APPLICATION FOR A STANDARD PATENT OR A STANDARD PATENT OF ADDITION

(a) Name(s) of applicant(s)..............................

DEERE & COMPANY

of (b) MOLINE, ILLINOIS, UNITED STATES OF AMERICA

We hereby apply for the grant of a (c) Standard Patent for an invention entitled (d) HYDROSTATIC TRANSMISSION FOR A FOUR-WHEEL DRIVE VEHICLE which is described in the accompanying complete specification.

(e) For a Convention application - details of basic application(s) -

<table>
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<th>NUMBER</th>
<th>COUNTRY</th>
<th>DATE OF APPLICATION</th>
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<tr>
<td>507,380</td>
<td>U.S.A.</td>
<td>24 JUNE 1983</td>
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(f) Our address for service is ARTHUR S. CAVE & CO., Patent and Trade Mark Attorneys, 1 Alfred Street, Sydney, New South Wales, Australia 2000.

(g) To: Commissioner of Patents

ARTHUR S. CAVE & CO.
PATENT AND TRADE MARK ATTORNEYS
SYDNEY

HYDROSTATIC TRANSMISSION FOR A FOUR-WHEEL DRIVE VEHICLE

Background of the Invention

The present invention concerns hydrostatic transmission systems for four-wheel drive vehicles and, particularly, those in which individual transmission systems for front and rear axles are provided. The basic form of hydrostatic transmission for four-wheel drive vehicles generally comprises a power take-off unit for driving the vehicle's wheels, a driving unit for driving the power take-off unit, and a variable drive unit for controlling the driving power from the driving unit to the power take-off unit. The variable drive unit is usually a fluid pump which is controlled by a variable driver to provide a variable driving power.
A transmission system for an off-the-road vehicle subjectible to varying propulsive loading and having a power source, a source of hydraulic fluid and drivable first and second axles comprising:

- a variable displacement hydraulic pump driven by the power source for receiving hydraulic fluid from the fluid source and forwarding it at load pressure, said pressure varying according to propulsive loading;
- a first hydraulic motor drivably connected to the first axle;
- a second hydraulic motor drivably connected to the second axle;
- a plurality of fluid lines for conveying fluid between the pump and the motors, forming a closed loop system and connecting the motors in parallel; and
- means automatically responsive to load pressures above a predetermined minimum for varying the displacement of the second motor within a predetermined range.

The transmission system of claim 8 wherein said lower displacement of the variable displacement motor remains constant in operations below a predetermined minimum load pressure and wherein at higher pressures, changes of displacement of the motor are directly proportional to changes in fluid load pressure.
Short Title: HYDROSTATIC TRANSMISSION FOR A FOUR-WHEEL DRIVE VEHICLE

The following statement is a full description of this invention, including the best method of performing it known to me:

ASC 48 & 49
HYDROSTATIC TRANSMISSION FOR A FOUR-WHEEL DRIVE VEHICLE

Background of the Invention

The present invention concerns hydrostatic transmission systems for four-wheel drive vehicles and, particularly, those in which individual transmission systems for front and rear axles are driven by a single hydraulic pump.

Four-wheel drive is used in many off-the-road vehicles and in many of them it would be desirable to provide an "ideal" propulsion system, offering ground speed infinitely and continuously variable over wide ranges of tractive effort and vehicle speed. Such a propulsion system would be particularly helpful in a machine such as a combine harvester in maintaining acceptable levels of field harvesting efficiency and transport convenience. Cost and efficiency considerations make it impractical to provide the desired drive characteristics in a single ratio hydrostatic transmission. It is known to use multi-ratio mechanical transmissions in combination with hydrostatic components but such arrangements have tended to require relatively complex and costly control systems which limit the applications in which they can be cost effective. It is also inherent in such combination systems that their overall torque/speed performance characteristic is markedly stepped so that they do not offer the convenience and advantages of a system which is continuously and infinitely variable over its whole range.

A typical example of the way in which the application of hydrostatic propulsion to four-wheel drive of harvesting vehicles has been limited is disclosed in U.S. patent 3,736,732, Jennings et al. This covers an auxiliary drive system for providing power selectively to the rear wheels of a combine. The useable speed range of the auxiliary drive system is limited to the lower harvesting or field operating speeds. For transporting, which is normally done at considerably higher speeds, the hydrostatic auxiliary system must be disconnected which means that the useful braking function, inherent in hydrostatic transmissions, is not available. In addition there is no internal interaction between the drives of the front and rear axles and making effective use of the auxiliary rear
Wheel drive often depends on judicious manual shifting of front wheel drive gears in order to get an appropriate torque ratio between front and rear. In the field, traction conditions vary constantly and so, typically, there is a constantly varying difference between front and rear axles with regard to traction ability and need. In a machine such as a self-propelled harvester, which includes a container for carrying harvested material, a further or overlying difference between front and rear axle conditions comes from a progressive shift in axle loading from (say) front-to-rear as the crop holding container fills during harvesting.

**Summary of the Invention**

Accordingly, it is an object of the invention to provide for a self-propelled vehicle such as a harvester, a hydrostatic transmission comprising relatively simple and low cost components; which is efficient in operation and requires only simple controls; which offers full-time four-wheel drive with infinitely variable speed control over a wide speed range, and automatic control of total torque and distribution of torque between the respective axles so as to enhance mobility of the vehicle in varying conditions of axle loading and ground surface condition.

In keeping with the invention, an engine powered variable displacement hydraulic pump transmits fluid power to front and rear axles by way of a pair of hydraulic motors each driving one of the axles of the vehicle. The displacement of at least one of the motors is variable and normally biased to a lower displacement condition and the system includes means responsive to load pressure to increase the displacement of the motor proportionally as pressure increases. Connection of at least one and preferably of both motors to the respective axles may be by way of a multiple ratio mechanical transmission. This arrangement provides, for each combination of transmission ratios (for each "gear" that is), an output torque speed characteristic which includes a continuously variable portion in which both torque and speed vary corresponding to the automatic shifting of displacement of the variable displacement motor. By appropriate selection of
ratios within the respective front and rear multiple ratio
transmissions and of motor sizes (including range of displac-
ment for the variable motor), a plurality of "gears" (transmis-
sion settings) may be established which together and prefer-
ably with some overlap, provide for propulsion of the vehicle
with a speed and torque range closely approximating that of an
"ideal" stepless and continuously variable system.

Important advantages of the automatic motor displacement
response include the provision of a wider speed range without
the need for particular additional manual control by the
operator; the maintenance of vehicle mobility through the
automatic response of the system to provide more torque on
demand even at maximum power at the expense of only acceptable
reductions in vehicle speed; and the automatic response may be
used to effect an appropriate predetermined shift in torque
distribution between the axles of the vehicle as load pres-
sures increase. Operator control is simple. Once a particu-
lar combination of gears has been selected, basic control of
vehicle speed is by a single lever, controlling displacement
of the main hydrostatic pump.

**Brief Description of the Drawings**

Fig. 1 is a semi-schematic side left-hand elevation of an
articulated combine harvester embodying the invention.

Fig. 2 is a simplified schematic representation of the
combination hydrostatic and mechanical transmission system.

Fig. 3 illustrates the controlled relationship between
displacement and load pressure for the variable displacement
motor.

Fig. 4 shows a generalized output torque/speed character-
istic for one gear setting of a transmission according to the
invention.

Fig. 5 tabulates exemplary gear ratios for the system.

Fig. 6 compares the torque/speed characteristics of a
transmission according to the invention and a corresponding
"single ratio" hydrostatic transmission.

**Description of the Preferred Embodiment**

The invention is embodied in an articulated combine of the
type shown in simplified form in Fig. 1. A combine of this
general type is described in some detail in U.S. patent 4,317,326, Riedinger which patent shares a common assignee with the present invention.

The combine comprises a front bogie 10 having a main body 12 supported above the ground on a pair of laterally spaced wheels 14. The combine gathers crop material from a field by means of a header 16 (only part of which is shown in Fig. 1) and feeds it to a crop processor such as separator 18. The combine is controlled from an operator's station 20.

A rear bogie 22 is pivotally connected to the front bogie 10 by upper and lower hinge assemblies 24 and 26 respectively and supported on a pair of laterally spaced wheels 28. The body 30 of the rear bogie 22 is primarily a container for receiving and temporarily holding processed crop material transferred from the front bogie. Material is unloaded by an unloading conveyor assembly 32.

The general arrangement of the vehicle propulsion system is indicated schematically in Fig. 1. The power source is engine 34 driving, in any conventional manner, a variable displacement pump 36 which draws hydraulic fluid from reservoir 37. Front and rear fluid line assemblies, 38 and 40 respectively, connect with front and rear transmission assemblies 42 and 44, respectively, and these in turn power the wheels 14 and 28.

Looking now in more detail at the propulsion system and referring particularly to the schematic of Fig. 2, the front transmission assembly 42 comprises, and receives its input through, a fixed displacement reversible hydraulic motor 50 driving the input shaft 52 of a multi-ratio speed reducing gear box 54. Output from the gear box is by shaft 56 through differential 58 to front axle 60 and through final drive 62 to the wheels 14. The gear box 54 provides three drive ratios as indicated in Fig. 5.

The arrangement of the rear axle transmission assembly 44 is similar to that of the front but here the hydraulic motor 70 is of the variable displacement reversible type and the speed reducing gear box 72, provides only two drive ratios for the rear wheels 28 (see Fig. 5).
Except as discussed below, control and connection of the hydraulic components of the system is generally conventional and includes the fluid line assemblies 38 and 40 comprising fluid lines 80, 82 and 84, 86 respectively connecting the pump 36 with the motors 50 and 70. The pump and motors are connected in a parallel closed loop so that oil from pump may flow to either motor according to output conditions. A pressure-compensated flow limiter 88 is included in each of the fluid lines 80, 82, 84 and 86 to avoid motor overspeed. As is well known, hydraulic parallel sets up a frictionless differential and motor speeds are related only to output conditions.

As indicated in Fig. 2, the displacement of rear axle motor 70 is automatically controlled by motor displacement control actuator 92 responsive to hydraulic load pressure sensed through fluid line 90. The actuator 92 is depicted schematically as a single acting piston-cylinder assembly in which piston 94 is biased by spring 96 to a stopped position corresponding to minimum displacement of the motor 70. The mechanism for making the motor swashplate position-responsive to the actuator 92 is conventional and not shown. The actuator and motor control combination is arranged to produce a displacement control characteristic for the rear axle motor 70 of the form shown in Fig. 3. At lower load pressures in the range A to B the actuator is held in its stopped condition under the action of bias spring 96, and the motor remains in a condition of nominal minimum displacement C. When the threshold pressure B is exceeded, piston 94, working against the bias of spring 96, moves to effect an increase of motor displacement proportional to the increase of load pressure, up to maximum displacement D at maximum load pressure E.

In operation, the potential performance (or limiting capacity) characteristic of the transmission system in any one gear is of the general shape indicated in Fig. 4. The curve of maximum potential output, portion MN, may be approached at its upper end by a pressure limited, constant torque, increasing speed portion LM, or at its other end by a flow limited, constant speed, increasing torque portion ON. It will be readily
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cass assembly, 40 comprising
necting the pump
kors are con-
edge in each of
tors overspeed.
a frictionless

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and pressure
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or speed
motor 70. The
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or speed
ears in the
or speed
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against the
or speed
limiting capac-
in any one gear
ve curve of
prachted at its
creasing
limited, con-
will be readily
understood that point N of Fig. 4 corresponds to point (B, C)
of Fig. 3, the threshold at which the rear axle motor 70 be-
gins to stroke (increase displacement). Increasing demand on
the propulsion system with corresponding increase in load pres-
sure will cause an increase of displacement accompanied of
course by a decrease in forward speed until the motor 70 is
fully stroked (at maximum displacement) corresponding to point
M in Fig. 4.
For convenience in further discussion of operation of the
system, some particular exemplary specifications will be used.
As described above and indicated in Fig. 5, the present embodi-
ment offers a choice of three transmission ratios for the
front axle and two for the rear. An exemplary combination of
ratios is shown in the table of Fig. 5, providing four overall
"gears" for the vehicle as a whole which together cover the
desired torque/speed range. The shape of the torque/speed
characteristic for each of these gears will of course, be
similar to that of Fig. 4 and together they produce the over-
all torque/speed characteristic for the vehicle indicated in
Fig. 6 where effective output torque is expressed compara-
tively in terms of rim pull ratio. Using well-known engineer-
ing considerations, specifications for the propulsion system
have been selected, with particular reference to motor and
pump capacity and gear box transmission ratios, so that the
individual ranges of speed and torque provided by each "gear"
collectively provide a predetermined desired total or overall
range of torque and speed. The respective characteristics
101, 102, 103, 104 of the four gears are shown together in
Fig. 6 which also includes a constant horsepower curve JK.
This curve of constant horsepower represents the maximum hy-
draulic power available from pump 36, driven by the vehicle
engine 34. Given that a stepless continuously variable tran-
mission is desirable, the curve JK may also be taken to repre-
sent an "ideal" output or performance characteristic for the
articulated combine of this embodiment. (As noted above, such
a single ratio transmission is not at present considered to be
economically feasible for off-the-road working vehicles, espe-
cially those used in agriculture.) As indicated in Fig. 6,
The curves of maximum output or capacity and represent the resultant potential output of the combination of the two motors 50 and 70 and the respective transmission ratios. The curves are steeper than the adjacent portions of the ideal curve in each case, reflecting actual efficiencies which may be expected, including lower motor efficiency at lower displacements.

As indicated in Fig. 6, components have been sized so that the capacity curves for each gear intersect the pump power curve JK. At higher torques, therefore, transmission performance will be limited by the power available from pump 36. Areas P', P'', etc., are thus not available and, at higher torques, the actual performance curve will coincide with the "ideal curve". Additionally, there are areas Q', Q'', etc., where the actual output falls below the "ideal", limited by the overall hydrostatic capacity of the system. However, as can be seen in Fig. 6, careful selection of components minimizes these "lost areas" (Q', Q'') and the composite output curve for this exemplary four-speed system conforms closely to the "ideal" constant power curve JK over the whole predetermined desired torque/speed range.

Thus it is seen that provision of automatic displacement response according to load pressure in a system where normally motor displacement is biased to a predetermined lower level, has important and useful results. First, in any given drive ratio, the speed range of the system is extended automatically. As long as required torque is below the limiting hydraulic capacity of the system, extra speed is available compared with a fixed displacement system of the same limiting capacity. Using only a relatively small number of mechanical transmission ratios, the system provides a performance characteristic which, over the whole desired torque/speed range, approximates very closely that which would be available from a
higher capacity and more expensive single ratio hydrostatic transmission system.

A second advantage over conventional transmissions is that of improving the maintenance of vehicle mobility by providing automatically a "modified" torque increase, on demand, whenever load pressures are close to or above the threshold pressure at which stroking of the motor 70 begins (see Fig. 3). Any change of operating conditions requiring greater tractive effort is sensed as an increase in load pressure at the actuator 92 and displacement of the rear motor 70 will be correspondingly increased. Thus the combined displacement of the two motors 50, 70 is increased, not only making more total torque available for keeping the vehicle in motion, (albeit at some reduction of forward speed) but also increasing the relative contribution of the rear axle. This effect is available even at maximum power when the automatic "shifting down" avoids inadvertent stalling of the vehicle.

In applying the invention, the allocation of the no load and low load distribution of torque potential and of motor displacement variability between the axles is a matter of design choice. It suits the configuration and duty of the typical combine (articulated or conventional) to place the variable motor in the rear axle transmission and size components so that initially more than half of the total tractive effort comes from the front axle. Filling of the grain tank progressively increases vertical loading of the rear axle. The system responds by automatically increasing the torque potential of the rear axle and hence its share of the total tractive effort. This helps to maintain overall tractive efficiency.

In addition, for efficient operation, a combine harvester must be capable of relatively high transport speeds, both in the field and on the road and it is seen that a transmission according to the invention, adequately provides this speed range through the employment of a combination of relatively low capacity hydrostatic components with simple mechanical transmission components. The full-time engagement of the four-wheel hydrostatic drive means of course, that the inherent
braking ability of the hydrostatic system is available at all speeds. This contributes to safety and/or avoids the need for providing alternate braking capacity specifically for use at transport speeds as is the case with combines utilizing a typical auxiliary rear wheel drive hydrostatic system.

Operator control is simple and straight-forward. Having selected any particular combination of gears, vehicle speed control requires only a single lever for controlling displacement of the hydrostatic pump 36. The flow limiters 8 and optional differential locks (not shown) prevent individual wheel spin-out and total loss of vehicle mobility without adversely inhibiting the functioning of the automatic motor displacement control and its attendant advantages.

The drawings and description make no particular reference to reverse operation but it will be understood that conventional controls and components may be readily applied to provide operation of the vehicle in reverse as well as forward and that the characteristics and advantages of the invention would be applicable to both directions of travel.
The claims defining the invention are as follows:

1. A transmission system for an off-the-road vehicle subjectible to varying propulsive loading and having a power source, a source of hydraulic fluid and drivable first and second axles comprising:
   a variable displacement hydraulic pump driven by the power source, receiving hydraulic fluid from the fluid source and forwarding it at load pressure, said pressure varying according to propulsive loading;
   a first hydraulic motor drivably connected to the first axle;
   a second hydraulic motor drivably connected to the second axle;
   a plurality of fluid lines for conveying fluid between the pump and the motors, forming a closed loop system and connecting the motors in parallel; and
   means automatically responsive to load pressures above a predetermined minimum for varying the displacement of the second motor within a predetermined range.

2. The transmission system of claim 1 wherein the connection between at least one of the hydraulic motors and its respective axle includes a variable ratio mechanical transmission.

3. The transmission system of claim 1 wherein the first hydraulic motor is of fixed displacement.

4. The transmission system of claim 1 wherein in the automatic control range, changes in displacement of the second motor are proportional to changes in load pressure.

5. The transmission system of claim 1 wherein the drivable connection between each hydraulic motor and axle includes a selectively variable ratio transmission, each transmission having at least two ratios, said transmissions together and in combination with the automatic displacement response of the second motor providing for the vehicle a plurality of torque/speed transmission ranges including a high range and a low range and at least one intermediate range and wherein said ranges in aggregate approximate that of an infinitely variable
transmission for the torque/speed range defined by the respective upper and lower limits respectively of the high and low ranges.

6. The transmission system of claim 1 and further including means for varying the displacement of the pump for controlling its output.

7. The transmission system of claim 1 wherein at least one of the fluid lines includes flow limiting means for limiting the rate of flow of fluid within the system and hence limiting its response to changes in external operating conditions.

8. In an articulated combine harvester for field operations requiring a variable tractive effort, the combine having a power source and a source of hydraulic fluid, a front bogie with a drivable axle, a rear bogie with a drivable axle and a grain tank included in the rear bogie, a transmission system comprising:
   a selectively variable displacement hydraulic pump drivably connected to the power source and in fluid communication with the source of hydraulic fluid for forwarding fluid under load pressure, said pressure varying according to tractive effort;
   a fixed displacement hydraulic motor carried by the front bogie, drivably connected to the front axle and in fluid communication with the pump;
   a variable displacement hydraulic motor carried by the rear bogie, drivably connected to the rear axle and in fluid communication with the pump, said motor including means for reducing it to a lower displacement;
   a selectively variable ratio mechanical transmission drivably connected between the fixed displacement motor and the front axle; and
   means responsive to load pressures above a predetermined minimum for increasing the displacement of the variable displacement motor so that displacement varies directly with pressure above said minimum.
9. The transmission system of claim 8 wherein said lower displacement of the variable displacement motor remains constant in operations below a predetermined minimum load pressure and wherein at higher pressures, changes of displacement of the motor are directly proportional to changes in fluid load pressure.

DATED this 30th day of May, 1984.

DEERE & COMPANY

By their Patent Attorneys

ARTHUR S. CAVE & CO.
Fig. 3

Fig. 5

<table>
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<tr>
<th>GEAR</th>
<th>RIM PULL RATIO MAX.</th>
<th>FRONT AXLE RATIO</th>
<th>REAR AXLE RATIO</th>
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<tr>
<td>4</td>
<td>.157</td>
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Fig. 6

VEHICLE SPEED - KPH

RIM PULL RATIO