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(54) **HYDRAULIC SYSTEM HAVING DIAGNOSTIC MODE OF OPERATION**

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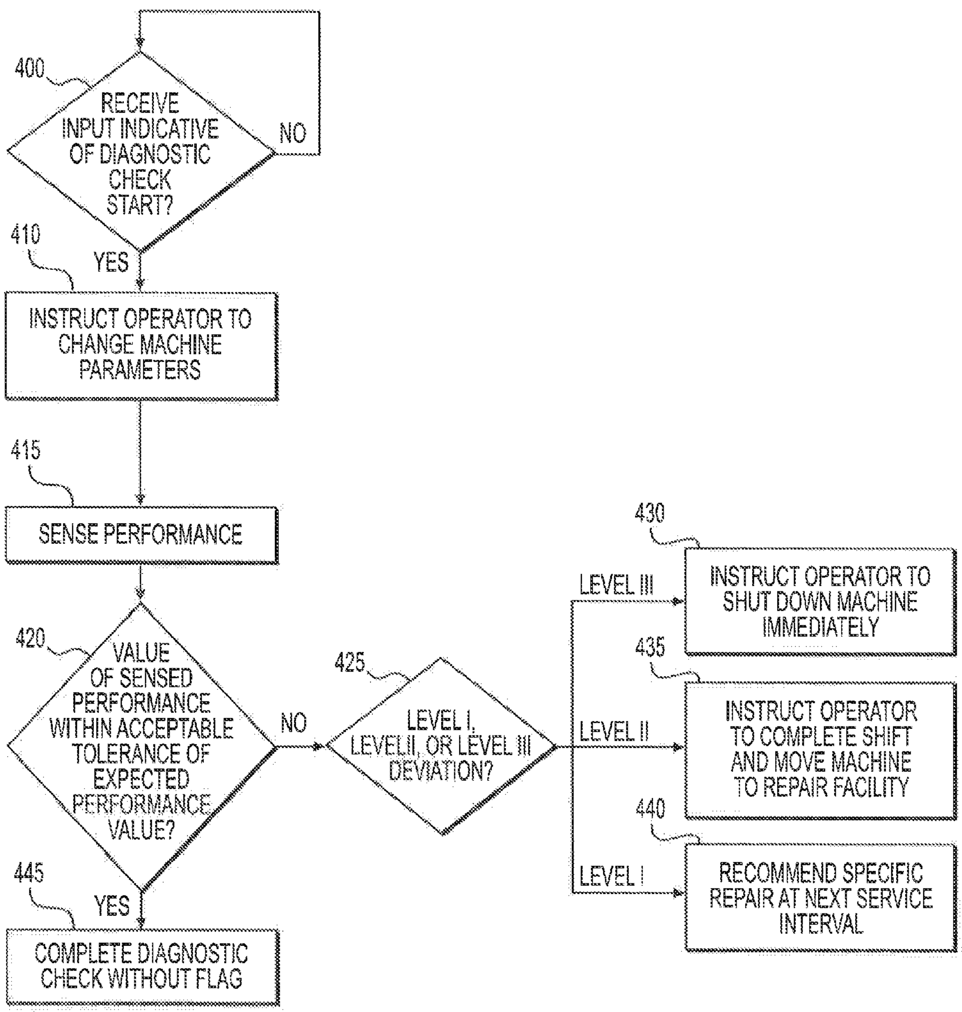
(57) **ABSTRACT**

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 cheek, 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.



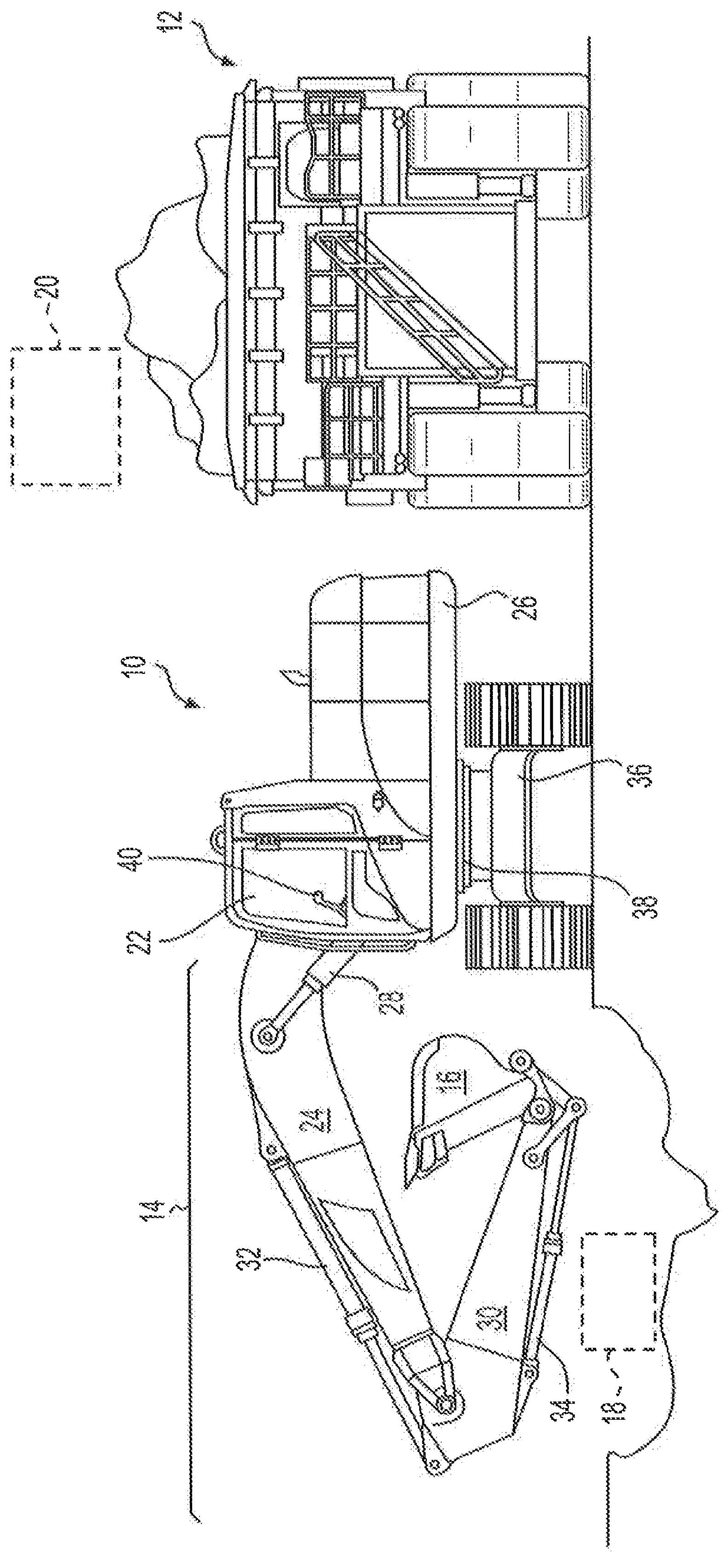
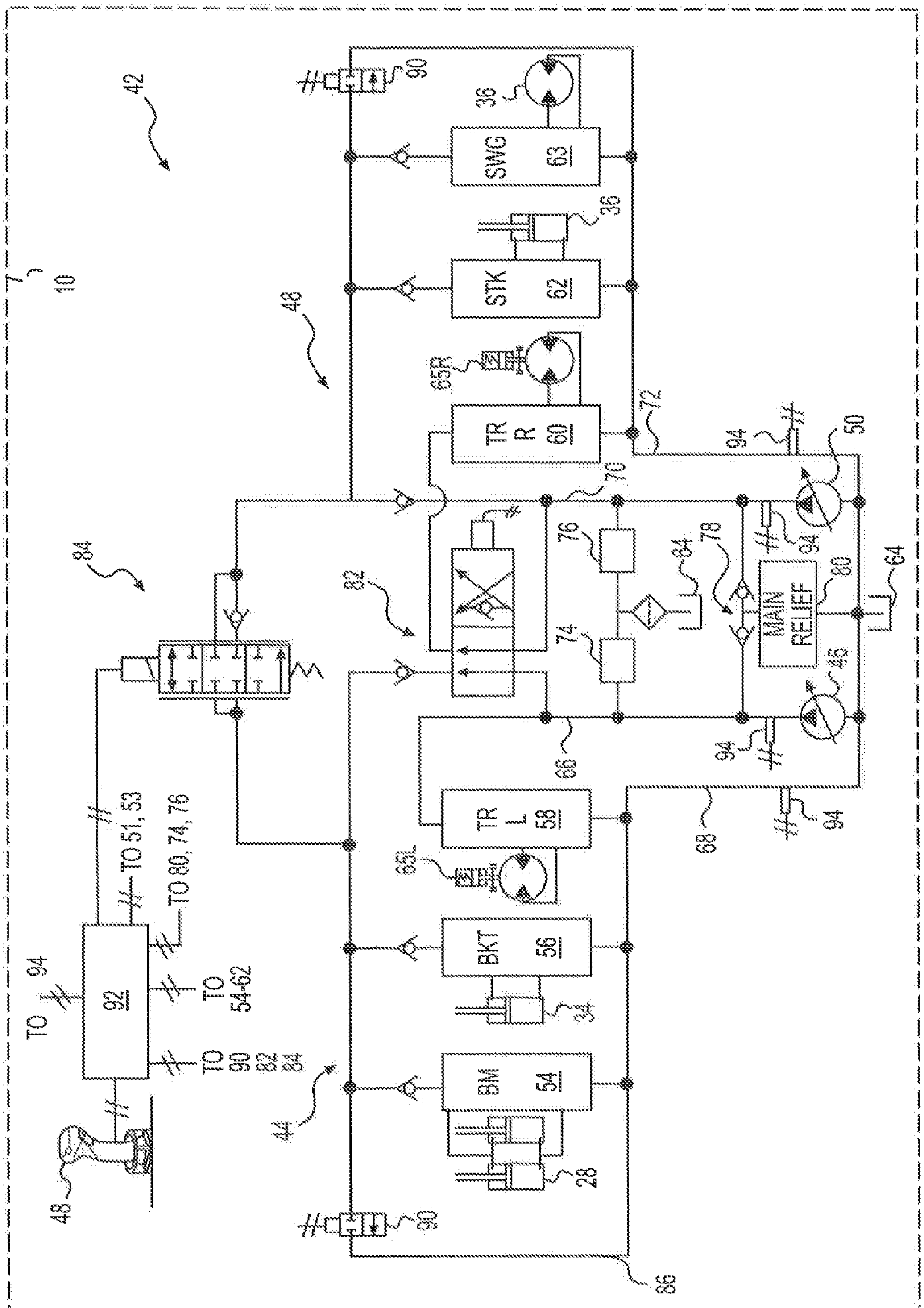


FIG. 1



42
10
48
84
82
44
90
36
SWG
63
STK
62
65R
TR
R
60
72
70
94
50
76
64
78
80
MAIN
RELIEF
74
46
66
TR
L
58
68
65L
BKT
56
34
BM
54
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86
92
TO
TO 51, 53
TO 80, 74, 76
TO
54-62
TO
90
82
84

FIG. 2

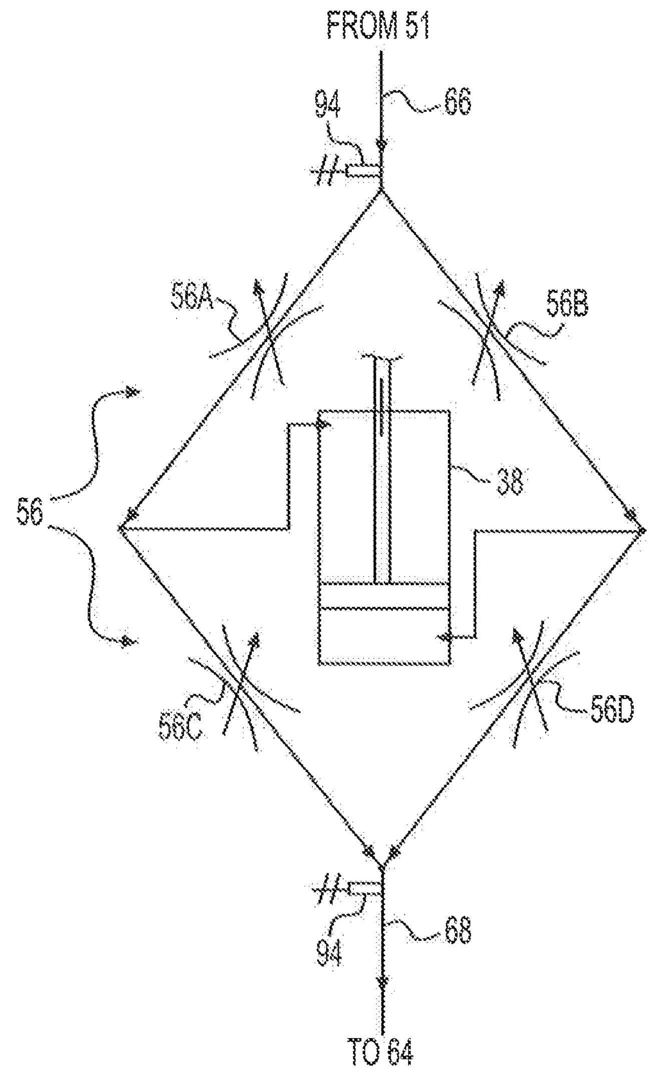

FIG. 3

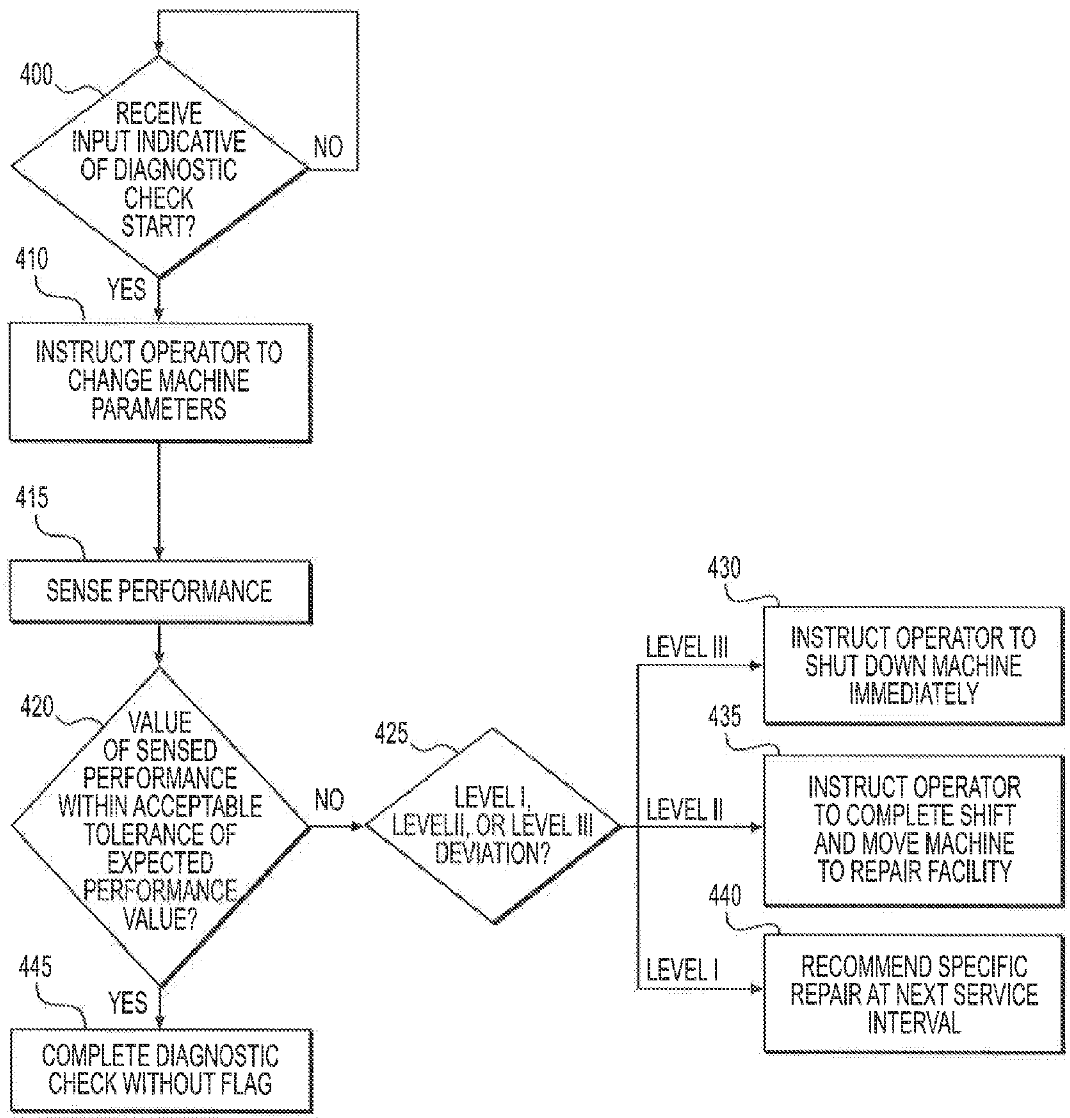
400
RECEIVE INPUT INDICATIVE OF DIAGNOSTIC CHECK START?
NO
YES
410
INSTRUCT OPERATOR TO CHANGE MACHINE PARAMETERS
415
SENSE PERFORMANCE
420
VALUE OF SENSED PERFORMANCE WITHIN ACCEPTABLE TOLERANCE OF EXPECTED PERFORMANCE VALUE?
NO
425
LEVEL I, LEVELII, OR LEVEL III DEVIATION?
LEVEL III
430
INSTRUCT OPERATOR TO SHUT DOWN MACHINE IMMEDIATELY
LEVEL II
435
INSTRUCT OPERATOR TO COMPLETE SHIFT AND MOVE MACHINE TO REPAIR FACILITY
LEVEL I
440
RECOMMEND SPECIFIC REPAIR AT NEXT SERVICE INTERVAL
445
YES
COMPLETE DIAGNOSTIC CHECK WITHOUT FLAG

FIG. 4

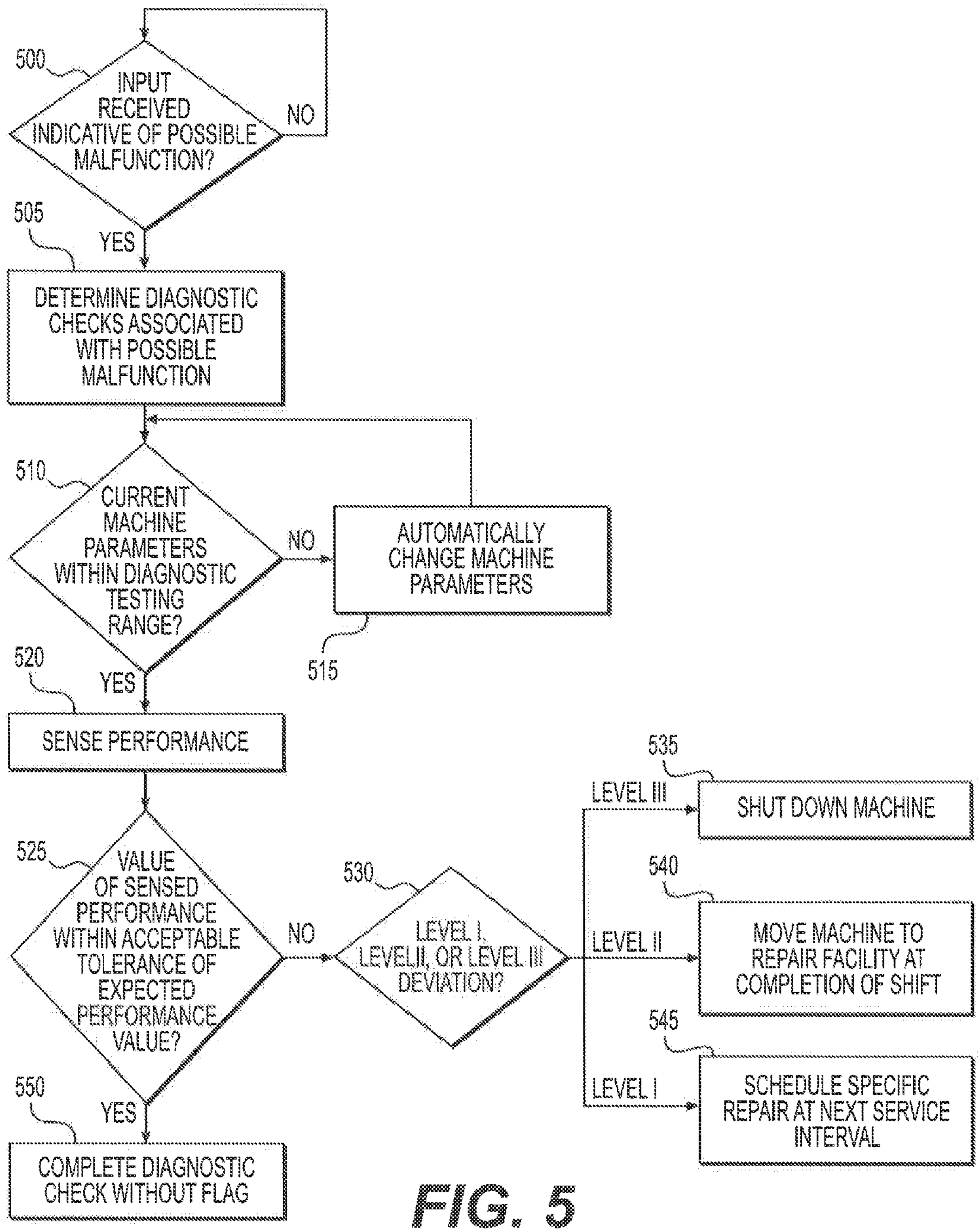
500
INPUT RECEIVED INDICATIVE OF POSSIBLE MALFUNCTION?
NO
YES
505
DETERMINE DIAGNOSTIC CHECKS ASSOCIATED WITH POSSIBLE MALFUNCTION
510
CURRENT MACHINE PARAMETERS WITHIN DIAGNOSTIC TESTING RANGE?
NO
AUTOMATICALLY CHANGE MACHINE PARAMETERS
515
YES
520
SENSE PERFORMANCE
525
VALUE OF SENSED PERFORMANCE WITHIN ACCEPTABLE TOLERANCE OF EXPECTED PERFORMANCE VALUE?
NO
530
LEVEL I, LEVELII, OR LEVEL III DEVIATION?
LEVEL III
535
SHUT DOWN MACHINE
LEVEL II
540
MOVE MACHINE TO REPAIR FACILITY AT COMPLETION OF SHIFT
LEVEL I
545
SCHEDULE SPECIFIC REPAIR AT NEXT SERVICE INTERVAL
YES
550
COMPLETE DIAGNOSTIC CHECK WITHOUT FLAG

FIG. 5

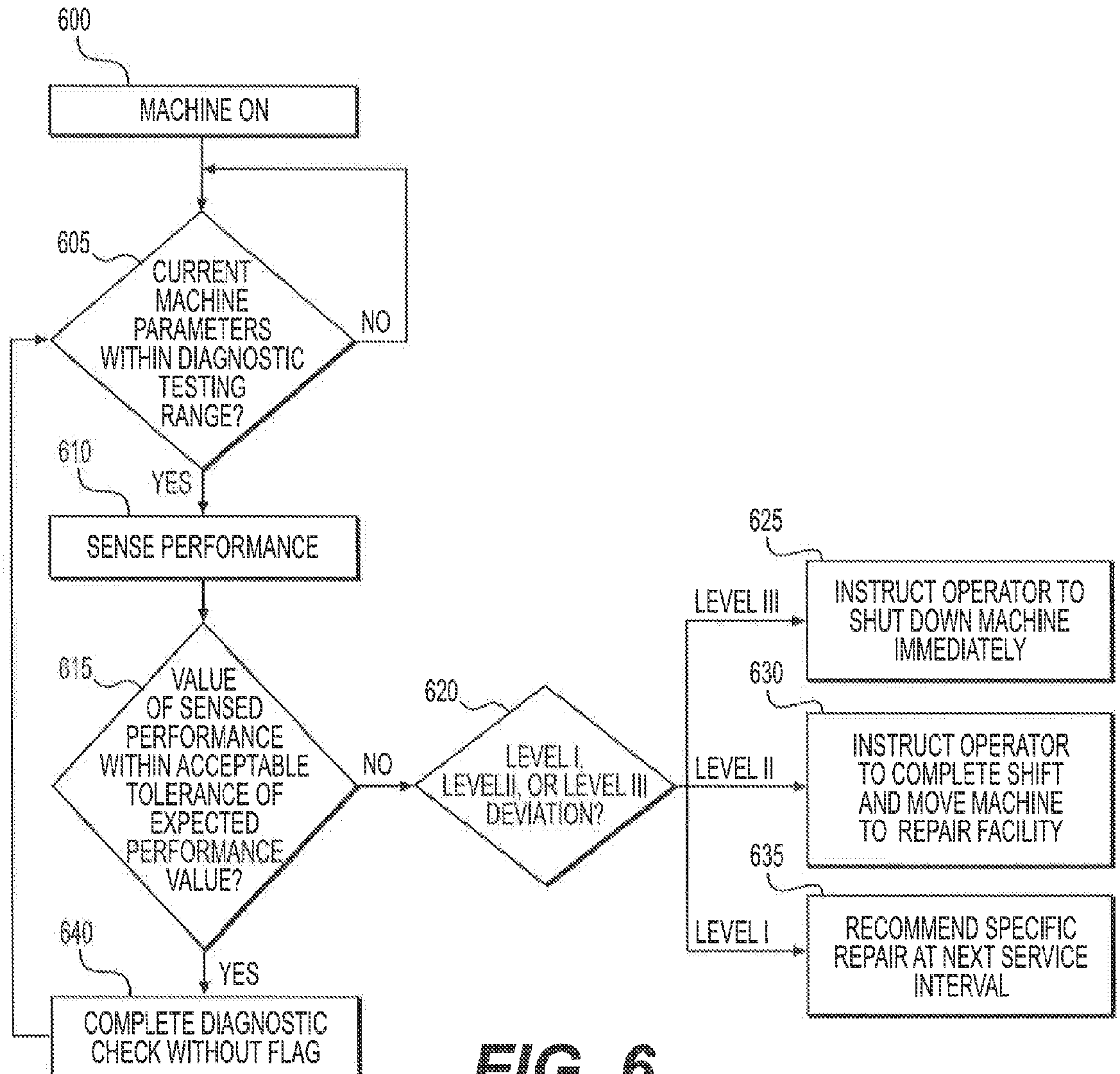
600
MACHINE ON
605
CURRENT MACHINE PARAMETERS WITHIN DIAGNOSTIC TESTING RANGE?
NO
YES
610
SENSE PERFORMANCE
615
VALUE OF SENSED PERFORMANCE WITHIN ACCEPTABLE TOLERANCE OF EXPECTED PERFORMANCE VALUE?
NO
620
LEVEL I, LEVELII, OR LEVEL III DEVIATION?
LEVEL III
625
INSTRUCT OPERATOR TO SHUT DOWN MACHINE IMMEDIATELY
LEVEL II
630
INSTRUCT OPERATOR TO COMPLETE SHIFT AND MOVE MACHINE TO REPAIR FACILITY
LEVEL I
635
RECOMMEND SPECIFIC REPAIR AT NEXT SERVICE INTERVAL
YES
640
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, less 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 swashplate angle sensor, a pump speed sensor, a head-end pressure/position/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.

[0010] 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**; and

[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 earthen 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 activate 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 **56**A, a first chamber drain element **56**C, a second chamber supply element **56**B, and a second chamber drain element **56**D. First and second chamber supply elements **56**A, **56**B 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 **56**C, **56**D 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 **56**A 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 **56**D 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 **56**B may be moved to fill the second chamber of bucket cylinder **34** with pressurized fluid, while first chamber drain element **56**C 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 **56**A to **56**C or from **56**B to **56**D), such that no movement of bucket cylinder **34** is realized. This may be done, for example, during a diagnostic routine. it is contemplated that both the supply and drain functions may alternatively be performed by a single element associated with the first chamber and a single element associated with the second chamber, or by a single valve that controls all filling and draining functions.

[0023] Returning to FIG. **2**, the common supply and drain passageways of first and second circuits **44**, **48** may be interconnected for makeup and relief functions. In particular, first and second common supply passageways **66**, **70** may receive makeup fluid from tank **64** by way of first and second bypass elements **74**, **76**, respectively fluid within first or second circuits **44**, **48** exceeds a predetermined pressure level, fluid from the circuit having the excessive pressure may drain to tank **64** by way of a shuttle valve **78** and a common main relief element **80**. Other arrangements of bypass and relief valves may be used, as is known in the art.

[0024] A straight travel valve **82** may selectively rearrange left and right travel control valves **58**, **60** into a parallel relationship with each other. In particular, straight travel valve **82** may include elements movable from a first position at which left and right travel control valves **58**, **60** are independently supplied with pressurized fluid, to a second position at which left and right travel control valves **58**, **60** are interconnected for dependent movement. The dependent movement of left and right travel motors **65**L, **65**R may function to provide substantially equal rotational speeds of left and right tracks **40**L, **40**R, thereby propelling machine **10** in a straight direction.

[0025] A combiner valve **84** may be used to selectively combine the first and second streams of pressurized fluid from first and second common supply passageways **66**, **70** for high speed movement of one or more fluid actuators. In particular, 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/or 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**.

[0030] 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.

[0031] 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.

[0032] 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**.

[0033] 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.

[0034] 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 **65**L (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 **65**R, 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.

[0035] 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

[0036] 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**.

[0037] 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.

[0038] 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.

[0039] 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 to he displayed within 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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.

[0044] 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**).

[0045] 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**.

[0046] 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.

[0047] 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 may 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 he 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 **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.

[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 I 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 he 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.

[0057] 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.

[0058] 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 performe 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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