**Title:** COMPONENT COMBINATION FOR A HYDROSTATICALLY DRIVEN VEHICLE

**Abstract:** A hydrostatically driven vehicle includes an engine operating at a first speed and operably connected to a variable displacement pump in fluid communication with a hydraulic circuit. The pump includes a rotating swashplate being adapted to operate at selective angles, which dictate pump displacement ranging from zero to a maximum displacement. The pump is capable of providing a pump flow rate at the first speed when the pump swashplate is set to the maximum displacement, wherein the pump flow rate is greater than the maximum flow rate that may be received by the hydraulic circuit.
Description

COMPONENT COMBINATION FOR A HYDROSTATICALLY DRIVEN VEHICLE

Technical Field

This patent disclosure relates generally to hydrostatically driven vehicles and, more particularly, to a combination of components sized to provide operational efficiency.

Background

Hydrostatically driven vehicles typically include a hydraulic pump driven by an engine or motor. The hydraulic pump propels a flow of fluid to one or more actuators, typically hydraulic motors, connected to wheels or other driving features of the vehicle. The flow of fluid from the pump passes through each actuator, causing the vehicle to move along at a travel speed. An operator adjusting a control input, for example, a lever, pedal, or any other appropriate device controls motion of the vehicle. When the operator displaces the control input, a signal is generated by a displacement sensor integrated with the control input or, alternatively, by displacement of a mechanical linkage. The signal is conveyed to a controller associated with the vehicle where it is interpreted and an appropriate command is issued to an actuator associated with the hydraulic pump, the actuator being arranged to move a control arm of the pump operating to change the displacement of the pump. Alternatively, the control input may be mechanically connected to the pump, for example, by cable, which causes the control arm of the pump to move in response to displacement of the control input.

Displacement of the control arm of the pump causes a change in the pump's displacement by changing the angle of operation of a swashplate within the pump and, accordingly, a change in the pressure and flow rate of fluid
propelled through the pump. Modulation of the flow rate of fluid also modulates
the rate of rotation of hydraulic motors driving the wheels of the vehicle and,
therefore, the travel speed of the vehicle. Additional systems may be available
for control of the travel speed of the vehicle, for example, braking systems or
transmissions may be used to decelerate the vehicle when the operator so desires.

Even though these types of control are generally effective in
controlling the vehicle, such hydrostatically driven vehicles generally do not
operate efficiently with regard to fuel consumption most of the time. The engine
for a typical vehicle, for example, a soil compactor, is arranged for steady state
operation at or about 2300 revolutions per minute (RPM). When the vehicle is
operating at full power, the pump is set to its highest setting and inefficiencies
of the pump cause an increase in fuel consumption. Accordingly, it is desirable to
provide an arrangement that overcomes or minimizes one or more of these
shortcomings.

Summary

A hydrostatically driven vehicle includes an engine operating at a
first speed and operably connected to a variable displacement pump. The pump
includes a rotating swashplate being adapted to operate at selective angles, which
dictate pump displacement. Pump displacement ranges from zero to a maximum
displacement. A hydraulic circuit is adapted to receive a flow of fluid from the
pump, the flow of fluid circulating at a flow rate through the hydraulic circuit.
The hydraulic circuit is capable of operating at or below a maximum hydraulic
circuit flow rate. The pump is capable of pumping the maximum hydraulic
circuit flow rate of fluid into the hydraulic circuit while the engine operates at the
first speed and while the swashplate is disposed at an operating angle
corresponding to an operating displacement that is less than the maximum
displacement.
Brief Description of the Drawings

FIG. 1 is an outline view of a soil compactor as one example for a hydrostatically driven vehicle in accordance with the disclosure.

FIG. 2 is a schematic diagram of a hydraulic system in accordance with the disclosure.

FIG. 3 is a schematic cross section of a simplified variable displacement pump.

FIG. 4 is a graph qualitatively plotting flow rate versus outlet pressure for a variable displacement pump.

FIG. 5 is a comparison of two graphs, each corresponding to a variable displacement pump, in accordance with the disclosure.

Detailed Description

This disclosure relates to hydrostatically operated machines. The examples presented for illustration relate to a hydrostatically driven vehicle and, more specifically, to a combination of components of the vehicle that yield a reduced engine operating speed for optimization of most operating conditions. The present disclosure is applicable to any type of machine having a hydraulic system associated therewith. In the exemplary vehicle presented, the engine can operate at a lower engine speed and torque output when the demand of the vehicle is less than a maximum demand and the flow of fluid is at a maximum flow. According to the disclosure, this reduction in engine speed is accomplished by use of a pump having a larger maximum displacement than pumps used in the past, even though the pump may be so sized that it will never operate at a maximum displacement setting because the hydraulic system of the vehicle is incapable of accepting such a flow. In this manner, the operation of the vehicle and, accordingly, any other hydraulically operated machine, may be optimized.

FIG. 1 shows an outline view of a vehicle 100 as one example of a hydrostatically driven vehicle. Although a soil compactor is illustrated in FIG. 1, the term "vehicle" may refer to any hydrostatic machine that performs some type
of operation associated with an industry such as mining, paving, construction, farming, transportation, or any other industry known in the art. For example, the vehicle 100 may be an earth-moving machine, such as a wheel or track loader, excavator, dump truck, backhoe, motor-grader, material handler or the like.

The vehicle 100 includes an engine frame portion 102 and a non-engine frame portion 104. An articulated joint 106 that includes a hinge 108, which allows the vehicle 100 to steer during operation, connects the two portions of the frame 102 and 104. The engine portion 102 of the frame includes an engine 110 and a set of wheels 112 (only one wheel visible). The engine 110 can be an internal combustion engine, for example, a compression ignition engine, but, in general, the engine 110 can be any prime mover that provides power to various systems of the vehicle by consuming fuel.

In the exemplary vehicle 100 presented herein, the non-engine frame 104 accommodates a drum 114 that rotates about a centerline thereof while the vehicle 100 is in motion. An operator occupying a cab 116 typically operates the vehicle 100. The cab 116 may include a seat 118, a steering mechanism 120, a speed-throttle or control lever 122, and a console 124. An operator occupying the cab 116 can control the various functions and motion of the vehicle 100, for example, by using the steering mechanism 120 to set a direction of travel for the vehicle 100 or using the control lever 122 to set the travel speed of the vehicle. As can be appreciated, the representations of the various control mechanisms presented herein are generic and are meant to encompass all possible mechanisms or devices used to convey an operator's commands to a vehicle.

A simplified circuit diagram for a hydraulic system 200 including electrical controls is shown in FIG. 2. The system 200, shown simplified for purposes of illustration, includes a portion of the drive circuit for driving the drum 114 of the vehicle 100. As can be appreciated, hydraulic components and connections to drive the wheels 112, or vibrators (not shown) within the drum 114 are not shown for the sake of simplicity. Similar hydraulic components and connections may be provided in alternate hydrostatically driven vehicles to
perform operations such as, by way of example only, lifting and/or tilting of
attached implements.

The hydraulic circuit 200 includes a variable displacement pump
202 connected to a prime mover, in this case, the engine 204 of the vehicle. The
pump 202 has an inlet conduit 206 connected to a vented reservoir or drain 208.
When the engine 204 (such as engine 110) is operating, the pump 202 draws a
flow of fluid from the reservoir 208 that it pressurizes before sending it to a four-
port two-way (4-2) valve 210 via a supply line or conduit 212. A drain port of
the valve 210 is connected via a drain passage 213, which drains to the reservoir
208. A control lever 214 is connected to a swashplate (not shown) internal to the
pump 202 and arranged to change the angle of the swashplate in response to
motion of control lever 214. Motion of the control lever 214 is accomplished by
an actuator 216 connected to the control lever 214. The displacement or angle of
the control lever 214, which is equivalent to the angle of the swashplate of the
pump 202, may be sensed or measured with a sensor 218. The sensor 218 may
be, for example, an analog or digital sensor measuring the angle (or, equivalently,
the displacement) of the control lever 214 and, hence, the position of the
swashplate within the pump 202.

In use, the pump 202 functions to propel a flow of fluid through
the supply line 212 when the engine 204 operates. Depending on the position of
the 4-2 valve 210, the flow of fluid from the supply line 212 is routed into one of
two conduits, a first conduit 220 and a second conduit 222, which are
respectively connected to either side of a hydraulic motor 224. The position of
the 4-2 valve 210 is controlled by a valve actuator 226 disposed to reciprocally
move the 4-2 valve 210 between two positions causing the motor 224 to move in
the desired direction. In an alternate embodiment, the 4-2 valve may be replaced
by a bidirectional variable displacement pump (not shown) capable of routing
fluid to the motor 224 in both directions.

The motor 224 is connected to a wheel or drum 227 of the vehicle
(such as wheel 112 or drum 114) and arranged to rotate the wheel or drum 227
when the vehicle is travelling. A brake 228, shown schematically, is arranged to
arrest or stall motion of the drum 227 when actuated by an actuator 230. The
brake actuator 230 shown in this embodiment is electronic and actuates the brake
228 causing friction to arrest motion of the drum 227, but other configurations
may be used. For example, a pin may be inserted into an opening of a rotating
disk connected to the drum 227 such that motion of the disk and drum 227 with
respect to the pin is stalled, and so forth. Further, the brake 228 is shown external
to the drum 227 for illustration, but more conventional designs such as those
having the brake 228 protected within the drum 227 may be utilized.

An electronic controller 232 is connected to the vehicle and
arranged to receive information from various sensors on the vehicle, process that
information, and issue commands to various actuators within the system during
operation. Connections pertinent to the present description are shown but, as can
be appreciated, a great number of other connections may be present relative to the
controller 232. In this embodiment, the controller 232 is connected to a control
input 234 (such as control lever 122) via a control signal line 236. The control
input 234, shown schematically, may be, for example, a lever moveable by the
operator of the vehicle used to set a desired speed setting for the vehicle. The
position of the control input 234 may be translated to a command signal through
a sensor 238 associated with the control input 234. The control signal relayed to
the controller 232 may be used in a calculation, along with other parameters, for
example, the speed of the engine 204, the temperature of fluid within the
reservoir 208, and so forth, to yield a desired angle for the swashplate that causes
the vehicle to move at the desired speed.

When the operator commands motion of the vehicle by displacing
the control input 234, a command signal is relayed to the controller 232 via the
command input line 236. This signal, as is described in further detail below,
causes the pump actuator 216 to move the control lever 214 by an appropriate
extent to achieve a desired angle. The desired angle of the control lever 214,
which translates into a desired setting for the swashplate of the pump 202, causes
an appropriate flow of motive fluid through the hydraulic motor 224, which
results in rotation of the drum 227 achieving the desired travel speed of the
vehicle.

The various fluid conduits and actuators, for example, the
hydraulic motor 224, belonging to the hydraulic system 200 are sized relatively to
a maximum flow rate of fluid through the system 200. For example, a calculation
for the maximum flow of the system 200 by a designer may account for various
parameters, such as, the weight of the vehicle, the maximum travel speed, any
grades the vehicle should be capable of traversing during operation, and so forth.

A cross section of a typical arrangement for a variable
displacement pump 300 (such as pump 202) is shown in FIG. 3. The variable
displacement pump 300 includes a housing 302 forming a plurality of cylindrical
bores 304, which are radially arranged parallel to each other within the housing
302. Each bore 304 sealably and reciprocally accepts a plunger 306. Each
plunger 306, shown simplified, forms an actuation linkage 308 extending from
the plunger 306 and contacting an angled rotating plate or swashplate 310. The
swashplate 310 is connected to a rotating shaft 312 and is capable of rotating at
an angle 314 with respect to the rotating shaft 312. The angle 314 can be
adjusted such that the stroke of each plunger 306 can be altered, thus altering the
displacement of the variable displacement pump 300. In a typical arrangement,
the shaft 312 rotates under action of a rotating machine, for example, the engine
or transmission of a vehicle. Motion of the plungers 306 caused by rotation of
the swashplate 310 acts to compress a fluid within a plurality of compression
volumes 316 defined between each respective bore 304 and plunger 306. The
volume of each compression volume depends on the angle 314 of the swashplate
310.

A qualitative efficiency chart for an exemplary variable
displacement pump is shown in FIG. 4. The chart of FIG. 4 is a graphical
illustration of parameters plotted against a vertical axis 402, representing a rate of
flow for fluid being compressed in a variable displacement pump, and a
horizontal axis 404, representing an outlet pressure of the pump. The graph illustrates the relationship between outlet flow versus pressure of the pump as well as the corresponding pumping efficiencies of the pump for various angles or settings of the swashplate, tested under a steady state rate of rotation of an input shaft of the pump, for example, 2300 RPM.

A series of flow curves 406 illustrate the negative correlation between flow rate of the pump and the outlet pressure. The curvature of each flow curve 406 can change depending on the angle setting of the pump. For example, a flow curve 408 corresponding to a low angle setting of the pump has a concave curvature, indicating that flow rates decrease faster as pressure increases from a low pressure condition than they decrease at higher pressure conditions. In contrast, a flow curve 410 corresponding to a high or steep angle setting of the pump has a convex curvature, indicating that the flow rate may decrease faster as pressure increases from a higher pressure condition than it does at a lower pressure. The shape of each flow curve 406 corresponding to an angle setting of the pump is indicative of the efficiency of the pump, with higher efficiencies exhibited for angles corresponding to flow curves 406 having concave shapes. One can surmise that a flow curve 411 corresponding to an intermediate angle will have a generally straight shape at the transition between the concave and convex shaped flow curves 406.

The efficiency of the pump, which can be determined as a ratio between the hydraulic power at the pump outlet and mechanical power at the driving shaft at nominal pressure, angular velocity, and fluid viscosity, is represented on the graph by a plurality of efficiency curves 412, each corresponding to a respective angle setting of the pump. Each efficiency curve 412 has an inflection point indicative of optimum pump performance for each angle setting. It can be appreciated that the relative drop in efficiency when, for example, the pressure deviates from the optimum performance, will increase as the angle settings of the pump increase. It can also be appreciated that low or
declining efficiencies of the pump during operation cause a waste of energy and an increase in fuel consumption of the vehicle.

For this and other reasons, issues of increased fuel consumption may advantageously be avoided by incorporation of a larger pump into a vehicle that would have been typically incorporated a smaller pump. By increasing the size of the pump, even to the extent that the pump may never be used at its maximum angle setting, one can advantageously operate the larger pump at a higher efficiency and at a lower shaft speed, thus reducing the fuel consumption of the vehicle while still operating at a high efficiency.

Two qualitative charts indicative of the flow and pressure characteristics of two exemplary pumps are shown for comparison in FIG. 5. The first graph 500 includes flow curves 502 and efficiency curves 504 plotted for data indicative of performance of a first pump 506, a smaller frame pump, while the second graph 501, shown below the first graph 500, includes flow curves 503 and efficiency curves 505 plotted for data generated by a second pump 507, a larger frame pump. The first pump 506 may operate at a steady shaft speed of 2300 RPM, and the second pump 507 may operate at a steady shaft speed of 1600 RPM. The data shown in the first and second graphs 500 and 501 is qualitative and does not represent actual data. Two operating points have been selected for illustration of the operating conditions of each pump under the assumption that they are each used in the same or similar hydraulic systems.

In both charts, a first operating point, O1, corresponds to a pressure, Pl, at the outlet of each pump and to a flow rate, Fl. Similarly, a second operating point, O2, corresponds to a pressure, P2, at the outlet of each pump and to a flow rate, F2. Dashed lines are used to identify each operating point on both graphs 500 and 501.

Regarding the first pump 506, the operating point O1 can be attained by setting the first pump 506 to a second angle setting, A2. The operating point O2, however, can only be approached, but not attained, by setting the pump at a maximum angle setting, Amax, representing a maximum
displacement setting for the pump 506. Operation of the first pump 506 at the maximum angle setting A_{\text{max}} occurs at a very low efficiency, E_1. Based on the description above, the combination of the high angle setting A_{\text{max}}, along with operation at the high pressure P_2 yields the very low pump efficiency E_1 because the first pump 506 is operating at a high angle setting and a high pressure. This condition can be readily seen in the first graph 500 where the low efficiency E_1 lies beyond the maximum efficiency E_{\text{max}} for the corresponding angle setting A_{\text{max}}.

Regarding the second pump 507, the operating point O_1 can be attained by setting the second pump 507 to a first angle setting, A_1, which is relatively less than the second angle setting A_2 used on the first pump 506. In contrast with the first pump 506, the second pump 507 can easily attain the second operating point 0 2 by setting the second pump 507 at a third angle setting, A_3, which, for this pump, is also advantageously less than the maximum setting. Operation of the second pump 507 at either the first or second angle settings A_1 and A_3 can occur at relatively high efficiencies and at a lower shaft speed. If the second operating point 0 2 is assumed to be representative of the maximum flow rate that a hydraulic system can accept, it can be appreciated that the second pump 507 is capable of pumping the maximum flow rate of fluid into the hydraulic circuit, while operating at 1600 RPM, and while the swashplate is disposed at an operating angle corresponding to an operating displacement that is less than the maximum displacement. In comparing the displacement of the second pump 507 with that of the first pump 506, while both pumps are operating at the operating point 0 2 at their respective speeds, it can further be appreciated that the displacement of the second pump 507 at the second operating point O_2 is at least less than 70% of the maximum displacement.

**Industrial Applicability**

The present disclosure is applicable to hydrostatically driven vehicles having an engine or motor driving a variable displacement pump.
Typical vehicles use a maximum displacement condition for the pump to size the pump such that the maximum flow rate can be pushed into the hydraulic system of the vehicle when the engine operates at its maximum useable RPM. As described above, this mode of matching a specific pump size to an engine can often lead to operation of the vehicle that is both wasteful of fuel, due to the engine's operation at high speeds, as well as detrimental to the efficiency of the system. The present disclosure, in one aspect, describes using a larger pump paired with the engine that, even if the full displacement of the pump may never be used, allows the system to operate at a high efficiency state. Moreover, the engine operates at a lower RPM during most operating conditions. The advantages of this configuration can be readily appreciated as fuel economy and noise are reduced during operation, and the efficiency of the system is increased.

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

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

1. A hydrostatically driven vehicle (100) comprising:
   an engine (204) operating at a rotational speed during operation of
   the vehicle (100);
   a variable displacement pump (202, 300) operably connected to
   said engine (204), said pump (300) including a rotating swashplate (310) being
   adapted to operate at selective angles (314), said angle (314) of the swashplate
   (310) dictating a pump displacement, the pump displacement ranging from a zero
   displacement to a maximum displacement;
   a hydraulic circuit (200) adapted to receive a flow of fluid from
   said pump (202), said pump (202) being adapted to circulate the flow of fluid at a
   flow rate through said hydraulic circuit (200), said hydraulic circuit capable of
   operating at or below a maximum hydraulic circuit flow rate;
   said pump (202) is capable of pumping the maximum hydraulic
   circuit flow rate of fluid into the hydraulic circuit (200) while the engine (204)
   operates at the rotational speed and while the swashplate (310) is disposed at an
   operating angle (314) corresponding to an operating displacement that is less than
   the maximum displacement.

2. The hydrostatically driven vehicle (100) of claim 1, wherein the rotational speed is 1600 revolutions per minute.

3. The hydrostatically driven vehicle (100) of either of claims
   1 or 2, wherein the operating angle (314) corresponds to an operating
   displacement that is less than 70% of the maximum displacement.

4. The hydrostatically driven vehicle (100) as recited in any
   of claims 1 through 3, wherein the pump (202) is capable of providing a pump
flow rate at the rotational speed when the pump swashplate (310) is set to the maximum displacement, the pump flow rate at the rotational speed when the pump swashplate (310) is set to the maximum displacement being greater than the maximum hydraulic circuit flow rate.

5. The hydrostatically driven vehicle (100) of claims 1 through 4, further including a hydraulic motor (224) adapted to receive at least a portion of the flow of fluid circulating in the hydraulic circuit (200).

6. The hydrostatically driven vehicle (100) of claim 5, wherein the hydraulic motor (224) is capable of operating at or below the maximum hydraulic circuit flow rate.

7. The hydrostatically driven vehicle (100) of claim 6, wherein the hydraulic motor is operably connected to a wheel (112).

8. A method for operating a hydraulic system (200), comprising:

operating to compress a flow of hydraulic fluid with a variable displacement pump (202);

circulating the flow of hydraulic fluid through a hydraulic circuit having a maximum flow capacity;

controlling a rate of flow of the hydraulic fluid by changing a displacement setting (214) of the pump (202), the displacement setting of the pump controllable between a zero displacement setting and a maximum displacement setting;

wherein the pump (202) is capable of pumping a fluid at the maximum flow capacity of the hydraulic circuit at an intermediate displacement
setting that is higher than the zero displacement setting and lower than the maximum displacement setting.

9. The method of claim 8, further comprising propelling a vehicle (100) by rotating a wheel (112) connected to the hydraulic motor (224).

10. The method of claim 8, further comprising operating a vibrator arrangement connected to the hydraulic motor (224).
### INTERNATIONAL SEARCH REPORT

**A. CLASSIFICATION OF SUBJECT MATTER**

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**C. ADDITIONAL INFORMATION**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

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

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

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**D. DOCUMENTS CONSIDERED TO BE RELEVANT**

- *Special categories of cited documents:
  - 'X': document defining the general state of the art which is not considered to be of particular relevance
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**Date of mailing of the international search report:**

**Form PCT/ISA/210 (second sheet) (April 2005)**
# INTERNATIONAL SEARCH REPORT

Information on patent family members

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