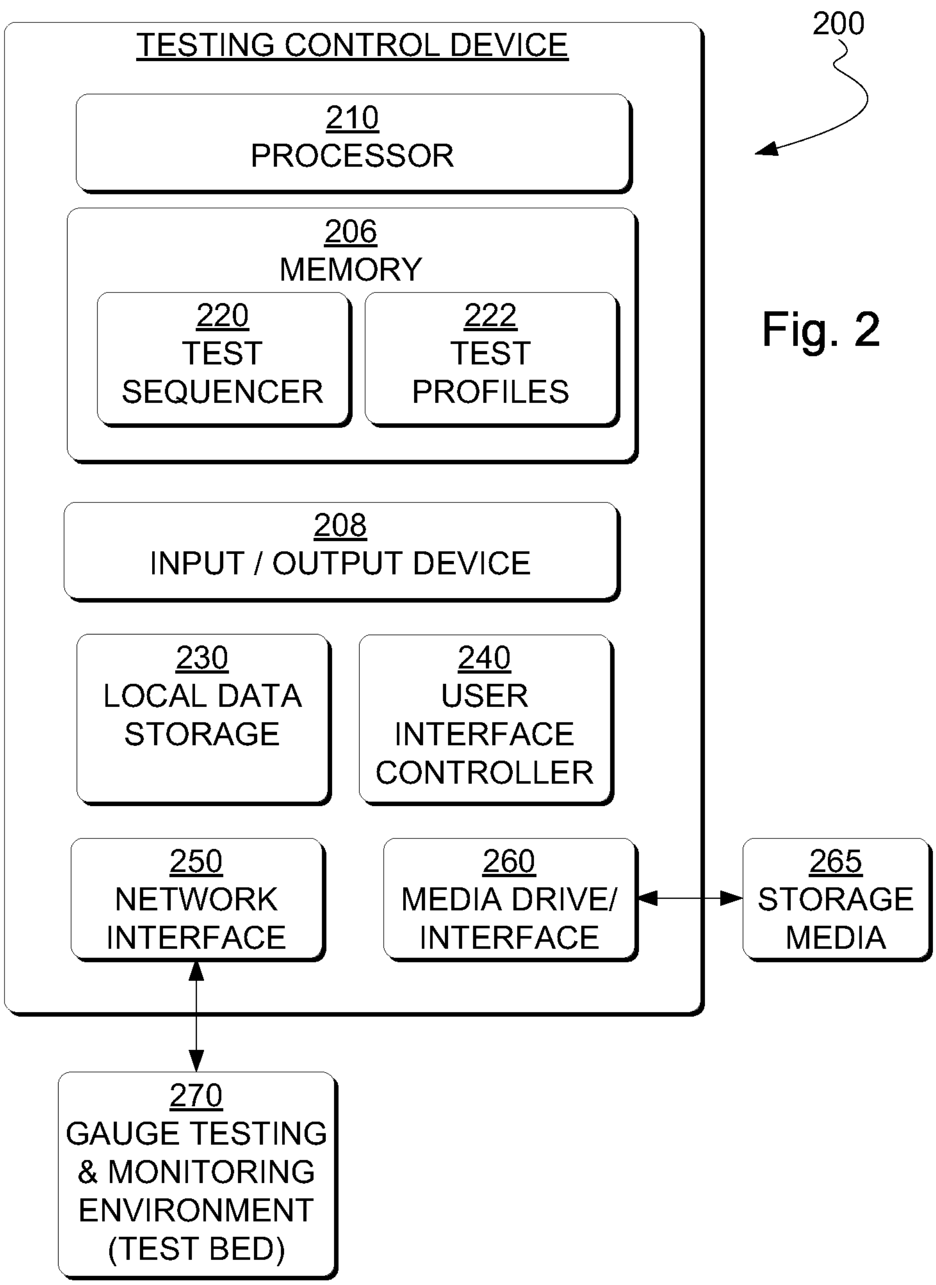

200
TESTING CONTROL DEVICE
210
PROCESSOR
206
MEMORY
220
TEST
SEQUENCER
222
TEST
PROFILES
208
INPUT / OUTPUT DEVICE
230
LOCAL DATA
STORAGE
240
USER
INTERFACE
CONTROLLER
250
NETWORK
INTERFACE
260
MEDIA DRIVE/
INTERFACE
265
STORAGE
MEDIA
270
GAUGE TESTING
& MONITORING
ENVIRONMENT
(TEST BED)

Fig. 2

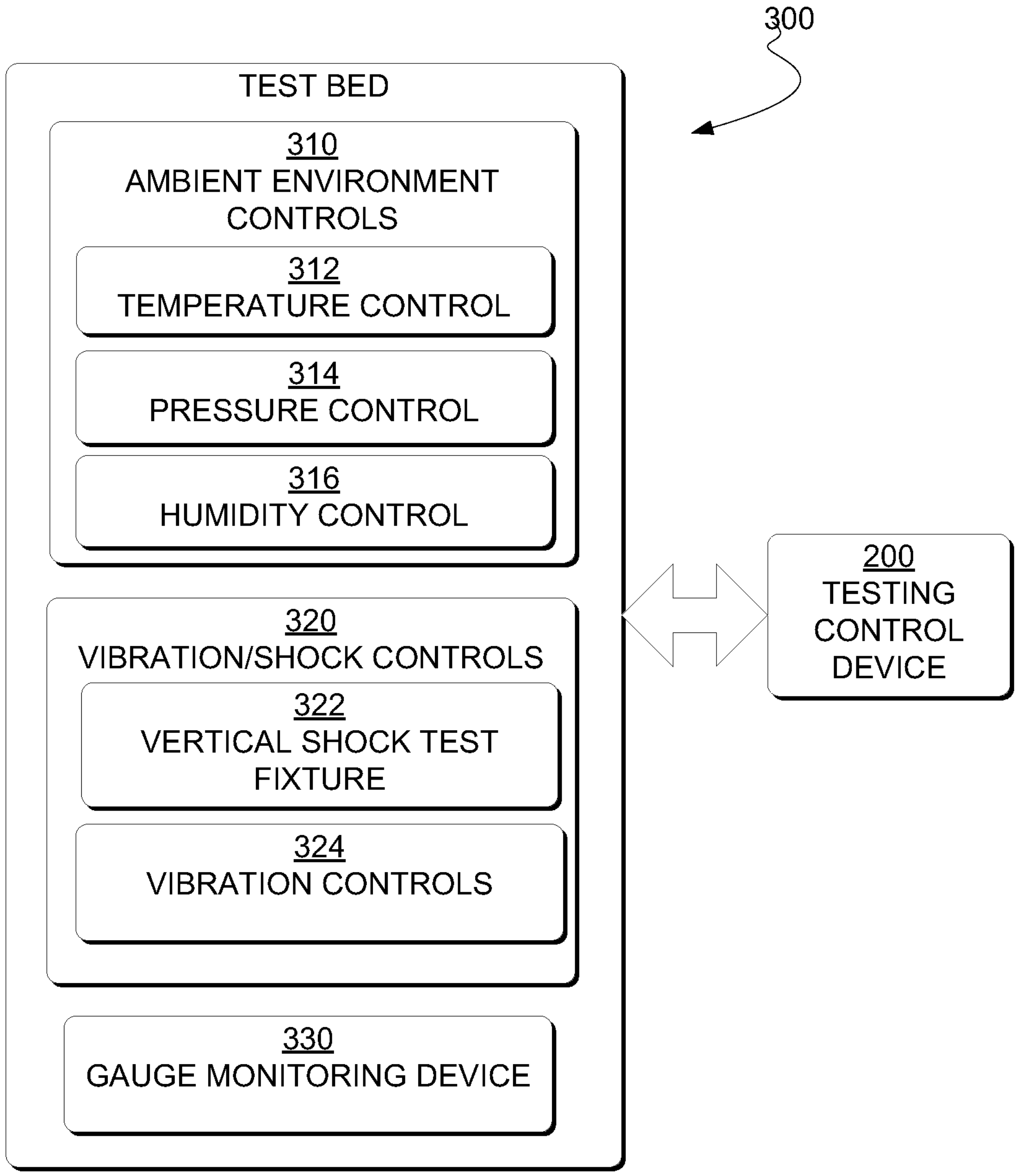

300
TEST BED
310
AMBIENT ENVIRONMENT CONTROLS
312
TEMPERATURE CONTROL
314
PRESSURE CONTROL
316
HUMIDITY CONTROL
320
VIBRATION/SHOCK CONTROLS
322
VERTICAL SHOCK TEST FIXTURE
324
VIBRATION CONTROLS
330
GAUGE MONITORING DEVICE
200
TESTING CONTROL DEVICE

Fig. 3

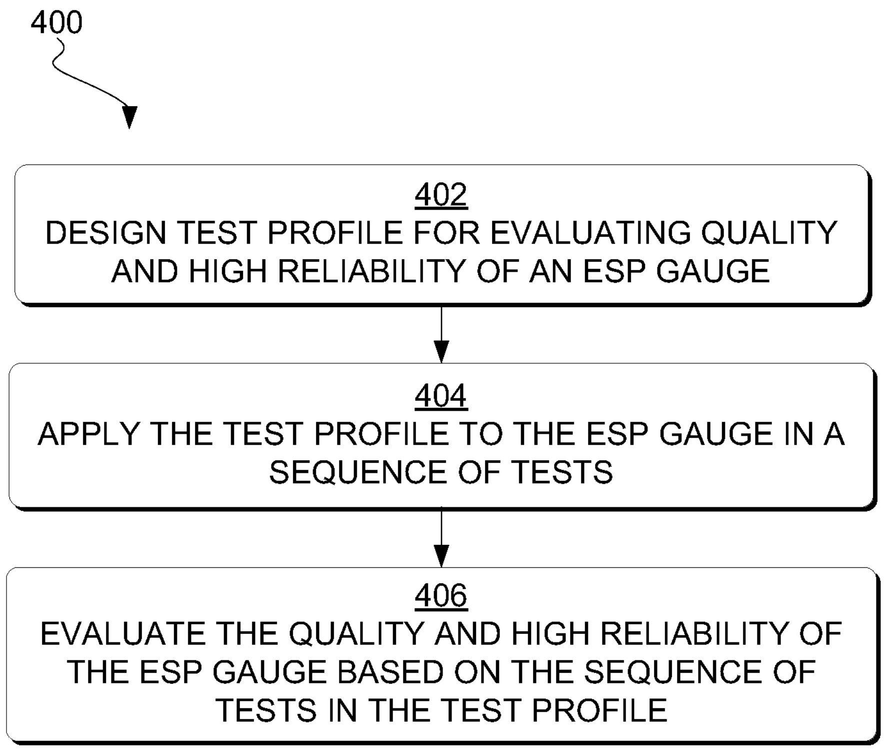

400
402
DESIGN TEST PROFILE FOR EVALUATING QUALITY AND HIGH RELIABILITY OF AN ESP GAUGE
404
APPLY THE TEST PROFILE TO THE ESP GAUGE IN A SEQUENCE OF TESTS
406
EVALUATE THE QUALITY AND HIGH RELIABILITY OF THE ESP GAUGE BASED ON THE SEQUENCE OF TESTS IN THE TEST PROFILE

Fig. 4

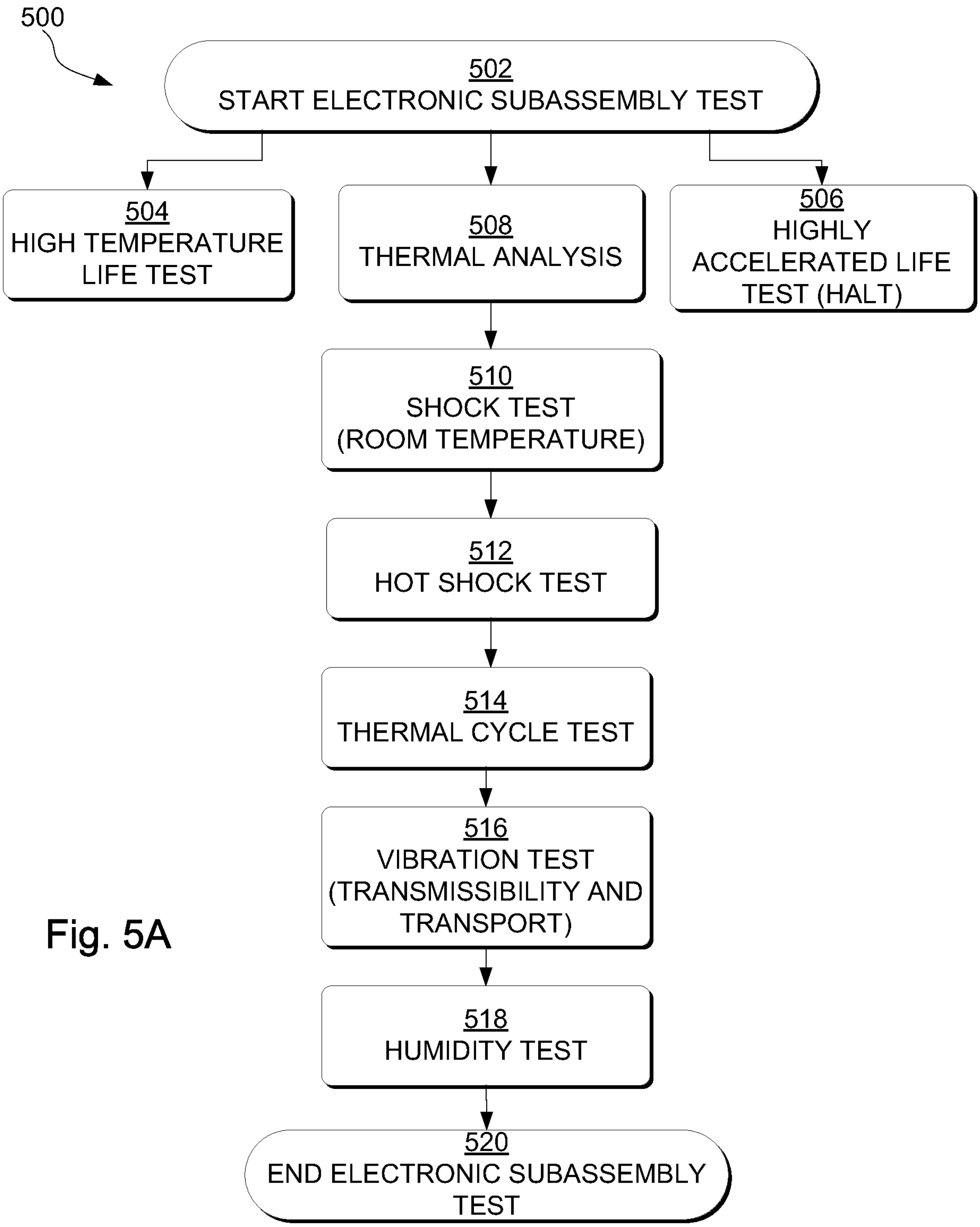

500
502
START ELECTRONIC SUBASSEMBLY TEST
504
HIGH TEMPERATURE LIFE TEST
508
THERMAL ANALYSIS
506
HIGHLY ACCELERATED LIFE TEST (HALT)
510
SHOCK TEST (ROOM TEMPERATURE)
512
HOT SHOCK TEST
514
THERMAL CYCLE TEST
516
VIBRATION TEST (TRANSMISSIBILITY AND TRANSPORT)
518
HUMIDITY TEST
520
END ELECTRONIC SUBASSEMBLY TEST

Fig. 5A

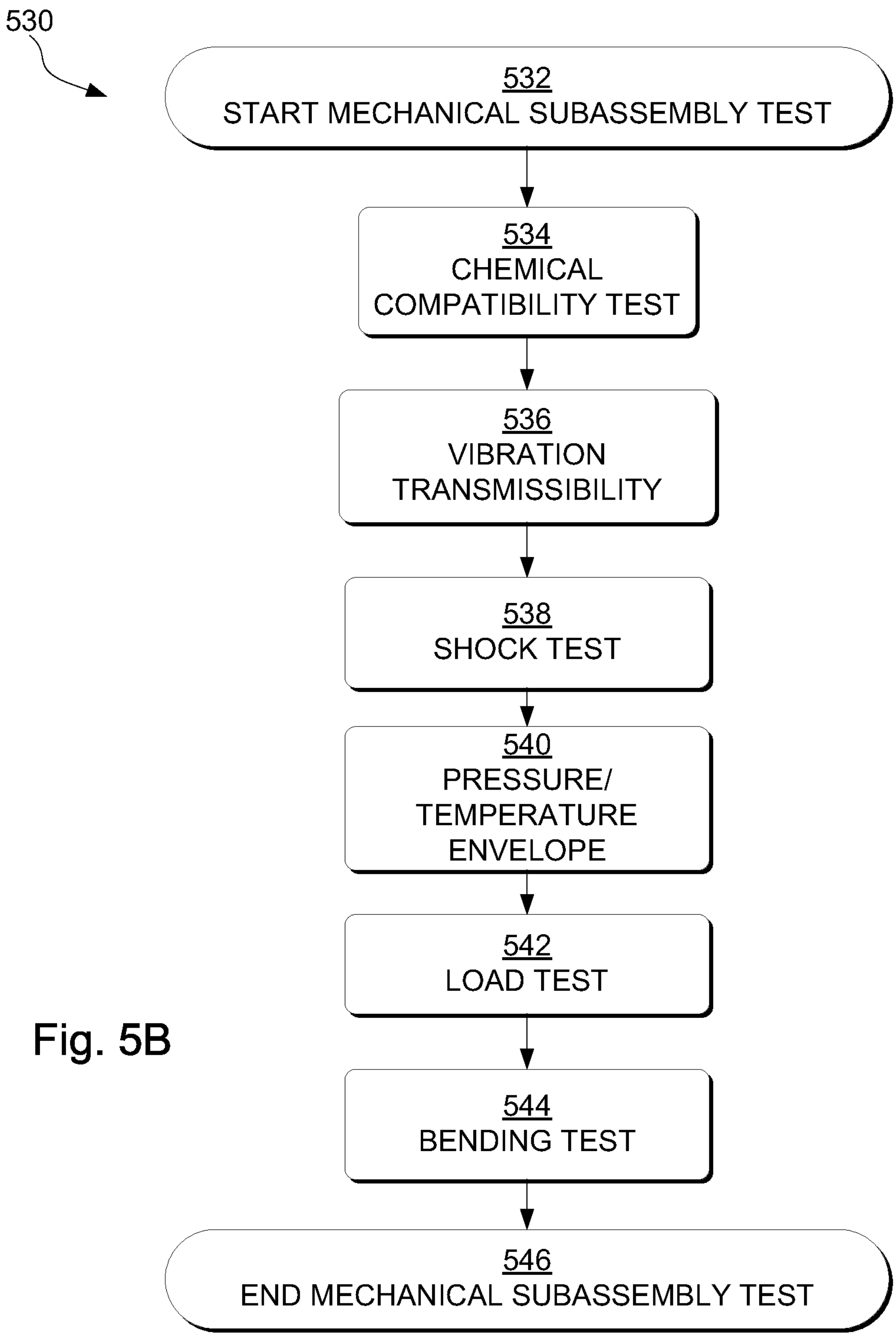

530
532
START MECHANICAL SUBASSEMBLY TEST
534
CHEMICAL COMPATIBILITY TEST
536
VIBRATION TRANSMISSIBILITY
538
SHOCK TEST
540
PRESSURE/ TEMPERATURE ENVELOPE
542
LOAD TEST
544
BENDING TEST
546
END MECHANICAL SUBASSEMBLY TEST

Fig. 5B

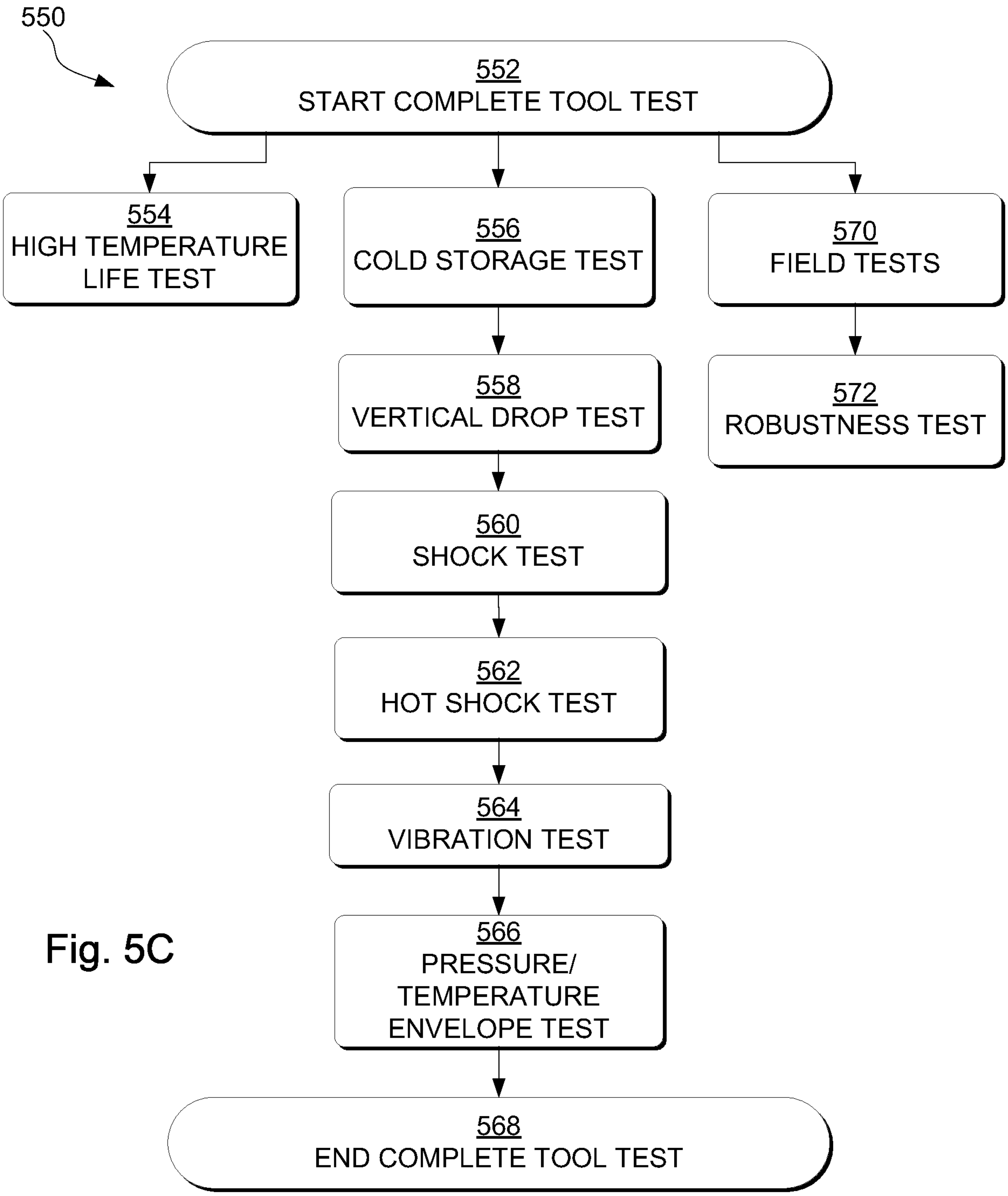

550
552
START COMPLETE TOOL TEST
554
HIGH TEMPERATURE LIFE TEST
556
COLD STORAGE TEST
570
FIELD TESTS
558
VERTICAL DROP TEST
572
ROBUSTNESS TEST
560
SHOCK TEST
562
HOT SHOCK TEST
564
VIBRATION TEST
566
PRESSURE/ TEMPERATURE ENVELOPE TEST
568
END COMPLETE TOOL TEST

Fig. 5C

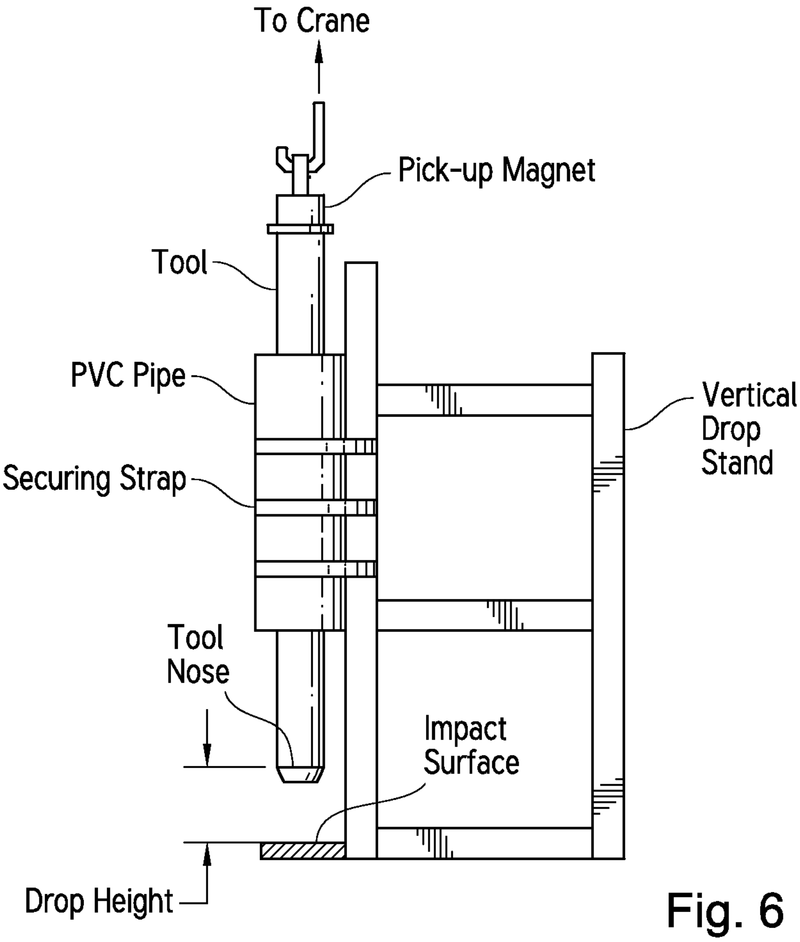

To Crane
Pick-up Magnet
Tool
PVC Pipe
Securing Strap
Vertical
Drop
Stand
Tool
Nose
Impact
Surface
Drop Height

Fig. 6

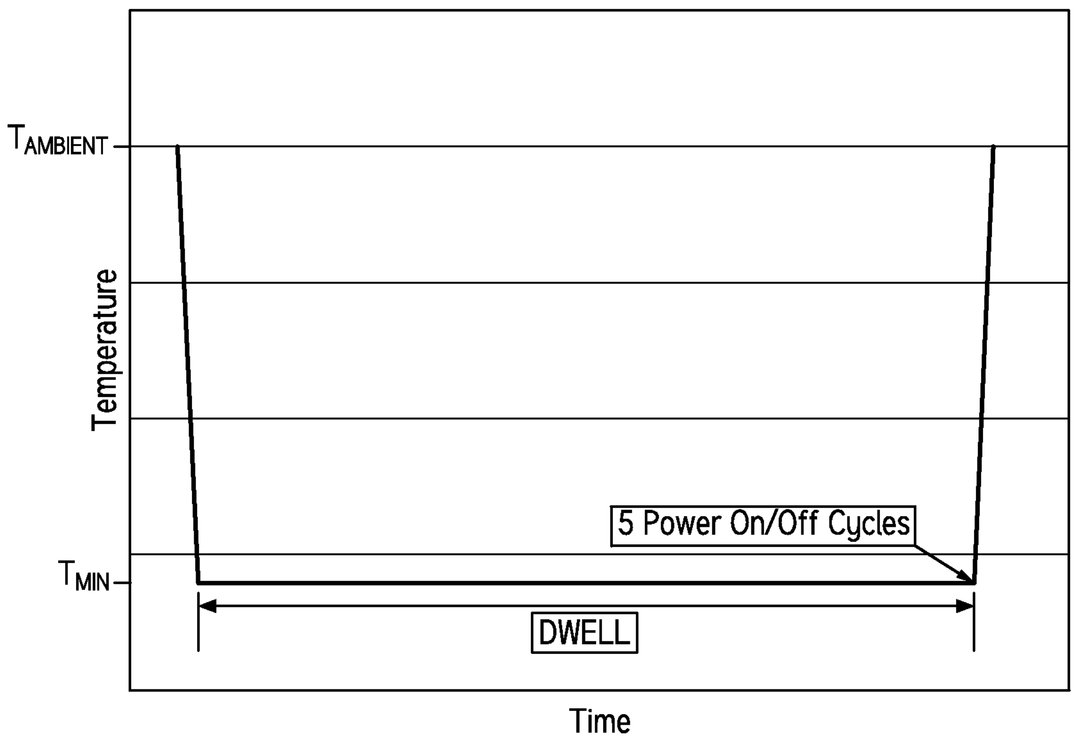
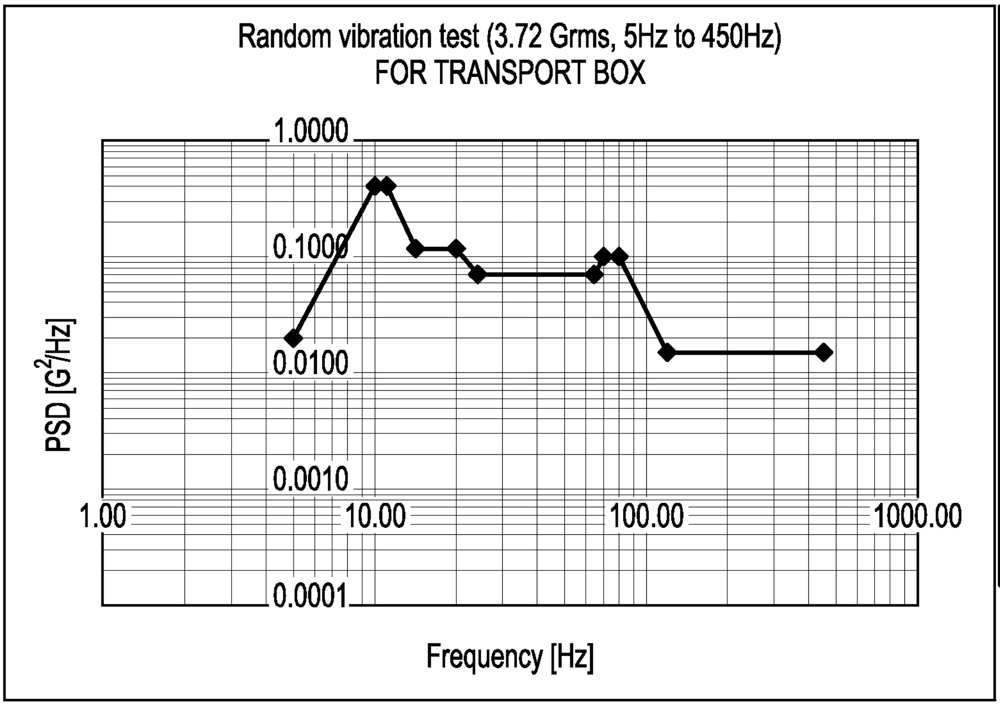

$T_{AMBIENT}$
Temperature
T_{MIN}
5 Power On/Off Cycles
DWELL
Time

Fig. 7



Freq (Hz)	PSD (G^2/Hz)
5.00	0.0200
10.00	0.4000
11.00	0.4000
14.00	0.1200
20.00	0.1200
24.00	0.0700
65.00	0.1000
70.00	0.1000
80.00	0.1000
120.00	0.0150
450.00	0.0150

Fig. 8

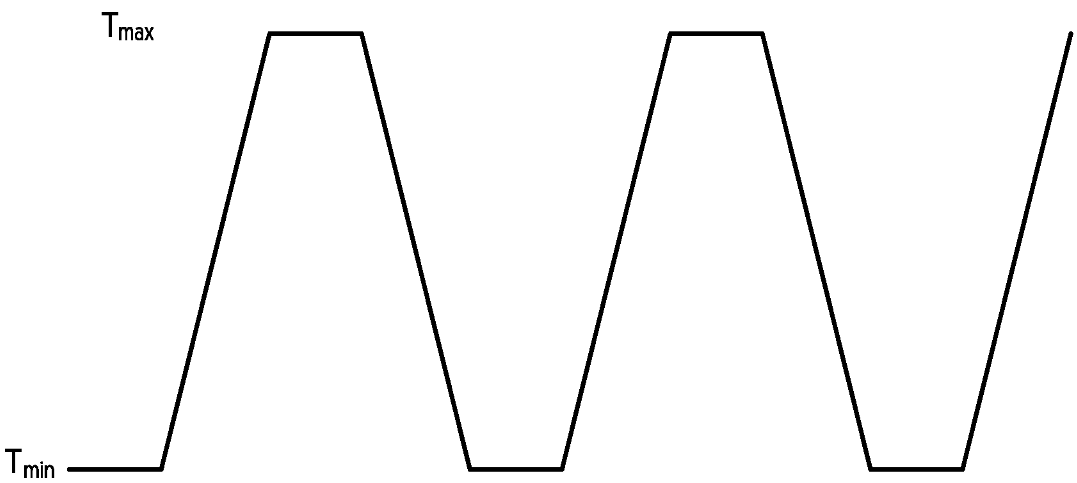


Fig. 9

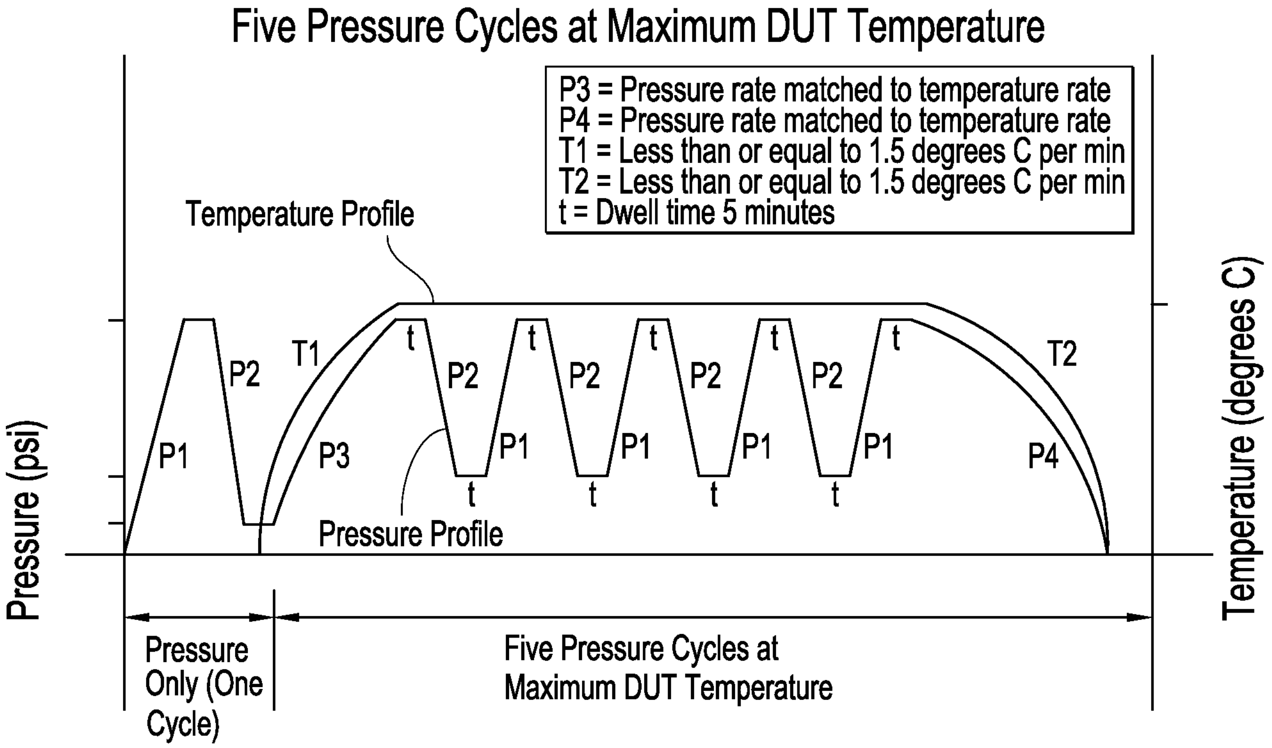

Five Pressure Cycles at Maximum DUT Temperature
P3 = Pressure rate matched to temperature rate
P4 = Pressure rate matched to temperature rate
T1 = Less than or equal to 1.5 degrees C per min
T2 = Less than or equal to 1.5 degrees C per min
t = Dwell time 5 minutes
Temperature Profile
Pressure Profile
Pressure (psi)
Temperature (degrees C)
P1
P2
P3
P4
T1
T2
t
Pressure Only (One Cycle)
Five Pressure Cycles at Maximum DUT Temperature

Fig. 10

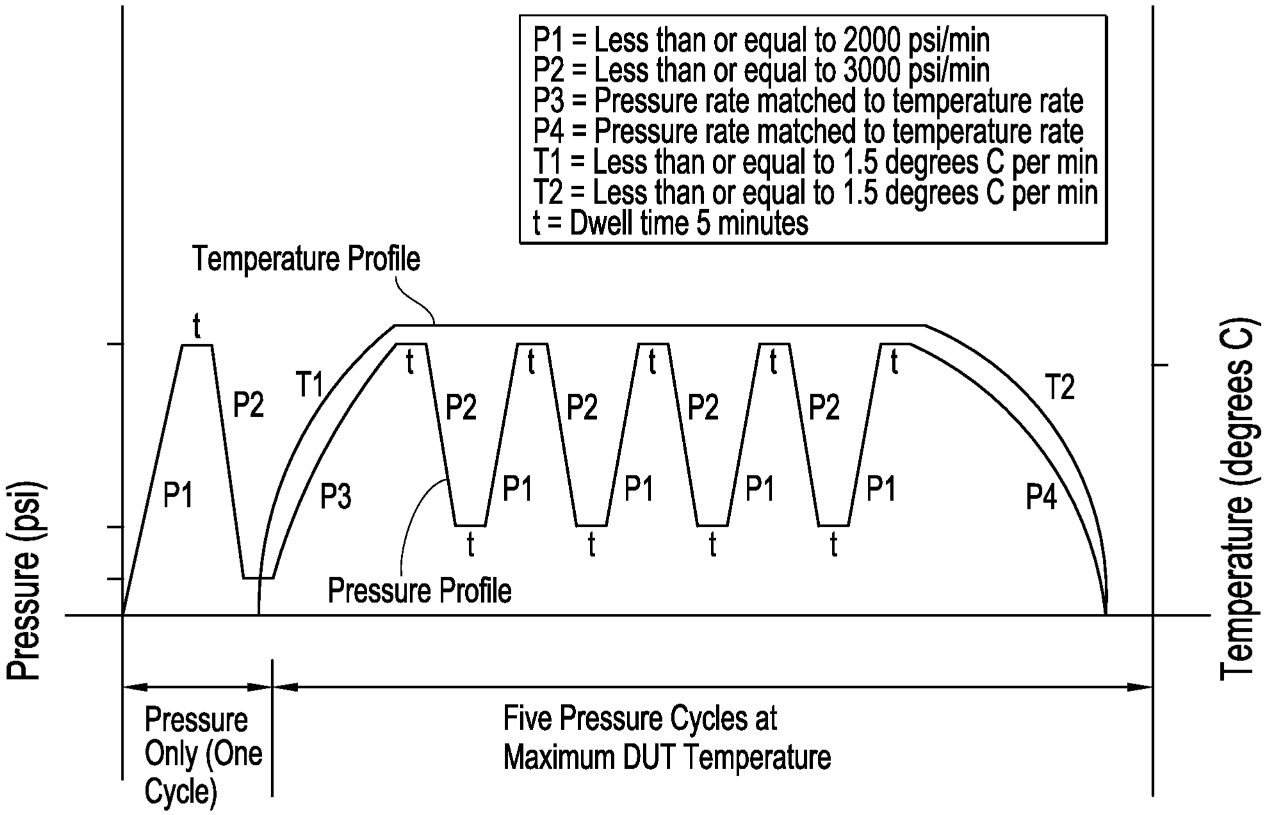

P1 = Less than or equal to 2000 psi/min
P2 = Less than or equal to 3000 psi/min
P3 = Pressure rate matched to temperature rate
P4 = Pressure rate matched to temperature rate
T1 = Less than or equal to 1.5 degrees C per min
T2 = Less than or equal to 1.5 degrees C per min
t = Dwell time 5 minutes
Temperature Profile
Pressure Profile
Pressure (psi)
Temperature (degrees C)
P1
P2
P3
P4
T1
T2
t
Pressure Only (One Cycle)
Five Pressure Cycles at Maximum DUT Temperature

Fig. 13

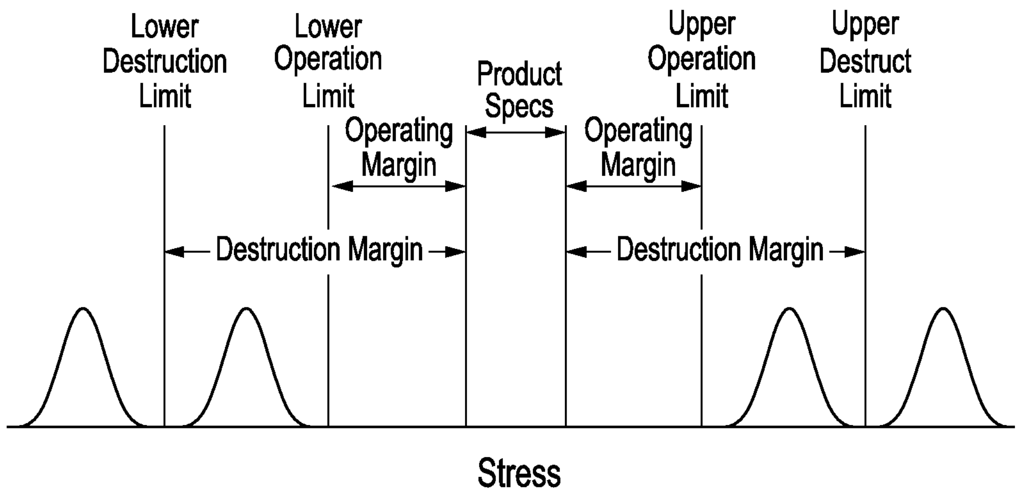


Fig. 11A

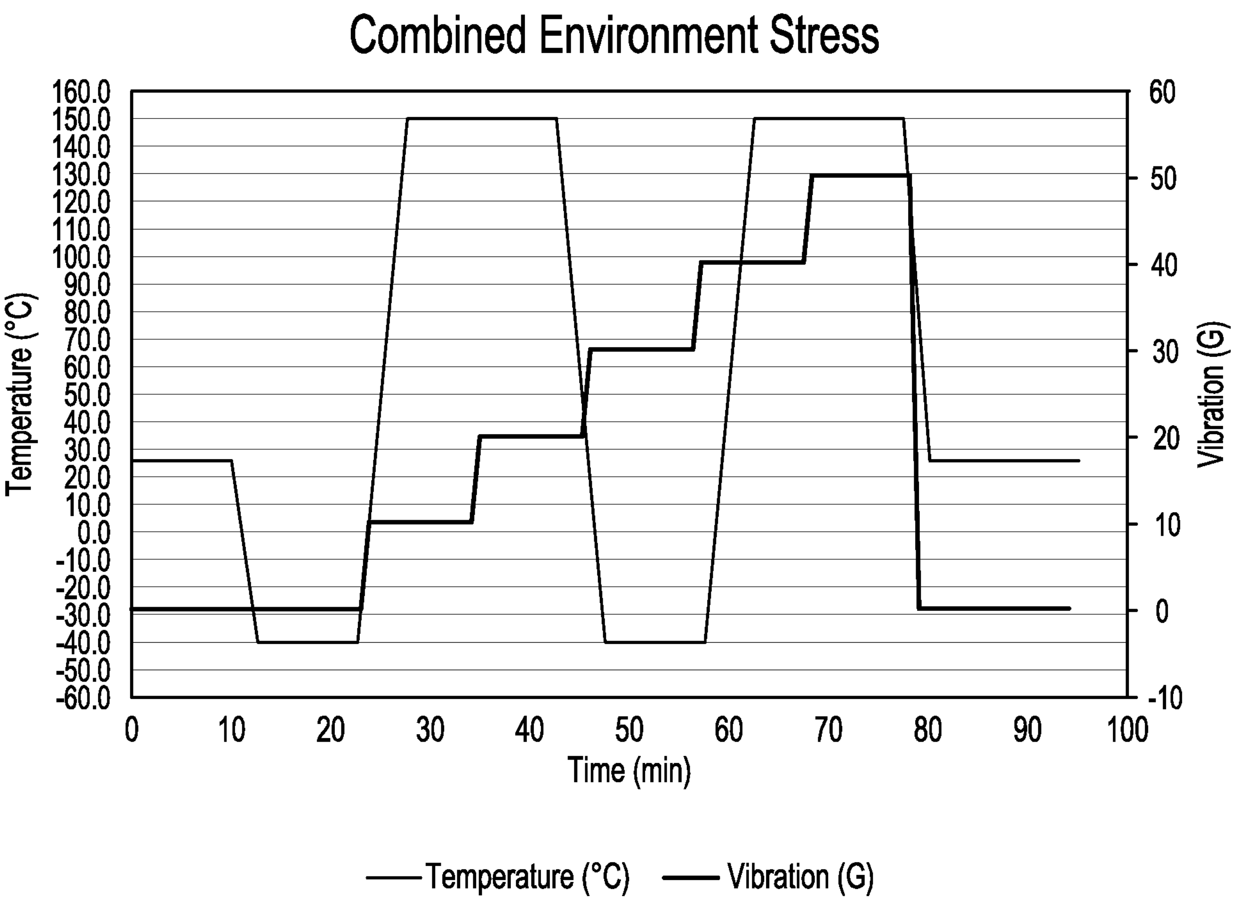


Fig. 11B

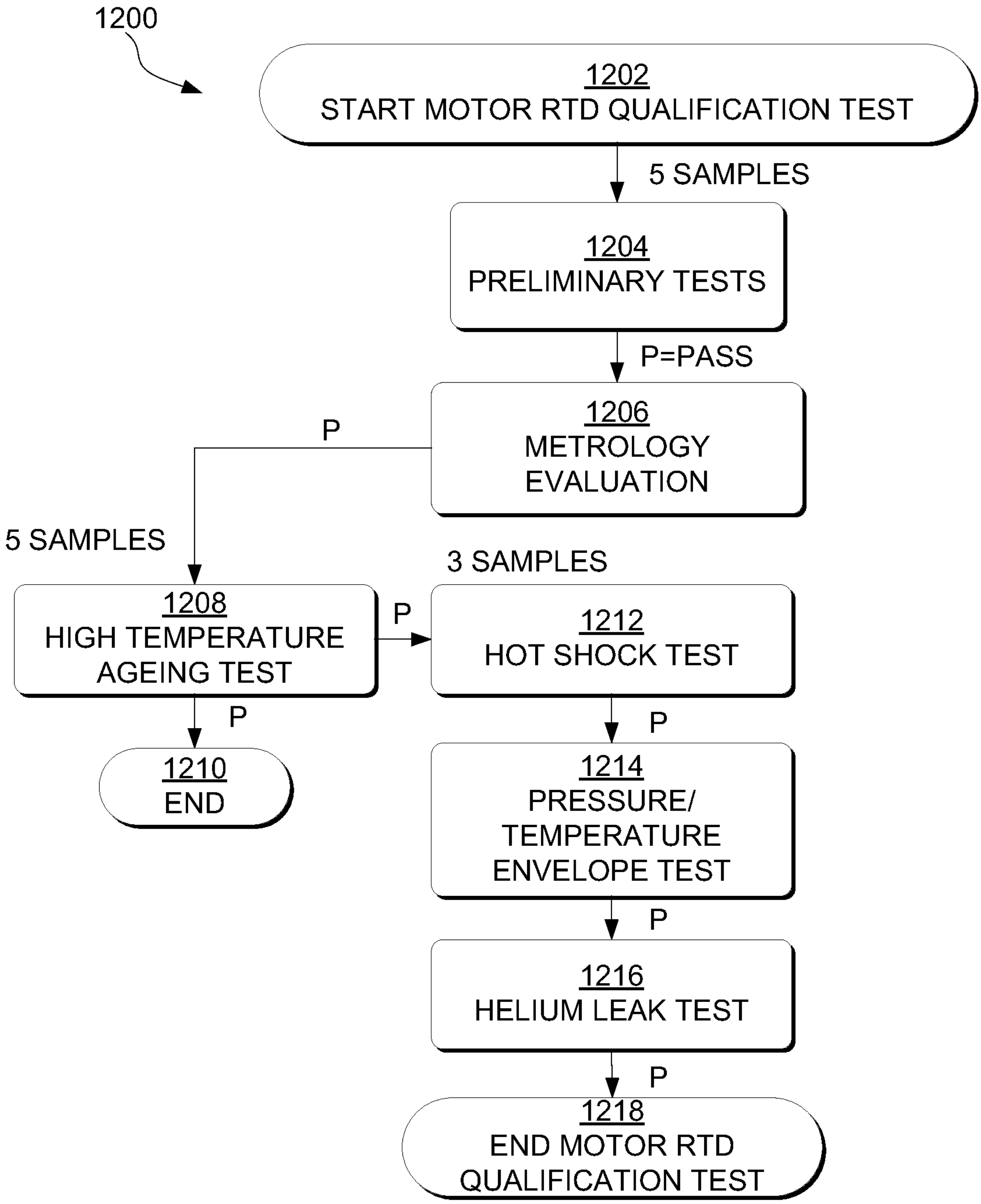

1200
1202
START MOTOR RTD QUALIFICATION TEST
5 SAMPLES
1204
PRELIMINARY TESTS
P=PASS
1206
METROLOGY
EVALUATION
P
5 SAMPLES
3 SAMPLES
1208
HIGH TEMPERATURE
AGEING TEST
P
1212
HOT SHOCK TEST
P
1210
END
P
1214
PRESSURE/
TEMPERATURE
ENVELOPE TEST
P
1216
HELIUM LEAK TEST
P
1218
END MOTOR RTD
QUALIFICATION TEST

Fig. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/041835

A. CLASSIFICATION OF SUBJECT MATTER

E21B 43/12(2006.01)i, E21B 47/06(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
E21B 43/12; E21B 47/00; G01V 3/00; E21B 43/00; G01V 1/40; F25B 1/00; E21B 47/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: test profile, processor, ESP gauge, gauge monitoring device, and detector

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011-0270525 A1 (HUNTER, SCOTT) 03 November 2011 See abstract, paragraphs [0033],[0038],[0041], and figures 1-2.	1-23
A	US 6082454 A (TUBEL, PAULO S.) 04 July 2000 See abstract, column 4, line 51 - column 5, line 38, and figure 1.	1-23
A	US 2010-0214120 A1 (MEANS et al.) 26 August 2010 See abstract, paragraphs [0032]-[0036], and figure 3.	1-23
A	US 2006-0213659 A1 (MCCOY, ROBERT H.) 28 September 2006 See abstract, paragraphs [0018]-[0022], and figure 1.	1-23
A	US 7913498 B2 (ROWATT, JOHN DAVID) 29 March 2011 See abstract, column 3, line 65 - column 4, line 10, and figure 1.	1-23

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

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 September 2014 (30.09.2014)	**01 October 2014 (01.10.2014)**

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Authorized officer
LEE, Jong Kyung
Telephone No. +82-42-481-3360

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 2006-0213659 A1	28/09/2006	US 7588080 B2	15/09/2009
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