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Inventor(s)	Damm; Shawn M. et al.

Control of an impeller clutch of a torque converter for a gaseous fuel engine

Abstract

A hydraulic fracturing pump system may include a hydraulic fracturing pump, a gaseous fuel engine configured to drive the hydraulic fracturing pump, and a transmission system including a gear system mechanically coupled to the hydraulic fracturing pump and torque converter configured to fluidly couple the gaseous fuel engine and the gear system. The torque converter may include an impeller, a turbine fluidly coupled to the impeller and mechanically coupled to the gear system, a stator positioned between the impeller and the turbine, an impeller clutch configured to mechanically couple the impeller to the gaseous fuel engine, and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system.

Inventors: **Damm; Shawn M. (Houston, TX), Harms; Rodney D. (Houston, TX), Kabrich; Todd Ryan (Tomball, TX), He; Yuesheng (Sugar Land, TX), Uddanda; Sri Harsha (Cypress, TX)**

Applicant: **Caterpillar Inc.** (Peoria, IL)

Family ID: **1000008765184**

Assignee: **Caterpillar Inc. (Peoria, IL)**

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Primary Examiner: Fluhart; Stacey A

Background/Summary

TECHNICAL FIELD

(1) The present disclosure relates generally to torque converters and, for example, to control of an impeller clutch of a torque converter for a gaseous fuel engine.

BACKGROUND

(2) Hydraulic fracturing is a well stimulation technique that typically involves pumping hydraulic fracturing fluid into a wellbore at a rate and a pressure (e.g., up to 15,000 pounds per square inch

(psi)) sufficient to form fractures in a rock formation surrounding the wellbore. This well stimulation technique often enhances the natural fracturing of a rock formation to increase the permeability of the rock formation, thereby improving recovery of water, oil, natural gas, and/or other fluids. A hydraulic fracturing pump (or a "well stimulation pump") may be powered by a diesel engine or a diesel/natural gas dual-fuel engine (e.g., a dynamic gas blending (DGB) engine), which are capable of handling high load rise rates. However, diesel engines and diesel/natural gas dual-fuel engines are associated with high levels of greenhouse gas emissions and high fuel costs.
(3) Gaseous fuels, such as natural gas, may be less expensive than other hydrocarbon fuels, more readily available in remote areas, and may burn relatively cleaner during operation. A typical gaseous fuel internal combustion engine differs from a traditional, liquid fuel internal combustion engine primarily in that a gaseous fuel (e.g., methane, natural gas, ethane, and/or propane) is burned in the engine rather than an atomized mist of liquid fuel from a fuel injector or carburetor. Most gaseous fuel engines operate using spark ignition by a conventional spark plug. While gaseous fuel engines have a number of benefits, gaseous fuel engines are typically associated with poor load acceptance or otherwise poor response to changes in load. This is because a gaseous fuel engine may be associated with a relatively long path between cylinders of the engine and a fuel inlet to the engine, and it may take several seconds before a volume of gaseous fuel in the engine can be adjusted to a new level. Accordingly, a gaseous fuel engine generally has been considered unsuitable for driving a hydraulic fracturing pump because of the high load rise rates associated with hydraulic fracturing operations due to gear shifts or due to a hydraulic fracturing pump being brought online in the middle of a fracturing stage.
(4) The torque converter of the present disclosure solves one or more of the problems set forth above and/or other problems in the art.
SUMMARY
(5) A hydraulic fracturing pump system may include a hydraulic fracturing pump, a gaseous fuel engine configured to drive the hydraulic fracturing pump, and a transmission system including a gear system mechanically coupled to the hydraulic fracturing pump and a torque converter configured to fluidly couple the gaseous fuel engine and the gear system. The torque converter may include an impeller, a turbine fluidly coupled to the impeller and mechanically coupled to the gear system, a stator positioned between the impeller and the turbine, an impeller clutch configured to mechanically couple the impeller to the gaseous fuel engine, and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system.
(6) A transmission system may include a gear system configured to couple to a hydraulic fracturing pump and a torque converter configured to fluidly couple a gaseous fuel engine and the gear system. The torque converter may include an impeller; a turbine fluidly coupled to the impeller and mechanically coupled to the gear system, a stator positioned between the impeller and the turbine, an impeller clutch configured to mechanically couple the impeller to the gaseous fuel engine, and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system.
(7) A torque converter to fluidly couple a gaseous fuel engine and a gear system mechanically coupled to a hydraulic fracturing pump may include an impeller, a turbine fluidly coupled to the impeller, a stator positioned between the impeller and the turbine, an impeller clutch configured to couple the impeller to the gaseous fuel engine, and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a diagram illustrating an example hydraulic fracturing system.
(2) FIG. **2** is a diagram illustrating an example pump system.

(3) FIG. **3** is a flowchart of an example process associated with control of an impeller clutch of a torque converter for a gaseous fuel engine.

DETAILED DESCRIPTION

(4) FIG. **1** is a diagram illustrating an example hydraulic fracturing system **100**. For example, FIG. **1** depicts a plan view of an example hydraulic fracturing site along with equipment that is used during a hydraulic fracturing process. In some examples, less equipment, additional equipment, or alternative equipment to the example equipment depicted in FIG. **1** may be used to conduct the hydraulic fracturing process.

(5) The hydraulic fracturing system **100** includes a well **102**. Hydraulic fracturing is a well-stimulation technique that uses high-pressure injection of fracturing fluid into the well **102** and corresponding wellbore in order to hydraulically fracture a rock formation surrounding the wellbore. While the description provided herein describes hydraulic fracturing in the context of wellbore stimulation for oil and gas production, the description herein is also applicable to other uses of hydraulic fracturing.

(6) High-pressure injection of the fracturing fluid may be achieved by one or more pump systems **104** (e.g., hydraulic fracturing pump systems) that may be mounted (or housed) on one or more hydraulic fracturing trailers **106** (which also may be referred to as "hydraulic fracturing rigs") of the hydraulic fracturing system **100**. Each of the pump systems **104** includes at least one fluid pump **108** (referred to herein collectively, as "fluid pumps **108**" and individually as "a fluid pump **108**"). The fluid pumps **108** may be hydraulic fracturing pumps. The fluid pumps **108** may include various types of high-volume hydraulic fracturing pumps, such as triplex or quintuplex pumps. Additionally, or alternatively, the fluid pumps **108** may include other types of reciprocating positive-displacement pumps or gear pumps. A type and/or a configuration of the fluid pumps **108** may vary depending on the fracture gradient of the rock formation that will be hydraulically fractured, the quantity of fluid pumps **108** used in the hydraulic fracturing system **100**, the flow rate necessary to complete the hydraulic fracture, the pressure necessary to complete the hydraulic fracture, or the like. The hydraulic fracturing system **100** may include any number of trailers **106** having fluid pumps **108** thereon in order to pump hydraulic fracturing fluid at a predetermined rate and pressure.

(7) In some examples, the fluid pumps **108** may be in fluid communication with a manifold **110** via various fluid conduits **112**, such as flow lines, pipes, or other types of fluid conduits. The manifold **110** combines fracturing fluid received from the fluid pumps **108** prior to injecting the fracturing fluid into the well **102**. The manifold **110** also distributes fracturing fluid to the fluid pumps **108** that the manifold **110** receives from a blender **114** of the hydraulic fracturing system **100**. In some examples, the various fluids are transferred between the various components of the hydraulic fracturing system **100** via the fluid conduits **112**. The fluid conduits **112** include low-pressure fluid conduits **112**(**1**) and high-pressure fluid conduits **112**(**2**). In some examples, the low-pressure fluid conduits **112**(**1**) deliver fracturing fluid from the manifold **110** to the fluid pumps **108**, and the high-pressure fluid conduits **112**(**2**) transfer high-pressure fracturing fluid from the fluid pumps **108** to the manifold **110**.

(8) The manifold **110** also includes a fracturing head **116**. The fracturing head **116** may be included on a same support structure as the manifold **110**. The fracturing head **116** receives fracturing fluid from the manifold **110** and delivers the fracturing fluid to the well **102** (via a well head mounted on the well **102**) during a hydraulic fracturing process. In some examples, the fracturing head **116** may be fluidly connected to multiple wells.

(9) The blender **114** combines proppant received from a proppant storage unit **118** with fluid received from a hydration unit **120** of the hydraulic fracturing system **100**. In some examples, the proppant storage unit **118** may include a dump truck, a truck with a trailer, one or more silos, or other types of containers. The hydration unit **120** receives water from one or more water tanks **122**. In some examples, the hydraulic fracturing system **100** may receive water from water pits, water

trucks, water lines, and/or any other suitable source of water. The hydration unit **120** may include one or more tanks, pumps, gates, or the like.
(10) The hydration unit **120** may add fluid additives, such as polymers or other chemical additives, to the water. Such additives may increase the viscosity of the fracturing fluid prior to mixing the fluid with proppant in the blender **114**. The additives may also modify a pH of the fracturing fluid to an appropriate level for injection into a targeted formation surrounding the wellbore. Additionally, or alternatively, the hydraulic fracturing system **100** may include one or more fluid additive storage units **124** that store fluid additives. The fluid additive storage unit **124** may be in fluid communication with the hydration unit **120** and/or the blender **114** to add fluid additives to the fracturing fluid.
(11) In some examples, the hydraulic fracturing system **100** may include a balancing pump **126**. The balancing pump **126** provides balancing of a differential pressure in an annulus of the well **102**. The hydraulic fracturing system **100** may include a data monitoring system **128**. The data monitoring system **128** may manage and/or monitor the hydraulic fracturing process performed by the hydraulic fracturing system **100** and the equipment used in the process. In some examples, the management and/or monitoring operations may be performed from multiple locations. The data monitoring system **128** may be supported on a van, a truck, or may be otherwise mobile. The data monitoring system **128** may include a display for displaying data for monitoring performance and/or optimizing operation of the hydraulic fracturing system **100**. In some examples, the data gathered by the data monitoring system **128** may be sent off-board or off-site for monitoring performance and/or performing calculations relative to the hydraulic fracturing system **100**.
(12) The hydraulic fracturing system **100** includes a controller **130**. The controller **130** may be a system-wide controller for the hydraulic fracturing system **100** or a pump-specific controller for a pump system **104**. The controller **130** may be communicatively coupled (e.g., by a wired connection or a wireless connection) with one or more of the pump systems **104**. The controller **130** may also be communicatively coupled with other equipment and/or systems of the hydraulic fracturing system **100**.
(13) As indicated above, FIG. **1** is provided as an example. Other examples may differ from what is described with regard to FIG. **1**.
(14) FIG. **2** is a diagram illustrating an example pump system **200**. The pump system **200** may correspond to a pump system **104**, described herein. The pump system **200** includes a powertrain that includes a pump **202**, a transmission system **204**, and an engine **206**. The transmission system **204** may include a torque converter **208** and a gear system **230**.
(15) The pump **202** may be a hydraulic fracturing pump. For example, the pump **202** may correspond to a fluid pump **108**, described herein. The gear system **230** is mechanically coupled to the pump **202**. The gear system **230** provides multiple gear ratios (or “gears”) to allow driving of the pump **202** at various speeds and torques. The transmission system **204** may be a type of automatic transmission. The engine **206** may be a gaseous fuel engine (e.g., an engine operable by spark ignition of a gaseous fuel). The engine **206** may include a crankshaft (not shown), configured for rotation in the engine **206** to rotate a flywheel (not shown). The engine **206** is configured to drive (e.g., provide power to) the pump **202** via the transmission system **204**.
(16) The torque converter **208** (e.g., a fluid coupling device) is configured to fluidly couple the engine **206** and the gear system **230**. The torque converter **208** includes an impeller **210** (shown as “I” in FIG. **2**), a turbine **212** (shown as “T” in FIG. **2**), and a stator **214** (shown as “S” in FIG. **2**), positioned between the impeller **210** and the turbine **212**, within a housing **216**. The housing **216** is filled with a fluid (e.g., transmission fluid). In operation, a toroidal fluid flow circuit is created by the impeller **210**, the turbine **212**, and the stator **214**.
(17) The housing **216** is mechanically coupled to the engine **206**. For example, the housing **216** may be mechanically coupled to (e.g., mounted on) the flywheel of the engine **206**. The turbine **212** is mechanically coupled to the gear system **230**. For example, the turbine **212** may be operatively

coupled to an output shaft **218** (which may also be referred to as a "transmission input shaft") that is coupled to the gear system **230**.

(18) Operation of the engine **206** rotates the housing **216**, and the housing **216** transfers rotational forces to the impeller **210** (e.g., which may be coupled to an interior surface of the housing **216**). The impeller **210** includes an array of blades that directs fluid toward the turbine **212** in response to rotation of the impeller **210**. The turbine **212** is fluidly coupled to the impeller **210**. For example, the turbine **212** is hydrodynamically coupled to the impeller **210** so that rotation of the impeller **210** drives the turbine **212**. Thus, fluid pumped by the impeller **210** rotates the turbine **212**, thereby transferring torque from the engine **206** to the gear system **230**. The turbine **212** also includes an array of blades that directs fluid toward the impeller **210** in response to rotation of the turbine **212**. The stator **214**, positioned between the impeller **210** and the turbine **212**, redirects fluid exiting from the turbine **212** toward the impeller **210**. The stator **214** also includes an array of blades configured to control a direction of fluid flow exiting from the turbine **212** to align with a direction of the fluid flow with respect to the impeller **210**, which produces a torque multiplication effect when the engine **206** is operating at a low speed (e.g., when a speed of the engine **206** is less than a speed of the pump **202**). The stator **214** may be restricted against rotating in an opposite direction of the fluid flow (e.g., via a one-way clutch).

(19) The torque converter includes a lockup clutch **220** and an impeller clutch **222**. In some implementations, the gear system **230** and the torque converter **208** (including the lockup clutch **220** and the impeller clutch **222**) may be housed together.

(20) The lockup clutch **220** is configured to mechanically couple (e.g., selectively) the engine **206** and the gear system **230** (e.g., via the torque converter **208** without fluid coupling). For example, the lockup clutch **220** may be configured to mechanically couple the turbine **212** to the engine **206**. The lockup clutch **220** may be located in the housing **216** (e.g., between the turbine **212** and an interior surface of the housing **216**). The lockup clutch **220** may be configured to couple the turbine **212** to the housing **216**, such that the housing **216** transfers rotational forces to the turbine **212** during operation of the engine **206**. The lockup clutch **220** may be a friction clutch.

(21) The lockup clutch **220** is configured to transition between a disengaged state and an engaged state (e.g., by hydraulic control of the lockup clutch **220**). The lockup clutch **220** may be slipped (e.g., partially engaged) when transitioning between engagement and disengagement or between disengagement and engagement. Disengagement of the lockup clutch **220** results in fluid coupling of the engine **206** and the gear system **230** via the torque converter **208**. Engagement of the lockup clutch results in mechanical coupling of the engine **206** and the gear system **230** via the torque converter **208**. The lockup clutch **220** may be engaged when a speed of the turbine **212** corresponds to (e.g., is substantially the same as) a speed of the impeller **210**. Mechanical coupling of the engine **206** and the gear system **230** more efficiently transfers power from the engine **206** to the gear system **230** relative to fluid coupling.

(22) The impeller clutch **222** may be configured to mechanically couple (e.g., selectively) the impeller **210** to the engine **206**. The impeller clutch **222** may be located in the housing **216** (e.g., between the impeller **210** and an interior surface of the housing **216**). The impeller clutch **222** may be configured to couple the impeller **210** to the housing **216**, such that the housing **216** transfers rotational forces to the impeller **210** during operation of the engine **206**. The impeller clutch **222** may be a friction clutch. In some implementations, the impeller clutch **222** may include a disc stack of alternating friction discs and separator plates. A piston plate may be positioned on an end of the disc stack. One or more actuators (e.g., hydraulically actuated pistons) may be configured to engage the piston plate to compress the disc stack.

(23) The impeller clutch **222** is configured to transition between a disengaged state and an engaged state (e.g., by hydraulic control of the impeller clutch **222**). The impeller clutch **222** may be slipped (e.g., partially engaged) when transitioning between engagement and disengagement or between disengagement and engagement. For example, the impeller clutch **222** may be slipped for a period

of time that is based on a size, a material, and/or a number of discs of the impeller clutch **222** and/or based on a speed and torque of the engine **206**. Disengagement of the impeller clutch **222** results in decoupling of the engine **206** and the gear system **230** (e.g., decoupling of the engine **206** and the impeller **210**). Engagement of the impeller clutch **222** results in fluid coupling of the engine **206** and the gear system **230** via the torque converter **208** (e.g., coupling of the engine **206** and the impeller **210**). Slipping the impeller clutch **222** gradually engages or disengages the engine **206** from the pump **202**, thereby spreading a load change over a longer period of time and reducing a load rise rate at the engine **206**.

(24) The pump system **200** may include a controller **224**. The controller **224** may include one or more electronic control modules (ECMs) associated with the engine **206**, the transmission system **204**, the gear system **230**, and/or the torque converter **208**. For example, the controller **224** may be associated with the transmission system **204**, as shown. The controller **224** may correspond to the controller **130**, described herein. Moreover, the transmission system **204** may include a gear system control **232** for the gear system **230**, and the pump system **200** may include an engine control **234** for the engine **206**. The gear system control **232** and the engine control **234** may be communicatively coupled with the controller **224**.

(25) The controller **224** may include one or more memories and one or more processors communicatively coupled to the one or more memories. A processor may include a central processing unit, a graphics processing unit, a microprocessor, a controller, a microcontroller, a digital signal processor, a field-programmable gate array, an application-specific integrated circuit, and/or another type of processing component. The processor may be implemented in hardware, firmware, or a combination of hardware and software. The processor may be capable of being programmed to perform one or more operations or processes described elsewhere herein. A memory may include volatile and/or nonvolatile memory. For example, the memory may include random access memory (RAM), read only memory (ROM), a hard disk drive, and/or another type of memory (e.g., a flash memory, a magnetic memory, and/or an optical memory). The memory may store information, one or more instructions, and/or software (e.g., one or more software applications) related to the operation of the controller **224**.

(26) The controller **224** may be configured to control engagement and disengagement of the lockup clutch **220** and/or the impeller clutch **222**. For example, the controller **224** may control engagement and disengagement of the lockup clutch **220** and/or the impeller clutch **222** in connection with a gear shift of the gear system **230**. The controller **224** may control engagement and disengagement of the lockup clutch **220** via a first clutch control **226** and/or the controller **224** may control engagement and disengagement of the impeller clutch **222** via a second clutch control **228**. The clutch controls **226**, **228** may include hydraulic actuators, valves, or the like. For example, the clutch controls **226**, **228** may include electronic clutch pressure controls (ECPCs).

(27) The controller **224** may detect that an upshift of the gear system **230** is to be performed (e.g., based on a current gearshift status at the gear system **230**). For example, the controller **224** may receive a request to perform the upshift (e.g., from an engine ECM) or the controller **224** may determine to perform the upshift. The upshift may be a shift into first gear (e.g., from neutral into first gear), which may be associated with a large load step. Alternatively, the upshift may be a shift from a lower gear to a higher gear (e.g., a skip shift from the lower gear to the higher gear that skips one or more intermediate gears between the lower gear and the higher gear). In a similar manner as described above, the controller **224** may detect that a downshift of the gear system **230** is to be performed.

(28) Based on detection of the upshift (or in some cases, the downshift), the controller **224** may determine whether to disengage (e.g., to drop) the impeller clutch **222**. Based on determining to disengage the impeller clutch **222**, the controller **224** may cause disengagement of the impeller clutch **222** prior to the upshift. The controller **224** may determine to disengage the impeller clutch **222** based on an estimate (e.g., a prediction) of a load step attributable to the upshift (e.g., based on

the estimate of the load step satisfying a threshold). For example, the controller **224** may cause disengagement of the impeller clutch **222** based on an auxiliary load, a current powertrain load, a flow rate of the pump **202**, a pressure of the pump **202**, and/or a future (e.g., anticipated) powertrain load (e.g., due to the upshift). As an example, the controller **224** may cause disengagement of the impeller clutch **222** when the upshift is a shift into first gear or a skip shift. By disengaging the impeller clutch **222**, an impact to the engine **206** with respect to the changing load can be minimized. The controller **224** may cause disengagement of the impeller clutch **222** at a disengagement rate (e.g., corresponding to disengagement of the impeller clutch **222** over a particular time period). For example, the controller **224** may cause slipping of the impeller clutch **222** over a time period to disengage the impeller clutch **222**. The disengagement rate may be based on a status of a load on the engine **206** (e.g., a load on the engine **206** from the pump **202** and the transmission system **204**) and/or a speed of the engine **206**. The controller **224** may control the disengagement rate directly or via control of a pressure change rate.

(29) In some examples, the controller **224** may determine that the impeller clutch **222** is not to be disengaged (e.g., the impeller clutch **222** is to remain engaged). Accordingly, the controller **224** may cause the upshift (or in some cases, the downshift) of the gear system **230** with the impeller clutch **222** engaged. For example, with the impeller clutch **222** engaged, the controller **224** may cause disengagement of the lockup clutch **220** prior to the gear shift, cause the gear shift to be performed, and then cause engagement of the lockup clutch **220** (e.g., once a speed of the turbine **212** corresponds to a speed of the impeller **210**). In other examples, the controller **224** may cause the gear shift to be performed while the lockup clutch **220** remains engaged.

(30) In some implementations, based on detection of the upshift (or in some cases, the downshift), the controller **224** may cause disengagement of the lockup clutch **220** (e.g., if the lockup clutch **220** is currently engaged). The controller **224** may cause disengagement of the lockup clutch **220** prior to the upshift and based on determining to disengage the impeller clutch **222** (e.g., if the controller **224** determines to disengage the impeller clutch **222**, then the controller **224** may cause disengagement of the impeller clutch **222** and the lockup clutch **220**). The controller **224** may cause disengagement of the lockup clutch **220** after, before, or concurrently with disengagement of the impeller clutch **222**.

(31) The controller **224** may cause disengagement of the lockup clutch **220** at a disengagement rate (e.g., corresponding to disengagement of the lockup clutch **220** over a particular time period). For example, the controller **224** may cause slipping of the lockup clutch **220** over a time period to disengage the lockup clutch **220**. The disengagement rate may be based on a status of a load on the engine **206** and/or a speed of the engine **206**, in a similar manner as described above. The controller **224** may control the disengagement rate directly or via control of a pressure change rate.

(32) Based on disengagement of at least the impeller clutch **222** (e.g., disengagement of the impeller clutch **222** and disengagement of the lockup clutch **220**), the controller **224** may cause the upshift (or in some cases, the downshift) of the gear system **230**. For example, the controller **224** may cause the upshift of the gear system **230** by transmitting a control signal to cause engagement of a gear of the gear system **230** (e.g., the control signal may cause pressurization of a clutch associated with the gear).

(33) After performing the upshift (or the downshift), the controller **224** may cause engagement of the impeller clutch **222**. The controller **224** may cause engagement of the impeller clutch **222** at an engagement rate (e.g., corresponding to engagement of the impeller clutch **222** over a particular time period). For example, the controller **224** may cause slipping of the impeller clutch **222** over a time period to engage the impeller clutch **222**. As an example, the time period, such as 10 seconds, may be much greater than a time needed to perform the upshift. The engagement rate may be based on a load on the engine **206** and/or a speed droop of the engine **206** (e.g., due to increasing the load). For example, to engage the impeller clutch **222**, the controller **224** may monitor the load and/or the speed droop, and the engagement rate may be based on the load and/or the speed droop.

As an example, the controller **224** may cause slipping of the impeller clutch **222** at the engagement rate until satisfying the load on the engine **206**. In other words, if the speed droop of the engine **206** satisfies a threshold value (e.g., meets or exceeds the threshold value), engagement of the impeller clutch **222** may be delayed (e.g., by lowering the engagement rate) until the speed droop does not satisfy the threshold value (e.g., speed droop below the threshold value). For example, as the engagement rate is decreased, or lowered, delay in engaging of the impeller clutch **222** is increased, and as the engagement rate is increased, or raised, delay in engaging of the impeller clutch **222** is decreased. Accordingly, the controller **224** may manipulate the engagement rate (e.g., by decreasing and/or increasing the engagement rate) to achieve a particular delay in engagement of the impeller clutch **222** (e.g., based on how speed droop is responding as the impeller clutch **222** is partially engaged). The controller **224** may control the engagement rate directly or via control of a pressure change rate. Disengaging and subsequently engaging the impeller clutch **222** in connection with the upshift facilitates improved load acceptance by the engine **206**, which otherwise would exhibit poor load acceptance resulting in substantial loss of speed.
(34) In some implementations, the controller **224** may monitor whether the pump system **200** is stabilized (e.g., whether the engine **206**, a powertrain load, a load of the pump **202**, or the like, is stabilized). For example, the controller **224** may monitor whether the engine **206** is stabilized. The controller **224** may monitor whether the pump system **200** is stabilized (e.g., whether the engine **206** is stabilized) based on an auxiliary load, a current powertrain load, a flow rate of the pump **202**, a pressure of the pump **202**, a speed of the engine **206**, and/or a torque of the engine **206**. Based on a determination that the engine **206** is not stabilized (after performing the upshift), the controller may cause engagement of the impeller clutch **222**. Engagement of the impeller clutch **222** may apply load from the pump system **200** to the engine **206** to cause the engine **206** to be stabilized. Based on a determination that the pump system **200** is stabilized (after performing the upshift), the controller may cause engagement of the impeller clutch **222**.
(35) In some implementations, after the upshift (or the downshift) and after engagement of the impeller clutch **222**, the controller **224** may cause engagement of the lockup clutch **220** (e.g., once a speed of the turbine **212** corresponds to a speed of the impeller **210**). The controller **224** may cause engagement of the lockup clutch **220** at an engagement rate (e.g., corresponding to engagement of the lockup clutch **220** over a particular time period). For example, the controller **224** may cause slipping of the lockup clutch **220** over a time period, such as 20 seconds, to engage the lockup clutch **220**. The engagement rate may be based on a powertrain load and/or a load of the pump **202**. For example, to engage the lockup clutch **220**, the controller **224** may monitor the powertrain load and/or the load of the pump **202**, and the engagement rate may be based on the powertrain load and/or the load. As an example, the controller **224** may cause slipping of the lockup clutch **220** at the engagement rate until satisfying the powertrain load and/or the load of the pump **202**. The controller **224** may control the engagement rate directly or via control of a pressure change rate.
(36) A first time duration for disengagement of the impeller clutch **222** may be less than a second time duration for disengagement of the lockup clutch **220**. For example, the controller **224** may cause disengagement of the impeller clutch **222** before causing disengagement of the lockup clutch **220**, and the controller **224** may cause re-engagement of the impeller clutch **222** before causing re-engagement of the lockup clutch **220**.
(37) As indicated above, FIG. **2** is provided as an example. Other examples may differ from what is described with regard to FIG. **2**.
(38) FIG. **3** is a flowchart of an example process **300** associated with control of an impeller clutch of a torque converter for a gaseous fuel engine. One or more process blocks of FIG. **3** may be performed by the controller **224**. For example, the controller **224** may be a transmission ECM. In some examples, one or more process blocks of FIG. **3** may be performed by the transmission system **204**.

(39) Process **300** may begin when the engine **206** is running and the impeller clutch **222** (shown in FIG. **3** as “IC”) is engaged (block **310**). In some examples, the lockup clutch **220** (shown in FIG. **3** as “LUC”) may also be engaged. Process **300** may include receiving an upshift request (block **320**). The controller **224** may determine that an upshift request is received and/or determine a higher gear in which to shift based on one or more inputs, such as a gearshift status, as described herein.
(40) Process **300** may include determining whether to disengage the impeller clutch **222** (block **330**). For example, the controller **224** may determine whether to disengage the impeller clutch **222** based on one or more inputs, such as an auxiliary load, a current powertrain load, a flow rate of the pump **202**, a pressure of the pump **202**, and/or a future (e.g., anticipated) powertrain load, as described herein. Based on a determination that the impeller clutch **222** is not to be disengaged (block **330**—NO), process **300** may include causing the upshift to be performed with the impeller clutch **222** engaged (block **340**). For example, with the impeller clutch **222** engaged, the controller **224** may cause disengagement of the lockup clutch **220** prior to the upshift and then cause the upshift to be performed, as described herein. Based on a determination that the impeller clutch **222** is to be disengaged (block **330**—YES), the controller **224** may cause the impeller clutch **222** to be disengaged, and process **300** may include causing the lockup clutch **220** to be disengaged (block **350**). The controller **224** may determine disengagement rates for the impeller clutch **222** and the lockup clutch **220** based on one or more inputs, such as status of an engine load and/or speed, as described herein. Process **300** may include causing the upshift to be performed (block **360**).
(41) Process **300** may include determining whether a powertrain or pump load is stabilized (block **370**). For example, the controller **224** may determine whether the powertrain or pump load is stabilized based on one or more inputs, such as an auxiliary load, a current powertrain load, a flow rate of the pump **202**, and/or a pressure of the pump **202**, as described herein. Based on a determination that the powertrain or pump load is not stabilized (block **370**—NO), process **300** may include returning to block **370** (e.g., the controller **224** may wait to proceed until the powertrain or pump load is stabilized). Based on a determination that the powertrain or pump load is stabilized (block **370**—YES), process **300** may include causing engagement of the impeller clutch **222** (block **380**). The controller may cause engagement of the impeller clutch **222** at an engagement rate based on one or more inputs, such as an engine load and/or an engine speed droop, as described herein. Process **300** may include causing engagement of the lockup clutch **220** (block **390**). The controller may cause engagement of the lockup clutch **220** at an engagement rate based on one or more inputs, such as a powertrain or pump load, as described herein.
(42) Although FIG. **3** shows example blocks of process **300**, in some implementations, process **300** may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. **3**. Additionally, or alternatively, two or more of the blocks of process **300** may be performed in parallel.

INDUSTRIAL APPLICABILITY

(43) The torque converter described herein may be used with any powertrain that includes a gaseous fuel engine. For example, the torque converter may be used to couple a gaseous fuel engine with a gear system to drive a hydraulic fracturing pump. Gaseous fuel engines are typically associated with poor load acceptance or otherwise poor response to changes in load. Accordingly, a gaseous fuel engine generally has been considered unsuitable for driving a hydraulic fracturing pump because of the high load rise rates associated with hydraulic fracturing operations due to gear shifts or due to a hydraulic fracturing pump being brought online in the middle of a fracturing stage.
(44) The torque converter described herein includes an impeller clutch that enables an impeller of the torque converter to be selectively coupled to the gaseous fuel engine. This is useful for gear shifts of the gear system, such as upshifts, associated with a large load step. In particular, the impeller clutch may be disengaged prior to an upshift of the gear system, and slowly re-engaged after the upshift is performed, to minimize an impact to the gaseous fuel engine with respect to the

changing load. In this way, the impeller clutch of the torque converter facilitates improved load acceptance by the gaseous fuel engine, thereby enabling use of the gaseous fuel engine in hydraulic fracturing applications associated with high load rise rates. By using the gaseous fuel engine, compared to a diesel engine or a diesel/natural gas dual-fuel engine conventionally used for hydraulic fracturing applications, greenhouse gas emissions and fuel costs may be reduced.
(45) The foregoing disclosure provides illustration and description, but is not intended to be exhaustive or to limit the implementations to the precise forms disclosed. Modifications and variations may be made in light of the above disclosure or may be acquired from practice of the implementations. Furthermore, any of the implementations described herein may be combined unless the foregoing disclosure expressly provides a reason that one or more implementations cannot be combined. Even though particular combinations of features are recited in the claims and/or disclosed in the specification, these combinations are not intended to limit the disclosure of various implementations. Although each dependent claim listed below may directly depend on only one claim, the disclosure of various implementations includes each dependent claim in combination with every other claim in the claim set.
(46) As used herein "a," "an," and a "set" are intended to include one or more items, and may be used interchangeably with "one or more." Further, as used herein, the article "the" is intended to include one or more items referenced in connection with the article "the" and may be used interchangeably with "the one or more." Further, the phrase "based on" is intended to mean "based, at least in part, on" unless explicitly stated otherwise. Also, as used herein, the term "or" is intended to be inclusive when used in a series and may be used interchangeably with "and/or," unless explicitly stated otherwise (e.g., if used in combination with "either" or "only one of").

Claims

1. A hydraulic fracturing pump system, comprising: a hydraulic fracturing pump; a gaseous fuel engine configured to drive the hydraulic fracturing pump; a transmission system comprising a gear system mechanically coupled to the hydraulic fracturing pump and a torque converter configured to fluidly couple the gaseous fuel engine and the gear system, the torque converter comprising: an impeller; a turbine fluidly coupled to the impeller and mechanically coupled to the gear system; a stator positioned between the impeller and the turbine; an impeller clutch configured to mechanically couple the impeller to the gaseous fuel engine; and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system; and a controller configured to: cause disengagement of the impeller clutch; and cause an upshift of the gear system based on disengagement of the impeller clutch.
2. The hydraulic fracturing pump system of claim 1, wherein the impeller, the turbine, and the stator are within a housing of the torque converter that is coupled to the gaseous fuel engine.
3. The hydraulic fracturing pump system of claim 2, wherein the impeller clutch is configured to couple the impeller to the housing, and the lockup clutch is configured to couple the turbine to the housing.
4. The hydraulic fracturing pump system of claim 1, wherein the controller is further configured to: detect that the upshift of the gear system is to be performed, wherein, to cause disengagement of the impeller clutch, the controller is configured to: cause disengagement of the impeller clutch based on detecting that the upshift of the gear system is to be performed.
5. The hydraulic fracturing pump system of claim 1, wherein the upshift is a shift into first gear.
6. The hydraulic fracturing pump system of claim 1, wherein the controller, to cause disengagement of the impeller clutch, is configured to: cause disengagement of the impeller clutch at a disengagement rate that is based on a status of at least one of a load on the gaseous fuel engine, from the hydraulic fracturing pump and the transmission system, or a speed of the gaseous fuel engine.

7. The hydraulic fracturing pump system of claim 1, wherein the controller is further configured to: cause engagement of the impeller clutch after the upshift of the gear system.
8. The hydraulic fracturing pump system of claim 7, wherein the controller, to cause engagement of the impeller clutch, is configured to: monitor whether the gaseous fuel engine is stabilized; and cause engagement of the impeller clutch further based on a determination that the gaseous fuel engine is not stabilized, wherein engagement of the impeller clutch is configured to apply load from the hydraulic fracturing pump system to the gaseous fuel engine to cause the gaseous fuel engine to be stabilized.
9. The hydraulic fracturing pump system of claim 1, wherein the controller is further configured to: cause disengagement of the lockup clutch prior to causing the upshift of the gear system; and cause engagement of the lockup clutch after the upshift of the gear system and engagement of the impeller clutch.
10. A transmission system, comprising: a gear system configured to couple to a hydraulic fracturing pump; and a torque converter configured to fluidly couple a gaseous fuel engine and the gear system, the torque converter comprising: an impeller; a turbine fluidly coupled to the impeller and mechanically coupled to the gear system; a stator positioned between the impeller and the turbine; an impeller clutch configured to mechanically couple the impeller to the gaseous fuel engine; and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system; and a controller configured to: cause disengagement of the impeller clutch; and cause an upshift of the gear system based on disengagement of the impeller clutch.
11. The transmission system of claim 10, wherein the controller is further configured to: cause disengagement of the lockup clutch prior to the upshift of the gear system.
12. The transmission system of claim 11, wherein a first time duration for disengagement of the impeller clutch is less than a second time duration for disengagement of the lockup clutch.
13. The transmission system of claim 11, wherein the controller, to cause disengagement of the lockup clutch, is configured to: cause disengagement of the lockup clutch at a disengagement rate that is based on a status of at least one of a load on the gaseous fuel engine or a speed of the gaseous fuel engine.
14. The transmission system of claim 11, wherein the controller, to cause engagement of the lockup clutch, is configured to: cause engagement of the lockup clutch at an engagement rate that is based on a load of the hydraulic fracturing pump.
15. The transmission system of claim 10, wherein the upshift is a shift into first gear.
16. A torque converter to fluidly couple a gaseous fuel engine and a gear system mechanically coupled to a hydraulic fracturing pump, the torque converter comprising: an impeller; a turbine fluidly coupled to the impeller; a stator positioned between the impeller and the turbine; an impeller clutch configured to couple the impeller to the gaseous fuel engine; and a lockup clutch configured to mechanically couple the gaseous fuel engine and the gear system; and a controller configured to: cause disengagement of the impeller clutch; and cause an upshift of the gear system based on disengagement of the impeller clutch.
17. The torque converter of claim 16, further comprising: a first clutch control configured to control engagement and disengagement of the lockup clutch; and a second clutch control configured to control engagement and disengagement of the impeller clutch.
18. The torque converter of claim 16, wherein the impeller, the turbine, and the stator are within a housing of the torque converter that is coupled to the gaseous fuel engine.
19. The torque converter of claim 18, wherein the impeller clutch is configured to couple the impeller to the housing, and the lockup clutch is configured to couple the turbine to the housing.
20. The torque converter of claim 16, wherein the controller is further configured to: cause disengagement of the lockup clutch prior to the upshift of the gear system.