

April 2, 1968

M. W. KRASCHNEWSKI ETAL

3,375,892

STEPPING-TYPE PROPULSION MEANS FOR EXCAVATORS

Filed Nov. 3, 1965

6 Sheets-Sheet 1

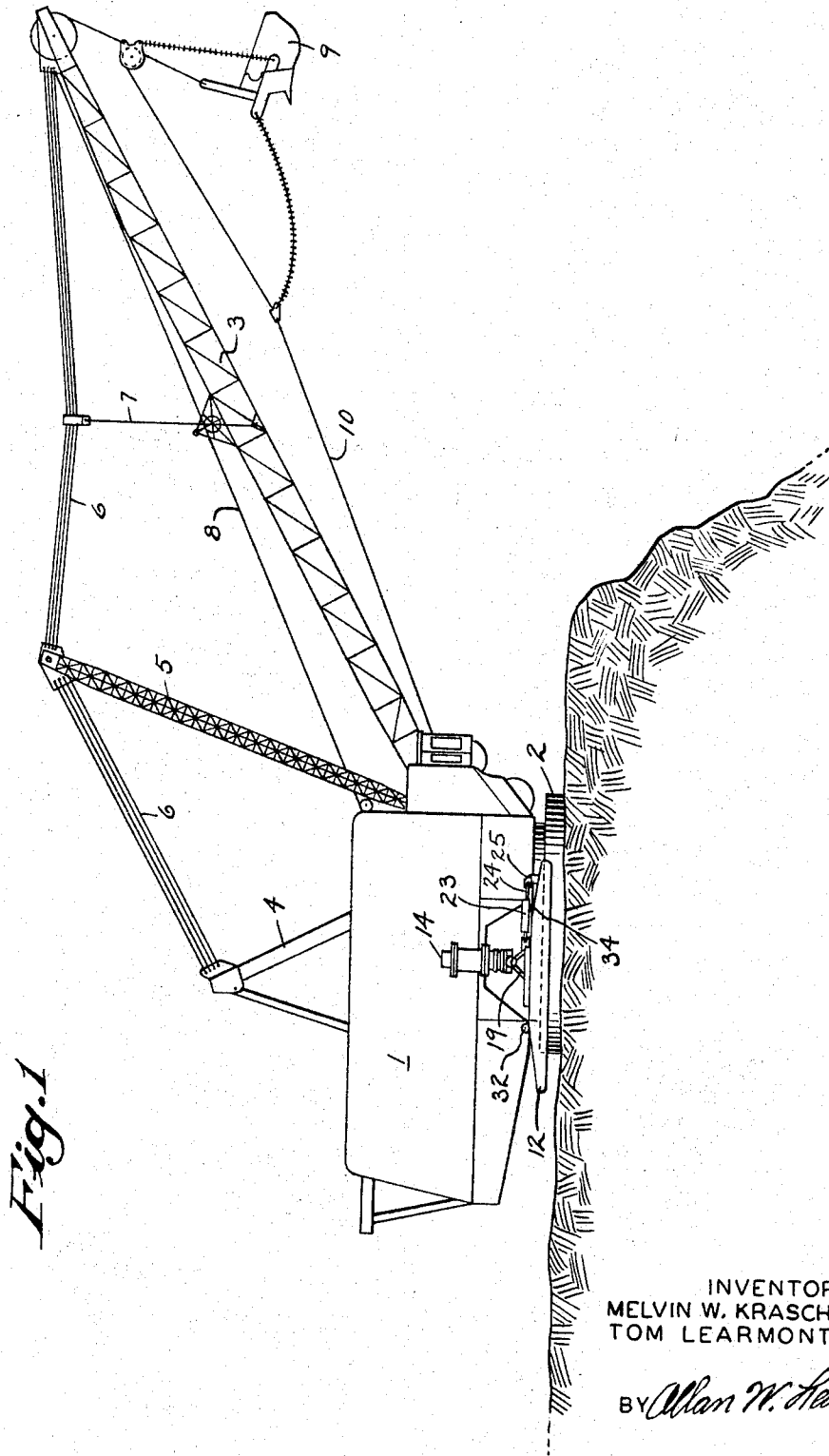


Fig. 1

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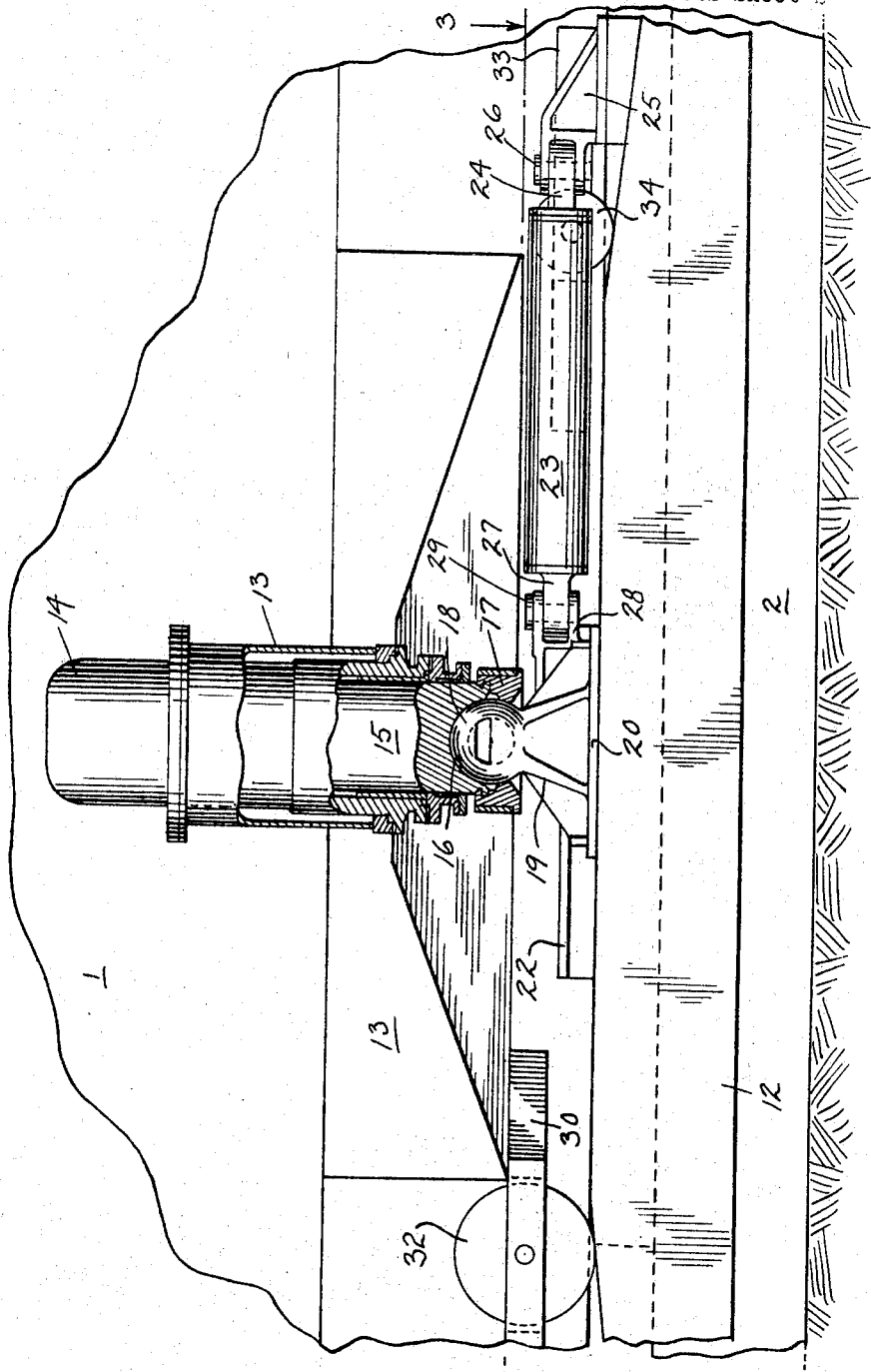
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STEPPING-TYPE PROPULSION MEANS FOR EXCAVATORS

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6 Sheets-Sheet 2

*Fig. 2*



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STEPPING-TYPE PROPULSION MEANS FOR EXCAVATORS

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6 Sheets-Sheet 3

Fig. 3

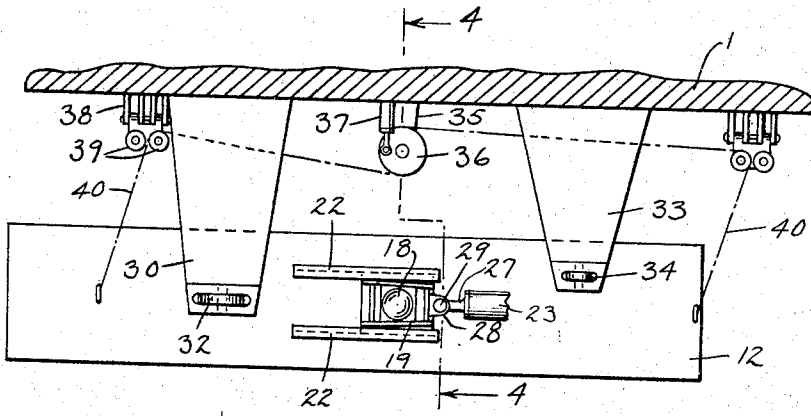
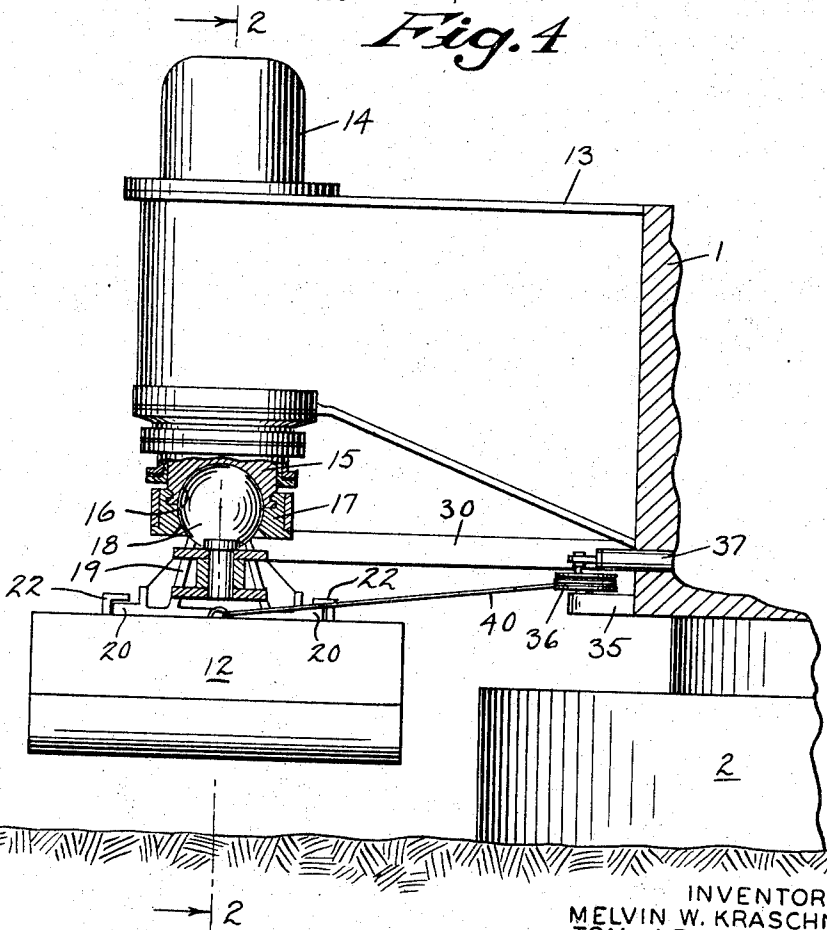


Fig. 4



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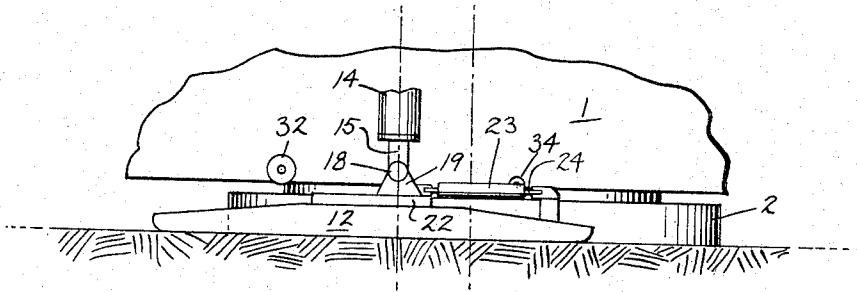
M. W. KRASCHNEWSKI ETAL 3,375,892

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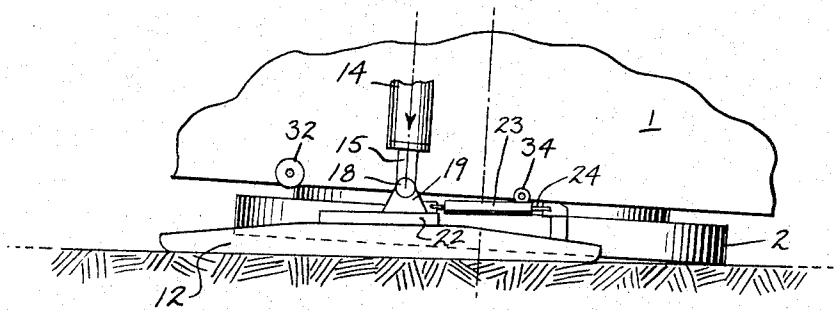
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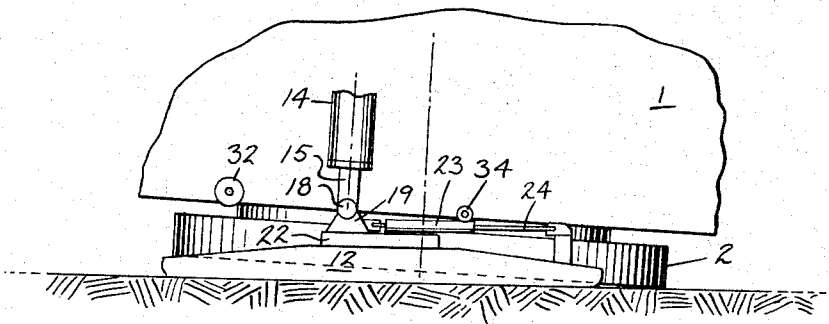
*Fig. 5*



*Fig. 6*



*Fig. 7*



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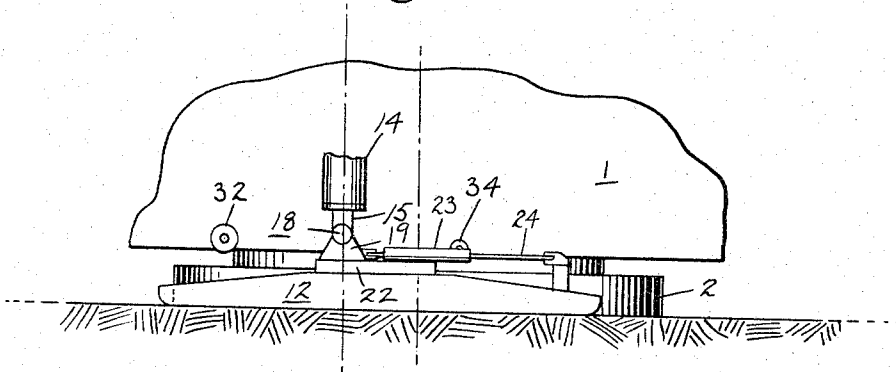
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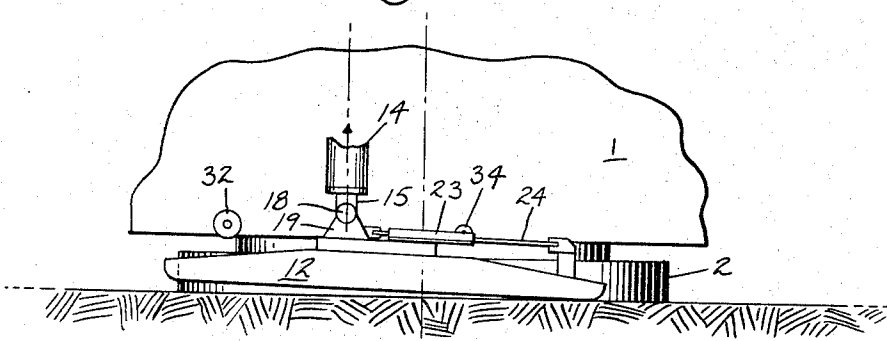
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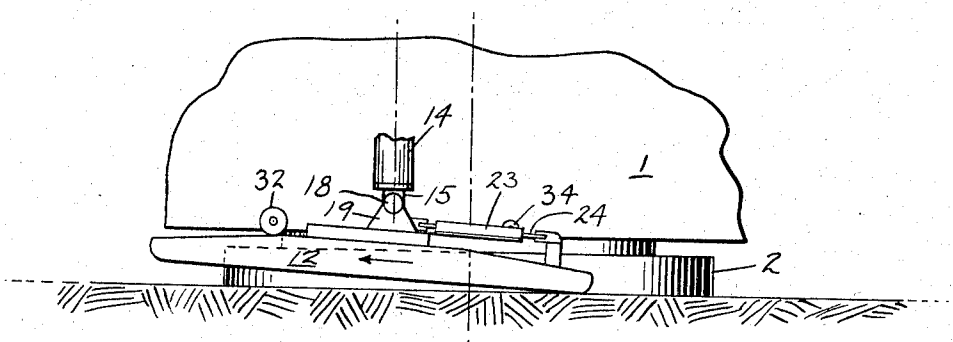
*Fig. 8*



*Fig. 9*



*Fig. 10*



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STEPPING-TYPE PROPULSION MEANS FOR EXCAVATORS

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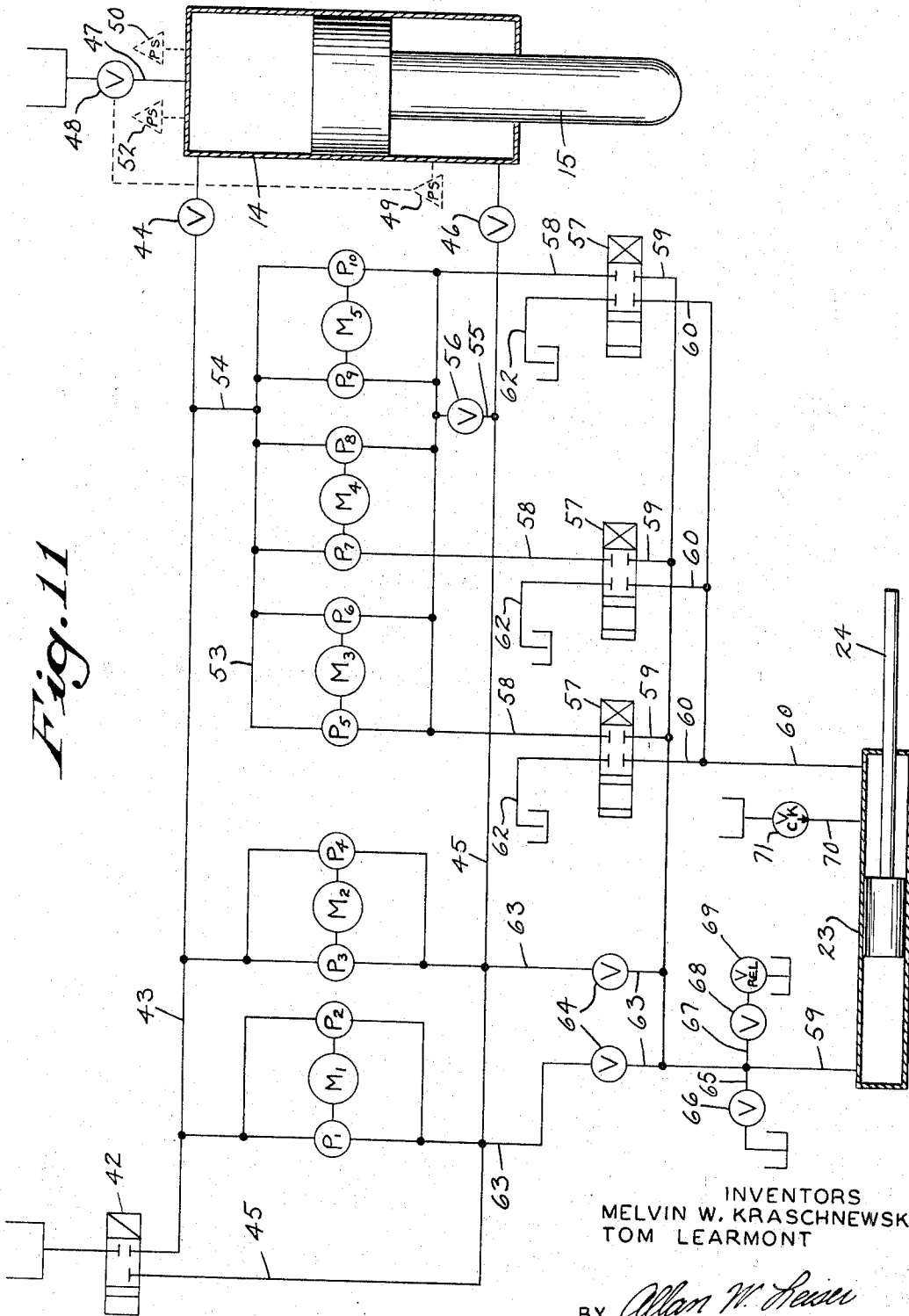


Fig. 11

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3,375,892

**STEPPING-TYPE PROPULSION MEANS FOR EXCAVATORS**

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 Filed Nov. 3, 1965, Ser. No. 506,207  
 10 Claims. (Cl. 180-8)

**ABSTRACT OF THE DISCLOSURE**

A walking dragline has a central tub, a revolving frame, and a pair of shoes on opposite sides which are movable vertically and horizontally to provide a stepping-type propulsion. A pair of hydraulic lift cylinders on the frame have ball and socket connections with slides which are received in slideways on the shoes, the lift cylinders thus being adapted to effect vertical movement of the shoes. A hydraulic push cylinder is connected between each shoe and slide to effect horizontal movement. The ball and socket connections are substantially the only connections between the shoes and the frame so that the shoes are capable of three degrees of movement during walking. The shoes are urged toward a parallel relationship with the frame by means of ropes leading from the ends of the shoes to a sheave on the frame which is held against rotation by means of a hydraulic cylinder. The shoes are also aligned with respect to the frame by means of rollers on the frame that engage the upper surface of the shoes at laterally and longitudinally spaced points. A plurality of pumps operate the cylinders, and these are divided into two sets. All of the pumps drive the lift cylinder when the machine is being lifted and all of the pumps drive the push cylinder when the machine is being moved, but one set of pumps drives the lift cylinder and the other set of pumps simultaneously drives the push cylinder during a portion of the return movement of the shoe.

This invention relates to stepping-type propulsion means for excavators, and resides more specifically in a hydraulic propulsion system particularly suitable for extremely large excavating machines.

Stepping-type propulsion means have been widely used for excavators, particularly draglines; and various mechanical, hydraulic or combination propulsion systems have been devised. Some examples of hydraulic or partially hydraulic systems can be found in U.S. Patents Nos. 1,615,055 to Turner, 2,132,184 to Posche, 2,452,632 to Cameron, 2,660,253 to Davidson and 2,785,761 to Becker.

Neither the systems shown in the foregoing patents nor other known prior art systems are, however, suitable for the immense excavating machines required for modern applications. The particular propulsion system shown herein, for example, has been designed for a dragline having a bucket capacity of 150 cubic yards, a working weight of some 14 million pounds, overall width and body length of 116 and 115 feet, respectively, and two walking shoes each of which is 78 feet long and 15 feet wide and weighs about 400,000 pounds. Known prior art propulsion systems simply do not allow for sufficient mechanical strength to withstand the stresses and forces encountered in moving a machine of these gigantic proportions.

In addition to basic mechanical inadequacies, the prior art systems do not solve certain problems which are common to all walking excavators, but which are greatly magnified for extremely large machines. These include, for example, providing limited freedom of movement for the walking shoes to compensate for ground irregularities and providing means to center, align and level the shoes during walking. Solving such problems becomes quite dif-

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ficult in a very large machine where mechanical strength is an overriding factor.

Further, it is necessary in extremely large and heavy machines to have a very smooth cycle of operation, since any lurching or sluing would result in tremendous stresses and be likely to cause breakage or serious damage.

With an extremely large machine, settling also presents a serious problem in providing a smooth cycle of operation. Because of the weight of the machine, the tub may easily sink several feet or more into the ground while the machine is working, and both the shoes and the tub are likely to sink considerably during walking. To have a smooth cycle of operation, therefore, it is necessary to provide some means to insure that the machine and shoes are lifted above ground level before they are moved forward.

There are other problems unique to machines of the size contemplated herein. One of these is the tremendous release of potential energy which occurs when the machine and shoes are lowered to the ground after having been lifted. In many machines, this energy is merely converted into heat and it is relatively simple to provide an adequate heat sink. With an extremely large machine, however, the potential energy is so great that it would cause an insurmountable heat problem if released in this fashion. Accordingly, it becomes necessary to provide some other means to dissipate the released energy.

It is the general object of this invention to provide a hydraulic propulsion means which overcomes the foregoing and other disadvantages of prior art constructions and is suitable for extremely large excavating machines, particularly draglines. It will be obvious, however, that propulsion means according to this invention may also be useful in smaller machines and in excavating machines other than draglines.

It is one specific object of the invention to provide propulsion means which allows the walking shoes freedom of movement in three planes by means of a universal connection to compensate for ground irregularities, which means is sufficiently strong to be used in extremely large excavators.

It is another object of the invention to provide means of sufficient mechanical strength to center, level and align the shoes for walking.

It is a further object of the invention to provide a propulsion system utilizing a particularly advantageous cycle of operation for extremely large and heavy machines.

It is another object of the invention to provide a propulsion system including unique and effective actuation and control circuitry to provide the desired cycle of operation.

It is a further object of the invention to provide a propulsion system in which heat problems resulting from the release of energy are eliminated and in which the released energy is actually utilized in the operation of the machine.

It is another object of the invention to provide a propulsion system incorporating the foregoing and other advantages which is long wearing and relatively simple and inexpensive from the standpoints of manufacture, assembly and repair.

The foregoing and other objects and advantages will appear more clearly from the description to follow. In the description, reference is made to the accompanying drawings, which form a part hereof and in which a preferred embodiment of the invention is shown, by way of illustration and not of limitation.

In the drawings:

FIG. 1 is a side view in elevation showing a walking dragline incorporating a propulsion system formed according to this invention.

FIG. 2 is an enlarged fragmentary view with parts

shown broken away and in cross section, taken through the plane 2—2 shown in FIG. 4,

FIG. 3 is an enlarged fragmentary view, with parts shown broken away and in cross section, taken through the plane 3—3 shown in FIG. 2,

FIG. 4 is an enlarged fragmentary view, with parts shown broken away and in cross section, taken through the plane 4—4 shown in FIG. 3,

FIGS. 5 through 10 comprise a series of fragmentary schematic views illustrating the walking operation of the dragline of FIG. 1, and

FIG. 11 is a schematic diagram of a hydraulic circuit for the propulsion system of FIG. 1.

#### *Dragline and propulsion system structure*

Referring again to FIG. 1, the dragline shown therein includes a main frame or body 1 that includes a circular tub 2 on which the major portion of the frame 1 is rotatably supported. A boom 3 has its inner end pivotally supported on the frame 1 and its outer end supported from an A-frame 4 and an auxiliary mast 5 by means of pendants 6 and an auxiliary cable arrangement 7. A hoist rope 8 leading from a winch mechanism (not shown) on the frame 1 passes about the end of the boom 3 and is connected to a drag bucket 9. A drag rope 10 is connected between the bucket 9 and a second winch mechanism (not shown) on the frame 1. This overall arrangement is conventional, and the various elements noted above have not been shown and will not be described in detail since they are well known to those skilled in the art, and since the propulsion system of this invention may be useful in other types of equally well known machines.

A pair of shoes 12 are disposed on opposite sides of the frame 1 and are actuated in stepping fashion as will be described to move the machine forwardly, to the left as seen in FIG. 1. The shoes 12 and the other noted elements are all connected to the frame 1 above the tub 2, so that they can turn with respect to the tub 2 so that the direction of movement of the machine can be changed. Only one shoe 12, together with a set of associated elements that will be described, has been shown in the drawings and will be described below. It will be understood, however, that the same arrangement is used on both sides of the machine is accordance with usual practice.

As can be seen most clearly in FIG. 4, a lateral extension 13 of the frame 1 overhangs the shoe 12. A conventional double acting hydraulic lift cylinder 14, which may be of any suitable design, is rigidly mounted on the frame extension 13 with its extensible rod 15 directed downwardly toward the shoe 12. The bottom surface of the rod 15 is hollowed out to define a hemispherical recess 16, and a split retaining collar 17 of any suitable configuration is removably attached to the lower end of the rod 15 in alignment with the recess 16.

As can be seen clearly in FIGS. 2 and 4, the collar 17 and recess 16 together form a spherical socket which receives and holds captive the ball head 18 of a slide 19. The bottom surface of the slide 19 is flat and is provided with opposite, parallel laterally extending flanges 20.

A pair of generally parallel, L-shaped guides 22 are fixed to the upper surface of the shoe 12 in overhanging relationship to the flanges 20. The guides 22 thus establish a slideway providing for relative horizontal movement between the shoe 12 on the one hand and the cylinder 14, and frame, 1 on the other. Preferably, the guides 22 are made to converge slightly from left to right as seen in FIG. 3 to provide a centering action as the shoe 12 moves to the left as seen in FIG. 3. Since the shoe 12 is, in effect, connected to the frame 1 only through the ball and socket or universal connection, it has limited freedom of movement in three planes.

As can be seen most clearly in FIG. 2, a conventional double acting hydraulic push cylinder 23 is mounted atop the shoe 12 and connected between the shoe 12 and the slide 19. The outer end of the rod 24 of the cylinder 23,

which extends to the right as seen in FIG. 2, is apertured and is received in a bifurcated, apertured bracket 25 on the shoe 12. A vertical pin 26 extends through these elements and establishes a pivotal connection between the rod end of the cylinder 23 and the shoe 12. The blank or piston end of the cylinder 23 is provided with an apertured mounting ear 27 which is received in an apertured, bifurcated bracket 28 formed integrally with the slide 19. A vertical pin 29 passes through these elements and, therefore, establishes a pivotal connection between the piston end of the cylinder 23 and the slide 19.

It will be obvious that actuation of the lift cylinder 14 will cause relative vertical movement between the shoe 12 and frame 1, while actuation of the push cylinder 23 will cause relative horizontal movement between the shoe 12 and frame 1. Sequential actuation of the cylinders 14 and 23 is used to alternately lift and transport the shoe 12 with respect to the frame 1 and vice versa to effect a walking action, all as will be described more fully hereinafter.

As can be seen most clearly in FIG. 3, a front roller support 30, which is a rigid lateral extension of the frame 1, overhangs the shoe 12 forwardly, to the left as seen in FIG. 3, of the guides 22 and serves to rotatably support a front roller 32 that is engageable with the upper surface of the shoe 12. Similarly, a rear roller support 33 extends laterally from the frame 1 and rotatably supports a rear roller 34 engageable with the upper surface of the shoe 12 rearwardly, to the right as seen in FIG. 3, of the guides 22. The rear roller 34 is spaced inwardly with respect to the forward roller 32. The rollers 32 and 34 serve to level and align the shoe 12 during walking as will be described.

Extending laterally from the frame 1, approximately midway between the roller supports 30, 33, is a bracket 35 which rotatably supports a horizontally disposed sheave 36. A constant pressure hydraulic cylinder 37 is mounted and operable between the frame 1 and the sheave 36 to hold the latter against rotation in either direction. A pair of bifurcated brackets 38 are mounted on and extend outwardly from the frame 1 on opposite sides of the bracket 35 and the roller supports 30, 33. A pair of horizontally disposed, double sheave blocks 39 are pivotally mounted on the brackets 38 and are pivotal in vertical planes generally transverse to the length of the frame 1. A pair of ropes 40 have their inner ends anchored to the sheave 36 at approximately diametrically opposite points and thence extend through respective sheave blocks 39 and are anchored, respectively, near the front and rear ends of the shoe 12.

The ropes 40 and their associated elements tend to keep the shoe 12 substantially parallel to the frame 1 since any tendency of the shoe 12 to rotate in a horizontal plane either clockwise or counterclockwise as seen in FIG. 3 will be resisted by the constant force exerted by the cylinder 37 on the sheave 36. The use of the double sheave blocks 39 which are pivotally mounted compensates for vertical and horizontal movement of the shoe 12 with respect to the frame 1, thus insuring aligning action regardless of the position of the shoe 12 with respect to the frame 1.

#### *The hydraulic circuit*

FIG. 11 shows, schematically, a hydraulic circuit for the lift cylinder 14 and push cylinder 23. Again, the circuit shown is only for the cylinders 14, 23 on one side of the machine, and there will be an identical arrangement for the other side of the machine.

The circuit includes five conventional electric induction motors,  $M_1$ — $M_5$ . Each of the motors  $M_1$ — $M_5$  drives two hydraulic pumps, there being ten pumps, numbered  $P_1$ — $P_{10}$ , in all. The pumps  $P_1$ — $P_{10}$  are all of the reversible, variable delivery type. As a result, they have three positions: a right position in which flow is directed upwardly as seen in FIG. 11, a left position in which flow



is directed downwardly as seen in FIG. 11, and a center position in which there is no flow through the pumps so that they act in effect as closed valves.

The circuit also includes a two position supply valve 42 which has an inlet leading to a reservoir and two outlets. A first main line 43 leads from one of the outlets of the valve 42 to the blank or piston end of the lift cylinder 14, and is controlled by a conventional valve 44. A second main line 45 leads from the other outlet of the valve 42 to the rod end of the cylinder 14 and is controlled by a valve 46. The valve 42 has a centered, closed position, a left position in which the line 45 is connected to the reservoir and a right position in which the line 43 is connected to the reservoir.

A prefill line 47 leads from the piston end of the cylinder 14 to the reservoir and is controlled by a prefill valve 48 which is in turn controlled by a minimum pressure switch 49 that is adapted to sense the pressure in the rod end of the cylinder 14. Two additional pressure switches 50 and 52 are adapted to sense the pressure in the piston end of the cylinder 14 for purposes that will be described.

The first four pumps,  $P_1$ - $P_4$ , form a set and are arranged in two groups of two, each group being connected across the lines 43 and 45. The remaining six pumps,  $P_5$ - $P_{10}$ , are connected in parallel to form a set of pumps designated generally by the reference numeral 53. The set 53 is connected to the line 43 by a line 54 and is connected to the line 45 by a line 55 which is controlled by a valve 56.

A set of three crisscross valves 57 is provided, each of which has two inlet openings and two outlet openings. The valves 57 have center, closed positions, right positions providing straight through connections and left positions providing crisscross connections. A set of three lines 58 connect the pump set 53 to one of the inlets of each valve 57. A branched line 59 connects the opposite outlet of each valve 57 to the blank or piston end of the push cylinder 23. A second branched line 60 leads from the rod end of the cylinder 23 to the other outlets of the valves 57. The other inlets of the valves 57 are connected to the reservoir by lines 62.

A pair of lines 63 are connected across the lines 45 and 59 and are controlled by a pair of valves 64. A line 65 branches from the line 59 near the piston end of the cylinder 23 to the reservoir and is controlled by a valve 66. A second line 67, controlled by a valve 68, branches from the line 59 at approximately the same point and leads to a relief valve 69. A line 70 leads from the rod end of the cylinder 23 to the reservoir and is controlled by a check valve 71 which allows flow from but not to the reservoir.

All the reservoir connections shown are of course to a single reservoir.

#### Operation

In FIG. 1, the dragline is shown in its normal working position. That is, the tub 2 is resting on the ground and the shoes 12 are raised off the ground and are in a forward position, to the left as seen in FIG. 1, with respect to the frame 1.

The first phase of a walking action involves extending the lift cylinder 14 to lower the shoe 12 directly to the ground, to the position of FIG. 5. This is accomplished by turning all of the pumps  $P_1$ - $P_{10}$  to full right position, so that they pump upwardly as seen in FIG. 11, and opening the valves 44, 46, 48 and 56. All ten pumps  $P_1$ - $P_{10}$  will then be delivering fluid under pressure through the line 43 and valve 44 to the piston end of the cylinder 14. Fluid from the rod end of the cylinder 14 will flow through the valve 46 and lines 45 and 55 to the left, lower, sides of the pumps  $P_1$ - $P_{10}$ .

Assuming all the lines to be full of fluid, there is a brief period during the lowering of the shoe 12 in which the pumps  $P_1$ - $P_{10}$  are actually pumping fluid to the piston end of the cylinder 14. Almost immediately, however, the tremendous weight of the shoe 12, approximately 600-

000 pounds in the embodiment shown, which is in effect pulling downwardly on the rod 15 causes fluid to be forced out of the rod end of the cylinder 14 and to be moved under pressure toward and into the pumps  $P_1$ - $P_{10}$ . Thus, the primary force acting to lower the shoe 12 is a gravity force.

As stated, the motors  $M_1$ - $M_5$  are induction motors and at the outset of a lowering action are operating to drive the pumps  $P_1$ - $P_{10}$ . In a very short time, however, the fluid forced into the pumps by the weight of the shoe 12 begins to take over as the driving force for the pumps  $P_1$ - $P_{10}$ , so that they are in effect being driven by the released mechanical energy of the shoe 12. This gradually reduces the load on the induction motors  $M_1$ - $M_5$  to zero and then causes the motors  $M_1$ - $M_5$  to be speeded up to and beyond synchronous speed. When the motors  $M_1$ - $M_5$  reach synchronous speed, beyond which they cannot be speeded up and still act as motors, they begin to act as generators so that further mechanical energy supplied by the dropping shoe 12 is converted to electrical energy. This energy is absorbed in the electrical system of the machine which, of course, encompasses many elements other than the propulsion system.

Converting the energy released in dropping the shoe 12 into electrical energy is quite advantageous. If this were not done, the energy would have to be released in the form of heat and would, considering the weight of the shoe 12, present an almost insurmountable heat problem. The present plan solves the heat problem, and additionally converts the released energy into usable electrical energy.

Since the volume of the space in the rod end of the cylinder 14 is less than that in the cylinder end due to the space taken up by the rod 15, the amount of fluid expelled from the rod end of the cylinder 14 will not be sufficient to fill the piston end of the cylinder 14 for any given length of travel. For this reason, the line 47 and valve 48 are opened and additional fluid in the necessary amount is supplied from the reservoir to prevent drawing a vacuum.

Lowering of the shoe 12 continues until it is resting on the ground. When the shoe 12 is on the ground, there will be very low or zero pressure in the rod end of the cylinder 14. This condition is sensed by the pressure switch 49, which is set to close at a selected pressure in the range of about 0 to 500 p.s.i. Closing of the switch 49 causes the valve 48 to be closed. The pumps  $P_1$ - $P_{10}$  remain in full right position to be ready for the next phase of the walking action, raising the machine.

Raising of the machine involves a further extension of the cylinder 14. Since the shoe 12 is on the ground, such further extension will cause the frame 1 to be raised. Raising is accomplished by moving the valve 42 to its left position wherein the line 45 is connected to the reservoir. The pumps  $P_1$ - $P_{10}$ , which remained in full right position at the conclusion of the shoe lowering phase, continue to pump upwardly, and the valves 44, 46, and 56 remain open. Thus, fluid under pressure is forced by all ten pumps  $P_1$ - $P_{10}$  through the line 43 into the piston end of the cylinder 14 resulting in further extension of the rod 15 until the machine reaches the position of FIG. 6. The cylinders 14 are located forwardly, to the left as seen in FIG. 6, of the center of gravity of the machine so that this lifting will cause the machine to be tilted to raise its forward or left hand edge off the ground while its rear or right hand edge remains on the ground. The ball and socket connection between the shoe 12 and frame 1 allows such tilting.

During raising of the machine, fluid for the pumps  $P_1$ - $P_{10}$  is supplied from the reservoir through the line 45. In addition, there will be fluid supplied from the rod end of the cylinder 14.

It is during the raising of the machine that the freedom of movement afforded by the universal ball and socket connection becomes important. Any ground irregularities or differences in elevation will tend to cause the shoe 12

to twist as the frame 1 is raised. The ball and socket connection gives the shoe 12 freedom of movement in three degrees, however, so that such twisting is not transmitted to the frame 1. Although other universal connections could be used, the ball and socket arrangement is advantageous in that it provides the required freedom while still allowing for sufficient mechanical strength and bearing area. It is also important to note that the push cylinder 23 is connected below the ball and socket connection. It is thus free to move in all planes with the shoe 12 without necessitating the provision of universal connections for its ends.

Raising of the machine continues until the machine has been raised to a desired height and until it is fully supported by the shoe 12 and cylinder 14. The fact that the machine is being supported is reflected in terms of pressure in the piston end of the cylinder 14, and the required pressure is sensed by the pressure switch 50, which is set to operate at a preselected pressure of about 1700 p.s.i. Requiring a certain pressure to be developed before the next step of walking is accomplished ensures against the possibility of the machine being moved when, for example, one shoe 12 is in soft ground and is not supporting the machine. To ensure that the machine has been raised far enough to clear ground obstructions or the hole created by settling of the tub 2, a limit switch (not shown) is provided, which is closed only when the rod 15 has been extended a preselected distance. When both the switch 50 and the limit switch have closed, the valves 44, 46 and 56 are closed and the pumps  $P_1-P_{10}$  are returned to center position.

After the machine has been raised to the position of FIG. 6, the push cylinder 23 is extended and serves in effect to propel the frame 1 to the left or forwardly with respect to the shoe 12 to the position of FIG. 7. Since the valves 44 and 46 are closed, the cylinder 14 remains in its extended position. To accomplish propelling, the valve 42 is shifted to its right position connecting the line 43 with the reservoir. The valves 64 are opened, and the valves 57 are shifted to their right positions connecting the line 60 to the lines 62 and the lines 58 to the line 59. The pumps  $P_1-P_{10}$  are moved to full left position wherein they are pumping downwardly as seen in FIG. 3. All ten pumps,  $P_1-P_{10}$  are then delivering fluid under pressure to the line 59 and into the piston end of the cylinder 23. Fluid for the pumps  $P_1-P_{10}$  is supplied from the reservoir through the valve 42 and line 43. Fluid forced out of the rod end of the cylinder 23 passes through the line 60, the valves 57 and the lines 62 into the reservoir. A limit switch (not shown) senses full extension of the cylinder 23 and returns the pumps  $P_1-P_{10}$  to center and closes the valves 42, 57 and 64.

After the machine has been moved to the position of FIG. 7, it is lowered to the ground to the position of FIG. 8. During lowering, and since the valves 57 have been closed, the cylinder 23 is left in its extended position. To accomplish lowering, the pumps  $P_1-P_{10}$  are placed in full left positions, the valve 42 is shifted to its left position connecting the line 45 to the reservoir, and the valves 44, 46 and 56 are opened. As in the case of lowering the shoes 12, the tremendous weight of the frame 1 will cause it to move downwardly without any substantial pumping being required. Fluid thus forced out of the piston end of the cylinder 14 will be directed to the top or right side of the pumps  $P_1-P_{10}$  through the lines 43 and 54, again resulting in the generation of electrical energy thus absorbing the released mechanical energy of the lowering machine. After passing through the pumps  $P_1-P_{10}$ , the bulk of the fluid will be directed through the line 45 and valve 42 into the reservoir. As much as may be required will, however, pass through the valve 46 and into the rod end of the cylinder 14. The fact that the machine is resting on the ground is sensed by the pressure switch 52 which is a minimum pressure switch set to close at an appropriate low pressure. When the switch 52 closes, the pumps  $P_1-$

$P_{10}$  are returned to center, and the valves 42, 44 and 56 are closed.

When the machine has reached the position of FIG. 8, a walking step has practically been completed, and it remains only to move the shoe 12 back to the position of FIG. 1. This is, however, advantageously accomplished in two separate steps. First, the shoe 12 is raised slightly to the position of FIG. 9 wherein its forward edge is off the ground while its rear edge remains on the ground. This insures against the shoe 12 being moved forwardly before it has cleared the ground. Raising the shoe 12 to this intermediate position is accomplished by opening the valve 48 and shifting the valve 42 back to its right position connecting the line 43 to the reservoir. The valve 46 has remained open. The first four pumps  $P_1-P_4$  are moved to full left, but the set 53 of six pumps  $P_5-P_{10}$  is inoperative. Fluid under pressure is then directed downwardly through the four left hand pumps,  $P_1-P_4$ , through the line 45 and valve 46 to the rod end of the cylinder 14 causing it to be retracted to lift the shoe 12 upwardly. Fluid forced out of the piston end of the cylinders 14 passes through the valve 48 and into the reservoir. Fluid for the pumps  $P_1-P_4$  is supplied from the reservoir through the valve 42 and line 43. The fact that the shoe 12 has been raised to its intermediate position is sensed by an intermediate limit switch (not shown).

When the shoe 12 has been raised to the position of FIG. 9, it is then simultaneously raised and moved to the left through the position of FIG. 10 back to the position of FIG. 1. This is accomplished by additionally moving the pump set 53 to full left and shifting the valves 57 to their left positions establishing connections between the lines 58 and lines 60 and the lines 62 and line 59. Also, the valve 66 is opened. In this position of the control circuit, the four left hand pumps  $P_1-P_4$  continue to deliver fluid as before to the rod end of the cylinder 14 thus causing the shoe 12 to be raised further. The set 53 of six pumps  $P_5-P_{10}$  causes fluid to be pumped downwardly through the lines 58 through the valves 57 to the line 60 and into the rod end of the cylinder 23 causing it to be retracted to slide the shoes 12 to the left from the position of FIG. 9 through the position of FIG. 10 back to the position of FIG. 1. The fluid for the pumps  $P_5-P_{10}$  is also supplied from the reservoir through the valve 42 and line 43. In addition, the check valve 71 allows fluid to flow directly from the reservoir to the rod end of the cylinder 23 to avoid drawing a vacuum. Fluid expelled from the piston end of the cylinder 23 passes through the line 59 and 65 and valve 66 into the reservoir.

After the completion of a walking step, with the various elements of the machine back to the position of FIG. 1, all of the valves are closed with the exception of the valve 71, which is always open to allow flow from the reservoir, and the valve 68 which is opened. The valve 68 and relief valve 69 serve as a cushion for releasing the kinetic energy of the shoe 12 if a walking cycle is completed while the machine is going downhill, in which case there would be a tendency for the shoe 12 to keep moving. The pressure developed in the piston end of the cylinder 23 as the result of such movement is relieved through the valves 68 and 69, the valve 69 being set to provide deceleration to zero within an inch or two of movement. The valve 71 admits fluid to prevent drawing a vacuum in the rod end of the cylinder 23 during such movement.

If walking is to continue, the valve 68 is then closed and the entire cycle is repeated. If, however, the machine is to be worked, the elements remain in the position of FIG. 1. To guard against movement of the shoe 12 during working as the result of leakage, an auxiliary, pressure-compensated pump (not shown) of any suitable type can be connected to the rod ends of the cylinders 14 and 23 to maintain a holding pressure. If desired, the same pump could be used to operate the cylinder 37. During working, it is best to have the push cylinder 23 fully re-

tracted or bottomed. To accomplish this, the valve 68 can be closed after a suitable time delay allowing for deceleration, and the valve 66 opened. The auxiliary pump will then be able to move the cylinder 23 gradually to fully retracted position.

The rollers 32 and 34 contact the upper surface of the shoe 12 to align it in a vertical plane generally parallel to its direction of movement. When the shoe 12 is moved from the position of FIG. 8 back to the position of FIG. 1, and because its center of gravity in the position of FIG. 8 is to the rear of the lift cylinder 14, it first moves through the position of FIG. 9 to the tilted position of FIG. 10 where its forward end contacts the roller 32. Further movement causes the shoe 12 to pivot about its ball and socket connection to the cylinder 14 to the point where its rear end contacts the roller 34.

During the first phase of movement after initial contact with the roller 32, the rear edge of the shoe is being dragged along the ground. To prevent the shoe from being tilted about its longitudinal axis during this phase, the roller 32 is placed approximately on the longitudinal centerline of the shoe 12 where it is in alignment with the center of gravity of the shoe 12, which is also on the centerline. The roller 34 is spaced inwardly from the roller 32 so that when the shoe 12 is in the position of FIG. 1 it is held in a predetermined position of alignment against rotation about its longitudinal axis. Since the roller 32 is on the centerline of the shoe 12 and in alignment with its center of gravity, however, it would be possible for the shoe 12 to rock slightly in a clockwise direction as seen in FIG. 4 during working. To guard against this, the roller 34 is preferably set slightly lower than the roller 32 to cause slight clockwise tilting of the shoe 12. When it is slightly out of equilibrium in this fashion, the shoe 12 tends to rotate in a counterclockwise direction and is thus held tight against the roller 34.

The ropes 40 and their associated elements serve to align the shoe 12 so that it is moved into a position parallel to the frame 1 as it is being raised and moved in preparation for a succeeding walking step. This function is aided by the tapered guides 22. The ropes 40 are primarily operable when the shoe 12 is being moved in preparation for another step and are not of sufficient strength to align the shoe 12 as the machine is being moved. That is, any ground irregularities which would tend to cause the shoe 12 to be twisted as the machine is being walked generate forces far greater than those which the cylinder 37 is capable of absorbing so that it will simply be overridden.

The rollers 32 and 34, ropes 40 and tapered guides 22 thus provide relatively simple means for aligning and leveling the shoe 12 in all planes, to insure that the shoe 12 will be properly aligned for succeeding steps.

Having the pumps  $P_1-P_{10}$  divisible into two sets, the set 53 and the set of four pumps  $P_1-P_4$ , is very advantageous in that it allows all ten pumps to be used for raising and propelling the frame 1, when the load is greatest, and when the energy released as a result of lowering the frame 1 or the shoe 12 is to be absorbed. The pumps are broken into the two sets for raising and moving the shoe 12, however, since the load is then less and so that these steps can be effected simultaneously with a considerable saving of time.

Ten pumps  $P_1-P_{10}$  and various multiple connecting lines and valves have been shown herein, but this is necessary only as a result of the tremendous size of the machine and the capacities of commercially feasible pumps and valves. That is, for a smaller machine, or with larger pumps and valves for the same size machine, the number of pumps could be reduced to two, one of the group  $P_1-P_4$  and one of the group  $P_5-P_{10}$ . More pumps could of course be used if necessary or desired. Further, the line connections and valving arrangement could be varied. Non-reversible pumps could be used with appropriate additional valves and lines.

In essence, to effect the desired walking action, it is necessary only that there be two sets of pumps, comprising at least one pump each. There must also be a line or lines, the lines 43 and 54 in the embodiment shown, connecting both sets to the upper end of lift cylinder 14, which could be either the rod or piston end by a simple reversal of parts, to provide for lifting. Further, there must be a line or lines connecting both sets of pumps to one end of the push cylinder 23, which can be either the rod or piston end depending on the arrangement of parts, to effect a propelling of the frame 1. In the embodiment shown, the lines 58 and 59 connect the pump set 53 to the piston end of the cylinder 23, while the lines 63 lead from the connections of the pumps  $P_1-P_4$  to the line 45 to the line 59 to connect these pumps to the piston end of the cylinder 23. Finally, there must be a line or lines connecting one set of pumps to the bottom end of the lift cylinder 14, the set  $P_1-P_4$  and line 45 herein, and a line or lines, the lines 58 and 60 herein, connecting the other set of pumps, the set 53 herein, to the other end of the push cylinder 23. To have means for all ten pumps to receive fluid ejected as a result of the dropping of the shoe 12 or frame 1, there must also be a line or lines, the line 55 herein, connecting the other set of pumps, 53, to the bottom end of the cylinder 14.

To have the energy absorbing action, and using reversible pumps, there should be lines leading from both ends of the cylinder 14, the lines 43 and 45, herein. Also, one set of pumps,  $P_1-P_4$  herein, should be connectable across these lines, and the other set of pumps 53, should also be connectable across the lines, which is accomplished herein by the lines 54 and 55 and the valve 56. Further, there should be an alternate connecting line or lines, the lines 58 herein, leading from the one pump set, the set 53 herein. There should also be lines, 59 and 60 herein, leading from both ends of the push cylinder 23 and a line or lines, 63 herein, effecting a connection between the first pump set and one of the lines, 59 herein, to the cylinder 23. Finally, there should be means, the valves 57 herein, to effect a connection between the alternate connecting line or lines from the second pump set and both lines leading from the push cylinder 23.

It will be appreciated that certain portions of the propulsion system have been omitted or shown somewhat schematically for the sake of clarity and simplicity. Thus, for example, a suitable electrical circuit will have to be provided for operation of the machine including means such as solenoids to operate the various valves. Various electrical and hydraulic safeguards might be added. It will of course be advisable to interlock the circuits for the two sides of the machine to insure companion operation. Such interlocking would insure, for example, that both shoes 12 are lowered before the machine is raised and that both are extended and serving to support the machine before it is moved forwardly. Those skilled in the art will, however, be fully able to understand and practice the invention in accordance with the disclosure herein.

Further, although a preferred embodiment of the invention has been shown and described herein, it will be obvious that modifications might be made without departure from the invention. The invention is not intended, therefore, to be limited by the showing herein, or in any other manner, except insofar as limitations appear specifically in the following claims.

We claim:

1. In stepping-type propulsion means for an excavator having a frame, the combination comprising: a vertical hydraulic lift cylinder mounted on the frame; a slide; a universal connection between the slide and the lift cylinder; a shoe; a slideway on the shoe that receives the slide, the shoe thus being mounted for vertical movement with respect to the frame in response to the lift cylinder and for horizontal movement with respect to the frame; a horizontal hydraulic push cylinder connected and operable between the shoe and the slide to effect horizontal

movement of the shoe with respect to the frame; and a pair of rollers supported from the frame that are engageable with the upper surface of the shoe at laterally and longitudinally spaced points to align the shoe with respect to the frame in vertical planes parallel and transverse to the length of the shoe.

2. Propulsion means according to claim 1, including a plurality of pumps divided into two sets of at least one each, connections between the pumps and the lift and push cylinders, and a control circuit to establish a cycle of operation having at least three phases, in one of which all of the pumps drive the lift cylinder in one direction, in another of which all of the pumps drive the push cylinder in one direction, and in the other of which one set of pumps drives the lift cylinder in the other direction while the other set of pumps drives the push cylinder in the other direction.

3. In stepping-type propulsion means for an excavator having a frame, the combination comprising: a vertical hydraulic lift cylinder mounted on the frame; a slide; a universal connection between the slide and the lift cylinder; a shoe; a slideway on the shoe that receives the slide, the shoe thus being mounted for vertical movement with respect to the frame in response to the lift cylinder and for horizontal movement with respect to the frame; a horizontal hydraulic push cylinder connected and operable between the shoe and the slide to effect horizontal movement of the shoe with respect to the frame; a rotatable sheave supported from the frame near the lift cylinder; means to exert a constant force resisting rotation of said sheave in either direction; and a pair of rope means anchored to said sheave and to opposite ends of the shoe, the shoe thereby being urged toward parallel relationship with the frame.

4. Propulsion means according to claim 3 wherein the universal connection is a ball and socket connection and the push cylinder is connected to the slide below the ball and socket connection, the shoe and push cylinder thus having limited freedom of movement with respect to the frame in three planes; and including a pair of rollers supported from the frame that are engageable with the upper surface of the shoe at laterally and longitudinally spaced points to align the shoe with respect to the frame in vertical planes parallel and transverse to the length of the shoe.

5. An operating and control circuit for stepping-type propulsion means for an excavator having a frame, said propulsion means including a shoe, a hydraulic lift cylinder to effect relative vertical movement between the shoe and the frame, and a hydraulic push cylinder to effect relative horizontal movement between the shoe and the frame, said circuit including: a plurality of pumps divided into two sets of at least one each; and connections between the pumps and cylinders whereby all of the pumps can be connected to drive one cylinder in one direction, and all of the pumps can be connected to drive the other cylinder in one direction, and one set can be connected to drive one cylinder in its other direction while the other set is connected to drive the other cylinder in its other direction.

6. A circuit according to claim 5 wherein the connections include means to connect both sets of pumps to the top end of the lift cylinder, means to connect both sets of pumps to one end of the push cylinder, and means to effect a simultaneous connection between one set of pumps and the bottom end of the lift cylinder and the other set of pumps and the other end of the push cylinder.

7. A circuit according to claim 5 wherein the pumps are reversible and including: a first main line leading from the upper end of the lift cylinder; a second main line leading from the lower end of the lift cylinder, both sets of pumps being connectable across the main lines; a line leading from one end of the push cylinder; a line leading from the other end of the push cylinder; means to connect one set of pumps to the line from one end of the push cylinder; and means to connect the other set of pumps alternatively to both lines leading from the push cylinder.

8. A circuit according to claim 7 wherein there is a cycle of operation in which the lift cylinder is first partially extended to lower the shoe to the ground, the lift cylinder is then further extended to raise the frame, the push cylinder is then extended to move the frame forwardly with respect to the shoe, the lift cylinder is then partially retracted to lower the frame to the ground, the lift cylinder is then further partially retracted to raise the shoe at least partially from the ground, and the lift cylinder is then further retracted to raise the shoe completely off the ground while the push cylinder is simultaneously retracted to move the shoe forwardly with respect to the frame.

9. A circuit according to claim 8 wherein fluid is expelled from the ends of the lift cylinder by the weight, respectively, of the shoe and frame as they are lowered, and the pumps are driven by electric induction motors, and the fluid thus expelled passes through the pumps and raises the speed of the motors to the point where they act as generators.

10. In a stepping-type excavator having a central tub adapted to rest on the ground, a revolving frame on the tub, and a single pair of shoes on opposite sides of the tub, and a single pair of shoes on opposite sides of the excavator which are adapted to be moved horizontally and vertically with respect to the frame and tub to effect a stepping-type propulsion of the excavator, the combination therewith of: a single pair of vertical hydraulic lift cylinders mounted on the frame above respective shoes, each lift cylinder having an extensible and retractable lower end facing downwardly toward the associated shoe; a longitudinally extending slideway on each shoe; a slide received in each slideway and facing the lower end of the associated lift cylinder, the engagement of the slides in the slideways providing for simultaneous vertical movement of the slides and shoes while allowing relative horizontal movement therebetween; a pair of horizontal hydraulic push cylinders, one connected between each shoe and its associated slide to effect relative horizontal movement thereof; and ball and socket connections between the lower end of each lift cylinder and the associated slide above the connection of the slide to the push cylinder, the ball and socket connections constituting substantially the only connections between the shoes and the frame.

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