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(54) **HIGH MOBILITY VEHICLE**

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Related U.S. Application Data

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(60) Provisional application No. 60/030,245, filed on Nov. 7, 1996.

(51) **Int. Cl.**^{7} **B60K 17/00**

(52) **U.S. Cl.** **180/347**; 180/8.2; 180/8.3; 180/209; 280/5.514; 280/5.52; 280/6.15

(58) **Field of Search** 180/347, 209, 180/8.3, 8.2; 280/5.5, 5.514, 5.52, 6.15

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(57) **ABSTRACT**

A vehicle, for driving over a ground surface, has a body with a left side, a right side, a front and a back. The vehicle includes left and right drive mechanisms. Each mechanism includes first and second traction elements for engaging the ground surface and transmitting a driving force between the vehicle and ground surface. Each mechanism includes first and second arms coupled to the first and second traction elements for relative rotation about first and second axis respectively. Each mechanism includes a rotor having a third axis, the rotor coupled to the body for rotation about the third axis and coupled to the first and second arms for relative rotation about the third axis. The mechanism includes first and second drive motors for driving the first and second traction elements and first and second transmissions, driven by the first and second motors and engaging the rotor. Driving the first and second traction elements simultaneously rotates the rotor relative to the first and second arms, respectively.
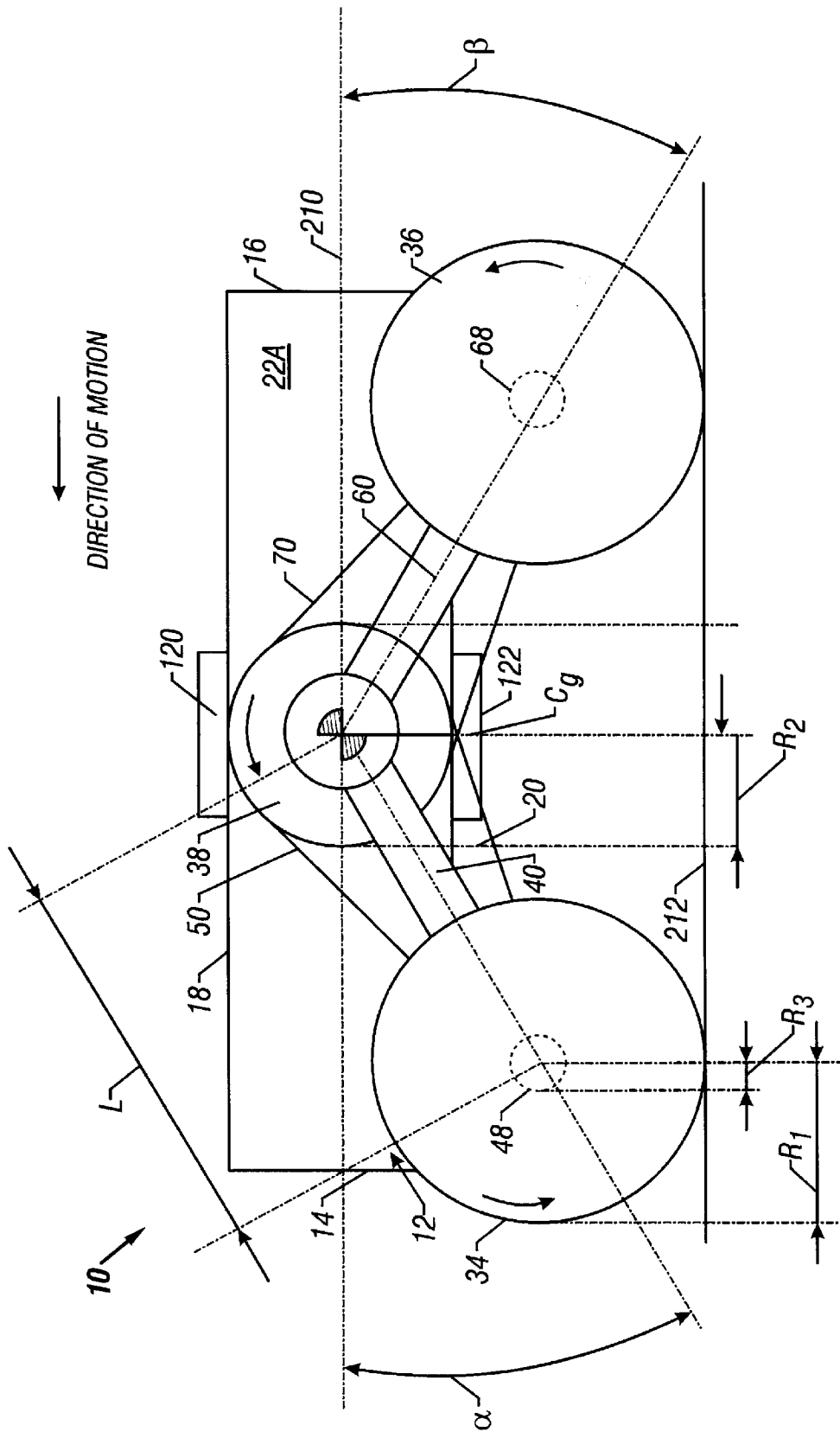
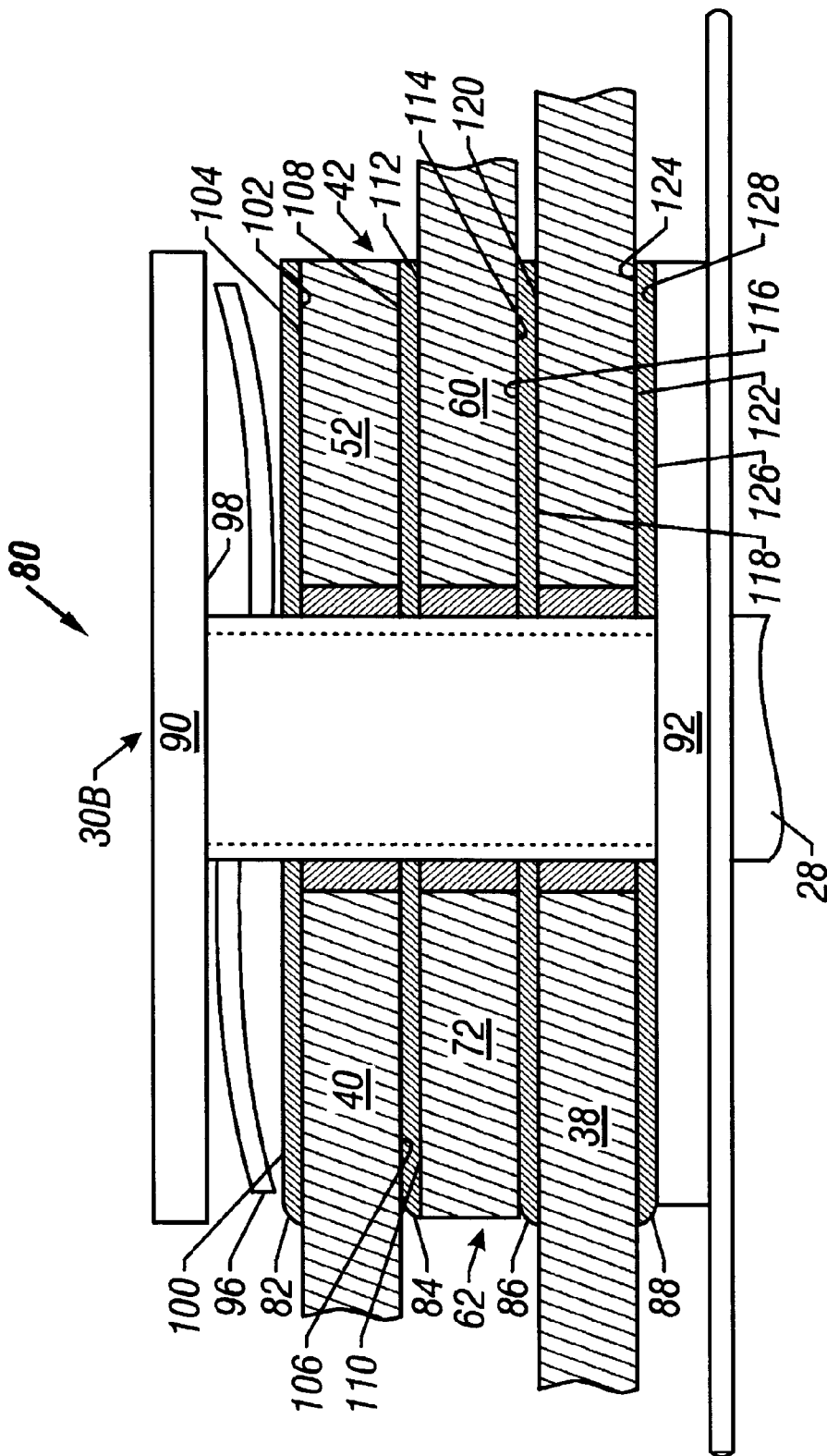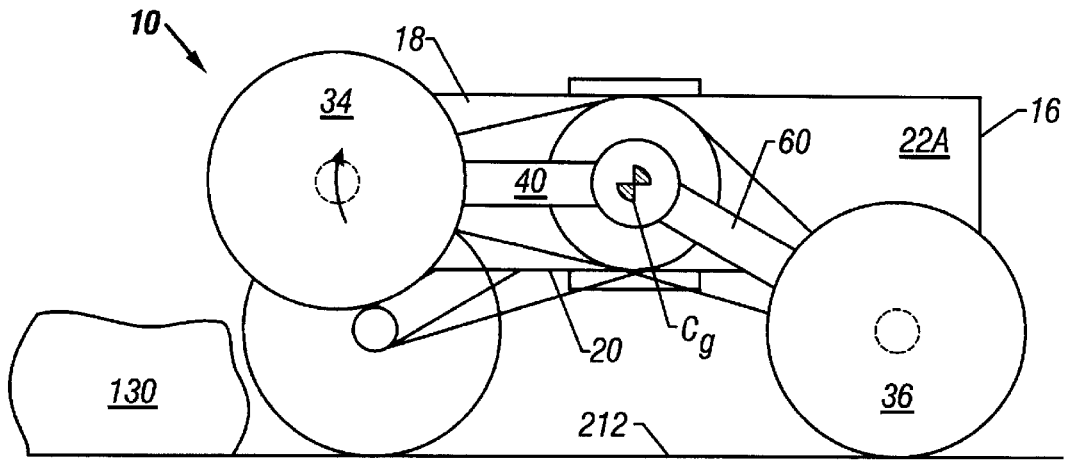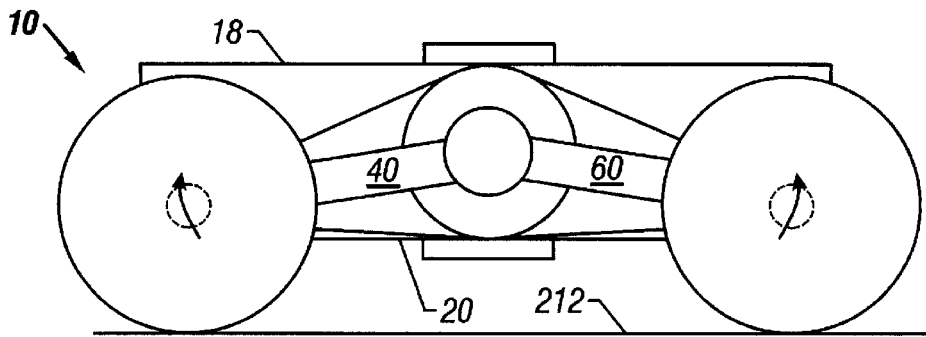**4 Claims, 8 Drawing Sheets**

FIG. 1

FIG. 2
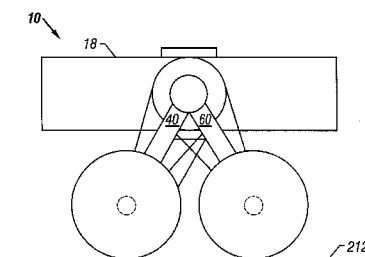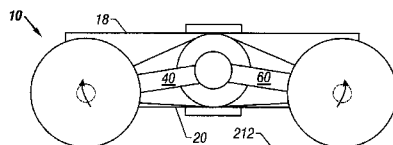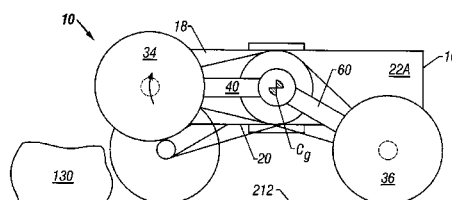
FIG. 3

FIG. 4

FIG. 5
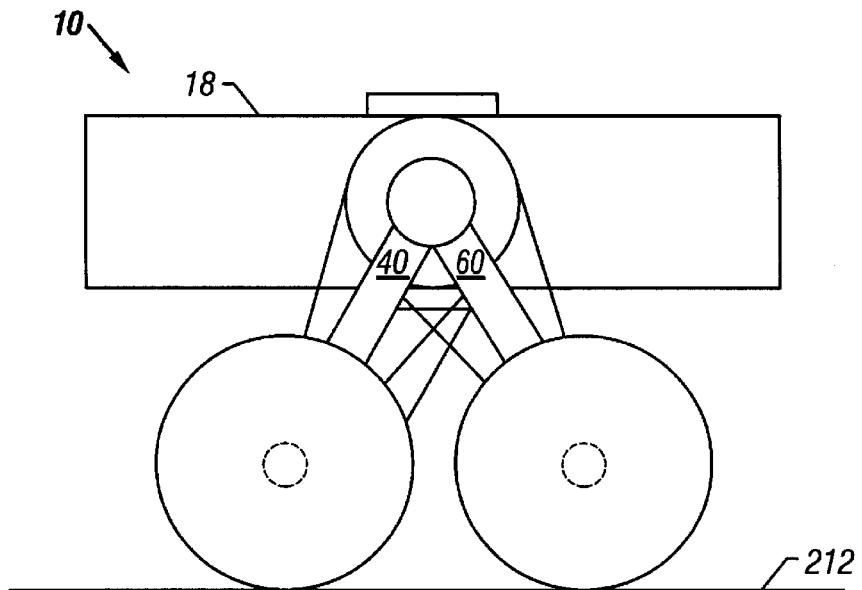
FIG. 6
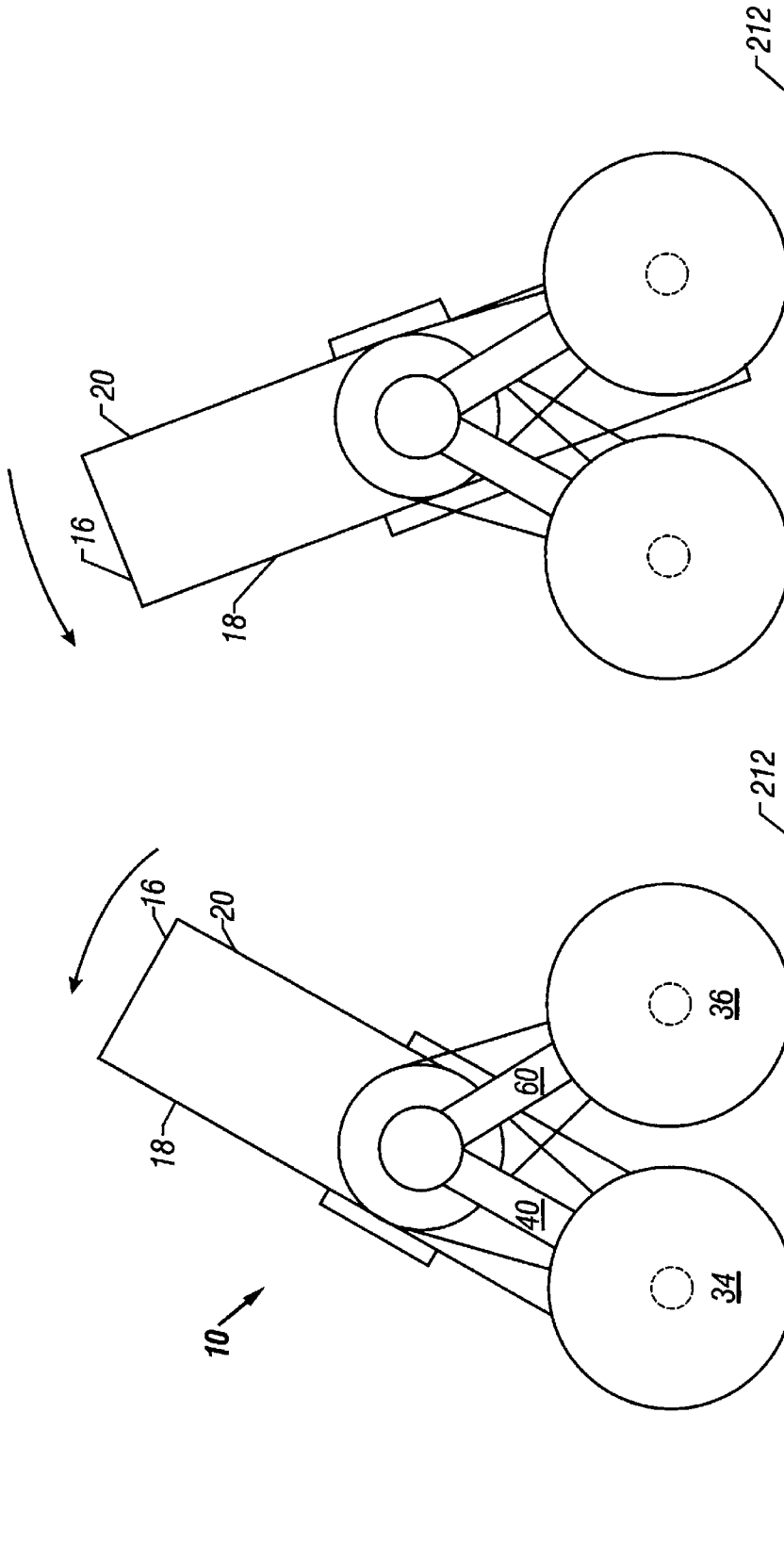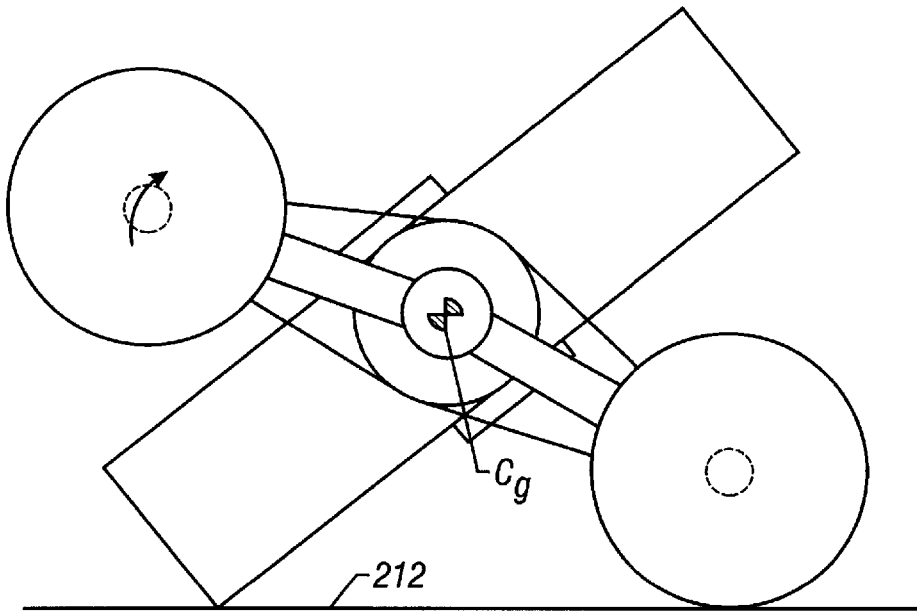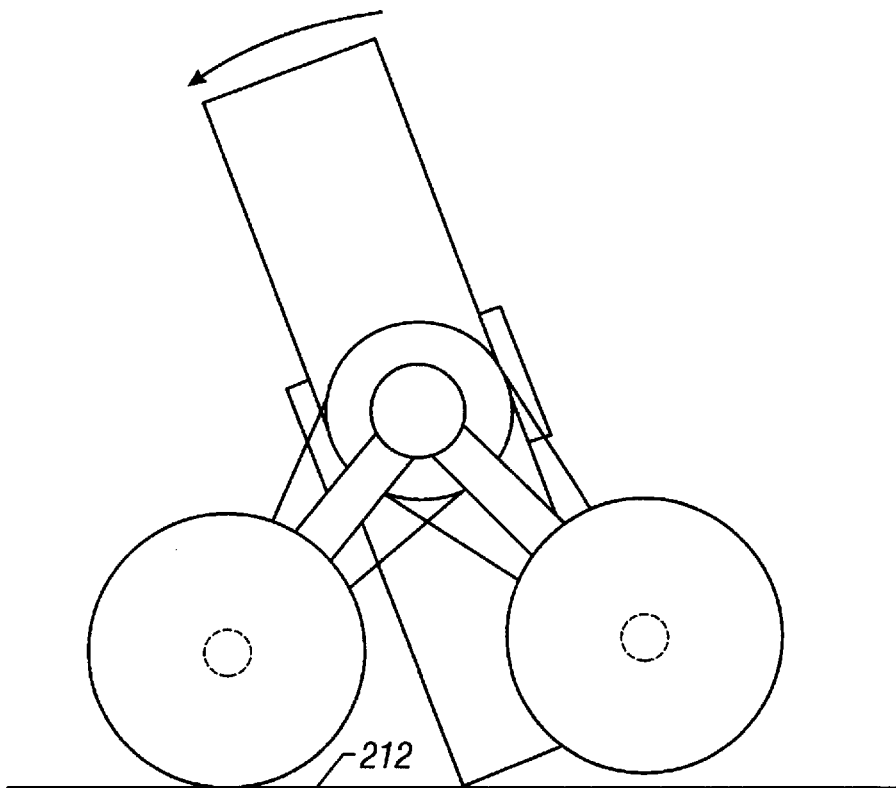
FIG. 8

FIG. 7

FIG. 9

FIG. 10

FIG. 11

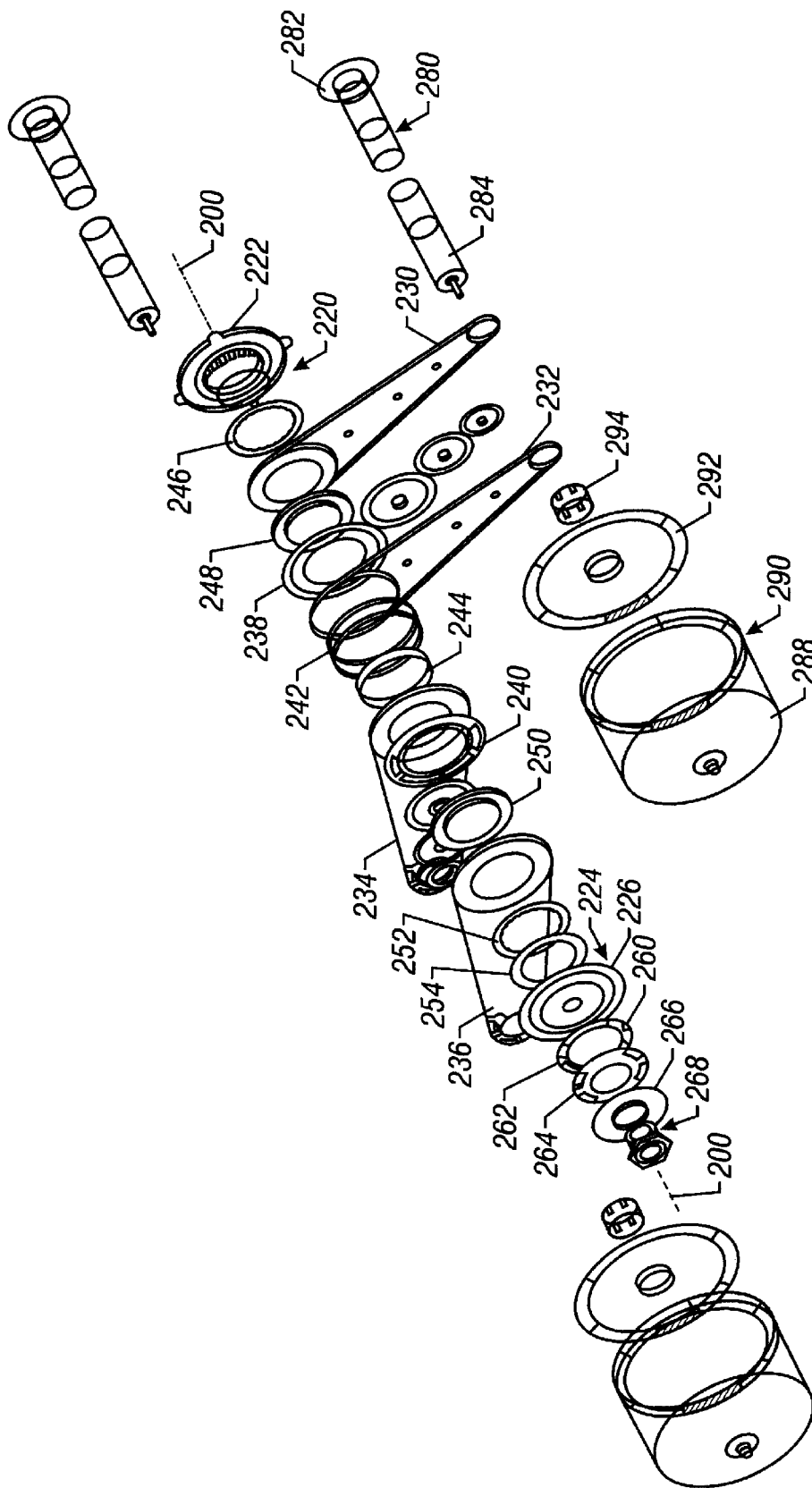FIG. 12

HIGH MOBILITY VEHICLE

CROSS REFERENCE TO RELATED APPLICATIONS

This is a divisional of U.S. application Ser. No. 08/966,
104, filed Nov. 7, 1997, now issued as U.S. Pat. No.
6,112,843 which claims benefit to Provisional Application
60/030245 filed Nov. 7, 1996.

STATEMENT AS TO FEDERALLY SPONSORED RESEARCH

The invention described herein was made in the perfor-
mance of work under a NASA contract, and is subject to the
provisions of Public Law 96-517 (35 USC 202) in which the
Contractor has elected to retain title.

BACKGROUND OF THE INVENTION

A variety of high mobility/all-terrain vehicles have been
made or proposed. These include a wide variety of tracked
and wheeled vehicles.

A number of vehicles have been proposed for extrater-
restrial use. Two which have been put into actual use are the
four-wheeled lunar rover of the Apollo program and the
six-wheeled robotic vehicle, Sojourner, of the Mars Path-
finder program. The suspensions of such vehicles are uni-
directional; that is to say they function only when the vehicle
is in a generally vertical orientation.

A variety of suspension systems may be used to maintain
engagement of the vehicle's wheels with the ground surface.
To ensure wheel engagement with particularly uneven
surfaces, it is desirable that the suspension be mechanically
actuated, either passively or actively, such as by hydraulics,
pneumatics, motors or other actuators. In the case of a
vehicle with more than three wheels, any three wheels will
typically form a tripod upon which the vehicle may rest. To
ensure engagement of the remaining wheels, it is necessary
that the suspension have at least N-3 actuated degrees of
freedom, where N is the number of wheels of the vehicle. If
control over the ride height, and/or orientation are required
then a system with N actuated degrees of freedom is
necessary. The particular character of the actuated degrees of
freedom will depend upon the chosen suspension design.

For example, the simplest of all designs would have one
actuator vertically reciprocating each wheel. In the case of
the Sojourner robot, each rear wheel is mounted on an arm
which is pivotally actuated about a transverse axis of the
robot. Each pair of front and middle wheels is carried by an
arm extending between the axes of the wheels (a "rocker
bogie"). The rocker bogie is pivotally moved on another arm
which is pivotally actuated about the transverse axis of the
robot. This provides the necessary three pivotal degrees of
freedom on each side of the vehicle.

For maximizing traction, it is desirable that all wheels be
driven. If individual motors are associated with each of the
N wheels and individual actuators are associated with each
of the N suspension degrees of freedom, then a total of 2N
devices (actuators and motors) are required.

SUMMARY OF THE INVENTION

The present invention describes a vehicle where the drive
motors may also be used to articulate the vehicle's suspen-
sion.

One preferred application for such a vehicle is as a rover
used to explore extraterrestrial bodies, especially bodies

such as asteroids where gravitational fields are much lower
than on earth. In such low gravity environments, the static
and dynamic forces due to gravity and vehicular momentum
will be smaller than on earth and will thus interfere less with
articulation of the suspension. The abilities of the vehicle to
traverse rough terrain and orient and position the vehicle
body for purposes of sample collecting, instrument
positioning, etc. are especially advantageous in such raw
environments.

In the case of many higher speed terrestrial vehicles, it is
a goal to minimize the unsprung weight; e.g. that which is
not carried by the suspension. This tends to increase the
sprung weight; e.g. that which is carried by the suspension.
The same does not necessarily apply to a vehicle for
operation in low gravity environments. The cost of trans-
porting the vehicle to the target environment places enor-
mous penalties on total weight. Thus, by shifting weight
from sprung weight to unsprung weight, the size and
strength of suspension components may be reduced along
with their associated weight. Furthermore, while operating
at relatively low speeds, the extra weight of unsprung
components may not have a significant effect on vehicle
performance. By no means finally, the reduction of the
sprung mass will generally have a tendency to lower the
vehicle's center of gravity, and thereby increase its stability.
It is therefore advantageous that the relatively heavy drive
motors be included in the unsprung mass of the vehicle. This
may be achieved by providing gear motors located partially
or entirely within each wheel for driving the wheel. By
utilizing the same motors to actuate the degrees of freedom
of the suspension, significant weight savings may be
achieved by avoiding separate actuators for the suspension.

Thus, in one aspect, the invention is directed to a vehicle
having a body with a left side, a right side, a front, and a back
and having left and right drive mechanisms. Each drive
mechanism includes first and second traction elements for
engaging the ground surface and transmitting a driving force
between the vehicle and the ground surface. Each drive
mechanism further includes first and second arms, respec-
tively coupled to the first and second traction elements for
relative rotation about first and second axes. Each mecha-
nism further includes a rotor having a third axis. Each
mechanism further includes first and second drive motors for
driving the first and second traction elements, respectively.
Each mechanism further includes first and second transmis-
sions which are driven by the first and second motors,
respectively, and engaged to the rotor so that respective
driving of the first and second traction elements simulta-
neously rotates the rotor relative to the first and second arms.

The third axis of the left drive mechanism and the third
axis of the right drive mechanism may be coincident and
fixed relative to the body. Each drive mechanism may
include a plurality of friction disks, normally irrotatably
coupled to each other and carried along the third axis. The
friction disks may hinder rotation of the rotor, first arm and
second arm. Each drive mechanism may include a splined
shaft extending along the third axis and carrying the friction
disks, the rotor and the first and second arms. Each drive
mechanism may further include a spring maintaining com-
pressive engagement between the disk, rotor and first and
second arms.

Each rotor may alternatively comprise an externally-
toothed gear. Each transmission may comprise a gear train
coupling the associated motor to the externally-toothed gear.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic side view of a vehicle.

FIG. 2 is a top view of the vehicle of FIG. 1.

FIG. 3 is an top cross-sectional view of a clutch mechanism of the vehicle of FIG. 1.

FIGS. 4–10 are schematic side views of the vehicle of FIG. 1 with suspensions in various articulations.

FIG. 11 is a schematic side view of a second vehicle.

FIG. 12 is an exploded view of a drive mechanism of a vehicle.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1 and 2 show a vehicle 10 having a body 12. The body has a front 14, a rear 16, a top 18, a bottom 20, and left and right sides 22A and 22B, respectively. The body has a center of gravity C_g through which a transverse axis 200 and longitudinal vertical center plane 202(FIG. 2)extend.

Shown in FIG. 2, a transverse shaft 28 is fixed to the body 12. The shaft 28 extends coaxially with the axis 200. The shaft 28 has a left end 30A and a right end 30B. At the respective left and right ends 30A and 30B of the shaft 28 are left and right drive mechanisms 32A and 32B.

Each drive mechanism 32A, 32B includes a first wheel 34 having a central transverse axis 204A, 204B and a second wheel 36 10 having a central transverse axis 206A, 206B. The first and second wheels 34 and 36 each have a radius R_1. A central pulley 38 is carried by the shaft 28 for rotation about the axis 200 which forms a central longitudinal axis of the pulley. The pulley 38 has a radius R_2.

Each drive mechanism 32A, 32B has a first arm 40 which couples the first wheel 34 to the body 12. The first arm 40 has a proximal end 42 which is rotatably carried by the shaft 28 and a distal end 44 at which the first arm is rotatably coupled to the first wheel 34 for relative rotation about the axis 204A, 204B. The first arm 40 has an effective lever length L measured between the axis 200 and the axis 204A, 204B. A first drive motor 46 rotates the first wheel 34 relative to the first arm 40 about the axis 204A, 204B. A first pulley 48 is rigidly coupled to the first wheel 34, centered about the axis 204A, 204B. The pulley 48, having a radius R_3, is coupled by a belt 50 to the pulley 38. Thus, when the motor 46 rotates the first wheel 34 relative to the arm 40 it also rotates the pulley 38 relative to the arm 40.

Similarly, a second arm 60 couples the second wheel 36 to the body 12. The second arm 60 has a proximal end 62 which is rotatably carried by the shaft 28 and a distal end 64 at which the second arm is rotatably coupled to the second wheel 36 for relative rotation about the axis 206A, 206B. The second arm 60 also has an effective lever arm length L measured between the axis 200 and the axis 206A, 206B. A second drive motor 66 rotates the second wheel 36 relative to the second arm 60 about the axis 206A, 206B. A second pulley 68 is rigidly coupled to the second wheel 36. The second pulley 68 is centered about the axis 206A, 206B. The second pulley 68, also having a radius R_3, is coupled by a belt 70 to the pulley 38. Thus, when the motor 66 rotates the second wheel 36 relative to the arm 60 it also rotates pulley 38 relative to the arm 60.

Each drive mechanism 32A, 32B includes a clutch mechanism 80 (FIG. 3) including first, second, third and fourth friction disks 82, 84, 86, 88, respectively, splined to the shaft 28 adjacent the associated shaft end 30A, 30B. The friction disks thus can not rotate relative to the shaft. The friction disks are secured between an outer collar 90 and an inner collar 92, which collars are axially secured to the shaft. At respective proximal ends 42 and 62 of first and second arms 40 and 60 there are formed disk-shaped protuberances

52 and 72. The protuberances 52 and 72 interact with the pulley 38 and friction disks 82, 84, 86 and 88 to resist movement of the arms 40 and 60 and the pulley 38 relative to the shaft 28. The protuberances 52 and 72 and the pulley 38 are each centrally apertured for carrying a bearing to minimize direct friction with the shaft 28.

A spring 96 is compressed between an inner face 98 of the collar 90 and an outer face 100 of the disk 82, to press the disk 82 inward and compressively sandwich the disks, protuberances and central pulley. The spring 96 is configured to apply approximately uniform pressure to the disk 82. The inner face 102 of disk 82 bears against the outer face 104 of the protuberance 52. The inner face 106 of the protuberance 52 bears against the outer face 108 of disk 84. The inner face 110 of the disk 84 bears against the outer face 112 of the protuberance 72. The inner face 114 of the protuberance 72 bears against the outer face 116 of the disk 86. The inner face 118 of disk 86 bears against the outer face 120 of the central pulley 38. The inner face 122 of the central pulley 38 bears against the outer face 124 of disk 88. The inner face 126 of disk 88 bears against the outer face 128 of the collar 92. The bearing of adjacent disks against the faces of the protuberances and central pulley produces friction between the disks and adjacent protuberances and central pulley. This produces resistance to rotation of the protuberances and pulley relative to the shaft because the disks are splined to the shaft.

For purposes of exposition, the static and dynamic friction properties of the disks, protuberances and central pulley are assumed to be equivalent. The protuberances are formed of the same material as the central pulley and have identical contact areas with adjacent disks. Thus, for given frictional properties, dimensions, and normal force from the spring 96, a certain torque, relative to the body, must be applied to the central pulley or to one of the individual protuberances to induce rotation of that central pulley or protuberance relative to the body. This torque, designated T, is evenly split between breaking friction between the element and each of the two friction disks on either side of the element.

In an initial driving condition shown in FIG. 1, the respective first and second arms 40 and 60 are at angles α and β from the transverse longitudinal center plane 210 of the body 12. With the vehicle on a flat horizontal ground surface 212, and the plane 210 extending parallel to the ground surface, the angles α and β are equal, leaving an angle γ (not shown) between the arms of $180°-\alpha-\beta$. In this configuration, to drive the vehicle forward, the first and second drive motors 46 and 66 are powered. The motors may be controlled by software running on a central computer (not shown) which may receive inputs from a variety of torque, speed, or other sensors (also not shown). The belts 50 and 70 rigidly link rotation of the associated wheels to rotation of the central pulley 38. Therefore, in order for the vehicle to move, the combined effect of the motors must be sufficient to produce a torque at least equal to the threshold torque T on the central pulley 38. The action of each motor produces a torque on its associated protuberance which is equal in magnitude and opposite in direction to the torque applied by that motor to the central pulley 38. If each motor applies a torque to the pulley 38 which is slightly greater than T/2, the pulley will begin to rotate about the axis 200 as the total torque on the pulley exceeds T. Since the responsive torque on each protuberance is only slightly greater than T/2, this torque is insufficient to break friction between the protuberance and the adjacent friction disks. Thus, the arms 40 and 60 remain fixed relative to each other and relative to the body 12. The wheels 34 and 36 then rotate with the central

pulley 38 and the vehicle proceeds forward. If opposite torque were applied by the motors, the vehicle would proceed rearward. To increase the acceleration of the vehicle, the torque applied by the motors 46 and 66 may be increased just up to the threshold where they each apply a torque T to the central pulley 38 and thus to their associated protuberance. Any further increase in torque will break friction between the protuberances and their adjacent disks causing the suspension geometry to alter. The vehicle may be skid-steered by running the motors on the left and right sides at different speeds or directions.

The angles α and β between the arms 40 and 60 and the plane 210 may be controlled by action of the motors 46 and 66. If it desired to alter the angle α of an initially stationary vehicle, the first motor 46 may be powered while the second motor 66 remains unpowered. With the second motor unpowered, the torque required to be applied by the first motor to cause rotation of the central pulley 38 is not simply the torque T required to break friction between the pulley and its adjacent friction disks. Rather, since the second belt 70 links rotation of the pulley to rotation of the second arm 60 so as to lock the pulley and second arm 60 to each other, in order to rotate the pulley, the friction between the second protuberance 72 and its adjacent friction disks must also be broken. The required torque is thus 2 T. The first motor, however, is incapable of exerting such torque on the pulley 38. When the torque exerted by the first motor on the pulley 38 exceeds T, the friction torque threshold is exceeded and friction between the first protuberance 52 and the adjacent friction disks will be broken. This causes the arm 40 to rotate relative to the body 12, thus altering the angle α.

By reducing the angle α, the front of the vehicle, at the wheel 34, may be lowered relative to the ground or the wheel 34 raised, such as to ascend an obstacle. As shown in FIG. 4, to raise the wheel 34 the motor 46 applies a torque in a direction which would otherwise cause the wheel 34 to rotate clockwise relative to the arm 40. This is the direction associated with forward movement of the vehicle when both motors on each side are engaged. Since however the pulley 38 is held fixed, the effect is that the arm 40 is caused to rotate clockwise thus raising the wheel. Similarly, by increasing a the vehicle may be raised or wheel lowered, such as to track a depression in the ground by reversing the direction of torque applied by the motor.

A wheel may be raised while driving up a side of an obstacle. Alternately, however, as shown in FIG. 4, the wheel may be raised off the ground surface prior to contacting the obstacle 130. The vehicle may then be driven forward on the remaining wheels so that the raised wheel is above the obstacle. The raised wheel may then be lowered and placed atop the obstacle. Such a mode may be useful when the shape or properties of the obstacle prohibit a traction ascent. In such a mode, the three remaining wheels may need to be raised or lowered to stabilize the center of gravity within the tripod formed by the remaining wheels. This may be done by raising the diagonally opposite wheel, lowering the longitudinally opposite wheel, raising the transversely opposite wheel, or various combinations of such movements.

If it is desired to raise or lower the entire vehicle relative to the ground, the first and second wheels on each side may be raised or lowered sequentially. Alternatively, they may be raised or lowered together. To accomplish this, the motors 46 and 66 are powered to rotate to operate in opposite directions. Each motor 46 and 66 imparts an equal and opposite torque on the central pulley 38. These torques approximately cancel (i.e.; algebraically add to less than T) so the pulley

will remain stationary. However, when the magnitude of the torque applied by each motor 46 and 66 exceeds T the counter torque is sufficient to break the friction between the protuberances 52 and 72 and their adjacent disks to simultaneously either increase or decrease the angles α and β. Thus, the entire side of the vehicle may be lowered or raised relative to the ground surface. If the mechanisms on both sides are similarly actuated, the entire vehicle may be lowered (FIG. 5) or raised (FIG. 6). Thus, the vehicle may be lowered to place its bottom 20 or a portion thereof or fixture thereon in contact with the ground. This may be useful for taking soil samples or performing other operations. The body 12 may then be raised to resume movement. For purposes of exposition, the modes wherein the angles α and β are simultaneously respectively increased and decreased are referred to "contraction" and "extension" modes.

By differentially raising or lowering the sides of the vehicle, the vehicle may be made to rotate about a longitudinal axis ("roll") in one direction or another relative to the ground surface. Similarly, by differentially raising or lowering the ends of the vehicle, rotation about a transverse axis ("pitch") may be controlled. Control over pitch and roll may be used to maintain a given attitude of the vehicle while traversing non-level terrain or may be used to orient the vehicle in a particular orientation, for example so as to provide a particular view for an instrument on the vehicle.

If the vehicle were to become inverted, it may nevertheless continue to navigate by articulating the arms 40, 60 in the extension mode so that the angles α and β go through zero and become negative. In such a way, the vehicle may navigate in an inverted orientation. Furthermore, the vehicle can be caused to flip by drawing one corresponding arm of each drive mechanism toward the opposite end of the vehicle until the wheels associated with such arms are below the center of gravity. Thereafter, the vehicle will flip over about those wheels and land in an inverted configuration.

In low gravity environments, the relative significance of inertial forces relative to gravitational forces is increased. Thus, a sudden encounter with an obstacle may very easily cause a vehicle in a low gravity environment to flip over. This is especially true when the vehicle is confronted with uneven or unpredictable terrain. It is therefore highly advantageous that the vehicle be configured for self-righting from an inverted state. Self righting may be achieved in a number of other ways. For example, if the length of the body is sufficiently short, the suspension may be contracted and the body simply pivoted approximately 180° about the shaft axis. With the body in the relatively raised and the suspension in the relatively contracted positions of FIG. 6, the arms 40 and 60 on both sides of the vehicle may be sequentially rotated about the axis 200 by small increments. If, as shown in the drawing, the arms are sequentially rotated clockwise relative to the body, the effect will be that the body will rotate relative to the ground surface 212 so that the rear end 16 raises while the front end 14 lowers. This process may be repeated to permit the vehicle to invert the body relative to the ground surface. Alternately, if the body length is sufficiently small, a first pair of wheels at a first end of the body may be raised so as to lower the end of the body into contact with the ground (FIG. 9), the longitudinally opposite pair of wheels may then be lowered while being driven toward the first end of the body. This will cause the body to flip about the first end whereupon the first pair of wheels are brought back into engagement with the ground (FIG. 10).

Optionally, the body may be provided with a significant degree of top to bottom symmetry. For example, in the case

of a solar-powered vehicle both the top and bottom may be provided with solar cells (not shown) to allow the vehicle to function with either the top or bottom facing away from the ground surface. For economy and space efficiency, different instruments may be provided on the top and bottom. For example, the top might bear one or more cameras **120** while corresponding areas of the bottom bear probes **122** for taking samples. The body may be sequentially inverted to permit sequential use of the instruments on the top and bottom.

In low gravity environments, such as when a vehicle is used to explore an asteroid, the contraction mode may be used to induce the vehicle to hop up from the ground surface. For example, on a small asteroid with a surface gravity of $0.0002 \, m/s^2$ an induced initial upward velocity of 2 cm/s will cause the vehicle to hop upward about 1 m.

The loss of traction of a single wheel does not inherently cause the loss of motive forces from the motor associated with that wheel. A wheel may lose traction for a variety of reasons. For example: it may be on particularly loose soil; it may have naturally come out of contact with the ground, such as when traversing a crevasse; or it may have been intentionally raised out of engagement with the ground. In such a situation, it may still be possible to utilize the drive motor associated with the disengaged wheel to add power to a wheel that remains engaged. A torque up to the threshold torque T may be applied by the motor of the disengaged wheel parallel to the torque of the motor of the associated engaged wheel. In such a way, it will add to the drive torque and force between the engaged wheel and the ground surface.

A variety of considerations influence the selection of components geometries and properties. A preferred property of all-terrain vehicles is that there is enough available drive torque at each wheel so that the rim thrust is approximately equal to the vehicle's weight. The rim thrust is the net drive torque applied to the wheel divided by the wheel radius. The drive torque is net of any torque which must be transmitted to the central pulley or rotor to cause its rotation. It is further desirable that enough net actuation torque is capable of being applied to a given arm to lift the vehicle's weight. This net actuation torque is thus the vehicle's weight multiplied by the arm's length. Combining these considerations, a preferred proportion involves having an equal ratio of central pulley radius R_2 to wheel pulley radius R_3 and arm length L to wheel radius R_1. Although preferred, the radii of the front and rear wheels need not be the same. If different, it is preferred that the ratios be preserved. Thus, if the rear wheel has a radius R_1 and has a wheel pulley of radius R_3 and an arm of length L while the dimensions of the front wheel and its associated wheel pulley and arm are R_1', R_3' and L', respectively it is preferred that R_1 dived by the product of R_3 and L be equal to R_1' divided by the product of R_3' and L'. This is for the case where both front and rear wheels are acting upon a pulley of the same radius.

The need to actuate the arms into asymmetric angles in the presence of gravitational forces places a lower bound on the threshold torque T and thus on the friction imposed by the clutch mechanisms. However, the higher the friction, the more torque which is required of the motors both to actuate the suspension and simply to drive the vehicle. Thus, concerns for light weight and efficiency will indicate the desirability of a relatively low threshold torque.

FIG. **11** shows a vehicle **310** having four wheels per side. The drive mechanism **332** includes front and back sub-mechanisms **333** and **335** at each side, which may be

otherwise similar to the drive mechanisms **32** of vehicle of FIG. **1**. The central pulleys of the sub-mechanisms **333** and **335** are coupled to a central pulley **338** of the mechanism **332** via arms and belts in similar fashion to the coupling of the wheels **34** and **36** to the central pulley **38a, 38b** of the drive mechanism **32** of the vehicle of FIG. **1**. A clutch mechanism **380** may couple the central pulley **338** and arms **340** and **360**, as previously described relative to drive mechanism **32**. The mechanism **332** need not have the illustrated symmetry for example, the arm **340** could couple the pulley **338** directly to a wheel instead of to a sub-mechanism. In such a way, a vehicle with three wheels on each side would be obtained. Other, more complex mechanism, are also possible.

FIG. **12** shows an exploded view of an alternate drive mechanism featuring gear trains instead of belts and pulleys. A shaft section is formed along the axis **200** by an inboard internally threaded sleeve **220** mated with an outboard externally threaded sleeve **224**. The sleeve **220** has a collar **222** at its inboard end. The collar **222** may include mounting features for securing the sleeve to the vehicle body and the sleeve is splined along an inboard section. The sleeve **224** includes a collar **226** formed at its outboard end. The sleeve **224** is similarly splined adjacent its outboard end so that the assembled shaft section includes inboard and outboard splined sections and a central unsplined section.

An inboard arm is formed with inner and outer shell sections **230** and **232**, respectively. Similarly, an outboard arm is formed with inner and outer shell sections **234** and **236**, respectively. Each arm contains a proximal to distal extending train of gears. The proximal gears **238** and **240** in the respective trains of the inboard and outboard arms are affixed to each other by the housing **242** of a bearing assembly. The housing **242** spans and extends through openings in the outer shell **232** of the inboard arm and the inner shell **234** of the outboard arm along the axis **200**. The ball bearing unit **244** rides along the central unsplined portion of the shaft to allow the assembled gears **238** and **240** to rotate. With the mechanism assembled, a first friction disk **246** is irrotatably carried by the sleeve **220** with an outboard annular surface of the disk **246** engaging an inboard annular surface of the proximal end of the inner shell section **230** of the first arm. A corresponding outboard annular surface of the inner shell section **230** engages the inboard annular surface of a second friction disk **248** which is also irrotatably held by the sleeve **220**. This engagement between the inner shell section **230** and the disks **246** and **248** resists rotation of the first arm about the axis **200**. The outboard annular surface of the second friction disk **248** engages the inboard annular surface of the gear **238**. The outboard annular surface of the gear **240** engages the inboard annular surface of a third friction disk **250** which is irrotatably held by the sleeve **224**. This engagement between the disks **248** and **250** and gears **238** and **240** resists rotation of the gears **238** and **240** about the axis **200**.

The outboard annular surface of the third friction disk **250** engages an inboard annular surface of the proximal end of the outer shell section **236** of the outboard arm. A corresponding outboard annular surface of the outer shell section **236** engages the inner annular surface of a fourth friction disk **252** which is also irrotatably held by the sleeve **224**. This engagement between the outer shell section **236** and the disks **250** and **252** resists rotation of the outboard arm about the axis **200**. A backing ring **254** is positioned against the outboard annular surface of the fourth friction disk **252** and located immediately inboard of the collar **226**. Outboard of the collar **226** is a pusher ring **260** with a plurality of

inwardly-directed pins **262** extending through holes in the collar **226** and engaging the outboard annular surface of the backing ring **254**. A spring **264** is held between the pusher ring and a collar **266**. A hollow bolt **268** secures the collar **266** to the sleeve **224**, holding the spring **264** in compression between the collar **266** and pusher ring **260**. Via the pins **262**, the compression is transferred to the backing ring **254** and thus to the various friction disks and the elements the friction disks engage. The pusher ring **260** and the backing ring **254** allow the compressive force from the spring **264** to be uniformly transmitted through the stack of friction disks while reducing the possibility of the intrusion of dust or other foreign matter. Also, the housing design minimizes gaps through which foreign matter may enter the assembly.

At the distal end of each arm, a motor carrier **280** is secured by a flange **282** to the inner shell section **230, 234**. The motor carrier carries a motor **284** with a shaft **286** secured to the outboard web **288** of a wheel **290** such as by a clamp (not shown). A splined aperture in an inboard web **292** of the wheel **290** irrotatably receives a sleeve **294** which extends through a distal aperture in the outer shell section **232, 236**. The inboard end of the sleeve **294** bears external teeth and serves as the distal gear in the gear train.

In operation, torque from the motors **284** is transmitted to the wheels and up through the gear trains to the proximal gears **238** and **240**. The attached proximal gears **238** and **240** have a similar rotor function to the pulley **38**.

A number of embodiments of the present invention have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. For example, wheels with grousers or other traction increasing features may be provided and traction elements other than wheels may be used. These may include belts or tracks. In place of the belt and pulley or gear train transmissions, other mechanisms may be used such as chains and sprockets, shafts, etc. More advanced or complex clutch mechanisms may be used in place of the illustrated friction disk and spring arrangement. For example, a latching mechanism or clutch may be provided which is actuated by differential wheel torques or motions analogous to the operation of the previously-described friction clutch mechanism. Such a system may substantially eliminate energy losses through the friction clutch during driving of the vehicle. Computer-controlled latching mechanisms or clutches may be used and may be configured to selectively lock and unlock the arms and rotor from each other. Various modes of operation may be combined simultaneously or seriatim and other modes are possible. By no means finally, the principles of the invention may be extended to vehicles with more than two wheels (or other traction elements) per side, vehicles other than skid-steered vehicles, and vehicles with more complex suspension geometries. Furthermore, a variety of complex feedback control systems may be employed taking inputs from torque and force sensors on the various components so as to determine the interaction between each wheel and the environment and optimally apportion the drive and orientation forces applied by the motors to each wheel. Accordingly, other embodiments are within the scope of the following claims.

What is claimed is:

1. A method for maneuvering a vehicle, which vehicle includes:
 (a) a body having a left side, a right side, a front and a back; and
 (b) left and right drive mechanisms, coupled to said body, each of said left and right drive mechanisms comprising:

 a first traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface;
 a second traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface;
 a first arm, coupled to the first traction element; and
 a second arm, coupled to the second traction element, the method comprising:
  altering the height of one side of the body relative to the ground surface by:
   driving the first traction element on the one side in a first direction; and
   driving the second traction element on the one side in a second direction, opposite the first direction, so as to alter a separation between said first traction element and said second traction element and an angle between the first arm on the one side and the second arm on the one side.

2. A method for maneuvering a vehicle, which vehicle includes:
 (a) a body having a left side, a right side, a front and a back; and
 (b) left and right drive mechanisms, coupled to said body, each of said left and right drive mechanisms comprising:
 a first traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface;
 a second traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface;
 a first arm, coupled to the first traction element; and
 a second arm, coupled to the second traction element, the method comprising:
  altering a position of the body relative to the first traction element on one side by:
   driving the first traction element on the one side in a first direction; and
   maintaining the second traction element on the one side, so as to alter a separation between said first traction element and said second traction element and an angle between the first arm on the one side and the second arm on the one side, while a position of the second traction element on the one side remains fixed relative to the body.

3. A method for maneuvering a vehicle, which vehicle includes:
 (a) a body having a left side, a right side, a front and a back; and
 (b) left and right drive mechanisms, coupled to said body, each of said left and right drive mechanisms comprising:
 a first traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface;
 a second traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface, the method comprising:
  applying a first torque in a first direction to the first traction element on the one side; and
  applying a second torque in a second direction, substantially opposite said first direction, to the second traction element on the one side, said first torque and said second torque cooperating to alter

a suspension geometry of the vehicle from a first stable condition to a second stable condition.

4. A method for maneuvering a vehicle, which vehicle includes:

(a) a body having a left side, a right side, a front and a back; and

(b) left and right drive mechanisms, coupled to said body, each of said left and right drive mechanisms comprising:

a first traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface;

a second traction element, to engage a ground surface and transmit a driving force between the vehicle and the ground surface, the method comprising:

driving the first traction element on the one side at a first angular velocity; and

driving the second traction element at a second angular velocity, differing from said first angular velocity, so as to alter a suspension geometry of the vehicle from a first stable condition to a second stable condition.

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