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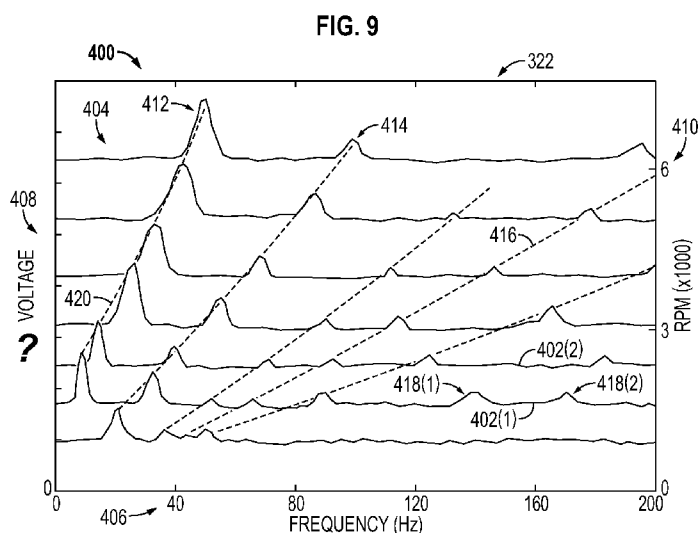
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(54) Title: TRANSIENT VIBRATION TIME-FREQUENCY-TRANSFORMATION FOR ESP PROGNOSIS HEALTH MONITORING

(57) Abstract: Systems and methods of determining a health of an ESP includes collecting transient vibration signature data from one or more sensors disposed in proximity to an operating ESP, analyzing the collected data, and diagnosing the health of the ESP.





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TRANSIENT VIBRATION TIME-FREQUENCY-TRANSFORMATION FOR ESP
PROGNOSIS HEALTH MONITORING

BACKGROUND

[0001] This section provides background information to facilitate a better understanding of the various aspects of the disclosure. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art.

[0001] When pumping downhole fluids with an electric submersible pump (ESP), it is possible to measure and analyze vibration signatures of the ESP. Vibration signatures can vary with time. Measuring transient vibration signatures of the ESP, as opposed to taking a snapshot of a vibration signature at specific moment in time, enables a more detailed analysis of the ESP to be performed. Such transient analysis of vibration signatures present during operating of the ESP makes it possible to detect and diagnose potential problems within the ESP. For example, utilizing sensors placed throughout the ESP, it is possible to detect a vibration signature that may indicate various ESP problems such as a rotating shaft imbalance, a loose bearing, pump cavitation, etc.

SUMMARY

[0002] In accordance to one or more aspects, a system and method for monitoring an operational health of an electric submersible pump (ESP) and a data acquisition unit in communication with the sensor to collect a transient vibration signature of the operating ESP. Operational health of the ESP may be determined in accordance to an aspect of the disclosure by comparing an analysis of the transient vibration signature performed by the data acquisition unit with that of a database. An operating condition of the ESP may be adjusted in response to the analysis. In accordance to some aspect of the disclosure, a remote analysis unit may communicate with the data acquisition unit to analyze the transient vibration signature data at a site remote from the wellbore. After the remote analysis unit has analyzed the transient vibration signature data and determined an operational health of the ESP, the remote analysis unit can communicate with the

data acquisition unit to effect operating changes to the ESP. The analysis may be performed continuously or iteratively during operation of the ESP to provide continuous feedback regarding the operational health of the ESP.

[0003] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of various features may be arbitrarily increased or reduced for clarity of discussion.

[0005] Figure 1 is a schematic view of an electric submersible pump (ESP) system according to one or more aspects of the disclosure deployed in a wellbore.

[0006] Figure 2 is a partial sectional view of a radial flow style pump stage incorporating one or more sensors in accordance to one or more aspects of the disclosure.

[0007] Figure 3 is a sectional view of an ESP motor incorporating one or more sensors according to one or more aspects of the disclosure.

[0008] Figure 4 is a sectional view of an ESP protector incorporating one or more sensors according to one or more aspects of the disclosure.

[0009] Figure 5 is an exploded sectional view of a thrust bearing incorporating one or more sensors according to one or more aspects of the disclosure.

[0010] Figure 6 is a sectional view of an ESP pump incorporation one or more sensors according to one or more aspects of the disclosure.

[0011] Figure 7 is a spectrogram display of a periodic vibration signature in both a time domain and a frequency domain according to one or more aspects of the disclosure.

[0012] Figure 8 is a spectrogram display of a transient vibration signature in both a time domain and a frequency domain according to one or more aspects of the disclosure.

[0013] Figure 9 is a spectrogram waterfall display of a transient vibration signature in a frequency domain according to one or more aspects of the disclosure.

[0014] Figure 10 is a schematic of a data acquisition unit and a remote analysis unit according to one or more aspects of the disclosure.

[0015] Figure 11 is a flow diagram of a method of monitoring health of an ESP.

DETAILED DESCRIPTION

[0016] It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0017] As used herein, the terms connect, connection, connected, in connection with, and connecting may be used to mean in direct connection with or in connection with via one or more elements. Similarly, the terms couple, coupling, coupled, coupled together, and coupled with may be used to mean directly coupled together or coupled together via one or more elements. Terms such as up, down, top and bottom and other like terms indicating relative positions to a given point or element are may be utilized to more clearly describe some elements. Commonly, these terms relate to a reference point such as the surface from which drilling operations are initiated.

[0018] Figure 1 is a schematic illustration of a system, generally denoted by the numeral 10, for monitoring the prognosis and operational health of an electric submersible pump (ESP) 110 disposed in a wellbore 100 in accordance to one or more aspects of the disclosure. The downhole equipment includes a tubing string 102 that is held by a hangar 104 located near an earth surface 106 from which the wellbore 100 extends. The tubing string 102 includes a tubing 108 that has an inner bore through which fluids 115 can flow (e.g., production fluids or injection fluids). An electric submersible pump (ESP) 110 (or other type of pump) that is also part of the tubing string 102 is attached to the tubing 108. The ESP 110 can assist in creating fluid flow to produce fluids 115 from a reservoir 112 surrounding the wellbore 100 through the tubing 108 to the earth surface 106. Instead of the ESP 110, other downhole components, such as valves, motors, etc., can be provided in the tubing string 102. As depicted in Figure 1, perforations 114 are formed into the reservoir 112 to enable fluids 115 from the reservoir 112 to flow into the

wellbore 100 for production through the tubing 108. Non-limiting examples of systems for detecting downhole acoustic events are disclosed for example in United States Patent 8,020,616, the teachings of which are fully incorporated herein by reference.

[0019] Operation of the ESP 110 is associated with a certain level of vibration. For example, the ESP 110, also referred to from time to time as an ESP string, includes various moving parts, such as a pump 152 (see e.g., see Figure 2), a motor 200 (e.g., see Figure 3), and a protector 250 (e.g., see Figure 4), each of which may create a vibration signature. Over the life of the ESP 110, the moving parts within the ESP 110 can wear out or begin to fail for various reasons. As such moving parts wear out or begin to fail, the vibration signatures associated with the ESP 110 changes. Vibration signatures created by the ESP 110 can be detected as acoustic waves (pressure waves) or as particle motion. The vibration signatures associated with the ESP 110 can be measured and analyzed by locating one or more sensors 118 in proximity to the outside of the ESP 110, or by locating one or more sensors 119 within the ESP 110. Sensors 118 and 119 may include various sensor types that are suitable for measuring vibration signatures. For example, sensors 118 and 119 may be seismic, hydrophone, accelerometer, or other types of vibration sensors.

[0020] Sensor 118 may be for example a seismic sensor disposed in the wellbore external of the ESP. In Figure 1, sensor 118 is illustrated in communication with a data acquisition unit (e.g., controller) via a communication link 116. Communication link 116 may include without limitation a physical conductor such as cable, optic fibers, twisted wires, wired pipe, and the motor and power cables (i.e., communication over power line). Physical conductors may be disposed inside of the borehole and/or external of the borehole, for example behind the casing via inductive coupling. In accordance to some embodiments, communication link 116 may be wireless, for example via acoustic telemetry. In Figure 1, communication link 116 is illustrated and described as an optical fiber 116 that extends along tubing string 102 to a data acquisition unit 122 located in the Figure 1 example at surface 106. It will be understood by those skilled in the art with benefit of this disclosure that the data acquisition unit may be located in whole or in part down downhole. An optic fiber system includes a light source for producing optical signals

that are transmitted into the fiber optic cable 116. The light source can be included in a communications interface 184 (see, e.g. Fig. 10). Backscattered light is received by a detector for example in the data acquisition unit 122. In the presence of a vibration signature, the sensor 118 can cause a strain on a fiber optic cable portion 120 to change in response to the vibration signature. This interaction also effectively causes a change in the backscattered light from the fiber optic cable portion 120. The vibration signatures that are detected by the data acquisition unit 122 may be transmitted at 124 to a remote analysis unit 126. The data acquisition unit 122 and/or the remote analysis unit 126 may be used to analyze the data corresponding to the detected vibration signatures to determine whether any problem is present in the wellbore 100. Again, the data acquisition unit and/or the remote analysis unit 126 may be located in the wellbore, for example incorporated in the electrical submersible pump. Data can be acquired by the data acquisition unit 122 in real time, and the data acquisition unit 122 and/or the remote analysis unit 126 can analyze such data in real time in order to provide instantaneous (or nearly instantaneous) status updates of downhole conditions or conditions of ESP 110. Background noise may be initially detected (such as by monitoring backscattered signals from the fiber optic cable 116 when an external sensor 118 is used before any downhole operation is started). This background noise can then be removed from subsequent data considered by the data acquisition unit 122 and/or the remote analysis unit 126 for more accurate processing.

[0021] The optical fiber 116 can be one of several different types of fiber optic cables: (1) a permanent fiber optic cable that is laid into the cable during manufacturing; (2) a fiber optic cable that is pumped into a control line that is provided in the wellbore 100; or (3) a bare optical fiber that is run from the earth surface to the area of interest downhole (e.g., in proximity to the ESP 110).

[0022] As shown in Figure 1, the sensor 118 is depicted as being attached to the optical fiber 116. In some embodiments, a plurality of sensors 118 may be located on the communication link 116. In some embodiments, the optic fiber may be the sensor and the vibration signature detected by the optical fiber 116 alone, for example in a distributed sensor. The acoustic waves that impinge upon a local portion 120 of the optical fiber 116 in the proximity of the ESP 110

may cause a characteristic of the fiber optic cable portion 120 to change, which affects characteristics of backscattered light from the fiber optic cable portion 120. A portion of the optical fiber 116 in the proximity of the ESP 110 (or other downhole equipment being monitored) means that the portion of the optical fiber 116 is capable of detecting vibration noise associated with the downhole equipment being monitored.

[0023] One or more sensors 119 may be placed within the ESP 110. Implementations of the one or more sensors 119 will be discussed in more detail with respect to Figures 2-6. Examples of instrumented electric submersible pumps are disclosed for example in United States Patent Application Publication US 2013/0272898, the teachings of which are fully incorporated herein by reference. It should be noted that sensor 119 generally refers to an internal sensor. Specific sensors 119 will be described with respect to Figures 2-6 and given unique part numbers. Sensors 119 may communicate with the data acquisition unit 122 via one or more cables that pass through the tubing string 102. The output of the various sensors 119 may be multiplexed to communicate with the data acquisition unit 122 using a minimum of communication wires, or a single optical fiber cable.

[0024] Refer now to Figure 2 illustrating a partial sectional view of a stage 150 of a pump 152 of an ESP that incorporates a sensor 178 in accordance to one or more aspects of the disclosure. The pump 152 comprises a plurality of stages 150. Each stage 150 may include an impeller 154 coupled to a shaft 156 that is rotatable about a central axis 158. Rotation of shaft 156 by a motor 200, see for example Figure 3, of the ESP 110 causes impellers 154 to rotate within an outer pump housing 160. Each impeller 154 draws fluid 115 in through an impeller or stage intake 162 and routes the fluid 115 along an interior impeller passageway 164 before discharging the fluid 115 through an impeller outlet 156 and into an axially adjacent diffuser 168. The interior passageway 164 is defined by the shape of an impeller housing 170, and impeller housing 170 may be formed to create an impeller for a floater stage, as illustrated in Figure 2, or for a compression stage. Additionally, the impeller housing 170 may be designed to create a mixed-flow stage, a radial-flow stage, axial-flow stage, or another suitable stage style for use in the

pump 152. Figure 2 is only one example of submersible pump construction provided to show an example of sensor placement.

[0025] An inner thrust member 172, which may be a thrust washer or bearing, is positioned to resist thrust loads, i.e., to resist downthrust loads created by the rotating impeller 154. The thrust member 172 may be positioned in the profile of an impeller feature 174, such as a recess formed in an upper portion of impeller housing 170. The thrust member 172 may be disposed between the impeller 154 and a radially inward portion 176 of the next adjacent upstream diffuser 168. In an implementation, at least one sensor 178 may be placed near, against, or within the thrust member 172 and wired through stationary parts of the diffuser housing, such as radially inward portion 176. The sensor 178 can be used to monitor vibration, but other sensor types (e.g., temperature, load, and position or proximity sensors) may be applied to the thrust member 172 to monitor the thrust member 172. Monitoring vibration of the thrust member 172 can provide information regarding a health/operational condition of the thrust member 172. For example, the sensor 178 may provide information about aging of the thrust member 172, as well as load characteristics, e.g., for purposes of adjusting the load to spare the thrust bearing or to lengthen the lifespan of the thrust member 172.

[0026] Refer now to Figure 3 illustrating a sectional view of a motor 200 of an ESP in accordance to one or more aspects of the disclosure. For example, the motor 200 may power the stages 150 of Figure 2. The motor 200 includes various hardware components and may include one or more sensors 119. The motor 200 may have a motor head 202, a motor base 204, and an outer housing 206. A rotor 208, supported by rotor bearings 210, drives rotation of a shaft 212. A stator 214 with laminations provides a rotating magnetic field to drive the rotor 208.

[0027] The stator 214 has windings 216, which create electromagnetic fields when electricity flows. The rotor 208 may also have windings 216, to induce electromagnetic fields that interact with the electromagnetic fields of the stator 214. Alternatively, the rotor 208 may have permanent magnets instead of windings 216. The motor 200 may have other features, such as a drain and fill valve 218 for motor oil, such as dielectric oil. A coupling 220 at the motor head 202 connects with, for example, the pump 152 or a protector 250 of Figure 4. Bearings for the

shaft 212 may have associated thrust members 222 or a thrust ring to bear the axial load generated by the thrust of one or more operating pumps 152. Electrically, the motor 200 may have a power cable extension 224 that connects to a terminal 226.

[0028] Various types of sensors 119 may be included in the motor 200 to monitor many aspects, including a vibration signature, of the above components. Sensors 119 may be placed at multiple locations throughout the ESP 110. For example, each bearing and thrust member within the motor 200 may have a sensor 228 to monitor various properties (e.g., vibration, temperature) of the motor 200. For example, a sensor 228 may be placed at rotor bearings, such as bearing 210, and at thrust members, such as the thrust member 222. There may also be a pothead sensor 230 to monitor vibration, temperature, etc. at the pothead. Monitoring vibration of the bearing 210 or the thrust member 222 can provide information regarding the operational condition of these components and can help diagnose an overall health of the ESP 110. Although not shown, it is noted that additional sensors can be provided to measure other properties of the motor 200 and its components. Other sensors include current leakage, temperature, strain, rpm, torque, chemical, water cut, and proximity, among other sensors.

[0029] Refer now to Figure 4 illustrating a sectional view of the protector 250 of the ESP 110. The protector 250, which is located between the motor 200 and the pump 152 includes various hardware components and may include one or more sensors 119. The protector 250 includes a shaft 252, shaft seal 254, and a shaft bearing 256. At least one shaft bearing may have an associated thrust bearing 258 to bear an axial load of the shaft 252 generated by thrust from the pump 152. In one aspect, the thrust bearing 258 is instrumented by addition of one or more sensors for vibration, temperature, strain, and proximity to monitor status of the thrust bearing 258 (e.g., see Figure 5). The protector 250 may include various types of sensors to monitor and improve operation of the protector 250. For example, the protector 250 may also include for each bearing, such as shaft bearing 256 or thrust bearing 258, a vibration sensor 260. Monitoring the shaft bearing 256 and/or the thrust bearing 258 can provide information regarding the operational condition of these components and can help diagnose an overall health of the ESP 110. Although not shown, it is noted that additional sensors can be provided to measure other

properties of the protector 250 and its components. Other various sensors include temperature and pressure, among other sensors.

[0030] Refer now to Figure 5 illustrating an exploded view of a thrust bearing, such as thrust bearing 258 from Figure 4. The thrust bearing 258 may be instrumented by addition of at least one sensor 119, for example a vibration sensor 268, as well as other sensors such as a temperature sensor 262, a strain sensor 264 (e.g., a load cell), and a proximity sensor 266 to monitor status of the thrust bearing 258.

[0031] Refer now to Figure 6 illustrating a sectional view of the pump 152 and an associated intake 270. The pump 152 may be a centrifugal pump, but it should be understood that another type of submersible pump, such as a diaphragm pump or a progressing cavity pump could be used as desired. The pump 152 has a fluid inlet or intake 270 and a fluid discharge 272. The pump 152 may have various bearings, such as a bearing 274 and a bearing 276. Each bearing 274 and 276 may have an associated vibration sensor 278. The fluid intake 270 may also have at least one vibration sensor 280. Likewise, the fluid discharge 272 may have a vibration sensor 282. Monitoring the bearings 274 and 276 can provide information regarding the operational condition of these components and can help diagnose an overall health of the ESP 110. Although not shown, it is noted that additional sensors can be provided, such as to measure other properties of the pump 152 and its components. Other various sensors include flow, temperature, chemical, water cut, density, viscosity, and pressure, among other sensors.

[0032] With reference generally to Figures 7-10 and Table 1, health of the ESP 110 can be studied by measuring transient vibration signatures from different locations in and around the ESP 110. Transient vibration signatures of the ESP 110 can be measured, for example, by using one or more of sensors 118 and 119. Sensors 118 and 119 may include for example and without limitation one or more of sensors 178, 228, 230, 236, 260, 268, 278, 280, and 282 discussed with reference to Figures 1-6. Transient vibration signatures are signatures that are measured over a period of time, as opposed to snapshot or instantaneous signatures. Measuring transient vibration signatures of the ESP 110 provides more information than an instantaneous signature and permits an identification of a source of a vibration and a possible diagnosis of a problem

within the ESP 110. For example, by measuring transient vibration signatures during startup, it is possible to diagnose a shaft imbalance due to a bent shaft, bearing looseness, and so on. After a problem is diagnosed through analysis of the transient vibration signature, an operator of the ESP 110 can react accordingly to address the problem. For example, in response to detecting a shaft imbalance, the speed of the pump 152 can be varied to reduce vibration and prolong a service life of the ESP 110. In other situations, analysis of the transient vibration signature may predict a potential failure in the near future. Such a diagnosis allows for planning for ESP intervention to minimize the production interruption.

[0033] Refer now to Figure 7 illustrating a non-transient periodic vibration signature shown in both the time domain and the frequency domain. A spectrogram display 300 is shown displaying a periodic vibration signature 302 in a time domain 304 and in a frequency domain 306. The periodic vibration signature 302 represents data that was collected by one or more sensors positioned in proximity to the ESP 110 during operation. The data collected by the sensors is transmitted to the data acquisition unit 122, where it can be analyzed onsite or transmitted to the remote analysis unit 126 for offsite analysis.

[0034] As shown in Figure 7, the time domain 304 includes an x-axis 308 describing time in milliseconds and a y-axis 310 describing a voltage associated with the amplitude of the periodic vibration signature 302. The frequency domain 306 displays the periodic vibration signature 302 after application of a Fast Fourier Transform (FFT) algorithm by the data acquisition unit 122 or the remote analysis unit 126. Processing the periodic vibration signature 302 with FFT transforms the data associated therewith into a series of peaks 316(1)-(4), each of which identifies a frequency that, in the aggregate, makes up the periodic vibration signature 302. In the frequency domain 306, an x-axis 312 describes frequency in Hertz and a y-axis 314 describes voltage associated with the amplitude of the periodic vibration signature 302.

[0035] When a vibration signature is periodic (e.g., the vibration signature repeats itself over time), such as the periodic vibration signature 302, FFT may be used to determine which frequencies 316 are present. Depending on the specific conditions encountered during operation of the ESP 110, the frequencies 316 that make up the periodic vibration signature 302 can vary.

As shown in Figure 7, application of FFT to the periodic vibration signature 302 reveals peaks 316(1)-(4) of approximately 11 Hz, 25 Hz, 52 Hz, and 101 Hz, respectively. With the frequency makeup of the periodic vibration signature 302 determined, an analysis can be performed based upon the frequencies associated with peaks 316(1)-(4) to provide a diagnosis of the periodic vibration signature 302. However, if the measured vibration instead comprises a random or transient vibration, which could be detected during the normal operation of the ESP 110 or when certain ESP 110 activity is being performed, such as starting, stopping, or pump speed adjustment of the ESP 110, using FFT will not provide information regarding the transient vibration signature, which will not provide insight regarding how vibration signature changes over time.

[0036] Refer now generally to Figures 8 and 9. By continuously monitoring transient vibration detected at the ESP 110 or at an area in proximity to the ESP 110, it is possible to analyze the transient vibration signature and match the analysis with information in a database 188 (see Figure 10) to provide a diagnosis of the health of the ESP 110. The database 188 contains diagnostic data regarding transient vibration signatures that has been previously collected or created and stored to enable diagnosis of a health of an ESP. For example, a known transient vibration signature for a bearing failure can be stored in the database 188 so that a reference sample exists to diagnose bearing failures in other ESPs. The database 188 can also store transient vibration signature data 190 that has been collected by the data acquisition unit 122 so that the newly collected data can be used for future diagnosis. For example, the newly collected data 190 may identify a new type of failure of the ESP 110, the identification of which would be useful to have stored in the database 188 so that the failure can be readily identified in the future.

[0037] The database 188 can be associated with the data acquisition unit 122 or the remote analysis unit 126. Upon diagnosing the health of the ESP 110, corrective actions, such as reducing a speed of the pump 152, can be taken as needed. Implementation of corrective actions can be fully automated at the earth surface 106 using a programmed computer or processor, such as the data acquisition unit 122 or the remote analysis unit 126.

[0038] Refer now to Figure 8 illustrating a transient vibration signature in both a time domain and a frequency domain. A spectrogram display 320 is shown displaying a transient vibration signature 322 in a time domain 324 and in a frequency domain 326. The transient vibration signature 322 represents data 190 that was collected by one or more sensors, for example sensors 118 and 119, positioned in proximity to the ESP 110 during operation. The data 190 collected by the sensors 118 and/or 119 is transmitted to the data acquisition unit 122, where it can be analyzed onsite or transmitted to the remote analysis unit 126 for offsite analysis.

[0039] As shown in Figure 8, the time domain 324 includes an x-axis 328 describing time in milliseconds and a y-axis 330 describing a voltage associated with the amplitude of the transient vibration signature 322. The frequency domain 326 displays the transient vibration signature 322 after application of a Short Time Fourier Transform (STFT) or Wavelet Transform algorithm by the data acquisition unit 122 or the remote analysis unit 126. In the frequency domain 326, an x-axis 332 describes frequency in Hertz and a y-axis 334 describes voltage associated with the amplitude of the transient vibration signature 322.

[0040] In contrast to the periodic vibration signature 302, the transient vibration signature 322 describes a vibration signature that changes over time. Because the transient vibration signature 322 changes over time, processing the transient vibration signature 322 with FFT is not an option because FFT does not account for a change of the frequency over time. Instead, the transient vibration signature 322 can be processed with STFT, which takes into account the time component of the transient vibration signature 322. After application of STFT, a series of peaks 336(1)-(4), each of which identifies a frequency that, in the aggregate, makes up the transient vibration signature 322, can be identified. Peaks 336(1)-(4) represent frequencies present in the transient vibration signature 322 during the period of measurement of the transient vibration signature 322.

[0041] Application of STFT to the transient vibration signature 322 reveals that peaks 336(1)-(4) are approximately 11Hz, 25 Hz, 51 Hz, and 101 Hz, respectively. The frequencies identified by peaks 336(1)-(4) are the same values as the frequencies identified by peaks 316(1)-(4) from Figure 7. However, the data associated with peaks 336(1)-(4) describes a different operational

scenario of the ESP 110 because the data associated with peaks 336(1)-(4) also includes a time component. Inclusion of the time component for the analysis of the vibration signature 322 provides additional insight into the operating condition of the ESP 110 because the timing for various vibrations encountered can be determined. For example, as shown by the time domain 324, the transient vibration signature 322 begins with a high frequency signature that changes over time to a much lower frequency. Through application of STFT, it can be shown that peak 336(4) occurs first, followed by peak 336(3), 336(3), and 336(1). This additional insight is not obtainable through analysis of a periodic vibration signature. Using this type of information in conjunction with the database 188 can assist with the diagnosis of the ESP 110.

[0042] After the transient vibration signature 322 has been analyzed using the data acquisition unit 122 or the remote analysis unit 126, a diagnosis of the health of the ESP 110 can be made. Diagnosis of the vibration signature 322 can be achieved by comparing the data associated with peaks 336(1)-(4) with a transient vibration signature database 188. The transient vibration signature database 188 stores information that relates vibration frequency to diagnostic information. Table 1 below illustrates possible diagnostics outcomes from analysis of transient vibration signatures 322.

Table 1

Spectrum	Frequency Range (Hz)	Possible Diagnostic or Source of the Problem
Subsynchronous	25-30	i. Bearing looseness and rotor rub ii. Oil whirl instability
Rotating Frequency	60 (assumed)	i. Rotating imbalance ii. Misalignment iii. Bent shaft iv. Bearing looseness and rotor rub v. Bearing sleeve wear
Twice Rotating Frequency	120	i. Bent shaft ii. Misalignment iii. Bearing looseness and rotor rub
Vane (Impeller) Passing Frequency	480	i. Pulsation of rotating impeller
Above Vane Passing Frequency	>480	i. Pump cavitation

[0043] Table 1 includes columns identifying a spectrum, a frequency range, and a possible diagnostic or source of the problem. The spectrum column describes the frequency range as it relates to components within the system. For example subsynchronous refers to a resonance phenomenon in which a resonant frequency of a rotating shaft, such as the string 102, falls below an actual operating speed of a motor, such as the motor 200. If the transient vibration signature 322 includes a peak 336 at the subsynchronous frequency range, a possible diagnostic is bearing looseness and rotor rub, or oil whirl instability.

[0044] The rotating frequency describes the operating speed of the ESP 110. For example, one or more rotating components within the ESP 110 may be operating at a frequency of 60 Hz. If the transient vibration signature 322 includes a peak 336 at the rotating frequency, a possible diagnostic may be one or more of a rotating imbalance, a misalignment, a bent shaft, a bearing looseness and rotor rub, a bearing sleeve wear.

[0045] Twice the rotating frequency describes a multiple of the operating speed of the ESP 110. A peak 336 at twice the rotating frequency may indicate, for example, a bent shaft, a misalignment, bearing looseness and rotor rub.

[0046] Vane (Impeller) Passing Frequency describes a frequency at which vanes of an impeller pass a diffuser vane. A peak 336 at the vane passing frequency may indicate pulsation of the impeller as it rotates.

[0047] Above vane passing frequency describes frequencies that are higher than the vane passing frequency for a given ESP 110. A peak 336 above the vane passing frequency may indicate pump cavitation.

[0048] The information contained within Table 1 is an example and not to be construed as limiting. The database 188 can include additional information not expressly shown in Table 1. Additionally, the database 188 can include information for different models of ESP and different operating conditions of an ESP. For example, the database 188 can include information describing: pump startup, pump shut down, different operating speeds, etc.

[0049] Refer now to Figure 9 illustrating a spectrogram of transient vibration signature measured during pump startup. A display 400 shows a transient vibration signature 402. The transient vibration signature 402 has been processed with STFT. An x-axis 406 of the display 400 describes frequency in Hertz of the transient vibration signature 402, a first y-axis 408 describes a voltage associated with an amplitude of a frequency, and a second y-axis 410 describes an RPM of a rotor of an ESP, such as the rotor 208.

[0050] The display 400 shows the transient vibration signature 402 displayed in a waterfall 404 made up of transient vibration signatures 402(1)-(n), where (n) represents a number of data sets collected for the transient vibration signature 402. The waterfall 404 displays the transient vibration signature 402 in a stepped fashion to show how the transient vibration signature 402 changes as the RPMs of the rotor change. For example, transient vibration signature 402(1) represents the frequencies present at a first rotor speed and transient vibration signature 402(2) represent the frequencies present at a second rotor speed. Data 190 for a number of transient

vibration signatures 402(1) through (n) may be collected as desired. For an analysis of a pump startup, it may be sufficient to collect data 190 from a rotor RPM of zero up to an operating RPM. Data 190 may instead be collected for longer or shorter periods of time depending upon the analysis being conducted.

[0051] An arrow 412 indicates a vibration at a frequency that is one half of the RPM of the rotor. Such vibrations are typical of oil whirl. An arrow 414 indicates a vibration at a frequency that is equal to the RPM of the rotor. Such vibrations are typical of imbalances present in rotating components, such as shafts and the like. An arrow 416 indicates a vibration at a frequency that is twice that of the rotor RPM. Such vibrations are often related to electrical frequency of an ESP motor. Arrows 418(1) and (2) indicate high harmonic vibrations typical of shaft misalignment and rotor eccentricity. An arrow 420 indicates low-frequency resonance vibrations typical of bearings. The display 400 generally shows that as the rotor RPM increases, the frequency of the vibrations associated with arrows 412, 414, 416, 418(1)-(2), and 420 generally increase in a linear fashion.

[0052] After data 190 for the transient vibration signature 402 has been collected by the data acquisition unit 122, the data 190 can be analyzed onsite by the data acquisition unit 122 or by the remote analysis unit 126. To analyze the transient vibration signature 402, the data acquisition unit 122 or the remote analysis unit 126 can compare the waterfall 404 to one or more waterfalls contained in the database 188. The database 188 contains waterfalls that identify both normal and abnormal or problematic operating conditions of an ESP, such as ESP 110. If analysis of the waterfall 404 indicates a normal operating condition, operation of the ESP can continue. If analysis of the waterfall 404 indicates one or more problems, operating of the ESP can be stopped or one or more conditions of the ESP may be altered in an effort to alleviate the problem. For example, a speed of the motor may be reduced.

[0053] Refer now to Figure 10 illustrating schematic representations of a data acquisition unit and a remote analysis unit. The data acquisition unit 122 comprises one or more CPUs 180 connected to a memory 182 and a communications interface 184. Memory 182 comprises

software 186, the database 188, and data 190. The communications interface 184 communicates with the sensors 118 and 119 and with the ESP 110.

[0054] The software 186 is executable on the one or more central processing units (CPUs) 180. The software 186 analyzes the data 190, which comprises transient vibration signature data collected by the communications interface 184 from the one or more sensors 118 and 119, and compares the analysis to information in the database 188. The database 188, as discussed above, includes information enabling diagnosis of ESP health based upon measured transient vibration signatures. Upon diagnosing an ESP, the one or more CPUs 180 can instruct the communications interface 184 to alter one or more operating conditions of the ESP 110. For example, CPU 180 can instruct the ESP 110 to shut down and/or CPU 180 can instruct the communications interface 184 to notify an operator of the ESP 110 of a potential problem.

[0055] The remote analysis unit 126 is not required. When present, the remote analysis unit 126 can similarly comprise a CPU 192, a communications interface 194, the memory 182, the software 186, the database 188, and the data 190. The remote analysis unit 126 may communicate with the data acquisition unit 122. Communication between units 122 and 126 may be accomplished via the link 124. The link 124 may be wired or wireless. Analysis performed by the remote analysis unit 126 may be performed in the following manner. Data 190 is collected by the communications interface 184 from sensors 118 and 119. The data acquisition unit 122 then transmits the data 190 via the link 124 to the remote analysis unit 126, whereupon the analysis of the data is carried out by the one or more CPUs 192, the memory 182, the software 186, and the database 188 in much the same way as the analysis performed by the data acquisition unit 122. If a determination is made by the remote analysis unit 126 that one or more operating conditions of the ESP 110 should be altered, the remote analysis unit 126 transmits the desired change to the data acquisition unit 122 via the link 124. The data acquisition unit 122 may then implement the change via the communications interface 184.

[0056] Instructions of the software 186 are loaded for execution on a processor such as the one or more CPUs 180. The processor may include microprocessors, microcontrollers, processor modules or subsystems (including one or more microprocessors or microcontrollers), or other

control or computing devices. A "processor" can refer to a single component or to plural components.

[0057] Data and instructions (of the software) are stored in respective storage devices, which are implemented as one or more computer-readable or computer usable 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).

[0058] Refer now to Figure 11 a flow diagram of an example method 500 of monitoring health of an ESP. In the flow diagram, operations are represented by individual blocks. The example method may be performed by hardware and software elements, such as by the hardware and software elements described herein above.

[0059] At block 502, an ESP 110 is inserted into a wellbore. At block 504, transient vibration signature data 190 is received by the communications interface 184 of the data acquisition unit 122 from one or more sensors 118 and/or 119. At block 506, the received transient vibration signature data 190 is analyzed. Analysis of the transient vibration signature data 190 may be performed by the data acquisition unit 122 or by the remote analysis unit 126. If the analysis is to be performed by the remote analysis unit 126, the transient vibration signature data 190 is transmitted via the link 124 to the communications interface 194 of the remote analysis unit 126.

[0060] At block 508, a determination of the operational health of the ESP 110 is made by comparing the analysis of the transient vibration signature data 190 to information stored in the database 188. After the operational health of the ESP 110 has been determined, at block 510, one or more operating conditions of the ESP 110 may be adjusted if desired. The method 500 may be performed continuously or iteratively as desired to provide ongoing information regarding the operational health of the ESP 110.

[0061] The foregoing outlines features of several embodiments so that those skilled in the art may better understand the aspects of the disclosure. Those skilled in the art should appreciate that they may readily use the disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the disclosure. The scope of the invention should be determined only by the language of the claims that follow. The term "comprising" within the claims is intended to mean "including at least" such that the recited listing of elements in a claim are an open group. The terms "a," "an" and other singular terms are intended to include the plural forms thereof unless specifically excluded.

WHAT IS CLAIMED IS:

1. A system for monitoring an electric submersible pump (ESP), comprising:
an ESP;
a vibration sensor in communication with the ESP; and
a data acquisition unit in communication with the vibration sensor to collect and analyze
transient vibration signature data from the vibration sensor and to determine an
operating condition of the ESP based upon the analyzing.
2. The system of claim 1, further comprising a database containing diagnostic data for
comparison to the transient vibration signature data to diagnose an operating health of the
ESP string.
3. The system of claim 1, wherein the vibration sensor is external to the ESP.
4. The system of claim 1, wherein the vibration sensor is located within the ESP.
5. The system of claim 1, further comprising a remote analysis unit in communication with
the data acquisition unit for remotely analyzing the transient vibration signature data.
6. The system of claim 1, wherein the data acquisition unit further comprises a
communications interface that communicates with the ESP to instruct the ESP to change
an operating condition responsive to the analyzing.

7. The system of claim 1, wherein the data acquisition unit continuously collects and analyzes the transient vibration signature data.
8. A method of monitoring an electric submersible pump (ESP), comprising:
receiving transient vibration signature data from a vibration sensor deployed in a wellbore in proximity to the ESP;
analyzing the received transient vibration signature data; and
determining an operational health of the ESP based on the analyzing.
9. The method of claim 8, wherein the analyzing further comprises comparing the received transient vibration signature data to diagnostic information in a database.
10. The method of claim 8, further comprising instructing the ESP to change an operating condition in response to the determining.
11. The method of claim 8, further comprising sending the received transient vibration signature data to a remote analysis unit to perform the analyzing.
12. The method of claim 8, wherein the vibration sensor is external to the ESP.
13. The method of claim 8, wherein the vibration sensor is internal to the ESP.

14. The method of claim 8, wherein the receiving and the analyzing are done continuously to provide ongoing information about the health of the ESP.
15. A method of diagnosing an electric submersible pump (ESP), comprising:
receiving transient vibration signature data from a vibration sensor deployed in a wellbore in proximity to the ESP;
analyzing the received transient vibration signature data to identify a frequency contained within the transient vibration signature data; and
comparing the identified frequency to diagnostic data to determine an operational health of the ESP.
16. The method of claim 15, further comprising changing an operating condition of the ESP in response to the comparing.
17. The method of claim 15, wherein the vibration sensor is one of an internal ESP sensor or an external ESP sensor.
18. The method of claim 15, wherein the comparing includes comparing a length of time of the transient vibration signature data with a length of time of the diagnostic data.

19. The method of claim 15, further comprising adding the analyzed transient vibration signature data to a database.
20. The method of claim 15, wherein the analyzing is performed by a remote analysis unit.

FIG. 1

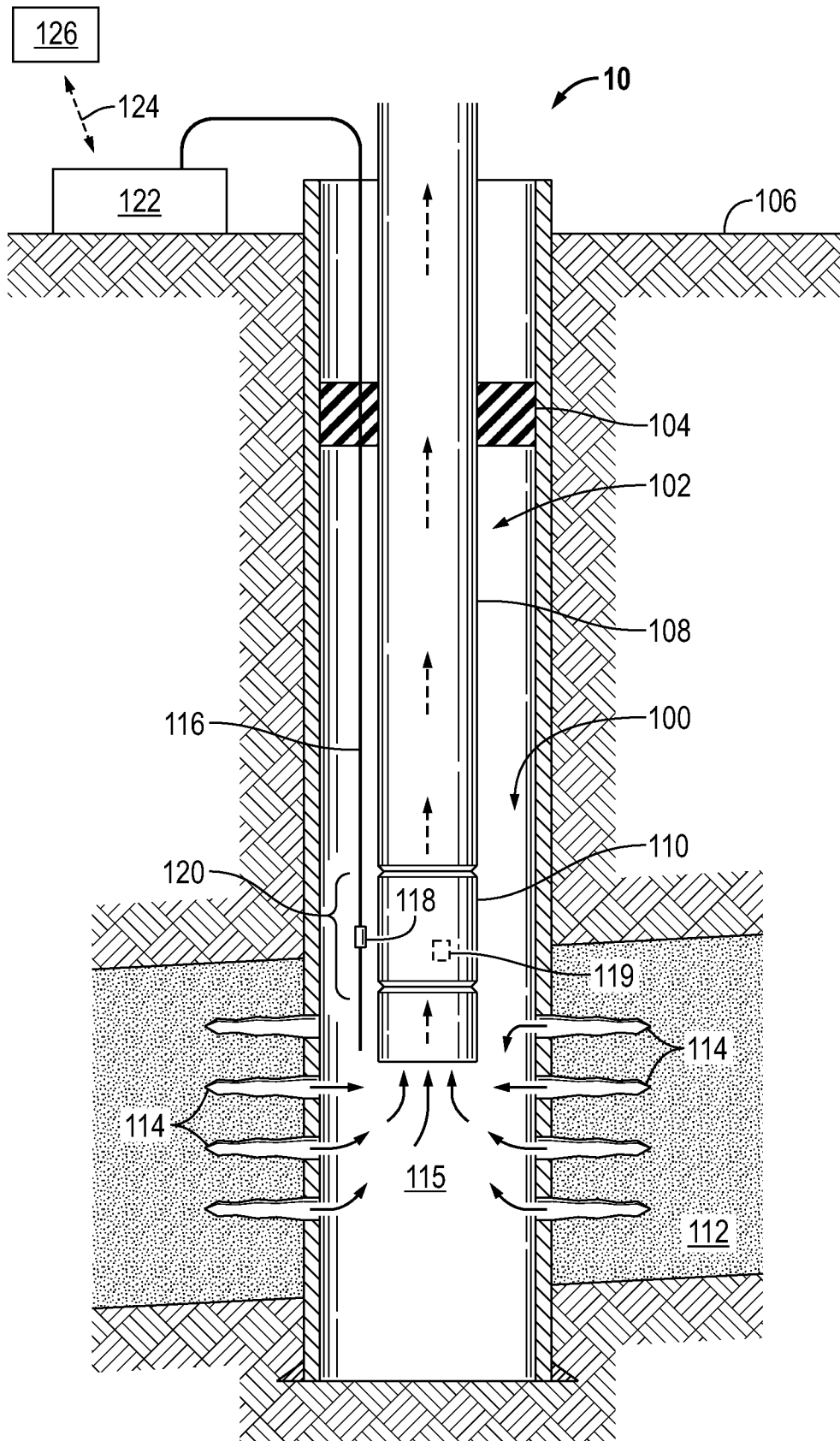


FIG. 2

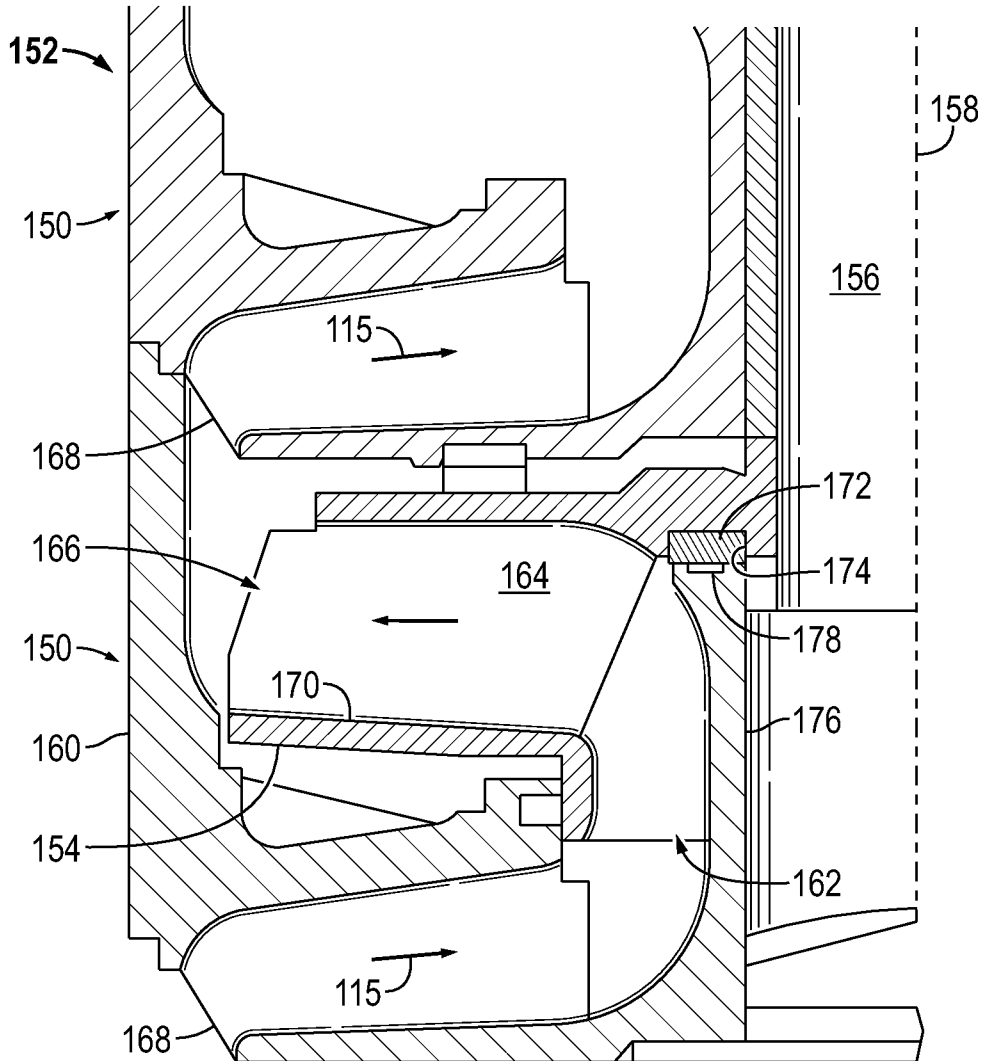


FIG. 3

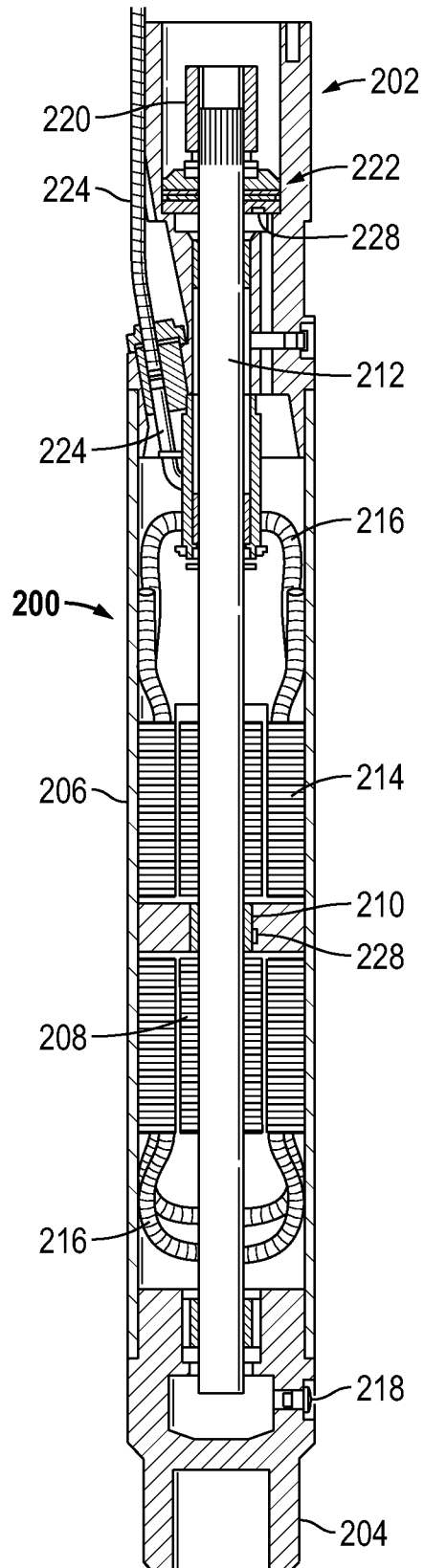


FIG. 4

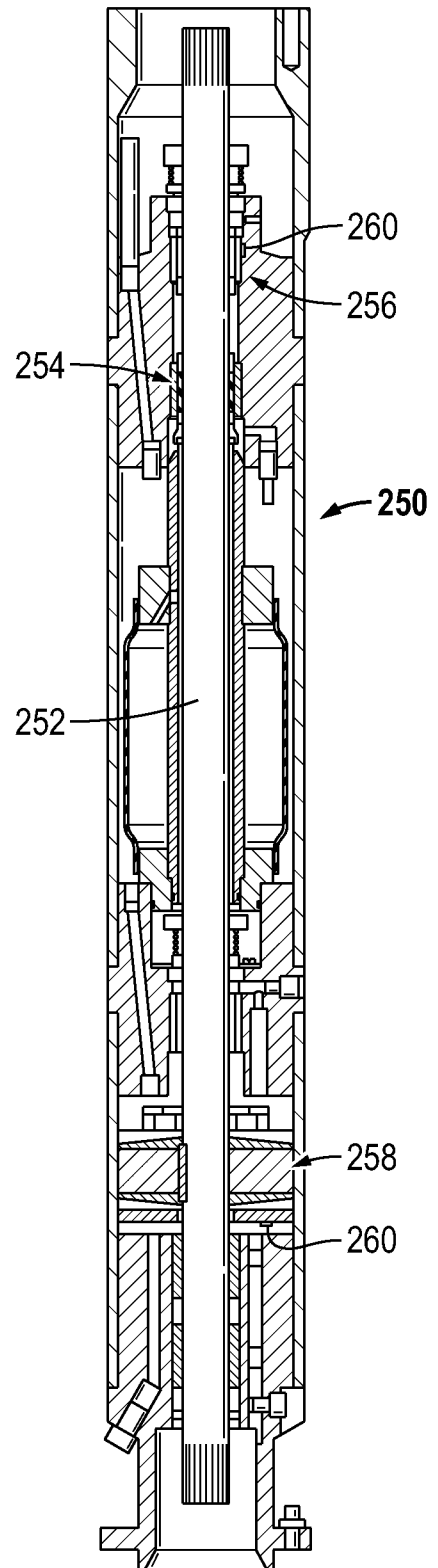


FIG. 5

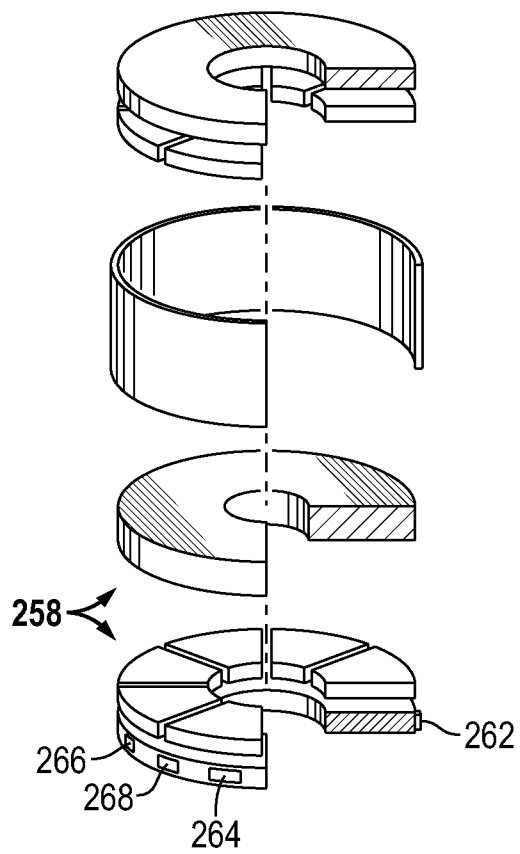


FIG. 6

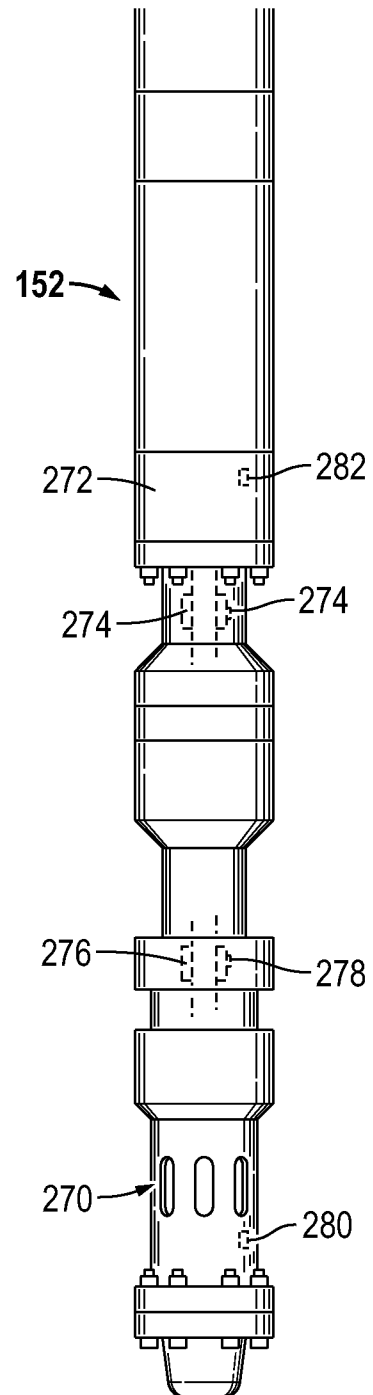
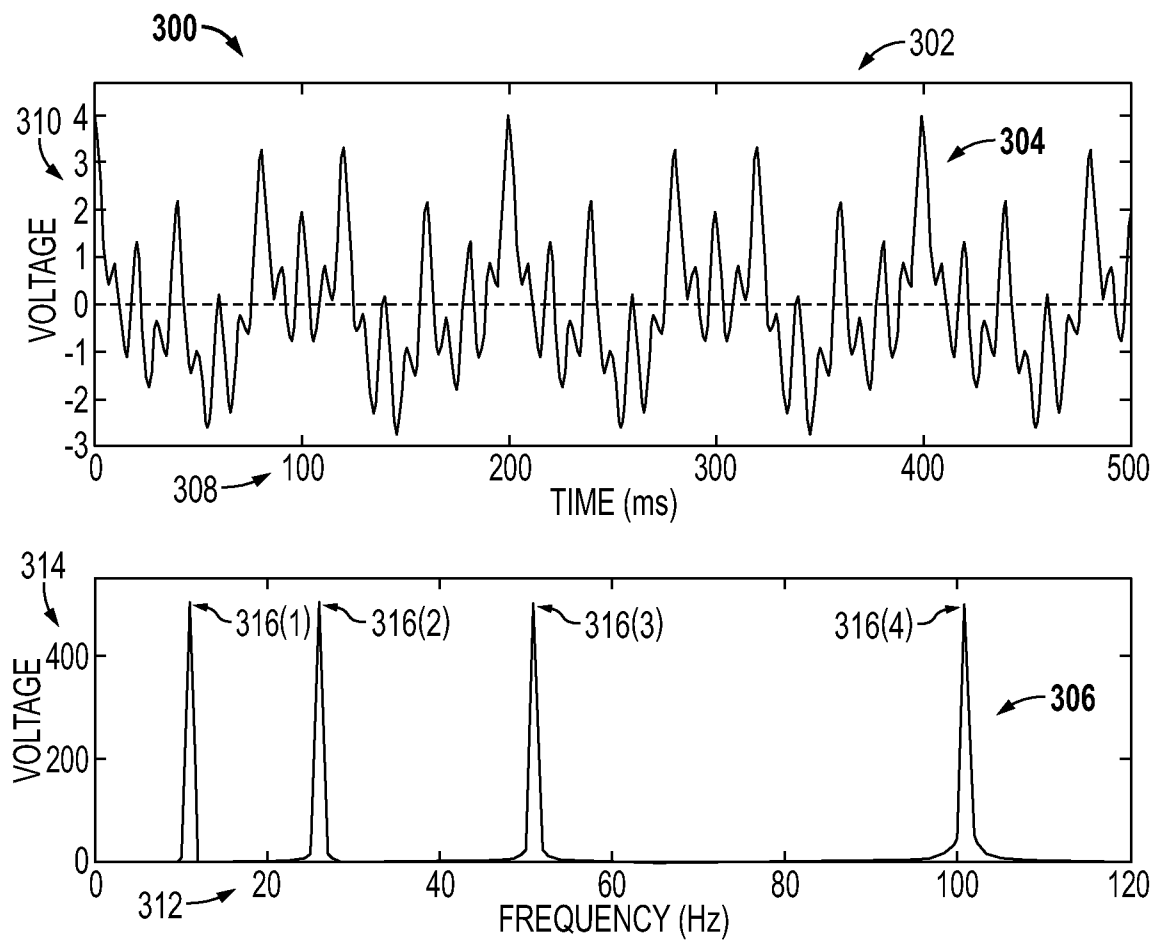


FIG. 7

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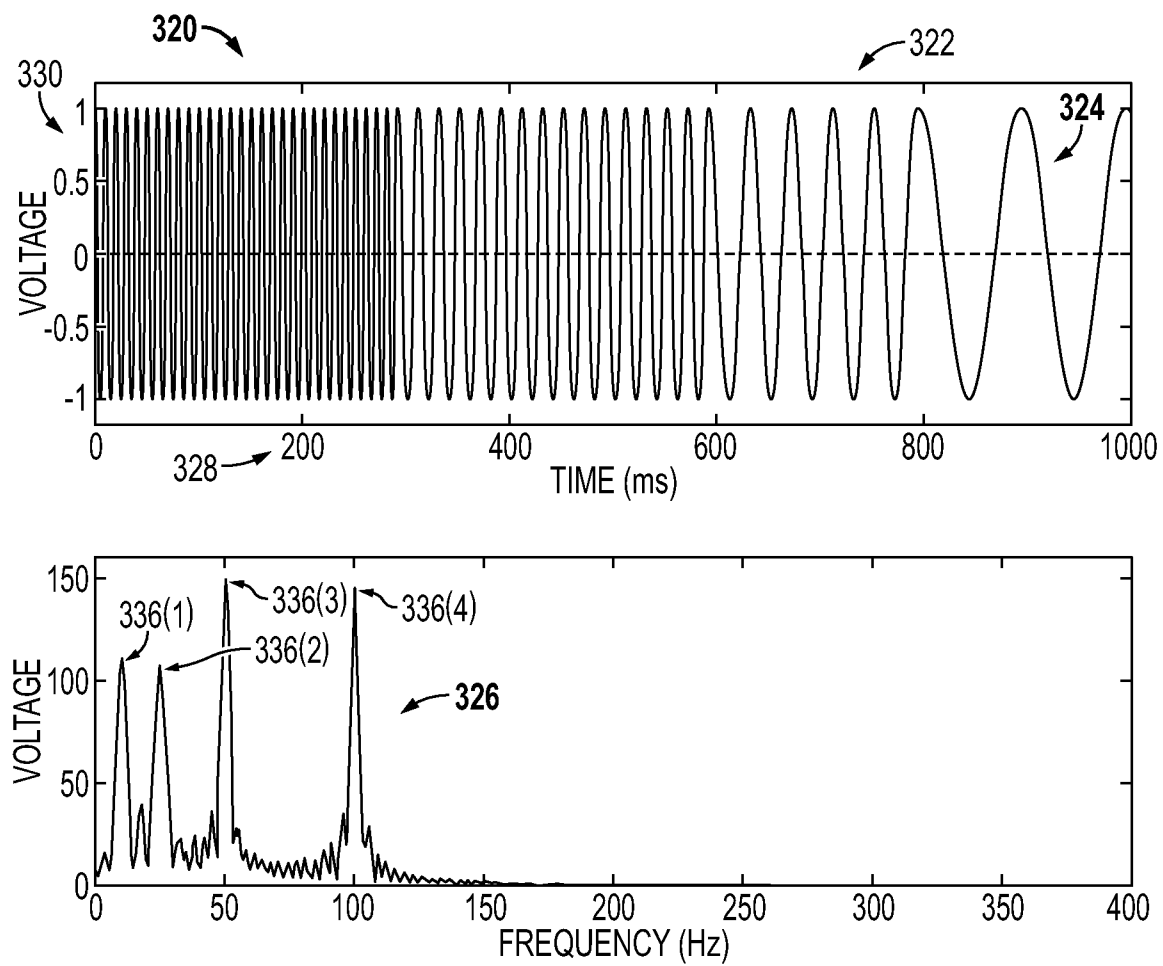
FIG. 8

FIG. 9

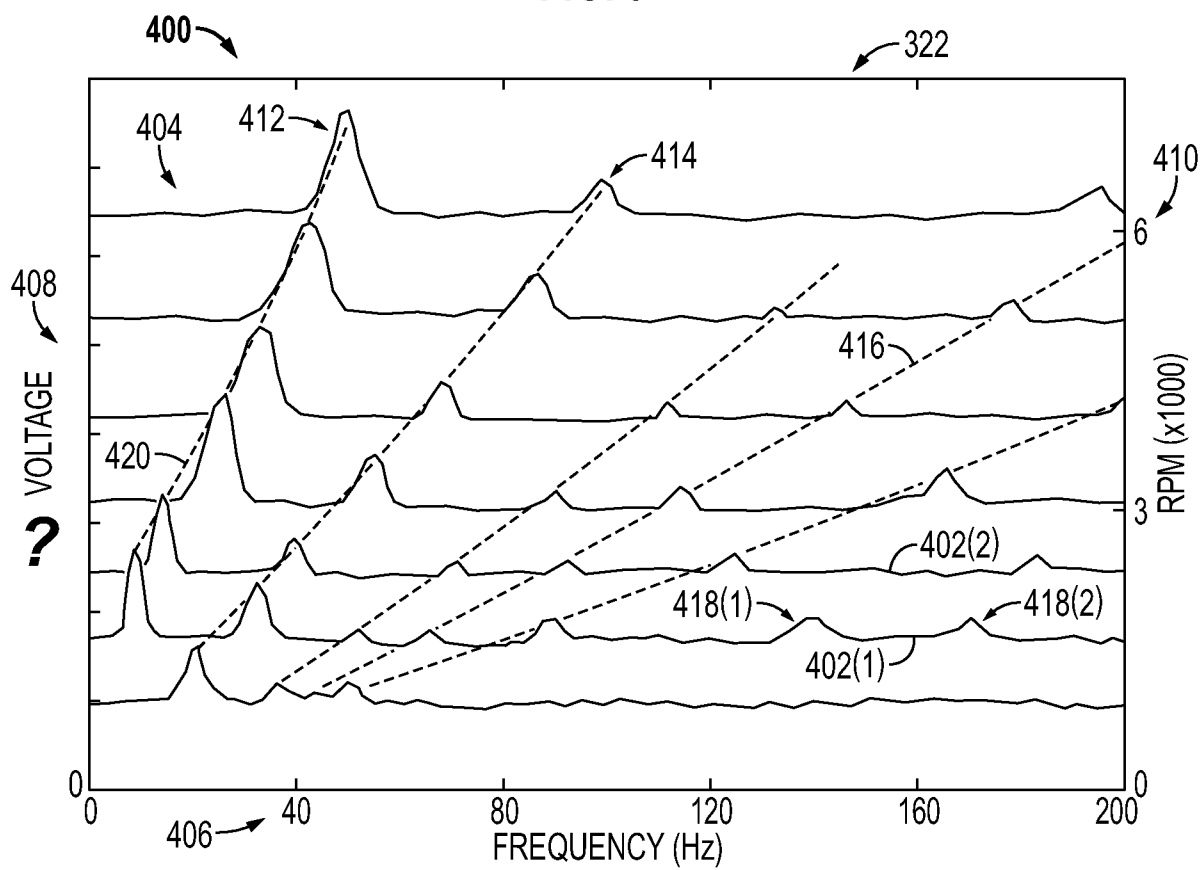


FIG. 10

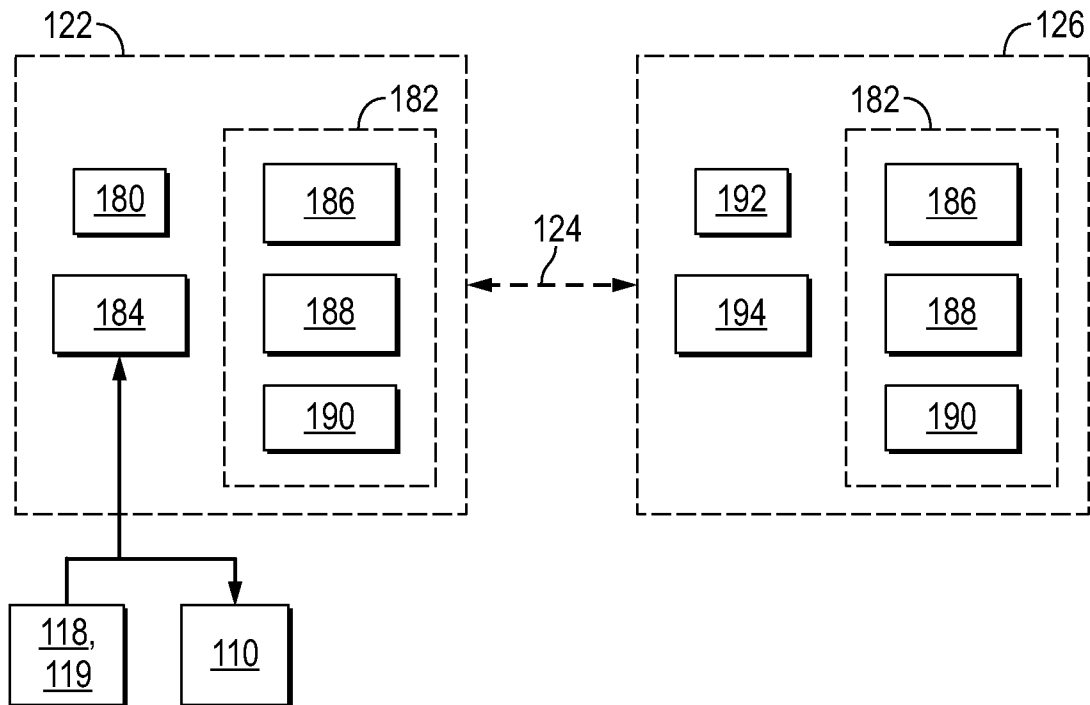
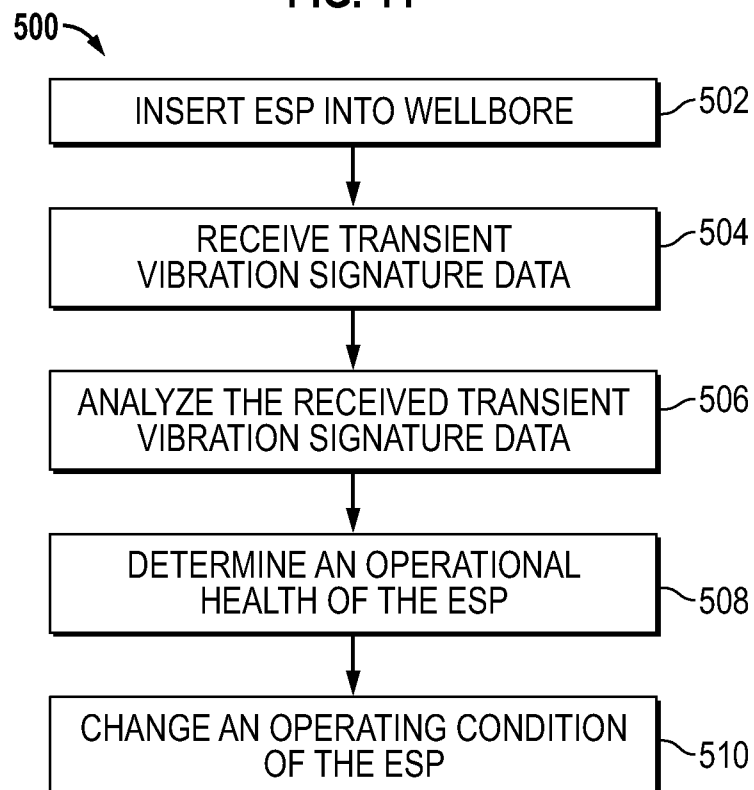


FIG. 11



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/029599**A. CLASSIFICATION OF SUBJECT MATTER****E21B 43/12(2006.01)i, E21B 21/08(2006.01)i, E21B 47/12(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; G06F 11/30; E21B 47/00; H02H 7/097; G08B 21/00; F04D 15/00; G01V 1/52; E21B 21/08; E21B 47/12

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: wellbore, ESP, vibration sensor, data acquisition unit, signature data, compare, determine, condition, and frequency

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010-0038079 A1 (GREENAWAY, ROBERT) 18 February 2010 See paragraphs [0013]-[0028], [0049] and figures 1-5.	1-20
A	US 2013-0272898 A1 (SCHLUMBERGER TECHNOLOGY CORPORATION) 17 October 2013 See paragraphs [0048]-[0057] and figure 7.	1-20
A	US 2007-0252717 A1 (FIELDER, LANCE I.) 01 November 2007 See abstract and paragraphs [0023]-[0029].	1-20
A	US 2011-0050144 A1 (KNOX et al.) 03 March 2011 See paragraphs [0033]-[0034] and claim 1.	1-20
A	US 2005-0251362 A1 (OLLRE et al.) 10 November 2005 See paragraphs [0029]-[0040] and figure 7.	1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

18 December 2015 (18.12.2015)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/029599

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