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PUMP MANAGEMENT SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 62/214,458 filed on September 4, 2015, the disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Multiple positive displacement pumps (PD pumps) are frequently used in combination to provide desired flow rates and operational pressures. Unfortunately, the simultaneous operation of PD pumps frequently results in coincidental operation of the pumps. Coincidental operation of PD pumps can lead to significant periodic pressure spikes in fluid conduits downstream of the pumps. An example of such pressure spikes is found in FIG. 6B. Continued operation under these conditions can produce premature failure of the fluid conduits.

[0003] The following disclosure describes configurations and methods designed to preclude coincidental operation of PD pumps. Thus, these configurations lead to out of phase operation, i.e. non-coincidental operation, of the PD pumps. As a result, the disclosed configurations and methods substantially reduce or eliminate periodic pressure spikes associated with the simultaneous operation of PD pumps.

SUMMARY

[0004] In one embodiment, the present disclosure describes a system for managing a plurality of positive displacement pumps in a manner to reduce or eliminate pressure deviations in fluid components and conduits downstream of the positive displacement pumps. The system described comprises a fluid source in fluid communication with a supply flowline. The supply flowline providing fluid to at least two positive displacement pumps. Each of the positive displacement pumps has a fluid input and a fluid output. The fluid input of each positive displacement pump is in fluid communication with the supply flowline. Each of the positive displacement pumps is driven by a prime mover such as an electric motor, a hydrocarbon powered engine and any other motive means suitable for driving a positive displacement pump. The prime mover may incorporate a transmission to provide maximum efficiency for driving the positive displacement pump. In fluid communication with the fluid output of each positive displacement pump is at least one pressure flowline. The at least one pressure flowline provides fluid communication between the positive displacement pumps and a pressure-side manifold.

The pressure-side manifold has at least one inlet in fluid communication with the at least one pressure flowline. The pressure-side manifold also has at least one outlet in fluid communication with a conduit, which provides fluid communication to elements downstream of the press-side manifold. The pressure flowline providing fluid pumped by the positive displacement pumps to a downstream operation. The system also includes at least one pressure sensor configured to measure pressure and output a pressure signal indicative of the measured pressure. The at least one pressure sensor may be positioned at one or more of the following locations: in the pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, and any connections there-between. The system also includes a pump management system configured to receive and transmit data. The pump management system is configured to receive fluid pressure data from said at least one pressure sensor. Further, the pump management system is also configured to control each prime mover. Additionally, the system includes at least one first data link providing data communication between the at least one pressure sensor and said pump management system. The first data link provides the pressure signal produced by the at least one pressure sensor to the pump management system. At least one second data link provides data communication between the pump management system and the prime mover thereby allowing the pump management system to use said pressure signal to manage operation of each prime mover to maintain non-coincidental operation of the positive displacement pumps.

[0005] In one embodiment, the present disclosure describes a system for managing a plurality of positive displacement pumps in a manner to reduce or eliminate pressure deviations in fluid components and conduits downstream of the positive displacement pumps. The system described comprises a fluid source in fluid communication with a supply flowline. The supply flowline providing fluid to at least two positive displacement pumps. Each of the positive displacement pumps has a fluid input and a fluid output. The fluid input of each positive displacement pump is in fluid communication with the supply flowline. Each of the positive displacement pumps is driven by a drivetrain, which may include a prime mover such as an electric motor, a hydrocarbon powered engine or any other motive means suitable for driving a positive displacement pump. The drivetrain may incorporate a transmission to provide maximum efficiency for driving the positive displacement pump. Thus, the combination of a positive displacement pump with a prime mover and drivetrain is a positive displacement pump/drivetrain assembly. The prime mover may optionally include an electronic control module configured to direct control of prime mover RPM and to provide data on prime mover

operation. In fluid communication with the fluid output of each positive displacement pump is at least one pressure flowline. The at least one pressure flowline provides fluid communication between the positive displacement pumps and a pressure-side manifold. The pressure-side manifold has at least one inlet in fluid communication with the at least one pressure flowline. The pressure-side manifold also has at least one outlet in fluid communication with a downstream conduit. The pressure flowline providing fluid pumped by the positive displacement pumps to a downstream operation. The system also includes a pump management system configured to control at least two positive displacement pumps and the prime movers driving the pumps. The pump management system comprises a multiple pump controller configured to receive and transmit data, a multiple drivetrain controller configured receive and transmit data and a local pump system control configured to monitor and manage the operation of each positive displacement pump/drivetrain assembly. The local pump system control includes a local engine controller configured to receive and transmit data and a local pump controller configured to receive and transmit data. The local pump controller and local engine controller are in data communication within one another. Additionally, the multiple engine controller and multiple pump controller are in data communication. Further, the multiple engine controller is in data communication with each local engine controller and the multiple pump controller is in data communication with each local pump controller. The system also includes at least one pressure sensor configured to measure pressure and output a pressure signal indicative of the measured pressure. The at least one pressure sensor is positioned at one of the following locations: in the pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, and any connections there-between. A data link provides the pressure signal generated by the pressure sensor and indicative of the measured pressure to the multiple engine controller. The multiple engine controller is configured to receive data and to direct at least one local pump system to change operation of at least one engine monitored and managed by said local pump system. Additionally, the multiple engine controller is configured to use the pressure signal to manage operation of each local pump system to maintain non-coincidental operation of said positive displacement pumps.

[0006] Additionally, the present disclosure describes a method for non-coincidental operation of positive displacement pumps. The method comprises the steps of using a first prime mover to drive a first positive displacement pump at a first pumping rate thereby forcing a fluid through at least a first pressure flowline into a pressure-side manifold. Additionally, the method provides for

using at least one additional prime mover to drive at least one additional positive displacement pump at a first pumping rate thereby forcing a fluid through at least a second pressure flowline into a pressure-side manifold. During pumping operations, the method monitors fluid pressure at least at one of the following locations: in the at least a first pressure flowline, in the at least a second pressure flowline, the pressure-side manifold and any connections there-between. Subsequently, the method transmits fluid pressure data concerning the monitored fluid pressure to a pump management system. The pump management system has been configured to control each prime mover and to receive fluid pressure data. Thereafter, the pump management system uses the fluid pressure data to determine the degree of coincidental operation of the first positive displacement pump and the at least one additional positive displacement pump(s). To maintain substantially non-coincidental operation of the first positive displacement pump and the at least one additional positive displacement pump, the pump management system transmits a signal to the first prime mover or to the at least one additional prime mover thereby directing a change in the driving operation of the first positive displacement pump or the at least one additional positive displacement pump to a second pumping rate. The pump management system maintains the second pumping rate until the pump management system receives transmitted fluid pressure data reflecting substantially non-coincidental operation of the first positive displacement pump and the at least one additional positive displacement pump(s).

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Figure 1 is a schematic view of a wellbore servicing system in an operational environment according to an embodiment of the disclosure.

[0008] Figure 2 is a schematic view of the wellbore servicing system of Figure 1.

[0009] Figure 3A is a schematic view of an embodiment of the distributed network control architecture for the pump management system of FIG. 2.

[0010] Figure 3B is block diagram of the embodiment of the pump management system of FIG. 2 showing the signal communications at the local pump truck control level.

[0011] Figure 4A is a block diagram of a centralized control architecture for the pump management system of FIG. 2.

[0012] Figure 4B is block diagram of the embodiment of the pump management system of FIG. 2 showing the signal communications at the local pump truck control level.

[0013] Figure 5 is a schematic view of an embodiment of a least mean squared finite impulse response adaptive filter algorithm.

[0014] Figure 6A is a diagram illustrating pressure deviation at the output flow conduit from a single positive displacement pump is a schematic view of an embodiment of the pump management control manifold.

[0015] Figure 6B is a diagram illustrating pressure deviation in a common flow conduit as a result of the unmanaged operation of eight positive displacement pumps.

[0016] Figure 7 is a diagram illustrating pressure deviations within a common flow conduit as a result of operating eight positive displacement pumps under control of the disclosed pump management system.

DETAILED DESCRIPTION

[0017] Disclosed herein are apparatuses, systems, and methods for managing two or more pumps. The disclosed embodiments of the pump management system 400 include apparatuses, systems, and methods that will effectively diminish or eliminate momentary fluctuations in dynamic pressure within common flow conduits downstream of a plurality of positive displacement (PD) pumps. As described herein, a momentary fluctuation in pressure refers to a temporary, dynamic deviation in pressure from a baseline (or average) operating pressure due to the operation of two or more PD pumps. The following non-limiting embodiments relating to downhole operations are merely exemplary of the improvements provided by the present disclosure. The methods, systems and apparatuses discussed herein may be adapted to a variety of operations, which utilize two or more positive displacement pumps.

[0018] FIG. 1 depicts an exemplary embodiment operating as part of a wellbore servicing system 110. The wellbore servicing system 110 is deployed at a wellsite 100 and is fluidly coupled to a wellbore 120. The wellbore 120 penetrates a subterranean formation 130 for the purpose of recovering hydrocarbons, storing hydrocarbons, disposing of carbon dioxide, or the like. In FIG. 1, a pipe string 140 (e.g., a drill string, segmented tubing, coiled tubing, etc.) is disposed within the wellbore 120. A wellbore servicing tool 150, configured for one or more wellbore servicing operations, is integrated within the pipe string 140. In some embodiments, additional downhole tools are included with or integrated within the wellbore servicing tool 150 and/or the pipe string 140, for example, one or more isolation devices (for example, a packer).

[0019] In various embodiments, portions of the wellbore 120 are vertical, deviated, horizontal, and/or curved. In the embodiment of FIG. 1, a portion of the pipe string 140 is secured into position within the wellbore 120. Although one or more of the figures may exemplify a given operating environment, the principles of the devices, systems, and methods disclosed may be similarly applicable in other operational environments, such as offshore and/or subsea wellbore applications.

[0020] In FIG. 1, the wellbore servicing system 110 is coupled to a wellhead 180 via a conduit 190, and the wellhead 180 is coupled to the pipe string 140. In various embodiments, pipe string 140 comprises a casing string, a liner, a production tubing, coiled tubing, a drilling string, the like, or combinations thereof. Pipe string 140 may extend from the earth's surface 160 downward within the wellbore 120 to a predetermined or desirable depth, for example, such that the wellbore servicing tool 150 is positioned substantially proximate to a portion of the subterranean formation 130 to be serviced. Arrows 202 indicate a route of fluid communication from the wellbore servicing system 110 to the wellhead 180 via conduit 190, from the wellhead 180 to the wellbore servicing tool 150 via pipe string 140, and from wellbore servicing tool 150 into the subterranean formation 130. In various embodiments, wellbore servicing tool 150 is configured to perform one or more servicing operations, for example, fracturing formation 130, hydrojetting and/or perforating casing (when present) and/or formation 130, expanding or extending a fluid path through or into subterranean formation 130, producing hydrocarbons from formation 130, or other servicing operation.

[0021] FIG. 2 schematically illustrates an embodiment of fluid delivery system 205 and pump management system 400. In FIG. 2, fluid delivery system 205 generally comprises one or more storage vessels (for example, storage vessels 200, 210, and 220) a blender 240, a supply-side manifold 250a, a pressure-side manifold 250b, and one or more PD pumps 270. In the embodiment of FIG. 2, PD pumps 270 and associated equipment are housed in pump trucks 280. In FIG. 2, water from storage vessel 200 is introduced, either directly or indirectly, into the blender 240 where the water is mixed with various other components and/or additives from storage vessels 210 and 220 to form a wellbore servicing fluid. The wellbore servicing fluid passes from the blender 240 into a low-pressure side of the supply-side manifold 250a via flowline 260 and from the supply-side manifold 250a to the PD pumps 270 via supply flowlines 295.

[0022] To provide the necessary pressure for downhole operations such as fracturing, operation of PD pumps 270 forces the wellbore service fluid into a pressure-side manifold 250b via pressure flowlines 290 and subsequently from pressure-side manifold 250b to wellhead 180 via conduit 190. During fracturing operations and other downhole operations PD pumps 270 operate at a rate such that the pressure within pressure-side manifold 250b and subsequent downstream lines via conduit 190 is at a significantly higher pressure. In various embodiments, the supply-side manifold 250a and/or the pressure-side manifold 250b may include a truck, trailer, skid, or platform on which one or more flow conduits for receiving, organizing, and/or distributing wellbore servicing fluids during wellbore servicing operations are disposed. Thus, the distance from each pump 270 to pressure-side manifold 250b may vary from pump to pump.

[0023] In fracturing operations, wellbore servicing fluids, such as particle (e.g., proppant) laden fluids, are pumped at a relatively high-pressure into the wellbore 120. The particle laden fluids may then be introduced into a portion of the subterranean formation 130 at a pressure and velocity sufficient to cut and/or abrade a casing and/or initiate, create, or extend perforation tunnels and/or fractures within the subterranean formation 130. Proppant (e.g., grains of sand, glass beads, shells, ceramic particles, etc.,) may be mixed with the wellbore servicing fluid to keep the fractures open so that hydrocarbons may be produced from the subterranean formation 130 and flow into the wellbore 120.

[0024] FIG. 2 depicts fluid delivery system 205 in a configuration having four pump trucks 280 also known as pump units 280. However, fluid delivery system 205 may include any number of pump trucks 280 as deemed appropriate for the pumping operation. Each pump truck 280 carries at least one PD pump 270 and a drivetrain 276. Each of the PD pumps 270 is driven by drivetrain 276 which may include a prime mover such as an electric motor, a hydrocarbon powered engine, a variable frequency drive or any other motive means suitable for driving a positive displacement pump. Drivetrain 276 may incorporate a transmission to provide maximum efficiency for driving the positive displacement pump. Thus, the combination of a PD pump 270 with drivetrain 276 is a positive displacement pump/drivetrain assembly. Each PD pump 270 includes one or more pistons/plungers each piston/plunger configured to reciprocate within a cylinder. PD pumps 270 may include two cylinders (e.g., a duplex pump), three cylinders (e.g., a triplex pump), four cylinders (a quadraplex pump), and five cylinders (a quintuplex pump); however, a PD pump 270 can have even greater number of cylinders. A connecting rod secures each piston/plunger to a crankshaft. Drivetrain 276 provides

the necessary power to rotate the crankshaft. In a conventional configuration, the transmission will be located between the prime mover and the crankshaft of PD pump 270. Finally, PD pump 270 may be an electric pump configured to receive electrical input from any convenient source including but not limited to a variable frequency drive, brushless DC drive or servohydraulic or hydrostatic fluid power drives.

[0025] In operation, each cycle (i.e., stroke or reciprocation) of a piston/plunger draws a volume of the fluid being pumped into the cylinder associated with the piston/plunger and discharges that volume of into the pressure-side manifold 250b at an increased pressure. Generally, the pressure within the flow conduits common to a plurality of pumps 270 (e.g., the pressure-side manifold 250b, conduit 190, and wellhead 180) can be characterized as an average pressure resulting from the operation of all PD pumps 270. Thus, with reference to FIG. 2, the pressure within pressure-side manifold 250b, conduit 190 and at wellhead 180 will be the average pressure due to the operation of PD pumps 270.

[0026] In the exemplary embodiment of FIG. 2, supply-side manifold 250a is coupled to any number of high-pressure PD pumps 270 via supply flow lines 295 and pressure flow lines 290. FIG. 2 depicts four PD pumps 270; however, in alternative embodiments, the number of PD pumps 270 used will vary depending upon the operation served by PD pumps 270. Supply flowlines 295 supply fluid to PD pumps 270 from the low-pressure side of the supply-side manifold 250a. Pressure flowlines 290 from PD pumps 270 communicate the highly pressurized wellbore servicing fluid to the pressure-side manifold 250b. Each of PD pumps 270 provides sufficient pumping force to generate the necessary downhole pressure as measured at wellhead 180 for the operation to be performed. For example, operation of PD pumps 270 increases the pressure applied by the wellbore servicing fluid such that the measured pressure within the high-pressure side of the wellbore services manifold 250 is at least about 8,000 psi (about 55,158 kilopascals), about 10,000 psi (about 68,948 kilopascals), alternatively, about 15,000 psi (about 103,422 kilopascals), alternatively, about 20,000 psi (about 137,896 kilopascals) or higher. Also, in an embodiment, PD pumps 270 increase the combined flowrate of the wellbore servicing fluid such that the flowrate of the wellbore servicing fluid through pressure-side manifold 250b is from about 1 bbl/min (about 159 liters/min) to about 200 bbl/min (about 31,798 liters/min), alternatively from between about 50 bbl/min (about 7,950 liters/min) to about 150 bbl/min (about 23,849 liters/min), alternatively from about 100 bbl/min (about 15,899 liters/min) to about 120 bbl/min (about 19,079 liters/min)

[0027] The pumping process of a single PD pump 270 produces dynamic variations of pressure within a downstream conduit. For example, FIG. 6A depicts the changes in fluid pressure of an output flow conduit as a result of a single PD pump 270. When operating a plurality of PD pumps 270, the dynamic variations of pressure within downstream conduits can be amplified due to PD pumps 270 operating in phase. FIG. 6B depicts the effect of eight PD pumps 270 operating such that the dynamic pulses produced by the plungers are in phase or coincident. While operation of PD pumps 270 generally maintains a constant average pressure within the common flow conduits, both high and low dynamic pressure variations occur as a result of coincident, i.e. in phase, pump operation. Not intending to be bound by theory, the highest magnitude pressure fluctuations occur when all PD pumps 270 operate coincidently. Observations in the field have indicated that during normal operation the relative phasing of the PD pumps 270 frequently vary as pumping demands vary during the performance of an operation. PD pumps 270 have been observed to exhibit a tendency to vary towards coincidence. When operating in coincidence, the pumps generate the previously discussed significant cycling of high and low dynamic pressure depicted in FIG. 6B. As a result, downstream conduits and other components experience extremes of high and low pressure stresses ultimately leading to metal fatigue and failure of components.

[0028] As reflected by FIG. 7, the disclosed pump management system 400 effectively reduces or eliminates the dynamic pressure pulses commonly associated with operating a plurality of PD pumps 270. FIG. 7 demonstrates that the proper control and management of pump trucks 280 by pump management system 400 provides the ability to reduce stress and fatigue on common fluid components downstream of PD pumps 270. The configuration of pump management system 400 provides overall operational control for the ongoing pumping operation and local control of each PD pump 270 by controlling drivetrain 276. While the configuration of the system may vary depending upon the pumping operation, an exemplary embodiment of pump management system 400 is provided with reference to FIGS. 2, 3A, 3B, 4A and 4B in the exemplary environment of a downhole operation. Details concerning the operation and control of pump management system 400 are provided below with reference to FIGS. 2-4B.

[0029] With reference to FIGS. 2-4B, pump management system 400 includes an application controller 401. Application controller 401 manages the overall pumping operation. Application controller 401 receives real time data (analog or digital) via data links from sensors and data processors monitoring fluid pressure and pump operations. In one embodiment, data links 187a,

187b and 187c provide data from sensors and other data processors associated with pump trucks 280, pressure-side manifold 250b and other monitored operations to application controller 401. Additional datalinks (not shown) may be used to provide for increased data communications between the sensors and other data processors associated with pump trucks 280, pressure-side manifold 250b and other monitored operations to application controller 401 and optionally to pump system control 420. In particular, data from pump trucks 280 will include at least information on the position the pistons, RPM and output pressure within the PD pump 270. All data links discussed herein may be hard-wired connections such as a connection between serial ports, Ethernet ports, USB ports, fieldbus networks and industrial networks (e.g. CANbus, Modbus, etc.) or combinations thereof. Alternatively, the data links may be wireless connections. Typically, the datalinks provide bidirectional communication of signals; however, depending on the nature of the data other configurations may be used.

[0030] Details on two exemplary embodiments of controls systems on board each pump truck will be discussed with reference to FIGS. 3A-4B. In the exemplary embodiments, a pressure sensor 185 monitors fluid pressure within pressure-side manifold 250b. Data from pressure sensor 185 is transmitted via data link 187a to application controller 401. Similarly, data links 187b and 187c provide data generated by each pump truck 280. Application controller 401 may also receive data directly or indirectly from sensors monitoring wellhead 180. Additionally, fluid pressure and flow rates downstream of each PD pump 270 are monitored by sensors associated with the common fluid conduits and pressure-side manifold 250b. Sensors, not shown, monitor both static pressure and dynamic pressure fluctuations within the common fluid conduits and pressure-side manifold 250b. Application controller 401 utilizes all of the data received to manage operation of all pumping operations to minimize and preferably eliminate coincidental operation of pumps 270.

[0031] FIGS. 3A and 3B provide a more detailed schematic view of one exemplary embodiment of pump management system 400 associated with a plurality of pump trucks 280. As depicted in FIG. 3A, application controller 401 receives data relating to fluid pressure and flow demands of the downhole operation currently underway from sensors, not shown, associated with wellhead 180 and from pressure sensor 185 associated with pressure side manifold 250b. Application controller 401 also receives data from each pump truck 280 managed by application controller 401 via data links 187b and 187c. In the embodiment of

FIG. 3A, application controller 401 includes a multiple drive train controller 402 and a multiple pump controller 403.

[0032] FIG. 3B depicts the components of each pump truck 280. As discussed above, each pump truck 280 includes drivetrain 276. Each engine of drivetrain 276 includes an associated electronic control module (ECM) 415 suitable for monitoring and managing engine operations. ECM 415 monitors engine parameters such as, but not limited to, engine piston position, spark management, throttle position and management and other common engine management operations typically managed or monitored by an ECM. Each pump truck 280 also includes a local pump system control 420. Local pump system control 420 includes a local pump controller 410 and a local drivetrain controller 405. PD pump 270 may include an optional piston monitoring sensor, not shown. However, ECM 415 or the local pump control 420 will be able to determine the position of each piston in PD pump 270 due to the direct relationship of PD pump 270 with drivetrain 276. Alternatively, an optional transmission or driveline position sensor may provide data reflecting the position of PD pump 270 piston(s).

[0033] In one embodiment, a signal indicative of top dead center for the pistons in PD pump 270 will be provided to application controller 401 to maintain non-coincidental operation of PD pumps 270. That signal is provided by using ECM 415, local pump truck controller 420 or a piston position sensor associated with PD pump 270. For example, the piston position sensor outputs a signal once with each revolution of the PD pump's 270 crankshaft. Because the pistons/plungers are coupled to the crankshaft in a fixed relationship, the position of the crankshaft can be used to derive the position of each piston/plunger associated therewith. In an embodiment, the piston position sensor is a rotary encoder-type sensor (e.g., a shaft encoder), such as an absolute rotary encoder or an incremental rotary encoder. In FIG. 3B, the piston position sensor provides either digital or analog data reflecting the position of the pistons in PD pump 270 to local pump controller 410 via a datalink 187c.

[0034] FIG. 3B also provides details relating to the data input and output of application controller 401 and local pump control system 420. As depicted in FIG. 3B, each local pump controller 410 provides data to multiple pump controller 403. The data exchanged includes but is not limited to: PD pump 270 piston position, engine RPM, and pressure data from common downstream fluid conduits including pressure-side manifold 250b. Multiple drivetrain controller 402 is in electronic communication with local drivetrain controller 405. Local

drivetrain controller 405 manages operation of the drivetrain 276 by managing throttle or other engine control mechanism.

[0035] As discussed above, application controller 401 provides overall control of pumping operations. Within each truck 280, the local pump control system 420 manages the operation of the drivetrain 276 to drive pump 270 at the desired rate. Local pump controller 410 receives data input from ECM 415, including but not limited to engine RPM, piston position and PD pump 270 outlet pressure. Local pump controller 410 communicates this data via data link 187c to multiple pump controller 403. Local drivetrain controller 405 also receives RPM and power data from ECM 415. Additionally, local drivetrain controller 405 receives data via data links 187b from pressure side manifold 250b and/or wellhead 180 as well as data from multiple drivetrain controller 402 via data link 187b, local pump controller 410 and from multiple pump controller 403 via data link 187c. Typically, the data from pressure side manifold 250b and/or wellhead 180 includes outlet flow rates, outlet pressure at the outlet of pressure side manifold 250b and supply pressure at wellhead 180. In this embodiment, local drivetrain controller 405 communicates via data link 187b with multiple drivetrain controller 402 and local pump controller 410 communicates with multiple pump controller 403 via data link 187c. Data is shared between the multiple drivetrain controller 402 and multiple pump controller 403 via a data link internal to the application controller 401.

[0036] Under normal operating conditions, application controller 401, through multiple drivetrain controller 402 and multiple pump controller 403, controls the operation of each local pump control system 420. The data links between application controller 401 and local pump system control 420 are two-way data links. Thus, application controller 401 receives data previously received by local pump controller 410 and local drivetrain controller 405.

[0037] The operational parameters input into application controller 401 determine the desired pressure and flow rates at pressure side manifold 250b and wellhead 180. Upon variation from the desired settings, multiple drivetrain controller 402 will signal each local drivetrain controller 405 to increase or decrease pumping operations. The resulting change in pumping operations will restore the desired pressure and flow rates at pressure side manifold 250b and wellhead 180. However, such changes frequently allow PD pumps 270 to trend towards coincidental operation. Sensor 185 monitors fluid pressure at pressure side manifold 250b for pressure spikes associated with coincidental PD pump operation as depicted in FIG. 6B. Optionally, other sensors at wellhead 180 or elsewhere on the downstream side of pressure

side manifold 250b will monitor fluid pressure in order to detect pressure deviations such as depicted in FIG. 6B.

[0038] Continuing with the embodiment of FIGS. 3A and 3B, the primary adjustment to preclude coincidental operation of PD pumps 270 is a momentary change in drivetrain 276 operation, e.g. a change in engine (prime mover) RPM. As depicted in FIG. 3B, local pump system control 420 provides two paths to achieve a change in throttle position necessary for producing a change in engine RPM. Both paths proceed from application controller 401 via multiple pump controller 403 to local pump controller 410. In the first path, local pump controller 410 transmits a throttle change command to local drivetrain controller 405 and local drivetrain controller 405 signals a throttle change to ECM 415. In the second path, local pump controller 410 transmits an RPM change command to ECM 415. In this path, ECM 415 changes engine RPM in response to the change in RPM signal from ECM 415. The change in RPM directs a change in drivetrain 276 operation (e.g., such as a change in the throttle or engine operation). Either path provides control over PD pump 270 speed through change in engine RPM. Application controller maintains the new engine RPM until pressure signals from sensor 185 and other downstream sensors or the piston position sensor no longer reflect coincidental pump operation. Finally, in the embodiments with a pressure-side manifold 250b, application controller 401 compensates for differences in distance between each PD pump 270 and pressure-side manifold 250b. Thus, when compared to prior art dynamic pressure fluctuations as depicted in FIG. 6B, pump management system 400 provides a significant improvement.

[0039] Depending upon the type of pump pressure sensor utilized, multiple pump controller 403 will execute instructions that include the steps necessary to determine an average pressure within common fluid conduits as reported by well head pressure sensor(s) 185. Additionally, multiple pump controller 403 will determine dynamic pressure within pressure-side manifold 250b, conduit 190 and wellhead 180. Utilizing the determined average pressure, inputted desired average pressure, dynamic pressure, data from piston position sensors, multiple pump controller 403 will determine the appropriate adjustment in operations necessary to minimize dynamic pressure fluctuations. Upon selection of the adjustment needed, multiple pump controller 403 will direct local pump controller 410 to signal the necessary changes in throttle position to control pump RPM and piston position. To achieve the desired average pressure with a minimal dynamic pressure change within pressure-side manifold 250b, conduit 190 and wellhead 180, multiple pump controller 403 continues to make adjustments in response

to data input to manage local pump controller 410. Thus, multiple pump controller 403 directs each PD pump 270 to operate in a manner such that the dynamic pressure pulses produced by one pump effectively cancels the dynamic pressure pulses of another pump. The cancellation of dynamic pressure pulses by PD pumps 270 within pump management system 400 produces a pressure deviation trace as depicted in FIG. 7.

[0040] As discussed above, the pressure data will be used to determine the average pressure at a given point in time. The step of determining the average pressure based upon the pump pressure data includes the step of calculating a mean (e.g., a running or rolling mean) from the pump pressure data. For instance, the signal from each of the pump pressure sensors 430 is representative of pressure at various points in time. Therefore the inputs (e.g., pump pressure data) constitute an array of pressure values with respect to time (e.g., in the time domain). The step of determining the average pressure may include utilizing a finite impulse response (FIR) filter to calculate the average pressure over a period of time (e.g., for a number of samples). In an alternative embodiment, the step of determining the average pressure may include utilizing an infinite impulse response (IIR) filter (e.g., operating as a high pass filter) to calculate the average pressure over a period of time. If desired, wellhead pressure from sensor 185 may be included in the average pressure determination. Further, the step of determining the pressure deviation (e.g., a fluctuation from an average pressure) for each pump may include the step of calculating the difference between the pressure at each pump (e.g., as represented by the signal from each of the pump pressure sensors 430) and the average pressure. The result of the calculation is the pressure deviation (e.g., error) at each pump with respect to time (e.g., in the time domain).

[0041] Multiple pump controller 403 uses at least one of: the pressure data, piston position data or other data input, e.g. pump flow rate, in a least mean squared finite impulse response adaptive filter algorithm, as depicted in FIG. 5, to determine when to signal an individual local pump control system 420 to make adjustments in order to preclude coincidental PD pump 270 operation. The least mean squared (LMS) adaptive filter utilizes the pressure deviation at each PD pump 270 in the time domain to iteratively adapt a control signal based upon the output therefrom. Referring to FIG. 5, an example of a LMS scheme is illustrated. In the embodiment of FIG. 5, generally, $x(n)$ is an input signal to a linear filter, $y(n)$ is an output signal, $d(n)$ is an input signal to the adaptive filter, and $e(n)$ is the error signal, for example, the difference in $d(n)$ and $y(n)$. The LMS adaptive filter converts the pressure deviation with respect to time

(in the time domain) to pressure deviation with respect to a PD pump 270 operating parameter, for example, pump angular orientation (in the frequency domain). The pressure deviation with respect to pump angular orientation is used to calculate a change in angular orientation (i.e., Δ°) for each pump, that is, one or more of PD pumps 270 (i.e., $\Delta^\circ_{\text{Pump } 1}$, $\Delta^\circ_{\text{Pump } 2}$, $\Delta^\circ_{\text{Pump } 3}$, $\Delta^\circ_{\text{Pump } 4}$, etc.). The change in angular orientation for each PD pump 270 is added to the angular orientation for each PD pump 270, respectively, to yield an array of pump orientation angles that, if implemented, will reduce the magnitude of the pressure deviations, both at each PD pump 270, at pressure side manifold 250 and at the wellhead 180. Use of a LMS algorithm, as discussed above, is well known to those skilled in the art as demonstrated by the following United States patents: US5713438; US5619581; US5487027; US5627896 and US5745580.

[0042] As such, the output from the LMS adaptive filter includes a determination that a change to one or more operating parameters of one or more PD pumps 270 effective to correct the pressure deviations. For example, a determination that an increase in the operating speed (RPMs) of one or more PD pumps 270 is necessary to correct the pressure deviation (e.g., that the RPMs of a PD pump 270 be increased to/by a particular RPMs). Additionally or alternatively, that a decrease in the operating speed (RPMs) of one or more PD pumps 270 is necessary to correct the pressure deviation (e.g., that the RPMs of a PD pump be decreased to/by a particular RPMs). Additionally or alternatively, that a positive shift in the orientation of one or more PD pumps 270 is necessary to correct the pressure deviation (e.g., that the angular orientation of a PD pump 270 be increased by a particular angle). Additionally or alternatively, that a negative shift in the angular orientation of one or more PD pumps 270 is necessary to correct the pressure deviation (e.g., that the orientation of a PD pump 270 be decreased by a particular angle).

[0043] Thus, as discussed above, depending upon the configuration of pump management system 400, either multiple pump controller 403 or application controller 401, will determine the need for a change in the operating parameter of the one or more PD pumps 270 and output a signal directing local pump controller 410 to produce a change in engine 376 RPM and thereby a change in PD pump 270 operation. The resulting change in angular orientation of PD pump 270 will maintain non-coincidental operation of PD pumps 270 thereby minimizing or eliminating pressure spikes in pressure side manifold 250 and subsequent downstream conduits.

[0044] The configuration of pump management system 400 depicted in FIGS. 3A and 3B provides several backup operational modes. As depicted in FIG. 3A, each truck 280 operates independently with PD pump 270 for each truck controlled by application controller 401 as discussed above. Thus, to achieve non-coincidental PD pump 270 operation application controller 401 may alter engine RPM in two or more trucks 280. However, each local pump controller 410 may also be capable of operating as multiple pump controller 403. Therefore, in the event of the failure of multiple pump controller 403, or a failure of data link 187c, a previously designated local pump controller 410 may assume overall control of multiple pump controller 403 of the pump management system 400 as each local pump controller 410 is also in data communication with all other local pump controllers 410 via data link 187c. Thus, in this mode, local pump controller 410 utilizes at least one of: the pressure data, piston position data or other input data, e.g. pump flow rate, in the least mean squared finite impulse response adaptive filter algorithm in the same manner as multiple pump controller 403. Additionally, if one or more local pump controller 410 fails or data link 187c for that local pump controller 410 fails, then the truck 280 associated with that particular local pump controller 410 will continue to function in response to local drivetrain controller 405 and multiple drivetrain controller 402. However, the truck 280 with the failed local pump controller 410 will not be able to manage PD pump 270 in order to maintain non-coincidental operations. Thus, non-coincidental PD pump 270 operation for the overall pump management system 400 must be produced by management of the remaining trucks 280 with operational local pump controller 410. If more than a designated number of local pump controllers 410 fail, then multiple drivetrain controller 402 will assume management of pump management system 400. Thus, pump management system 400 will be able to maintain effective pump control in spite of the failure of one or more local pump controllers 410. In general, if at least 50% of pump trucks 280 systems operate as designed, then non-coincidental pump operation will remain possible. Further, non-coincidental pump operation may be maintained with as few as 35% of pump trucks 280 systems operating as designed. If greater than 50% of pump truck 280 systems fail, then pump control may no longer be effective and the pump management system will revert to the nominal control architecture where only the multiple drivetrain controller 402 and local drivetrain controller 405 are active.

[0045] In another backup operational mode, in the event of a failure, such as loss of a local pump controller 410, each local pump system control 420 may include a pump “enable” signal. The pump enable signal is generated by local drivetrain controller 405. The enable signal provides data necessary for local pump controller 410 to proceed with non-coincidental PD

pump 270 control. In the event of the loss of a local pump controller 410 and the loss of the enable signal, the local pump control operation would cease until one or both abilities are restored.

[0046] FIGS. 4A and 4B depict an alternative embodiment of pump management system 400. This embodiment differs from that of FIGS. 3A and 3B by adding an optional data acquisition (DAQ) system 413 to a combination of local pump controller 410 and local drivetrain controller 405. In this embodiment, the functionality of local drivetrain controller 405 is consolidated into local pump controller 410. Thus, the combination of data acquisition (DAQ) system 413 and local pump controller 410 manages the operation of drivetrain 276 and control of PD pump 270. Additionally, application controller 401 has been modified by combining the functions of multiple pump controller 403 and multiple drivetrain controller 402 into a single centralized controller 404. With regard to the other components of pump management system 400, no other changes have been made and like components have been identified by like numbers.

[0047] Operation of the embodiment of FIGS. 4A and 4B is similar to that of the embodiment depicted in FIGS. 3A and 3B. In the embodiment of FIGS. 4A and 4B, DAQ system 413 receives data from pressure sensor 185 and other pressure or flow sensors, not shown, associated with downstream operations such as wellhead 180. Additionally, DAQ system 413 receives data from piston position sensors, not shown, located on PD pump 270 or alternatively engine piston position information from engine operating data or from transmission sensors, not shown. DAQ system 413 provides the received data directly to local pump truck controller 410 as local pump truck controller 410 is in data communication with application controller 401. Centralized controller 404 receives data from each local pump system control 420 as well as data links 187b and 187c and directs an individual local pump system control 420 to make necessary throttle changes to maintain non-coincidental operation of the PD pump 270 associated with that local pump system control 420. Thus, in the embodiment of FIGS. 4A and 4B, centralized controller 404 uses at least one of: the pressure data, piston position data or other input data, e.g. pump flow rate, in the least mean squared finite impulse response adaptive filter algorithm in the same manner as multiple pump controller 403.

[0048] The embodiment of FIGS. 4A and 4B also provides an alternative operational mode in the event of a failure of either a local pump system control 420, the failure of application controller 401 or data link 187c. In the event of a failure of centralized controller 404, a previously designated local pump controller 410 will assume control of pump management

system 400. To enable this action, the previously designated local drivetrain controller 405 must be programmed with the desired operational parameters for the pumping operation. In the event of a failure of one or more local pump truck control 420, that pump truck 280 will be taken off-line and if possible pumping operations handled by the remaining pump trucks 280. The embodiment of FIGS. 4A and 4B simultaneously provide nominal pump truck control and manage operation of PD pumps 270 to ensure non-coincidental PD pump 270 operation occurs during all normal operational conditions.

[0049] With continued reference to FIGS. 4A and 4B, the support functionality of DAQ 413 provides the ability to simultaneously monitor the operational condition of the components making up pump truck 280. Thus, DAQ 413 can be used as a monitoring system. The monitoring system functionality provides the ability to verify that non-coincidental pump operation has reduced drivetrain stresses by monitoring vibrations in pressure flowlines 290 and conduit 190. Thus, the monitoring system can verify reduction in high-pressure dynamics experienced by pump management system 400. The data links used to provide information to and from local pump truck control 420 and DAQ 413, as described above, can also be used to convey information necessary to permit use of DAQ 413 as a monitoring system.

[0050] Other embodiments of the current invention will be apparent to those skilled in the art from a consideration of this specification or practice of the invention disclosed herein. Thus, the foregoing specification is considered merely exemplary of the current invention with the true scope thereof being defined by the following claims.

CLAIMS

What is claimed is:

1. A system comprising:
 - a fluid source;
 - at least one supply flowline in fluid communication with the fluid source;
 - at least two positive displacement pumps, each of the positive displacement pumps having a fluid input and a fluid output, the fluid input of each positive displacement pump in fluid communication with the supply flowline;
 - each of said positive displacement pumps driven by a prime mover;
 - at least one pressure flowline in fluid communication with the fluid output of each positive displacement pumps;
 - a manifold having an inlet in fluid communication with the at least one pressure flowline, said manifold having an outlet;
 - a conduit in fluid communication with the manifold outlet;
 - at least one sensor configured to measure an operational condition of said positive displacement pump and output a data signal indicative of the measured condition, said at least one sensor positioned at least at one of the following locations: in the at least one pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, any connection between the manifold and conduit in fluid communication with the manifold outlet, and on said positive displacement pump;
 - a pump management system configured to receive and transmit data and said pump management system configured to receive data from said at least one sensor;
 - said pump management system also configured to control at least two prime movers;
 - at least one first data link providing data communication between said at least one sensor and said pump management system, said first data link providing said data signal to said pump management system;
 - at least one second data link providing data communication between said pump management system and said prime mover;
 - said pump management system further configured to use said data signal to manage operation of each prime mover to maintain non-coincidental operation of said positive displacement pumps.
2. The system of claim 1, wherein said at least one sensor is selected from the group consisting of: pressure sensors, piston position sensors and fluid flow rate sensors.

3. The system of claim 1, wherein said system comprises at least one pressure sensor and at least one piston position sensor and wherein said pump management system uses both said signal corresponding to piston position and said pressure signal to manage operation of each prime mover to maintain non-coincidental operation of said positive displacement pumps.
4. The system of claim 1, wherein said pump management system is configured to implement a least mean squared (LMS) finite impulse response adaptive filter to maintain non-coincidental operation of said positive displacement pumps.
5. The system of claim 1, wherein said pump management system comprises:
 - a multiple pump controller configured to receive and transmit data;
 - a multiple drivetrain controller configured to receive and transmit data;
 - and,
 - at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;
 - said local pump system control comprising:
 - a local engine controller configured to receive and transmit data;
 - a local pump controller configured to receive and transmit data; said local pump controller and said local engine controller are in data communication within one another;
 - said multiple engine controller and said multiple pump controller are in data communication;
 - said multiple engine controller is in data communication with each local engine controller;
 - said multiple pump controller is in data communication with each local pump controller.
6. The system of claim 5, wherein said multiple engine controller is configured to receive data and to direct at least one local pump system to change operation of at least one engine monitored and managed by said local pump system.
7. The system of claim 1, wherein said pump management system comprises:
 - a centralized controller configured to receive and transmit data; and,
 - at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;

said local pump system control comprising:

a data acquisition system configured to receive data, said data acquisition system in data communication with a local pump controller configured to receive and transmit data;

said local pump controller and said centralized controller are in data communication within one another.

8. A system comprising:

a fluid source;

at least one supply flowline in fluid communication with the fluid source;

at least two positive displacement pumps, each of the positive displacement pumps having a fluid input and a fluid output, the fluid input of each positive displacement pump in fluid communication with the supply flowline;

each of said positive displacement pumps driven by a prime mover;

at least one pressure flowline in fluid communication with the fluid output of each positive displacement pumps;

a manifold having an inlet in fluid communication with the at least one pressure flowline, said manifold having an outlet;

a conduit in fluid communication with the manifold outlet;

at least one pressure sensor configured to measure pressure and output a pressure signal indicative of the measured pressure, said at least one pressure sensor positioned at least at one of the following locations: in the at least one pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, and any connections there-between;

a pump management system configured to receive and transmit data and said pump management system configured to receive fluid pressure data from said at least one pressure sensor;

said pump management system also configured to control each prime mover;

at least one first data link providing data communication between said at least one pressure sensor and said pump management system, said first data link provide said pressure signal to said pump management system;

at least one second data link providing data communication between said pump management system and said prime mover;

said pump management system further configured to use said pressure signal to manage operation of each prime mover to maintain non-coincidental operation of said positive displacement pumps.

9. The system of claim 8, wherein said positive displacement pump has at least one piston and further comprising:

a second data link;

a piston position sensor configured to determine when said at least one piston is at top dead center, said piston position sensor transmitting a signal corresponding to top dead center for said at least one piston to said pump management system, wherein said pump management system uses either or both said signal corresponding to top dead center and said pressure signal to manage operation of each prime mover to maintain non-coincidental operation of said positive displacement pumps.

10. The system of claim 8, wherein said pump management system is configured to implement a least mean squared (LMS) finite impulse response adaptive filter to maintain non-coincidental operation of said positive displacement pumps.

11. The system of claim 8, wherein said pump management system comprises:

a multiple pump controller configured to receive and transmit data;

a multiple drivetrain controller configured to receive and transmit data;

and,

at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;

said local pump system control comprising:

a local engine controller configured to receive and transmit data;

a local pump controller configured to receive and transmit data; said local pump controller and said local engine controller are in data communication within one another;

said multiple engine controller and said multiple pump controller are in data communication;

said multiple engine controller is in data communication with each local engine controller;

said multiple pump controller is in data communication with each local pump controller.

12. The system of claim 11, wherein said multiple engine controller is configured to receive data and to direct at least one local pump system to change operation of at least one engine monitored and managed by said local pump system.

13. The system of claim 8, wherein said pump management system comprises:
- a centralized controller configured to receive and transmit data; and,
 - at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;
- said local pump system control comprising:
- a data acquisition system configured to receive data, said data acquisition system in data communication with a local pump controller configured to receive and transmit data;
 - said local pump controller and said centralized controller are in data communication within one another.
14. A system comprising:
- a fluid source;
 - at least one supply flowline in fluid communication with the fluid source;
 - at least two positive displacement pumps, each of the positive displacement pumps having a fluid input and a fluid output, the fluid input of each positive displacement pump in fluid communication with the supply flowline;
 - each of said positive displacement pumps driven by a prime mover;
 - at least one pressure flowline in fluid communication with the fluid output of each positive displacement pumps;
 - a manifold having an inlet in fluid communication with the at least one pressure flowline, said manifold having an outlet;
 - a conduit in fluid communication with the manifold outlet;
 - at least one piston position sensor configured to monitor at least one piston of said positive displacement pump and output a signal indicative of the piston position;
 - a pump management system configured to receive and transmit data and said pump management system configured to receive piston position data from said at least one piston position sensor;
 - said pump management system also configured to control each prime mover;
 - at least one first data link providing data communication between said at least one piston position sensor and said pump management system, said first data link provide said data signal to said pump management system;
 - at least one second data link providing data communication between said pump management system and said prime mover;

said pump management system further configured to use said data signal to manage operation of each prime mover to maintain non-coincidental operation of said positive displacement pumps.

15. The system of claim 14, wherein said positive displacement pump has at least one piston and further comprising:

a second data link;

at least one pressure sensor configured to measure pressure and output a pressure signal indicative of the measured pressure, said at least one pressure sensor positioned at least at one of the following locations: in the at least one pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, and any connections there-between, wherein said pump management system uses either or both said signal corresponding to piston position and said pressure signal to manage operation of each prime mover to maintain non-coincidental operation of said positive displacement pumps.

16. The system of claim 14, wherein said pump management system is configured to implement a least mean squared (LMS) finite impulse response adaptive filter to maintain non-coincidental operation of said positive displacement pumps.

17. The system of claim 14, wherein said pump management system comprises:

a multiple pump controller configured to receive and transmit data;

a multiple drivetrain controller configured to receive and transmit data;

and,

at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;

said local pump system control comprising:

a local engine controller configured to receive and transmit data;

a local pump controller configured to receive and transmit data; said local pump controller and said local engine controller are in data communication within one another;

said multiple engine controller and said multiple pump controller are in data communication;

said multiple engine controller is in data communication with each local engine controller;

said multiple pump controller is in data communication with each local pump controller.

18. The system of claim 17, wherein said multiple engine controller is configured to receive data and to direct at least one local pump system to change operation of at least one engine monitored and managed by said local pump system.

19. The system of claim 14, wherein said pump management system comprises:
a centralized controller configured to receive and transmit data; and,
at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;

said local pump system control comprising:

a data acquisition system configured to receive data, said data acquisition system in data communication with a local pump controller configured to receive and transmit data;

said local pump controller and said centralized controller are in data communication within one another.

20. A system comprising:

a fluid source;

at least one supply flowline in fluid communication with the fluid source;

at least two positive displacement pumps, each of the positive displacement pumps having a fluid input and a fluid output, the fluid input of each positive displacement pump in fluid communication with the at least one supply flowline;

each of said positive displacement pumps driven by an engine;

an electronic control module providing direct control of engine RPM;

at least one pressure flowline in fluid communication with the fluid output of each positive displacement pumps;

a manifold having an inlet in fluid communication with the at least one pressure flowline, said manifold having an outlet;

a conduit in fluid communication with the manifold outlet;

a pump management system configured to control at least two positive displacement pumps and engines, said pump management system comprising:

a multiple pump controller configured to receive and transmit data;

a multiple drivetrain controller configured to receive and transmit data;

and,

at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;

said local pump system control comprising:

a local engine controller configured to receive and transmit data;

a local pump controller configured to receive and transmit data; said local pump controller and said local engine controller are in data communication within one another;

said multiple engine controller and said multiple pump controller are in data communication;

said multiple engine controller is in data communication with each local engine controller;

said multiple pump controller is in data communication with each local pump controller;

at least one pressure sensor configured to measure pressure and output a pressure signal indicative of the measured pressure, wherein said at least one pressure sensor is positioned at least at one of the following locations: in the pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, and any connections there-between;

a data link providing said pressure signal indicative of the measured pressure to said multiple engine controller;

said multiple engine controller configured to receive data and to direct at least one local pump system to change operation of at least one engine monitored and managed by said local pump system;

said multiple engine controller further configured to use said pressure signal to manage operation of each local pump system to maintain non-coincidental operation of said positive displacement pumps.

21. The system of claim 20, wherein at least one local pump controller is configured assume operation of said pump management system if said multiple pump controller fails.

22. A system comprising:

a fluid source;

at least one supply flowline in fluid communication with the fluid source;

at least two positive displacement pumps, each of the positive displacement pumps having a fluid input and a fluid output, the fluid input of each positive displacement pump in fluid communication with the at least one supply flowline;

each of said positive displacement pumps driven by an engine;

an electronic control module providing direct control of engine RPM;

at least one pressure flowline in fluid communication with the fluid output of each positive displacement pumps;

a manifold having an inlet in fluid communication with the at least one pressure flowline, said manifold having an outlet;

a conduit in fluid communication with the manifold outlet;

a pump management system configured to control at least two positive displacement pumps and engines, said pump management system comprising:

a centralized controller configured to receive and transmit data; and,

at least two local pump system controls, each local pump control system control configured to monitor and manage operations of at least one engine and positive displacement pump;

said local pump system control comprising:

a data acquisition system configured to receive data, said data acquisition system in data communication with a local pump controller configured to receive and transmit data;

said local pump controller and said centralized controller are in data communication within one another;

at least one pressure sensor configured to measure pressure and output a pressure signal indicative of the measured pressure, wherein said at least one pressure sensor is positioned at least at one of the following locations: in the pressure flowline, the manifold, the conduit in fluid communication with the manifold outlet, and any connections there-between;

a data link providing said pressure signal indicative of the measured pressure to said multiple engine controller;

said multiple engine controller configured to receive data and to direct at least one local pump system to change operation of at least one engine monitored and managed by said local pump system;

said multiple engine controller further configured to use said pressure signal to manage operation of each local pump system to maintain non-coincidental operation of said positive displacement pumps.

23. The system of claim 22, wherein at least one local pump controller is configured assume operation of said pump management system if said centralized controller fails.

24. A method for non-coincidental operation of positive displacement pumps comprising:

- using a first prime mover to drive a first positive displacement pump at a first pumping rate thereby forcing a fluid through at least a first pressure flowline into a pressure-side manifold;
- using at least one additional prime mover to drive at least one additional positive displacement pump at a first pumping rate thereby forcing a fluid through at least a second pressure flowline into a pressure-side manifold;
- monitoring fluid pressure at least one of the following locations: in said at least a first pressure flowline, in said at least a second pressure flowline, the pressure-side manifold and any connections there-between;
- transmitting fluid pressure data concerning the monitored fluid pressure to a pump management system, said pump management system configured to control each prime mover and to receive fluid pressure data;
- said pump management system using said fluid pressure data to determine the degree of coincidental operation of said first positive displacement pump and said at least one additional positive displacement pump;
- maintaining substantially non-coincidental operation of said first positive displacement pump and said at least one additional positive displacement pump by transmitting a signal from said pump management system to said first prime mover or to said at least one additional prime mover thereby changing the driving operation of said first positive displacement pump or said at least one additional positive displacement pump to a second pumping rate;
- maintaining the second pumping rate until said pump management system receives transmitted fluid pressure data reflecting substantially non-coincidental operation of said first positive displacement pump and said at least one additional positive displacement pump.

25. A method for non-coincidental operation of positive displacement pumps comprising:

- using a first prime mover to drive a first positive displacement pump at a first pumping rate thereby forcing a fluid through at least a first pressure flowline into a pressure-side manifold, said positive displacement pump having at least one piston;
- using at least one additional prime mover to drive at least one additional positive displacement pump at a first pumping rate thereby forcing a fluid through at least a second pressure flowline into a pressure-side manifold, said positive displacement pump having at least one piston;

monitoring piston position or monitoring fluid pressure at least one of the following locations: in said at least a first pressure flowline, in said at least a second pressure flowline, the pressure-side manifold and any connections there-between;

transmitting at least one data signal reflecting either the piston position or the monitored fluid pressure to a pump management system, said pump management system configured to control each prime mover and to receive fluid pressure data;

said pump management system using said data to determine the degree of coincidental operation of said first positive displacement pump and said at least one additional positive displacement pump;

maintaining substantially non-coincidental operation of said first positive displacement pump and said at least one additional positive displacement pump by transmitting a signal from said pump management system to said first prime mover or to said at least one additional prime mover thereby changing the driving operation of said first positive displacement pump or said at least one additional positive displacement pump to a second pumping rate;

maintaining the second pumping rate until the data signal transmitted to said pump management system reflects substantially non-coincidental operation of said first positive displacement pump and said at least one additional positive displacement pump.

1/10

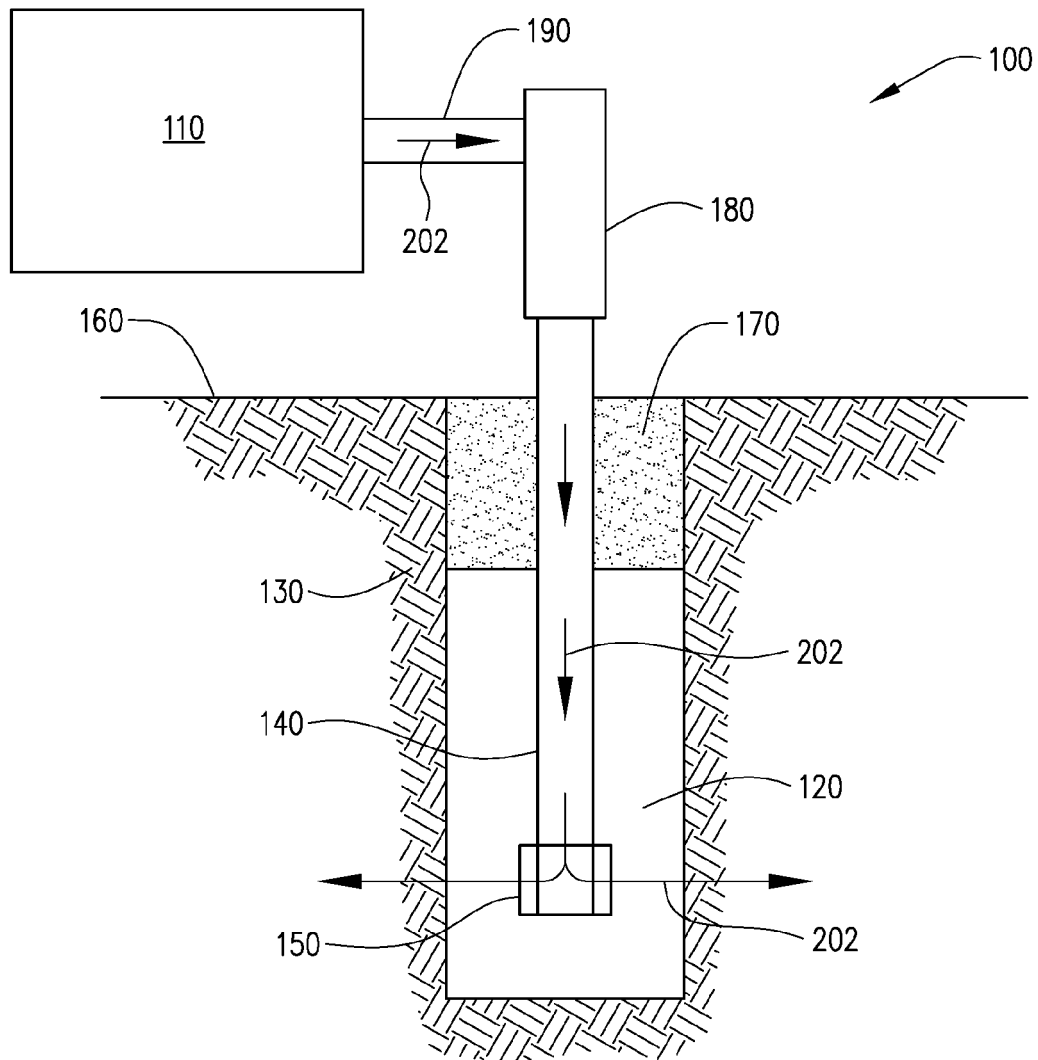


FIG. 1

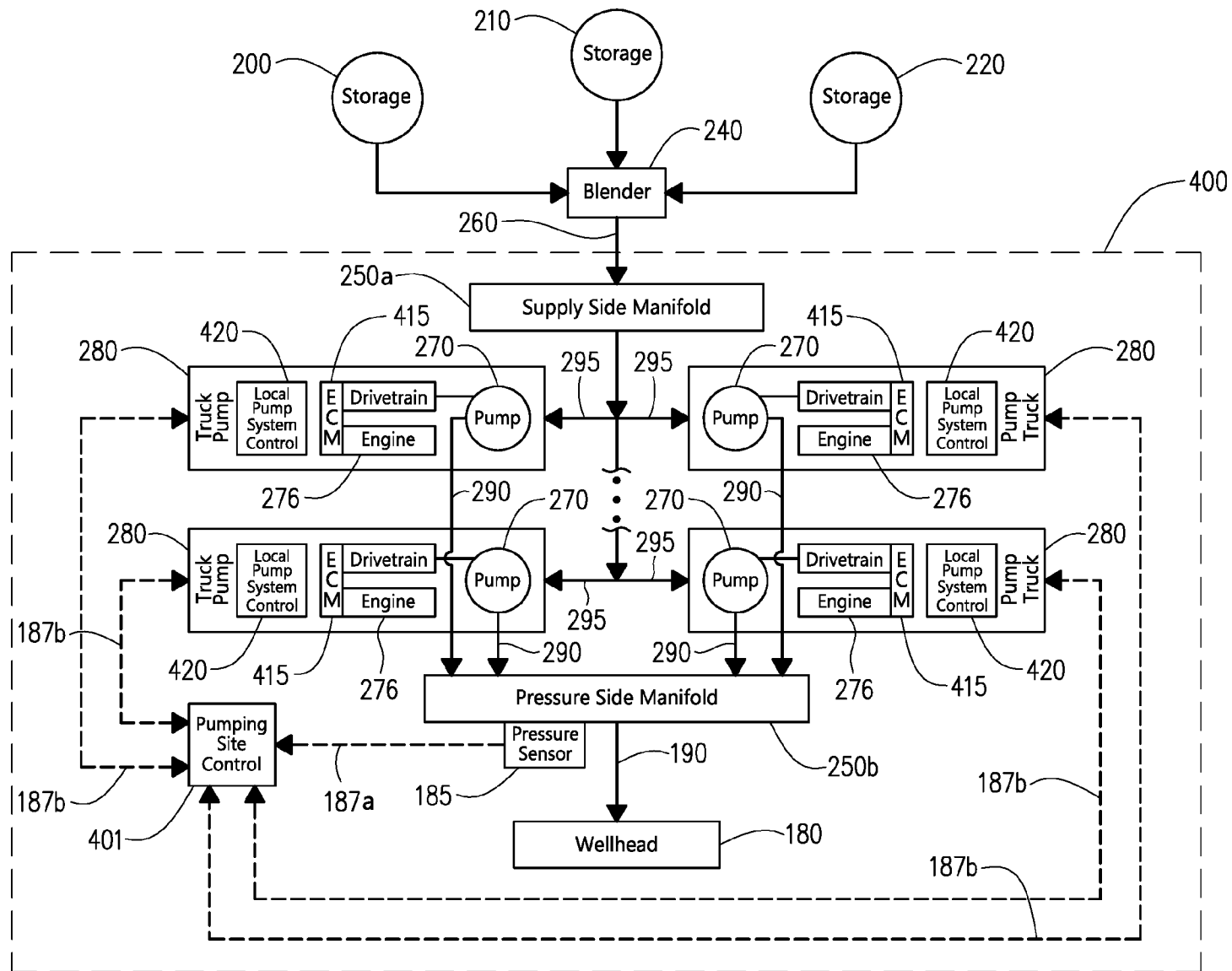


FIG. 2

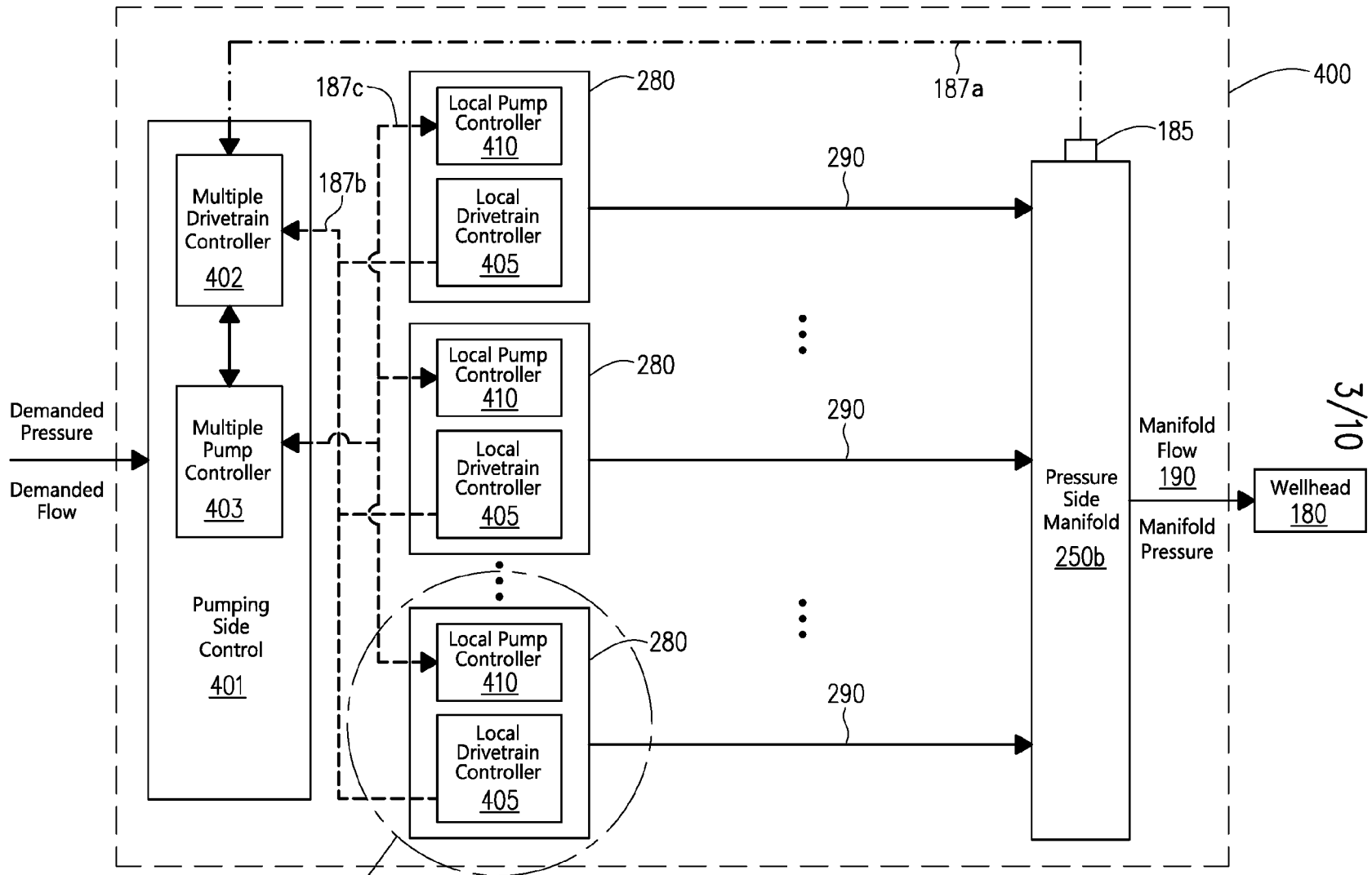


FIG. 3B

FIG. 3A

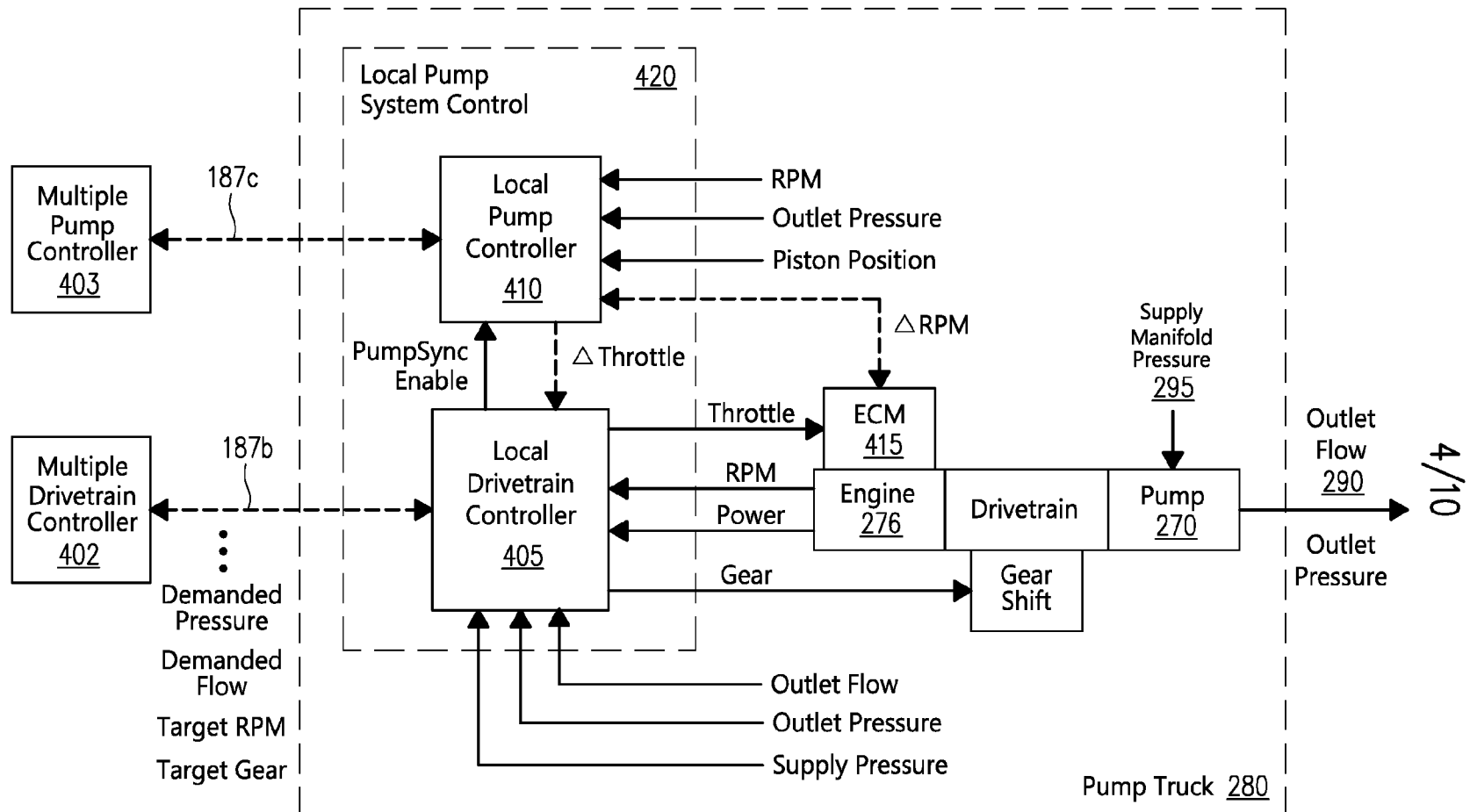
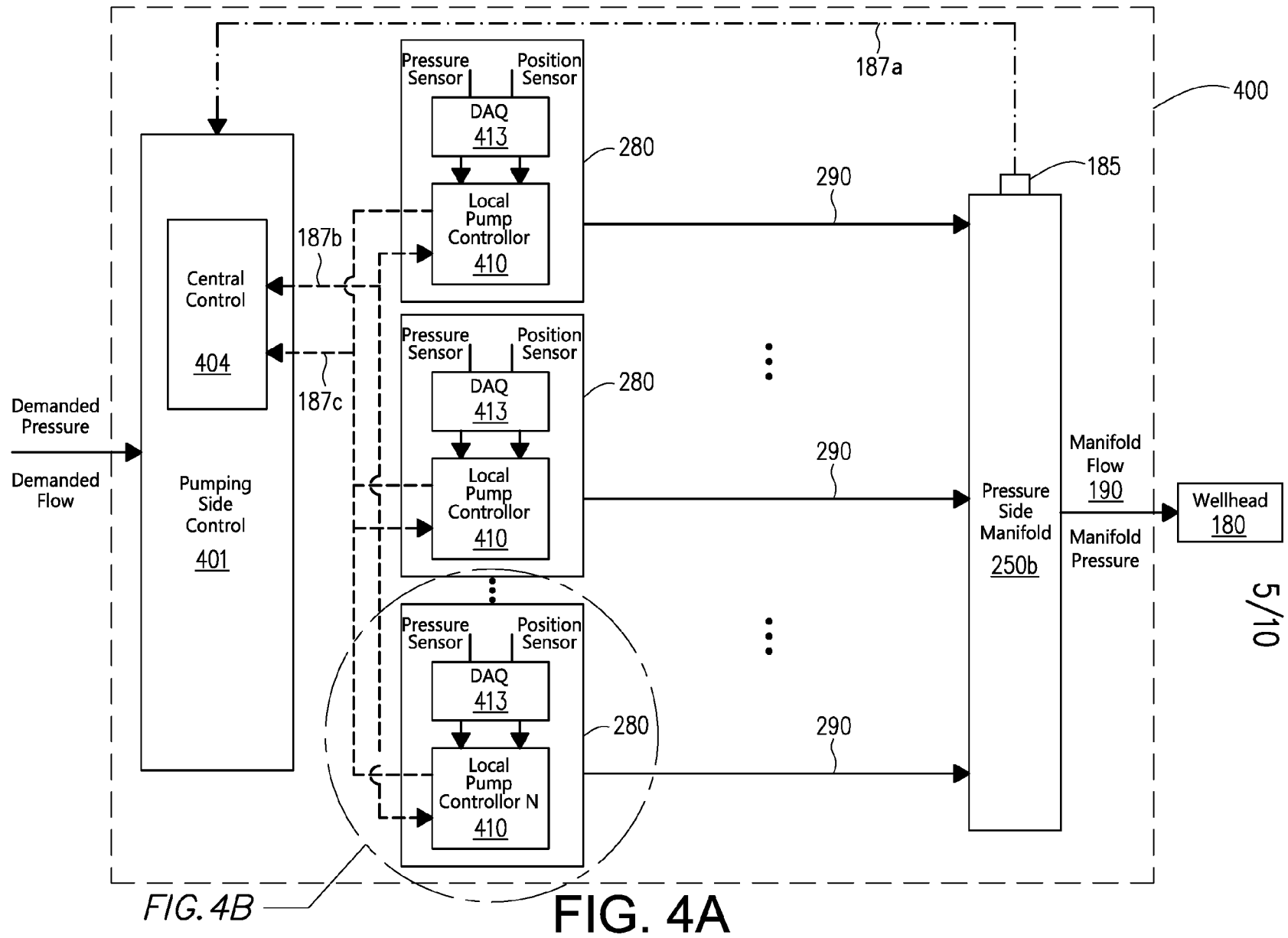


FIG. 3B



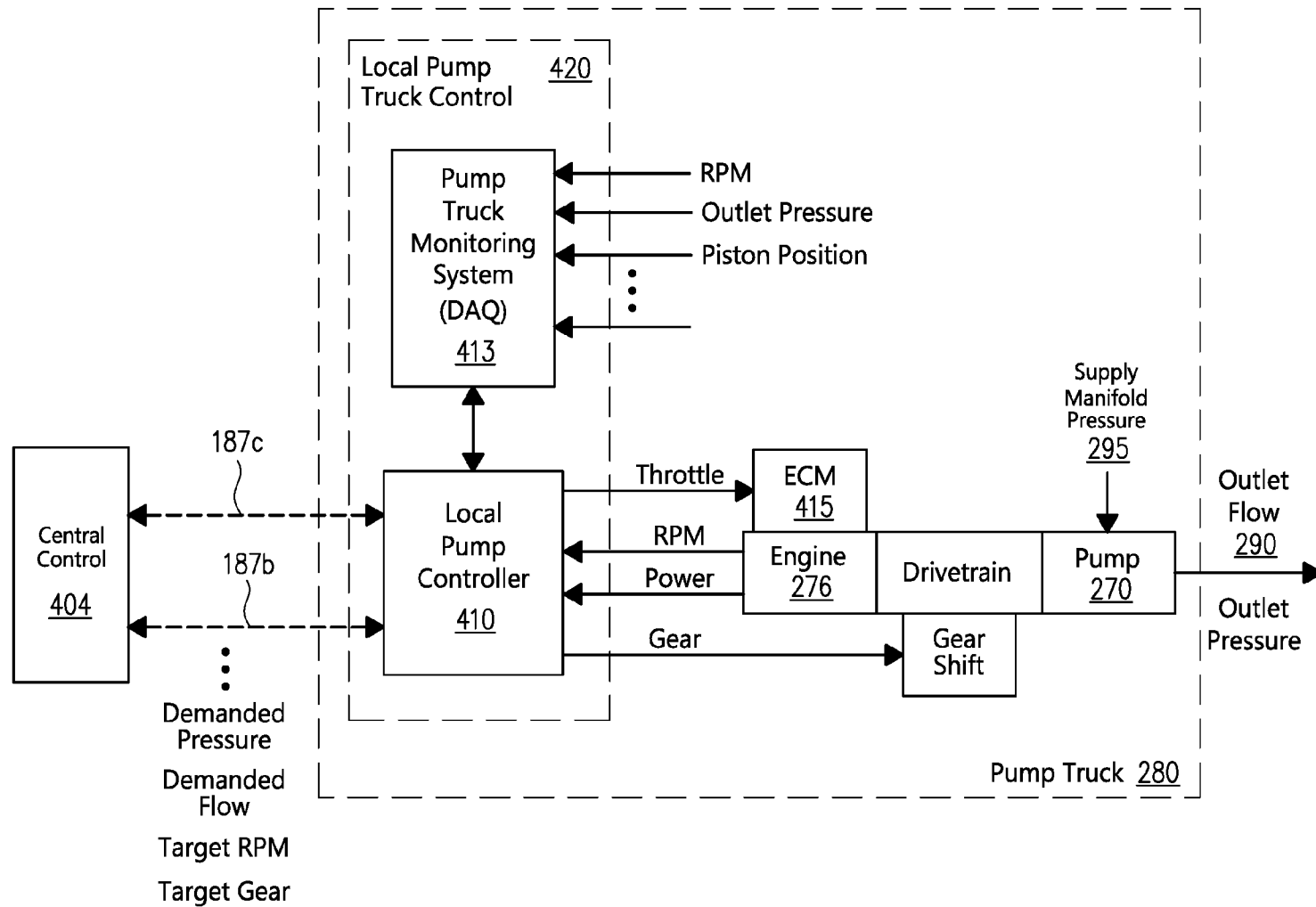


FIG. 4B

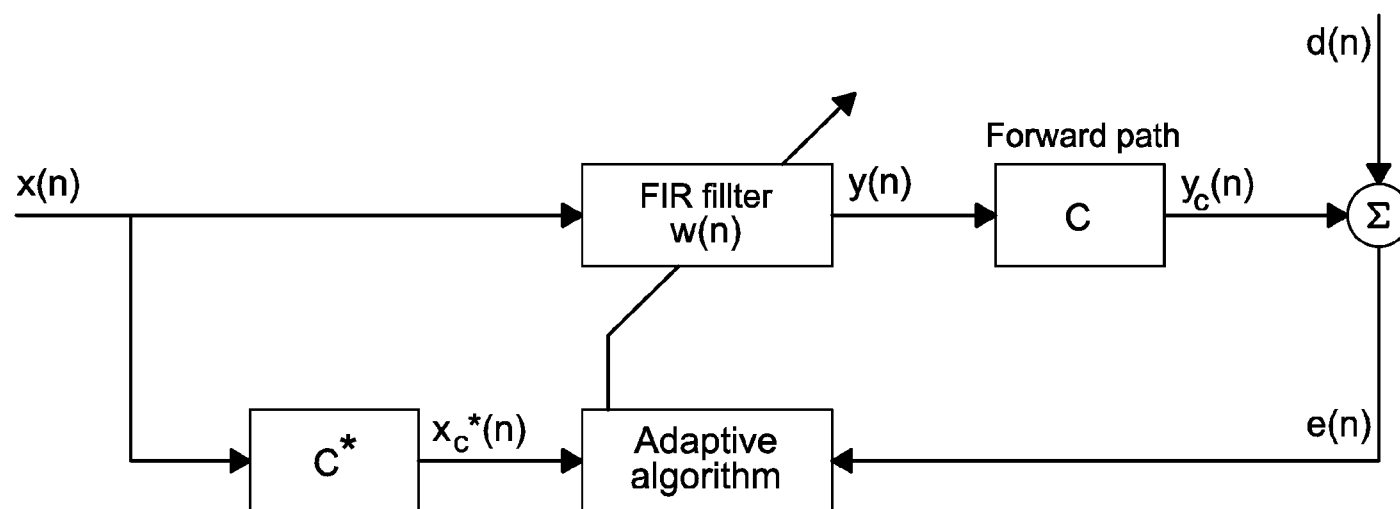


FIG. 5
PRIOR ART

7/10

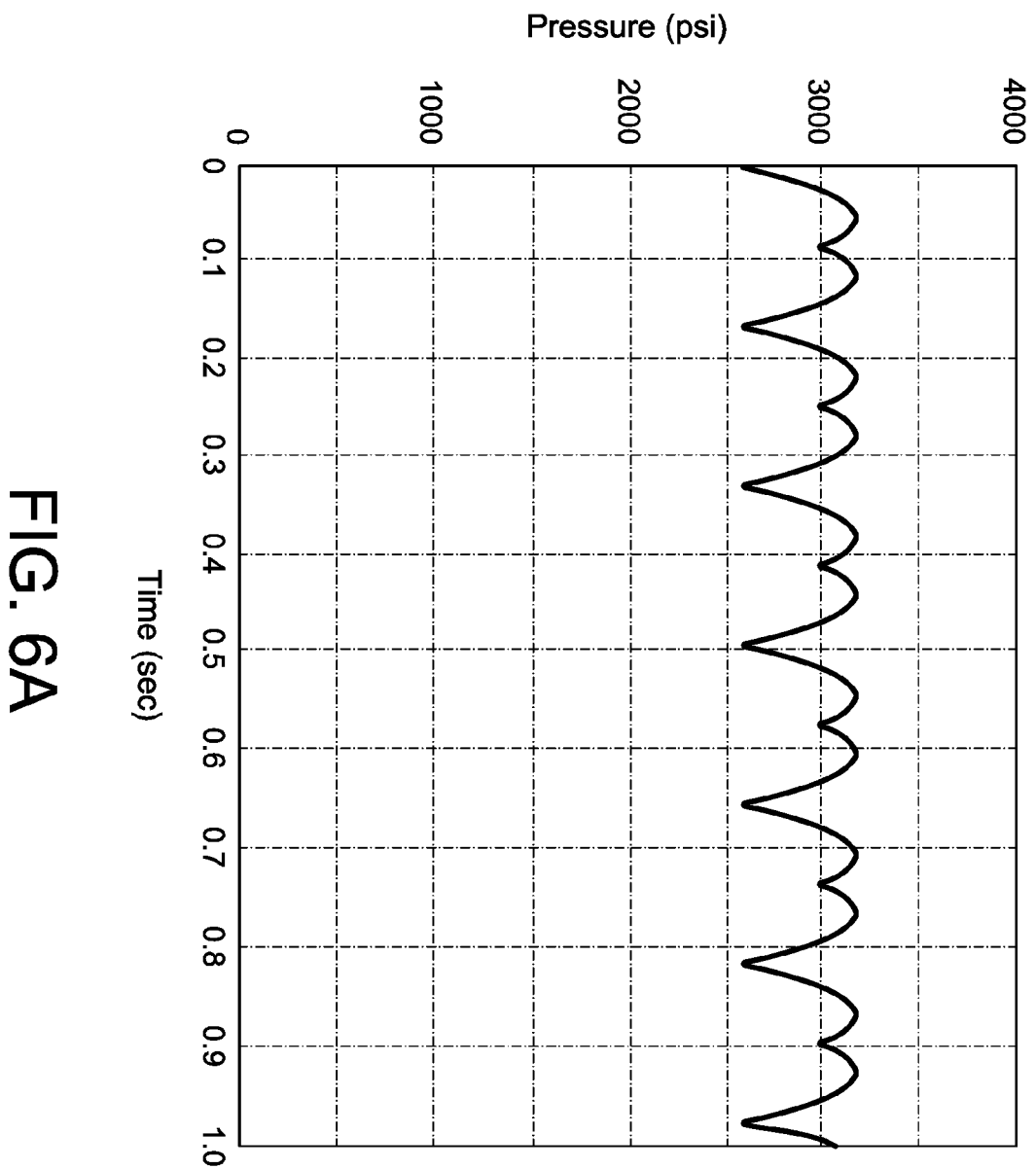


FIG. 6A

8/10

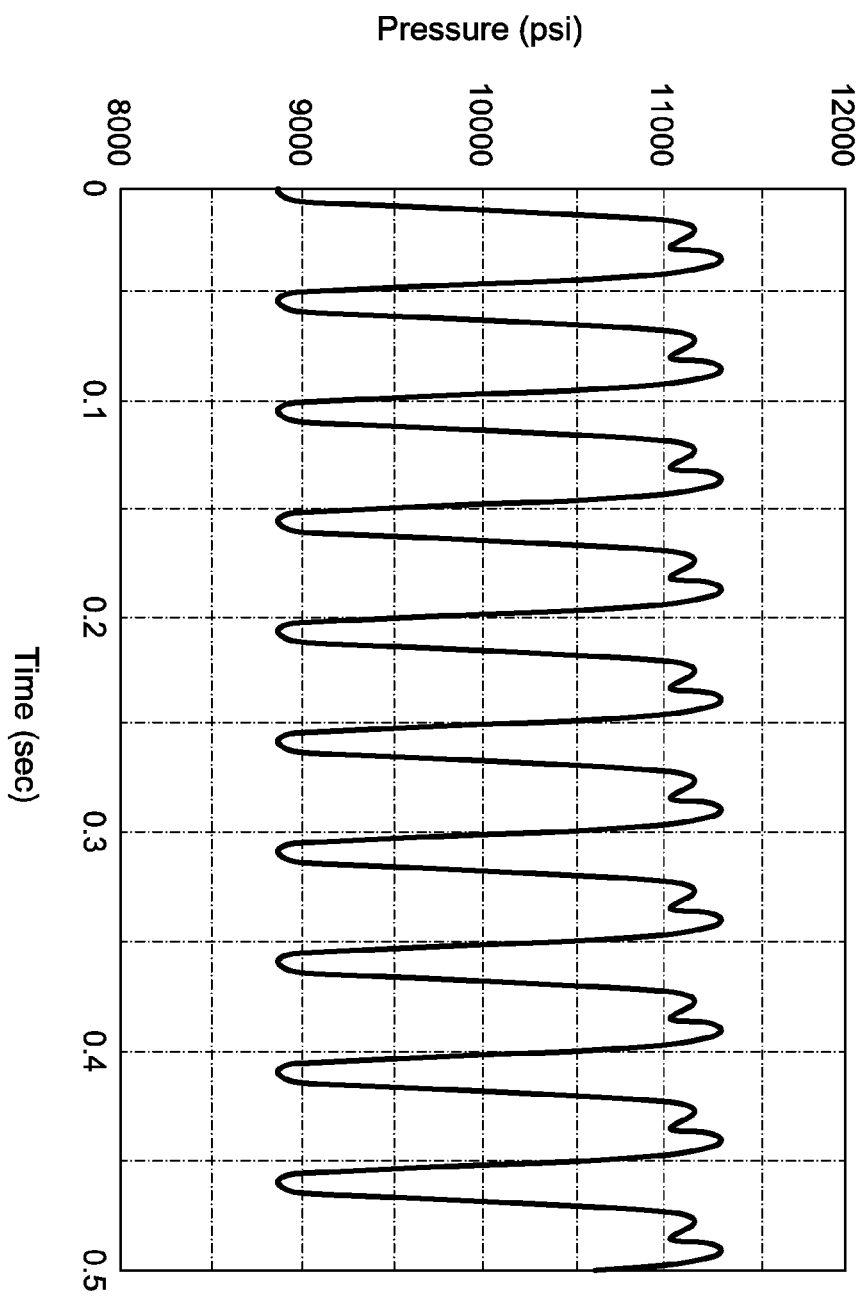


FIG. 6B

9/10

10/10

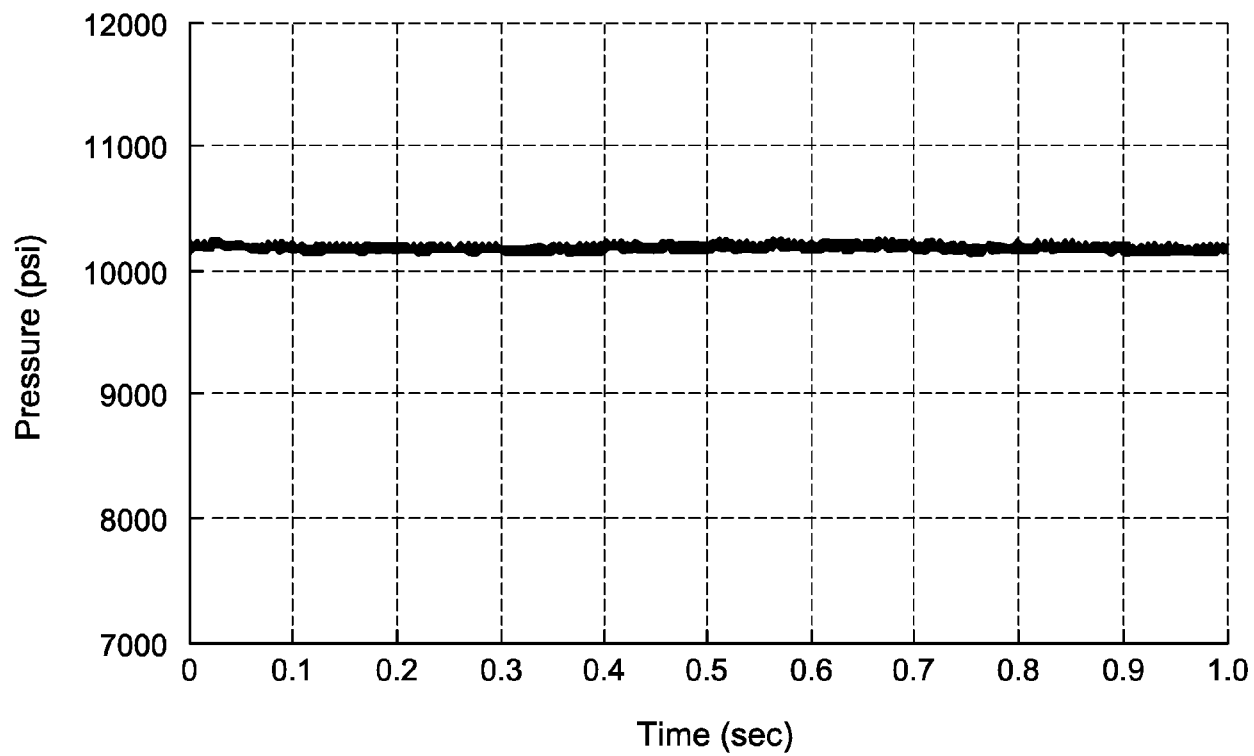


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/050103

A. CLASSIFICATION OF SUBJECT MATTER

INV. F04B11/00 F04B23/02 F04B49/02 F04B49/06 F04B49/08
ADD.

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)

F04B

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)

EP0-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/065304 A1 (MELOCHE JOSEPH L [US] ET AL) 22 March 2007 (2007-03-22) abstract; figures 11,12 paragraphs [0004], [0026] - [0036]; claims 1,2,12,19 -----	1-25
X	US 2010/310384 A1 (STEPHENSON STANLEY V [US] ET AL) 9 December 2010 (2010-12-09) abstract; figure 1 paragraphs [0060], [0068] - [0074]; claims 24-30 -----	1-25
A	US 4 584 654 A (CRANE HAROLD E [US]) 22 April 1986 (1986-04-22) abstractcolumn 5, lines 50-65; figures -----	1-25

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

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Information on patent family members

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