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METHOD FOR REAL-TIME HYDRAULIC CYLINDER DRIFT MONITORING

Abstract

A method of monitoring drift in a hydraulic cylinder, including providing a work machine having an implement actuated by the hydraulic cylinder, a sensor attached to the hydraulic cylinder configured to measure a displacement of the hydraulic cylinder and a controller; identifying a cycle start of the hydraulic cylinder; identifying a cycle end of the hydraulic cylinder; calculating a drift rate of the hydraulic cylinder; determining if the drift rate is greater than a drift threshold; and if the drift rate is greater than the drift threshold, notifying service personnel that service of the hydraulic cylinder is required.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure generally relates to work machines, and more specifically relates to hydraulic cylinders for implements of work machines.

BACKGROUND

[0002] Mobile work machines may be used in the heavy industries such as mining, construction, and the like to transport materials and personnel. These work machines are often large in size, and require an operator, e.g., a driver, to manually operate the machine in order for the machine to perform its designated/intended operations.

[0003] Certain work machines, such as loaders, use implements to perform various tasks on a work site. These implements may be required to carry and transfer heavy loads, and as such, may utilize hydraulic systems to aid in operating mechanisms for the implements. These hydraulic systems are required to be robust in order to withstand the heavy loads, and failure of hydraulic components can often lead to treacherous results.

[0004] In the field of hydraulic systems, the phenomenon of hydraulic cylinder drift poses a significant challenge. Hydraulic cylinder drift refers to the unintended and gradual movement of the piston within a hydraulic cylinder, often in a downward direction. Hydraulic cylinder drift may be caused by a variety of factors such as internal fluid leakage such as oil leaking from seals within the cylinder, faults in the hydraulic system such as faulty relief valves, external leaks, or other factors. Hydraulic cylinder drift may occur at a drift rate defined as a certain amount of drift over time, and may be small, for example, only on the order of 10-100 mm per minute, and may be difficult for an operator to detect.

[0005] Hydraulic cylinder drift can lead to inefficiencies and potential hazards in various industrial and mechanical applications. Addressing hydraulic cylinder drift is crucial for maintaining system precision, stability, and overall operational safety.

[0006] In light of the aforementioned shortcomings, there remains a need to a method for monitoring hydraulic cylinder drift in real time. There also remains a need for a method for monitoring hydraulic cylinder drift that can notify operators and service personnel that a hydraulic cylinder requires servicing.

SUMMARY OF THE DISCLOSURE

[0007] In accordance with one aspect of the disclosure, a work machine may be provided. The work machine may include a frame, a ground engaging member supporting the frame, an engine supported by the frame, and a controller configured to control operation of the work machine. The work machine may include an implement supported by the frame. The work machine may include a hydraulic cylinder connected to the implement and the frame, configured to be actuated by an operator input connected to the controller. The work machine may include a sensor attached to the hydraulic cylinder and connected to the controller. The sensor of the work machine may be configured to measure an actuation of the hydraulic cylinder over time. The controller may be configured to receive an actuation data from the sensor, evaluate a drift rate of the hydraulic cylinder, and provide a service notification if the drift rate is greater than a drift threshold.

[0008] In accordance with another aspect of the disclosure, a hydraulic cylinder may be provided. The hydraulic cylinder may include a cylinder body having a first body end and a second body end, the cylinder body having a cylinder connector at the second body end, the cylinder body being hollow. The hydraulic cylinder may include a rod having a first rod end and a second rod end, the rod having a rod connector at the first rod end. The hydraulic cylinder may include a piston connected to the second rod end, the piston interfacing with an inside wall of the cylinder body. The hydraulic cylinder may include a sensor disposed on the hydraulic cylinder, the sensor configured to measure an actuation of the hydraulic cylinder. The hydraulic cylinder may include a controller connected to the sensor. The controller may be configured to receive a measurement of the actuation from the sensor, evaluate a drift rate of the hydraulic cylinder, and provide a service notification if the drift rate is greater than a drift threshold.

[0009] In accordance with yet another aspect of the disclosure, a method of monitoring drift in a hydraulic cylinder may be provided. The method may include providing a work machine having an implement actuated by the hydraulic cylinder, providing a sensor attached to the hydraulic cylinder configured to measure a displacement of the hydraulic cylinder, and providing a controller. The method may include identifying a cycle start of the hydraulic cylinder and identifying a cycle end of the hydraulic cylinder. The method may include calculating a drift rate of the hydraulic cylinder and determining if the drift rate is greater than a drift threshold. The method may include notifying service personnel that service of the hydraulic cylinder is required, if the drift rate is greater than the drift threshold.

[0010] These and other aspects and features of the present disclosure will be more readily understood when read in conjunction with the accompanying drawings.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a perspective view of a work machine constructed in accordance with an embodiment of the present disclosure.

[0012] FIG. **2** is a perspective view of a work machine with an implement arm having a hydraulic cylinder constructed in accordance with an embodiment of the present disclosure.

[0013] FIG. **3** is a cross-sectional view of a hydraulic cylinder constructed in accordance with an embodiment of the present disclosure.

[0014] FIG. **4** is a flowchart depicting a sample sequence of steps for monitoring drift in a hydraulic cylinder, which may be practiced in accordance with the locomotive of the present disclosure.

DETAILED DESCRIPTION

[0015] Referring now to the drawings, and with specific reference to FIG. **1**, a work machine is depicted and generally referred to using reference numeral **10**. The work machine **10** is exemplarily embodied in the form of a loader. While the work machine **10** is depicted as a loader, it should be noted that a type of machine used is merely exemplary and illustrative in nature. It will be acknowledged that the teachings of the present disclosure can be similarly applied to other types of work machines including but not limited to on and off highway trucks, excavators, track-type tractors, mining vehicles, and other types of machines having hydraulic cylinders known to persons skilled in the art.

[0016] Work machines, and specifically loaders, may be used to lift, transport, and deposit material from one spot to another. The work machine **10** is supported by a frame **11**. The work machine **10** may include a drivetrain **12** powered by an engine **13** and driving ground-engaging members **14** contacting the ground and supporting the frame **11** in order to operate the work machine **10**.

[0017] The work machine **10** may also include an implement **15** to perform a work job. In the view of FIG. **1**, since the work machine **10** is a loader, the implement **15** is exemplarily depicted as a dump body, but with other machines the implement may be other types of work implements known to persons skilled in the art. The implement **15** may be connected to the frame **11** of the work machine by an implement arm **16**, and may be actuated by a hydraulic cylinder **17**. The work machine **10** may also include an operator cabin **18** for an operator to control the operation of the work machine **10**. The operator cabin **18** may include a controller **19** for the operator to use to direct the work machine **10**.

[0018] FIG. **2** depicts the work machine **10** in its capacity as a loader loading material onto a dump truck **20**. The operator of the work machine **10** controls operation of the implement arm **16** and the implement **15** through the controller **19** to scoop material, lift the material, and deposit the material within the dump truck **20**. In the quantities that the work machine **10** may be capable of accumulating, assistance is required to lift the load, and in order to do so, the hydraulic cylinder **17** is disposed on the work machine.

[0019] In the work machine **10** of FIG. **2**, several of the hydraulic cylinder **17** are connected to various components of the work machine **10** such that the operator can control operation of several movements, such as the implement **15** relative to the implement arm **16**, the implement arm **16** relative to the frame **11**, among others. While the work machine **10** is depicted having multiple of the hydraulic cylinder **17**, other machines as known may include one or more of the hydraulic cylinder **17** where hydraulic actuation assistance is required.

[0020] FIG. **3** depicts the hydraulic cylinder **17** in a cross-sectional view. The hydraulic cylinder **17** may be composed of a cylinder body **30** with an outside surface **31** and an inside surface **32**. The cylinder body **30** may have a first body end **33** and a second body end **34**. In the hydraulic cylinder **17** of FIG. **3**, the first body end **33** is depicted having a cylinder connector **35**, which may be an eye end connector, or any other connector as known. The second body end **34** is shown in FIG. **3** as having a cap **36** to seal the second body end **34**, however, other embodiments of the second body end **34** may include enclosures that are integral with the cylinder body **30**. In order to connect the cap **36** to the cylinder body **30**, fasteners **37** may be provided. In the depiction of FIG. **3**, the fasteners **37** are depicted as bolts, but any other fasteners as known may be utilized.

[0021] A rod **40** is disposed within the cylinder body **30**. The rod **40** may also have a first rod end **41** and a second rod end **42**. The rod **40** may also include a rod connector **43** disposed on the first rod end **41**. As with the cylinder connector **35**, the rod connector **43** may also be an eye end connector, or may be any other connector as known. A rod orifice **44** may be formed into the cap **36** of the cylinder body **30** such that the rod **40** may move relative to the cylinder body **30**.

[0022] The rod **40** includes a piston **45** disposed on the second rod end **42**. The piston **45** may be attached to the second rod end **42** through fasteners **46**, which in FIG. **3** are also shown as bolts, but as with fasteners **37**, other fasteners or connection techniques as known may be utilized to connect the piston **45** to the second rod end **42**. The piston **45** extends outwardly within the hydraulic cylinder **17** such that an outer surface of the piston **45** interacts with the inside surface **32** of the cylinder body **30**.

[0023] Due to this extending of the piston **45**, two volumes are formed within the hydraulic cylinder **17**. A first volume **50** is formed between the first body end **33** and the piston **45**, and a second volume **51** is formed between the second body end **34** and the piston **45**. The second volume **51** surrounds the rod **40** within the cylinder body **30**. A first orifice **52** may be provided at the first body end **33** of the cylinder body **30**, and may connect to the first volume **50** via a first fluid passage **53**. Similarly, a second orifice **54** may be provided at the second body end **34**, and may connect to the second volume **51** via a second fluid passage **55**. As depicted in FIG. **3**, the second orifice **54** and the second fluid passage **55** may be disposed within the cap **36**.

[0024] In order to actuate the hydraulic cylinder **17**, a hydraulic system may be provided to send hydraulic fluid to both the first volume **50** and the second volume **51**. The hydraulic system may include a pump **60** and hydraulic line **61** to deliver hydraulic fluid to the first orifice **52** and the second orifice **54**. Hydraulic fluid is required to be contained within the first volume **50** and the second volume **51**, especially during actuation of the rod **40** within the cylinder body **30**. Therefore, a piston seal **56** is disposed on an outside surface of the piston **45** to maintain bifurcation between the first volume **50** and the second volume **51**, and a rod seal **57** is disposed at the second body end **34** about the rod **40** in order to prevent fluid leaks from the second volume **51** though the rod orifice **44**.

[0025] A sensor **70** may be disposed on the hydraulic cylinder **17** in order to measure various actuation parameters of the hydraulic cylinder **17**. The sensor **70** may be a position sensor, and actuation of the hydraulic cylinder **17** is measured as the displacement of the rod **40** relative to the cylinder body **30**. The sensor **70** may also be an angle sensor, and actuation of the hydraulic cylinder **17** is measured as change in a rotational position of the hydraulic cylinder **17**. Additionally, the hydraulic system may include a first volume pressure sensor **71** and a second volume pressure sensor **72** in order to monitor the fluid pressures of the first volume **50** and the second volume **51**, respectively.

INDUSTRIAL APPLICABILITY

[0026] In operation, the teachings of the present disclosure can find applicability in many industries including but not limited to work machines used in the earth moving, mining, agricultural, and construction industries. While depicted and described in conjunction with a loader, such teachings can also find applicability with other machines such as on and off highway trucks, excavators, track-type tractors, mining vehicles, and other types of machines having hydraulic cylinders known to persons skilled in the art.

[0027] FIG. **4** illustrates a visual representation of a method **100** for monitoring drift in the hydraulic cylinder **17**. In a first step **101**, the controller **19** performs a preliminary read of the sensor **70** as well as the first volume pressure sensor **71** and the second volume pressure sensor **72**, and in a second step **102**, identifies that certain conditions are true corresponding to a start of an actuation of the hydraulic cylinder **17**. These conditions may include a starting pressure in both the first volume **50** and the second volume **51** indicative of the implement **15** being unloaded, a starting displacement of the hydraulic cylinder **17**, and identifying that zero input has been provided from the operator. Concurrently, if the conditions are true, in a third step **103** the controller **19** may determine whether a cycle has started. If not, in a fourth step **104**, the controller **19** may record the start displacement and start time of a cycle start of the hydraulic cylinder **17**.

[0028] Once the actuation of the hydraulic cylinder **17** has been completed, in a fifth step **105**, the controller **19** may identify certain conditions register false, for instance ending pressure in the first volume **50** and the second volume **51**, ending displacement of the hydraulic cylinder **17**, and identifying that zero input is again provided by the operator. The controller **19** may identify whether the cycle is complete. If so, once again, the controller **19** may record the end displacement and an end time of a cycle end of the hydraulic cylinder **17** in a sixth step **106**.

[0029] The controller **19** may then calculate a drift rate of the hydraulic cylinder **17** during the cycle. In a seventh step **107**, the controller **19** may calculate a change in displacement for the cycle (also known as delta displacement), and may calculate a change in time for the cycle (also known as delta time). The controller **19** may be programmed to only accept data for cycles that have a delta time greater than a minimum time. In an eighth step **108**, the controller **19** references the minimum time to determine if the delta time for a specific cycle is greater than the minimum time. If not, the cycle data is not used, and in a ninth step **109** the controller **19** resets the cycle.

[0030] If the delta time is greater than the minimum time, in a tenth step **110**, the controller **19** calculates drift rate as delta displacement over delta time. Optionally, the controller may take the calculated drift rate and, in an eleventh step **111**, apply a digital filter to the calculated drift rate in order to remove outliers and excess noise. While the digital filter of the eleventh step **111** is depicted as a moving average filter, any other digital filter as known may be utilized. The controller **19**, in a twelfth step **112**, determines whether the drift rate is greater than a drift threshold. If not, in a thirteenth step **113** the cycle data is logged by the controller **19**, and the method **100** is restarted. If so, in a fourteenth step **114**, the controller **19** provides a notification through an operator display in the operator cabin **18** of the work machine **10**, or may provide notification through telematics to a remote location where service personnel may be located. The method **100** may be repeated many times during operation of the work machine **10**, for instance for each actuation of the hydraulic cylinder **17**.

[0031] Optionally, the controller **19** may use the captured data to predict when the drift rate may exceed the threshold in the future. For example, the drift rate may increase over several cycles. In a fifteenth step **115**, the controller **19** may estimate this rate of change of the drift rate, provide a prediction of when the drift rate will be greater than the drift threshold in a sixteenth step **116**, and provide a notification in a seventeenth step **117** similar to the service notification of the fourteenth step **114**.

[0032] The method **100** for monitoring drift in a hydraulic cylinder describes operation of the work machine **10** of the primary embodiment, and how in operation, the work machine **10** may evaluate operability of any of the hydraulic cylinder **17** operated by the work machine **10**. The method **100** allows for the work machine **10** to identify when drift of the hydraulic cylinder **17**, if any, becomes excessive before an operator can. Real time monitoring, as specified in the method **100**, would negate the need for additional service tests of the hydraulic cylinder **17**. However, once excessive drift is identified, service personnel would still be required to diagnose the cause of the drift, whether it be seal wear, faulty valves, external leakage, or other causes.

[0033] The method **100** can be adapted to any work machine **10**, requiring only a software update to retrofit. The method **100** can also be adapted to other industries and any machine utilizing hydraulic cylinders to actuate mechanisms of the machine.

[0034] It should be evident that this disclosure is by way of example and that various changes may be made by adding, modifying or eliminating details without departing from the fair scope of the teaching contained in this disclosure. The invention is therefore not limited to particular details of this disclosure except to the extent that the following claims are necessarily so limited. The sensor **70** may also be an other sensor as known that may be used to measure change in the hydraulic cylinder **17** than may be attributed to actuation of the hydraulic cylinder **17**.

Claims

1. A work machine comprising: a frame; a controller configured to control operation of the work machine; an implement supported by the frame; a hydraulic cylinder connected to the implement and the frame, configured to be actuated by an operator input connected to the controller; and a sensor attached to the hydraulic cylinder and connected to the controller, the sensor configured to gather actuation data, the controller configured to receive the actuation data from the sensor, evaluate a drift rate of the hydraulic cylinder, and provide a service notification if the drift rate is greater than a drift threshold.

2. The work machine of claim 1, wherein the actuation data from the sensor further comprises a displacement of the hydraulic cylinder.

3. The work machine of claim 1, wherein the actuation data from the sensor further comprises a rotational position of the implement relative to the frame.

4. The work machine of claim 1, wherein the sensor comprises a plurality of sensors.

5. The work machine of claim 4, wherein the plurality of sensors further comprises a position sensor.

6. The work machine of claim 4, wherein the plurality of sensors further comprises an angle sensor.

7. The work machine of claim 4, wherein the plurality of sensors further comprises a cylinder pressure sensor.

8. A hydraulic cylinder, comprising: a cylinder body having a first body end and a second body end, the cylinder body having a cylinder connector at the second body end, the cylinder body being hollow; a rod having a first rod end and a second rod end, the rod having a rod connector at the first rod end; a piston connected to the second rod end, the piston interfacing with an inside wall of the cylinder body; a sensor disposed on the hydraulic cylinder, the sensor configured to measure an actuation of the hydraulic cylinder; and a controller connected to the sensor, the controller configured to receive a measurement of the actuation from the sensor, evaluate a drift rate of the hydraulic cylinder, and provide a service notification if the drift rate is greater than a drift threshold.

9. The hydraulic cylinder of claim 8, further comprising a first volume within the cylinder body between the piston and the second body end and a second volume within the cylinder body, surrounding the rod, between the piston and the first body end.

10. The hydraulic cylinder of claim 9, further comprising a first orifice at the first body end of the cylinder body having a first fluid passage connecting the first orifice to the first volume.

11. The hydraulic cylinder of claim 10, further comprising a second orifice at the second body end of the cylinder body having a second fluid passage connecting the second orifice to the second volume.

12. The hydraulic cylinder of claim 11, further comprising a first pressure sensor configured to measure a first pressure of the first volume, and a second pressure sensor configured to measure a second pressure of the second volume, the controller configured to calculate the actuation of the hydraulic cylinder from changes in the first pressure and the second pressure.

13. The hydraulic cylinder of claim 8, wherein the sensor is a position sensor, and the actuation of the hydraulic cylinder is measured as displacement of the rod relative to the cylinder body.

14. The hydraulic cylinder of claim 8, wherein the sensor is an angle sensor, and the actuation of the hydraulic cylinder is measured as change in a rotational position of the hydraulic cylinder.

15. A method of monitoring drift in a hydraulic cylinder, comprising: providing a work machine having an implement actuated by the hydraulic cylinder, a sensor attached to the hydraulic cylinder configured to measure a displacement of the hydraulic cylinder and a controller; identifying a cycle start of the hydraulic cylinder; identifying a cycle end of the hydraulic cylinder; calculating a drift rate of the hydraulic cylinder; determining if the drift rate is greater than a drift threshold; and notifying service personnel that service of the hydraulic cylinder is required, if the drift rate is greater than the drift threshold.

16. The method of claim 15, the step of identifying the cycle start further comprising recording a start displacement of the hydraulic cylinder, and a start time; and the step of identifying the cycle end further comprising recording an end displacement of the hydraulic cylinder, and an end time.

17. The method of claim 16, wherein calculating the drift rate further comprises calculating a delta displacement between the start displacement and the end displacement, and calculating a delta time between the start time and the end time.

18. The method of claim 17, wherein calculating the drift rate further comprises determining if the delta time is greater than a minimum time, and calculating the drift rate as the delta displacement divided by the delta time.

19. The method of claim 15, after calculating the drift rate further comprising the steps of: calculating a rate of change of the drift rate; predicting a target date when the drift rate will exceed the drift threshold; and notifying service personnel that service of the hydraulic cylinder is required at the target date.

20. The method of claim 15, further comprising applying a digital filter after calculating the drift rate in order to remove excess noise or outlier points.