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Zhang et al.

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(54) **PUMP MONITORING AND NOTIFICATION SYSTEM**

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(51) **Int. Cl.**

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F04B 19/22	(2006.01)
F04B 47/02	(2006.01)
F04B 49/10	(2006.01)
F04B 51/00	(2006.01)

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CPC ***F04B 49/103*** (2013.01); ***F04B 1/053*** (2013.01); ***F04B 1/0538*** (2013.01); ***F04B 9/02*** (2013.01); ***F04B 17/05*** (2013.01); ***F04B 17/06*** (2013.01); ***F04B 19/22*** (2013.01); ***F04B 47/02*** (2013.01); ***F04B 51/00*** (2013.01); *E21B 43/26* (2013.01); *F04B 2203/0605* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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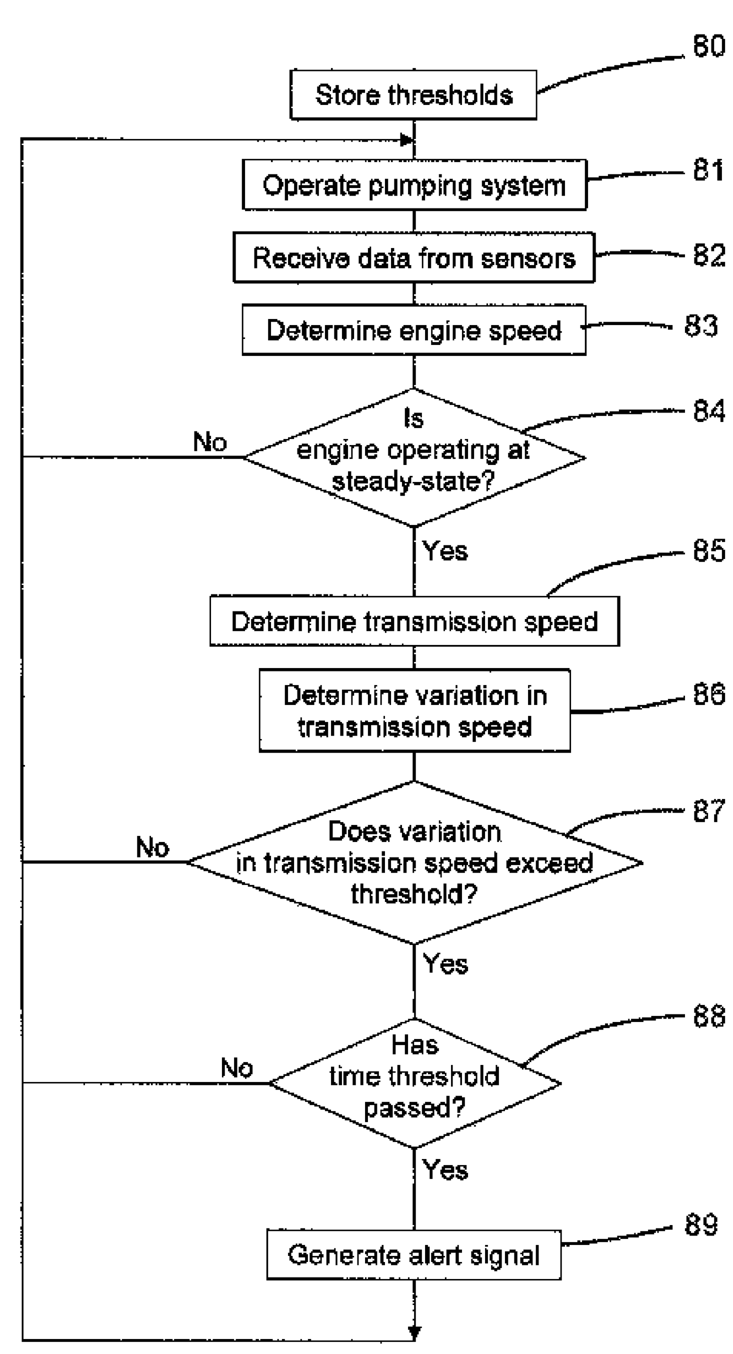
(57) **ABSTRACT**

A pump monitoring and notification system for a hydraulic pump includes a transmission speed sensor and a controller. The transmission speed sensor is associated with a transmission connected to the pump to determine an output speed of the transmission. The controller is configured to access a transmission threshold, access a time threshold, and determine a rotational speed of the transmission based upon the transmission speed sensor. The controller is further configured to determine a variation in rotational speed of the transmission based upon the rotational speed, compare the variation in rotational speed of the transmission to the transmission threshold, and generate an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for a time period exceeding the time threshold.

20 Claims, 6 Drawing Sheets



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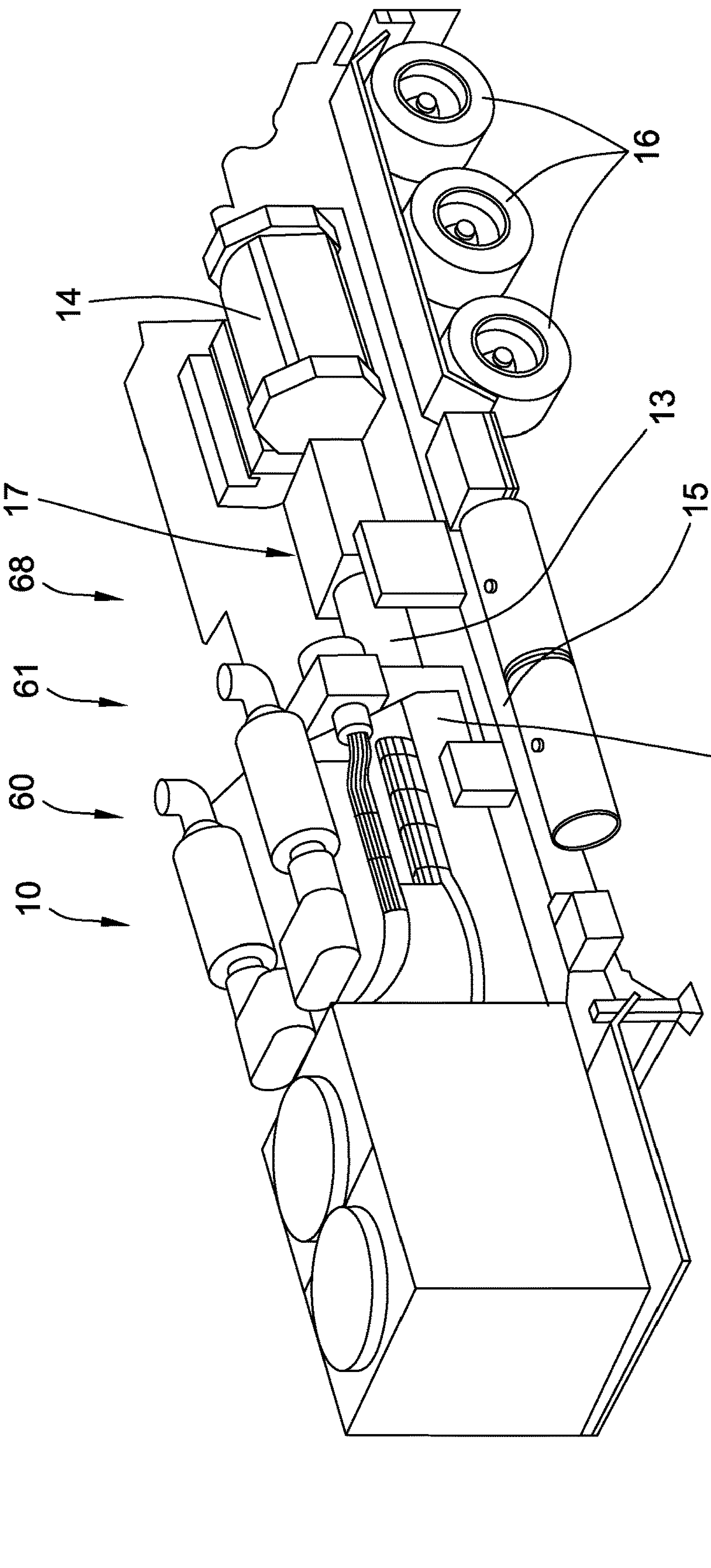

FIG. 1

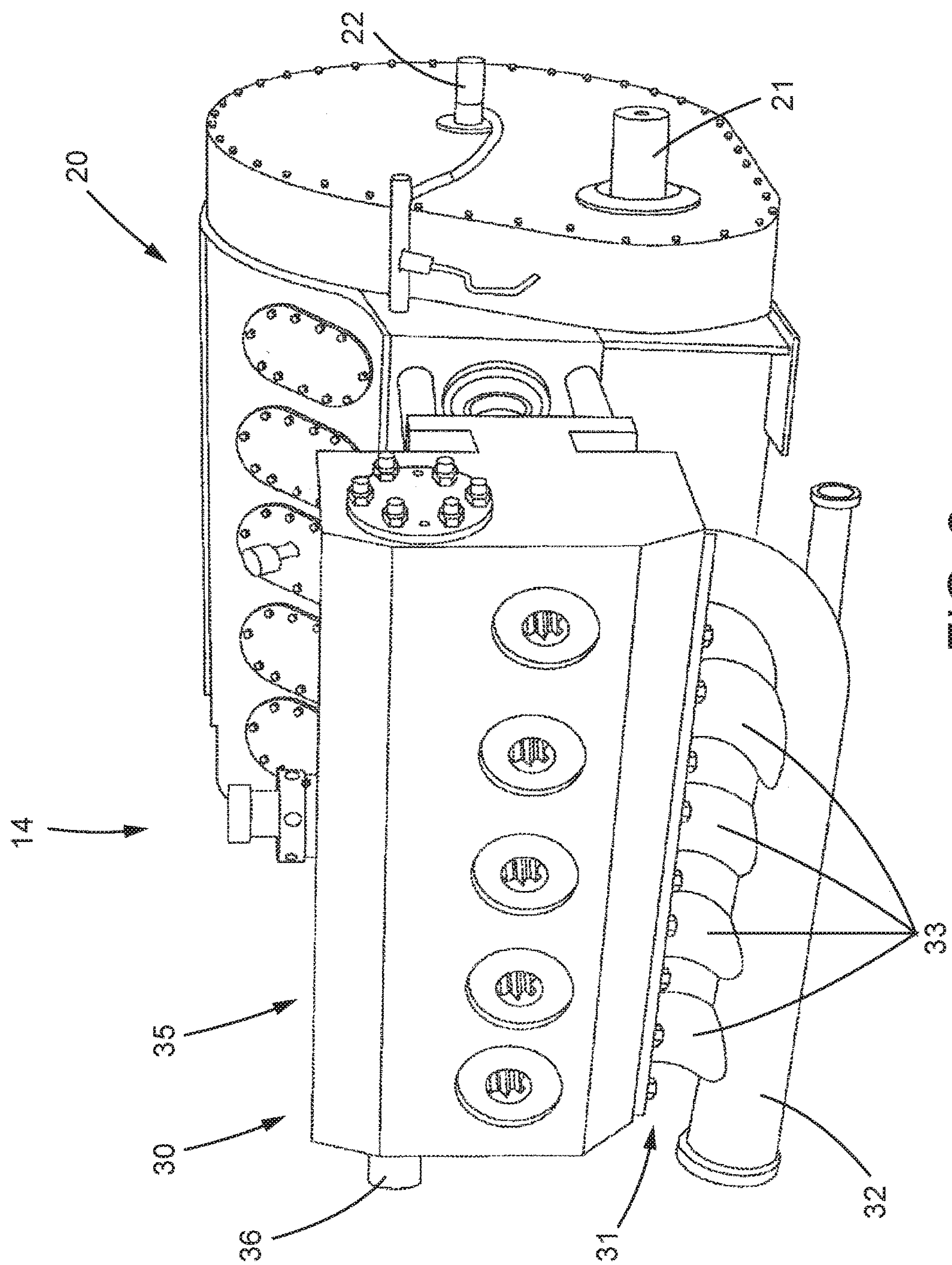

FIG. 2

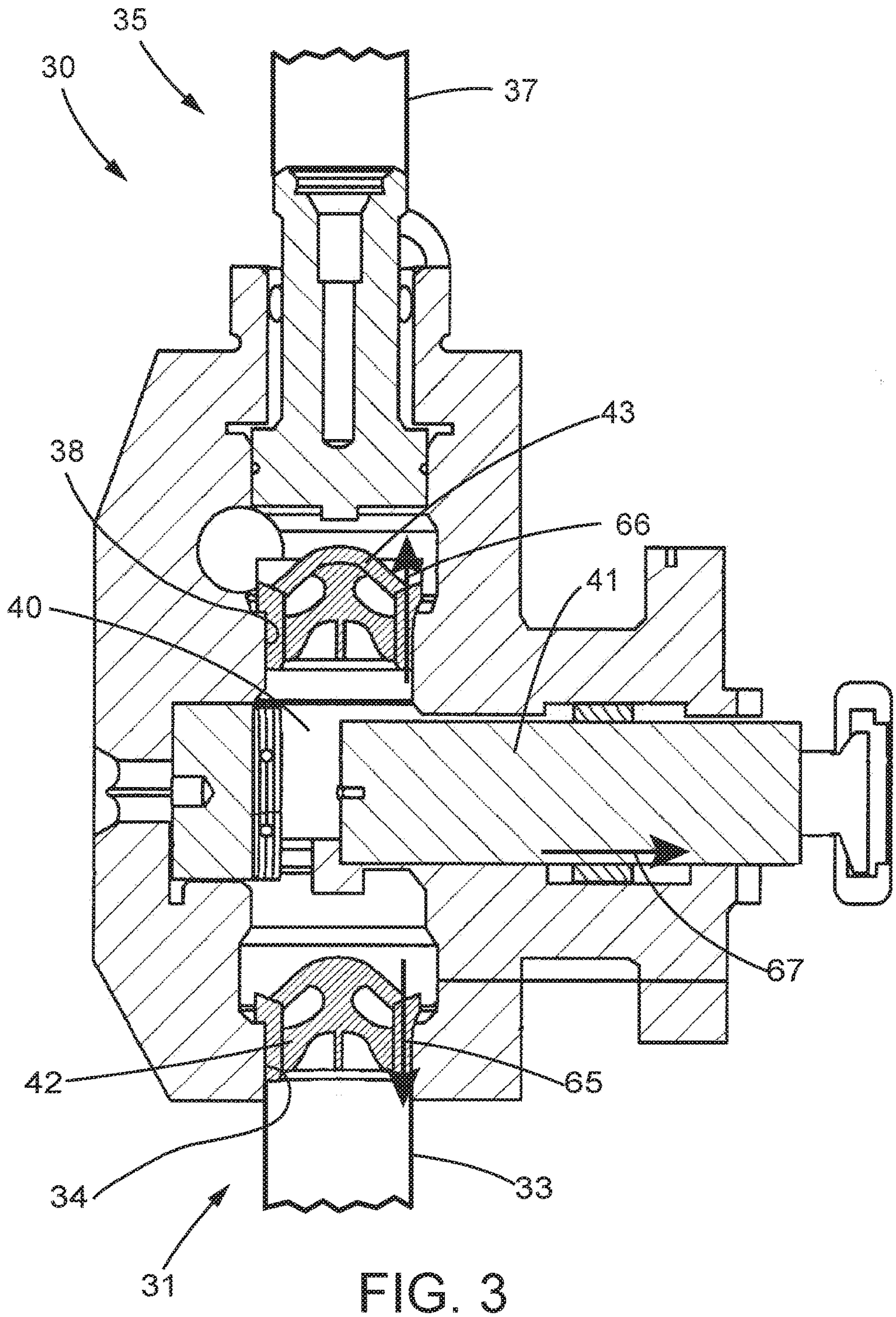

FIG. 3

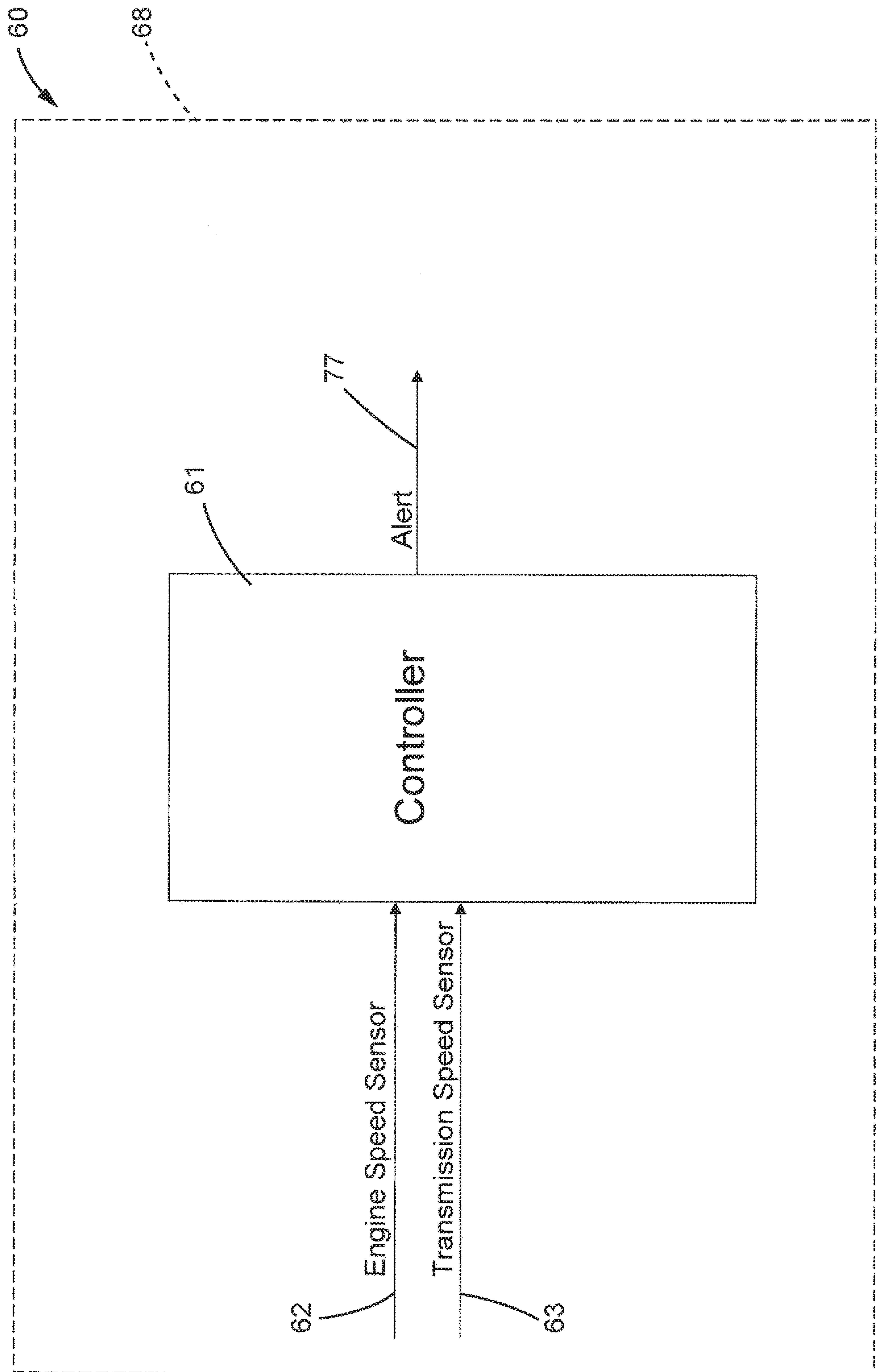
60
68
61
77
Alert
Controller
Engine Speed Sensor
Transmission Speed Sensor
62
63

FIG. 4

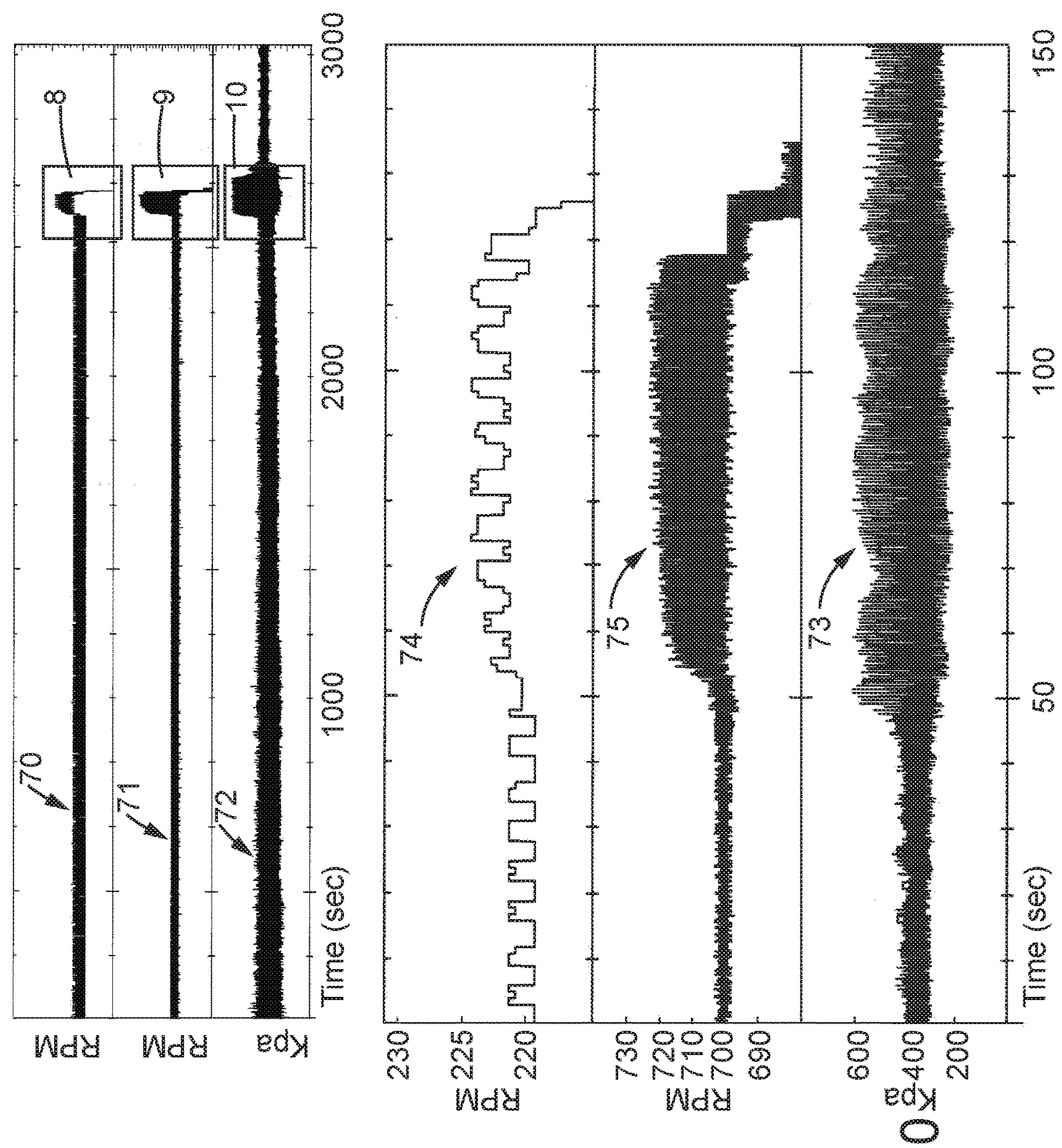

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

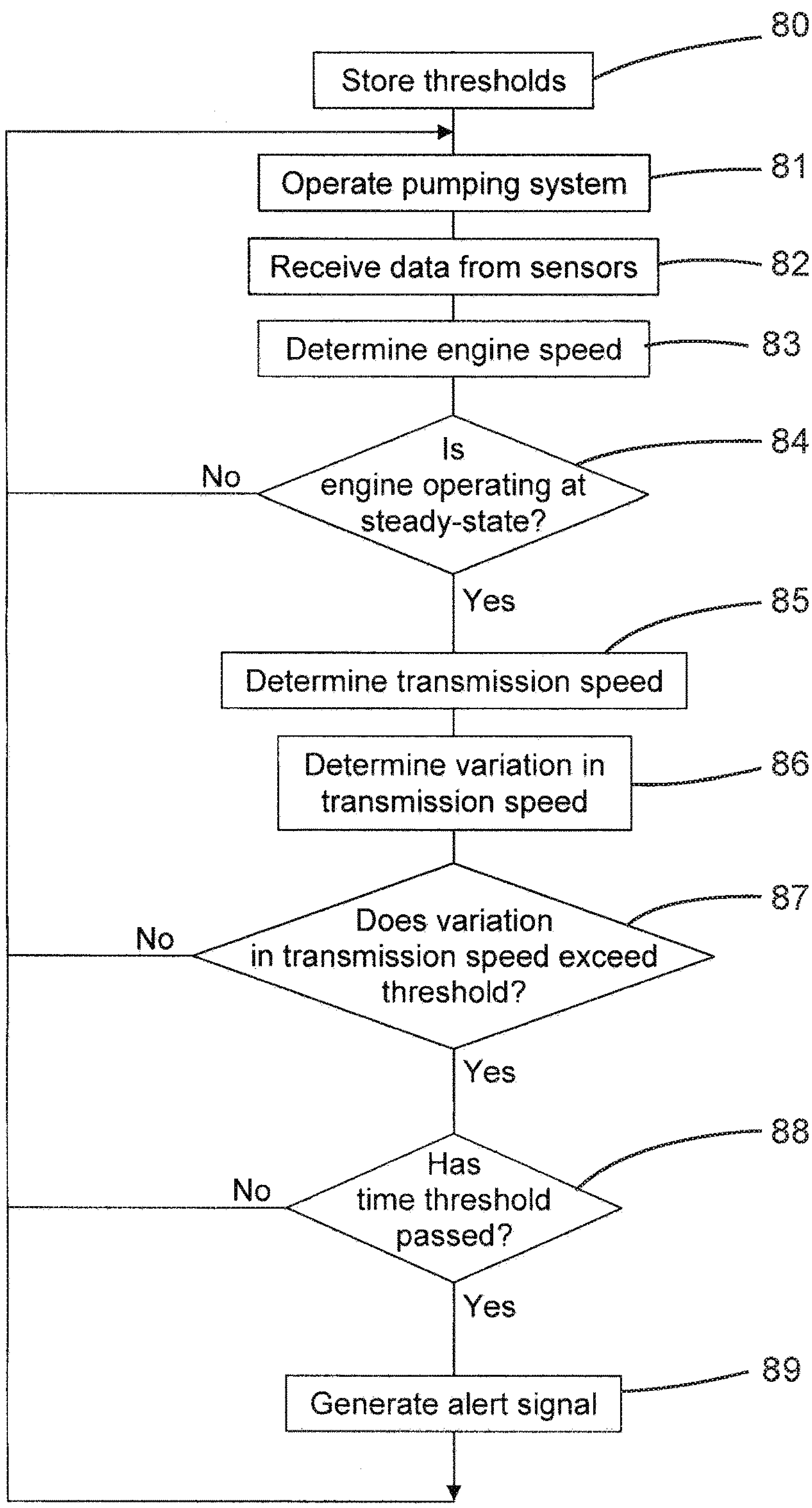
80
Store thresholds
81
Operate pumping system
82
Receive data from sensors
83
Determine engine speed
84
Is engine operating at steady-state?
No
Yes
85
Determine transmission speed
86
Determine variation in transmission speed
87
Does variation in transmission speed exceed threshold?
No
Yes
88
Has time threshold passed?
No
Yes
89
Generate alert signal

FIG. 11

PUMP MONITORING AND NOTIFICATION SYSTEM

TECHNICAL FIELD

This application relates generally to a monitoring system and, more particularly, to a system and method of monitoring the performance of a hydraulic pump and generating a notification upon a failure of the pump.

BACKGROUND

Hydraulic fracturing or fracking operations are often used during well development in the oil and gas industry. For example, in formations in which oil or gas cannot be readily or economically extracted from the earth, a hydraulic fracturing operation may be performed. Such a hydraulic fracturing operation typically includes pumping large amounts of fracking fluid at high pressure to induce cracks in the earth, thereby creating pathways via which the oil and gas may flow. Hydraulic fracturing or fracking pumps are typically relatively large positive displacement pumps. Fracking fluid often contains water, proppants and other additives and is pumped downhole by the fracking pump at a sufficient pressure to cause fractures and fissures to form within the well.

As a result of the abrasive and sometimes corrosive nature of the fracking fluid and the high pressures to which the fracking pumps are subjected, fracking pumps may be at a relatively high risk of failure. Systems have been proposed for monitoring pump failures. For example, U.S. Patent Publication No. 2016/0168976 discloses a system for detecting leakage in a fracking by monitoring the suction pressure, the discharge pressure, and a pump cylinder pressure. Each pressure may be measured by a different pressure sensor. A simplified system for monitoring a fracking pump would be desirable.

The foregoing background discussion is intended solely to aid the reader. It is not intended to limit the innovations described herein, nor to limit or expand the prior art discussed. Thus, the foregoing discussion should not be taken to indicate that any particular element of a prior system is unsuitable for use with the innovations described herein, nor is it intended to indicate that any element is essential in implementing the innovations described herein. The implementations and application of the innovations described herein are defined by the appended claims.

SUMMARY

In one aspect, a pump monitoring and notification system for a hydraulic pump includes a transmission speed sensor and a controller. The transmission speed sensor is associated with a transmission operatively connected to the hydraulic pump and generates transmission speed data indicative of an output speed of the transmission. The controller is configured to access a transmission threshold, with the transmission threshold being based upon variations in a rotational speed of the transmission, access a time threshold, and determine a rotational speed of the transmission based upon the transmission speed data from the transmission speed sensor. The controller is further configured to determine a variation in rotational speed of the transmission based upon the rotational speed, compare the variation in rotational speed of the transmission to the transmission threshold, and generate an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for a time period exceeding the time threshold.

In another aspect, a method of monitoring a hydraulic pump that is operatively connected to a transmission includes accessing a transmission threshold, with the transmission threshold being based upon variations in a rotational speed of the transmission, accessing a time threshold, and determining a rotational speed of the transmission based upon the transmission speed data from the transmission speed sensor associated with the transmission. The method further includes determining a variation in rotational speed of the transmission based upon the rotational speed, comparing the variation in rotational speed of the transmission to the transmission threshold, and generating an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for a time period exceeding the time threshold.

In still another aspect, a pump system includes a prime mover, a transmission operatively connected to and driven by the prime mover, and a hydraulic pump operatively connected to and driven by the transmission. The pump system further includes a state sensor for generating data indicative of whether the prime mover is operating at a steady-state, a transmission speed sensor associated with the transmission for generating transmission speed data indicative of an output speed of the transmission, and a controller. The controller is configured to access a transmission threshold, with the transmission threshold being based upon variations in a rotational speed of the transmission, access a time threshold, and determine a rotational speed of the transmission based upon the transmission speed data from the transmission speed sensor. The controller is further configured to determine a variation in rotational speed of the transmission based upon the rotational speed, compare the variation in rotational speed of the transmission to the transmission threshold, and generate an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for a time period exceeding the time threshold.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a pumping system supported on a trailer for transportation;

FIG. **2** is a perspective view of a hydraulic pump of the pumping system depicted in FIG. **1**;

FIG. **3** is a sectional view of a portion of the fluid section of the hydraulic pump depicted in FIG. **2**;

FIG. **4** is a block diagram of a pump monitoring and notification system in accordance with the disclosure;

FIG. **5** is an exemplary graph of rotational speed of a hydraulic pump;

FIG. **6** is an exemplary graph of rotational speed of a transmission coupled to the hydraulic pump and corresponding to the rotational speed of the hydraulic pump depicted in FIG. **5**;

FIG. **7** is an exemplary graph of inlet pressure of the hydraulic pump corresponding to the rotational speed of the hydraulic pump depicted in FIG. **5**;

FIG. **8** is an enlarged view the portion identified as **8** in FIG. **5**;

FIG. **9** is an enlarged view the portion identified as **9** in FIG. **6**;

FIG. **10** is an enlarged view the portion identified as **10** in FIG. **7**; and

FIG. **11** is a flowchart of a process of operating the pump monitoring and notification system.

DETAILED DESCRIPTION

Referring to FIG. **1**, an example of a pumping system **10** is illustrated that is particularly suited for use with geological fracturing processes to recover oil and/or natural gas from the earth. The pumping system **10** may include a prime mover such as an internal combustion engine **12**, a transmission **13** that is operatively connected to and driven by engine **12**, and a hydraulic pump **14** that is operatively connected to and driven by the transmission **13**. In one example, the engine **12** may be a compression ignition engine that combusts diesel fuel. The hydraulic pump **14** may be configured to pump hydraulic or fracking fluid into the ground to fracture rock layers during the fracturing process. Because the fracturing process may require introduction of hydraulic fluids at different locations about the fracturing site, the components of the pumping system **10** may be supported on a mobile trailer **15** disposed on wheels **16** to enable transportation of the system about the fracturing site.

The transmission **13** may be configured with a plurality of gears operative between the engine **12** and the output shaft (not shown) of the transmission to alter the rotational speed of the output from the engine. In some instances, a fixed gear mechanism or coupling depicted generally at **17** may be provided between the output shaft of the transmission **13** and the drive shaft **21** of the hydraulic pump **14** to further change or reduce the rotational speed between the engine **12** and the pump.

As depicted in FIG. **2**, hydraulic pump **14** includes a power section **20** and a fluid section **30**. The power section **20** may include an input or drive shaft **21** operatively connected to and driven by the transmission **13**. The drive shaft **21** may be operatively connected to an additional shaft **22** through gears (not shown) or other structure or mechanisms to convert rotational movement of the driveshaft into a linear movement at the fluid section **30** of the hydraulic pump **14**.

Referring to FIG. **3**, the fluid section **30** may include an inlet end **31** and an outlet end **35**, spaced from the inlet end, with one or more cylinders **40** disposed between the inlet end and the outlet end. Each cylinder **40** may include a reciprocating member such as a piston **41** disposed for reciprocating sliding movement therein.

Referring to FIG. **2**, an inlet conduit (not shown) may be fluidly connected to an inlet manifold **32** positioned at the inlet end **31**. The inlet manifold **32** may include a plurality of inlet lines **33** with each inlet line being fluidly connected to one of the cylinders **40**. The inlet end **31** may include a suction or inlet valve **42** (FIG. **3**) positioned along inlet wall **34** between each inlet line **33** and its associated cylinder **40**. In one embodiment, the inlet valve **42** may be biased in a closed condition or position and moved to its open position to permit fracking fluid to pass therethrough upon the piston **41** generating a sufficient vacuum or negative pressure.

A discharge or outlet conduit (not shown) may be fluidly connected to an outlet manifold **36** positioned at the outlet end **35**. The outlet manifold may include a plurality of outlet lines **37** with each outlet line being fluidly connected to one of the cylinders **40**, such as at a location opposite the inlet lines **33**. The outlet end **35** may include a discharge or outlet valve **43** (FIG. **3**) positioned along outlet wall **38** between each outlet line **37** and its associated cylinder **40**. In one embodiment, the outlet valve **43** may be biased in a closed condition or position and moved to its open position to permit fracking fluid to pass therethrough upon the piston **41** generating a sufficient or high enough pressure.

During a pumping process, operation of the engine **12** may drive rotation of the transmission **13** and ultimately rotation of the drive shaft **21** of the hydraulic pump **14**. Rotation of the drive shaft **21** causes reciprocating movement of the pistons **41** within cylinders **40**. The reciprocating movement of the pistons **41** may cause fracking fluid to be drawn through the inlet manifold **32** from the inlet conduit (not shown) and into the cylinders **40** through the inlet lines **33** and past the inlet valves **42**. Fracking fluid is driven by the pistons **41** past the outlet valves **43** through the outlet lines **37** and into outlet manifold **36**.

The pumping system **10** may be controlled by the control system **60** as shown generally by an arrow in FIG. **1** indicating association with the pumping system. The control system **60** may include an electronic control module or controller **61** as shown generally by an arrow in FIG. **1** and a plurality of sensors. The controller **61** may control the operation of various aspects of the pumping system **10**.

The controller **61** may be an electronic controller that operates in a logical fashion to perform operations, execute control algorithms, store, retrieve, and access data and other desired operations. The controller **61** may include or access memory, secondary storage devices, processors, and any other components for running an application. The memory and secondary storage devices may be in the form of read-only memory (ROM) or random access memory (RAM) or integrated circuitry that is accessible by the controller. Various other circuits may be associated with the controller **61** such as power supply circuitry, signal conditioning circuitry, driver circuitry, and other types of circuitry.

The controller **61** may be a single controller or may include more than one controller disposed to control various functions and/or features of the pumping system **10**. The term "controller" is meant to be used in its broadest sense to include one or more controllers and/or microprocessors that may be associated with the pumping system **10** and that may cooperate in controlling various functions and operations of the pumping system. The functionality of the controller **61** may be implemented in hardware and/or software without regard to the functionality. The controller **61** may rely on one or more data maps relating to the operating conditions and the operating environment of the pumping system **10** and the work site at which the pumping system is operating that may be stored in the memory of or associated with the controller. Each of these data maps may include a collection of data in the form of tables, graphs, and/or equations.

The control system **60** and controller **61** may be located on the trailer **15** or may be distributed with components also located remotely from or off-board the trailer.

Pumping system **10** may be equipped with a plurality of sensors that provide data indicative (directly or indirectly) of various operating parameters of elements of the system and/or the operating environment in which the system is operating. The term "sensor" is meant to be used in its broadest sense to include one or more sensors and related components that may be associated with the pumping system **10** and that may cooperate to sense various functions, operations, and operating characteristics of the element of the system and/or aspects of the environment in which the system is operating.

An engine speed sensor **62** (FIG. **4**) may be provided on or associated with the engine **12** to monitor the output speed of the engine. The engine speed sensor **62** may generate engine speed data indicative of the output speed of engine

12. The engine speed sensor **62** may be used to determine whether the engine is operating at a steady state. Other manners (e.g., combinations of other sensors) may be used as a speed sensor to generate speed data indicative of the engine speed or whether the engine is operating at a steady state. A transmission speed sensor **63** (FIG. **4**) may be provided on or associated with the transmission **13** to monitor the output speed of the transmission. The transmission speed sensor **63** may generate transmission speed data indicative of the output speed of transmission **13**.

In some instances, the hydraulic pump **14** may not include a significant number of sensors. In one example, the trailer **15** may not include electrical connections adjacent the hydraulic pump **14** and therefore the pump may not include sensors that require electrical input. In addition, the nature of and operating environment associated with the operation of the engine **12**, the transmission **13**, and the hydraulic pump **14** may result in fewer sensors being associated with the pump. For example, the hydraulic or fracking fluid may be abrasive and/or corrosive and thus the fluid section **30** of the hydraulic pump **14** may require maintenance substantially more frequently than the engine **12** or the transmission **13**. Accordingly, it may be desirable to reduce the number of sensors associated with the hydraulic pump **14**, when possible.

The abrasive and/or corrosive nature of the fracking fluid being pumped may cause substantial wear on the components of the hydraulic pump **14** and, in particular, the fluid section **30**. Leaks are often more likely to occur at locations in which components of the hydraulic pump **14** move. More specifically, leaks may be likely to occur along the inlet wall or at the inlet valve **42** as indicated by the arrow **65** in FIG. **3**, along the outlet wall or at the outlet valve **43** as indicated by the arrow **66**, and/or along the path of the piston **41** through cylinder **40** as indicated by the arrow **67**. Such leaks may reduce the performance of the hydraulic pump **14** and may be indicative of more significant future failures.

In addition to avoiding leaks in the hydraulic pump **14**, it is desirable to avoid cavitation within the pump. Cavitation may be caused by various conditions including leaks as described above as well as low pressure or low flow at the inlet end **31**. In addition to reduced performance of the hydraulic pump **14**, cavitation may also cause significant damage to the pump.

The control system **60** may include a pump monitoring and notification system **68** as shown generally by an arrow in FIG. **1** that monitors aspects of the operation of the pumping system **10**. The pump monitoring and notification system **68** may monitor the operation of the engine **12** and the transmission **13** to determine whether the hydraulic pump **14** is leaking or experiencing cavitation. In doing so, upon the engine meeting specified operating conditions, the pump monitoring and notification system **68** may analyze variations in the rotational speed of the transmission **13** to determine whether its performance is within a desired operating window.

Referring to FIGS. **5-7**, in one example, under steady state operating conditions with no leakage or cavitation, variations in the rotational speed of the hydraulic pump **14** are approximately 3 RPM as depicted at **70** in FIG. **5**, variations in the rotational speed of the transmission **13** are approximately 5 RPM as depicted at **71** in FIG. **6**, and variations in the inlet or suction pressure at or leading into the inlet lines **33** are approximately 100 kPa as depicted at **72** in FIG. **7**.

As leakage or cavitation begins to occur within the hydraulic pump **14**, vibrations will begin to occur within the pump. Such vibrations may result in and be evident as an increase in the variations in the rotational speed of the hydraulic pump **14**. In addition, the vibrations within the hydraulic pump **14** may be transferred to the transmission **13** through the coupling **17** between the pump and transmission and result in an increase in the variations in the rotational speed of the transmission. As depicted in FIG. **10**, variations in the inlet or suction pressure at or leading into the inlet lines **33** have increased substantially to approximately 350 kPa as depicted at **73** as a result of a pump failure caused by a leak or cavitation. At approximately the same time, the vibrations within the hydraulic pump **14** increase due to the pump failure and, as depicted at **74** in FIG. **8**, result in an increase in the variations in the rotational speed of the hydraulic pump **14** to approximately 5 RPM as well as slightly increase the maximum rotational speed. Vibrations within the hydraulic pump **14** are transferred to the transmission **13** through the coupling **17** between the pump and transmission. As depicted in FIG. **9**, the transferred vibrations results in an increase in the variations in the rotational speed of the transmission **13** to approximately 25 RPM as depicted at **75**. Leaks along the outlet line **37** such along outlet wall **38** or at outlet valve **43** or along the path of the piston **41** through the cylinder **40** may also cause similar changes in the variations in the rotational speed of the transmission **13** and the hydraulic pump **14**.

In one embodiment, the pump monitoring and notification system **68** may be configured to monitor the variations in the speed of rotation of the transmission **13** and generate an alert signal once the variations are equal to or greater than a predetermined transmission speed variation threshold. When monitoring the variations in the speed of the transmission **13**, the speed of the transmission is measured relatively frequently, such as every millisecond. In order to determine the variation or difference between the maximum rotational speed of the transmission **13** and the minimum rotational speed of the transmission, the speeds may be measured over a predetermined period of time while operating the transmission at a steady state. As used herein, "steady state" refers to maintaining a constant or generally constant average speed. Accordingly, the transmission speed variation threshold may be defined as a difference between the maximum rotational speed of the transmission **13** and a minimum rotational speed of the transmission over a predetermined period of time while operating the transmission at a steady state. In some instances, the transmission **13** may only be operating at steady state if the rotational input to the transmission from the engine **12** is operating at a steady state.

In one example, the transmission speed variation threshold may be approximately 25 RPM. In other examples, the pump monitoring and notification system **68** may utilize other variation in rotational speed thresholds. For example, the pump monitoring and notification system **68** may be configured to use a smaller transmission speed variation threshold such as approximately 10, 15 or 20 RPM or a larger transmission speed variation threshold such as approximately 40 or 50 RPM. In another example, the transmission speed variation threshold may be between 10-60 RPM. In still another example, the transmission speed variation threshold may be between 20-50 RPM. In a further example, the transmission speed variation threshold may be at least 10 RPM or at least 15 RPM. Still other transmission speed variation thresholds are contemplated.

In another embodiment, the pump monitoring and notification system **68** may be configured to monitor the variations in the speed of rotation of the transmission **13** and generate an alert signal if the ratio between the current variation in the operational speed of the transmission **13** and the variation in rotational speed of the transmission during steady state operation exceeds a predetermined variation ratio threshold. The variation ratio threshold may be defined as a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating at a steady state divided by a variation in the rotational speed of the transmission while operating the transmission at a steady state and without a hydraulic pump failure.

In the example depicted in FIGS. **5-10**, the variation in the rotational speed of the transmission **13** upon a leakage or cavitation is approximately 25 RPM and the variation in the rotational speed of the transmission at steady state is approximately 5 RPM. Accordingly, for such an example, the variation ratio threshold may be set at approximately 5. In other examples, the pump monitoring and notification system **68** may require a greater or lesser variation ratio threshold. For example, the pump monitoring and notification system **68** may be configured to use a smaller variation ratio threshold such as approximately 2.5, 3 or 4 or a larger variation ratio threshold such as approximately 8 or 10. In another example, the variation ratio threshold may be between 2.5 and 12. In still another example, the variation ratio threshold may be between 4 and 10. In a further example, the variation ratio threshold may be at least 2.5 or 3. Still other variation ratio thresholds are contemplated.

The pump monitoring and notification system **68** may monitor the variations in the rotational speed of the transmission **13** by measuring the rotational speed at predetermined intervals. For example, the rotational speed of the transmission **13** may be measured once every millisecond. Other measurements intervals are contemplated. In order to reduce the likelihood of false warnings or alerts, the pump monitoring and notification system **68** may be configured to require the transmission speed variation threshold or variation ratio threshold to be met or exceeded for a predetermined length of time. In one example, the pump monitoring and notification system **68** may require the transmission speed variation threshold or variation ratio threshold to be met or exceeded for 60 seconds before generating an alert signal.

In other examples, the pump monitoring and notification system **68** may require the threshold to be met or exceed for longer or shorter periods of time. For example, the time threshold may be 30 seconds, 120 seconds, or any other desired time period.

If desired, the pump monitoring and notification system **68** may include, in addition or in the alternative, an accumulator function to account for the extent or degree to which the relevant transmission threshold (e.g., transmission speed variation threshold or variation ratio threshold) is exceeded. The accumulator function may integrate the extent to which the threshold is exceeded and establish an additional or accumulator threshold for the accumulator function. The accumulator function may sum the amount by which the threshold is exceeded and the sum or accumulated result compared to the accumulator threshold. Upon exceeding the accumulator threshold, the alert signal may be generated.

As an example, the pump monitoring and notification system **68** may be configured to permit the hydraulic pump **14** to operate for a relatively long period of time before generating an alert signal if the transmission speed variation threshold or variation threshold ratio is exceeded by a relatively small amount (e.g., 10%). However, the pump monitoring and notification system **68** may generate an alert signal relatively quickly if the transmission speed variation threshold or variation threshold ratio is exceeded by a relatively large amount (e.g., 75%).

Alert signals generated by the pump monitoring and notification system **68** may take any desired form. In one example, an alert signal may provide a notice or warning to personnel or systems at the work site and/or remote from the work site. In another example, an alert signal may, in addition or in the alternative, include a command to shut-down or reduce the operation of the pumping system **10** in order to reduce the likelihood of further damage to the hydraulic pump **14**.

The pump monitoring and notification system **68** may be configured so that the controller **61** receives information from various sensors and systems of the pumping system **10** and processes the information to determine when pump leakage or cavitation is occurring without directly using or requiring the operating characteristics of the hydraulic pump **14** (e.g., input pressure, output pressure, rotational speed of the pump). As such, the pump monitoring and notification system **68** may determine that pump leakage or cavitation is occurring without sensors directly monitoring the operating characteristics of the hydraulic pump **14**.

As depicted in FIG. **4**, the controller **61** may receive data from the engine speed sensor **62** to determine the rotational speed of the engine **12** and receive data from the transmission speed sensor **63** to determine the rotational speed of the transmission **13**. Upon the engine **12** operating at a steady state condition, the pump monitoring and notification system **68** may generate an alert signal **77** when the variation in the rotational speed of the transmission **13** exceeds the transmission speed variation threshold or variation ratio threshold. In some instances, the pump monitoring and notification system **68** may be configured to require the variation in the rotational speed of the transmission **13** to exceed the transmission speed variation threshold or variation ratio threshold for a predetermined time threshold.

INDUSTRIAL APPLICABILITY

The industrial applicability of the system described herein will be readily appreciated from the foregoing discussion. The pump monitoring and notification system **68** may be used with pumping systems **10** that include a prime mover, such as an engine **12**, operatively connected to drive transmission **13**, and with the transmission operatively connected to drive the hydraulic pump **14**. The pump monitoring and notification system **68** may determine whether the hydraulic pump **14** is experiencing leakage or cavitation based upon variations in the rotational speed of the transmission **13** without monitoring additional aspects or operating characteristics of the pump.

FIG. **11** depicts one example of the operation of the pump monitoring and notification system **68**. At block **80**, a plurality of thresholds may be set or stored. The thresholds may include any type of transmission threshold based upon variations in rotational speed of the transmission **13**, such as a transmission speed variation threshold of the transmission speed, an engine speed variation threshold, and a time threshold or period of time that the variation in rotational speed of the transmission **13** must exceed the transmission speed variation threshold. In another embodiment described below, the transmission threshold may be a variation ratio threshold of the transmission speed may be set or stored.

The pumping system **10** may be operated at block **81**. Data from the engine speed sensor **62** and the transmission speed sensor **63** may be received at block **82**. At block **83**, the controller **61** may determine the engine speed based upon the engine speed data received from the engine speed sensor **62**. The controller **61** may determine at decision block **84** whether the engine **12** is operating at a steady state so that the pump monitoring and notification system **68** may be operated in an accurate manner.

If the engine **12** is not operating in a steady state manner, analysis of the variations in the transmission speed may not provide reliable data. Accordingly, when the engine **12** is not operating in a steady state manner, the pumping system **10** may continue to be operated and blocks **81**-**84** repeated.

If the engine **12** is operating in a steady state manner, the controller **61** may determine at block **85** the speed of the transmission **13** based upon the transmission speed data received from the transmission speed sensor **63**. Based upon the transmission speed, the controller **61** may determine at block **86** the magnitude of the variation in the transmission speed.

The controller **61** may access the transmission speed variation threshold and compare the magnitude of the variation in transmission speed to the transmission speed variation threshold. If the variation in transmission speed does not exceed the transmission speed variation threshold at decision block **87**, the pumping system **10** may continue to be operated and blocks **81**-**87** repeated. If the variation in transmission speed does exceed the transmission speed variation threshold, the controller **61** may access the time threshold and determine at decision block **88** whether the time during which the variation in transmission speed exceeds the transmission speed variation threshold also exceeds the time threshold. If the time threshold has not been reached, the pumping system **10** may continue to be operated and blocks **81**-**88** repeated. If the time threshold has been reached, an alert signal may be generated by controller **61** at block **89**. In some instances, the pumping system **10** may continue to be operated and blocks **81**-**89** repeated. In other instances, the alert signal may also include a command to shut down or reduce the operation of the pumping system **10**.

Other configurations of the operation of the pump monitoring and notification system **68** are contemplated. For example, rather than setting or storing a transmission speed variation threshold at block **80**, a variation ratio threshold may be set or stored that defines a threshold ratio between the magnitude of steady state operation of the transmission and the magnitude of the variation in transmission speed during a pump failure. An example using the variation ratio threshold may operate generally in accordance with the example depicted in FIG. **11** except that the magnitude of the variation of the transmission speed during steady state operation must be determined or otherwise set or stored within the controller **61**. In one embodiment, the magnitude of the variation in transmission speed during steady state operation may be set or stored by an operator or other personnel. In another embodiment, the magnitude of the variation in transmission speed during steady state operation may be determined during steady state operation of the pumping system **10**.

In another aspect of the second example that is different from the example depicted in FIG. **11**, the controller **61** may determine after block **86** the variation ratio threshold by dividing the magnitude of the variation of the transmission speed based upon the transmission speed as determined at block **85** by the variation of the transmission speed during steady state operation. Further, decision block **87** is modified to determine whether the ratio determined by the controller **61** exceeds the variation ratio threshold.

It will be appreciated that the foregoing description provides examples of the disclosed system and technique. However, it is contemplated that other implementations of the disclosure may differ in detail from the foregoing examples. All references to the disclosure or examples thereof are intended to reference the particular example being discussed at that point and are not intended to imply any limitation as to the scope of the disclosure more generally. All language of distinction and disparagement with respect to certain features is intended to indicate a lack of preference for those features, but not to exclude such from the scope of the disclosure entirely unless otherwise indicated.

Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context.

Accordingly, this disclosure includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the disclosure unless otherwise indicated herein or otherwise clearly contradicted by context.

The invention claimed is:

1. A pump monitoring and notification system for a hydraulic pump, comprising:
- a transmission speed sensor associated with a transmission operatively connected to the hydraulic pump, the transmission speed sensor being configured to generate transmission speed data indicative of an output speed of the transmission; and
- a controller configured to:
  - access a transmission threshold;
  - access a time threshold;
  - determine a rotational speed of the transmission based upon the transmission speed data from the transmission speed sensor;
  - determine a variation in rotational speed of the transmission based upon the rotational speed;
  - compare the variation in rotational speed of the transmission to the transmission threshold;
  - determine leakage or cavitation in the, pump based upon whether the variation in rotational speed of the transmission exceeds the transmission threshold for a time period exceeding the time threshold; and
  - generate an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for the time period exceeding the time threshold.

2. The pump monitoring and notification system of claim **1**, wherein the transmission threshold is a transmission speed variation threshold defined by a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating the transmission at a steady state.

3. The pump monitoring and notification system of claim **2**, wherein the transmission speed variation threshold is at least 10 RPM.

4. The pump monitoring and notification system of claim **1**, wherein the transmission threshold is a variation ratio threshold defined by a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating at a steady state divided by a variation in the rotational speed of the transmission while operating the transmission at a steady state and without a hydraulic pump failure.

5. The pump monitoring and notification system of claim **4**, wherein the variation ratio threshold is at least 2.5.

6. The pump monitoring and notification system of claim **1**, wherein the controller is further configured to only generate the alert signal if a rotational input to the transmission is operating at a steady state.

7. The pump monitoring and notification system of claim **6**, further comprising a speed sensor for generating speed data indicative of an output speed of a prime mover operatively connected to the transmission, and the controller is configured to determine a rotational speed of the prime mover based upon the speed data from the speed sensor and determine whether the rotational input to the transmission is operating at a steady state based upon the rotational speed of the prime mover.

8. The pump monitoring and notification system of claim **1**, wherein the hydraulic pump does not include a rotational speed sensor on the hydraulic pump.

9. The pump monitoring and notification system of claim **8**, wherein the alert signal includes a command to shutdown the hydraulic pump.

10. The pump monitoring and notification system of claim **1**, wherein the hydraulic pump is a fracking pump.

11. The pump monitoring and notification system of claim **1**, wherein the controller is further configured to access an accumulator threshold, integrate an extent to which the transmission threshold is exceeded to define an accumulated result, compare the accumulated result to the accumulator threshold, and generate an alert signal when the accumulated result exceeds the accumulator threshold.

12. A method of monitoring a hydraulic pump, the hydraulic pump being operatively connected to a transmission, the method comprising:

- accessing a transmission threshold;
- accessing a time threshold;
- determining a rotational speed of the transmission based upon transmission speed data from a transmission speed sensor associated with the transmission;
- determining a variation in rotational speed of the transmission based upon the rotational speed;
- comparing the variation in rotational speed of the transmission to the transmission threshold;
- determining leakage or cavitation in the pump based upon whether the variation in rotation speed of the transmission exceeds the transmission threshold for a time period exceeding the time threshold; and
- generating an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for the time period exceeding the time threshold.

13. The method of claim **12**, wherein the transmission threshold is a transmission speed variation threshold defined by a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating the transmission at a steady state, the transmission speed variation threshold being at least 10 RPM.

14. The method of claim **12**, wherein the transmission threshold is a variation ratio threshold defined by a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating at a steady state divided by a variation in the rotational speed of the transmission while operating the transmission at a steady state and without a hydraulic pump failure, the variation ratio threshold being at least 2.5.

15. The method of claim **12**, wherein the alert signal is only generated if a rotational input to the transmission is operating at a steady state.

16. The method of claim **12**, wherein the alert signal is generated without determining a rotational speed of the hydraulic pump.

17. The method of claim **16**, wherein the alert signal is generated without determining an input pressure of fluid entering the hydraulic pump or a discharge pressure of fluid discharged from the hydraulic pump.

18. A pump system comprising:

- a prime mover;
- a transmission operatively connected to and driven by the prime mover;
- a hydraulic pump operatively connected to and driven by the transmission;
- a state sensor for generating data indicative of whether the prime mover is operating at a steady state;
- a transmission speed sensor associated with the transmission for generating transmission speed data indicative of an output speed of the transmission; and
- a controller configured to:
  - access a transmission threshold;
  - access a time threshold;
  - determine that the prime mover is operating at a steady state based upon data from the state sensor;
  - determine a rotational speed of the transmission based upon the transmission speed data from the transmission speed sensor;
  - determine a variation in rotational speed of the transmission based upon the rotational speed;
  - compare the variation in rotational speed of the transmission to the transmission threshold;
  - determine leakage or cavitation n the pump based upon whether the variation in rotational speed of the transmission exceeds the transmission threshold for time period exceeding the time threshold; and
  - generate an alert signal when the variation in rotational speed of the transmission exceeds the transmission threshold for the time period exceeding the time threshold.

19. The pump system of claim **18**, wherein the transmission threshold is a transmission speed variation threshold defined by a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating the transmission at a steady state, the transmission speed variation threshold being at least 10 RPM.

20. The pump system of claim **18**, wherein the transmission threshold is a variation ratio threshold defined by a difference between a maximum rotational speed of the transmission and a minimum rotational speed of the transmission over a predetermined period of time while operating at a steady state divided by a variation in the rotational speed of the transmission while operating the transmission at a steady state and without a hydraulic pump failure, the variation ratio threshold being at least 2.5.

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