(12) UK Patent Application (19) GB (11) 2558610 (13) A

(43) Date of A Publication 18.07.2018

(21) Application No: 1700379.9

(22) Date of Filing: 10.01.2017

(71) Applicant(s):
J.C. Bamford Excavators Limited
Lakeside Works, Rocester, Uttoxeter, Staffordshire, ST14 5JP, United Kingdom

(72) Inventor(s):
Darryl Cottingham

(74) Agent and/or Address for Service:
Withers & Rogers LLP
4 More London Riverside, LONDON, SE1 2AU, United Kingdom

(51) INT CL:
F15B 21/14 (2006.01) ***E02F 9/22*** (2006.01)

(56) Documents Cited:
GB 2533224 A **CN 102864811 A**

(58) Field of Search:
INT CL **E02F, F15B**
Other: **WPI; EPODOC**

(54) Title of the Invention: **Energy recovery system**
Abstract Title: **An energy recovery system for use with a load handling machine**

(57) A hydraulic system, incorporating an energy recovery system for use with a load handling machine, is provided. The hydraulic system includes: a hydraulic machine 60 having a first port 62 and a second port 63 and a drive shaft 61; a hydraulic actuator 3B; and a kinetic energy storage device J. The kinetic energy storage device J is operably coupled to the drive shaft 61 of the hydraulic machine 60. The hydraulic system is configured such that: the hydraulic machine 60 is capable of acting as a pump by configuring the kinetic energy storage device J to transfer energy to the hydraulic machine 60 via the drive shaft 61 such that the drive shaft rotates in a first rotational direction R2 and the hydraulic machine 60 receives hydraulic fluid through the first port 62 and provides pressurised hydraulic fluid to the actuator 3B via the second port 63; and the hydraulic machine 60 is capable of acting as a motor by configuring the hydraulic machine t60 o transfer energy to the kinetic energy storage device J via the drive shaft 61 such that the drive shaft rotates in the first rotational direction R2 and the hydraulic machine 60 receives pressurised hydraulic fluid from the actuator 3B via the second port 63 and vents hydraulic fluid through the first port 62.

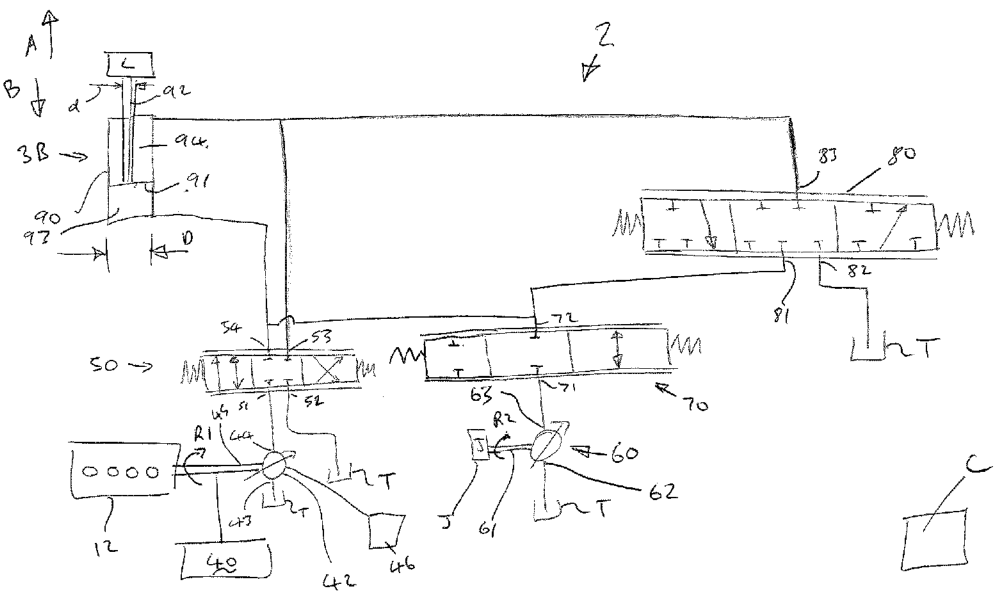


FIG 2.

GB 2558610 A

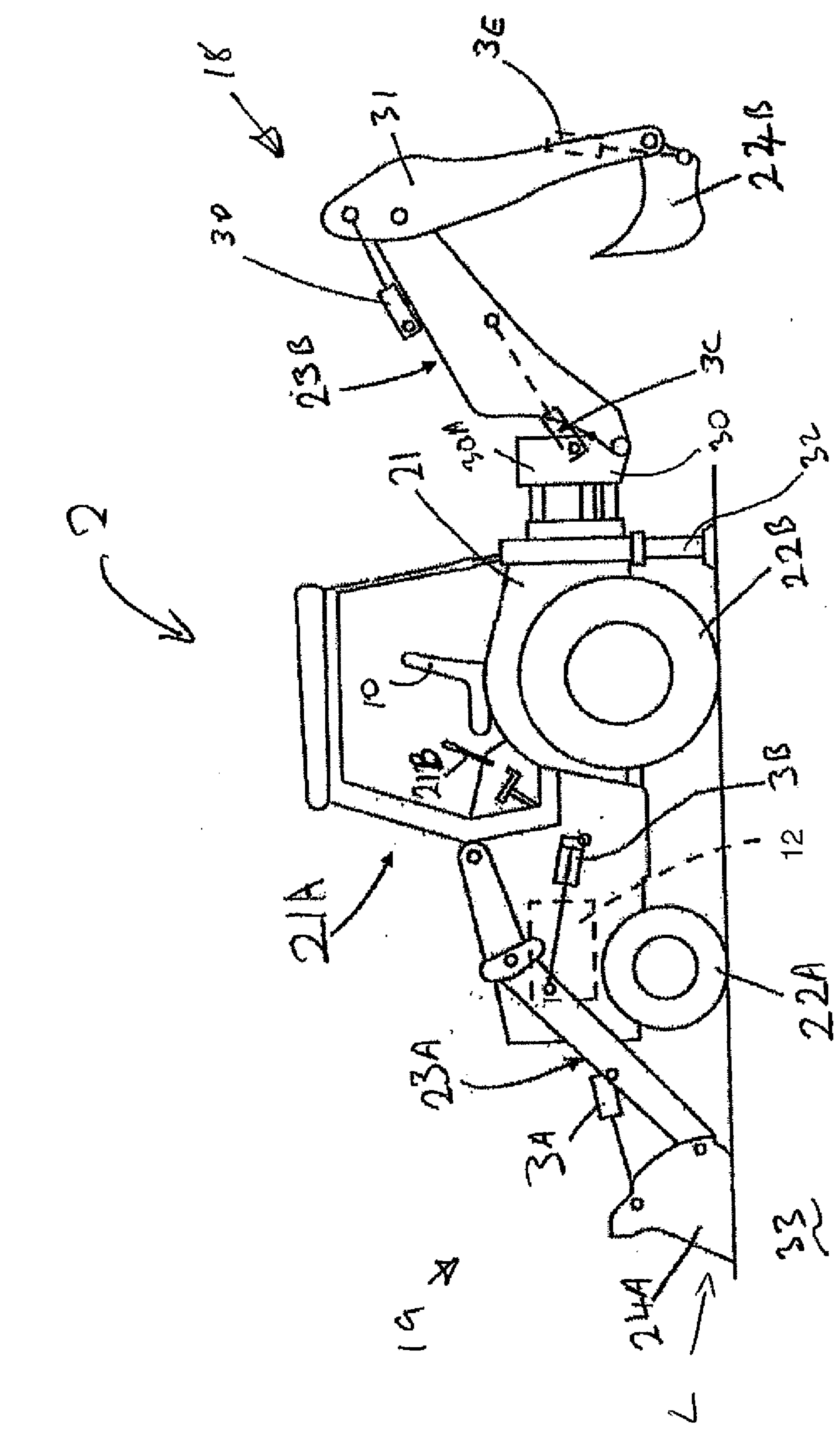
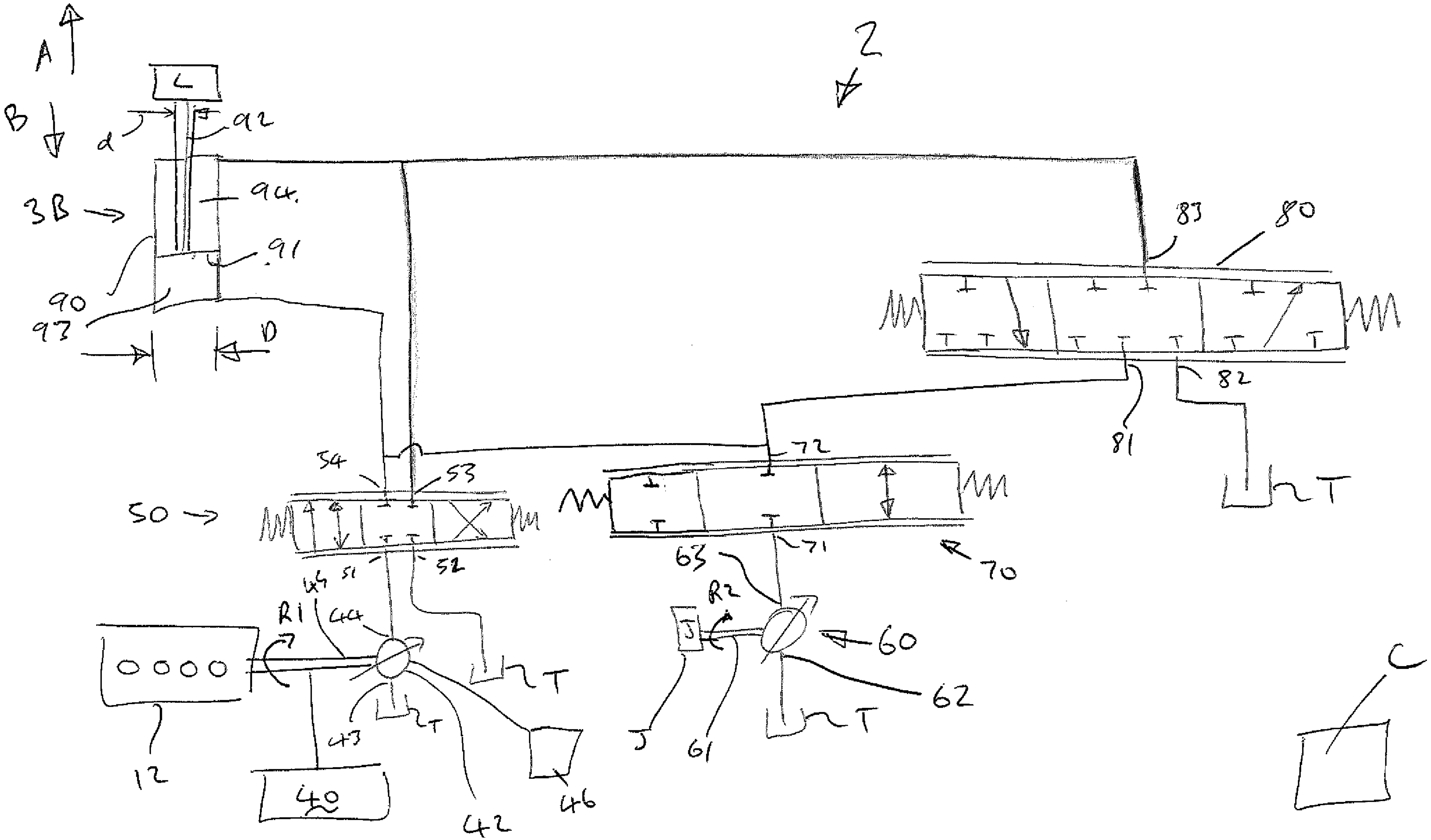

2
18
19
21
21A
21B
22A
22B
23A
23B
24A
24B
3A
3B
3C
3D
3E
10
12
30
30A
31
32
33
L

FIG. 1



A
B
d
L
92
3B
94
91
90
93
D
2
83
80
81
82
T
72
54
53
50
70
71
63
51
52
R1
44
R2
60
62
12
43
42
40
46
J
61
C

FIG. 2

W&R Reference: P346485GB

Energy Recovery System.

The present invention relates to an energy recovery system, in particular for use with a load handling machine.

Load handling machines, such as back hoe loaders, excavators and telehandlers, are known whereby material can be moved from one place to another. The material may be discreet material, for example telehandling machine may move palletised material. Alternatively the material may be loose material such as earth which could be dug using an excavator. In either case, energy is required to move the material. Under certain circumstances, kinetic energy, for example the forward motion of a load handling machine, or potential energy, for example the centre of gravity of a lifting arm above ground level, can be wasted during operation of the machine. The object of the present invention is to provide a means of recovering energy that would otherwise be wasted.

According to one aspect of the present invention there is provided a hydraulic system including:

hydraulic fluid,

a hydraulic machine having a first port and a second port and a drive shaft,

a hydraulic actuator, and

a kinetic energy storage device,

the kinetic energy storage device being operably coupled to the drive shaft of the hydraulic machine, the hydraulic system being configured such that:

the hydraulic machine is capable of acting as a pump by configuring the kinetic energy storage device to transfer energy to the hydraulic machine via the drive shaft such that the drive shaft rotates in a first rotational direction and the hydraulic machine receives hydraulic fluid through the first port and provides pressurised hydraulic fluid to the actuator via the second port, and

the hydraulic machine is capable of acting as a motor by configuring the hydraulic machine to transfer energy to the kinetic energy storage device via the drive shaft such that the drive shaft rotates in the first rotational direction and the hydraulic machine receives pressurised hydraulic fluid from the actuator via the second port and vents hydraulic fluid through the first port.

The hydraulic machine may be a variable capacity hydraulic machine.

The hydraulic machine may include a movable swash plate.

The swash plate may be movable in a first direction from a neutral position to enable the hydraulic machine to act as a pump and is movable in a second direction from the neutral position to enable the hydraulic machine to act as a motor.

According to another aspect of the present invention there is provided a method of operating a hydraulic system, the hydraulic system including:

hydraulic fluid,

a hydraulic machine having a first port and a second port and a drive shaft,

a hydraulic actuator, and

a kinetic energy storage device,

the kinetic energy storage device being operably coupled to the drive shaft of the hydraulic machine,

the method comprising the steps of:

1) operating the hydraulic machine as a pump by configuring the kinetic energy storage device to transfer energy to the hydraulic machine via the drive shaft such that the drive shaft rotates in a first rotational direction and the hydraulic machine receives hydraulic fluid through the first port and provides pressurised hydraulic fluid to the actuator via the second port, then

2) operating the hydraulic machine as a motor by configuring the hydraulic machine to transfer energy to the kinetic energy storage device via the drive shaft such that the drive shaft rotates in the first rotational direction and the hydraulic machine receives pressurised hydraulic fluid from the actuator via the second port and vents hydraulic fluid through the first port.

The hydraulic machine may be a variable capacity hydraulic machine.

The hydraulic machine may include a movable swash plate.

The swash plate may be movable in a first direction from a neutral position to enable the hydraulic machine to act as a pump and is movable in a second direction from the neutral position to enable the hydraulic machine to act as a motor.

According to a further aspect of the present invention there is provided a hydraulic system including:

hydraulic fluid,

a hydraulic machine having a drive shaft,

a double acting hydraulic ram having a head side chamber defined by a first effective piston area and a rod sided chamber defined by a second effective piston area, the second effective piston area being smaller than the first effective piston area,

a kinetic energy storage device, the kinetic energy storage device being operably coupled to the drive shaft of the hydraulic machine, and

a hydraulic circuit,

the hydraulic system being configured such that:-

upon retraction of the hydraulic ram, hydraulic fluid flowing out of the head side chamber is provided via the hydraulic circuit to both:-

a) the hydraulic machine so as to act as a motor and transfer energy to the kinetic energy storage device via the drive shaft, and

b) to the rod side chamber as the rod side chamber expands.

The hydraulic circuit may include a first valve between the head side chamber and the hydraulic machine.

The hydraulic circuit may include a second valve between the head side chamber and the rod side chamber.

The hydraulic circuit may include a third valve between the rod side chamber and a hydraulic tank.

One or more of the first valve, second valve and third valve may comprise a variable valve providing a variable restriction.

The second valve and third valve may be at least provided on a common spool.

The first valve may be distinct from the common spool of the second and third valves.

The first effective piston area may be between 1.25 and 2.5 times larger than the second effective piston area.

According to a further aspect of the present invention there is provided a method of operating a hydraulic system, the hydraulic system including:

hydraulic fluid,

a hydraulic machine having a drive shaft,

a double acting hydraulic ram having a head side chamber defined by a first effective piston area and a rod side chamber defined by a second effective piston area, the second effective piston area being smaller than the first effective piston area,

a kinetic energy storage device, the kinetic energy storage device being operably coupled to the drive shaft of the hydraulic machine, and

a hydraulic circuit,

the method comprising the steps of:

1) supporting a load with the hydraulic ram by providing a first headside pressure in the head side chamber, then

2) retracting the hydraulic ram such that hydraulic fluid flowing out of the head side chamber is provided via the hydraulic circuit to both:-

a) the hydraulic machine so as to act as a motor and transfer energy to the kinetic energy storage device via the drive shaft, and

b) to the rod side chamber as the rod side chamber expands thereby increasing the pressure in the rod side chamber.

During step 2)b) the increase in pressure in the rod side chamber may cause an increase in the pressure in the head side chamber to a second head side pressure, the second head side pressure being greater than the first head side pressure.

During step 1) a first rod side pressure may be provided in the rod side chamber and during step 2) the pressure in the rod side chamber increases to a second rod side pressure, the second rod side pressure being greater than the first rod side pressure.

The second rod side pressure may be greater than the first head side pressure.

During step 2)a) the hydraulic fluid provided to the hydraulic machine may be provided at a pressure greater than the first head side pressure.

Advantageously, energy that would otherwise be wasted can be stored in the kinetic energy storage device. The stored energy can later be used. Because the hydraulic machine is operable to transfer energy from the hydraulic fluid received from the hydraulic actuator to the kinetic energy storage device, then the kinetic energy storage device can act to resist the actuator in a controlled manner. For example, when the actuator controls the centre of gravity of a lifting arm above ground, and the kinetic energy storage device is a flywheel, by ensuring the flywheel speeds up in a controlled manner ensures that the lifting arm descends in a controlled manner. Similarly, when the actuator controls the speed of an associated vehicle across the ground, and the kinetic energy storage device is a flywheel, by ensuring the flywheel speeds up in a controlled manner ensures that the speed of the vehicle across the ground is reduced in a controlled manner.

The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a view of a machine including hydraulic system according to the present invention, and

Figure 2 is a schematic representation of part of the machine of figure 1.

With reference to Figure 1 there is shown a working machine 2, in this case a back hoe loader machine. The machine includes a chassis 21 supported on front wheels 22A and rear wheels 22B. The machine includes a cab 21A and manually operable controls 21B which can be operated by an operator sitting in seat 10. Pivotally mounted on the chassis is a front loading arm 23A, on the front of which is pivotally mounted a loading shovel 24A. A carriage 30 is slideably mounted on the chassis at rear of the machine. The carriage can be caused to slide laterally relative to the chassis, i.e. towards or away from a viewer viewing figure 1. A back hoe arm 23B is pivotally mounted on the carriage 30. A dipper arm 31 is pivotally mounted on an end of the back hoe arm 23B. A bucket 24B is pivotally mounted on an end of the dipper arm 31. Stabilising legs 32 are extendible towards the ground 33 and engageable therewith to stabilise the chassis when the back hoe 18 is being used. The stabilising legs are retractable away from the ground 33 for example when the wheels are being used to propel the working machine across the ground.

The working machine includes an engine 12. The engine 12 drives a transmission 40 (see figure 2) which in turn drives the rear wheels 22B to propel the vehicle along the ground when required. The engine also drives a hydraulic pump 42 which, by virtue of a control system and a hydraulic circuit, selectively supplies pressurised hydraulic fluid to actuators 3A, 3B, 3C, 3D and 3E.

Actuator 3A is a hydraulic ram which causes the bucket 24A to pivot relative to the front loading arm 23A.

Actuator 3B is a hydraulic ram which causes the front loading arm 23A to pivot relative to the chassis 21.

Actuator 3C is a hydraulic ram which causes the back hoe arm 23B to pivot about a generally horizontal axis relative to the carriage 30.

Actuator 3D is a hydraulic ram which causes the dipper arm 31 to pivot relative to the back hoe arm 23B.

Actuator 3E is a hydraulic ram which causes the bucket 24B to pivot relative to the dipper arm 31.

Further actuators (not shown) causes extension and/or retraction of the stabilising legs.

A further actuator (not shown) causes the carriage 30 to move laterally relative to the chassis 21.

A further actuator (not shown) causes rear portion 30A of carriage 30 to "slew" relative to the chassis 21, i.e. pivot about a substantially vertical axis relative to chassis 21.

The actuators shown in figure 1 and the actuators just described are known as "hydraulic services" and are supplied with pressurised hydraulic fluid from the hydraulic pump 42. A person skilled in the art would readily appreciate that other types of hydraulic services are known.

Consideration of figure 1 shows that actuator ram 3B causes the front loading arm 23A to pivot relative to the chassis 21. The extension of ram 3B causes lifting of the front loading arm 23A and retraction of hydraulic ram 3B causes lowering of the loading arm 23A. Clearly, lifting of the loading arm 23A requires energy input, whereas typically lowering of the loading arm 23A does not, since the loading arm will fall under the influence of gravity from a raised position to a lowered position.

Similarly, crowding of the bucket 24A requires energy input into service 3A, whereas dumping of the bucket typically does not, since the bucket will dump under the influence of gravity.

The lifting of the back hoe arm 23B requires energy whereas lowering typically does not. Lifting of the dipper arm 31 requires energy whereas lowering of the dipper arm typically does not. Crowding of the bucket 24B typically requires energy, whereas dumping of the bucket 24B typically does not. Lowering of the stabilising legs 32 requires energy in order to lift the rear wheels of the backhoe loader off the ground, but, for example, where the rear wheels have been lifted off the ground, raising of the stabilising legs 32 to the point where the weight of the machine is taken on the rear wheels does not.

As will be appreciated, energy input is required into certain actuators when they are operated in certain directions but when operated in an opposite direction (or sense) then, under many circumstances energy input is not required since movement of the associated component is assisted by gravity. In particular, when the front loading arm is lowered from a relatively high position to a relatively low position, the centre of gravity of that lifting arm moves from a relatively high position to a relatively low position. In the present invention this potential energy can be recovered.

As mentioned above, an actuator (not shown) causes a rear portion 30A of carriage 32 to slew relative to the chassis 21. Since the back hoe arm, dipper arm and bucket are all attached to the rear portion 30A of the carriage, then these components also slew relative to the chassis. In order to start the slew motion, energy is required to overcome the inertia of the slewed components. However, in order to stop the slew motion in a controlled manner, in the prior art this is carried out by dissipating the kinetic energy as heat within the hydraulic system. The present invention allows recovery of the kinetic slew energy.

Some working machines have a hydrostatic transmission to propel them along the ground and when it is necessary to slow the vehicle, the kinetic energy of the vehicle is dissipated as heat energy within the friction brakes. The present invention allows recovery of this kinetic energy.

With reference to figure 2, a schematic representation of part of the working machine 2 of figure 1.

Figure 2 shows a main control valve 50 and example hydraulic service, in this case actuator 3B, a hydraulic pump/motor 60 (also known as a hydraulic machine), a valve 70, a valve 80 and a main controller C.

As mentioned above, actuator 3B is a hydraulic ram and includes a cylinder 90, having internal diameter D, within which moves a piston 91. Piston 91 is connected to a rod 92 having diameter d.

The piston 91 defines a head side chamber 93 and a rod side chamber 94. The head side effective piston area is the cross section area of the cylinder, i.e. $\pi D^2/4$. The rod side effective piston area is the cross section area of the cylinder minus the cross section area of the rod, i.e. $\pi \ (D^2 - d^2)/4$.

A load L is shown schematically on figure 2 and represents, for example, a load in shovel 24A. As will be appreciated from figures 1 and 2 in order to raise the load the piston 91 must move in the direction of arrow A, and in order to lower the load the piston must move in the direction of arrow B. In order to raise the load, energy is required. The load is such that gravity will cause the load to lower unless otherwise restrained.

Main control valve 50 controls flow of fluid from pump 42 to the head side chamber 92 or rod side chamber 94, and draining of fluid from head side chamber 93 or rod side chamber 94 to a low pressure region for example tank T under certain circumstances as will be further described below.

Valve 70 controls a flow of hydraulic fluid from hydraulic pump/motor 60 to and from the head side chamber 93 as will be further described below.

Valve 80 controls flow of hydraulic fluid from the head side chamber 93 to the rod side chamber 94 under certain circumstances as will be further described below. Valve 80 also controls flow of hydraulic fluid from the rod side chamber 94 to a low pressure region for example to tank T under alternative circumstances as will be further described below.

Pump 42 is driven from engine 12 and as such only ever rotates in one direction, as shown in figure 2 in direction R1. Pump 42 is a variable displacement pump in this case having a swash plate.

The main controller C receives command signals e.g. from an operator controls and controls valves 50, 70 and 80 at least in order to execute the required demand signal. The controller may be a computer.

The hydraulic pump/motor 60 has a first port 62 which is connected to a low pressure region for example to tank T and a second port 63 which is connected to valve 70. Hydraulic pump/motor 60 is a variable displacement pump/motor. In this case the hydraulic pump/motor is a swash plate pump/motor and the swash plate can be positioned at various positions:-

At a null position of the swash plate rotation of the pump in the direction of R2 (see figure 2) does not cause any fluid transfer.

If the swash plate is moved in a positive direction away from the null position, then rotation of the hydraulic pump/motor in the direction of R2 causes the hydraulic pump/motor to act as a pump and receive hydraulic fluid through the first port 62 and provide pressurised hydraulic fluid at the second port 63.

However, if the swash plate is moved in a negative direction from the null position, then rotation of pump/motor in the direction of R2 causes the hydraulic pump/motor 60 to act as a motor and receive pressurised fluid from the second port 63 and vent hydraulic fluid out of the first port 62 to a low pressure region for example to tank.

Table 1 below summarises operation of hydraulic pump/motor 60.

Table 1

Operation	**Direction of Rotation**	**Swash plate orientation**	**1st port 62**	**2nd port 63**
Pump	R2	+ve	Low pressure inlet	High pressure outlet
Motor	R2	−ve	Low pressure outlet	High pressure inlet

It should be noted that the hydraulic pump/motor 60 always rotates in the same direction R2.

The first port 62 is always a low pressure port, but when the hydraulic pump/motor 60 is acting as a pump the first port 62 is an inlet whereas when the hydraulic pump/motor 60 is acting as a motor the first port 62 becomes an outlet.

By analogy, the second port 63 is always a high pressure port, though it is an outlet when the hydraulic pump/motor 60 is acting as a pump but an inlet when acting as a motor.

As will be appreciated, even though the direction of flow of hydraulic fluid through the hydraulic pump/motor 60 can be reversed depending upon whether it is acting as a pump or a motor, nevertheless the direction of rotation of the hydraulic pump/motor 60 is always the same (i.e. in the direction of R2). This is achieved by virtue of the swash plate being able to move in both a positive and negative direction from null, i.e. the swash plate can move "over centre".

The hydraulic pump/motor is connected to a kinetic energy storage device, in this example a flywheel J via drive shaft 61. The flywheel may rotate at the same speed as drive shaft 61, though in further embodiments the flywheel may be geared to rotate faster than the drive shafts 61.

Valve 50 is a proportional spool valve which is sprung loaded to the central position as shown in figure 2 wherein ports 51, 52, 53 and 54 are all isolated from each other. The spool can be moved to the right when viewing figure 2 by the main controller C thereby connecting port 51, with port 54 and separately connecting port 53 with port 52.

Alternatively the spool can be moved to the left when viewing figure 2 by the main controller C thereby connecting port 51 with port 53 and separately connecting port 54 with port 52.

Valve 70 in this case is a proportional spool valve. As shown in figure 2 the spool is sprung loaded to a central position wherein port 71 of valve 70 is isolated from port 72 of valve 70. The main controller C is capable of moving the spool block to the left when viewing figure 2 thereby connecting port 71 with port 72.

Spool 80 is a proportional spool valve having ports 81, 82 and 83. The spool is sprung loaded to the central position as shown in figure 3 wherein ports 81, 82 and 83 are all isolated from each other. The main controller C can move the spool to the right when viewing figure 2 thereby connecting port 83 to port 82 but maintaining port 81 as an isolated port. Alternatively the main controller C can move the spool to the left when viewing figure 2 thereby connecting port 81 with port 83 whilst maintaining port 82 as an isolated port.

As can be seen from figure 2:-

Inlet 43 of hydraulic pump 42 is connected to a low pressure region, for example tank T.

Outlet 44 of hydraulic pump 42 is connected to port 51.

Port 52 is connected to a low pressure region, for example tank T.

Ports 54, 72, 81 and the head side chamber 93 are all connected together.

Port 53, 83 and the rod side chamber 94 are all connected together.

The second port 63 is connected to port 71 of valve 70.

The first port 62 of the hydraulic pump/motor is connected to a low pressure region, for example tank T.

The port 82 of valve 80 is connected to a low pressure region, for example tank T.

Operation of the working machine is as follows:

<u>Lifting a load using engine 12</u>

Consider the example where the loading shovel 24A is on the ground as shown in figure 1 and includes a load. The flywheel J is stationary. The valves 50, 70 and 80 are in the position as shown in figure 2. The engine 12 is running and the pump shaft 45 is being driven by the engine and hence pump shaft 45 and pump 42 are both rotating in the direction of R1. Pump 42 is a variable displacement pump and since no flow is required as shown in figure 2 (port 51 is closed) then the pump controller 46 ensures that the swash plate of the hydraulic pump 42 is at or near a null position.

If an operator wishes to lift the load L, then the operator operates operator controls (not shown) which provides a signal to cause the main controller C to cause the spool of main control valve 50 to move to the right when viewing figure 2 thereby connecting port 51 with 54 and separately connecting port 53 with 52. Substantially simultaneously, the pump controller 46 will move the swash plate of the hydraulic pump 42 so as to draw in hydraulic fluid through inlet port 43 and thereby pressurise outlet port 44. As will be appreciated from figure 2, outlet port 54 will be connected, via the main control valve 50, to the head side chamber 93, to port 72 (which is closed) and to port 81 (which is closed). Therefore all the hydraulic fluid from hydraulic pump 42 will flow into the head side chamber 93 thereby progressively raising the load L. As the load L rises the volume of the rod side chamber 94 becomes smaller and therefore vents hydraulic fluid. The rod side chamber 94 is connected to port 83 (which is closed) and to port 53, which is connected to port 52, which in turn is connected a low pressure region for example to tank T. Accordingly all of the hydraulic fluid venting from the rod side chamber 94 passes through valve 50 and into tank T.

When the load has reached the desired height, the operator will release the operator controls which will cause the main controller C to allow spool valve 50 to return to the position as shown in figure 2. Once in the position shown in figure 2 the head side chamber 93 is connected to ports 54, 72 and 81, all of which are closed. Therefore, the load L will be held at the desired height.

Lowering the load to regenerate energy

As mentioned above, in this example the flywheel J is stationary. Thus when the operator wishes to lower the load, the potential energy of the load being positioned at a height can be converted into kinetic energy of the flywheel J as follows:-

The operator actuates an operator control which provides a signal to lower the load. The main controller causes the spool valve 80 to move to the left when viewing 2, thereby causing port 81 to become connected with port 83 whilst keeping port 82 isolated.

The effect of hydraulically coupling port 81 to port 83 is that the pressure in the head side chamber 93 is applied to the rod side chamber 94. An increase in pressure in the rod side chamber 94 in turn causes an increase in pressure in the head side chamber 93, which increase in pressure in the head side chamber 93 is again reflected as an increase in pressure in the rod side chamber 94.

Because port 72 is still closed, then the load L will still be supported but the pressures in the head side chamber and rod side chamber will now both be greater.

By way of example assume that prior to the spool of valve 80 moving the pressure in the head side chamber 93 is 100 bar and the pressure in the rod side chamber is zero.

Assume the rod side effective piston area is X mm^2 and assume the head side effective piston area is 2X mm^2, i.e. head side effective piston area is twice the rod side effective piston area.

Assume the compressive force in the rod equals the load L.

Since load L = pressure × area, then the load L = 100 bar × 2X mm^2 which equals 200 bar mm^2.

Then consider the situation when the spool of valve 80 is moved so as to connect the head and rod side chambers. Once the pressure in the head side chamber and rod side chamber is the same, then, knowing a load, and knowing the head side effective piston area and the rod side effective piston area, the pressure Z can be calculated as follows.

Load L + (rod side effective piston area × Pressure Z) = head side effective piston area × Pressure Z

$$200 + (X.Z) = 2XZ$$

Solving for Z, the head side and rod side pressure when load L is applied (port 72 is closed and port 81 is open) is 200 bar. As will be appreciated, in this example, the head side pressure doubled (going from 100 bar to 200 bar) due to the fact that the head side effective piston area was twice that of the rod side effective piston area.

Thus, as described above once valve 80 is moved such that port 81 is connected to port 83, the pressure in the head side chamber increases, and this increased pressure is then applied to the hydraulic pump/motor 60 via valve 70 once the main controller C causes the spool of the valve 70 to move to the left when viewing figure 2, thereby connecting port 71 and 72. The main controller C moves the swash plate of hydraulic pump/motor 60 in a negative direction such that the hydraulic pump/motor 60 acts as a motor with the second port 63 acting as a high pressure inlet and the first port 62 acting as an outlet. With the hydraulic pump/motor 60 acting as a motor, it causes the drive shaft 61 to rotate in the direction of R2 thereby spinning up the flywheel J so that it too rotates in the direction of R2.

Once the load has been lowered to a desired height, then the operator releases the operator controls and the main controller C returns the spool valve 80 to the position as shown in figure 2 and returns the spool of valve 70 to the position as shown in figure 2. Thus, with ports 54, 72 and 81 all closed, then the load will be held at the desired position, but now the flywheel J is rotating, i.e. it has stored some energy.

Re-raising load using energy from the flywheel

If the operator wishes to re-raise the load, then rather than using energy from the engine 12, the energy stored in the flywheel J can be used as follows:-

The operator moves the operator controls to provide a lift signal to the main controller. The main controller C moves the spool of valve 70 to the left when viewing figure 2 such that port 71 is connected to port 72. Simultaneously the main controller C moves the spool of valve 80 to the right when viewing figure 2 such that port 83 is connected to port 82 but port 81 remains isolated.

The main controller C causes the swash plate of hydraulic pump/motor 60 to move in a positive direction such that the hydraulic pump/motor 60 acts as a pump with port 62 becoming a low pressure inlet and port 63 becoming a high pressure outlet. The hydraulic pump/motor 60 is driven by the flywheel J. Since ports 54 and 81 are closed, then all of the hydraulic fluid flowing through valve 70 is fed to the headside chamber 93, thereby raising the load L. As the load L is raised, then the flywheel J progressively slows down (as it loses energy) and the main controller C modulates the position of the swash plate of the hydraulic pump/motor 60 to accommodate the progressive loss of energy of flywheel J so as to ensure the load raises as desired by the operator.

As the load is raised, then the rod side chamber volume progressively decreases and hydraulic fluid flowing out of the rod side chamber flows through port 83 and valve 80 to port 82 and hence onto tank. Note in this scenario port 53 is closed and hence no hydraulic fluid from the rod side chamber 94 flows through valve 50. Once the load has reached the desired height (assuming there is sufficient energy in flywheel J) then the operator releases the operator controls and the main controller C moves the spool of valve 70 back to the position shown in figure 2 and moves the spool of valve 80 back to the position shown in figure 2. The load is therefore held at the desired height.

The flywheel J has a maximum energy capacity. Under certain circumstances the height and weight of the load L and the distance through which the operator wishes to lower the load L may result in more potential energy being available than the maximum kinetic energy limit of the flywheel. Under these circumstances the load will initially be lowered such that fluid from the head side chamber 93 is passed through valve 70 in order to regenerate that energy via the flywheel, but once the maximum speed of the flywheel has been reached, then the main controller C will return the spool of valve 70 to the position shown in figure 2 and move the spool of valve 50 to the left when viewing figure 2 thereby connecting port 54 with port 52 and allowing the hydraulic fluid exiting the head side chamber 93 to flow through port 54, through valve 50 and through port 52 to tank. Under these circumstances the volume of the rod side chamber 94 will progressively be increased and hydraulic fluid will flow through hydraulic pump 42, port 51, valve 50 and port 53 to the head side chamber.

Similarly, the energy in the flywheel J may not be sufficient to lift a large load to a large height. Under these circumstances the load will initially be lifted by using the energy from the flywheel J. However, once the energy in flywheel J has become depleted, then the main controller C will move the spool of valve 70 to the position shown in figure 2, move the spool of valve 80 to the position shown in figure 2 and move the spool of valve 50 to the right when viewing figure 2 thereby allowing the engine 12 to drive the hydraulic pump 42 to lift the load, as described above.

As will be appreciated, valves 50, 70 and 80 are all proportional valves and this assists controller to provide a seamless change when lifting and lowering the loads.

As will be appreciated, during energy recovery, connecting the head side chamber to the rod side chamber, which consequently results in an increase in pressure in the head side chamber results in the pump/motor 60 being supplied with higher pressure hydraulic fluid than would otherwise be the case when acting as a motor. Furthermore, since, in the example above, the head side effective piston area is twice that of the rod side effective piston area, then half of the hydraulic fluid flowing out of the head side chamber when energy is being recovered is fed to the rod side chamber. Consequently, when the hydraulic pump/motor is acting as a motor during energy recovery, it sees a higher pressure and a lower flow than would otherwise be the case. This allows the hydraulic pump/motor to be a smaller and more compact device than would otherwise be the case. Typically, the maximum design pressure for a rod side chamber is lower than the maximum design pressure for a head side chamber. The controller ensures that the design pressure for the rod side chamber is not exceeded when there is a particularly heavy load and the head side chamber and rod side chamber are connected together via a valve 80. However, the applicant is the first to realise that during the majority of operation of a typical load handling machine, such as a back hoe loader, the pressure in the head side chamber when energy recovery is available will be sufficiently low (when comparing the head side effective piston area and rod side effective piston area) such that coupling the head side chamber and rod side chamber together will result in a pressure in the rod side chamber which does not exceed its design limit.

Furthermore, as will be appreciated, the flow through the hydraulic pump/motor 60 reverses when comparing energy absorption of flywheel J and energy release from flywheel J. However, the direction of rotation of the hydraulic pump/motor 60 is always the same (R2) whether it is acting as a pump or whether it is acting as a motor. This is because the swash plate can move in a positive direction from null and also a negative direction from null. Using a swash plate that can move "over centre" means that port 63 can act as both an inlet port and an outlet port depending upon the circumstances, and port 62 can also act as an inlet port and an outlet port depending upon the circumstances. This means that there is no need to put any complicated system of valves to ensure that flow through the pump/motor is always in the same direction i.e. that one port is always an inlet port and one port is always an outlet port.

As described above kinetic energy storage device is a flywheel and is therefore capable of storing energy in a kinetic form, i.e. when the flywheel is rotating the rotating mass of the flywheel stores energy in a kinetic form (this can be contrasted with an electric cell of a battery which stores energy in mechanical form).

In the example above, the effective piston area of the head side chamber was twice that of the effective piston area of the rod side chamber. In further examples, this need not be the case. By way of example, the effective piston area of the head side chamber may be anywhere in the range 1.25 to 2.5 times greater than the effective piston area in the rod side chamber.

Claims

1. A hydraulic system including:

hydraulic fluid,

a hydraulic machine having a first port and a second port and a drive shaft,

a hydraulic actuator, and

a kinetic energy storage device,

the kinetic energy storage device being operably coupled to the drive shaft of the hydraulic machine, the hydraulic system being configured such that:

the hydraulic machine is capable of acting as a pump by configuring the kinetic energy storage device to transfer energy to the hydraulic machine via the drive shaft such that the drive shaft rotates in a first rotational direction and the hydraulic machine receives hydraulic fluid through the first port and provides pressurised hydraulic fluid to the actuator via the second port, and

the hydraulic machine is capable of acting as a motor by configuring the hydraulic machine to transfer energy to the kinetic energy storage device via the drive shaft such that the drive shaft rotates in the first rotational direction and the hydraulic machine receives pressurised hydraulic fluid from the actuator via the second port and vents hydraulic fluid through the first port.

2. A hydraulic system as defined in claim 1 wherein the hydraulic machine is a variable capacity hydraulic machine.

3. A hydraulic system as defined in claim 1 or 2 wherein the hydraulic machine includes a movable swash plate.

4. A hydraulic system as defined in claim 3 wherein the swash plate is movable in a first direction from a neutral position to enable the hydraulic machine to act as a pump and is movable in a second direction from the neutral position to enable the hydraulic machine to act as a motor.

5. A method of operating a hydraulic system, the hydraulic system including:

hydraulic fluid,

a hydraulic machine having a first port and a second port and a drive shaft,

a hydraulic actuator, and

a kinetic energy storage device,

the kinetic energy storage device being operably coupled to the drive shaft of the hydraulic machine,

the method comprising the steps of:

1) operating the hydraulic machine as a pump by configuring the kinetic energy storage device to transfer energy to the hydraulic machine via the drive shaft such that the drive shaft rotates in a first rotational direction and the hydraulic machine receives hydraulic fluid through the first port and provides pressurised hydraulic fluid to the actuator via the second port, then

2) operating the hydraulic machine as a motor by configuring the hydraulic machine to transfer energy to the kinetic energy storage device via the drive shaft such that the drive shaft rotates in the first rotational direction and the hydraulic machine receives pressurised hydraulic fluid from the actuator via the second port and vents hydraulic fluid through the first port.

6. A method as defined in claim 5 wherein the hydraulic machine is a variable capacity hydraulic machine.

7. A method as defined in claim 5 or 6 wherein the hydraulic machine includes a movable swash plate.

8. A method as defined in claim 7 wherein the swash plate is movable in a first direction from a neutral position to enable the hydraulic machine to act as a pump and is movable in a second direction from the neutral position to enable the hydraulic machine to act as a motor.

Intellectual Property Office

Application No:	GB1700379.9	**Examiner:**	Mr Kevin Hewitt
Claims searched:	1 to 8	**Date of search:**	29 June 2017

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-3, 5-6	CN 102864811 A (SANY HEAVY MACHINERY) See especially the EPODOC & WPI Abstracts Accession Number 2013-D88004, and hydraulic pumps/motors 7, 8 in the Figure.
X	1-3, 5-7	GB 2533224 A (ROBERT BOSCH) See especially the Abstract; and hydraulic pump/motor 6 in Figures 1 & 2.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

E02F; F15B

The following online and other databases have been used in the preparation of this search report

WPI; EPODOC

International Classification:

Subclass	**Subgroup**	**Valid From**
F15B	0021/14	01/01/2006
E02F	0009/22	01/01/2006