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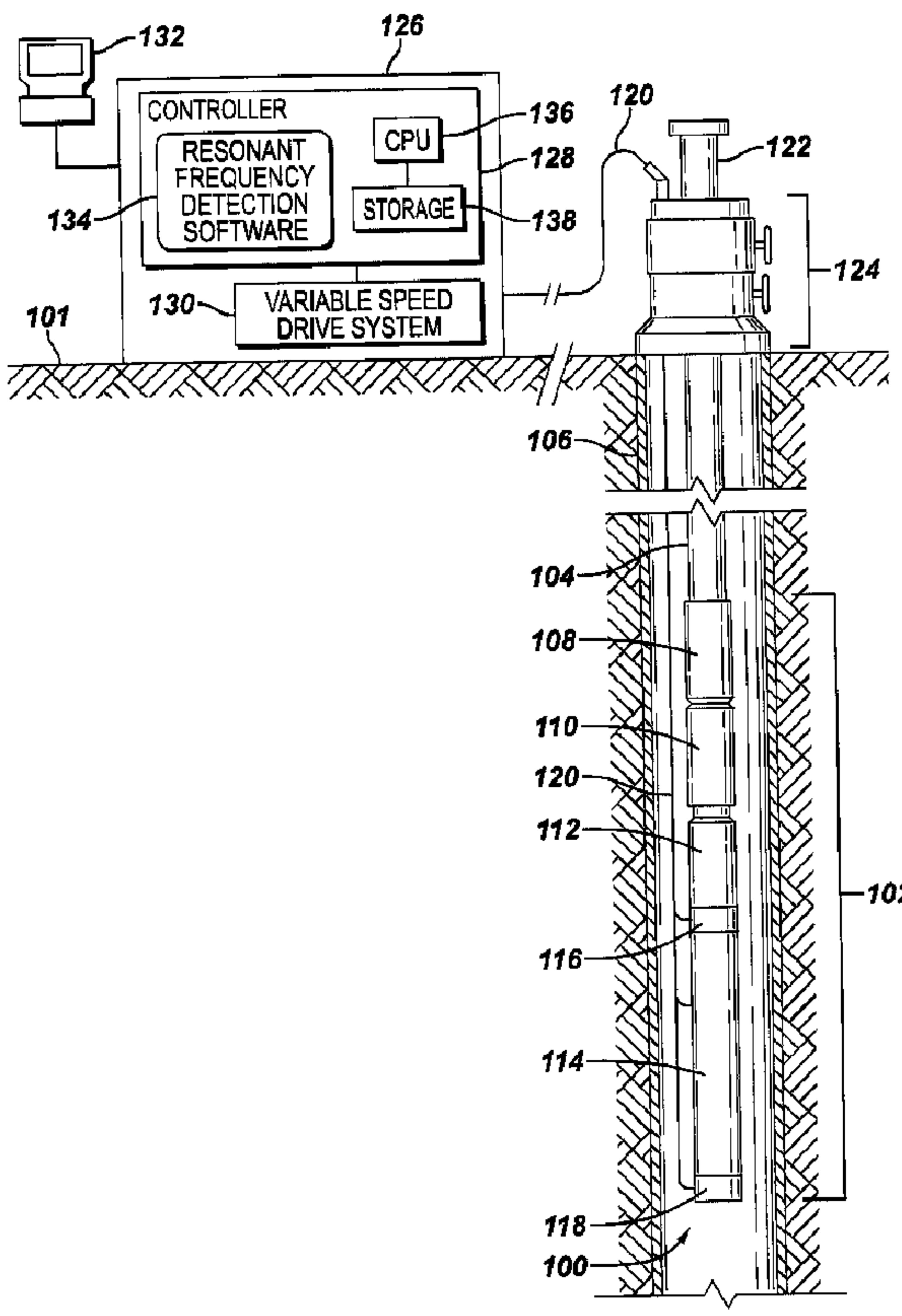
(54) **Titre :** DETECTION AUTOMATIQUE DE LA FREQUENCE DE RESONANCE D'UN SYSTEME DE FOND DE TROU
(54) **Title:** AUTOMATIC DETECTON OF RESONANCE FREQUENCY OF A DOWNHOLE SYSTEM



(57) **Abrégé/Abstract:**
A system includes a downhole tool adapted to be run at plural operating frequencies, a drive system to control an operating frequency of the downhole tool, and a controller to control the drive system to, in a test procedure, vary the operating frequency of the downhole tool. The controller automatically detects a resonance frequency of the downhole tool in the test procedure.

ABSTRACT

A system includes a downhole tool adapted to be run at plural operating frequencies, a drive system to control an operating frequency of the downhole tool, and a controller to control the drive system to, in a test procedure, vary the operating frequency of the downhole tool. The controller automatically detects a resonance frequency of the downhole tool in the test procedure.

AUTOMATIC DETECTION OF RESONANCE FREQUENCY OF A DOWNHOLE SYSTEM

BACKGROUND

[0001] To produce hydrocarbons from a well, an artificial lift mechanism that utilizes a pump is sometimes used. One type of pump is an electrical submersible pump that can be operated at different frequencies. The electrical submersible pump can be controlled by a variable speed drive system that is able to vary the operational frequency of the electrical submersible pump.

[0002] It is desired that the electrical submersible pump not be run at its resonance frequency, as excessive vibration may occur when the electrical submersible pump is run at the resonance frequency. The resonance frequency of an object is the natural frequency of vibration of the object, determined by the physical parameters of the object.

[0003] Conventionally, to identify the resonance frequency of the electrical submersible pump, a manual procedure is performed. The manual procedure involves controlling the variable speed drive system (normally located at the earth surface) to perform a frequency sweep of the electrical submersible pump. The vibration of the electrical submersible pump is monitored by the well operator over the frequency sweep. Normally, the frequency associated with the maximum amount of vibration is considered the resonance frequency, which is recorded by the well operator conducting the test. The variable speed drive system is then manually set to skip the resonance frequency during normal operation of the electrical submersible pump.

[0004] Such manual testing of the electrical submersible pump is time-consuming and labor intensive, which increases the cost of deploying a completion into a well.

SUMMARY OF THE INVENTION

According to the present invention, there is provided an apparatus comprising: a downhole system adapted to be run at plural operating frequencies; a drive system to control an operating frequency of the downhole system; and a controller to control the drive system to, in a test procedure, vary the operating frequency of the downhole system, the controller to automatically detect a resonance frequency of the downhole system in the test procedure.

Also according to the present invention, there is provided a method to perform a test procedure in a downhole tool deployed in a wellbore, comprising: varying, in response to control of a control module, an operating frequency of the downhole tool across a predefined frequency range in the test procedure; receiving, by the control module, vibration data of the downhole tool as the operating frequency of the downhole tool is varied across the predefined frequency range; and automatically determining, by the control module, a resonance frequency of the downhole tool based on the vibration data.

According to the present invention, there is further provided an article comprising at least one storage medium containing instructions that when executed cause a control module to: control a drive system to vary an operating frequency of a downhole tool across a predefined frequency range during a test procedure; and determine a resonance frequency of the downhole tool based on information received from the downhole tool during the test procedure as the operating frequency of the downhole tool is varied across the predefined frequency range.

[0005] In general, a downhole system (*e.g.*, an electrical submersible pump) can be run at plural frequencies, and a drive system controls an operating frequency of the downhole system. A controller controls the drive system to, in a test procedure, vary the operating frequency of the downhole system, and to automatically detect a resonance frequency of the downhole system in the test procedure.

In some embodiments, the controller is also able to set the detected resonance frequency as an operating frequency to avoid.

[0006] Other or alternative features will become apparent from the following description, from the drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Fig. 1 illustrates a system with a pump located in a wellbore and a surface variable frequency drive and control system having a module to determine a resonance frequency of the pump, according to an embodiment.

[0008] Fig. 2 is a flow diagram of a process of detecting the resonance frequency of the pump of Fig. 1, according to an embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0009] In the following description, numerous details are set forth to provide an understanding of the present invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0010] As used here, the terms “up” and “down”; “upper” and “lower”; “upwardly” and downwardly”; “upstream” and “downstream”; “above” and “below”; and other like terms indicating relative positions above or below a given point or element are used in this description to more clearly describe some embodiments of the invention. However, when applied to equipment and methods for use in wells that are deviated or horizontal, such terms may refer to a left to right, right to left, or other relationship as appropriate.

[0011] Fig. 1 illustrates a system that includes a string deployed in a wellbore 100, where the string has a pump assembly 102 that is carried on a tubing 104. In one embodiment, the pump assembly 102 is an electrical submersible pump (ESP) assembly that is controlled electrically to pump fluids in the wellbore 100 up to the well or earth surface 101. The electrical submersible pump assembly 102 is an example of a downhole system that is capable of running at various operating frequencies. In other embodiments, other types of downhole systems are also capable of running at various operating frequencies. Also, instead of a tubing 104, other types of conveyance structures can be used for carrying the downhole system into the wellbore 100, such as wirelines, coiled tubing, cables and so forth.

[0012] The wellbore 100 is lined by a casing or liner 106 that extends from the well surface 101. Wellhead equipment 124 is provided at the well surface 101. A wellhead penetrator 122 is provided through the wellhead equipment 124 to enable electric power transmission from a surface variable speed drive system 130 to the submersible pump assembly 102 through the wellhead equipment 124.

[0013] According to one example, the electrical submersible pump assembly 102 includes a pump 108, a motor 114 for powering the pump 108, a protector 116 to prevent wellbore fluid entry into the motor, and an intake/gas separator 112 where wellbore fluid enters the pump 108. Also, the electrical submersible pump assembly 102 may include a gas handling device 110 for handling an amount of gas that cannot be handled by the submersible pump, and a downhole sensor module 118 (connected to associated transducers) for providing pressure, temperature, flow rate, current, and/or vibration readings associated with the wellbore 100 and submersible pump assembly 102. The components of the electrical submersible pump assembly 102 are provided for purposes of example, as other pump assemblies can have other components.

[0014] The motor 114 is connected to an electric cable 120 that extends through the wellhead equipment 124. The cable 120 further extends out from the wellhead equipment 124 to a control module 126 at the well surface 101.

[0015] The control module 126 includes a controller 128 and the variable speed drive system 130. Note that other components (not shown) can also be part of the control module 126. The variable speed drive system 130 controls the speed at which the motor 114 runs. The speed control affects the operating frequency of the electrical submersible pump assembly 102. The variable speed drive system 130 is connected to the controller 128, which controls (among others) the speed variation provided by the variable speed drive system 130. The variable speed drive system 130 also provides protection functions for the submersible pump assembly 102.

[0016] In accordance with some embodiment of the invention, the controller 128 includes a resonance frequency detection software 134 that is executable on a central processing unit (CPU) 136. The CPU 136 is connected to a storage 138 for storing data and software instructions. The resonance frequency detection software 134 provides an automated mechanism for automatically detecting the resonance frequency of the electrical submersible pump assembly 102 (or other type of downhole tool that is capable of operating at multiple frequencies). Using the resonance frequency detection software 134 in the controller 128 to perform the resonance frequency detection enables a well operator to automate the resonance frequency detection procedure, such that the well operator does not have to manually detect for the resonance frequency and to make adjustments in the variable speed drive system 130 for such resonance frequency. The resonance frequency detection software 134 works with an electric submersible pump assembly 102 that includes a downhole sensor module that is able to measure vibration at any point on the submersible pump assembly 102.

[0017] According to some embodiments of the invention, the resonance frequency detection software 134 is executable to detect the resonance frequency of the electrical submersible pump assembly 102, and to automatically set one of the resonance frequencies that the variable speed drive system 130 will skip, called "setting a jump frequency."

[0018] A user station 132 can be coupled to the control module 126. Using the user station 132, such as a notebook computer, a desktop computer, a personal digital assistant (PDA), or other user device, a user (such as a well operator) can invoke execution of the resonance frequency detection software 134 as well as view the results of the execution of resonance frequency detection software 134. Also, the user can monitor operation of the electrical submersible pump assembly 102. All of these can be accomplished through the local user interface on the control module 126.

[0019] In one embodiment, the user station 132 includes a user interface that displays control elements to control the resonance frequency detection software 134. The user interface also displays fields for outputting results of a test conducted by the resonance frequency detection software 134 for determining the resonance frequency of the electrical submersible pump assembly 102. Optionally, the user interface in the user station 132 can also be used to control the variable speed drive system 130.

[0020] The resonance frequency detection software 134 is an example of a module to automatically detect for a resonance frequency of a downhole system such as the electrical submersible pump assembly 102. In other embodiments, instead of being a software module, a module implemented in hardware or a combination of hardware and firmware can be used to perform automated resonance frequency detection.

[0021] According to one embodiment, to enable the test procedure for finding a resonance frequency by the resonance frequency detection software 134, a downhole sensor module 118 is provided in the electrical submersible pump assembly 102. The downhole sensor module 118 is connected to the cable 120 through the motor 104, while one or more transducers can be located at any point on the electrical submersible pump assembly 102.

[0022] As depicted in Fig. 2, to perform the test procedure, the resonance frequency detection software 134 is executable to receive or generate (at 202) minimum and maximum operating frequency values that define a frequency range over which a frequency sweep is to be performed in the test procedure. In one implementation, the minimum and maximum operating frequencies can be entered by a user at the user station 132 or through the user interface of the controller 128. For example, the user interface presented by the resonance frequency detection software 134 can have fields for receiving various parameters, including the minimum and maximum operating frequencies.

[0023] Alternatively, the minimum and maximum operating frequencies can be generated by the resonance frequency detection software 134 based on various data associated with the electrical submersible pump assembly 102. For example, the electrical submersible pump assembly 102 can be associated with motor "nameplate" data, including the maximum horsepower of the motor 114, and the motor nameplate frequency. The motor nameplate frequency is typically 50 Hz or 60 Hz, depending on power supply frequency. The maximum frequency for the frequency sweep is then derived using the following equation:

$$\text{MaxFreq} = \frac{\text{Motor Nameplate Frequency} *}{\sqrt{\textit{Motor Nameplate HP / HP Consumption At Motor Nameplate Frequency}}}$$

[0024] The HP consumption at motor nameplate frequency refers to the expected horsepower consumed by the pump 108, gas handling device 110 (if present), and intake/gas separator 112 being run by the motor at the motor nameplate frequency. The HP consumption at motor nameplate frequency can be entered by a user (such as through the user station 132), or can be derived from other information such as pressure or flow rate information from transducers located on the electrical submersible pump assembly 102.

[0025] After receiving or generating (at 202) the minimum and maximum operating frequencies at 102, the resonance frequency detection software 134 causes (at 204) the controller 128 to control the variable speed drive system 130 to run the electrical submersible pump assembly 102 from the minimum operating frequency to the maximum operating frequency. During this frequency sweep, the resonance frequency detection software 134 receives (at 206) vibration data from a sensor.

[0026] The vibration data is stored (at 208) and correlated to the operating frequencies. For example, the vibration data and corresponding operating frequencies can be stored in a table format. Based on the received vibration data, the resonance frequency detection software 134 determines (at 210) the resonance frequency, which is the frequency at which maximum vibration is detected (from the vibration data).

[0027] The detected resonance frequency is then stored (at 212) and optionally reported to the user at the user station 132. Also, the controller 128, based on the resonance frequency determined by the resonance frequency detection software 134, sets (at 214) the variable speed drive system 130 to skip the resonance frequency. For example, the variable speed drive system 130 can be associated with a jump frequency or jump frequencies that is or are to be skipped over during operation.

[0028] Instructions of the resonance frequency detection software 134 (Fig. 1) are stored on one or more storage devices in the controller 128 and loaded for execution on a processor (such as CPU 136). The processor includes microprocessors, microcontrollers, processor modules or subsystems (including one or more microprocessors or microcontrollers), or other control or computing devices. As used here, a “control module” refers to hardware, software, or a combination thereof. A “control module” can refer to a single component or to plural components (whether software or hardware).

[0029] Data and instructions (of the software) are stored in respective storage devices, which are implemented as one or more machine-readable storage media. The storage media include different forms of memory including semiconductor memory devices such as dynamic or static random access memories (DRAMs or SRAMs), erasable and programmable read-only memories (EPROMs), electrically erasable and programmable read-only memories (EEPROMs) and flash memories; magnetic disks such as fixed, floppy and removable disks; other magnetic media including tape; and optical media such as compact disks (CDs) or digital video disks (DVDs).

[0030] While the invention has been disclosed with respect to a limited number of embodiments, those skilled in the art, having the benefit of this disclosure, will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover such modifications and variations as fall within the true spirit and scope of the invention.

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CLAIMS:

1. An apparatus comprising:

a downhole system adapted to be run at plural operating frequencies;

a drive system to control an operating frequency of the downhole system; and

a controller to control the drive system to, in a test procedure, vary the operating frequency of the downhole system,

the controller to automatically detect a resonance frequency of the downhole system in the test procedure.

2. The apparatus of claim 1, the controller to further set the detected resonance frequency as a frequency to avoid in the drive system.

3. The apparatus of claim 2, wherein the controller sets the detected resonance frequency to avoid by setting the resonance frequency as a jump frequency in the drive system.

4. The apparatus of any one of claims 1 to 3, wherein the controller comprises a central processing unit and software executable on the central processing unit, the software executable to perform the control and detect tasks.

5. The apparatus of any one of claims 1 to 4, wherein the downhole system comprises a pump adapted to be run at the plural operating frequencies.

6. The apparatus of claim 5, wherein the pump comprises an electrical submersible pump.

7. The apparatus of any one of claims 1 to 6, further comprising a vibration sensor to detect vibration of the downhole system during the test procedure, the controller to receive data from the vibration sensor for detecting the resonance frequency.

8. The apparatus of claim 7, the controller to perform the test procedure by causing the operating frequency of the downhole system to be varied across a predefined frequency range.

9. The apparatus of any one of claims 1 to 8, further comprising at least one of a user station and a local user interface of the controller to display a result of the test procedure.

10. A method to perform a test procedure in a downhole tool deployed in a wellbore, comprising:

varying, in response to control of a control module, an operating frequency of the downhole tool across a predefined frequency range in the test procedure;

receiving, by the control module, vibration data of the downhole tool as the operating frequency of the downhole tool is varied across the predefined frequency range; and

automatically determining, by the control module, a resonance frequency of the downhole tool based on the vibration data.

11. The method of claim 10, further comprising displaying a result of the test procedure on a user interface.

12. The method of claim 10 or 11, further comprising setting, at a drive system that controls the operating frequency of the downhole tool, a frequency to avoid based on the determined resonance frequency.

13. The method of any one of claims 10 to 12, wherein varying the operating frequency of the downhole tool comprises varying the operating frequency of an electrical submersible pump.

14. The method of any one of claims 10 to 13, wherein receiving vibration data of the downhole tool comprises receiving vibration data from a vibration sensor in the downhole tool.

15. The method of any one of claims 10 to 14, further comprising receiving a minimum operating frequency and a maximum operating frequency that defines the predefined frequency range.

16. The method of claim 15, further comprising generating the maximum operating frequency based at least in part on flow rate information or pressure information received from one or more sensors in the downhole tool.

17. An article comprising at least one storage medium containing instructions that when executed cause a control module to:

control a drive system to vary an operating frequency of a downhole tool across a predefined frequency range during a test procedure; and

determine a resonance frequency of the downhole tool based on information received from the downhole tool during the test procedure as the operating frequency of the downhole tool is varied across the predefined frequency range.

18. The article of claim 17, wherein the instructions when executed cause the control module to further receive vibration data from a vibration sensor of the downhole tool, wherein determining the resonance frequency of the downhole tool is based on the vibration data.

19. The article of claim 17 or 18, wherein the instructions when executed further cause the control module to generate a maximum operating frequency of the predefined frequency range, the maximum operating frequency generated based on flow rate information or pressure information received from one or more sensors of the downhole tool.

20. The article of claim 19, wherein generating the maximum operating frequency is further based on horsepower information of the downhole tool.

21. The article of any one of claims 17 to 20, wherein controlling the drive system to vary the operating frequency of the downhole tool comprises controlling the drive system to vary the operating frequency of a pump assembly.

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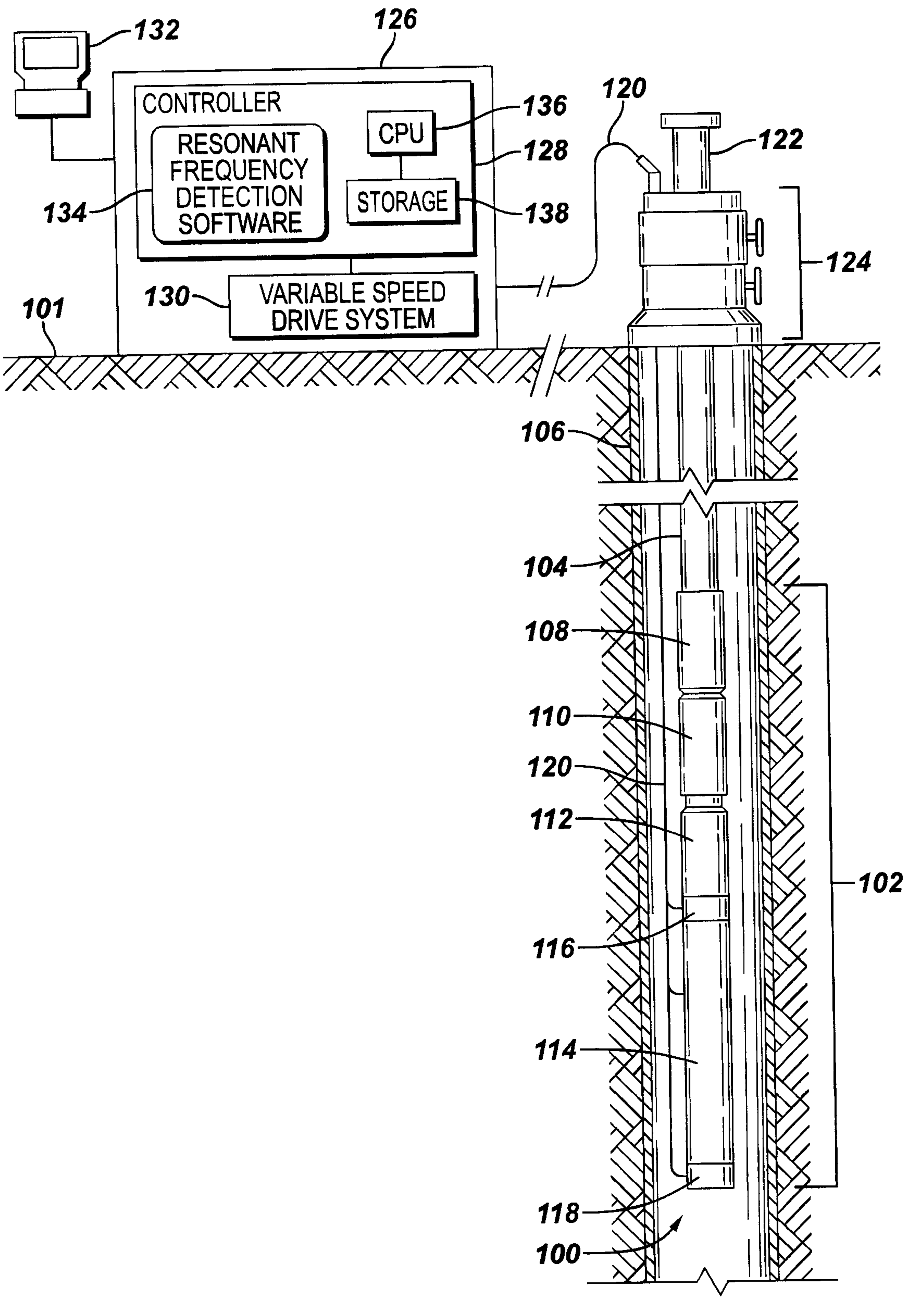
PATENT AGENTS

FIG. 1



132
126
CONTROLLER
CPU
136
120
122
128
RESONANT FREQUENCY DETECTION SOFTWARE
134
STORAGE
138
124
130
VARIABLE SPEED DRIVE SYSTEM
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106
104
108
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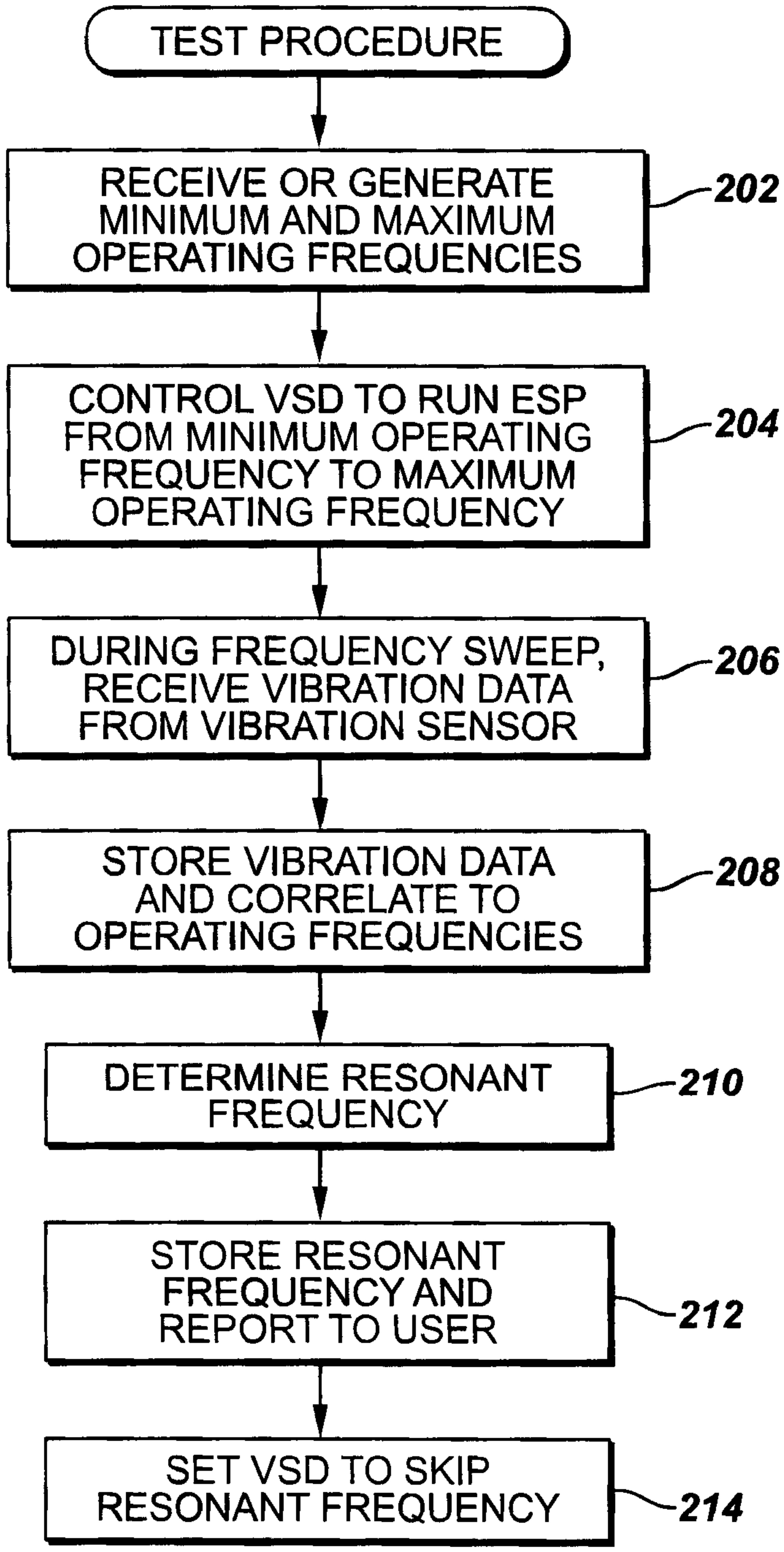
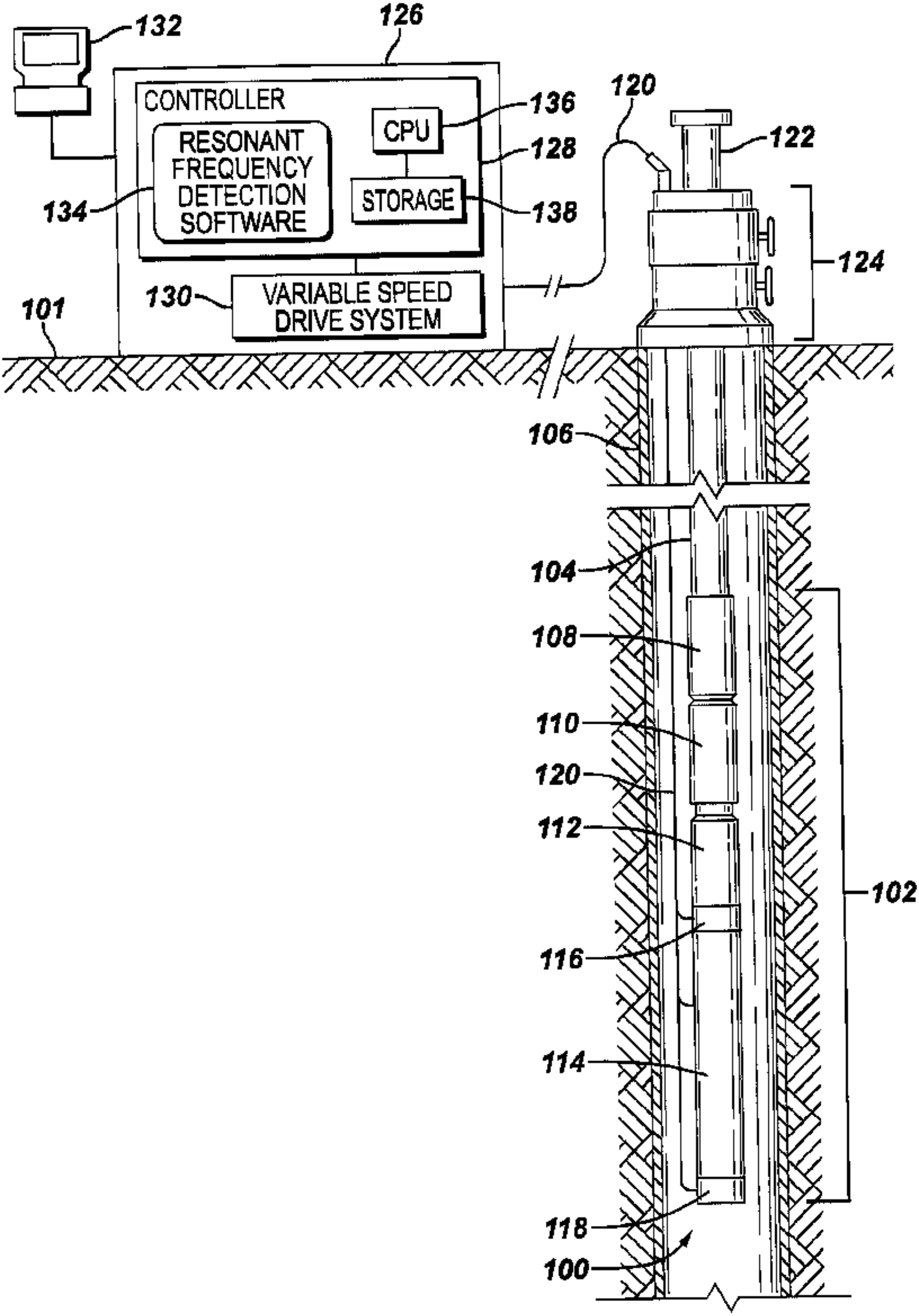
112
102
116
114
118
100

FIG. 2


TEST PROCEDURE
RECEIVE OR GENERATE MINIMUM AND MAXIMUM OPERATING FREQUENCIES
202
CONTROL VSD TO RUN ESP FROM MINIMUM OPERATING FREQUENCY TO MAXIMUM OPERATING FREQUENCY
204
DURING FREQUENCY SWEEP, RECEIVE VIBRATION DATA FROM VIBRATION SENSOR
206
STORE VIBRATION DATA AND CORRELATE TO OPERATING FREQUENCIES
208
DETERMINE RESONANT FREQUENCY
210
STORE RESONANT FREQUENCY AND REPORT TO USER
212
SET VSD TO SKIP RESONANT FREQUENCY
214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