Title: PUMP SYSTEM HAVING SPEED-BASED CONTROL

Abstract: A pump system (10) is disclosed. The pump system may have a power source (12), a pump (14), and a torque converter (16) configured to fluidly couple an output rotation of the power source to an input rotation of the pump. The pump system may also have a sensor (28) configured to generate a signal indicative of an output flow rate of the pump, and a controller (26) in communication with the sensor and the power source. The controller may be configured to selectively adjust a speed of the power source based on the signal.
Description

PUMP SYSTEM HAVING SPEED-BASED CONTROL

Technical Field

The present disclosure is directed to a pump system and, more particularly, to a pump system having speed-based control.

Background

A slurry pump increases the pressure of a liquid/solid particulate mixture, and converts potential energy associated with the increased pressure into kinetic energy. Slurry pumps are widely used to transport raw minerals and ore (e.g., coal, sand, oil, etc.), waste material (e.g., sewage), and refined products (e.g., cement). Different types of slurry include positive displacement plunger pumps, centrifugal pumps, a lobe pump, or a peristaltic hose pump.

A conventional slurry pump system includes a power source (e.g., an engine or electric motor) connected through a gear box to a pump. The gear box typically includes a single gear ratio of about 7:1 or higher. In some applications, multiple different gear ratios are available. The gear box provides a direct mechanical connection from the power source to the pump. In these configurations, the power source is typically operated at a constant speed to provide a single flow rate of slurry from the pump for each available gear ratio.

One problem with a conventional slurry pump system involves flow rate consistency. In particular, as a load on the pump changes due to changing conditions at an associated well or mine (e.g., due to a density change or plugged hose), the flow rate of slurry from the pump will likewise fluctuate. In some applications, this fluctuation is undesired.

An attempt to address fluctuations in pump flow rate is described in U.S. Patent No. 6,033,187 that issued to Addie on March 7, 2000 ("the '187 patent"). Specifically, the '187 patent discloses a way to determine an instantaneous pressure produced by a slurry pump. Using this pressure, along with an overall total pipeline resistance, an optimal operating speed of the pump may then be determined. This speed may then be controlled, for example by changing the output ratio of the gear box (if available), to improve stability of the pumping system.
Although the system of the '187 patent may be adequate for some applications, it may also suffer from drawbacks. In particular, it may be difficult and time consuming (or not even possible) to change the output ratio of the gear box. In addition, this change may only provide step-wise adjustment in pump speed, which may lack fine control necessary for some operations. Further, the gear box required to provide the desired ratio(s) may be large, heavy, and expensive.

The disclosed pump system of the present disclosure is directed at solving one or more of the problems set forth above and/or other problems in the art.

Summary

In one aspect, the present disclosure is directed to a pump system. The pump system may include a power source, a pump, and a torque converter configured to fluidly couple an output rotation of the power source to an input rotation of the pump. The pump system may also include a sensor configured to generate a signal indicative of an output flow rate of the pump, and a controller in communication with the sensor and the power source. The controller may be configured to selectively adjust a speed of the power source based on the signal.

In another aspect, the present disclosure is directed to a method of controlling a system having a power source fluidly coupled to a pump. The method may include sensing a parameter indicative of an actual output flow rate of the pump. The method may also include selectively adjusting a speed of the power source based on the parameter.

In yet another aspect, the present disclosure is directed to a method of forming a well with a power source fluidly coupled to a well-forming device. The method may include sensing a parameter indicative of an actual output of the well-forming device. The method may further include selectively adjusting a speed of the power source based on the parameter.

Brief Description of the Drawing

Fig. 1 is a schematic illustration of an exemplary disclosed pumping system.
Detailed Description

Fig. 1 illustrates an exemplary disclosed pumping system 10. Pumping system 10 may include, among other things, a power source 12 operatively connected to a pump 14 by way of a torque converter 16 and a gear box 18. Power source 12 may be configured to generate a rotational power output. Torque converter 16 may be configured to transfer at least a portion of the power output to gear box 18. Gear box 18 may convert the rotation received from torque converter 16 to a rotation having a different speed and torque, and deliver the converted rotation as an input to drive pump 14.

Power source 12 may produce a rotational output having both speed and torque components, and may embody an internal combustion engine. For example, power source 12 may be a diesel engine, a gasoline engine, a gaseous fuel-powered engine, or any other engine apparent to one skilled in the art. Power source 12 may contain an engine block having a plurality of cylinders (not shown), reciprocating pistons disposed within the cylinders (not shown), and a crankshaft operatively connected to the pistons (not shown). The internal combustion engine may use a combustion cycle to convert potential energy (usually in chemical form) within the cylinders to a rotational output of the crankshaft, which may in turn rotate an input of torque converter 16.

Torque converter 16 may be used to transmit power from the crankshaft of power source 12 into gear box 18. In the disclosed embodiment, torque converter 16 is a hydro-mechanical device that allows the crankshaft of power source 12 to rotate somewhat independently of an input shaft of gear box 18. In this example, torque converter 16 includes an impeller (not shown) fixedly connected to the crankshaft of power source 12, and a turbine (not shown) fixedly connected to the input shaft of gear box 18. The impeller may be fluidly coupled with the turbine, such that as the impeller rotates, a pressurized flow of fluid may be generated and directed through the turbine, driving the turbine to also rotate. At low fluid flow rates and pressures (or when pump 14 is heavily and/or suddenly loaded), the impeller may rotate at a higher speed relative to the turbine. However, as the pressure and the flow rate of the fluid conducted between the impeller and turbine increases (or when pump 14 is lightly loaded), the rotational speed of the turbine may approach the rotational speed of the impeller. This may allow power source 12 to rotate at a different
speed and torque than gear box 18, depending on operating conditions, with the
difference in speed and torque being accounted for by shearing losses (i.e., heat)
within the fluid.

It is contemplated that torque converter 16 could alternatively be
another type of fluidic or non-fluidic coupling, if desired. For example, torque
converter 16 could include friction plates coupled to the crankshaft and gear box
shaft. The friction plates would be configured to slidingly and rotationally
engage each other, and thereby transfer a percentage of the power generated by
power source 12 into gear box 18. Other configurations of torque converter 16
may also be possible.

In some embodiments, torque converter 16 may also include a
lockup clutch (generically represented by a box 20 in Fig. 1) disposed in parallel
with the impeller and turbine (or friction plates, if so equipped). Lockup clutch
20 may be configured to selectively and mechanically lock the crankshaft
directly to the gear box input shaft, such that both shafts rotate at the same speed.
Lockup clutch 20, if included, may be activated manually or automatically, as
will be described below.

Gear box 18 may include numerous components that interact to
transmit power received from power source 12 (via torque converter 16) to pump
14. In particular, gear box 18 may embody a mechanical transmission having
one or more forward gear ratios. In some embodiments, gear box 18 may also
include a neutral position and/or one or more reverse gear ratios. In
embodiments where more than one gear ratio is included, gear box 18 may
additionally include one or more clutches (not shown) for selectively engaging
predetermined combinations of gears (not shown) that produce a desired gear
ratio.

Gear box 18, if equipped with multiple gear combinations, may
be an automatic-type transmission wherein shifting between gear ratios is based
on a power source speed, a maximum operator selected gear ratio, a load from
pump 14, and/or a fluid pressure within gear box 18. Alternatively, gear box 18
may be a manual transmission, wherein the operator manually engages the
desired gear combinations. Regardless of the type of transmission, the output of
gear box 18 may be connected to rotatably drive an input shaft of pump 14.
In the disclosed embodiment, each ratio of gear box 18 may be about 7:1 or less. In particular, gear box 18 may be configured to produce an output speed that is about the same as or up to seven times less than an input speed received by gear box 18. This reduction may typically be too small to accommodate slurry pumping applications with high accuracy. That is, transmissions typically used in slurry pumping applications require speed reductions of 7:1 or greater. However, when used in conjunction with torque converter 16 in its unlocked state (i.e., during a torque converter drive mode), slippage between the impeller and the turbine (or between the friction plates) combines with the ratio reduction of gear box 18 to produce sufficiently high speed reductions (i.e., reductions greater than about 7:1). In this way, a smaller, lighter, and cheaper gear box 18 may be used to produce flow rates required in slurry pumping applications.

Pump 14, in the disclosed example, is a positive displacement plunger pump capable of generating an output flow rate of about 10-20 gallons per minute. In particular, pump 14 may include a crankshaft, one or more plungers rotatably connected to the crankshaft, and valves (e.g., one-way inlet and discharge valves) disposed within a common housing. Pump 14 may be configured to transport a fluid/particle mixture (e.g., oil sands, sewage, petroleum, petrochemicals, cement, etc.) by the conversion of rotational kinetic energy of the plunger(s) to hydrodynamic energy of the mixture. The mixture may be drawn into the housing through an inlet valve during an expanding stroke of the plunger(s), and pushed out of the housing through an outlet valve during a compressing stroke of the plunger(s). In this configuration, the crankshaft of the pump may be directly driven by the output shaft of gear box 18 at a speed that is about seven or more times slower than the output speed of power source 12. It is contemplated that pump 14 may be a different type of pump, if desired, such as a centrifugal pump, a lobe pump, or a peristaltic hose pump. Pump 14 may produce an output flow rate dependent on conditions of the fluid/particle mixture (e.g., density, viscosity, etc.), a size (e.g., area, stroke length, and/or swept volume) of the plunger(s), and the input rotation (i.e., speed and torque) provided by gear box 18.

A controller 26 may be associated with pumping system 10, and configured to regulate the output flow rate of pump 14. In particular, controller
26 may be configured to receive from a sensor 28 an indication of an actual
output flow rate of pump 14, receive from the operator an indication of a desired
output flow rate of pump 14, and responsively adjust operation of power source
12 to reduce an error between the actual and desired output flow rates. In one
example, sensor 28 is a speed sensor associated with the crankshaft of pump 14
and/or a shaft (input or output) of gear box 18. In this example, signals
generated by sensor 28 may be used by controller 26 to calculate the actual flow
rate of pump 14. It is contemplated, however, that sensor 28 could otherwise be
configured to directly sense the actual flow rate and/or sense other or additional
flow rate parameters (e.g., pressure) that subsequently may be used by controller
26 to calculate the actual output flow rate, if desired. Controller 26 may be
configured to adjust the speed of power source 12 by adjusting fueling of power
source 12.

Controller 26 may embody a single processor or multiple
processors that include a means for controlling an operation of pumping system
10. Numerous commercially available processors may perform the functions of
controller 26. Controller 26 may include or be associated with a memory for
storing data such as, for example, an operating condition, design limits,
performance characteristics or specifications of pumping system 10, operational
instructions, and corresponding fueling parameters. This data may be stored
within the memory of controller 26 in the form of one or more lookup tables, as
desired. Various other known circuits may be associated with controller 26,
including power supply circuitry, signal-conditioning circuitry, solenoid driver
circuitry, communication circuitry, and other appropriate circuitry. Moreover,
controller 26 may be capable of communicating with other components of
pumping system 10 (e.g., with a fuel system of the engine, with lockup clutch
20, with sensor 28, etc.) via either wired or wireless transmission and, as such,
controller 26 may be connected to or alternatively disposed in a location remote
from power source 12 and/or pump 14.

The operator of pumping system 10 may be able to input
instructions via one or more interface devices (e.g., a keyboard, touchscreen
monitor, etc.) located at a control panel that also houses controller 26. These
instructions may include, among other things, a desired output flow rate of pump
14, a desired gear ratio of gear box 18, and/or a status of lockup clutch 20 (e.g.,
engaged or disengaged). Signals indicative of these instructions may be directed to controller 26 for further processing.

Industrial Applicability

The disclosed pumping system may be used in any application to generate a flow of fluid. The disclosed pumping system may be particularly applicable to slurry pumping applications, where flow control accuracy over dense mixtures is important. The disclosed pumping system may provide for improved flow control accuracy of a relatively dense fluid/particle mixture in a lightweight, inexpensive configuration. Operation of pumping system 10 will now be described in detail.

One exemplary application for pumping system 10 is a cementing application. In a cementing application, a relatively dense cement slurry is directed into a well bore by pump 14 during drilling of the well. This slurry displaces drilling fluids in the bore, and forms a casing for the bore during the drilling process. In order for the integrity of the casing to be maintained, the flow rate of the slurry into the well bore must be tightly controlled.

To initiate operation of pumping system 10 during the cementing process, the operator may input, via the control panel, a desired output flow rate of pump 14, a desired ratio of gear box 18, and a desired state of lockup clutch 20. In most slurry pumping applications, lockup clutch 20 (if gear box 18 is equipped with lockup clutch 20) may remain disengaged, such that the input rotation of torque converter 16 is at least somewhat independent of the output rotation of power source 12. As described above, the torque converter drive mode of operation, in combination with the available ratios of gear box 18, may produce overall ratios of about 7:1 or higher. In some applications, gear box 18 may have only one available gear combination and/or controller 26 may be configured to automatically select a gear combination without receiving corresponding instruction from the operator. Accordingly, it may be possible that the operator is required to only input a desired output flow rate of pump 14.

While pumping the cement slurry into the well bore, the actual output flow rate of pump 14 may be monitored by way of sensor 28. Specifically, signals generated by sensor 28 may be directed to controller 26 and, based on the values of these signals, controller 26 may calculate or otherwise
determine the actual output flow rate of pump 14. Controller 26 may then determine an error as a function of the actual and desired output flow rates. For example, controller 26 may determine a difference between these flow rates.

If the supply of cement slurry is too fast or too slow, casing formation may be disrupted. Accordingly, controller 26 may be configured to reference the difference between the actual output flow rate and the desired output flow rate with the lookup table stored in memory to determine if a change in the speed of power source 12 is required to properly support the drilling operation. A new speed and/or fuel setting of power source 12 may then be determined that produces the required change output flow rate, and controller 26 may issue a command to power source 12 to operate at the new fuel setting and/or speed (i.e., controller 26 may only command a new speed setting, and a separate speed governor may then issue a corresponding fuel command). In other words, the output flow rate of pump 14 may be directly controlled via speed control of power source 12 when pumping system 10 is operating in the torque converter drive mode.

The disclosed pumping system 10 may provide an accurate way to control the output flow rate of pump 14. In particular, based on feedback from sensor 28, controller 26 may adjust the speed of (e.g., the fueling of) power source 12 until the actual output flow rate of pump 14 substantially matches the output flow rate desired by the operator (e.g., within a threshold amount). In the exemplary cementing application, controller 26 may adjust the speed of power source 12 to maintain a substantially constant output flow rate of about 10-20 gallons per minute, even with variations in load on pump 14. And, in contrast to the step-wise adjustment of conventional slurry pumping systems, the amount of power source speed adjustment may be infinitely variable, allowing for fine control.

The disclosed pumping system may also be lightweight and inexpensive. In particular, because gear box 18 may require fewer gear combinations (e.g., only one) and/or gear combinations provided by way of smaller and cheaper gear sets, the weight and cost of gear box 18 may be low. It will be apparent to those skilled in the art that various modifications and variations can be made to the pumping system of the present disclosure. Other embodiments of the pumping system will be apparent to those
skilled in the art from consideration of the specification and practice of the
invention disclosed herein. For example, it is contemplated that power source
12, torque converter 16, and transmission 18 could alternatively or additionally
be connected to drive at variable speed and torque another device utilized in the
well-forming process. For example, pump 14 may be replaced by or joined by a
tracking pump and/or a drill that is driven by the output shaft of transmission 18.
In these embodiments, the well-forming device(s) could be speed controlled in
the same manner described above with respect to pump 14 (i.e., the output of
these devices may be monitored and varied by adjusting operation of power
source 12). It is intended that the specification and examples be considered as
exemplary only, with a true scope of the invention being indicated by the
following claims and their equivalents.
Claims

1. A pump system (10), comprising:
a power source (12);
a pump (14);
a torque converter (16) configured to fluidly couple an output
rotation of the power source to an input rotation of the pump;
a sensor (28) configured to generate a signal indicative of an
output flow rate of the pump; and
a controller (26) in communication with the sensor and the power
source, the controller being configured to selectively adjust a speed of the power
source based on the signal.

2. The pump system of claim 1, wherein:
the power source is an engine; and
the controller is configured to selectively adjust the speed of the power
source by adjusting fueling of the engine.

3. The pump system of claim 2, wherein the controller includes a
table stored in memory relating the output flow rate of the pump to a speed of
the engine.

4. The pump system of claim 1, further including a mechanical
gear box (18) connected between the torque converter and the pump.

5. The pump system of claim 4, wherein the mechanical gear box
includes a plurality of selectable gear combinations.

6. The pump system of claim 5, wherein each of the plurality of
manually selectable gear combinations creates an input-to-output speed ratio of
7:1 or less.

7. The pump system of claim 6, wherein the controller is
configured to selectively adjust the speed of the power source to maintain a
pump output flow rate of about 10-20 gallons per minute.
8. The pump system of claim 1, further including an input device configured to manually receive from an operator a desired pump flow rate, wherein the controller is configured to selectively adjust the speed of the power source based further on the desired pump flow rate.

9. The pump system of claim 1, wherein:
   the torque converter includes a lockable clutch (20); and
   the controller is configured to selectively cause the lockable clutch to engage and mechanically connect the output rotation of the power source to the input rotation of the pump.

10. The pump system of claim 9, further including an input device configured to manually receive from an operator an indication of a desire to engage the lockable clutch, wherein the controller is configured to selectively cause the lockable clutch to engage based on the indication.
**A. CLASSIFICATION OF SUBJECT MATTER**

F04B 49/06(2006.01)i, F04B 17/03(2006.01)i, G05D 7/06(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

F04B 49/06; F04B 49/00; F04B 49/12; A62C 27/00; A62C 3/00; F04D 29/44; F04B 17/03; G05D 7/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

- Korean utility models and applications for utility models
- Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: pump, torque converter, transmission, sensor, controller, look-up table, input device, and gear combination

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>US 2006-0245934 (DEIVASIGAMANI, Sridhar) 02 November 2006 See paragraphs [0015]-[0021], [0028]-[0036], [0037] and figure 1.</td>
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Further documents are listed in the continuation of Box C.

- **"A"** document defining the general state of the art which is not considered to be of particular relevance
- **"E"** earlier application or patent but published on or after the international filing date
- **"H"** document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- **"O"** document referring to an oral disclosure, use, exhibition or other means
- **"P"** document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search

28 April 2015 (28.04.2015)

Date of mailing of the international search report

28 April 2015 (28.04.2015)

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