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(54) **AUTOMATIC MANAGED PRESSURE DRILLING UTILIZING STATIONARY DOWNHOLE PRESSURE SENSORS**

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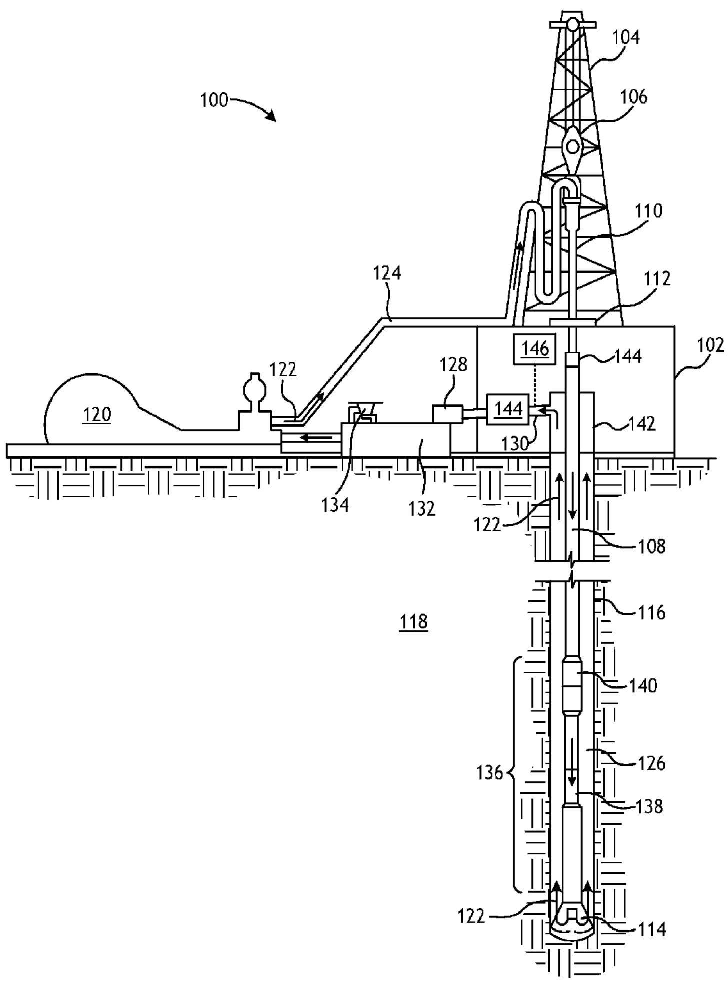
(57) **ABSTRACT**

Undertaking a wellbore operation while monitoring wellbore pressure with stationary pressure sensors coupled to tubing extended within the wellbore and thereby generating downhole annulus signals in real-time. The wellbore pressure is also monitored at or near a surface location during the wellbore operation with surface pressure sensors that generate a measured wellhead pressure. The downhole annulus pressure signals are received at an outer loop controller that provides a desired wellhead pressure based on a difference between the real-time downhole annulus pressure signals and a desired pressure setpoint. The measured and desired wellhead pressures are received with an inner loop controller that provides command signals based on a difference between the measured and desired wellhead pressures. The command signals are received by flow control devices that adjust a backpressure within the wellbore based on the command signals.



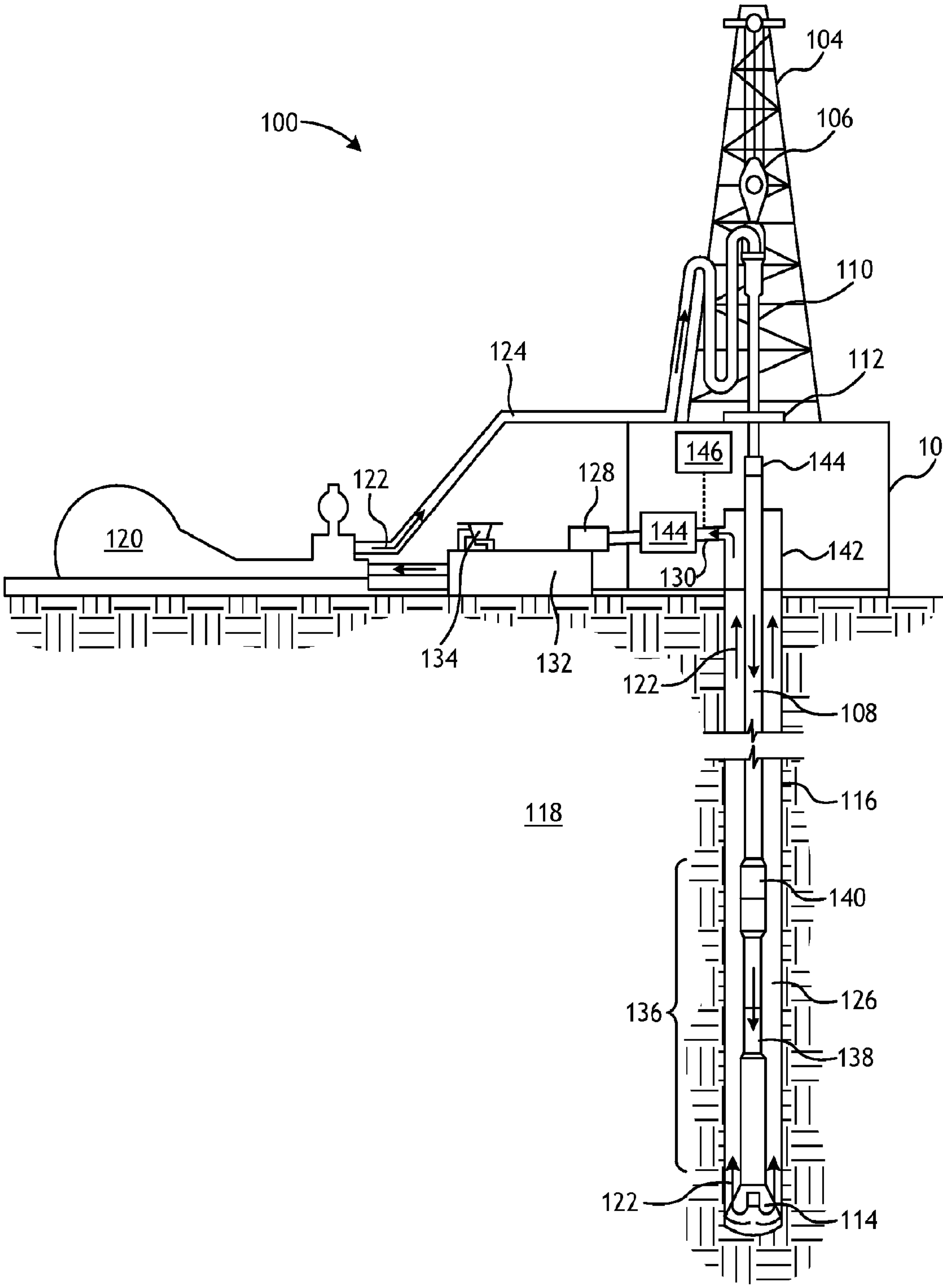

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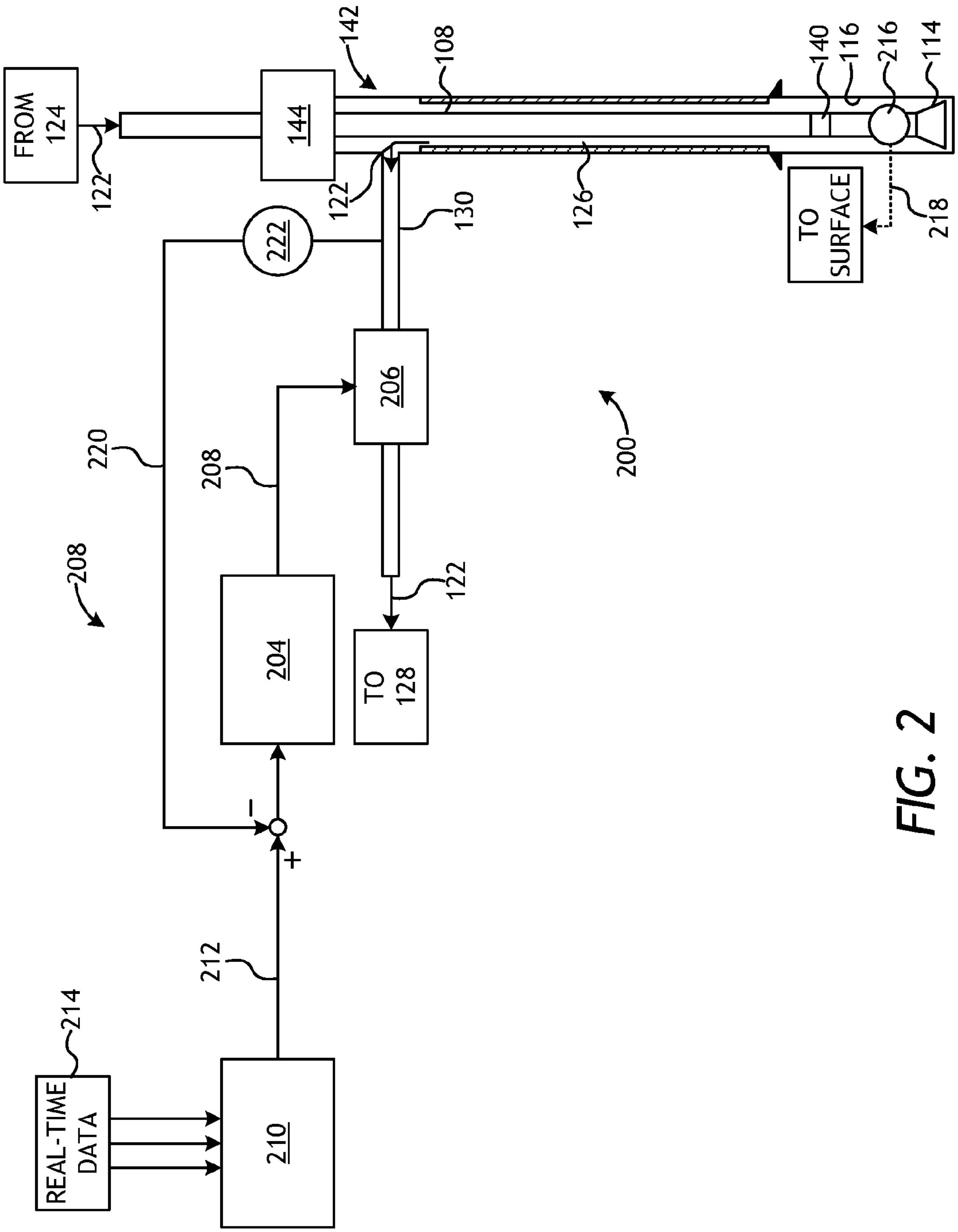
FIG. 1


FROM 124
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TO SURFACE
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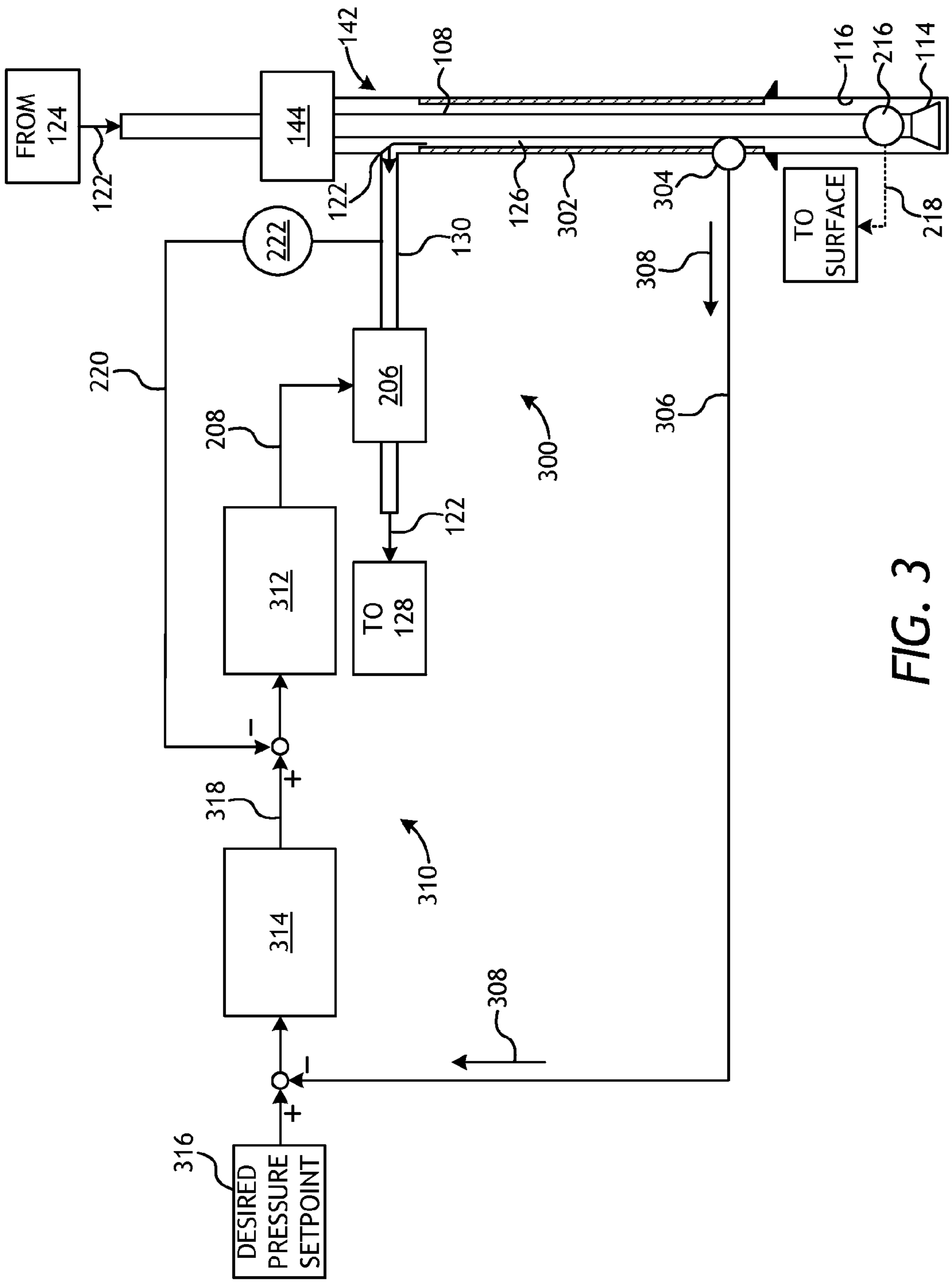
TO 128
212
214
REAL-TIME DATA
210
−
+

FIG. 2


FROM 124
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208
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122
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TO 128
−
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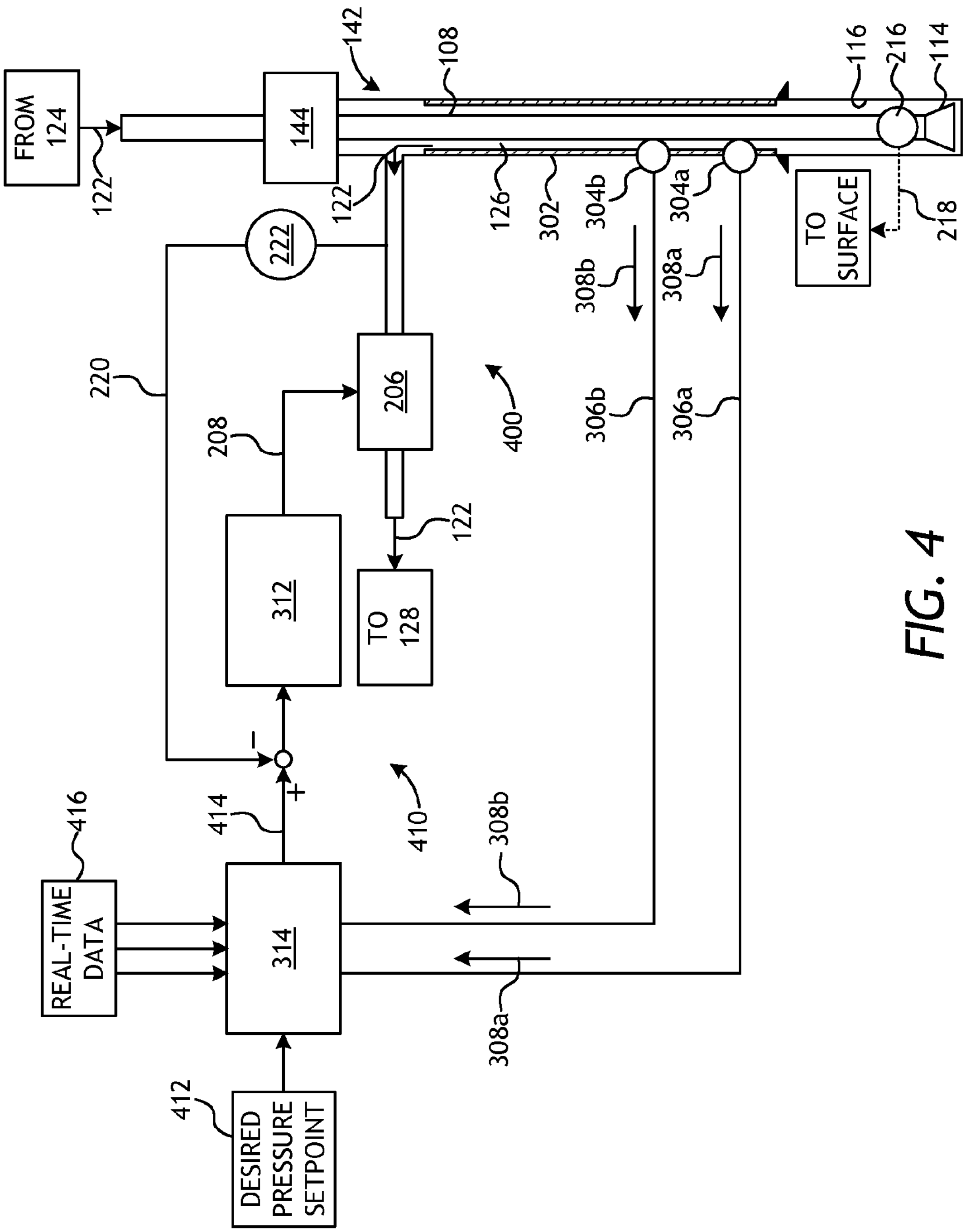
318
310
314
308
−
+
316
DESIRED PRESSURE SETPOINT

FIG. 3


FROM 124
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304a
TO SURFACE
218
222
220
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400
308b
308a
306b
306a
312
122
TO 128
314
410
414
416
REAL-TIME DATA
412
DESIRED PRESSURE SETPOINT
+
−

FIG. 4

AUTOMATIC MANAGED PRESSURE DRILLING UTILIZING STATIONARY DOWNHOLE PRESSURE SENSORS

BACKGROUND

[0001] To produce hydrocarbons from subterranean formations, a wellbore is drilled through the subterranean formations to a desired depth. This can be accomplished with a drill bit coupled to the distal end of a drill string. One or more orifices are often defined in the drill bit to allow fluid flow through the drill bit. As a result, drilling fluid is able to be circulated through the drill string from the surface, out the orifices of the drill bit, and subsequently returned to the surface via an annulus defined between the drill string and a wall of the wellbore. The drilling fluid serves several purposes, including removing cuttings and wellbore debris from the wellbore during drilling and cooling the drill bit.

[0002] After the wellbore is drilled to a desired first depth, the drill string is removed from the wellbore and a string of casing is then introduced downhole to line the wellbore to the first depth. Such casing is typically set within the wellbore by flowing cement into the annulus between the outer diameter of the casing and the wall of the wellbore. The drill string may then be introduced again into the wellbore to drill to a second desired depth below the first depth. After reaching the second depth, an additional string of casing is then lowered into the wellbore and set therein to the second depth, and thereby forming a continuous conduit along the entire length of the wellbore. This process can be repeated multiple times as the wellbore is drilled to a final desired depth.

[0003] During drilling operations, running the casing into the wellbore, and while cementing the casing, it is important to control the pressure within the wellbore, which is typically regulated with respect to the pressure exhibited by the formation or the "pore pressure." The well is balanced when the wellbore pressure and the pore pressure are equal. When the pore pressure is greater than the wellbore pressure, the well is considered underbalanced, which could result in an undesirable blowout or "kick" of fluid toward the surface of the wellbore. In contrast, when the wellbore pressure is greater than the pore pressure, the well is considered overbalanced, which could result in the fluids pumped downhole (i.e., drilling fluid, cement, etc.,) flowing into the formation and thereby causing loss of valuable fluids as well as a decrease in productivity of the formation.

[0004] The desirable pressure relationship between wellbore pressure and pore pressure varies in different situations. However, to avoid the potential disadvantageous results when drilling or completing substantially overbalanced or substantially underbalanced wells, it is desirable to accurately control the wellbore pressure

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following figures are included to illustrate certain aspects of the present disclosure, and should not be viewed as exclusive embodiments. The subject matter disclosed is capable of considerable modifications, alterations, combinations, and equivalents in form and function, without departing from the scope of this disclosure.

[0006] FIG. **1** is a schematic drawing of an exemplary drilling system that may employ the principles of the present disclosure.

[0007] FIG. **2** is a schematic diagram of a managed pressure well system.

[0008] FIG. **3** is a schematic diagram of another managed pressure well system.

[0009] FIG. **4** is a schematic diagram of another managed pressure well system.

DETAILED DESCRIPTION

[0010] The present disclosure is related to drilling and completion operations in the oil and gas industry and, more particularly, to managed pressure drilling and completion that incorporates the use of permanent or stationary downhole pressure sensors.

[0011] The embodiments discussed herein enable automated managed pressure drilling systems to maintain stable and accurate bottom-hole pressures by using measurements obtained from permanently installed pressure sensors available downhole in a well. The systems described herein may also be employed in other wellbore operations, such as running a liner or casing downhole, during completion operations, and during wellbore cementing operations. As described herein, an outer loop controller is disclosed that replaces the hydraulic model normally used in automatic managed pressure drilling operations. The outer controller receives real-time feedback from the permanently installed pressure sensors and makes the system into a closed loop automatic control system. The reliability of managed pressure drilling operations may be improved since the presently disclosed embodiments do not rely on pressure-while-drilling sensors, which are often non-operational during various wellbore operations. As opposed to the pressure-while-drilling sensors, which conventionally transmit downhole pressure data via time-lagged telemetry methods (i.e., acoustic, pressure pulse, etc.), the permanently installed pressure sensors may be hardwired to the surface to provide real-time pressure measurements processed by the outer loop controller.

[0012] Referring to FIG. **1**, illustrated is an exemplary drilling system **100** that may employ the principles of the present disclosure. It should be noted that while FIG. **1** generally depicts a land-based drilling assembly, those skilled in the art will readily recognize that the principles described herein are equally applicable to subsea drilling operations that employ floating or sea-based platforms and rigs, without departing from the scope of the disclosure. As illustrated, the drilling system **100** may include a drilling platform **102** that supports a derrick **104** having a traveling block **106** for raising and lowering a drill string **108**. The drill string **108** may include, but is not limited to, drill pipe and coiled tubing, as generally known to those skilled in the art. A kelly **110** supports the drill string **108** as it is lowered through a rotary table **112**. A drill bit **114** is attached to the distal end of the drill string **108** and is driven either by a downhole motor and/or via rotation of the drill string **108** from the well surface. As the bit **114** rotates, it creates a wellbore **116** that penetrates various subterranean formations **118**.

[0013] A pump **120** (e.g., a mud pump) circulates drilling fluid **122** through a feed pipe **124** and to the kelly **110**, which conveys the drilling fluid **122** downhole through the interior of the drill string **108** and through one or more orifices in the drill bit **114**. The drilling fluid **122** is then circulated back to the surface via an annulus **126** defined between the drill string **108** and the walls of the wellbore **116**. At the surface, the recirculated or spent drilling fluid **122** exits the annulus **126** and may be conveyed to one or more fluid processing unit(s) **128** via an interconnecting return line **130**. After passing through the fluid processing unit(s) **128**, a "cleaned" drilling fluid **122** is deposited into a nearby retention pit **132** (i.e., a mud pit). One or more chemicals, fluids, or additives may be added to the drilling fluid **122** via a mixing hopper **134** communicably coupled to or otherwise in fluid communication with the retention pit **132**.

[0014] The drilling system **100** may further include a bottom hole assembly (BHA) **136** arranged in the drill string **108** at or near the drill bit **114**. The BHA **136** may include any of a number of sensor modules **138**, which may include formation evaluation sensors and directional sensors, such as a measuring-while-drilling (MWD) tool, a logging-while-drilling (LWD) tool, and a pressure-while-drilling (PWD) tool. These sensor modules **138** generally provide at least pressure measurements, but may also provide temperature measurement, detection of drill string characteristics (e.g., vibration, weight on bit, stick-slip, etc.), formation characteristics (e.g., resistivity, density, etc.) and/or other measurements.

[0015] The BHA **136** may also include a telemetry module **140** used to transmit downhole sensor measurements derived from the sensor modules **138** to the surface via various forms of telemetry (e.g., acoustic, pressure pulse, etc.). In at least one embodiment, the telemetry module **140** comprises a mud pulser system that operates by encoding sensor data in the form of pressure fluctuations in the column of drilling fluid **122** present in the drill string **108**, and thereby transmitting the data to the surface. At the surface, the pressure pulses are detected by one or more surface sensors (not shown) and interpreted to provide the measured downhole data.

[0016] Control of bottom hole pressure (BHP) or wellbore pressure is an important aspect in managed pressure and underbalanced drilling operations.

[0017] Preferably, the bottom hole pressure is accurately controlled to prevent a variety of undesirable events, such as excessive loss of the drilling fluid **122** into the surrounding formation **118**, fracturing of the formation **118**, and the influx of fluids from the formation **118** into the wellbore **116**. In typical managed pressure drilling, it is desired to maintain the bottom hole pressure within the annulus **126** (i.e., the wellbore pressure) slightly above the pressure of the formation **118** (i.e., pore pressure) without exceeding the fracture pressure gradient of the formation **118**.

[0018] In the illustrated drilling system **100**, the wellbore pressure may be at least partially maintained by closing off the annulus **126** at a wellhead **142** installed at the surface and by using a rotating control device **144** to seal about the drill string **108** above the wellhead **142** as the drill string **108** rotates and advances into the wellbore **116**. The wellhead **142** may also include a blowout preventer (BOP) stack, as generally known in the art. As illustrated, the return line **130** may be fluidly coupled to the wellhead **142** to receive the spent drilling fluid **122** returning to the surface and otherwise exiting the annulus **126**. The spent drilling fluid **122** may be received by and conveyed through a choke manifold **144** fluidly coupled to the return line **130**. The choke manifold **144** may include one or more redundant chokes that may be selectively operated to variably restrict the flow of the drilling fluid **122** and thereby apply a desired backpressure on the annulus **126** to regulate the wellbore pressure to a required target pressure.

[0019] In some cases, the drilling system **100** may further include a backpressure pump **146** that supplies a fluid (i.e., additional drilling fluid **122**) to the return line **130** upstream of the choke or control valve manifold **144**. The backpressure pump **146** may pump the fluid into the annulus **126** when needed, such as when connections are being made in the drill string **108**, and thereby enable control of a desired backpressure on the annulus **126** to regulate the wellbore pressure. A rig pump diverter manifold (not expressly shown) can also be utilized to achieve the same functionality as the backpressure pump **146**. The rig pump diverter removes the need to mobilize a dedicated backpressure pump **146** as it diverts the flow from the rig pumps between circulating down the drill string **108** to just circulation on surface, allowing continuous flow through the choke manifold **144**. The choke or control valve manifold **144** and the backpressure pump **146** or rig pump diverter may operate together to regulate the wellbore pressure within a predetermined pressure threshold.

[0020] Referring now to FIG. **2**, with continued reference to FIG. **1**, illustrated is a schematic diagram of a managed pressure well system **200**. The managed pressure well system **200** (hereafter the "well system **200**") may be similar in some respects to the drilling system **100** of FIG. **1** and therefore may be best understood with reference thereto, where like numerals correspond to like elements or components not described again in detail. As illustrated, the well system **200** may include the drill string **108** and the drill bit **114** attached at its distal end, both of which are extended into the wellbore **116** for a drilling operation. The flow line **130** is depicted as extending from the wellhead **142** and otherwise from the annulus **126** to convey the spent drilling fluid **122** to the fluid processing unit(s) **128**. Rehabilitated drilling fluid **122** is then reintroduced to the drill string **108** from the feed pipe **124** to be recirculated into the wellbore **116**.

[0021] The well system **200** may also include a pressure control system **202** used to manage and otherwise regulate the wellbore pressure within the annulus **126**. As illustrated, the pressure control system **202** may include a controller **204** that is communicably coupled to one or more pressure control devices **206** arranged within the flow line **130** and used to manipulate and otherwise alter the fluid pressure in the annulus **126** near the surface. The pressure control devices **206** may include, for example, the choke manifold **144**, as described above. However, other types of pressure control devices **206** may be used, without departing from the scope of the disclosure. For instance, in some embodiments, in addition to the various choke valves in the choke manifold **144**, a normal control valve (not shown) may be used. While the choke valves of the choke manifold **144** are robust and exhibit a high-pressure rating, one or more control valves may alternatively be used, or otherwise in addition thereto for operations where control valves are more applicable. The controller **204** may be configured to regulate the wellbore pressure by sending one or more command signals **208** to the pressure control devices **206** (e.g., the choke manifold **144** and/or the backpressure pump **146**), which trigger action by the pressure control devices **206** to individually or cooperatively vary the backpressure applied to the annulus **126**.

[0022] The pressure control system **202** may further include a hydraulic model **210** in communication with the controller **204** and used to determine a desired pressure applied to the annulus **126** at or near the surface; e.g., a desired wellhead pressure **212**. In the well system **200**, the desired wellhead pressure **212** constitutes a target setpoint for a desired wellbore pressure. In calculating and otherwise determining the desired wellhead pressure **212**, the hydraulic model **210** takes into account real-time data **214** provided by various pieces of surface equipment that support operation of the well system **200**. The real-time data **214** may include, for example, movement of the drill string **108**, the pump rate of the drilling fluid **122**, the current depth of the drill bit **114**, the current depth of the wellbore **116**, etc.

[0023] The hydraulic model **210** may also take into account pressure measurements obtained downhole in determining the desired wellhead pressure **212**. In the illustrated embodiment, for instance, the well system **200** may further include one or more downhole pressure sensors **216** that are run downhole with the drill string **108** during the drilling operation. The downhole pressure sensors **216** may form part of the BHA **136** (FIG. **1**) and may otherwise include one or more pressure-while-drilling (PWD) tools. The downhole pressure sensors **216** may continuously or intermittently obtain pressure measurements and transmit PWD pressure signals **218** to the surface via the telemetry module **140**. The hydraulic model **210** may access and otherwise take into consideration the PWD pressure signals **218** in determining the desired wellhead pressure **212**. However, this may not normally occur since the PWD pressure signals **218** are often delayed due to the slow transmission methods of the telemetry module **140** and the overall unreliability of the data. As will be appreciated, these delays do not typically apply to wired drill pipe.

[0024] Once the desired wellhead pressure **212** is calculated, it may be compared to or against a measured wellhead pressure **220** obtained from one or more surface pressure sensors **222** arranged at various locations at the surface. As illustrated, at least one surface pressure sensor **222** may be fluidly coupled to the flow line **130**. The surface pressure sensor **222** may be able to measure the real-time pressure of the annulus **126** via the flow line **130** and thereby report the measured wellhead pressure **220**. The desired and measured wellhead pressures **212**, **220** may each be conveyed to the controller **204**, which calculates an error value (i.e., a difference) between the two pressures. In response to the calculated error value, the controller **204** outputs the command signal(s) **208** to the pressure control devices **206** to vary the backpressure applied to the annulus **126**.

[0025] The controller **204** may comprise, for example, a closed-loop control mechanism or program, such as a PID-type (proportional, integral, derivative) controller. If the measured wellhead pressure **220** is less than the desired wellhead pressure **212**, for example, then the command signal **208** to the pressure control device(s) **206** may result in an increase in the wellbore pressure. If, however, the measured wellhead pressure **220** is greater than the desired wellhead pressure **212**, then the command signal **208** to the pressure control device(s) **206** may result in a decrease in the wellbore pressure. When the desired and measured wellhead pressures **212**, **220** fall within a predetermined threshold limit (i.e., upper and lower pressure limits), the controller **204** may refrain from sending any command signal **208** or the command signal **208** may otherwise not result in action by the pressure control device(s) **206**.

[0026] The hydraulic model **210** used in managed pressure drilling operations is only a prediction and can often be inaccurate. For instance, pressure measurements from the downhole pressure sensors **216** are not always available, such as during drill string **108** connection operations or when the mud pumps **120** (FIG. **1**) are stopped. The downhole pressure sensors **216** are also often not available during wellbore operations other than drilling, such as while running liners or casing into the drilled wellbore **116** or during cementing operations that secure the casing within the wellbore **116**. During these times, the hydraulic model **210** may be operating on limited data and, therefore, the calculated desired wellhead pressure **212** may be imprecise.

[0027] Referring now to FIG. **3**, with continued reference to FIGS. **1** and **2**, illustrated is a schematic diagram of another managed pressure well system **300**, according to one or more embodiments of the present disclosure. The managed pressure well system **300** (hereafter the "well system **300**") may be similar in some respects to the well system **200** of FIG. **2** and therefore may be best understood with reference thereto, where like numerals correspond to like elements or components not described again in detail. As illustrated, the well system **300** may again generally depict a drilling operation that includes the drill string **108** and the drill bit **114** attached at its distal end and extended into the wellbore **116**. The flow line **130** extends from the wellhead **142** and conveys spent drilling fluid **122** from the annulus **126** to the fluid processing unit(s) **128**, following which a rehabilitated drilling fluid **122** is reintroduced to the drill string **108** from the feed pipe **124** to be recirculated into the wellbore **116**.

[0028] Similar to the well system **200**, the well system **300** may also be beneficial in managing wellbore pressure during drilling operations, as illustrated. Unlike the well system **200**, however, the well system **300** may further be configured to manage wellbore pressure during a variety of additional downhole operations besides drilling. For instance, the well system **300** may be able to manage wellbore pressure while running liners or casing into the wellbore **116**, during wellbore completion operations, and/or during cementing operations, without departing from the scope of the disclosure. During such operations, as indicated above, the downhole pressure sensors **216** (i.e., the PWD tool) are generally not available to help regulate the wellbore pressure. Instead, the well system **300** may employ and otherwise take advantage of one or more stationary or permanent pressure sensors installed within the wellbore **116** at various known locations.

[0029] In the illustrated embodiment, for example, the wellbore **116** is at least partially lined with tubing **302** and one or more stationary pressure sensors **304** (one shown) may be permanently coupled to the tubing **302** for measuring wellbore pressure within the annulus **126**. In some embodiments, the tubing **302** may comprise an elongate string of casing segments coupled end to end and secured within the wellbore **116** with cement. In other embodiments, however, the tubing **302** may comprise temporary or permanent production tubing, and the stationary pressure sensors **304** may be coupled thereto for operation. The stationary pressure sensor(s) **304** may comprise any type of downhole pressure gauge or transducer known to those skilled in the art. In some embodiments, the stationary pressure sensor(s) **304** may form part of the tubing **302** and used for operations related to through tubing drilling (TTD). In other embodiments, or in addition thereto, the stationary pressure sensor(s) **304** may provide pressure measurements to support downhole deployment valve operations where pressure sensors are required and otherwise utilized. In yet other embodiments, or in addition thereto, the stationary pressure sensor(s) **304** may be permanently coupled to the tubing **302** at predetermined locations for continuously or intermittently monitoring downhole conditions during hydrocarbon production operations.

[0030] The stationary pressure sensor(s) **304** may be hardwired to the surface via one or more wired telecommunication lines **306**. The wired telecommunication line(s) **306** may comprise, for example, one or more electrical wires or conductors, one or more optical fibers, or other known types of wired telecommunication means. In some embodiments, the wired telecommunication line(s) **306** may extend from the corresponding stationary pressure sensor(s) **304** on the outside of the tubing **302** to the surface. In other embodiments, the wired telecommunication line(s) **306** may extend from the corresponding stationary pressure sensor(s) **304** on the inside of the tubing **302** to the surface, or a combination of within or without the tubing **302**. In operation, the stationary pressure sensor(s) **304** may monitor and detect the wellbore pressure in the annulus **126** adjacent their particular location and thereby generate downhole annulus pressure signals **308**. Since the stationary pressure sensor(s) **304** are hardwired to the surface, the downhole annulus pressure signals **308** may be transmitted to the surface via the wired telecommunication lines **306** in real-time and with little to no signal disruption.

[0031] The well system **300** may further include a pressure control system **310** used to manage and otherwise regulate the wellbore pressure within the annulus **126**. As illustrated, the pressure control system **310** may include an inner loop controller **312** and an outer loop controller **314**. Similar to the controller **204** of FIG. **2**, the inner loop controller **312** may be communicably coupled to the one or more surface pressure sensors **222** and configured to receive the measured wellhead pressure **220** for processing. Moreover, the inner loop controller **312** may also be communicably coupled to the pressure control device(s) **206** fluidly coupled to the flow line **130**. Further, similar to the controller **204**, the inner loop controller **312** may comprise, for example, a closed-loop control mechanism or program, such as a PID-type (proportional, integral, derivative) controller. In operation, the inner loop controller **312** may be configured and otherwise used to control the fluid pressure in the annulus **126** near the surface, and may do so by sending command signals **208** to the pressure control devices **206**, which trigger action by the pressure control devices **206** to vary the backpressure applied to the annulus **126**.

[0032] The outer loop controller **314** may be communicably coupled to the stationary pressure sensor(s) **304** and may otherwise be configured to receive and process the downhole annulus pressure signals **308** either directly or indirectly from the wired telecommunication line(s) **306**. Similar to the inner loop controller **312**, the outer loop controller **314** may also comprise a closed-loop control mechanism or program, such as a PID-type (proportional, integral, derivative) controller. The outer loop controller **314** may also be configured to receive a desired pressure setpoint **316**, which may constitute the desired wellbore pressure for the specific location within the wellbore **116** where the stationary pressure sensor **304** is located. The desired pressure set point **316** may be derived from a connected computing system (not shown), or a well operator may otherwise manually input the desired pressure set point **316** for processing by the outer loop controller **314**. The desired pressure setpoint **316** may be determined based on the well conditions and objectives, most commonly for managed pressure drilling (MPD) operations set between the pore pressure and the fracture pressure. The desired pressure set point **316** will generally be derived from pre-job simulations and confirmed on the actual well during operation by conventional or dynamic formation integrity test (FIT), fingerprinting, or similar formation property confirmation tests.

[0033] The outer loop controller **314** may be configured to compare the downhole annulus pressure signals **308** against the desired pressure setpoint **316**, and otherwise calculate an error value (i.e., a difference) between the downhole annulus pressure signals **308** against the desired pressure setpoint **316**. In response to the calculated error value, the outer loop controller **314** may output and otherwise provide a desired wellhead pressure **318**. The desired wellhead pressure **318** may constitute a desired pressure applied to the annulus **126** at or near the surface that will result in a wellbore pressure that is at or near the desired pressure setpoint **316** at the location of the stationary pressure sensor **304**.

[0034] Once the desired wellhead pressure **318** is calculated, it may be conveyed to the inner loop controller **312** where it is compared to or against the measured wellhead pressure **220** obtained from the one or more surface pressure sensors **222**. The inner loop controller **312** may be configured to calculate an error value (i.e., a difference) between the desired wellhead pressure **318** and the measured wellhead pressure **220**. In response to the calculated error value, the inner loop controller **312** may output the command signal(s) **208** to trigger operation of at least one of the pressure control devices **206** (e.g., the choke manifold **144** and/or the backpressure pump **146**). For instance, if the measured wellhead pressure **220** is less than the desired wellhead pressure **318**, then the command signal **208** may trigger the pressure control device(s) **206** to actuate and otherwise operate to increase the wellbore pressure. If, however, the measured wellhead pressure **220** is greater than the desired wellhead pressure **318**, then the command signal **208** may trigger the pressure control device(s) **206** to actuate and otherwise operate to decrease the wellbore pressure. When the desired and measured wellhead pressures **212**, **220** fall within a predetermined threshold limit (i.e., upper and lower pressure limits), the controller **204** may refrain from sending any command signal **208** or the command signal **208** may otherwise not result in action by the pressure control device(s) **206**.

[0035] Accordingly, the pressure control system **310** may prove advantageous in maintaining a stable wellbore pressure at the position of the stationary pressure sensor **304**. Moreover, taking advantage of the real-time pressure measurements obtained from the stationary pressure sensor **304**, the pressure control system **310** may also be utilized in wellbore operations outside of drilling, such as while running liners or casing into the wellbore **116**, during wellbore completion operations, or during cementing operations, without departing from the scope of the disclosure. As will be appreciated, operation of the pressure control system **310** may be automated and otherwise undertaken with limited or no operator input.

[0036] Referring now to FIG. **4**, with continued reference to FIG. **3**, illustrated is a schematic diagram of another managed pressure well system **400**, according to one or more embodiments of the present disclosure. The managed pressure well system **400** (hereafter the "well system **400**") may be similar in some respects to the well system **300** of FIG. **3** and therefore may be best understood with reference thereto, where like numerals correspond to like elements or components not described again in detail. As illustrated, the well system **400** may again generally depict a drilling operation that includes the drill string **108** and the drill bit **114** attached at its distal end and extended into the wellbore **116**. The flow line **130** extends from the wellhead **142** and conveys spent drilling fluid **122** from the annulus **126** to the fluid processing unit(s) **128**, following which a rehabilitated drilling fluid **122** is reintroduced to the drill string **108** from the feed pipe **124** to be recirculated into the wellbore **116**.

[0037] Similar to the well system **300**, and besides being beneficial in managing wellbore pressure during drilling operations, as illustrated, the well system **400** may also be beneficial in managing wellbore pressure while running liners or casing into the wellbore **116**, during wellbore completion operations, and/or during cementing operations, without departing from the scope of the disclosure. To accomplish this, the well system **400** may again take advantage of the stationary pressure sensor(s) **304** coupled to the tubing **302** at various known locations within the wellbore **116**. In the illustrated embodiment, two stationary pressure sensors **304** are depicted as stationary pressure sensors **304***a* and **304***b*. In other embodiments, however, more or less than two stationary pressure sensors **304***a,b* may be used in the well system **400**, without departing from the scope of the disclosure.

[0038] Each stationary pressure sensor **304***a,b* may be hardwired to the surface via one or more wired telecommunication lines **306**, shown as wired telecommunication lines **306***a* and **306***b*. In operation, the stationary pressure sensors **304***a,b* may monitor and detect the wellbore pressure in the annulus **126** adjacent their particular location in the wellbore **116** and thereby generate corresponding downhole annulus pressure signals **308***a* and **308***b*, respectively. Since the stationary pressure sensors **304***a,b* are hardwired to the surface, the downhole annulus pressure signals **308***a,b* may be transmitted to the surface via the wired telecommunication lines **306***a,b*, respectively, in real-time and with little to no signal disruption.

[0039] The well system **400** may further include a pressure control system **410** used to manage and otherwise regulate the wellbore pressure within the annulus **126**. Similar to the pressure control system **310** of FIG. **3**, the pressure control system **410** may include the inner loop controller **312** and the outer loop controller **314**. The inner loop controller **312** is communicably coupled to the surface pressure sensor(s) **222** and the pressure control device(s) **206**, and configured to receive the measured wellhead pressure **220** for processing and subsequently send command signals **208** to the pressure control devices **206** to vary the backpressure applied to the annulus **126**. The outer loop controller **314** may be communicably coupled to one or all of the stationary pressure sensors **304***a,b* and may otherwise be configured to receive and process the downhole annulus pressure signals **308***a,b* either directly or indirectly from the wired telecommunication lines **306***a,b*.

[0040] The outer loop controller **314** may also be configured to receive a desired pressure setpoint **412**. The desired pressure setpoint **412** may be set for any point in the wellbore **116** where one or more of the stationary pressure sensors **304***a,b* may be located. Accordingly, the outer loop controller **312** may allow an operator to select a desired wellbore pressure and the depth within the wellbore **116** where the desired wellbore pressure is to be maintained. In some embodiments, for example, the desired pressure setpoint **412** may constitute a desired bottom-hole wellbore pressure for drilling operations or, more particularly, a desired pressure within the wellbore **116** at the end of the drill string **108**. In other embodiments, the desired pressure setpoint **412** may constitute a desired wellbore pressure at a casing shoe arranged at the bottom of a casing or liner being introduced into the wellbore **116**. In yet other embodiments, the desired pressure setpoint **412** may constitute a desired wellbore pressure at a location in the wellbore **116** where a drilling window may be small, for example due to a low fracture gradient at that point or abnormal pore pressure. The desired pressure setpoint **412** may be derived from a connected computing system (not shown), or a well operator may otherwise manually input the desired pressure set point **316**.

[0041] The desired pressure setpoint **412** can be determined based on knowledge of other wells drilled in generally the same area, and may be determined based on recommendations from a skilled geologist interpreting available field data. In some embodiments, for instance, the outer loop controller **314** may consist of and otherwise operate as a State Observer model designed to estimate the pressure at any position in the annulus **126**. It may also estimate other states, such as flow, standpipe pressure and the pressure at the wellhead **142**. Such estimated states may be compared to the downhole annulus pressure signals **308***a,b* and other real-time data **416** provided by various pieces of surface equipment that support operation of the well system **400**, and used as state feedback to the State Observer. The estimated pressure in the annulus **126** at a desired target location within the wellbore **116** may then be compared against the desired pressure setpoint **412**. In response, the outer loop controller **314** may output and otherwise provide a desired wellhead pressure **414**, which may constitute a desired pressure applied to the annulus **126** at or near the surface that will result in a wellbore pressure that is at or near the desired pressure setpoint **412** at the desired target location downhole.

[0042] In calculating and otherwise determining the desired wellhead pressure **414**, the outer loop controller **314** may alternatively operate as a hydraulic model, similar to the hydraulic model **212** of FIG. **2**. More particularly, to determine the desired wellhead pressure **414**, the outer loop controller **314** may further take into account the real-time data **416** provided by various pieces of surface equipment that support operation of the well system **400**. The real-time data **416** may include, but is not limited to, movement (axial and/or linear) of the drill string **108**, the pump rate of the drilling fluid **122**, the current depth of the drill bit **114** (or casing or liner being introduced downhole), the current depth of the wellbore **116**, etc. In operating as a hydraulic model, the outer loop controller **314** may be configured to calculate the wellbore pressure at the desired target location within the wellbore **116** and at the position of the stationary pressure sensors **304***a,b*. It may also contain a module that calculates what desired wellhead pressure **414** is required to achieve the desired pressure setpoint **412**. This may be accomplished by subtracting the calculated downhole pressure at the desired target position from the desired pressure setpoint **412**, and adding the difference between the measured downhole annulus pressure signals **308***a,b* and the calculated signals at the position of the stationary pressure sensors **304***a,b,* either directly, or through a filter or other processing.

[0043] Once the desired wellhead pressure **414** is calculated, it may be conveyed to the inner loop controller **312** where it is compared to or against the measured wellhead pressure **220** obtained from the one or more surface pressure sensors **222**. The inner loop controller **312** may be configured to calculate an error value (i.e., a difference) between the desired wellhead pressure **414** and the measured wellhead pressure **220**. In response to the calculated error value, the inner loop controller **312** may output the command signal(s) **208** to trigger operation of at least one of the pressure control devices **206** (e.g., the choke or control valve manifold **144** and/or the backpressure pump **146**). For instance, if the measured wellhead pressure **220** is less than the desired wellhead pressure **414**, then the command signal **208** may trigger the pressure control device(s) **206** to actuate and otherwise operate to increase the wellbore pressure. If, however, the measured wellhead pressure **220** is greater than the desired wellhead pressure **414**, then the command signal **208** may trigger the pressure control device(s) **206** to actuate and otherwise operate to decrease the wellbore pressure. When the desired and measured wellhead pressures **212**, **220** fall within a predetermined threshold limit (i.e., upper and lower pressure limits), the controller **204** may refrain from sending any command signal **208** or the command signal **208** may otherwise not result in action by the pressure control device(s) **206**.

[0044] Accordingly, the pressure control system **410** may prove advantageous in maintaining a stable wellbore pressure at the bottom of the wellbore **116** or otherwise at the positions of the stationary pressure sensor **304***a,b*. As will be appreciated, operation of the pressure control system **410** may be automated and otherwise undertaken with limited or no operator input.

[0045] Embodiments disclosed herein include:

[0046] A. A managed pressure well system that includes a wellbore extending from a surface location and having a tubing positioned therein, one or more stationary pressure sensors coupled to the tubing at a corresponding one or more locations within the wellbore to monitor wellbore pressure and thereby generate downhole annulus pressure signals in real-time, one or more surface pressure sensors in fluid communication with the wellbore to monitor the wellbore pressure at or near the surface location and generate a measured wellhead pressure, and a pressure control system. The pressure control system includes an outer loop controller that receives and calculates a downhole annulus pressure from the downhole annulus pressure signals and provides a desired wellhead pressure based on a difference between the downhole annulus pressure and a desired pressure setpoint, and an inner loop controller that receives the measured and desired wellhead pressures and provides one or more command signals based on a difference between the measured and desired wellhead pressures. The managed pressure well system further includes one or more flow control devices fluidly coupled to the wellbore at the surface location and communicably coupled to the inner loop controller to receive the one or more command signals and adjust a backpressure within the wellbore based on the one or more command signals.

[0047] B. A method that includes undertaking a wellbore operation within a wellbore extending from a surface location and having tubing positioned therein, monitoring wellbore pressure with one or more stationary pressure sensors coupled to the tubing at a corresponding one or more locations within the wellbore and thereby generating in real-time downhole annulus pressure signals during the wellbore operation, monitoring the wellbore pressure at or near the surface location during the wellbore operation with one or more surface pressure sensors and generating a measured wellhead pressure, calculating a downhole annulus pressure from the downhole annulus pressure signals with an outer loop controller and providing a desired wellhead pressure based on a difference between the downhole annulus pressure and a desired pressure setpoint, receiving the measured and desired wellhead pressures with an inner loop controller and providing one or more command signals based on a difference between the measured and desired wellhead pressures, receiving the one or more command signals with one or more flow control devices fluidly coupled to the wellbore at the surface location, and adjusting a backpressure within the wellbore with the one or more flow control devices based on the one or more command signals.

[0048] Each of embodiments A and B may have one or more of the following additional elements in any combination: Element 1: wherein the one or more stationary pressure sensors are hardwired to the surface location via a corresponding one or more wired telecommunication lines. Element 2: wherein one or both of the inner and outer loop controllers comprises a closed-loop control mechanism or program. Element 3: wherein the desired pressure setpoint comprises a desired wellbore pressure at the corresponding one or more locations within the wellbore. Element 4: wherein the desired pressure setpoint comprises a desired bottom-hole wellbore pressure. Element 5: wherein the desired pressure set point is derived from a computer system communicably coupled to the outer loop controller. Element 6: wherein the desired pressure set point is manually inputted by a well operator. Element 7: wherein the desired wellhead pressure comprises a desired pressure applied to the wellbore at or near the surface location that results in a wellbore pressure at or near the desired pressure setpoint at the corresponding one or more locations. Element 8: wherein the one or more pressure control devices comprise at least one of a choke or control valve manifold and a backpressure pump. Element 9: wherein, when the measured wellhead pressure is less than the desired wellhead pressure, the one or more command signals trigger the one or more pressure control devices to increase the wellbore pressure. Element 10: wherein, when the measured wellhead pressure is greater than the desired wellhead pressure, the one or more command signals trigger the one or more pressure control devices to decrease the wellbore pressure. Element 11: wherein the desired wellhead pressure is further based on real-time data provided by one or more pieces of surface equipment to the outer loop controller.

[0049] Element 12: further comprising transmitting the downhole annulus pressure signals to the surface location via a corresponding one or more wired telecommunication lines. Element 13: wherein providing the desired wellhead pressure comprises determining the desired wellbore pressure at the corresponding one or more locations within the wellbore. Element 14: wherein providing the desired wellhead pressure comprises determining the desired wellbore pressure at a bottom of the wellbore. Element 15: wherein providing the desired wellhead pressure comprises determining a desired pressure applied to the wellbore at or near the surface location that results in a wellbore pressure at or near the desired pressure setpoint at the corresponding one or more locations. Element 16: wherein adjusting the backpressure within the wellbore with the one or more flow control devices comprises increasing the wellbore pressure when the measured wellhead pressure is less than the desired wellhead pressure. Element 17: wherein adjusting the backpressure within the wellbore with the one or more flow control devices comprises decreasing the wellbore pressure when the measured wellhead pressure is greater than the desired wellhead pressure. Element 18: wherein providing the desired wellhead pressure comprises processing with the outer loop controller real-time data provided by one or more pieces of surface equipment. Element 19: wherein undertaking the wellbore operation within the wellbore comprises at least one of drilling a wellbore, running a liner or casing into the wellbore, undertaking a wellbore completion operation, or cementing at least a portion of the wellbore.

[0050] Therefore, the disclosed systems and methods are well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the teachings of the present disclosure may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered, combined, or modified and all such variations are considered within the scope of the present disclosure. The systems and methods illustratively disclosed herein may suitably be practiced in the absence of any element that is not specifically disclosed herein and/or any optional element disclosed herein. While compositions and methods are described in terms of "comprising," "containing," or "including" various components or steps, the compositions and methods can also "consist essentially of" or "consist of" the various components and steps. All numbers and ranges disclosed above may vary by some amount. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form, "from about a to about b," or, equivalently, "from approximately a to b," or, equivalently, "from approximately a-b") disclosed herein is to be understood to set forth every number and range encompassed within the broader range of values. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles "a" or "an," as used in the claims, are defined herein to mean one or more than one of the elements that it introduces. If there is any conflict in the usages of a word or term in this specification and one or more patent or other documents that may be incorporated herein by reference, the definitions that are consistent with this specification should be adopted.

[0051] As used herein, the phrase "at least one of" preceding a series of items, with the terms "and" or "or" to separate any of the items, modifies the list as a whole, rather than each member of the list (i.e., each item). The phrase "at least one of" allows a meaning that includes at least one of any one of the items, and/or at least one of any combination of the items, and/or at least one of each of the items. By way of example, the phrases "at least one of A, B, and C" or "at least one of A, B, or C" each refer to only A, only B, or only C; any combination of A, B, and C; and/or at least one of each of A, B, and C.

1. A managed pressure well system, comprising:

one or more stationary pressure sensors coupled to a tubing positioned within a wellbore extending from a surface location, the one or more stationary pressure sensors being positioned at a corresponding one or more locations within the wellbore to monitor wellbore pressure and thereby generate downhole annulus pressure signals in real-time;

one or more surface pressure sensors in fluid communication with the wellbore to monitor the wellbore pressure at or near the surface location and generate a measured wellhead pressure;

a pressure control system that includes:

an outer loop controller that receives and calculates a downhole annulus pressure from the downhole annulus pressure signals and provides a desired wellhead pressure based on a difference between the downhole annulus pressure and a desired pressure setpoint; and

an inner loop controller that receives the measured and desired wellhead pressures and provides one or more command signals based on a difference between the measured and desired wellhead pressures; and

one or more flow control devices fluidly coupled to the wellbore at the surface location and communicably coupled to the inner loop controller to receive the one or more command signals and adjust a backpressure within the wellbore based on the one or more command signals.

2. The managed pressure well system of claim **1**, wherein the one or more stationary pressure sensors are hardwired to the surface location via a corresponding one or more wired telecommunication lines.

3. The managed pressure well system of claim **1**, wherein one or both of the inner and outer loop controllers comprises a closed-loop control mechanism or program.

4. The managed pressure well system of claim **1**, wherein the desired pressure setpoint comprises a desired wellbore pressure at the corresponding one or more locations within the wellbore.

5. The managed pressure well system of claim **1**, wherein the desired pressure setpoint comprises a desired bottom-hole wellbore pressure.

6. The managed pressure well system of claim **1**, wherein the desired pressure set point is derived from a computer system communicably coupled to the outer loop controller.

7. The managed pressure well system of claim **1**, wherein the desired pressure set point is manually inputted by a well operator.

8. The managed pressure well system of claim **1**, wherein the desired wellhead pressure comprises a desired pressure applied to the wellbore at or near the surface location that results in a wellbore pressure at or near the desired pressure setpoint at the corresponding one or more locations.

9. The managed pressure well system of claim **1**, wherein the one or more pressure control devices comprise at least one of a choke or control valve manifold and a backpressure pump.

10. The managed pressure well system of claim **1**, wherein, when the measured wellhead pressure is less than the desired wellhead pressure, the one or more command signals trigger the one or more pressure control devices to increase the wellbore pressure.

11. The managed pressure well system of claim **1**, wherein, when the measured wellhead pressure is greater than the desired wellhead pressure, the one or more command signals trigger the one or more pressure control devices to decrease the wellbore pressure.

12. The managed pressure well system of claim **1**, wherein the desired wellhead pressure is further based on real-time data provided by one or more pieces of surface equipment to the outer loop controller.

13. A method, comprising:

undertaking a wellbore operation within a wellbore extending from a surface location and having tubing positioned therein;

monitoring wellbore pressure with one or more stationary pressure sensors coupled to the tubing at a corresponding one or more locations within the wellbore and thereby generating in real-time downhole annulus pressure signals during the wellbore operation;

monitoring the wellbore pressure at or near the surface location during the wellbore operation with one or more surface pressure sensors and generating a measured wellhead pressure;

calculating a downhole annulus pressure from the downhole annulus pressure signals with an outer loop controller and providing a desired wellhead pressure based on a difference between the downhole annulus pressure and a desired pressure setpoint;

receiving the measured and desired wellhead pressures with an inner loop controller and providing one or more command signals based on a difference between the measured and desired wellhead pressures;

receiving the one or more command signals with one or more flow control devices fluidly coupled to the wellbore at the surface location; and

adjusting a backpressure within the wellbore with the one or more flow control devices based on the one or more command signals.

14. The method of claim **13**, further comprising transmitting the downhole annulus pressure signals to the surface location via a corresponding one or more wired telecommunication lines.

15. The method of claim **13**, wherein providing the desired wellhead pressure comprises determining the desired wellbore pressure at the corresponding one or more locations within the wellbore.

16. The method of claim **13**, wherein providing the desired wellhead pressure comprises determining the desired wellbore pressure at a bottom of the wellbore.

17. The method of claim **13**, wherein providing the desired wellhead pressure comprises determining a desired pressure applied to the wellbore at or near the surface location that results in a wellbore pressure at or near the desired pressure setpoint at the corresponding one or more locations.

18. The method of claim **13**, wherein adjusting the backpressure within the wellbore with the one or more flow control devices comprises increasing the wellbore pressure when the measured wellhead pressure is less than the desired wellhead pressure.

19. The method of claim **13**, wherein adjusting the backpressure within the wellbore with the one or more flow control devices comprises decreasing the wellbore pressure when the measured wellhead pressure is greater than the desired wellhead pressure.

20. The method of claim **13**, wherein providing the desired wellhead pressure comprises processing with the outer loop controller real-time data provided by one or more pieces of surface equipment.

21. (canceled)

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