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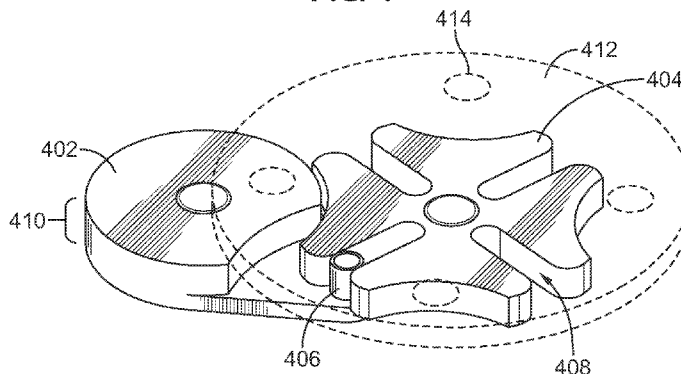
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(54) Title: DOWNHOLE OPTICAL FLUID ANALYZER HAVING INTERMITTENTLY DRIVEN FILTER WHEEL

FIG. 4



(57) Abstract: A downhole optical fluid analyzer having an intermittently driven filter wheel. In at least some embodiments, the tool operates by passing light along an optical path through a downhole sample cell to a detector. At least one filter wheel having multiple filter elements intersects the optical path to operate on the light. The filter wheel is preferably driven in a variable speed manner to prolong each filter element's residence time on the optical path. Such driving may be accomplished by converting the continuous rotation of an electrical motor to an intermittent motion of the filter wheel. Possible mechanisms for this conversion include a peg-and-slot mechanism in which a circulating peg engages successive slots in a slotted wheel to impart intermittent motion. Other suitable mechanisms are also described.

DOWNHOLE OPTICAL FLUID ANALYZER HAVING INTERMITTENTLY DRIVEN FILTER WHEEL

BACKGROUND

5 Engineers use downhole optical methods to monitor, analyze, or identify different fluid properties, such as contamination, composition, fluid type, and PVT (“pressure, volume, temperature”) properties. For example, a spectrometer may be coupled to a formation fluid sampling tool to analyze fluids in real time as they are drawn from the formation. During the sampling operation the spectrometer can monitor contamination levels from borehole fluids and, 10 once the contamination has fallen to an acceptable level, the spectrometer can measure spectral characteristics of the formation fluid to identify its components. Fluid component identification is helpful for determining whether and how production should be performed from a particular area of the well. It can provide indications of reservoir continuity, blowout risk, production value, etc.

15 Despite the evident utility of downhole spectrometers, the range of measurements that can be made by existing tools is somewhat limited. Besides the physical limitations, a trade-off exists between the number of measurements and the quality of measurements to be made by the downhole filter-wheel spectrometer. Measurement quality is impacted by each filter’s “residence time”, i.e., the amount of time that the filter spends in the light beam. However, to embed more 20 filters in the filter wheel requires reducing the size of each filter and hence the measurement residence times.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A shows an illustrative logging while drilling environment;

Fig. 1B shows an illustrative wireline logging environment;

Fig. 2 shows an illustrative downhole optical spectrometer;

Fig. 3 illustrates the operating principles of a filter-wheel spectrometer;

Fig. 4 shows a first illustrative intermittent drive mechanism;

5 Fig. 5 shows an alternative intermittent drive mechanism; and

Fig. 6 is a flow diagram of an illustrative method for operating a downhole fluid analyzer with an intermittently driven filter wheel.

DETAILED DESCRIPTION

10 Accordingly there is disclosed herein a downhole optical fluid analyzer having an intermittently driven filter wheel. In at least some embodiments, the tool operates by passing light along an optical path through a downhole sample cell to a detector. At least one filter wheel having multiple filter elements intersects the optical path to operate on the light. The filter wheel is preferably driven in a variable speed manner to prolong each filter element's residence time on
15 the optical path. Such driving may be accomplished by converting the continuous rotation of an electrical motor to an intermittent motion of the filter wheel. Possible mechanisms for this conversion include a peg-and-slot mechanism in which a circulating peg engages successive slots in a slotted wheel to impart intermittent motion. Other suitable mechanisms are also disclosed.

To further assist the reader's understanding of the disclosed systems and methods, we
20 describe a suitable environment for their use and operation. Accordingly, Fig. 1 shows an illustrative logging while drilling (LWD) environment. A drilling platform 102 is equipped with a derrick 104 that supports a hoist 106 for raising and lowering a drill string 108. The hoist 106 suspends a top drive 110 that is used to rotate the drill string 108 and to lower the drill string through the well head 112. Sections of the drill string 108 are connected by threaded connectors

107. Connected to the lower end of the drill string 108 is a drill bit 114. As bit 114 rotates, it creates a borehole 120 that passes through various formations 121. A pump 116 circulates drilling fluid through a supply pipe 118 to top drive 110, downhole through the interior of drill string 108, through orifices in drill bit 114, back to the surface via the annulus around drill string 108, and into a retention pit 124. The drilling fluid transports cuttings from the borehole into the pit 124 and aids in maintaining the integrity of the borehole 120.

Fig. 1B shows an illustrative wireline logging environment. At various times during the drilling process, the drill string 108 is removed from the borehole to allow the use of a wireline logging tool 134. The wireline logging tool is a sensing instrument sonde suspended by a cable 142 having conductors for transporting power to the tool and telemetry from the tool to the surface. The wireline logging tool 134 may have arms 136 that center the tool within the borehole or, if desired, press the tool against the borehole wall. A logging facility 144 collects measurements from the logging tool 134, and includes computing facilities for processing and storing the measurements gathered by the logging tool.

A downhole optical fluid analyzer can be employed to characterize downhole fluids in both of the foregoing logging environments. For example, Fig. 2 shows an illustrative formation fluid sampling tool 202 for use in a wireline environment. The formation fluid sampling tool 202 includes one or more cup-shaped sealing pads for contacting the formation, one or more spectrometers, and a multi-chamber sample collection cassette. Arms 204 and 206 are extended from the side of tool 202 to contact the borehole wall and force the tool to the opposite side of the borehole, where sealing pads 210A and 210B (with slits 209A and 209B) make contact to the formation. Probes 208A and 208B are coupled to a piston pump 212 to draw formation fluid samples in from the formation via slits 209A, 209B. With the cooperation of valves 216, the

piston pump 212 regulates the flow of various fluids in and out of the tool via a flow line 214. Ultimately, the fluid samples are exhausted to the borehole or captured in one of the sample collection module's 222 sample chambers. The illustrated tool further includes two optical analyzers 218 and 220 to perform in-situ testing of fluid samples as they travel along flow line
5 214.

Fig. 3 schematically illustrates the operating principles of a downhole filter wheel optical fluid analyzer. A light source 304 such as a tungsten filament, a halogen bulb, a fluorescent bulb, a laser, a light-emitting diode, etc., emits light along a light path 302. The illustrated light path 302 is shown as a straight line, but it may be defined in more complex ways using, e.g.,
10 apertures, mirrors, waveguides, fibers, lenses, prisms, and gratings. Light traveling along path 302 shines through a sample cell 307 via a first optically transparent window 306a, through the fluid, and then out a second window 306b. The fluid interacts with the light, thereby imprinting its spectral fingerprint on the light spectrum. As the light continues along the light path 302 it interacts with filters 309 in a rotating filter wheel 308 before reaching a light detector 310.
15 Various forms of light detectors are suitable for measuring light intensity include photodetectors and thermal detectors.

Aside from optional calibration elements such as an open aperture or a fully opaque light stop, the filters 309 are chosen to measure particular spectral characteristics suitable for identifying or otherwise characterizing the contents of the sample cell. As such, the filters may
20 include bandpass filters, bandstop filters, and multivariate optical elements (MOE). The intensity of the light striking the detector is thus a measure of some portion of the spectral fingerprint mentioned previously. To ensure an adequate signal-to-noise ratio, the filters must be larger or equal to some given size that is a function of the manufacturing specifications for the other

components (e.g., light source intensity, detector sensitivity, residence time, and sample cell size). To lengthen the residence time without having to enlarge the filter elements and in so doing reduce the number that can fit in the filter wheel, the analyzer may employ an intermittent drive mechanism. The intermittent drive mechanism further helps to increase signal-to-noise ratio by eliminating motion noise from the measurement. (Motion of the filter across the optical field usually introduces mechanical noise from alignment of the optical element, wobble of the filter wheel, and acoustical frequency noise communicated from the motor gearing and drive train vibrations.)

Fig. 4 illustrates one intermittent drive mechanism having a drive wheel 402 coupled to an electric motor for continuous rotation. Such continuous rotation is preferred for increased reliability, increased lifetime, and reduced power consumption. Moreover, in a limited power environment, the power budget savings offered by the intermittent drive can be instead used to increase the light intensity of the source, thereby, increasing the signal-to-noise ratio. Rotation of wheel 402 causes a pin 406 to orbit around the wheel's axis. On each orbit, the pin 406 engages a successive slot 408 of slotted wheel 404 and advances the rotation of the slotted wheel by one step before disengaging and completing another orbit. A raised blocking disc 410 fits within a recess of the slotted wheel to block the slotted wheel's rotation while the pin 406 is disengaged. This "self-locking" action ensures reliable operation. It is during this pause that a filter wheel 412 (attached to the slotted wheel 404) holds one of its filter elements 414 in the optical path. The pause provides a greater opportunity for the detector to collect measurements of the filtered light signal, thereby providing an enhanced measurement signal to noise ratio.

Fig. 5 illustrates an alternative intermittent drive mechanism having a drive wheel 508 coupled to an electric motor for continuous rotation. Rotation of the wheel 506 to orbit around

the drive wheel's axis. On each orbit, the pin 506 engages a successive slot 504 of a slotted wheel 502 and advances the rotation of the slotted wheel by one step before disengaging and completing another orbit. During the interval from the time the pin 506 disengages from one slot and the time that it engages the next slot, the slotted wheel 502 holds one of its filter elements 510 in the optical path. A friction pad may be employed to prevent rotation of the slotted wheel while the pin is disengaged from the slots. Alternatively, some other locking mechanism can be employed to ensure reliable operation.

The intermittent drive mechanisms illustrated in Figs. 4-5 each show a four-position slotted wheel, but each embodiment can be readily extended to any feasible number of filter element positions, e.g., 10 to 30. Each filter element provides a different measurement, and each measurement gets a consistent residence or "dwell" time in the optical path. The residence time is determined by the orbital rotation rate of the pegs and the fraction of the orbit that the peg spends between slots. To optimize the tradeoff between residence time and the slotted wheel's transition rate, the peg diameter, orbit diameter, and drive wheel axis can be varied as desired. Further, the intermittent drive can be designed to provide unequal "dwell" or residence times for different filters.

One of the potential advantages of the disclosed intermittent drive embodiments is the significant increase in the quality of data that is achievable for a given filter element size. The smaller the filter element size, the greater the number of filter element measurements that can be acquired and used for characterizing the fluid samples. In tool designs where the filter wheel diameter is limited to 3.188 inches, the intermittent drive mechanism permits the use of up to 20 optical filter elements.

Fig. 6 shows an illustrative optical analysis method for downhole fluids. In block 602, the tool emits light along an optical path that passes through a sample cell to reach a light detector. In block 604, a filter wheel positions a filter element in the optical path to modify the measurement being acquired by the detector. In block 606, the tool drives the filter wheel
5 intermittently to step from one filter element to the next. The intermittent driving enables an increased residence time for each filter element. A mechanism can be used to convert rotation from a continuously running electrical motor into such intermittent motion. A couple of illustrative mechanism have been shown, but other suitable mechanisms are known and may be used. For example, a clutch may couple the electric motor to the filter wheel, and the clutch can
10 be engaged and disengaged as desired to provide the intermittent rotation. As yet another alternative, the electric motor may be stopped and started, using a rotational indexing system to determine the appropriate halting positions. As still another alternative, a stepper motor may be employed to drive the filter wheel in an intermittent fashion.

Numerous variations and modifications will become apparent to those skilled in the art
15 once the above disclosure is fully appreciated. For example, the filter elements can be either transmissive or reflective filters, and the filter wheels can precede or follow the sample cell. Although the intermittent motion has been described as fully halting the rotation of the filter wheel to increase residence times, it can be readily seen that it may be sufficient in certain tool embodiments to simply vary the filter wheel's rotation speed so that each filter element moves
20 slowly through the optical path and moves quickly between such reduced velocity positions. It is intended that the following claims be interpreted to embrace all such variations and modifications.

CLAIMS

WHAT IS CLAIMED IS:

1. A method for optical analysis of fluids downhole, the method comprising:

passing light along an optical path through a downhole sample cell to a detector;

5 providing at least one filter wheel that intersects the optical path, wherein said filter wheel includes multiple filter elements; and

driving said filter wheel in an intermittent motion to increase each filter element's residence time on the optical path.

2. The method of claim 1, wherein said driving includes converting motion of a continuously
10 rotating motor to said intermittent motion.

3. The method of claim 2, wherein said converting conveys a peg around a circle to engage with each rotation successive slots in a slotted wheel, and wherein the slotted wheel rotates only when the peg is engaged in one of said slots.

4. The method of claim 1, wherein said driving employs a stepper motor.

15 5. The method of claim 1, wherein said driving employs a continuously rotating motor coupled to the filter wheel by a clutch.

6. The method of claim 1, wherein said driving employs a rotational index counter to pause the filter wheel's rotation at selected angles.

20 7. The method of claim 1, wherein the multiple filter elements include at least one multivariate optical element (MOE).

8. The method of claim 1, wherein the multiple filter elements include at least one of: a low pass optical filter, a high pass optical filter, and a bandpass optical filter.

9. The method of claim 1, wherein one of said filter elements has a residence time that differs from at least one other of said filter elements.

10. A downhole optical fluid analyzer that comprises:

- 5 a downhole sample cell containing a fluid;
- a light source that passes light along an optical path through the sample cell to a detector;
- a filter wheel that intersects the optical path with one of a plurality of filter elements; and
- a drive mechanism that provides intermittent rotation of the filter wheel to increase each filter element's residence time on the optical path.

10 11. The analyzer of claim 10, wherein downhole sample cell receives formation fluid via a probe that seats against a borehole wall.

12. The analyzer of claim 10, wherein the drive mechanism includes a continuously rotating motor and a system to convert said motor's rotation to intermittent rotation of the filter wheel.

13. The analyzer of claim 12, wherein said system rotates a peg along a circumference of a circle
15 to engage with each orbit successive slots in a slotted wheel, and wherein the slotted wheel rotates only when the peg is engaged in one of said slots.

14. The analyzer of claim 13, wherein said system blocks rotation of the slotted wheel when the peg is disengaged from said slots.

15. The analyzer of claim 10, wherein the drive mechanism employs a stepper motor.

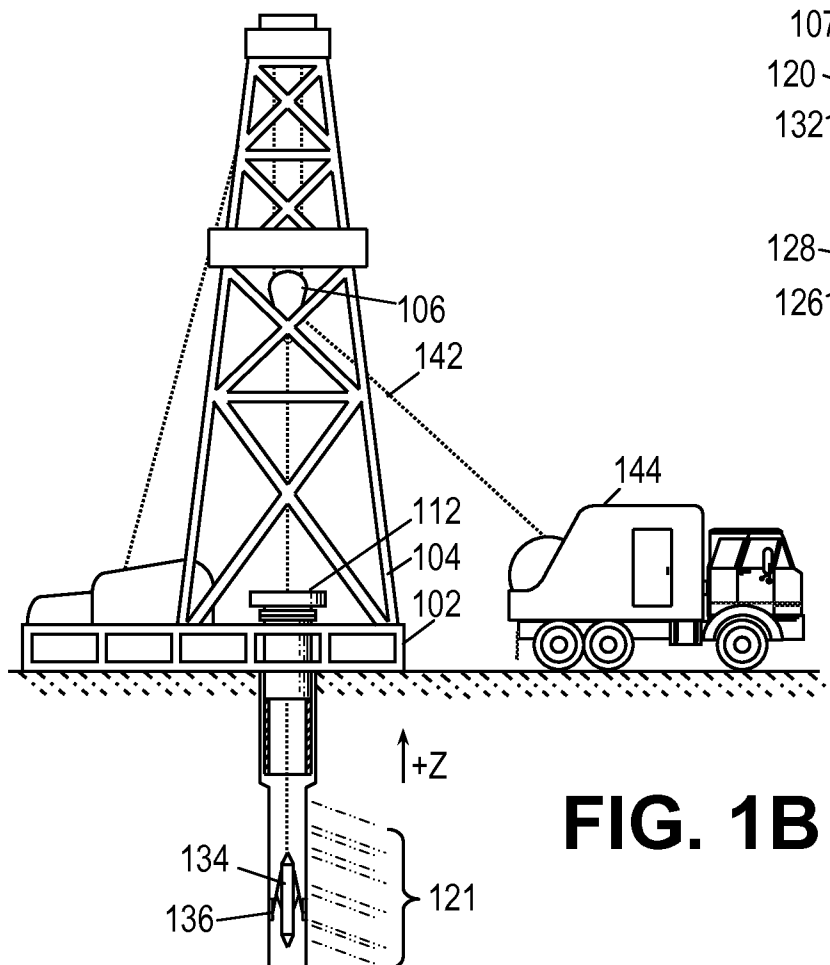
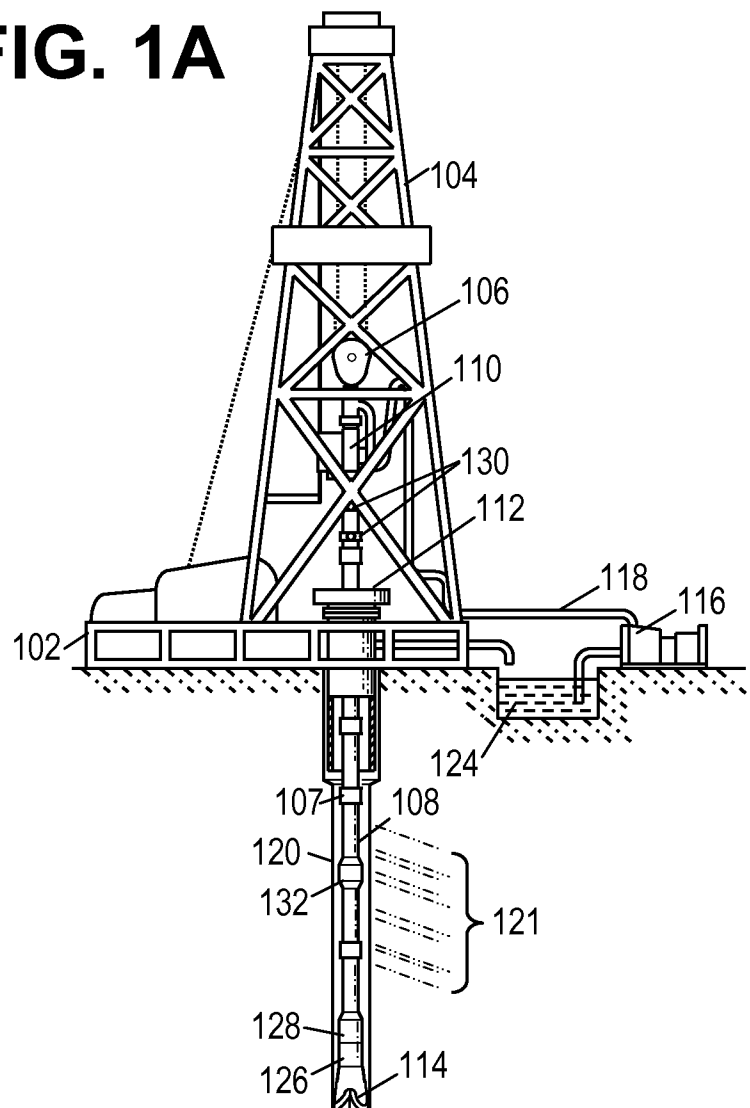
20 16. The analyzer of claim 10, wherein the drive mechanism employs a continuously rotating motor coupled to the filter wheel by a clutch.

17. The analyzer of claim 10, wherein the drive mechanism employs a rotational index counter to pause the filter wheel's rotation at selected angles.

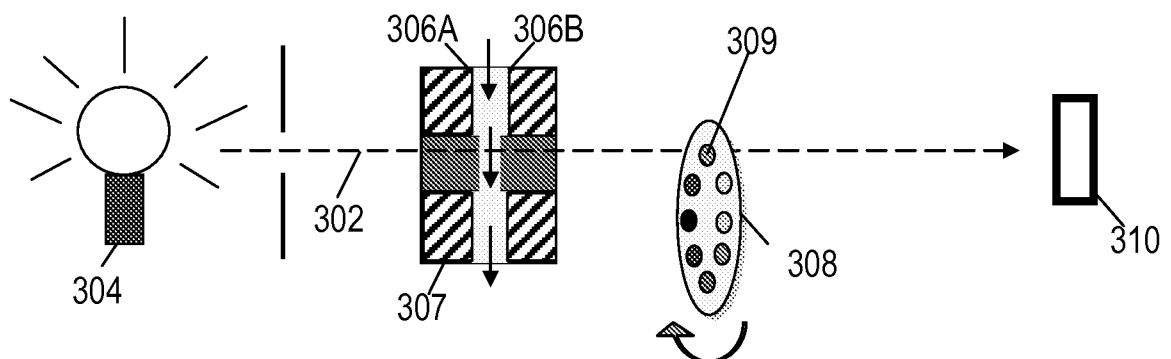
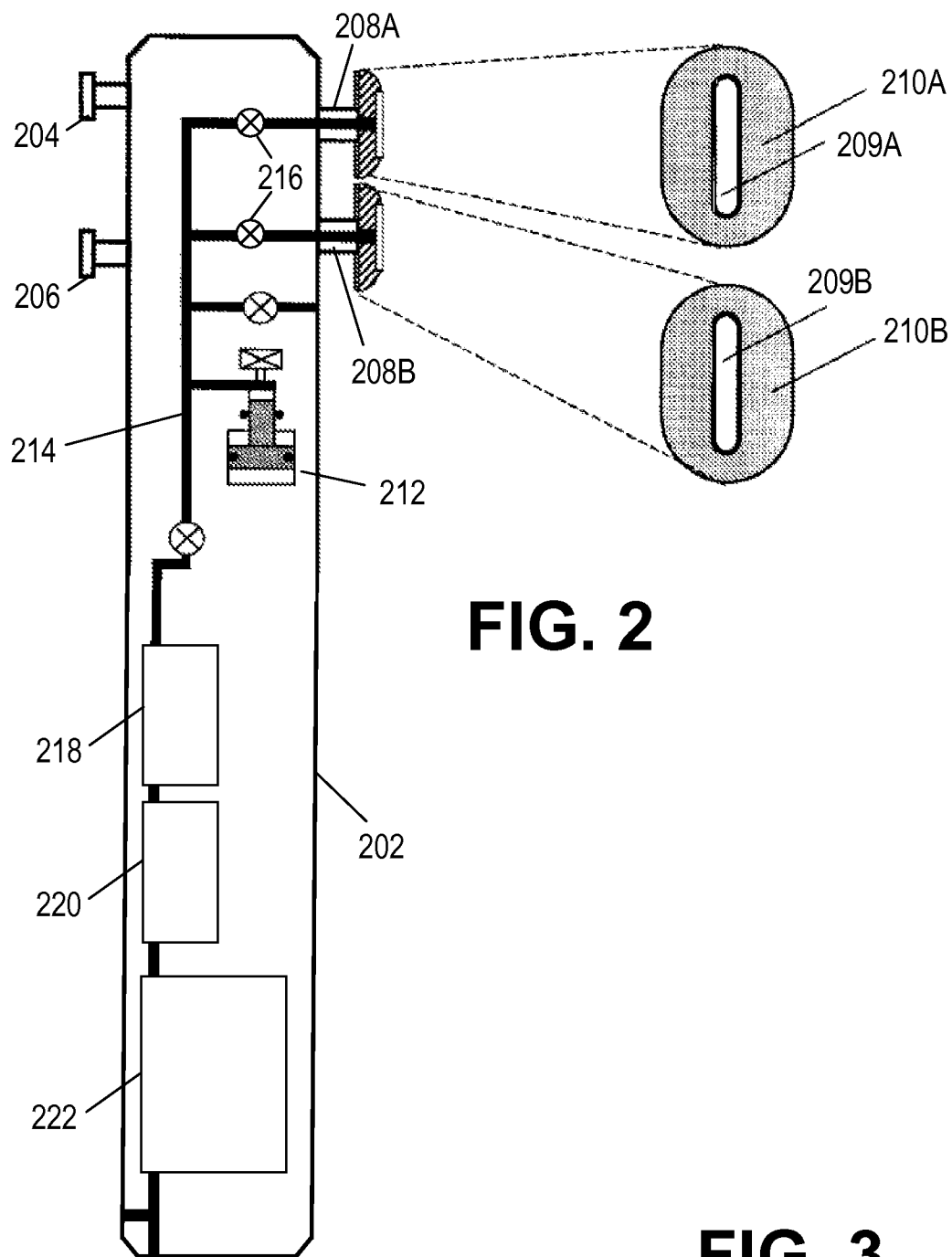
18. The analyzer of claim 10, wherein the plurality of filter elements includes at least one multivariate optical element (MOE).

19. The analyzer of claim 10, wherein the plurality of filter elements includes at least one of: a low pass optical filter, a high pass optical filter, and a bandpass optical filter.

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FIG. 1A**FIG. 1B**

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FIG. 4

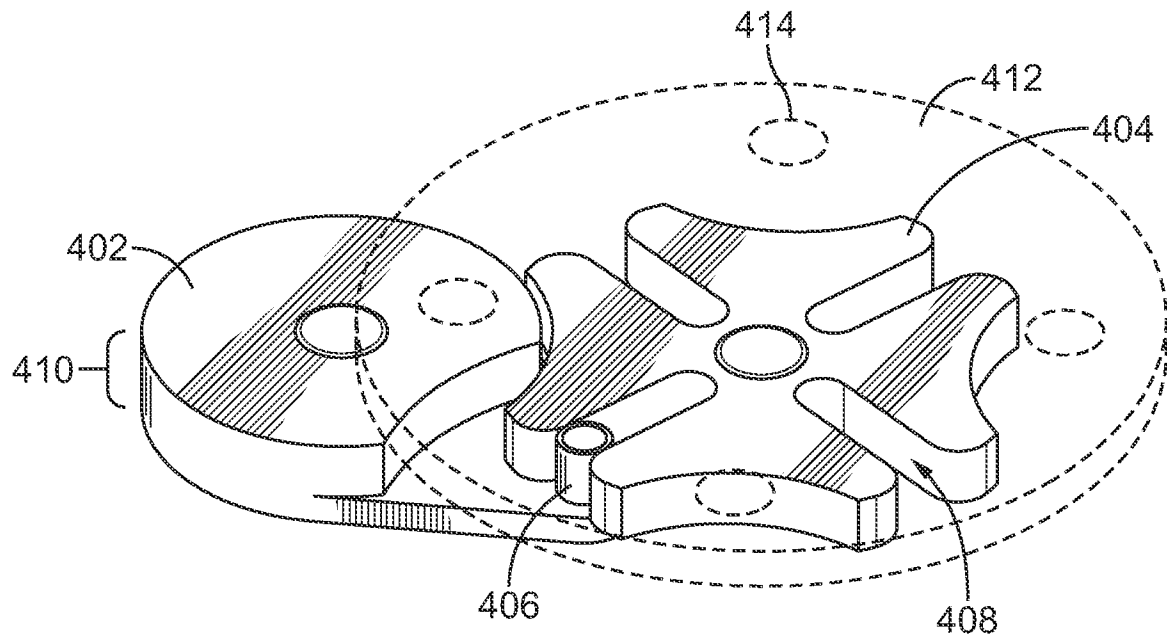


FIG. 5

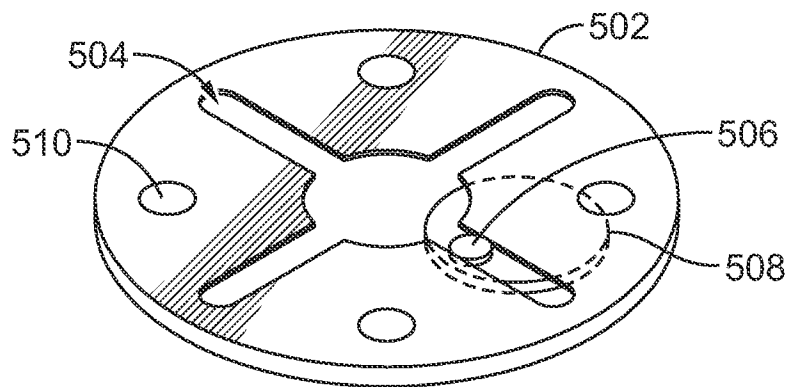
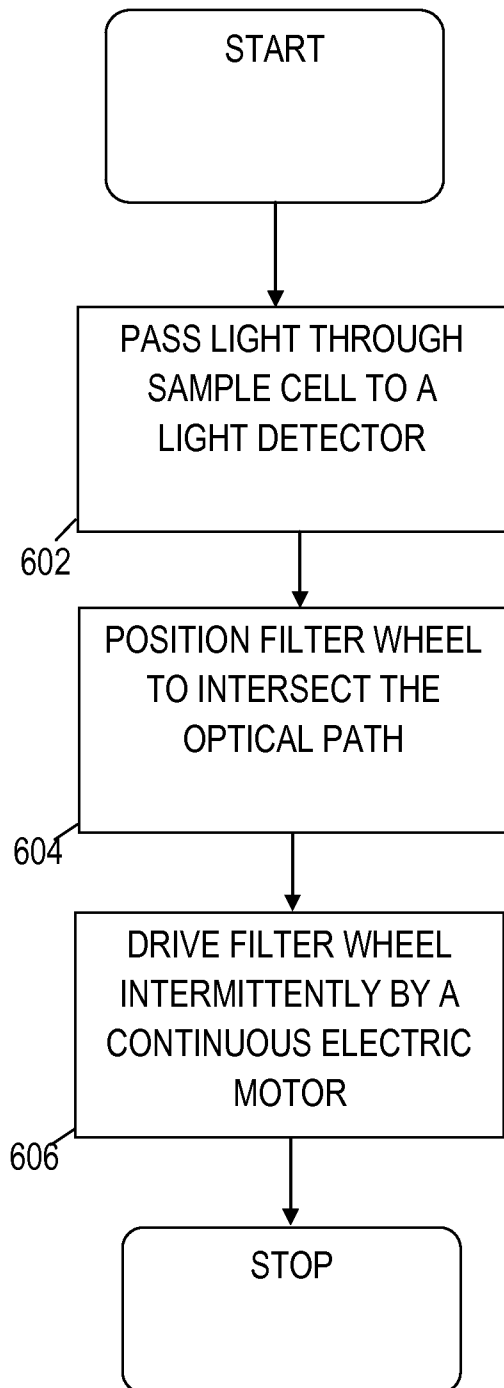


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/037662

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01V 8/12 (2011.01)

USPC - 250/269.1

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)

IPC(8) - G01V 8/10, 8/12; E21B 49/08, 49/10 (2011.01)

USPC - 250/256, 269.1; 73/152.55

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Patbase, Google Patents, Google

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/0108721 A1 (FORD et al.) 12 May 2011 (12.05.11) entire document	1, 4, 6, 8, 10, 15, 17, 19
Y		2, 3, 5, 7, 9, 11-14, 16, 18
Y	GB 1 282 108 A (SELGIN) 19 July 1972 (19.07.72) entire document	2, 3, 5, 12, 13, 14, 16
Y	US 2010/0245096 A1 (JONES et al.) 30 September 2010 (30.09.10) entire document	7, 18
Y	US 2009/0143711 A1 (BRAIG et al.) 04 June 2009 (04.06.09) entire document	9
Y	US 5,859,430 A (MULLINS et al.) 12 January 1999 (12.01.99) entire document	11

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19 August 2011

Date of mailing of the international search report

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