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(54) POWER TRANSFER SYSTEM

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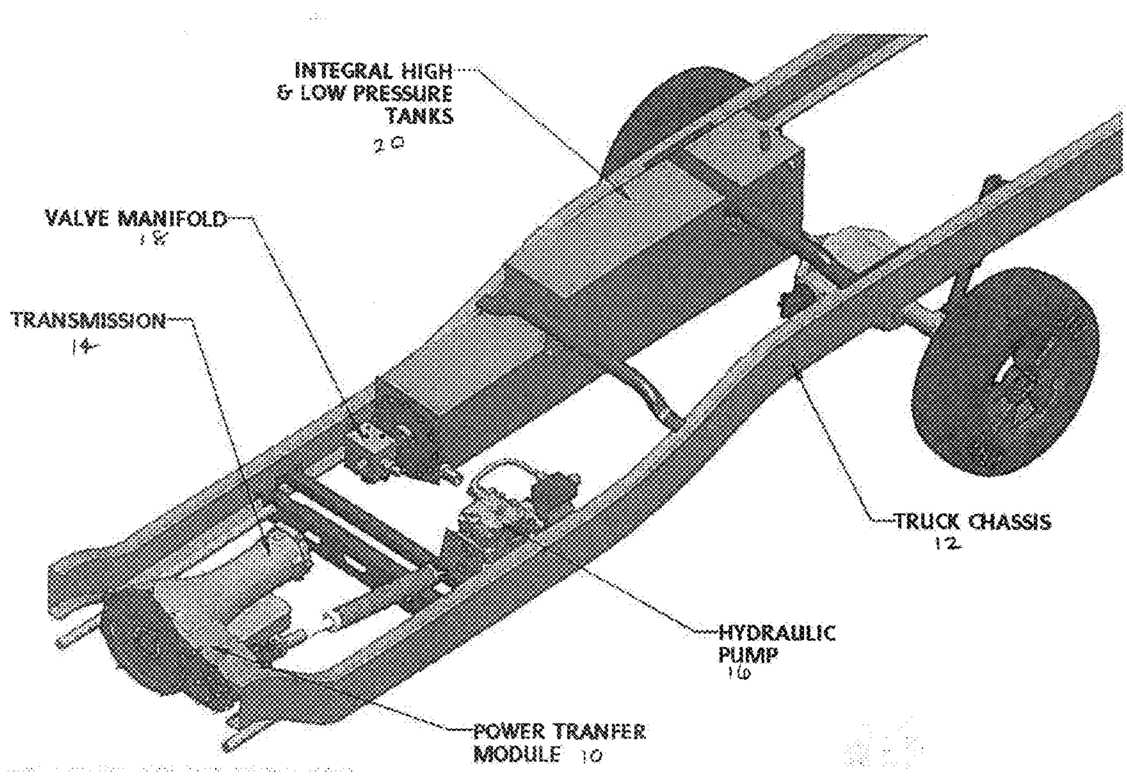
(52) **U.S. Cl.** **60/330**

(57) **ABSTRACT**

Embodiments relate to systems and methods for transferring power from a vehicle drive train to a hydraulic pump. One aspect of the present invention provides system including a torque converter; a torque converter hub connected to at least the torque converter; and a synchronous drive system coupled to at least the torque converter.



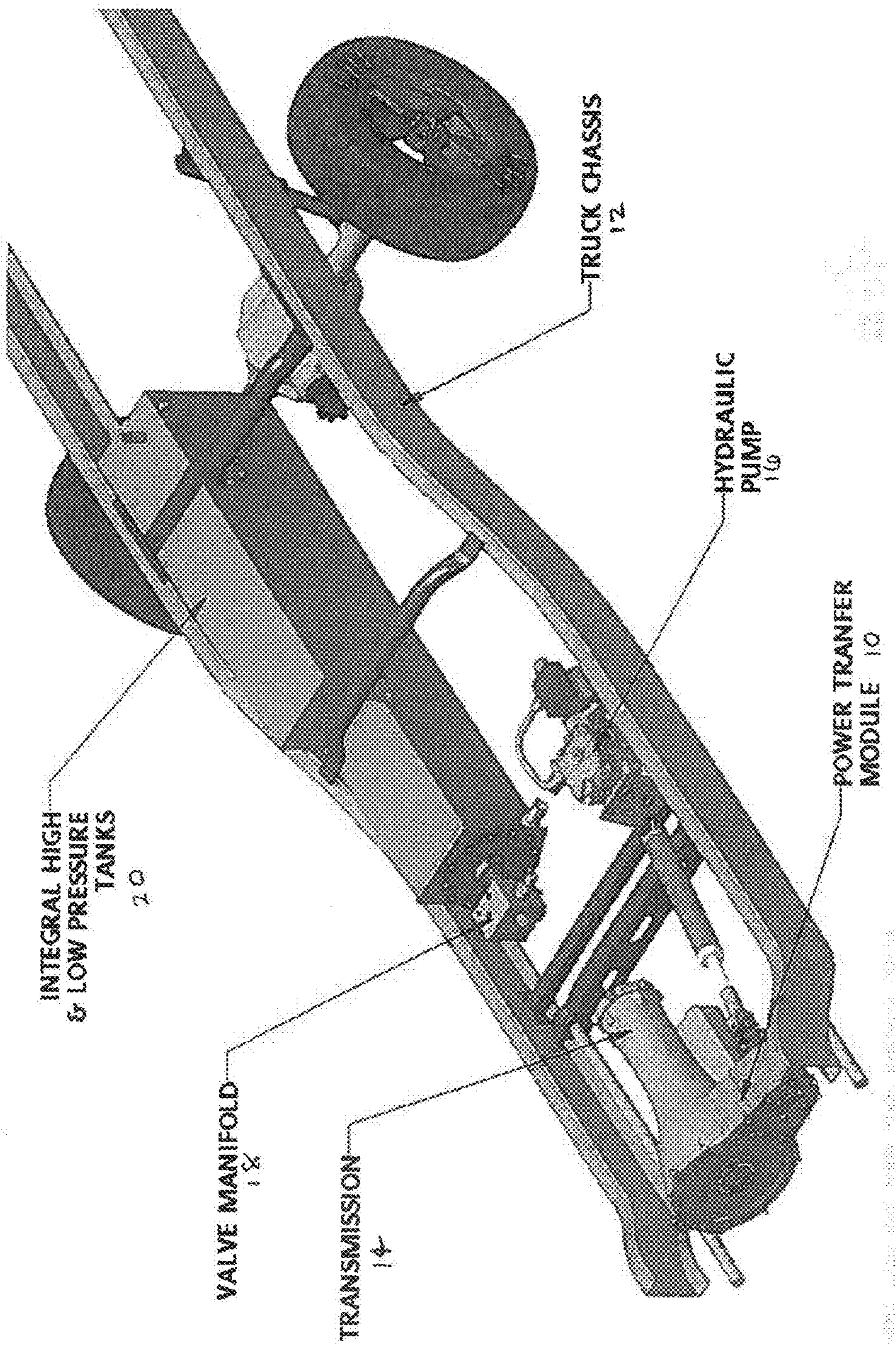

INTEGRAL HIGH
& LOW PRESSURE
TANKS
20
VALVE MANIFOLD
18
TRANSMISSION
14
TRUCK CHASSIS
12
HYDRAULIC
PUMP
16
POWER TRANFER
MODULE 10

Fig 1

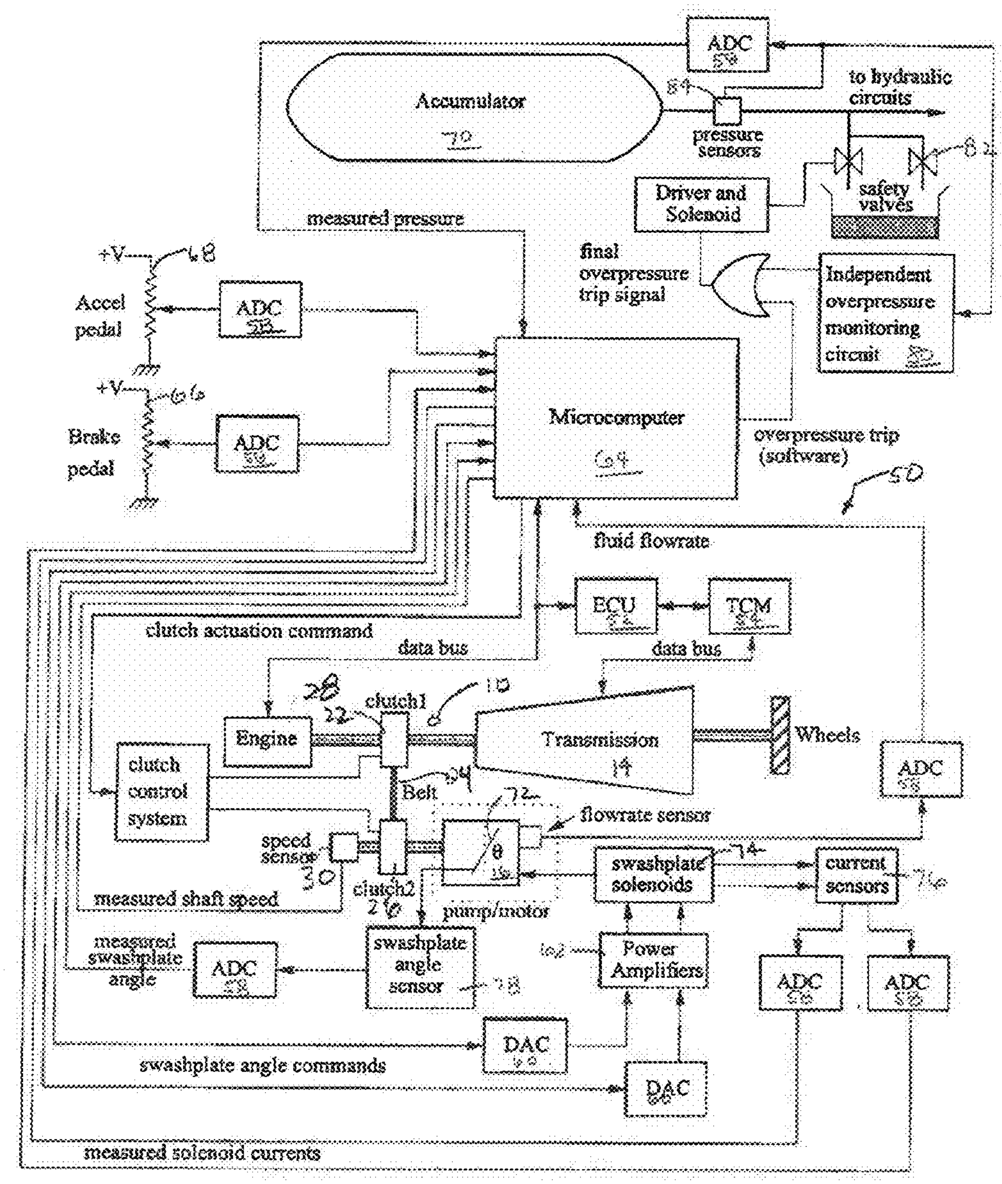

ADC
Accumulator
70
to hydraulic circuits
pressure sensors
Driver and Solenoid
safety valves
measured pressure
final overpressure trip signal
Independent overpressure monitoring circuit
Accel pedal
ADC
Brake pedal
ADC
Microcomputer
overpressure trip (software)
fluid flowrate
ECU
TCM
clutch actuation command
data bus
data bus
Engine
clutch1
Transmission
14
Wheels
clutch control system
Belt
ADC
flowrate sensor
speed sensor
clutch2
swashplate solenoids
current sensors
measured shaft speed
pump/motor
measured swashplate angle
ADC
swashplate angle sensor
Power Amplifiers
ADC
ADC
DAC
swashplate angle commands
DAC
measured solenoid currents

Fig. 2

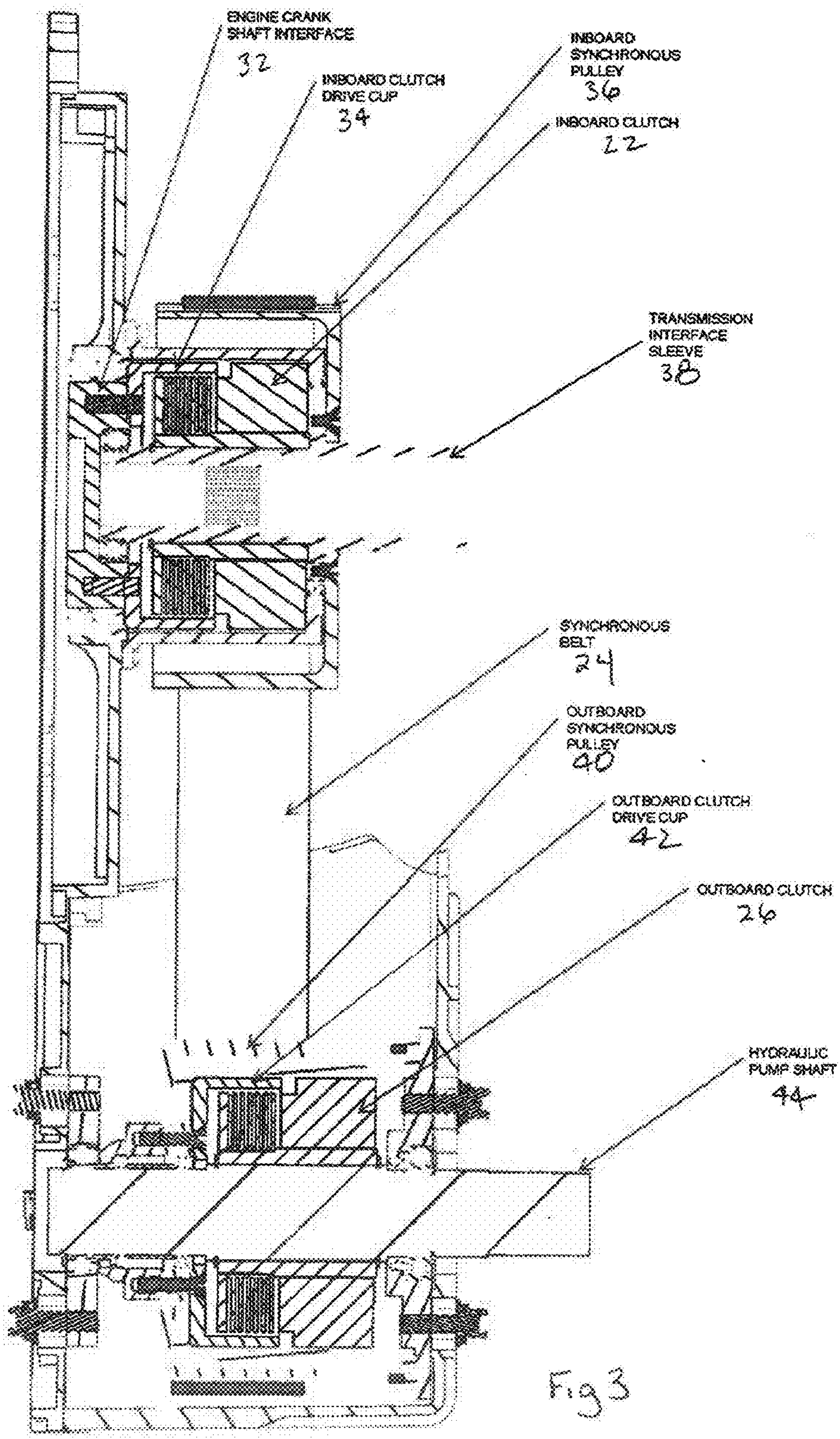

ENGINE CRANK SHAFT INTERFACE
32
INBOARD CLUTCH DRIVE CUP
34
INBOARD SYNCHRONOUS PULLEY
36
INBOARD CLUTCH
22
TRANSMISSION INTERFACE SLEEVE
38
SYNCHRONOUS BELT
24
OUTBOARD SYNCHRONOUS PULLEY
40
OUTBOARD CLUTCH DRIVE CUP
42
OUTBOARD CLUTCH
26
HYDRAULIC PUMP SHAFT
44

Fig 3

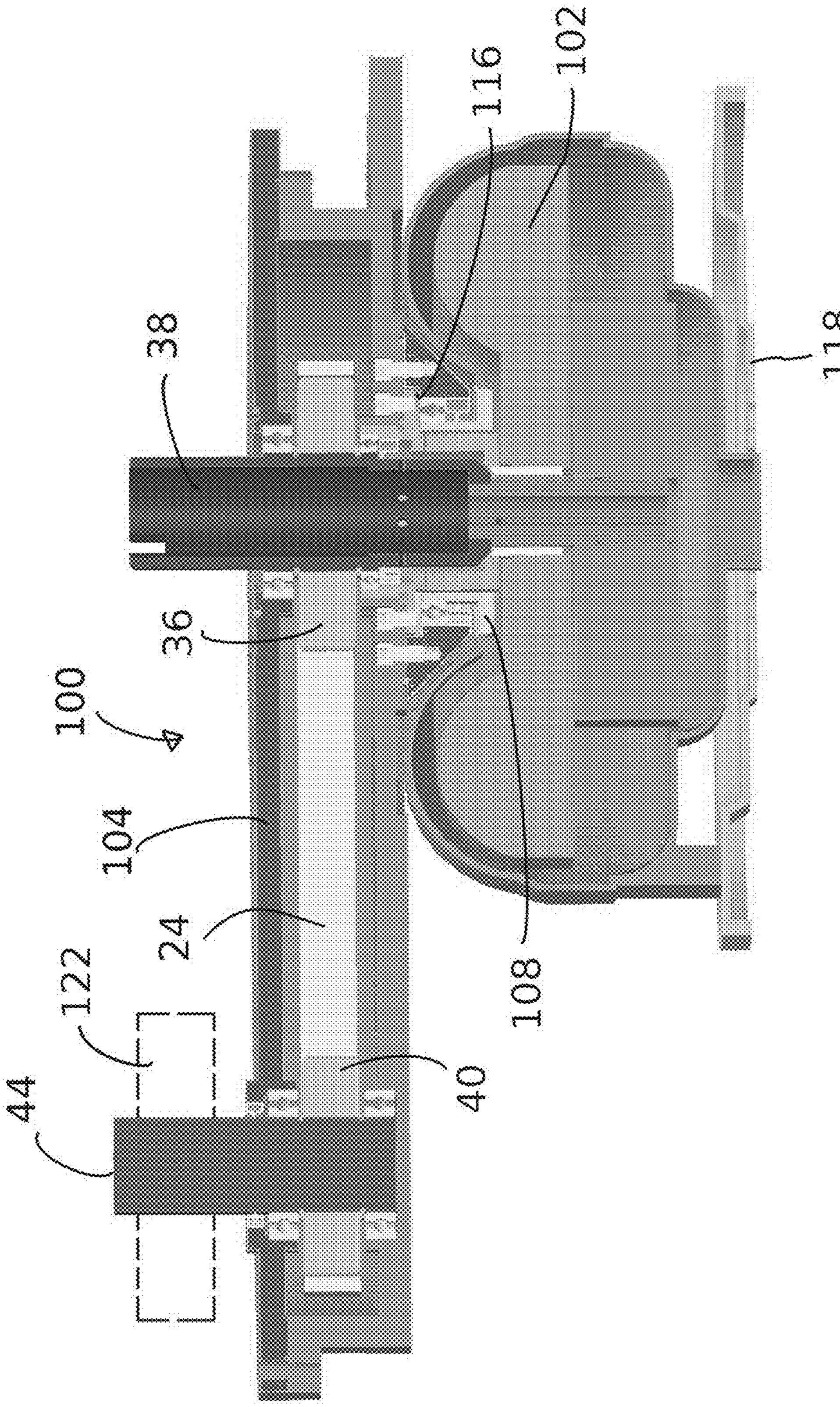


Fig. 4

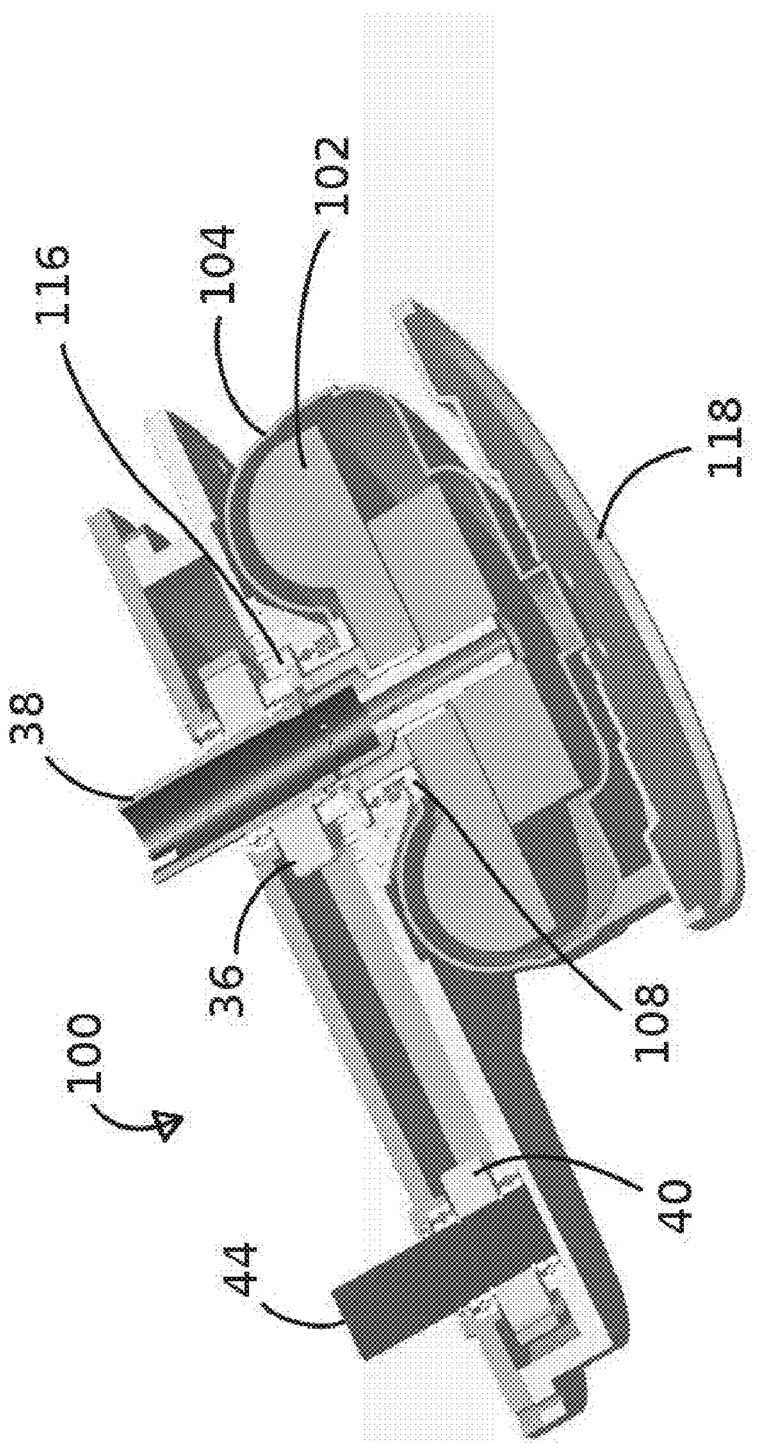


Fig. 5

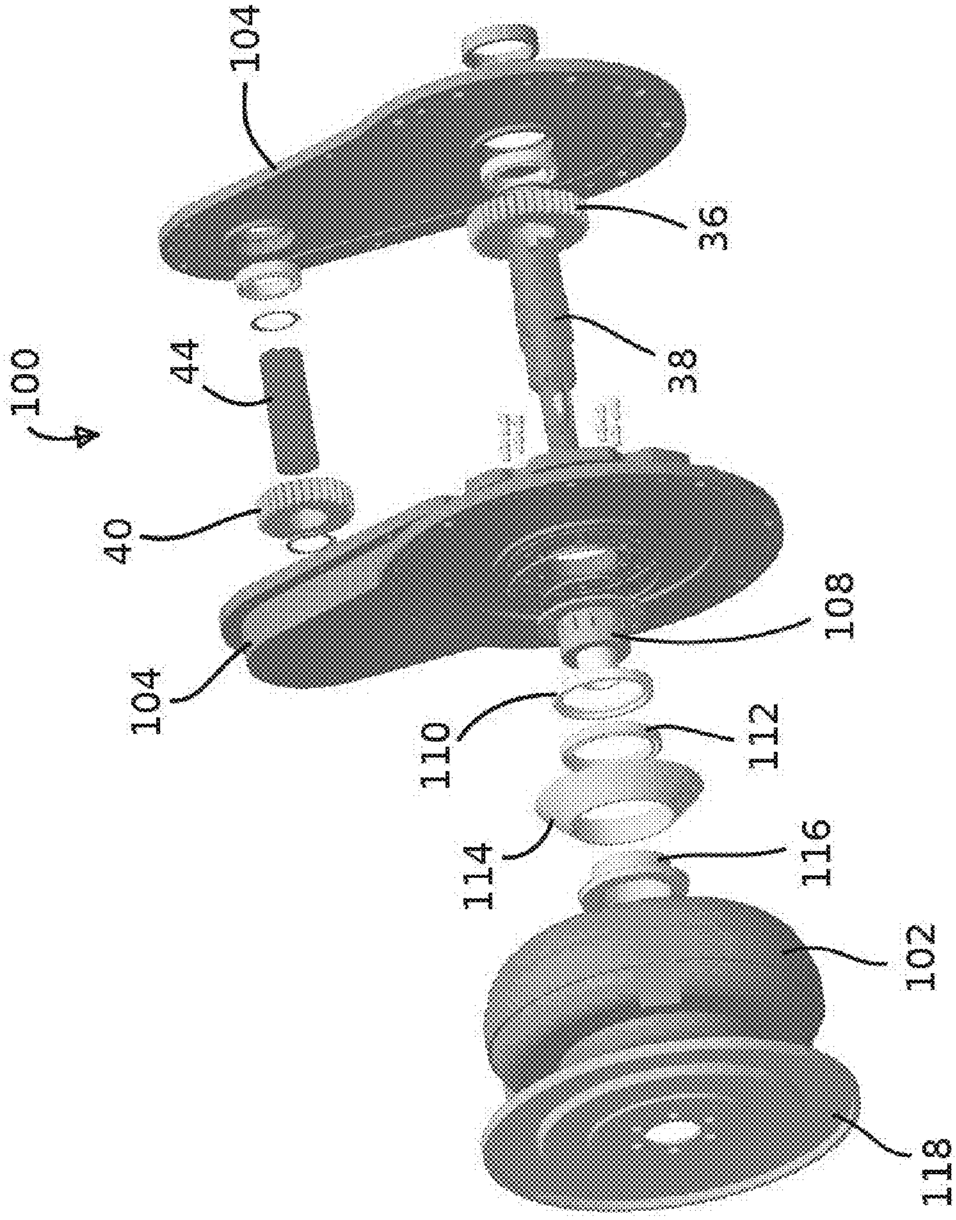


Fig. 6

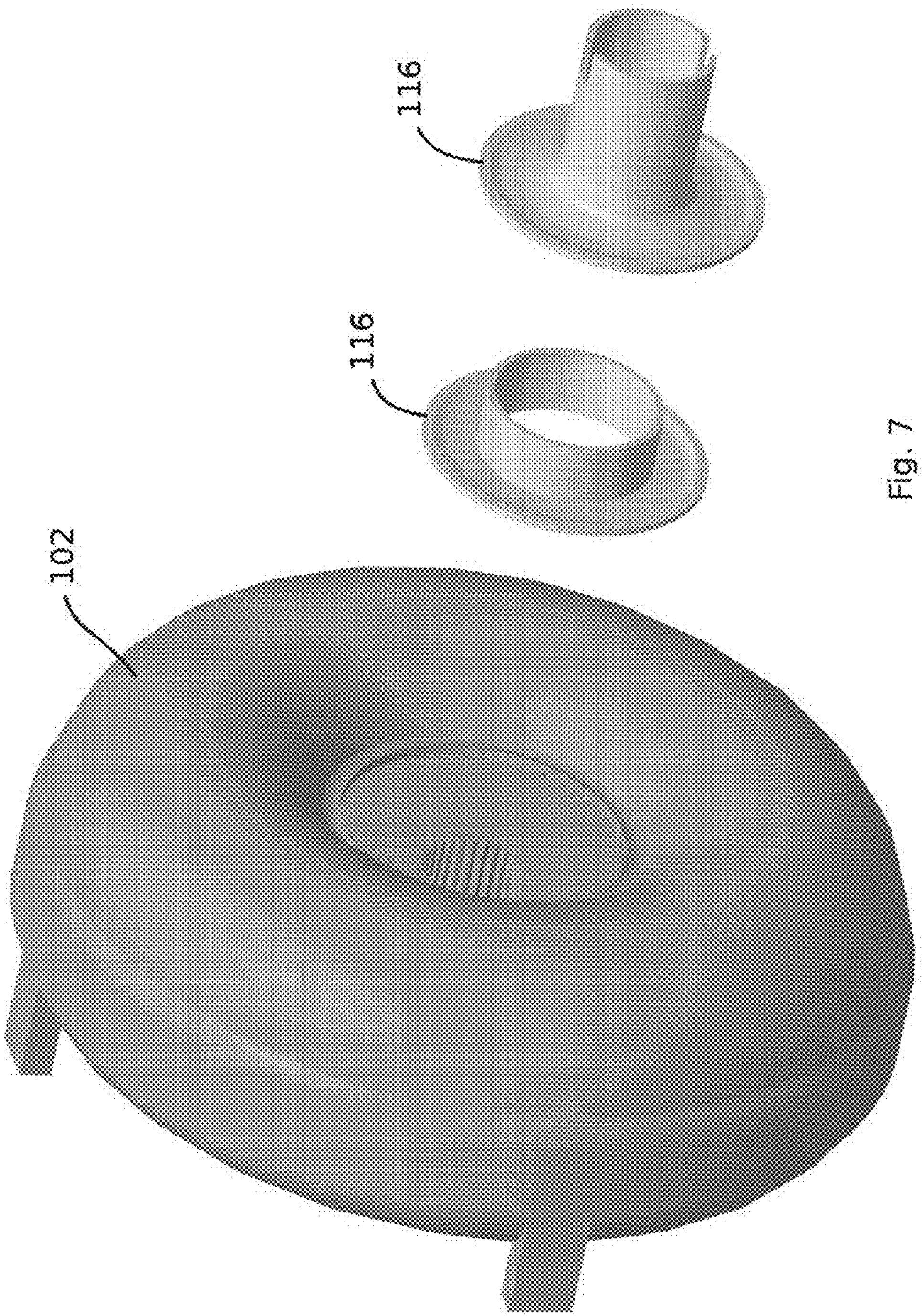


Fig. 7

POWER TRANSFER SYSTEM

CLAIM FOR PRIORITY

[0001] This application claims priority from U.S. Provisional Application Ser. No. 61/311,168 filed Mar. 5, 2010, the complete subject matter of which is incorporated herein by reference in its entirety.

CROSS-REFERENCE TO RELATED APPLICATIONS

[0002] The following related patent application, assigned to the same assignee hereof and filed on the same date herewith in the names of the same inventors as the present application, disclose related subject matter, the complete subject matter of which is incorporated herein by reference in its entirety: ACCUMULATOR/RESERVOIR SYSTEM, U.S. Ser. No. ______ (Attorney Docket No. 4510.9).

FIELD OF THE INVENTION

[0003] The invention relates to power transfer in vehicles. More particularly, embodiments relate to systems and methods for transferring power from a vehicle drive train to a hydraulic pump.

BACKGROUND OF THE INVENTION

[0004] The transfer of energy to or from a hydraulic pump (in a hybrid system, for example) involves energy losses and may not provide optimal operation between given power sources (i.e. engine and hydraulic pump). Some of the largest losses are due to the rotational mass of the engine. Another appreciable loss is due to the rotational mass of the hydraulic pump (applicable during operation at highway speeds for example).

[0005] One known solution is to use engine cylinder deactivation. While such cylinder deactivation reduces the energy losses due to operational backpressure, this method does not address the energy losses due to the rotating mass.

[0006] For the foregoing reasons, it would be desirable to provide a system and method that provides for transfer power from a vehicle drive train to a hydraulic pump that overcomes the above disadvantages.

SUMMARY OF THE INVENTION

[0007] One aspect of the present invention relates to a system for transferring power from a vehicle transmission to a vehicle hydraulic pump. The system comprises a first clutch drive cup adapted to move between an activated mode engaging the transmission and a deactivated mode. A first clutch is adapted to activate and deactivate the first clutch drive cup; while a first synchronous pulley is coupled to at least the first clutch drive cup. A second clutch drive cup is adapted to move between an activated mode engaging the hydraulic pump and a deactivated mode. A second clutch is adapted to activate and deactivate the second clutch drive cup; while a second synchronous pulley is coupled to at least the second clutch cup. A synchronous belt couples the first synchronous pulley and the second synchronous pulley.

[0008] Another aspect of the present invention relates to a system for transferring power. The system includes a torque converter; a torque converter hub connected to at least the torque converter; and a synchronous drive system coupled to at least the torque converter.

[0009] Another aspect of the present invention relates to a system for transferring power from a vehicle drive system to a vehicle fluid power system. The system includes a power torque converter connected to the vehicle drive system; a torque converter hub connected to at least the power torque converter; and a synchronous drive system coupled to at least the power torque converter whereby power is transferred between at least the vehicle drive system and the vehicle fluid power system.

[0010] The foregoing and other features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The drawings are not to scale. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a perspective view in accordance with the present invention;

[0012] FIG. **2** is a block diagram in accordance with the present invention;

[0013] FIG. **3** is a cross-sectional view of a power transfer module in accordance with one embodiment of the present invention;

[0014] FIG. **4** is a cross-sectional view of a power transfer module in accordance with another embodiment of the present invention;

[0015] FIG. **5** is another cross-sectional view of the power transfer module of FIG. **4** in accordance with another embodiment of the present invention;

[0016] FIG. **6** is a exploded view of the power transfer module of FIG. **4** in accordance with another embodiment of the present invention;

[0017] FIG. **7** is an another view of the torque converter and torque converter hub of the power transfer module of FIG. **4** in accordance with the present invention.

[0018] Throughout the various figures, like reference numbers refer to like elements.

DETAILED DESCRIPTION OF PRESENTLY PREFERRED EMBODIMENTS

[0019] Embodiments of the present invention may be applied to any vehicle having an automatic transmission and some means for power to be transferred from the output of that transmission to the drive wheel. In the conventional system, the vehicle has an internal combustion engine or some other type of prime mover coupled to the input of the transmission. The power transfer module in at least one embodiment is installed between the prime mover and the transmission. In accordance with one embodiment, an arrangement of two fluid clutches and a synchronous belt/pulley scheme are used during a regenerative braking cycle to transfer power from a vehicle's drive train to a hydraulic pump, or in the case of an acceleration cycle, the same arrangement transfers power from the hydraulic pump to the drive train. In another embodiment, a torque converter is used with the synchronous belt/pulley scheme to transfer power for the drive train to the hydraulic pump and back. One skilled in the art would appreciate that, in the transfer of energy between various power sources (i.e. engine and hydraulic pump), energy losses should be minimized during acceleration or braking.

Embodiments of the present invention provide for recovery of braking energy while minimizing energy losses at cruising or highway speeds for example.

[0020] FIG. **1** is a perspective view illustrating a power transfer module (alternatively referred to as "PTM"), generally designated **10**, coupled or joined to chassis or frame **12**. The PTM **10** is used to transfer power from a vehicle's drive train or transmission **14** to a hydraulic pump **16** in accordance with the present invention. FIG. **1** further illustrates a valve manifold **18** and integral high and low pressure tanks **20** coupled or joined to chassis **12**.

[0021] FIG. **2** is a block diagram which depicts power transfer module **10** in accordance with one embodiment of the present invention. A digital automatic control system **50** coordinates and sequences all tasks required to interface the operation of the electrohydraulic subsystems with the existing vehicle subsystems. In at least one embodiment, the digital automatic control system **50** includes data exchange between the Electronic Control Unit (ECU) **52**, the Transmission Control Module (TCM) **54** and the Hydraulic Control Interface (HCI) **56**. The HCI **56** consists of the devices that communicate with the hydraulic system such as one or more Analog to Digital Converters (ADCs) **58**, one or more Digital to Analog Converters (DACs) **60** and one or more power amplifiers **62** for example.

[0022] In one embodiment, the core of the control system **50** is a microcomputer **64** running a set of discrete-time sampled-data control algorithms which perform sensor monitoring and actuator command activities. A top-level supervisory algorithm is responsible for coordinating a number of subsystems, each managing its own set of measurement and control algorithms.

[0023] All of the functions described previously are, in one embodiment, executed automatically by the control system **50**. Without extremely precise control, a regenerative braking system cannot function at the efficiency levels needed to make it an economically viable addition to a vehicle system. One feature of the controller **50** is the manner in which it is integrated into the vehicle system. In order to make the system salable for post vehicle production application, the control system **50** must be integrated with the vehicle but handled by a separate controller.

[0024] The task of incorporating the necessary software in to the engine control unit **52** or other existing onboard computer **64** would be enormous. Also, it is unlikely that a computer **64** is able to pick up the extra computing overhead. To make the system as transparent as possible, it is desirable to reduce the number of extra control inputs for the user. Therefore, in accordance with one embodiment of the present invention, the control system **50** uses positions of the brake **66** and accelerator pedals **68** that the driver of the vehicle is already familiar with as input signals. These signals from the brake **66** and accelerator pedals **68** are used to inform the engine control unit **50** of the throttle position, which is used as a power demand input, telling the pump **16** how much power to add to the system while still fulfilling its function within the normal vehicle system. The controller **50** then determines how much energy is stored in the accumulator **70** and determines how it will use that power to meet the demand from the user. By monitoring the pressure and volume in the accumulator **70**, the controller **50** can determine the best gear ratio for the transmission **14** based on the available torque the pump **14** can provide. A pedal position sensor (not shown) is added to the brake pedal **66** to provide accurate braking demand inputs to the controller **50**.

[0025] As illustrated in FIG. **2**, the accumulator **70** pressure, hydraulic pump/motor shaft **60** speed, accelerator **68** position, brake **66** position, fluid flowrate, solenoid currents, and swashplate **72** angle are periodically sampled by ADCs **58**. In one embodiment, such sampling is performed in a sequential "round-robin" fashion at a fixed sample rate of fs Hz. The digitized signals are fed to the microcomputer **64** for processing by a set of measurement and control algorithms.

[0026] The energy stored in the accumulator **70** is monitored continuously by the control system **50** so that energy efficiency is maximized during all modes of vehicle operation. In at least one embodiment, the energy stored in the accumulator is determined by the pressure and volume measurements.

[0027] The hydraulic pump/motor **14** is controlled by turning or rotating a swashplate **72** through a given angle in order to control the volumetric flowrate of hydraulic fluid passing to or from the pump/motor **14**. The swashplate **72** movement is controlled by two solenoids **74**. In at least one embodiment, each solenoid **74** controls the opening of a valve which allows control pressure to move a piston connected to one side of the swashplate **72**. Each solenoid **74** is responsible for rotating the swashplate **72** in a particular (opposing) direction; one rotates clockwise from center position to control the pump operating mode and the other rotates counterclockwise from center position to control the motor operating mode. Since the force exerted by the magnetic field of the solenoid **74** is proportional to the applied current, a current control system **76** is used to supply an accurate current to each solenoid **74**.

[0028] The swashplate **72** angle is measured by a potentiometer **78** and fed to a closed loop servocontroller (not shown in FIG. **2**) which feeds the current control circuit **76** and enables a precise swashplate angle to be obtained from the command voltage. In at least one embodiment, the angle command voltage signal is determined by control algorithms in the firmware and delivered to the swashplate angle controller as a digital signal. The swashplate angle controller consists of two feedback loops. The inner feedback loop consists of a closed loop solenoid current controller with discrete-time digital compensator $Gc(z)$. The outer feedback loop is a standard position servo system with compensator $Gs(z)$. The overall system ensures that the measured swashplate position $\theta m(z)$ accurately tracks the commanded angle position $\theta s(z)$.

[0029] During both braking and accelerating modes, the digital control system **50** controls the flow of hydraulic fluid via the swashplate angle and rotational speed, thereby controlling the flow of energy through the vehicle drivetrain system. The controller **50** includes an overpressure safety system **80** to prevent the accumulator pressure from rising above a specified value. The safety system **80** is multiply redundant and consists of a mechanical safety release valve **82**, two independent pressure sensors **84** as well as two separate circuits that monitor the pressure sensors (via a majority voting scheme) and open the electrically operated safety valve **82** when required. In the event of a firmware failure, the auxiliary trip circuit opens the valve **82**.

[0030] During braking, energy is recovered by rerouting the braking energy from the vehicle's normal braking system and storing it as pressure in the gas bladder of the accumulator. In this way, instead of losing braking energy in the form of heat, the energy is stored in compressed nitrogen gas for later re-use during acceleration.

[0031] The microcomputer **64** monitors the position of the brake pedal **66** to determine the desired level of braking. The output signals of the vehicle's normal braking system are processed by a blending algorithm, which determines how to apportion braking force obtained from accumulator **70** pressure with that obtained from brake drum friction. The digital control system **50** monitors how much pressure the accumulator **70** has available and, based on the amount of braking desired, decides how much brake regeneration to apply.

[0032] In at least one embodiment, a brake pedal mechanism is used which incorporates a deadband nonlinearity into the overall braking system characteristic. The deadband is inserted at the beginning of the pedal's travel, so that for a specified initial portion of the travel, the normal braking system is effectively disconnected from the overall system until the threshold D is reached. Pedal travel beyond D results in a gradual addition of vehicle braking force. The braking force from the hydraulic system FH is added to the normal vehicle braking force FN to provide a combined braking force which acts on the mass M of the vehicle.

[0033] The vehicle deceleration $\alpha(z)$ is measured with an accelerometer and the value obtained is compared with the commanded deceleration value $\alpha d(z)$ obtained from the brake pedal position. A digital deceleration control system with discrete-time digital compensator GB(z) is used to control the hydraulic braking force via the swashplate angle servocontroller.

[0034] A separate emergency braking algorithm measures the brake pedal displacement and rate of movement and uses a peak detector and threshold comparator to determine if an emergency braking situation exists. In an emergency, the hydraulic braking system is effectively switched out causing the overall system to default to the vehicle's normal braking system. In this manner, the entire hydraulic braking system becomes transparent to it, allowing all features of an ABS system to work completely unhindered.

[0035] The top-level supervisory algorithm ensures that a specified minimum accumulator pressure is maintained, so that residual energy is always available for assistance with acceleration.

[0036] There are two modes of operation relating to acceleration:

[0037] 1. acceleration from standstill; and

[0038] 2. acceleration during forward motion.

[0039] The acceleration control algorithm monitors the accelerator pedal position sensor and determines the amount of acceleration desired. The vehicle's normal acceleration system is "drive-by-wire", in the sense that the pedal position generates a command signal for use by the vehicle's Electronic Control Unit (ECU). In this case, any modification of the accelerator command signal (such as adding a nonlinearity) can be implemented electronically without requiring any special linkages or adaptations to the existing pedal.

[0040] In the acceleration control system gain blocks Kv and Kh are the vehicle and hydraulic system scaling gains used to balance the acceleration torque magnitudes of the two systems. To ensure that stored energy is used before resorting to engine power, an adjustable deadband nonlinearity $D\alpha$, which is a function of the stored energy E and the pedal command value Φ, is used.

[0041] The amount of stored energy available is proportional to the pressure and volume of gas in the accumulator. The control system uses the desired acceleration and stored energy values to calculate the optimum swashplate command profile suitable to provide the required accelerating torque on the wheels of the vehicle in the most energy efficient way. The energy minimization algorithm takes measured acceleration, pedal position, fluid flowrate, shaft speed and accumulator pressure as inputs and uses them to calculate the best value of the variable $D\alpha(E,\Phi)$. When sudden, large accelerations are required, the value of $D\alpha(E,\Phi)$ can be large initially, allowing almost all of the extra energy stored in the accumulator to be quickly used to accelerate the vehicle until the pressure drops below a prescribed value.

[0042] The clutches illustrated in FIG. **2** are operated pneumatically and consist of proportional servo valves operating to control pneumatic pressure in the clutch, thereby controlling the clutching force. The valve opening is controlled by an electrically operated solenoid with actuation current controlled by a closed loop pressure control system which enables the force applied by the clutch to be accurately controlled by a voltage command signal.

[0043] FIG. **2** illustrates power transfer module **10** including a first, engine or inboard clutch **22** coupled to a second, pump or outboard clutch **26** via belt **24**. The inboard clutch **22** is shown coupled or in operable communication with transmission **14** and engine **28**, while the outboard clutch **23** is shown coupled or in operable communication with pump **16**.

[0044] FIG. **2** further illustrates the inboard clutch **22** enables isolation of the engine **28** from either cycle for example, while the outboard clutch **26** enables isolation of pump **16** during standard highway operation for example. The belt **24** and pulley scheme (not shown in FIG. **2**) provides the mechanical link between the two clutches **22** and **26**.

[0045] One important feature of the PTM **10** is the two wet clutches **22**, **26** that essentially replace the torque converter in an automatic transmission, providing large efficiency gains by enabling engine shutdown, and pump motoring without losses inherent to the movement of the internal combustion engine. FIG. **2** illustrates load paths that are possible because of the PTM's two clutches. A minimum energy level is always maintained in the accumulator so that the pump **16** can be used to speed match the engine **28** and transmission **14**. With the inboard clutch **22** disengaged, the engine **28** is completely disengaged from the drivetrain. Engaging the outboard clutch **26** couples the pump **16** to the drive-train. The pump **16** can produce its full torque at zero rotational speed. It can easily be coupled to the transmission **14** as they are both at zero rotational speed. Further clutch **22** doesn't require slippage in order to bring the transmission **14** and vehicle up to speed. As a fail safe mode so that the vehicle is still drivable if the pump **16** or some other part of the system is disabled, the integrated controller uses an engine load signal from the engine **29** to control engagement of inboard clutch **22** enabling the vehicle to operate as a semi-automatic transmission.

[0046] During a regenerative braking cycle, the inboard clutch **22** is deactivated allowing a clutch drive cup to spin freely. With the clutch drive cup directly linked to the crankshaft of engine **28** through the shaft interface, the engine **28** is isolated. With the inboard clutch **22** and inboard pulley directly coupled to the transmission **14** through the interface sleeve, all the braking energy is transmitted to the outboard pulley through the synchronous belt **24**. Additionally, the outboard clutch **26** (which is directly coupled to the hydraulic pump shaft) is activated, locking up the outboard drive cup (which is fixed to the outboard pulley) enabling the inputted energy to be transferred directly into the hydraulic pump **16**, where the braking energy is then recovered.

[0047] During an acceleration cycle, the inboard clutch **22** is deactivated, and the outboard clutch **26** is activated with the same effect, except that the input energy is supplied from the hydraulic pump **16**. The energy flows on the identical path as above but in the opposite direction. The energy transfers back through the drive train, accelerating the vehicle. However, other embodiments are contemplated for the acceleration cycle in which the inboard clutch **22** and outboard clutch are both activated.

[0048] During normal highway driving, the inboard clutch **22** is activated, while the outboard clutch **26** is deactivated. With the inboard clutch **22** activated the engine **28** is directly coupled to the transmission **14**. Though the synchronous pulley system is still active, with the outboard clutch **26** deactivated, the hydraulic pump **16** is decoupled from the system. Other embodiments are contemplated for the normal highway driving cycle in which the inboard clutch **22** and outboard clutch **26** are both activated.

[0049] The PTM **10** enables the engine **28** or hydraulic pump **16** to be utilized independently or together in any combination. By allowing the engine **28** to shutdown at braking and the pump **16** to recover braking energy, efficiency gains may be realized. The ability to declutch the engine **28** during a braking cycle also reduces or eliminates engine rotational mass energy losses and engine back pressure energy losses. Additionally, during standard highway operation, the pump **16** is isolated, reducing or eliminating pump rotational mass energy losses.

[0050] Table 1 provides possible scenarios illustrating clutch operation and control module status.

[0052] As illustrated, the second clutch module includes second, pump or outboard clutch **26** operably coupled to a second or outboard clutch drive cup **42** and adapted to activate and deactivate the outboard clutch drive cup **36**, such that the outboard clutch drive cup **42** moves between an activated mode, engaging the pump **16** through hydraulic pump shaft **44**, and a deactivated mode, disengaged from the pump **16**. The second clutch module likewise includes a second or outboard synchronous pulley **40** operably coupled to at least the outboard clutch drive cup **42**. A synchronous belt or drive device **24** operably couples the first synchronous pulley **34** and the second synchronous pulley **40**.

[0053] During a regenerative braking cycle, the inboard clutch **22** is deactivated allowing inboard clutch drive cup **34** to spin freely. With the clutch drive cup **34** directly linked to the crankshaft of engine **28** through the shaft interface **32**, the engine **28** is isolated. With the inboard clutch **22** and inboard pulley **36** directly coupled to the transmission **14** through the interface sleeve **38**, all the braking energy is transmitted to the outboard pulley **40** through the synchronous belt **24**. Additionally, the outboard clutch (which is directly coupled to the hydraulic pump shaft **44**) is activated, locking up the outboard drive cup **42** (which is fixed to the outboard pulley **40**) enabling the inputted energy to be transferred directly into the hydraulic pump **16**, where the braking energy is then recovered.

[0054] During the acceleration cycle, the inboard clutch **22** is deactivated, and the outboard clutch **26** is activated with the same effect, except that the input energy is supplied from the hydraulic pump **16**. The energy flows on the identical path as above but in the opposite direction. The energy transfers back through the drive train, accelerating the vehicle. As provided, other embodiments are contemplated for the acceleration cycle in which the inboard clutch **22** and outboard clutch **26** are both activated.

TABLE 1

Vehicle Function	Engine Clutch	Pump Clutch	ACS State	ECU State	TCM State
Idle in park	Disengaged	Disengaged	Passive	Normal	Normal
Idle in drive	standby if HP empty	engaged if HP full	Active Acceleration	see chart	Normal
Accelerating with pump	Disengaged	engaged	Active Acceleration	see chart	Normal
Transition from pump to engine power	Disengaged to engaged	engaged to disengaged	Active to passive	Piggybacked to normal	Piggybacked to normal
Braking with full accumulator	engaged	Disengaged	Passive	Normal	Normal
Regenerative braking	Disengaged	engaged	Active Braking	Piggybacked	Piggybacked

* A passive ACS state replicates normal vehicle operation.
* An active ACS state provides controlled pump integration
* A normal ECU or TCM state means they are getting "real" signals unmodified from the ACS

[0051] FIG. **3** is a cross-sectional view of the PTM **10** in accordance with the present invention. As illustrated, PTM **10** includes first clutch module coupled to an engine crank shaft interface **32** and operably connected to a second clutch module such that power is transferred from the vehicle transmission to the vehicle hydraulic pump. More specifically, the first clutch module includes first, engine or inboard clutch **22** operably coupled to a first or inboard clutch drive cup **34** and adapted to activate and deactivate the inboard clutch drive cup **34**, such that the inboard clutch drive cup **34** moves between an activated mode, engaging transmission **14** through transmission interface sleeve **38**, and a deactivated mode, disengaged from the transmission **14**. The first clutch module further includes a first or inboard synchronous pulley **34** operably coupled to at least the inboard clutch drive cup **34**.

[0055] During normal highway driving, the inboard clutch **22** is activated, while the outboard clutch **26** is deactivated. With the inboard clutch **22** activated the engine **28** is directly coupled to the transmission **14**. Though the synchronous pulley system is still active, with the outboard clutch **26** deactivated, the hydraulic pump **16** is decoupled from the system. Again, other embodiments are contemplated for the normal highway driving cycle in which the inboard clutch **22** and outboard clutch are both activated.

[0056] The PTM **10** enables the engine **28** or hydraulic pump **16** to be utilized independently or together in any combination. By allowing the engine **28** to shutdown at braking and the pump **16** to recover braking energy, efficiency gains may be realized. The ability to declutch the engine **28**

during a braking cycle also reduces or eliminates engine rotational mass energy losses and engine back pressure energy losses. Additionally, during standard highway operation, the pump **16** is isolated, reducing or eliminating pump rotational mass energy losses.

[0057] FIGS. **4** & **5** depict cross-sectional views of a power transfer module, generally designated **100**, in accordance with one embodiment of the present invention. Power transfer module **100** is similar in many ways to the power transfer module **10** as provided above. As illustrated, PTM **100** includes a torque converter **102** in contact with or in proximity to a housing or case **104** which contains a synchronous drive system **106**. In at least one embodiment, the synchronous drive system **106** includes a first or inboard synchronous pulley **34**, a second synchronous pulley **40** and the synchronous belt **24** similar to that provided previously. It should be appreciated that the synchronous drive system may include belt and pulleys as illustrated or chain and sprockets and the like. FIG. **4** illustrates the system **100** may additionally include a clutch **122**, similar to clutch **22** discusses. As illustrated, the engine, via torque converter **102** and transmission input shaft, engages the pump **16** through hydraulic pump shaft **44** and synchronous drive system **106**.

[0058] During a regenerative braking cycle, inboard pulley **36** is directly coupled to the transmission **14** through the interface sleeve **38**, such that all the braking energy is transmitted to the outboard pulley **40** through the synchronous belt **24**. In at least one embodiment, the outboard clutch **122** (which is directly coupled to the hydraulic pump shaft **44**) is activated, enabling the inputted energy to be transferred directly into the hydraulic pump **16**, where the braking energy is then recovered.

[0059] During the acceleration cycle, the input energy is supplied from the hydraulic pump **16**. The energy flows on the identical path as above but in the opposite direction. The energy transfers back through the drive train, accelerating the vehicle.

[0060] During normal highway driving, the engine **28** is directly coupled to the transmission **14**. Though the synchronous drive system **106** is still active and the hydraulic pump **16** is decoupled from the system via the outboard clutch **122**.

[0061] The PTM **100** enables the engine **28** or hydraulic pump **16** to be utilized independently or together in any combination. By allowing the engine **28** to shutdown at braking and the pump **16** to recover braking energy, efficiency gains may be realized. The ability to declutch or disengage the engine **28** during a braking cycle, via the loose fluid coupling of the torque converter or a sprague, also reduces or eliminates engine rotational mass energy losses and engine back pressure energy losses. Additionally, during standard highway operation, the pump **16** is isolated, reducing or eliminating pump rotational mass energy losses.

[0062] When the vehicle is at rest, the transmission **14** will also be at rest or have zero rotational speed. In order for an internal combustion engine **28** to produce any torque it must be running at some rotational speed greater than zero. The transmission **14** and vehicle must slowly be brought up to the same speed so that the engine **28** can build enough torque to drive the vehicle and so that a rapid shock load doesn't occur and break mechanical components or cause the driver to lose control. The hydraulic pump/motor unit can produce torque at zero rotational speed. If a minimum amount of pressurized fluid is kept in the accumulator, the pump **16** will exert a specific torque on the transmission **14** based on its displacement setting. At low displacement settings, the pump **16** has a low torque and at higher displacement settings has a higher torque, such that the overall value is proportional to the pressure that the accumulator is putting on the pumps working port. Controlling this displacement enables the pump **16** to accelerate the vehicle smoothly. The transmission **14** may be left in neutral and the engine **28** used to rotate the pump **16**, to build up stored energy. Then acceleration may be handled strictly by the pump **16**.

[0063] FIG. **6** is an exploded view of the power transfer module **100** of FIG. **4** in accordance with another embodiment of the present invention. FIG. **6** illustrates the PTM **100** includes the housing or case **104** containing the first or inbound synchronous pulley **36** connected to the transmission interface sleeve **38**, and the second or outbound synchronous pulley **40** connected to the hydraulic pump shaft **44**. FIG. **6** further illustrates the PTM **100** further includes a stator **108**, a bearing **110**, a seal **112**, hub interface **114** and a torque converter hub **116** connected to at least one of the transmission interface sleeve **38** and torque converter **102**. FIG. **6** further illustrates a flex plate **116** coupled to the torque converter **102** to the engine.

[0064] FIG. **7** is an another view of the torque converter and torque converter hub of the power transfer module **100** of FIG. **4** in accordance with the present invention. FIG. **8** illustrates the torque converter **102** and torque converter hub **116**.

[0065] This power transfer modules **10**/**100** include many unique features that make it an efficient device enabling regenerative braking using a hydraulic pump/motor. On top of the features provided above such as engine decoupling, engine shutoff, and combining pump and engine power, the present invention enables putting the pump power through a mechanical gear reduction or increase without adding any extra components. Because the pump/motor is positioned before the transmission, its torque is multiplied by the transmission depending on what gear is selected. Part of the control scheme for this device controls the transmissions shift patterns to optimize the energy use depending on whether the engine or the pump is powering the vehicle. The transmission is shifted during braking events so that the pump can be pumping in its most efficient modes of operation and the maximum amount of energy can be stored. Because of the torque multiplication the hydraulic system as a whole can be down sized, which is part of what makes this system economically and physically practical.

[0066] While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.

1. A system comprising:

a torque converter;

a torque converter hub connected to at least the torque converter; and

a synchronous drive system coupled to at least the torque converter.

2. The system of claim **1** wherein the synchronous drive system comprises a first synchronous pulley connected to at least the torque converter.

3. The system of claim **2** further comprising an interface sleeve connected to at least one of the first synchronous pulley, the torque device and the torque converter hub.

4. The system of claim **2** wherein the synchronous drive system further comprises a second synchronous pulley.

5. The system of claim **5** further comprising a hydraulic pump shaft connected to the second synchronous pulley.

6. The system of claim **4** further comprising a synchronous belt rotatably coupling the first synchronous pulley and the second synchronous pulley.

7. The system of claim **6** further comprising a housing containing at least the synchronous belt, the first synchronous pulley and the second synchronous pulley.

8. A system for transferring power from a vehicle drive system to a vehicle fluid power system, the system comprising:

a power torque converter connected to the vehicle drive system;

a torque converter hub connected to at least the power torque converter; and

a synchronous drive system coupled to at least the power torque converter, whereby power is transferred between at least the vehicle drive system and the vehicle fluid power system.

9. The system of claim **1** further wherein the synchronous drive system comprises a first synchronous pulley connected to at least the power torque converter.

10. The system of claim **9** further comprising an interface sleeve connected vehicle drive system and at least one of the first synchronous pulley, the power torque device and the torque converter hub.

11. The system of claim **10** wherein the synchronous drive system further comprises a second synchronous pulley.

12. The system of claim **11** further comprising a hydraulic pump shaft connected to the second synchronous pulley and the vehicle fluid power system.

13. The system of claim **12** further comprising a synchronous belt rotatably coupling the first synchronous pulley and the second synchronous pulley.

14. The system of claim **13** further comprising a housing containing at least the synchronous belt, the first synchronous pulley and the second synchronous pulley.

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