HYDRAULIC SYSTEM HAVING DIAGNOSTIC MODE OF OPERATION

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Publication Classification

400 - RE receipt INPUT INDICATIVE OF DIAGNOSTIC CHECK START?
410 - INSTRUCT OPERATOR TO CHANGE MACHINE PARAMETERS
415 - SENSE PERFORMANCE
420 - VALUE OF SENSED PERFORMANCE WITHIN ACCEPTABLE TOLERANCE OF EXPECTED PERFORMANCE VALUE?
425 - LEVEL I, LEVEL II, OR LEVEL III DEVIATION?
430 - INSTRUCT OPERATOR TO SHUT DOWN MACHINE IMMEDIATELY
435 - INSTRUCT OPERATOR TO COMPLETE SHIFT AND MOVE MACHINE TO REPAIR FACILITY
440 - RECOMMEND SPECIFIC REPAIR AT NEXT SERVICE INTERVAL
445 - COMPLETE DIAGNOSTIC CHECK WITHOUT FLAG

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ABSTRACT

A hydraulic system is disclosed for use with a machine. The hydraulic system may have an actuator, a valve associated with the actuator, at least one sensor configured to generate signals indicative of performance parameters of the hydraulic system, and a controller. The controller may be configured to determine at least one of a diagnostic movement and position of at least one of the fluid actuator and valve required to perform a health check, and to correlate the signals generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and valve are in the diagnostic position to values of the performance parameters. The controller may also be configured to make a comparison of the values of the performance parameters to expected values, and to determine a health of the hydraulic system based on the comparison.

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FIG. 4
FIG. 5

COMPLETE DIAGNOSTIC CHECK WITHOUT FLAG

540

YES

535

NO

VALUE OF SENSE PERFORMANCE WITHIN ACCEPTABLE TOLERANCE OF EXPECTED PERFORMANCE VALUE?

520

YES

NO

LEVEL I OR LEVEL III

LEVEL II

LEVEL III

515

510

505

500

DETERMINE DIAGNOSTIC CHECKS ASSOCIATED WITH POSSIBLE MALFUNCTION

515

YES

NO

CURRENT PARAMETERS WITHIN DIAGNOSTIC TESTING RANGE?

520

YES

NO

SENSE PERFORMANCE

535

525

RETURN FACTORY EXPECTED DEVIATION COEFFICIENT SHIFTS

550

EVE SCHEULERE SPECIFIC

REPAIR NEXT SERVICE COPEAT

550

INDICATIVE OF POSSIBLE MALFUNCTION?

540

NOT RECEIVED

545

540

536

535

MOVE MACHINE TO REPAIR FACILITY AT COMPLETION OF SHIFT

SCHEDULE SPECIFIC REPAIR AT NEXT INTERVAL

REPAIR AT NEXT SHIFT

SHUTDOWN MACHINE
600
MACHINE ON

605
CURRENT MACHINE PARAMETERS WITHIN DIAGNOSTIC TESTING RANGE?

610
YES

615
VALUE OF SENSED PERFORMANCE WITHIN ACCEPTABLE TOLERANCE OF EXPECTED PERFORMANCE VALUE?

620
NO

LEVEL I, LEVEL II, OR LEVEL III DEVIATION?

625
LEVEL III
INSTRUCT OPERATOR TO SHUT DOWN MACHINE IMMEDIATELY

630
LEVEL II
INSTRUCT OPERATOR TO COMPLETE SHIFT AND MOVE MACHINE TO REPAIR FACILITY

635
LEVEL I
RECOMMEND SPECIFIC REPAIR AT NEXT SERVICE INTERVAL

640
YES
COMPLETE DIAGNOSTIC CHECK WITHOUT FLAG

FIG. 6
HYDRAULIC SYSTEM HAVING DIAGNOSTIC MODE OF OPERATION

TECHNICAL FIELD

[0001] The present disclosure relates generally to a hydraulic system and, more particularly, to a hydraulic system having a diagnostic mode of operation.

BACKGROUND

[0002] Hydraulically operated machines, such as excavators, loaders, dozers, motor graders, and other types of heavy equipment, have multiple actuators (e.g., cylinders, motors, fans, brakes, etc.) connected to move the machines. High-pressure fluid is directed from one or more pumps on each machine to the actuators via corresponding valves. Each of the pumps, actuators, valves, and associated conduits and seals can wear over time and/or be damaged by operation of the machine within its normal environment. When these components wear or are damaged, operation of the machine degrades. For example, the machines may operate with less power, less speed, lower range of motion, lower efficiency, less stability, and/or less control when the hydraulic components are worn or damaged. In addition, excessive wearing of one hydraulic component (e.g., a pump) could result in catastrophic damage to the remaining hydraulic components, if the wear is not addressed in a timely manner. For this reason, it can be important to monitor a health of the components and quickly address any component issues in order to maintain the machines at a desired operating level.

[0003] Historically, hydraulic component health was monitored manually during periodic or as-needed checks by a technician. In particular, at a particular service interval or when malfunction of a particular component was suspected, the technician would have been called out to visit a particular machine. During the visit, the technician would connect one or more sensors to suspected circuits of the machine, monitor parameters (e.g., pressure, speed, range of motion, etc.) during particular movements of the machine, and then compare the monitored parameters to threshold ranges or values. If a significant deviation between the monitored and threshold parameter values existed, it could be concluded that a component was worn or damaged and was in need of repair.

[0004] Although perhaps acceptable in some situations, the historical method of component health monitoring may also be problematic. In particular, it may be difficult and time-consuming for the technician to know what sensors are appropriate to use in a particular situation, and for the technician to properly connect the sensors at the correct locations within the suspect circuit. In addition, the technician may be required to know the appropriate conditions under which parameter monitoring should be performed (e.g., temperature, machine kinematics and positions, movement speeds and loads, etc.), and to know the corresponding expected performance ranges or threshold values. The technician may then be required to perform comparison calculations and to judge a severity of a resulting deviation, which can be subject to the technician’s training and experience, the machine’s age and environment, and other similar factors. Accordingly, the historical process may be slow and expensive, and provide opportunity for error.

[0005] One attempt to address the issues discussed above is disclosed in U.S. Pat. No. 7,204,138 (the ’138 patent) by Du that issued on Apr. 17, 2007. In particular, the ’138 patent discloses a health indicator for a hydraulic system having a pump, a sump, a cylinder, and a valve connecting the cylinder to the pump and the sump. The health indicator includes a pump discharge pressure sensor, a swash plate angle sensor, a pump speed sensor, a head-end pressure/speed sensor, a rod-end pressure/position/speed sensor, and a controller. The controller is configured to compute, based on signals received from the sensors in real time during normal operation, an effective bulk modulus of the pump, aeration of the hydraulic system, and/or a cavitation condition of the pump. The controller is further configured to compare the effective bulk module, aeration, and/or cavitation condition to predetermined conditions stored within a health database. From this comparison, the controller determines a relative operating health of the hydraulic system. Based on the relative operating health of the hydraulic system, maintenance operations and repairs can be made to prevent catastrophic failure or before substantial deterioration of the system can occur.

[0006] Although the health indicator of the ’138 patent may be helpful in determining when a pump malfunction exists, it may be limited. In particular, the health indicator may do little to determine when a non-pump malfunction exists. In addition, there may be times when machine conditions are unfavorable for health checking, and the health indicator of the ’138 patent may be unable to account for these times. Further, the health indicator may provide only an indication as to proper or improper pump operation, which may still require some subjective judgment from the technician regarding how to address the operation.

[0007] The disclosed hydraulic system is directed to overcoming one or more of the problems set forth above and/or other problems of the prior art.

SUMMARY

[0008] One aspect of the present disclosure is directed to a hydraulic system. The hydraulic system may include a fluid actuator, a valve associated with the fluid actuator, at least one sensor configured to generate a signal indicative of a performance parameter of the hydraulic system, and a controller in communication with the at least one sensor. The controller may be configured to determine at least one of a diagnostic movement and a diagnostic position of at least one of the fluid actuator and the valve required to perform a health check of the hydraulic system, and to correlate the signal generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and the valve are in the diagnostic position to a value of the performance parameter. The controller may also be configured to make a comparison of the value of the performance parameter to an expected value, and to determine a health of the hydraulic system based on the comparison.

[0009] Another aspect of the present disclosure is directed to a method of determining a health of a hydraulic system having an actuator and a valve associated with the actuator. The method may include generating a signal indicative of a performance parameter of the hydraulic system, and determining at least one of a diagnostic movement and a diagnostic position of at least one of the fluid actuator and the valve required for diagnosing the health of the hydraulic system. The method may also include correlating the signal generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and
the valve are in the diagnostic position to a value of the performance parameter. The method may further include making a comparison of the value of the performance parameter to an expected value, and determining the health of the hydraulic system based on the comparison.

Yet another aspect of the present disclosure is directed to a machine. The machine may include a frame, a power source mounted to the frame, a linkage arrangement, and an actuator configured to move the linkage arrangement. The machine may also include a pump, a sump, and a valve disposed between the actuator, the pump, and the sump. The machine may further include a plurality of sensors configured to generate signals indicative of performance parameters of the machine, and a controller in communication with the plurality of sensors. The controller may be configured to receive input indicative of a suspected hydraulic component malfunction, and to determine at least one of a diagnostic movement and a diagnostic position of at least one of the fluid actuator and the valve required to perform a health check of the machine based on the suspected hydraulic component malfunction. The controller may also be configured to correlate the signals generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and the valve are in the diagnostic position to values of the performance parameters. The controller may further be configured to determine an age of the machine, to make an age-adjusted comparison of the values of the performance parameters to expected values, and to determine a health of the machine based on the age-adjusted comparison.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0011] FIG. 1 is a diagrammatic illustration of an exemplary disclosed machine in a working environment;

[0012] FIG. 2 is a schematic illustration of an exemplary disclosed hydraulic system associated with the machine of FIG. 1;

[0013] FIG. 3 is a schematic illustration of an exemplary disclosed control valve that may be used in conjunction with the hydraulic system of FIG. 2;

[0014] FIGS. 4, 5, and 6 are flowcharts illustrating exemplary disclosed processes that may be performed by the hydraulic system of FIG. 2.

**DETAILED DESCRIPTION**

[0015] FIG. 1 illustrates an exemplary machine 10 having multiple systems and components that cooperate to excavate and load earth material onto a nearby haul vehicle 12. In the depicted example, machine 10 is a hydraulic excavator. It is contemplated, however, that machine 10 could alternatively embody another type of excavation or material handling machine, such as a backhoe, front shovel, shovel, a motor grader, a dozer, or another similar machine. Machine 10 may include, among other things, a linkage 14 configured to move a work tool 16 between a dig location 18 within a trench or at a pile, and a dump location 20, for example over haul vehicle 12 during a well-known truck loading cycle. Machine 10 may also include an operator station 22 for manual control of linkage 14. It is contemplated that machine 10 may perform both cyclical and non-cyclical operations, including cyclical operations other than truck loading, if desired.

[0016] Linkage 14 may include a plurality of structural links that are pinned to fluid actuators, which generate movements of work tool 16. In the disclosed example, linkage 14 includes a boom 24 that is vertically pivoted relative to a machine frame 26 by one or more boom cylinders 28 (only one shown in FIG. 1), and a stick 30 that is vertically pivoted relative to boom 24 by a stick cylinder 32. Linkage 14 further includes a bucket cylinder 34 that operatively connects work tool 16 to a distal end of stick 30 for use in racking and dumping (i.e., curling) work tool 16. Frame 26 may be pivotally connected to an undercarriage 36 by a swing motor 38, such that frame 26, linkage 14, and work tool 16 may be swung together in a horizontal direction. It is contemplated that a greater or lesser number of fluid actuators may be connected with linkage 14 and/or connected in a manner other than described above, if desired.

[0017] Operator station 22 may be configured to receive input from an operator indicative of a desired work tool and/or machine movement. Specifically, operator station 22 may include one or more interface devices 40 located near an operator seat (not shown). In one example, interface devices 40 are embodied as proportional-type controllers configured to position and/or orient work tool 16 or undercarriage 36 by producing position signals indicative of a desired actuator speeds and/or forces in particular directions. The position signals may be used to actuate any one or more of cylinders 28, 32, 34 and/or swing motor 38.

[0018] It is contemplated that different interface devices 40 may alternatively or additionally be included within operator station 22. These devices may include, for example, wheels, knobs, push-pull devices, switches, pedals, touch-screen monitors, and other devices known in the art. The devices may be used to selectively initiate a mode of operation (e.g., an autonomous control mode), to initiate a function (e.g., a health checking function), and/or to receive training (e.g., to receive instructions and/or recommendations).

[0019] As illustrated in FIG. 2, machine 10 may include a hydraulic system 42 having a plurality of fluid components that cooperate to move work tool 16 (referring to FIG. 1) and machine 10. In particular, hydraulic system 42 may include a first circuit 44 configured to receive a first stream of pressurized fluid from a first source 46, and a second circuit 48 configured to receive a second stream of pressurized fluid from a second source 50. First circuit 44 may include a boom control valve 54, a bucket control valve 56, and a left travel control valve 58 connected to receive the first stream of pressurized fluid in parallel. Second circuit 48 may include a right travel control valve 60, a stick control valve 62, and a swing control valve 63 connected in parallel to receive the second stream of pressurized fluid. It is contemplated that additional control valve mechanisms may be included within first and/or second circuits 44, 48 such as, for example, one or more attachment control valves and other suitable control valve mechanisms.

[0020] The control valves of first and second circuits 44, 48 may be connected to allow pressurized fluid to flow to and drain from their respective actuators via common passageways. Specifically, the control valves of first circuit 44 may be connected to first source 46 by way of a first common supply passageway 66, and to a tank 64 by way of a first common drain passageway 68. The control valves of second circuit 48 may be connected to second source 50 by
way of a second common supply passageway 70, and to tank 64 by way of a second common drain passageway 72.

[0021] Because the elements of boom, bucket, left travel, right travel, stick, and swing control valves 54, 56, 58, 60, 62, 63 may be similar and function in a related manner, only the operation of bucket control valve 56 will be discussed in this disclosure. As shown in FIG. 3, bucket control valve 56 may include a first chamber supply element 56A, a first chamber drain element 56C, a second chamber supply element 56B, and a second chamber drain element 56D. First and second chamber supply elements 56A, 56B may be connected in parallel with fluid passageway 66 to fill their respective chambers with fluid from first source 46, while first and second chamber drain elements 56C, 56D may be connected in parallel with fluid passageway 68 to drain the respective chambers of fluid.

[0022] To retract bucket cylinder 34, first chamber supply element 56A may be moved to allow the pressurized fluid from first source 46 to fill the first chamber of bucket cylinder 34 with pressurized fluid via fluid passageway 66, while second chamber drain element 56D may be moved to drain fluid from the second chamber of bucket cylinder 34 to tank 64 via fluid passageway 68. To extend bucket cylinder 34, second chamber supply element 56B may be moved to fill the second chamber of bucket cylinder 34 with pressurized fluid, while first chamber drain element 56C may be moved to drain fluid from the first chamber of bucket cylinder 34. In some instances, it may also be possible to pass pressurized fluid directly from passage 66 to passage 68 via control valve 54, if desired (e.g., from 56A to 56C or from 56B to 56D), such that no movement of bucket cylinder 34 is realized. This may be done, for example, when a particular combination of functions associated with a particular circuit requires a rate of fluid flow greater than an output capacity of the associated single fluid source, fluid from the other circuit may be diverted to supply the required extra flow.

[0026] In one embodiment, hydraulic system 42 may include a warm-up circuit. That is, the common supply and drain passageways 66, 68 and 70, 72 of first and second circuits 44, 48, respectively, may be selectively communicated via first and second bypass passageways 86, 88 for warm-up and/or other bypass functions. A bypass valve 90 may be located in each of bypass passageways 86, 88 and configured to direct fluid from common supply passageways 66 and 70 to common drain passageways 68 and 72, respectively. It is contemplated that bypass passageways 86, 88 and bypass valves 90 may be omitted, if desired.

[0027] Hydraulic system 42 may also include a controller 92 in communication with operator interface device 40, first and second sources 46, 50, the supply and drain elements of control valves 54-62, combiner valve 84, and bypass valves 90. It is contemplated that controller 92 may also be in communication with other components of hydraulic system 42 such as, for example, first and second bypass elements 74, 76, common main relief element 80, straight travel valve 82, and other such components of hydraulic system 42. Controller 92 may embody a single microcontroller or multiple microcontrollers that include a means for controlling an operation of hydraulic system 42. Numerous commercially available microcontrollers can be configured to perform the functions of controller 92. It should be appreciated that controller 92 could readily be embodied in a general machine microcontroller capable of controlling numerous machine functions. Controller 92 may include a memory, a secondary storage device, a controller, and any other components for running an application. Various other circuits may be associated with controller 92 such as power supply circuitry, signal conditioning circuitry, solenoid driver circuitry, and other types of circuitry.

[0028] One or more maps relating the interface device position signal, actuator velocity, associated flow rates and pressures, and/or valve element and actuator positions may be stored in the memory of controller 92. Each of these maps may include a collection of data in the form of tables, graphs, and/or equations. Controller 92 may be configured to allow the operator to directly modify these maps and/or to select specific maps from available relationship maps stored in the memory of controller 92 to affect fluid actuator motion. It is contemplated that the maps may additionally or alternatively be automatically selectable based on active modes of machine operation.

[0029] In some embodiments, the maps stored in the memory of controller 92 may be modified or adjusted by controller 92 based on an age and/or condition of machine 10 and hydraulic system 42. That is, as machine 10 and hydraulic system 42 age, the relationships between pressures, velocities, flow rates, positions, and cycle times may change naturally due to expected wear of system components. If unaccounted for, the same combination of commands that initially resulted in a desired pressure, velocity, flow rate, position, cycle time, etc., may instead result in something unexpected and/or undesired. Accordingly, controller 92 may be configured to selectively adjust the values stored in the maps by amounts relating to the age of machine 10 and/or hydraulic system 42.
Controller 92 may be configured to receive input from operator interface device 40 and to command operation of control valves 54, 56, 58, 60, 62, 63 in response to the input and the relationship maps described above. Specifically, controller 92 may receive an interface device position signal indicative of a desired velocity of a particular actuator, and reference the selected and/or modified relationship maps stored in the memory of controller 92 to determine operating parameters for each of the corresponding supply and drain elements within control valves 54, 56, 58, 60, 62, 63. The operating conditions may then be commanded of the appropriate supply and drain elements to cause filling of the first or second chambers at a rate that results in the desired work tool movement, position, velocity, and/or force.

When a malfunction of a particular hydraulic system component occurs, fluid flow through hydraulic system 42 may be disrupted. This disruption may be manifest in a number of ways. For instance, one or more actuators and/or valves may move at a speed and/or with a force different than desired or move discontinuously. Resulting pressures, pressure differentials, flow rates, etc. may be lower or higher than normal. Desired positions of the valves and/or actuators may not be achieved. Other unexpected results may also occur. Accordingly, it can be important for the health of hydraulic system 42 to be periodically checked, such that performance of machine 10 may be continuous and reliable. Controller 92 may facilitate these checks by implementing one or more different diagnostic routines, as will be described in more detail below.

In some embodiments, controller 92 may communicate with the operator of machine 10 (e.g., via interface devices 40) to instruct the operator to manually cause movements and/or velocities of particular hydraulic system components that are conducive to the diagnostic routines performed by controller 92 during the health check of hydraulic system 42. For example, during the health check of system 42, controller 92 may be configured to reference one or more of the maps stored in the memory of controller 92 to determine particular positions and/or velocities that should be implemented during a particular one of the diagnostic routines. Controller 92 may then cause corresponding instructions to be shown on a display inside operator station 22, allowing the operator to manually implement the diagnostic positions and/or velocities. Controller 92 may also be configured, in other embodiments, to autonomously cause the particular diagnostic movements and velocities to be implemented, if desired. In yet other embodiments, controller 92 may simply be configured to recognize when the particular diagnostic movements and velocities are occurring naturally during normal operations of machine 10, and then responsively implement the associated diagnostic routines. These processes will be discussed in more detail in the following section, with reference to FIGS. 4-6.

Controller 92 may be configured to monitor the performance of hydraulic system 42 during completion of the diagnostic routines, for example by way of one or more sensors 94. These performance parameters may include, among other things, a time required to complete a particular known cycle (e.g., the truck loading cycle), a position and/or speed of a particular control valve or actuator, a pressure and/or pressure differential at a particular location within system 42, a pump displacement setting, an engine speed, etc. Controller 92 may then compare the monitored performance to age-adjusted expected values or ranges for the same parameters to determine if particular components of hydraulic system 42 are functioning properly.

In the disclosed embodiments of FIGS. 2 and 3, multiple pressure-type sensors 94 are shown. In particular, a first pressure sensor 94 is located to sense a pressure of common supply passage 66 (e.g., an outlet pressure of first source 46), while a second pressure sensor 94 is located to sense a pressure of common drain passage 68. In this manner, controller 92 may be able to calculate a pressure differential across any one or more of hydraulic cylinders 28, 32 and left travel motor 65L, (depending on which actuator is being used at the time of signal generation) based on signals from the first and second pressure sensors 94. Similarly, a third pressure sensor 94 is located to sense a pressure of common supply passage 70 (e.g., an outlet pressure of second source 50), while a fourth pressure sensor 94 is located to sense a pressure of common drain passage 72. In this manner, controller 92 may be able to calculate a pressure differential across any one or more of right travel motor 65R, hydraulic cylinder 34, or swing motor 38 based on signals from the first and second pressure sensors 94. Likewise, one or more pressure sensors 94 may be associated with some or all of control valves 54, 56, 58, 60, 62, 63 (see FIG. 3) or any other valve (e.g., bypass valves 74, 76, main relief valve 80, straight travel valve 82, combiner valve 84, etc.) for similar purposes. It is contemplated that any number of sensors of any type may be utilized and/or placed at different locations within hydraulic system 42, as desired.

FIGS. 4-6 are flowcharts depicting exemplary diagnostic operations of hydraulic system 42. FIGS. 4-6 will be discussed in more detail in the following section to further clarify the disclosed concepts.

INDUSTRIAL APPLICABILITY

The disclosed hydraulic system may be applicable to any machine having fluid components. The disclosed hydraulic system may help to maintain desired operation of the machine through implementation of health checks of the components. The disclosed hydraulic system may also help to diagnose a problem with the components via one or more different diagnostic routines (e.g., a manually triggered routine, an automatically triggered routine, and a continuously operating routine). These routines will now be described in detail with reference to FIGS. 4-6.

The manually triggered routine is shown in FIG. 4. As shown in this figure, the first step of the diagnostic routine may be for controller 92 to receive input from the operator of machine 10 that is indicative of a desire to start a diagnostic check of hydraulic system 42 (Step 400). This input may be generated via manipulation of interface device 40. For example, the operator of machine 10 may manipulate interface device 40 at the start of a shift, at the end of a shift, during a normal maintenance process, when a problem with hydraulic system 42 is suspected, or at any other convenient time.

Once the input from the operator is received, controller 92 may determine if the current operating parameters of machine 10 are within ranges necessary for accurate diagnostic testing to begin (Step 405). In particular, in some embodiments, controller 92 may be able to accurately check the health of machine 10 only when particular circumstances are present. These circumstances can be associated with, among other things, a particular position, orientation, or
movement of a particular valve or actuator, a particular pattern or sequence of movements (e.g., completion of a cycle such as the truck loading cycle), a particular speed of movement; movement under a particular load; movement when hydraulic temperatures and/or pressures are at certain levels; etc. In some embodiments, health checks of different hydraulic system components may require different circumstances to be present, in other embodiments, a circuit-level health check may require the circumstances to change in a particular order and at particular timings, as controller 92 sequentially checks each component within a particular circuit.

Accordingly, depending on the type of diagnostic check that has been requested by the operator, controller 92 may be configured to reference the type of diagnostic check with the maps stored in memory to determine a corresponding circumstance or set of circumstances that should be present during the diagnostic check to produce accurate results. Controller 92 may then instruct the operator of machine 10 to change machine operating parameters to provide the correct set of circumstances (Step 410). For example, controller 92 may cause the map to be displayed within the operator station 22 images, written instructions, and/or verbal instructions telling the operator to raise boom 24 (referring to FIG. 1) to a particular height, at a particular speed, with a particular load, or within a particular period of time; to complete a truck loading cycle; to rack work tool 16; to swing frame 26, etc. In some instances, the instructions may pertain to the simultaneous use of multiple valves and/or actuators. In other instances, however, the instructions may pertain to the independent use of a single valve and/or actuator. By using only a single valve and/or actuator at a time during diagnostic checking, a number of factors influencing hydraulic system performance may be reduced, and the remaining factors may be associated with only the particular valve or actuator being used. In this way, a component or circuit suspected of malfunctioning or failing may be independently tested.

During and/or after operator-caused movements of machine 10 that produce the circumstances required the operator-requested diagnostic check, controller 92 may sense the performance of machine 10 (Step 415). For example, while work tool 16 is being lifted to a particular height (or lifted at a particular velocity, under a particular load, during completion of a particular cycle, etc.) controller 92 may monitor signals (e.g., pressure or pressure differential signals) produced by one or more sensors 94 associated with one or more of the hydraulic system components (e.g., boom control valve 54, boom cylinders 28, first source 46, etc.) being used to do the lifting.

After completion of step 415, controller 92 may be further configured to compare the values of the signals sensed during step 415 to corresponding expected values or ranges to determine if the values are within acceptable tolerances of the expected performance values or ranges (Step 420). For example, controller 92 may compare the pressure differential monitored when lifting work tool 16 during completion of step 415 to an expected pressure differential value or range. The expected performance value and/or range may be stored within the memory of controller 92 for this purpose.

When the comparison made by controller 92 at step 420 shows that the monitored performance of machine 10 is not within an acceptable tolerance of the expected performance value or range, controller 92 may determine a deviation level associated with the results of the comparison (Step 425). In one example, controller 92 is configured to classify a deviation determined at step 420 as a Level I deviation, a Level II deviation, or a Level III deviation. In this example, a Level III deviation may be the most severe deviation possible and often corresponds with a significant failure of hydraulic system 42. In response to a deviation being classified as Level III, controller 92 may instruct the operator to immediately shut down machine 10 in order to prevent further damage of hydraulic system components (Step 430). Controller 92 may provide additional information to the operator regarding the failure, along with recommendations about what repairs should be performed.

A Level II deviation may be less severe than a Level III deviation, but still could result in costly damage to or downtime of machine 10 if not corrected in a timely manner. Accordingly, in response to a deviation being classified as Level II, controller 92 may instruct the operator to complete the current work shift (operation, task, etc.) and then, at a convenient time, to move machine 10 to a repair facility for service to be performed (Step 435). This may allow for the service to be performed at a time when the production of machine 10 will not be significantly impacted, and machine 10 may not be left stranded at a location inconvenient for the repairs to be made. As with a Level III deviation, controller 92 may provide additional information regarding the cause of the Level II deviation, along with recommendations about what repairs should be performed.

A Level I deviation may be less severe than a Level II deviation, but still have a long-term effect on the operating cost and/or profitability of machine 10, if not corrected. Accordingly, in response to a deviation being classified as Level I, controller 92 may recommend to the operator that a specific repair be performed at a next scheduled service interval (Step 440).

Returning to step 420, when machine 10 performs as expected (step 420:Y) and passes the diagnostic health check, controller 92 may complete the process without flagging any kind of failure or repair error (Step 445). This result may be reported to the operator of machine 10, and control may return to step 400.

The automatically triggered routine is shown in FIG. 5. As shown in this figure, the first step of the diagnostic routine may be for controller 92 to receive input that is indicative of a possible malfunction of hydraulic system 42 (Step 500). This input may be generated any time the value of a monitored performance parameter falls outside of an expected range. For example, when a temperature, pressure, cycle time, etc. generated by one or more sensors 94 is too high, too low, or outside of an expected range for an extended period of time, it may be possible for a failure to be the cause. In this situation, controller 92 may be automatically triggered to start a diagnostic routine in order to determine the source of the failure.

Once controller 92 is triggered to initiate a diagnostic routine, controller 92 may determine what diagnostic checks are associated with the possible malfunction (Step 505). In particular, controller 92 may be capable of performing the different diagnostic checks; each associated with a different component and/or circuit. Rather than performing all of the diagnostic checks in response to any sensed abnormality, controller 92 may instead narrow down the different diagnostic checks to a subset of checks associated...
with the particular component or circuit that is suspected of malfunctioning. In this way, a time and cost of the diagnostic checking may be reduced. Controller 92 may reference the abnormal value(s) used as triggers for step 500 with the maps stored in memory to determine the corresponding set of diagnostic checks.

[0048] As described above, controller 92 may then determine if the current operating parameters of machine 10 are within accuracy ranges necessary for testing of the subset of diagnostic checks to begin (Step 510). In particular, in some embodiments, controller 92 may be able to accurately check the health of machine 10 only when particular circumstances are present. These circumstances can be associated with, among other things, a particular position, orientation, or movement of a particular valve or actuator, a particular pattern or sequence of movements (e.g., completion of a cycle such as the truck loading cycle), a particular speed of movement; movement under a particular load; movement When hydraulic temperatures and/or pressures are at certain levels; etc. In some embodiments, health checks of different hydraulic system components may require different circumstances to be present. In other embodiments, a circuit-level health check may require the circumstances to change in a particular order and at particular timings, as controller 92 sequentially checks each component within a particular circuit.

[0049] Accordingly, depending on the type of diagnostic check that will be performed, controller 92 may be configured to reference the type of diagnostic check with the maps stored in memory to determine a corresponding circumstance or set of circumstances that should be present during the diagnostic check to produce accurate results. And when the current machine parameters do not match the parameters required for diagnostic testing, controller 92 may automatically make changes to machine operating parameters to provide the correct set of circumstances (Step 515). For example, controller 92 may automatically raise boom 24 (referring to FIG. 1) to a particular height, at a particular speed, with a particular load, or within a particular period of time; to complete a truck loading cycle; to rack work tool 16; to swing frame 26, etc. In some instances, the movements may be simultaneously commanded of multiple valves and/or actuators. In other instances, however, the movements may be commanded of a single valve and/or actuator.

[0050] During and/or after the autonomous movements of machine 10 that produce the circumstances required for the subset of diagnostic checks, controller 92 may sense the performance of machine 10 (Step 520). For example, while controller 92 is causing work tool 16 to be lifted to a particular height (or lifted at a particular velocity, under a particular load, during completion of a particular cycle, etc.) controller 92 may monitor signals (e.g., pressure or pressure differential signals) produced by one or more sensors associated with one or more of the hydraulic system components (e.g., boom control valve 54, boom cylinders 28, first source 46, etc.) being used to do the lifting.

[0051] After completion of step 520, controller 92 may be further configured to compare the values of the signals sensed during step 520 to corresponding expected values or ranges to determine if the values are within acceptable tolerances of the expected performance values or ranges (Step 525). For example, controller 92 may compare the pressure differential monitored when lifting work tool 16 during completion of step 520 to an expected pressure differential value or range. The expected performance value and/or range may be stored within the memory of controller 92 for this purpose.

[0052] When the comparison made by controller 92 at step 525 shows that the monitored performance of machine 10 is not within an acceptable tolerance of the expected performance value or range, controller 92 may determine a deviation level associated with the results of the comparison (Step 530). As described above with respect to the manual mode of operation, controller 92 may also be configured to classify a deviation determined at step 525 during operation in the automatic mode as the Level 1 deviation, the Level II deviation, or the Level III deviation. In response to a deviation being classified as Level III, controller 92 may automatically shut down machine 10 in a safe and controlled manner in order to prevent further damage of hydraulic system components (Step 535). Controller 92 may then communicate (e.g., to an onboard operator or to a remote back office) additional information regarding the failure, along with recommendations about what repairs should be performed.

[0053] In response to a deviation being classified as Level II, controller 92 may autonomously move machine 10 to a repair facility for service to be performed at completion of the current work shift (operation, task, etc.) (Step 540). This may allow for the service to be performed at a time when the production of machine 10 will not be significantly impacted, and machine 10 may not be left stranded at a location inconvenient for the repairs to be performed. As with a Level III deviation, controller 92 may provide additional information regarding the cause of the Level II deviation, along with recommendations about what repairs should be performed.

[0054] In response to a deviation being classified as Level I, controller 92 may automatically schedule a specific repair to be completed at a next scheduled service interval (Step 545).

[0055] Returning to step 525, when machine 10 performs as expected (step 525:Y) and passes the diagnostic health check, controller 92 may complete the process without flagging any kind of failure or repair error (Step 550).

[0056] The continuous mode of operation shown in FIG. 6 may not require a specific trigger in order to initiate diagnostic testing, other than machine 10 being turned on (Step 600). In particular, any time that machine 10 is operational, controller 92 may be continuously determining if the current operating parameters of machine 10 are within accuracy ranges necessary for completing any one of a plurality of diagnostic tests that controller 92 is capable of performing (Step 605). As described above, in some embodiments, controller 92 may be able to accurately perform certain diagnostic checks only when particular circumstances are present. Accordingly, depending on the current conditions, controller 92 may begin a particular diagnostic check and start sensing corresponding performance parameters any time that the associated circumstances are present (Step 610). For example, any time that boom 24 is being lifted at a particular speed, with a particular load, to a particular height, etc., without any simultaneous tilting, racking, or swinging, controller 92 may be configured to initiate a diagnostic check of boom control valve 54 and/or boom cylinders 28. Controller 92 may then complete steps 615-640, which may be substantially identical to steps 420-445 already described above.
Several benefits may be associated with the disclosed hydraulic system. For example, the disclosed hydraulic system may be configured to diagnose malfunctions associated with any hydraulic system component, including pump and non-pump components. In addition, a high degree of accuracy may be obtained during diagnostic checks, as initiation of the diagnostic checks may be based on current operating conditions being favorable for the checks. Further, the disclosed hydraulic system may provide not only an indication of a source of a system failure, but may also provide instructions on how to respond to the failure.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed hydraulic system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed hydraulic system. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A hydraulic system, comprising:
   a fluid actuator;
   a valve associated with the fluid actuator;
   at least one sensor configured to generate a signal indicative of a performance parameter of the hydraulic system; and
   a controller in communication with the at least one sensor and configured to:
   determine at least one of a diagnostic movement and a diagnostic position of at least one of the fluid actuator and the valve required to perform a health check of the hydraulic system;
   correlate the signal generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and the valve are in the diagnostic position to a value of the performance parameter;
   make a comparison of the value of the performance parameter to an expected value; and
   determine a health of the hydraulic system based on the comparison.

2. The hydraulic system of claim 1, wherein the at least one sensor is one of a pressure sensor, a position sensor, a displacement sensor, and a speed sensor.

3. The hydraulic system of claim 1, wherein the at least one sensor includes at least a first sensor located to sense a pressure inside a chamber of the fluid actuator.

4. The hydraulic system of claim 3, wherein the at least one sensor includes at least a second sensor configured to sense a pressure differential across the valve.

5. The hydraulic system of claim 4, further including a pump configured to direct pressurized fluid to the valve, wherein the at least one sensor includes at least a third sensor configured to sense a pressure differential across the pump.

6. The hydraulic system of claim 1, wherein the controller is configured to adjust a result of the comparison for an age of the hydraulic system.

7. The hydraulic system of claim 1, wherein the controller is configured to determine the at least one of the diagnostic movement and the diagnostic position based on a suspected malfunction of the hydraulic system.

8. The hydraulic system of claim 1, wherein the controller is manually triggered to perform the health check of the hydraulic system.

9. The hydraulic system of claim 8, wherein the controller is configured to instruct an operator to cause the at least one of the fluid actuator and the valve to perform the diagnostic movement or to achieve the diagnostic position.

10. The hydraulic system of claim 9, wherein the controller is further configured to selectively recommend one of three possible corrective actions based on the health of the hydraulic system.

11. The hydraulic system of claim 9, wherein the three possible corrective actions include:
   a first level action, wherein the operator is instructed to schedule a particular maintenance activity to occur at a next regular service interval;
   a second level action, wherein the operator is instructed to perform the particular maintenance activity at a next convenient time; and
   a third level action, wherein the operator is instructed to immediately shut down the hydraulic system and perform the particular maintenance activity.

12. The hydraulic system of claim 1, wherein the controller is automatically triggered to perform the health check of the hydraulic system based on a sensed performance parameter of the hydraulic system.

13. The hydraulic system of claim 12, wherein the controller is configured to automatically cause the at least one of the fluid actuator and the valve to perform the diagnostic movement or to achieve the diagnostic position.

14. The hydraulic system of claim 13, wherein the controller is further configured to automatically implement one of three possible corrective actions based on the health of the hydraulic system.

15. The hydraulic system of claim 9, wherein the three possible corrective actions include:
   a first level action, wherein the controller automatically schedules a particular maintenance activity to occur at a next regular service interval;
   a second level action, wherein the controller automatically schedules the particular maintenance activity to occur at a next convenient time; and
   a third level action, wherein the controller immediately shuts down the hydraulic system and generates a request for the particular maintenance activity to be performed before restart of the hydraulic system.

16. The hydraulic system of claim 1, wherein the controller is configured to continuously perform the health check of the hydraulic system whenever the at least one of the fluid actuator and the valve are in performance of the diagnostic movement or are in the diagnostic position.

17. A method of determining a health of a hydraulic system having a fluid actuator and a valve associated with the fluid actuator, the method comprising:
   generating a signal indicative of a performance parameter of the hydraulic system;
   determining at least one of a diagnostic movement and a diagnostic position of at least one of the fluid actuator and the valve required for diagnosing the health of the hydraulic system;
   correlating the signal generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and the valve are in the diagnostic position to a value of the performance parameter;
   making a comparison of the value of the performance parameter to an expected value; and
determining the health of the hydraulic system based on the comparison.

18. The method of claim 17, further including adjusting the comparison based on an age of the hydraulic system.

19. The method of claim 17, wherein determining the at least one of the diagnostic movement and the diagnostic position of the at least one of the fluid actuator and the valve includes determining the at least one of the diagnostic movement and the diagnostic position of the at least one of the fluid actuator and the valve based on a suspected malfunction of the hydraulic system.

20. A machine, comprising:
   a frame;
   a power source mounted to the frame;
   a linkage arrangement;
   a fluid actuator configured to move the linkage arrangement;
   a pump;
   a sump;
   a valve disposed between the fluid actuator, the pump, and the sump;
   a plurality of sensors configured to generate signals indicative of performance parameters of the machine; and
   a controller in communication with the plurality of sensors and configured to:
   receive input indicative of a suspected hydraulic component malfunction;
   determine at least one of a diagnostic movement and a diagnostic position of at least one of the fluid actuator and the valve required to perform a health check of the machine based on the suspected hydraulic component malfunction;
   correlate the signals generated only during completion of the diagnostic movement or only when the at least one of the fluid actuator and the valve are in the diagnostic position to values of the performance parameters;
   determine an age of the machine;
   make an age-adjusted comparison of the values of the performance parameters to expected values; and
   determine a health of the machine based on the age-adjusted comparison.

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