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METHOD FOR REDUCING BIAS DRIFT IN A MICROELECTROMECHANICAL SYSTEMS SENSOR

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the invention

[0003] The present invention is directed to a method for reducing bias drift in a microelectromechanical system accelerometer.

(2) Description of the Prior Art

[0004] Microelectromechanical system accelerometers are used in a variety of applications such as sonar systems and inertial measurement systems. However, the use of these accelerometers in heading assemblies can be limited due to bias drift. Bias drift can include a deviation from true values based on a combination of time, temperature, and

acceleration. The bias drift may occur even in stable microelectromechanical system sensors, which may present challenges when used for array sensors that provide heading information.

[0005] Additionally, a mechanical mounting of the accelerometer inside the heading sensor can be subject to small deformations resulting in relative motion between the accelerometer and the heading sensor assembly. These deformations can result in inaccurate feedback similar to the bias drift. These issues can affect accuracy despite an initial heading sensor calibration. As such, there is a demand for a conditioning method or process used to stabilize an accelerometer bias drift on a heading sensor.

[0006] Previous examples of stabilization include accelerated life testing temperature cycles, which may be applied to heading sensors or other products to age a product and find potential weak points. However, the accelerated life testing temperature cycles process is used to test the limits of the sensor and therefore uses higher and lower extreme temperatures which do not correct a bias drift.

SUMMARY OF THE INVENTION

[0007] The present invention comprises a method for reducing bias drift in an accelerometer. The method includes the steps of arranging at least one accelerometer in a chamber and initiating a plurality of temperature cycle sets. Each temperature cycle set has a minimum temperature, a maximum temperature, and a ramp rate.

[0008] In this way, the conditioning process of the present invention monitors the accelerometers until a bias drift is stabilized within a desired bias drift range. The minimum temperature and the maximum temperature limit a temperature range in which the accelerometer is cycled. Use of temperature limiting can quickly accelerate stabilization of the bias drift while also reducing degradation.

[0009] It is understood that the brief description above introduces concepts that are described in the detailed description. The summary is not intended to identify essential features of the claimed subject matter, the scope of which is defined by the claims that follow the detailed description. Furthermore, the claimed subject matter is not limited to implementations that solve any disadvantages noted above or in any part of the present application.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Features of illustrative embodiments may be understood from the accompanying drawings in conjunction with the detailed description. The elements in the drawings may not be drawn to scale. Some elements and/or dimensions are enlarged or minimized for the purpose of illustration and the understanding of the disclosed embodiments.

[0011] **FIG. 1** depicts an example of test equipment for a conditioning process in accordance with the present invention; and

[0012] **FIG. 2** depicts a flow chart illustrating the conditioning process in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0013] The following description relates to various embodiments of a conditioning process used to stabilize accelerometer bias drift on a heading sensor. The heading sensor can be a central control point for an autopilot system, wherein a plurality of sensors including a magnetic field sensor, a compass, or an electrical equivalent is used to provide a magnetic fluxgate that provides heading information.

[0014] A heading sensor assembly includes a plurality of microelectromechanical system accelerometers along with magnetometers and other heading sensor components. The sensor can be integrated into an end product, such as a toward array sonar module.

[0015] During the conditioning process, the heading sensor assembly is temperature-cycled. The temperature cycling can occur in a chamber, such as an environmental chamber, partially or fully separated from an ambient environment in order to allow accurate tracking of the accelerometer bias. The chamber provides the desired temperature changes and ramp rates while maintaining a humidity at or below a threshold to mitigate condensation on circuitry of the heading sensor.

[0016] As illustrated in **FIG. 1**, the facility includes equipment to measure the accelerometer bias during the temperature cycles. For example, a vibration isolation table is included so that the accelerometer is only measuring the force of gravity (as opposed to vibrations from a compressor or other device). The facility includes a computer configured to record and display accelerometer output.

[0017] The conditioning process can be configured to cycle the accelerometer along with the other components arranged

in the sensor assembly through a plurality of temperature cycles. Each temperature cycle set includes adjusting a temperature of the accelerometer to a minimum and a maximum temperature. The accelerometer is maintained at the minimum temperature for a threshold duration before the temperature is raised to and maintained at the maximum temperature for the threshold duration. Temperature cycle sets are accomplished until a bias drift is stabilized at a desired threshold.

[0018] Each of the temperature cycle sets can be identical. In another example, at least some of the temperature cycle sets can differ from one another. For example, a first cycle set includes cycles within a first temperature range and a first ramp rate. The first cycle set includes a threshold duration for a temperature soak at the maximum and minimum temperatures of the first temperature range.

[0019] A second cycle set includes cycles within a second temperature range and a second ramp rate. The temperature values of the second temperature range overlap with the temperature values of the first temperature range. The second cycle set includes the temperature soak for the threshold duration at the maximum and minimum temperatures of the second temperature range.

[0020] A third cycle set includes cycles within a third temperature range and a third ramp rate. The third temperature range includes temperature values overlapping with the first cycle set and the second cycle set. The third cycle set further includes a temperature soak at the maximum and minimum temperatures for the threshold duration.

[0021] During the second and third cycle sets, the heading sensor is powered on and the accelerometer data is monitored and recorded. The system accelerometer bias can stabilize as the cycles progress. Each accelerometer of the heading sensor assembly may include a slightly different character (e.g., bias). The second and third cycle sets can be repeated until the accelerometers include a bias stability within a desired range. The bias stability is indicated by the computing device.

[0022] The first cycle set can be a phase in-period, wherein data from the accelerometer is tracked. However, data from the accelerometer can be dismissed during the first cycle set as experimental data suggests that bias drift is not sufficiently corrected during this period. Following the first cycle set, the second and third cycle sets would include narrower temperature ranges relative to the first cycle set.

[0023] Upon achieving the desired bias stability, a rest period starts. The rest period includes a threshold rest duration at a threshold temperature, wherein the threshold temperature includes an ambient temperature range. Upon completion of the rest period, the second and third temperature cycles are repeated while monitoring biases of the accelerometers. If the biases have shifted since the second and third temperature cycles, then additional conditioning may be accomplished. Additional conditioning includes repeating the second and third temperature cycles along with the rest period until the biases no longer deviate from the desired bias stability.

[0024] Returning to **FIG. 1**, an embodiment **100** of the present invention is depicted with a chamber **102** having a vibration table **104**. The chamber **102** can be a facility, a room, a box, or other container separated from an ambient atmosphere. At least one of a temperature, pressure, and humidity of the chamber **102** is adjusted for at least one cycle set for conditioning a microelectromechanical system accelerometer of a heading assembly **110**.

[0025] In the example of the figure, the heading assembly **110** includes a plurality of microelectromechanical system accelerometers including a first accelerometer **112**, a second accelerometer **114**, and a third accelerometer **116**.

The microelectromechanical system accelerometers provide feedback to the heading assembly **110.**

[0026] The accelerometers may also be soldered to the circuit board of the heading assembly **110.** Alternatively, the accelerometers are physically coupled to a circuit board of heading assembly **110** via an underfill. The underfill can be an epoxy or similar bonding agent.

[0027] A controller **120** can be positioned outside of the chamber **102** and communicatively coupled to the heading assembly **110** by a cable **122.** As described in detail in **FIG. 2,** the controller **120** completes instructions stored on a non-transitory memory thereof that enable the controller to condition the accelerometers.

[0028] Alternatively, the controller **120** is wirelessly connected to the heading assembly **110.** The controller **120** is further coupled to a heating device **130** along with a temperature sensor **132,** wherein the controller can adjust the heating device **130** to increase, decrease, or hold a temperature applied to the heading assembly **110.** The temperature sensor **132** provides feedback to the controller **120** so that a temperature of the heading assembly **110** during the conditioning procedure is known.

[0029] **FIG. 2** depicts a flow chart illustrating the conditioning process or method in accordance with the

present invention. Instructions **200** for carrying out method may be executed by a controller based on the instructions stored on a controller memory and in conjunction with signals received from the sensors of the chamber, described with reference to **FIG. 1.**

[0030] The method **200** starts at Step **202,** which includes arranging a heading assembly in a chamber. The heading assembly is the heading assembly **110** and the chamber is chamber **102** of **FIG. 1.** The heading assembly **110** includes a plurality of microelectromechanical system accelerometers physically coupled to a circuit board.

[0031] The method **200** proceeds to Step **203,** which includes initiating temperature cycle sets. As described above, a temperature cycle set includes a minimum temperature and a maximum temperature, at each of which a temperature soak occurs. The temperature cycle set further includes a ramp rate at which a temperature of the accelerometer is adjusted.

[0032] The method **200** proceeds to Step **204,** which includes initiating a first cycle set of the conditioning method. The first cycle set includes a first temperature range. The first temperature range can be between -55° C to 80° C. The first cycle set includes a first ramp rate at which the temperature is ramped through forty cycles at Step **206.**

The first cycle set also includes a temperature soak for a threshold duration at a minimum and a maximum temperature at Step **208**.

[0033] The first cycle set can include where the temperature is set to a minimum temperature, such as equal to -55° C in one of the forty cycles, for a threshold duration. The threshold duration can be equal to one hour.

[0034] The temperature of the heading assembly **110** is increased at the first ramp rate of 3° C/minute. Once a maximum temperature of the first cycle set is reached, which may be as high as 80° C for at least one of the forty cycles; the temperature soak for the threshold duration is accomplished and one cycle of the forty cycles is complete. Upon completion of the forty cycles, the first cycle set is complete.

[0035] Each cycle of the forty cycles can include a different minimum temperature from which the cycle begins and a different maximum temperature at which the cycle ends. This may provide a greater stabilization of the accelerometers.

[0036] The method **200** may optionally proceed to Step **210**, which includes initiating a second cycle set. The second cycle set includes a second ramp rate through ten cycles at Step **212** within a temperature range from -54° C to 71° C.

The second ramp rate can be 10° C/ minute. At step **214**, the second cycle set further includes a temperature soak for a threshold duration at minimum and maximum temperatures.

[0037] The second cycle set can include where the temperature is set to a minimum temperature, such as -54° C in one of the ten cycles. The temperature soak is accomplished for the threshold duration at the minimum temperature before increasing the temperature equal to the second ramp rate. Upon reaching a maximum temperature of 71° C, the temperature soak is again accomplished for the threshold duration and one cycle of the ten cycles of the second cycle set is complete. Upon completion of the ten cycles, the second cycle set is complete.

[0038] Each cycle of the ten cycles of the second cycle set can include a different minimum temperature from which the cycle begins and a different maximum temperature at which the cycle finishes. This may provide a greater stabilization of the accelerometers.

[0039] The method **200** may optionally proceed to Step **216**, which includes initiating the third cycle set. The third cycle set includes a third ramp rate through nine cycles at Step **218** within a temperature range from -54° C to 71° C. The third ramp rate can be 1° C/minute. At Step **220**, the

third cycle set further includes a temperature soak for the threshold duration at minimum and maximum temperatures.

[0040] The third cycle set includes where the temperature is reduced a minimum temperature, such as -54° C in each of the nine cycles. The temperature soak is executed for the threshold duration at the minimum temperature before increasing the temperature at a rate equal to the third ramp rate to a maximum temperature, such as 71° C in each of the nine cycles. Upon completion of the nine cycles, the third cycle set is complete.

[0041] Each cycle of the nine cycles of the third cycle set can include a different minimum temperature from which the cycle begins and a different maximum temperature at which the cycle finishes. This may provide a greater stabilization of the accelerometers.

[0042] In the method **200**, each of the temperature cycle sets can be identical. In such a case, each temperature cycle set includes an identical minimum temperature, an identical maximum temperature, an identical ramp rate, and an identical threshold duration. The method **200** can execute temperature cycle sets (e.g., 50 or more), and then compares a sensed bias drift to a desired bias stability.

[0043] In some examples, the minimum temperature may be between -10° C to -60° C. In some examples, the minimum

temperature is between -10° C to -40° C. Alternatively, the minimum temperature is between -10° C to -25° C. In some examples, the maximum temperature may be between 30° C to 80° C. Alternatively, the maximum temperature may be between 30° C to 60° C. Alternatively, the maximum temperature may be between 30° C to 45° C.

[0044] Thus, the method **200** includes embodiments where each of the temperature cycle sets is identical or where there is are different temperature cycle sets for reducing the bias drift. Following completion of the temperature cycle sets, the method **200** proceeds to Step **222**, which includes determining if a bias stability is within a desired bias stability range. The microelectromechanical system accelerometer feedback is monitored and recorded via the computing system.

[0045] The accelerometer bias may stabilize as the second and third cycles progress. Each accelerometer may include slightly different bias characteristics. If each accelerometer does not include a bias value within the desired bias stability range, then the temperature cycles can be repeated.

[0046] A number of repeated cycles can be fewer than a number of previously completed temperature cycles. For example, prior to comparing the bias stability to the

desired bias stability range, 70 temperature cycles are executed. Following a comparison where the bias stability is still outside of the desired range, 20 temperature cycles may be repeated. The repeated temperature cycles can be identical to or different than one another.

[0047] If the bias of each accelerometer is within the desired stability range, then the method **200** proceeds to Step **224**, which includes initiating a rest period. At Step **226**, the method **200** includes storing the heading assembly **110** at room temperature for a threshold time. The room temperature can be between 19° C to 25° C and the threshold time can be 72 hours. The temperature and time of the rest period can be adjusted without departing from the scope of the present invention.

[0048] The method **200** proceeds to Step **228**, which includes repeating the second and third cycle sets, as described above at Step **210** and Step **216**. As such, the heading assembly **110** is powered on and bias values from the accelerometers are monitored.

[0049] The method **200** proceeds to Step **230**, which includes determining if the bias stability of each accelerometer is still within the desired bias stability range. If the bias stability of at least one of the accelerometers is no

longer within the desired range; then the method **200** proceeds to Step **224** and initiates the rest period.

[0050] If the bias stability of each accelerometer is still within the desired bias stability range, then the method **200** proceeds to Step **232**, which includes generating an output indicating the sensor is stable. As such, the microelectromechanical system accelerometer in the heading assembly **110** can be utilized for detecting acceleration forces.

[0051] In this way, the bias drift of the microelectromechanical system accelerometers are adjusted to meet a desired bias drift range via the conditioning method. The conditioning method or process cycles the accelerometers through a range of temperatures within their operating range until the bias drift stabilizes to a value within a desired bias stability range. The technical effect of the conditioning process is to more rapidly stabilize the bias drift of the sensors while avoiding temperature ranges used to age the accelerometers.

[0052] It will be appreciated that the configurations disclosed herein are exemplary in nature, and that these embodiments are not to be considered as limiting, because variations are possible. The present invention includes novel and non-obvious combinations and sub-combinations of

the various systems and configurations, and other features, functions, and/or properties disclosed herein.

METHOD FOR REDUCING BIAS DRIFT IN A MICROELECTROMECHANICAL SYSTEMS SENSOR

ABSTRACT OF THE DISCLOSURE

A method for reducing bias drift in electrical-mechanical systems sensor such as an accelerometer is provided. The method includes the steps of arranging at least one accelerometer in a chamber and initiating a plurality of temperature cycle sets. Each temperature cycle set has a minimum temperature, a maximum temperature, and a ramp rate. The conditioning method monitors the accelerometers until a bias drift is stabilized within a desired bias drift range. The minimum temperature and the maximum temperature limit a temperature range in which the accelerometer is cycled. Use of temperature limiting can quickly accelerate stabilization of the bias drift while also reducing degradation.

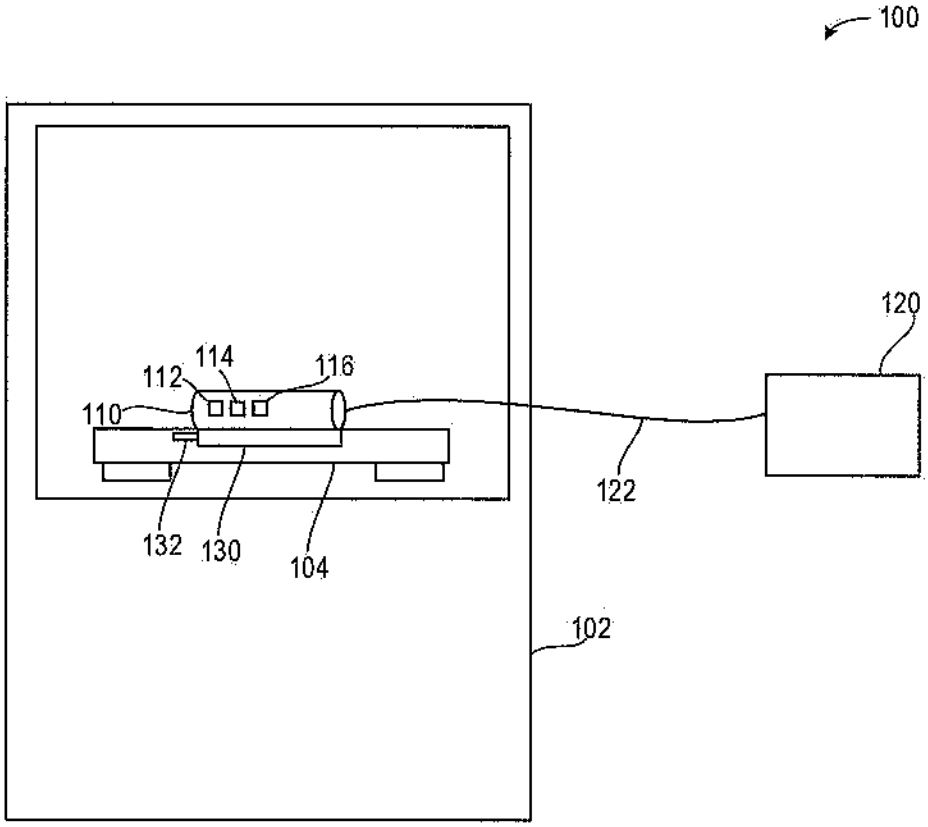

FIG. 1

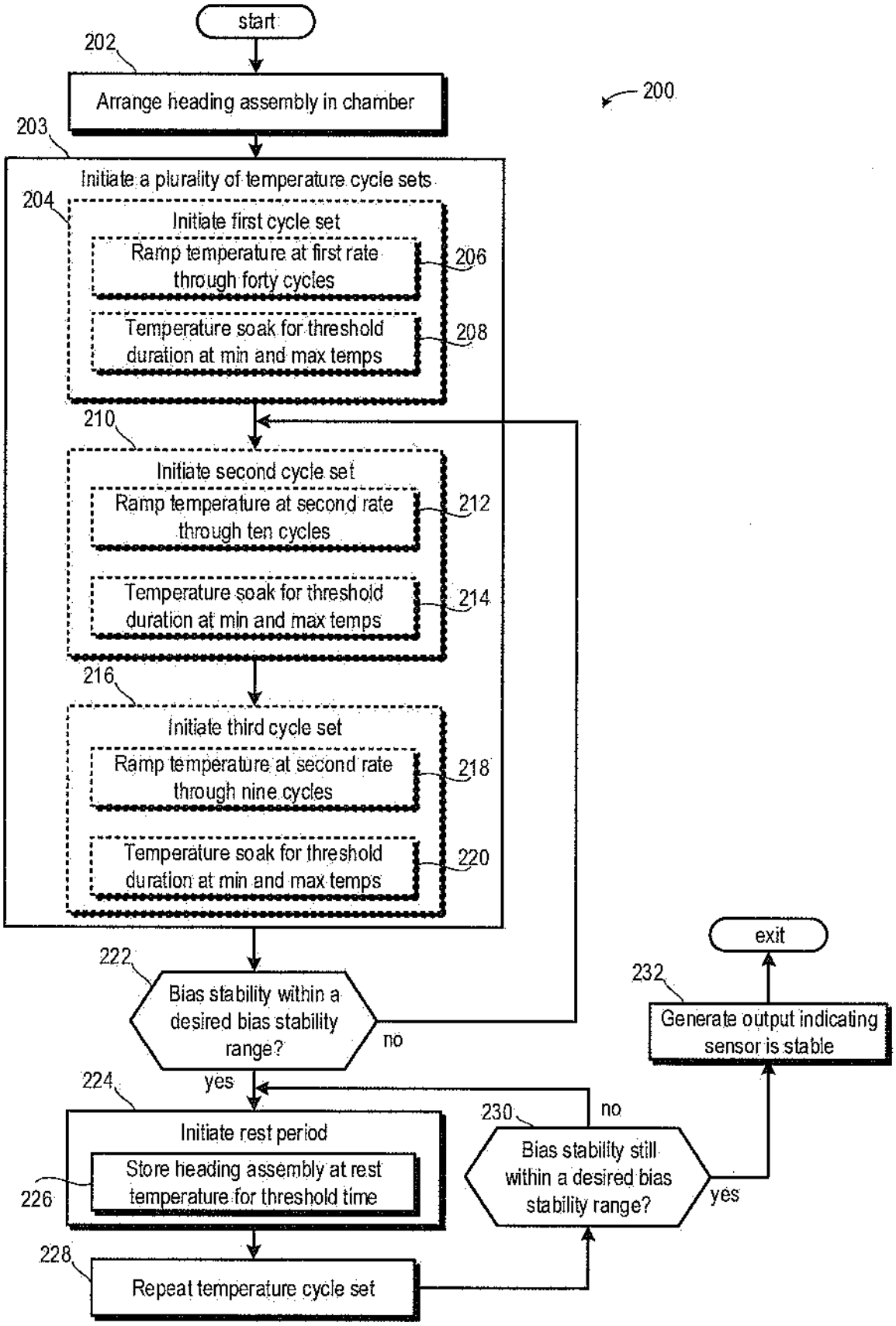
start
202
Arrange heading assembly in chamber
200
203
Initiate a plurality of temperature cycle sets
204
Initiate first cycle set
Ramp temperature at first rate through forty cycles
206
Temperature soak for threshold duration at min and max temps
208
210
Initiate second cycle set
Ramp temperature at second rate through ten cycles
212
Temperature soak for threshold duration at min and max temps
214
216
Initiate third cycle set
Ramp temperature at second rate through nine cycles
218
Temperature soak for threshold duration at min and max temps
220
222
Bias stability within a desired bias stability range?
no
yes
exit
232
Generate output indicating sensor is stable
224
Initiate rest period
Store heading assembly at rest temperature for threshold time
226
230
Bias stability still within a desired bias stability range?
no
yes
228
Repeat temperature cycle set

FIG. 2