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CONTINUOUS LOW SPEED ROTARY MECHANISM

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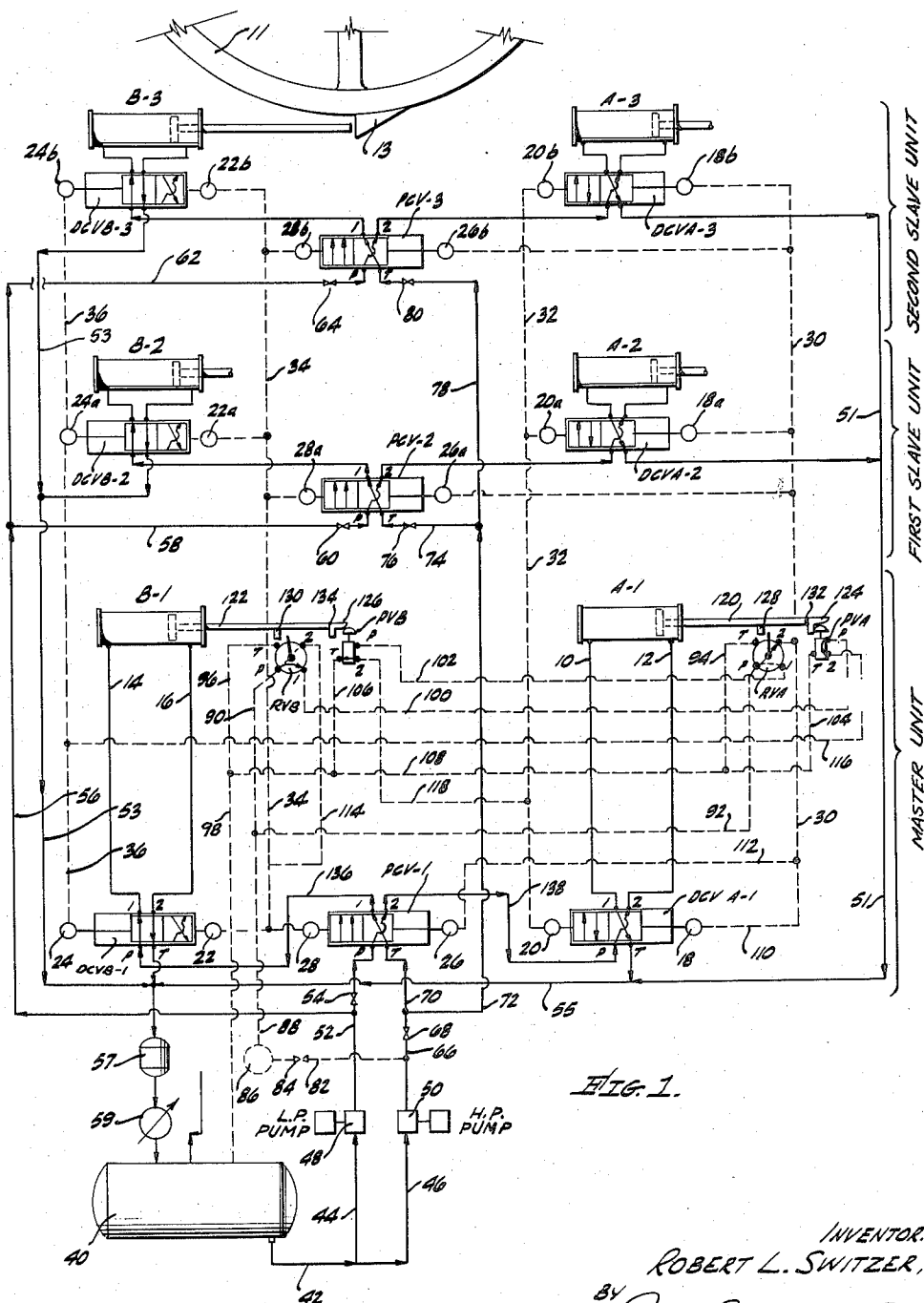


FIG. 1.

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CONTINUOUS LOW SPEED ROTARY MECHANISM

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This invention relates to rotating driving mechanisms of the high torque low speed variety, and particularly relates to a hydraulically driven, automatic, continuously rotating driving mechanism for turning mechanical devices at low rotary velocities while delivering power thereto at very high torque values.

Driving mechanisms for mechanical equipment which is to be turned at relatively low rotary velocities customarily consist of a relatively high speed prime mover, such as an internal combustion engine or an electric motor, coupled to the rotary load through a gear reduction system. With suitable gear reducers, ultimate rotary velocities in the very low range of from about 0.1 to about 100 revolutions per hour may be obtained. The gear reduction units however, besides being precision machinery and therefore relatively expensive, are quite heavy for the amount of power they deliver. Furthermore they require continuous lubrication, heat dissipation, they are bulky, and cannot be readily connected and disconnected from the load.

There are many well known applications for such equipment to deliver power at high torque values into a load which is turned at low rotary velocities such as in large diameter settlers and thickeners, in mixers and kilns, rotary casting tables, etc. One specific application is in the upflow shale retorting process and apparatus in which a vertically reciprocating piston feeder is supplied with crushed oil shale and feeds it upwardly as a dense mass through a perforated disengaging zone in which fluids are withdrawn from the rising mass, and then through a heat treating zone in which the shale oil and gas are produced from the solids. The upper portion of the moving solids bed is agitated by means of plows extending down into the top of the heat treating zone in order to facilitate burning of the spent shale with air to provide heat for the process. This plowing action also prevents the formation of clinkers in the burning zone caused by incipient or partial fusion of the burning solid material. In commercial scale apparatus the plows are rotated at velocities on the order of 0.25 to 10 revolutions per hour and the torque required is on the order of 20 million foot pounds. In this specific application and in many others, intermittent rotation of the plows is intolerable because of the upward motion of the shale and fatigue failures caused thereby in the plows. Thus continuous rotation is essential.

The present invention is directed to an improved driving mechanism which will generate a continuous rotary motion and deliver power at very high torque values and at very low rotary velocities without the use of the customary high speed prime mover and the expensive and bulky gear reduction equipment usually used.

It is accordingly a primary object of this invention to provide an improved driving mechanism which delivers power continuously at very low rotary velocities and at very high torque loadings.

It is a specific object of this invention to provide a

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hydraulically actuated mechanism for turning a relatively large diameter wheel continuously without the use of a gear reducer at rotary velocities of the order of 0.1 to 100 revolutions per hour.

It is another specific object of this invention to provide in the upflow shale retorting process an improved hydraulic driving mechanism for continuously rotating the plows employed to agitate the spent shale near the top of the equipment as it is burned to provide heat in the process.

Other objects and advantages of the present invention will become apparent to those skilled in the art as the description and illustration thereof proceed.

Briefly, the present invention comprises a hydraulically operated automatic system for generating power and supplying it to a load at high torque values and very low rotary velocities without the use of expensive precision-built reduction gears. The system employs a plurality of longitudinally acting force applying means, such as hydraulic driving cylinders or solenoids, arranged in a circle at the periphery of a driving ring and each adapted to act tangentially and intermittently against a surface of the ring so as to turn it. The force means are provided in at least two separate automatically operated sets which are actuated in a sequence so as to apply a continuous high torque low rotary velocity turning moment to the ring. In the specific application mentioned previously, namely shale retorting, the driving ring is disposed horizontally at the top of the shale kiln and has attached plows extending downwardly into the rising mass of shale. The hydraulic driving cylinders acting against the ring cause it to turn continuously at rotary velocities on the order of 1 to 10 revolutions per hour so as to permit uniform burning of the carbonaceous residue on the spent shale. The torque requirements in this service are of the order of between about 1 and about 50 million foot pounds depending on the size of the shale retort, although higher or lower torque values may be maintained by suitable modification of the hydraulic system hereinafter more clearly described.

The driving system of the present invention obtains a controlled steady rotary motion of the driving ring by operating the first set of the hydraulic driving or power cylinders so as to apply a force at the periphery of the driving ring while the second set of driving cylinders is being retracted, followed by a waiting period until near the end of the power stroke for the first set of cylinders, followed by a brief re-engagement of the second set with the ring just prior to the end of the power stroke of the first set, followed by an immediate commencement of a power stroke by the second set when the power stroke on the first set of cylinders has ended. Thus at the end of the power stroke for a given set of driving cylinders, the other set of driving cylinders has been actuated so that their push rods are already moved into engagement with the driving ring and ready for the application of force thereby so that the force application to the driving ring periphery is continuous.

In the present invention the load may be any low velocity load connected to the driving ring in any manner suitable to the specific installation. The ring is provided with a ratchet-like surface against which the hydraulic cylinder push rods act tangentially. As stated, the push rods are first pre-engaged with the ring at a very low power level. Following this the power is applied through these engaged push rods at the instant the other set of hydraulic cylinders have reached the end of their power stroke. The mechanical detail of the ring structure and the type of the load and the manner in which the load is attached to the ring can be very wide depending on the nature of the load. For the purpose of the present

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invention, any ring structure against which a plurality of hydraulic power cylinders can act is sufficient.

The present invention will be more readily understood by reference to the accompanying drawings showing schematic diagrams of two modifications of the hydraulic driving and control system of this invention. Figure 1 shows 6 power cylinders actuated alternately in two sets of 3 and Figure 2 shows 12 power cylinders actuated in sequence in sets of 8 to provide continuous rotary motion to the ring. Each cylinder passes through a sequence of operations including power delivery, push rod retraction, a delay, and re-engagement at low power level with the driving ring. It should be understood that in the accompanying illustrations the plurality of 6 or 12 power cylinders is illustrative only because any number of one or more in each set or bank can be employed. It should also be understood that in the drawing the power cylinders indicated A-1, A-2, A-3, B-1, B-2, B-3 etc. are actually disposed around the periphery of the driving ring so that their push rods may extend and engage the driving ring and act against a dog or the like on the ring in a tangential direction. The driving ring 11 and dog 13 are indicated in Figure 1 with respect to power cylinder B-3. The disposition of the power cylinders on the drawings therefore is purely schematic for the purposes of clarity of illustration. In Figure 1 it should be noted that the hydraulic power and control system is divided into several units including a master unit consisting of power cylinders A-1 and B-1 and the associated pilot valves and control valves, and two slave units consisting of power cylinders A-2 and B-2 and power cylinders A-3 and B-3, with their associated control valves. Obviously a fewer or a greater number of slave units may be employed as necessary for they are, if used, actuated by the pilot valves included within the master unit. In Figure 2 a slight modification is shown including only a master unit having a plurality of power cylinders connected in parallel in each bank. Finally, in both drawings the major hydraulic flow conduits are indicated as solid lines, while the instrumentation control or pilot fluid conduits are shown as broken lines for sake of clarity.

Arrangement of system, Figure 1

Referring now more particularly to Figure 1, the master unit of the apparatus consists of hydraulic power cylinders A-1 and B-1, a first and second signal means consisting of plunger valves PVA and PVB, and rotary pilot valves RVA and RVB, associated with the power cylinders. Power cylinder A-1 receives and vents hydraulic fluid through its 4-way directional control valve DCVA-1 by means of lines 10 and 12. The directional control valve controls the direction of movement, i. e., either extension or retraction, of the power cylinders. Hydraulic power cylinder B-1 receives and vents hydraulic fluid through its 4-way directional control valve DCVB-1 through lines 14 and 16. The 4-way control valves DCVA-1 and DCVB-1 are actuated at the appropriate time by means of hydraulic operators 18, 20, 22, and 24 connected thereto. These hydraulic actuators are in turn activated by pilot pressure supplied thereto through a hydraulic line indicated as broken lines on the drawing.

In the master unit hydraulic power cylinders A-1 and B-1 are provided with a pressure control valve PCV-1 which is also a 4-way control valve similar to the 4-way control valves DCVA-1 and DCVB-1. The pressure control valve PCV-1 is hydraulically operated by means of hydraulic operators 26 and 28 connected thereto and its function is to control the supply high pressure hydraulic oil to either hydraulic power cylinder A-1 or B-1 for the power stroke while at the same time controlling a supply of low pressure hydraulic oil to the other of the two so as to accomplish the retraction and pre-engagement of the push rod of the latter cylinder.

With this brief preliminary discussion of the major

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equipment in the master unit, it will be noted that the first slave unit is also provided with two power cylinders A-2 and B-2, with two 4-way directional control valves DCVA-2 and DCVB-2 which are actuated by hydraulic operators 18a and 20a, 22a and 24a respectively, and with a pressure control valve PCV-2 which similarly is actuated by hydraulic operators 26a and 28a.

In an analogous fashion the second slave unit is provided with two power cylinders A-3 and B-3, with two 4-way directional control valves DCVA-3 and DCVB-3 which are actuated by hydraulic operators 18b, 20b, 22b, and 24b, and with a pressure control valve PCV-3 actuated by hydraulic operators 26b and 28b.

It should be noted at this point that because the slave units are actuated by and simultaneous with the master unit, the hydraulic operators 18, 20, 22, 24, 26, and 28 in the master unit are connected in parallel with their counterparts in the slave units by means of the hydraulic control lines indicated on the drawing as broken lines. Specifically, all the hydraulic operators 18 (18, 18a, and 18b) are connected together by means of hydraulic line 30, which also interconnects all hydraulic operators 26, all operators 20 are connected together by means of line 32, all hydraulic operators 22 are connected together by means of line 34 which also connects all hydraulic operators 28, and all operators 24 are interconnected by line 36. The supply of pilot pressure through the control lines to actuate these hydraulic operators so as to actuate the 4-way directional control valves DCVA and DCVB and the pressure control valves PCV is through the rotary pilot valves RVA and RVB and the plunger valves PVA and PVB in the master unit. In this way all of the corresponding pressure control valves PCV operate simultaneously, the 4-way directional control valves DCVA operate simultaneously, and the 4-way directional control valves DCVB operate simultaneously in the master and slave units. Because of the foregoing all of the power cylinders in the A set operate simultaneously and in alternation with all the hydraulic power cylinders in the B set so as to provide a continuous application of force to the driving ring, not shown, so as to maintain the high torque low velocity rotation thereof.

Hydraulic fluid reservoir 40 is provided from which hydraulic fluid is pumped and to which it is returned. Outlet line 42 opens into lines 44 and 46 and into low pressure pump 48 and high pressure pump 50 respectively. The low pressure pump 48 is preferably a constant pressure variable volume pump so that the low pressure hydraulic fluid, used in the system for retraction of the power cylinders and for pre-engagement thereof with the driving ring, is provided at a fixed pressure and at a volume as needed. Hydraulic fluid returns from the power cylinders via lines 51 and 53 to low pressure manifold 55 and therefrom through filter 57 and cooler 59 to reservoir 40. Preferably high pressure pump 50 is a constant volume variable pressure pump so that the high pressure fluid supplied to the driving cylinder is provided at a constant volume to maintain uniform driving cylinder movement and at a variable pressure as needed to move the load at the rotary velocity required.

A constant pressure variable volume pump as preferred for low pressure pump 48 is a pump such as a centrifugal pump, a vane pump with a pressure control or relief valve, or the like. The constant volume variable pressure pump preferred for high pressure pump 50 is one such as a piston pump. The operating speed of the rotary mechanism is controlled by the high pressure oil supply rate. Decreases in the high pressure oil rate results in a proportional decrease in the speed of the rotary mechanism.

Low pressure hydraulic fluid is pumped by means of pump 48 through line 52 at a rate controlled by valve 54 into pressure control valve PCV-1 at port P. Simultaneously low pressure fluid is delivered through lines 56 and 58 at a rate controlled by valve 60 to pressure

control valve PCV-2 at port P in the first slave unit, and by means of line 62 at a rate controlled by valve 64 to pressure control valve PCV-3 at port P in the second slave unit.

High pressure oil for operating the driving cylinders during the power stroke is pumped by means of high pressure pump 50 through line 66 at a rate controlled by valve 68 or by the pump 50 and on through line 70 to pressure control valve PCV-1 at port T in the master unit. High pressure oil also passes through lines 72 and 74 provided with block valve 76 to pressure control valve PCV-2 at port T in the first slave unit, and also through line 78 provided with block valve 80 to pressure control valve PCV-3 at port T in the second slave unit. The high pressure oil flow rate is determined by pump 50 and valve 68, and they control the rate of load rotation. By means of block valves 76 and 80, any one or all of the slave units may be deactivated thereby reducing the torque and increasing the velocity of rotation.

The source of pilot pressure or the pilot flow of hydraulic fluid is the outlet of high pressure pump 50. From this outlet pilot fluid manifold 82 opens provided with control pressure reducing valve 84. This line is provided with accumulator 86. From accumulator 86 pilot fluid manifold 88 communicates with port P on rotary pilot valve RVB through line 90 and with port P on rotary pilot valve RVA through line 92. Each of these rotary pilot valves RVA and RVB is connected at port T through lines 94 and 96 respectively with fluid return manifold 98 which opens into hydraulic fluid reservoir 40, to vent ports 1 or 2 when pressure goes from port P to ports 2 or 1 respectively. The rotary pilot valve RVB is connected at port 1 through line 100 to port P of plunger valve PVA. Rotary pilot valve RVA is connected at port 1 through line 102 with plunger valve PVB at port P. The ports T of both plunger valves PVA and PVB are connected through lines 104 and 106 through manifolds 108 and 98 to vent hydraulic fluid back to reservoir 40. Rotary pilot valve RVA is connected at port 2 by means of line 30 and line 110 with hydraulic operator 18 and by means of line 112 with hydraulic operator 26 so as to move 4-way directional control valve DCVA-1 and pressure control valve PCV-1 to the left when rotary pilot valve RVA is internally connected between ports P and 2. Rotary pilot valve RVB is connected at port 2 through line 114 and to line 34 and thereby to hydraulic actuator 22 to move 4-way control valve DCVB-1 to the left, and the hydraulic actuator 28, to move pressure control valve PCV-1 to the right when rotary pilot valve RVB is internally connected between ports P and 2.

Plunger valve PVA is connected at port 2 through line 116 to line 36 and therethrough to hydraulic actuator 24 so as to move 4-way control valve DCVB-1 to the right when rotary pilot valve RVB is internally connected between ports P and 1 and plunger valve PVA is internally connected through ports P and 2. Plunger valve PVB is connected at port 2 through line 118 to line 32 and therethrough to hydraulic actuator 20 so as to move 4-way control valve DCVA-1 to the right when rotary pilot valve RVA is connected between its ports P and 1 and plunger valve PVB is interconnected between its ports P and 2.

The above description of the rotary pilot and plunger valve positions and their connections to the hydraulic operators to effect the specific movements of the 4-way control valves DCVA-1 and DCVB-1 and pressure control valve PCV-1 in the master unit also applies to the motions and positions of the 4-way control valves DCVA and DCVB and the pressure control valves PCV and the first and second and any other slave units which may be employed.

Rotary pilot valves RVA and RVB and plunger valves PVA and PVB are signal means which signal the location of the push rod within its restricted path of move-

ment. They are operated by physical contact with a part of or an element integrally rigidly connected to the push rods 120 and 122 of hydraulic power cylinders A-1 and A-2. These push rods are provided with kickers 124 and 126 which serve to depress plunger valves PVA and PVB a few seconds before the end of the power stroke thereby disconnecting ports T and 2 and connecting ports P and 2 of plunger valves PVA and PVB. Kickers 128 and 130 are also provided on push rods 120 and 122 respectively and serve to actuate rotary pilot valves RVA and RVB at the end of the power stroke of power cylinders A-1 and B-1 respectively after plunger valves PVA and PVB have been actuated. Kickers 124 and 126 in addition to actuating plunger valves PVA and PVB respectively near the end of the power stroke, also are provided with projections 132 and 134 respectively which actuate rotary pilot valves RVA and RVB during the return or retraction stroke of push rods 120 and 122 respectively. In so doing they disconnect ports P and 2 of either rotary pilot valve RVA or RVB and connect ports P and 1 therein.

Because of the foregoing connections between the rotary and plunger pilot valves and the relative physical position of kickers 128, 130, 132, and 134 on the push rods, the plunger valve PVA or PVB is first depressed a few seconds prior to the end of the power stroke of its associated hydraulic drive cylinder causing the other power cylinder to be re-engaged at low force level with the driving ring. After the plunger valve has been actuated and at the end of the stroke when the rotary pilot valve is actuated, pressure control valve PCV-1 is immediately actuated which applies low pressure oil to retract the power cylinder which has just completed the power stroke and to supply high pressure hydraulic fluid to the other power cylinder which has just completed the re-engagement stroke to begin immediately its power stroke at a high force level. The sequence then begins over again with the reverse cylinders of each set and is maintained continuously to supply constant force tangentially to the driving ring so as to maintain continuous low speed rotary motion.

Operation of system, Figure 1

Figure 1 shows the master unit of the hydraulic driving system of the present invention with its plunger valves PVA and PVB, its rotary pilot valves RVA and RVB, its 4-way directional control valves DCVA-1 and DCVB-1, and its pressure control valve PCV-1, and the corresponding elements in the slave units, in the positions they occupy during the power stroke of the B set of power cylinders and just after the termination of the power stroke of the A set of power cylinders. Starting from this point one complete cycle will be described in the following discussion listing each successive motion of each element in the master unit as the time progresses during the power stroke, remembering that each corresponding element in the slave units also moves simultaneously. It should be remembered also that during the power stroke at high force level of power cylinder B-1, which requires a relatively long time, the power cylinder A-1 is being retracted or returned, goes through a waiting period during which a substantial portion of the B power stroke is completed, and then is re-engaged with the driving ring at a low force level just before the end of the B power stroke. At the end of the B power stroke, the A power stroke begins, which occupies a relatively long period of time, and during this period the B cylinder is being retracted, goes through a waiting period during which a substantial portion of the A power stroke is completed, and is then re-engaged with the driving ring just before the end of the A power stroke. At this time the B power stroke begins again and the cycle continues.

At the beginning of the B power stroke, which coincides with the beginning of the A return stroke, the

rotary pilot valves RVA and RVB, the plunger valves PVA and PVB, the 4-way control valves CVA-1 and CVB-1, and the directional control valve DCV-1 are in the positions indicated with the specific internal connections therein between the ports noted. High pressure hydraulic fluid is pumped through lines 66 and 70 at a rate controlled by valve 68 or pump 50 through pressure control valve PCV-1 between ports T and 1. The oil further flows through line 136 and through valve DCVB-1 between ports P and 1 and therefrom through line 14 to power cylinder B-1 causing push rod 122 to move to the right supplying power to the driving ring in the manner shown in relation to cylinder B-3. Pilot fluid pressure supplied as previously described to rotary pilot valve RVB flows therethrough between connected ports P and 1 and the power stroke ends when RVB is rotated by kicker 130 so as to connect ports P and 2. This supplies pilot fluid pressure therethrough to hydraulic actuators 22 and 28, moving DCVB-1 to the left and PCV-1 to the right. This begins the A power stroke, the A-1 cylinder having been retracted, delayed, and re-engaged during the B power stroke, in which high pressure oil is supplied through PCV-1, ports T and 2, through line 138 to 4-way control valve DCVA-1 through ports P and 1 and on through line 10 to power cylinder A-1 forcing it to the right. Low pressure oil is supplied from pump 48 through line 52 and rate control valve 54 through ports P and 1 in pressure control valve PCV-1, through line 136 to port P in DCVB-1 which has now moved to the left as above noted, and therethrough between ports P and 2 through line 16 to power cylinder B-1 beginning the return or retraction stroke.

The B cylinder retraction stroke continues with low pressure oil flowing through line 16 to cylinder B-1 until at the end of the retraction stroke kicker 134 actuates rotary pilot valve RVB disconnecting ports P and 2 and rotating RVB so as to connect ports P and 1.

The power cylinder B-1 waiting period then begins with low pressure oil supplied from pump 48 through pressure control valve PCV-1 between ports P and 1 and through 4-way control valve DCVB-1 between ports P and 2, but there is no oil flow on through line 16 to power cylinder B-1 because push rod 122 is fully retracted to the left. The pilot fluid pressure in rotary pilot valve RVB is through ports P and 1 and therefrom from line 100 to plunger valve PVA to port P, which at this time, before completion of the A power stroke, is blocked at port P because the plunger is not depressed. At this time plunger valve PVA is in the same position as diagrammed at PVB. Also at this time there is no pilot fluid pressure on the hydraulic actuators which move 4-way control valve DCVB or control valve PCV so that their positions remain the same as during the return stroke. The waiting period ends when power cylinder A-1 depresses plunger valve PVA sometime before the end of the A power stroke, thereby interconnecting ports P and 2 and directing pilot pressure to hydraulic operator 24 of 4-way control valve DCVB-1 moving it to the right into the position shown and beginning the engaging stroke of power cylinder B-1.

During the engaging stroke in the B cylinder, low pressure oil is supplied by pump 48 through pressure control valve PCV-1, which has now been moved to the left as above noted, therethrough between ports P and 1, through line 136 to port P on 4-way directional control valve DCVB-1, therethrough between ports P and 1, and down through line 14 moving power cylinder B-1 to the right at a low force level into engagement with the driving ring. At this time rotary pilot valve RVB is in the position shown, pilot pressure is directed therethrough between ports P and 1, through line 100 to port P of plunger valve PVA, therethrough to the port 2 and through line 116 to line 36 to DCVB-1 holding it in the position shown. The B cylinder engaging stroke ends at the same time the power stroke in the A power

cylinder ends. This rotates rotary pilot valve RVA so as to connect ports P and 2 thereby supplying pilot fluid pressure through lines 30 and 112 to hydraulic operator 26 moving PCV-1 to the left. This action supplies high pressure fluid therethrough between ports T and 1 and through DCVB-1 to power cylinder B-1 beginning its power stroke, and supplies low pressure oil through PCV-1, ports P and 2, and through DCVA-1 ports P and 2 to power cylinder A-1 beginning its retraction or return stroke.

There follows with respect to the A cylinder an identical return stroke, waiting period, and re-engaging stroke as above described with respect to the B cylinder. The cycle automatically repeats itself at rates controlled by valve 68 or pump 50. Valves 54, 60, and 64 in the low pressure fluid lines individually control the rate at which the return and pre-engaging strokes are accomplished for the master and slave units. Valve 68, in high pressure fluid line 66, controls the rate of high pressure hydraulic fluid flow which controls the rate of power application to the driving ring, or the time of the cycle.

Arrangement of system; Figure 2

Referring now to Figure 2, another modification of the hydraulic driving mechanism of this invention is shown which is particularly applicable to driving systems in which very high torque requirements exist. In this modification the power cylinders in a given bank or set are connected in parallel so that a given set of control valves supply the hydraulic fluid into a plurality of two or more such cylinders connected in parallel. A minimum number of control valves is required in this system. There is therefore only a single master system employing in this case three banks of power cylinders, each bank containing 4 cylinders. One cylinder in each bank is provided as before with a rotary pilot valve and a plunger valve for exactly the same signalling purposes as described in connection with Figure 1. In the system shown in Figure 2 the sequence however is somewhat different in that at any given time two banks of power cylinders are in the power stroke, while the third bank is being retracted, and then being pre-engaged ready to apply power at the instant one of the other banks reaches the end of its power stroke. The banks of power cylinders therefore operate in a staggered sequence so that at all times two-thirds of the cylinders are applying power.

Referring now more particularly to Figure 2, the system is provided with hydraulic fluid or oil reservoir 40, main outlet line 42, low pressure oil pump 48 connected in series with high pressure pump 50. The high pressure hydraulic oil is supplied through line 66 at a rate controlled by pump 50 and valve 68 which regulate the rate of power application and accordingly the length of the cycle. Low pressure oil is taken from pump 48 through line 52 at a rate controlled by valve 54 which controls the rate of flow of low pressure oil and accordingly governs the speed at which the power cylinders are retracted and pre-engaged with the driving ring immediately before the beginning of the power stroke. High pressure oil is discharged from pump 50 into high pressure oil manifold 150 from which it is supplied to the rest of the system as hereinafter described. Low pressure oil is supplied from pump 48 through line 54 into low pressure oil manifold 152 from which it is supplied to the banks of power cylinders as needed. The displaced or vented hydraulic oil is collected in vent manifold 154 from the banks of power cylinders and is returned to reservoir 40 through line 156, filter 57, and cooler 59. As in the system of Figure 1 a source of pilot fluid pressure is required to operate the control valves of the system. This is taken in this case from low pressure manifold 152 at point 158 and is supplied through line 160 to the rotary pilot valves.

In the specific modification shown in Figure 2, three

banks of 4 power cylinders each are shown. These are the A, B, and C banks and the 4 cylinders in each bank are numbered from 1 through 4. Again it should be understood that these power cylinders are actually arranged peripherally around the driving ring so that the push rod of each cylinder engages a flat engaging surface or dog on the ring periphery as indicated in Figure 1. The cylinder location in Figure 2 is thus schematic only. The number 1 cylinder in each of the 3 banks is provided with rotary pilot valve RPA, RPB and RPC. The valve RPA is actuated by push rod kickers 162 and 164. At the end of the A bank power stroke kicker 162 actuates rotary pilot valve RPA so as to disconnect port P with port 1 and connect port P with port 2. The identical action is employed in rotary pilots RPB and RPC.

Also as in Figure 1, plunger valves PVA, PVB, and PVC are disposed near the end of the push rod stroke of each of the number 1 cylinders in the A, B, and C banks. The purpose is the same, namely to signal the time at which the push rods approach the end of the power stroke in one cylinder bank so as to begin the re-engagement of another bank of cylinders. When the plunger is depressed it disconnects port T from port 2 and connects port P with port 2.

The purpose of the rotary pilot valves and the plunger valves just described is to actuate in proper sequence the pressure control valves PCVA, PCVB, and PCVC which supply either high pressure hydraulic fluid for the power stroke or low pressure hydraulic fluid for the retraction and pre-engagement strokes to the corresponding power cylinder bank. They also actuate 4-way directional control valves DCVA, DCVB, and DCVC which control the port on the power cylinder to which fluid is provided and the port from which fluid is displaced or vented, that is, the direction of push rod movement. The pressure control valves PCVA, PCVB, and PCVC are in actuality 3-way control valves since port T on each is plugged.

Each of the pressure control valves and 4-way directional control valves referred to above is a so-called floating valve and is actuated by hydraulic operators on a pilot pressure impulse thereby moving the valve body from one position to the other, as in the drawing from left to right between two extreme positions as shown. In Figure 2 these hydraulic operators are not numbered since their function and purpose are identical to those described in connection with Figure 1.

Each bank of power cylinders is connected to a 4-way directional control valve DCV to receive and to vent fluid therethrough. Control valve DCVA is connected through lines 166 and 168 to the A bank of cylinders, 4-way control valve DCVB is connected through lines 170 and 172 to the B bank of cylinders, and valve DCVC is connected through lines 174 and 176 to the C bank of cylinders. Each power cylinder in each bank is provided with a pair of block valves, valves 178 and 180 for example are the block valves provided the number 4 cylinder in the A bank, namely cylinder A-4. The purpose of these valves is to cut off one or more power cylinders in a given bank while supplying a constant volume of high pressure fluid to the remaining cylinders. This increases the velocity of rotation of the driving ring while reducing the applied torque. Obviously a minimum of one cylinder per bank may be operated and any plurality of cylinders up to the maximum number. The maximum number of cylinders per bank may be increased from the 4 per bank shown in Figure 2 where necessary for higher applied torques.

Operation of System, Figure 3

With the foregoing identification of each essential element in this system, a brief description of the movements of each element through a complete cycle is believed to be the best way of describing the equipment and its operation. With each element in the position shown in

Figure 2, the cylinders in the A bank have just begun a power stroke, the cylinders in the C bank are approximately half way through a power stroke, and the cylinders in the B bank having just completed a power stroke simultaneously with the beginning of the A power stroke and are now beginning the retraction and re-engagement steps of the process. Push rod 182 retracts allowing plunger valve PVB to rise connecting ports T and 2. At the end of the retraction stroke rotary pilot valve RPB is thrown connecting ports P and 1, placing pilot oil pressure to port P of plunger valve PVC. At this time the B cylinders pause and remain in their present retracted position since port P of PVC is blocked and the pilot fluid can flow no further. Just before the end of the C power stroke, PVC is depressed connecting port P with port 2, allowing the pilot fluid pressure to continue through PVC to control valve DCVB moving it to the right, and this in turn permits low pressure hydraulic oil to flow through line 170 moving the B cylinders to the right and causing them to pre-engage with the driving ring just before the end of the C power stroke.

At the end of the C power stroke rotary pilot RPC is thrown so as to connect ports P and 2 allowing pilot fluid to flow therethrough moving DCVC to the left and PCVC to the right, blocking the high pressure oil flow through PCVC and placing low pressure oil through line 176 to commence retraction of the C power cylinders. This same actuation of rotary pilot RPC simultaneously moves PCVB to the left placing high pressure oil through line 170 into the B bank cylinders immediately beginning the B power stroke. At this time then the B bank cylinders are beginning their power stroke, the A bank cylinders are roughly half way through their power stroke, and the C bank cylinders are beginning their retraction, pause, and pre-engagement part of the cycle.

As the C bank cylinders retract, plunger valve PVC rises connecting ports T and 2 and at the end of the C retraction stroke, rotary pilot RPC is actuated connecting ports P and 1, thereby placing pilot fluid pressure therethrough to PVA. Because the A bank is part way through a power stroke, port P of PVA is blocked and therefore the C cylinders pause in the retracted position. Near the end of the A power stroke, PVA is depressed connecting ports P and 2 placing pilot oil pressure therethrough to DCVC moving it to the right. PCVC is already in the right-hand position from the previous actuation and this movement of DCVC places low pressure oil through ports P and 2 on DCVC causing the C bank of cylinders to pre-engage. At the end of the A power stroke, RPA is actuated interconnecting ports P and 2 placing pilot oil pressure therethrough moving DCVA to the left and PCVA to the right. This blocks the high pressure oil supply to the A bank and supplies low pressure oil through DCVA to the A bank cylinders beginning the retraction step. Simultaneously with these movements of DCVA and PCVA, PCVC is moved to the left blocking low pressure pre-engagement oil to the C bank and supplies high pressure oil through DCVC ports P and 2 to start the C power stroke.

At this point the C bank is just beginning its power stroke, the B bank is roughly half way through a power stroke, and the A bank has just begun the retraction and pre-engagement part of its cycle.

Shortly after the beginning of the A bank retraction plunger valve PVA rises connecting ports P and 2. At the end of the A bank retraction rotary pilot RPA is actuated interconnecting ports P and 1 thereby placing pilot oil pressure therethrough to PVB associated with the B bank of cylinders which is roughly half way through its power stroke. Since PVB is not depressed, port P is blocked and therefore the A cylinders pause in the retracted position. Near the end of the B power stroke, PVB is depressed connecting ports P and 2 placing pilot oil pressure on DCVA moving it to the right.

With PCVA already at the right, low pressure oil is placed through PCVA and DCVA to the A bank of cylinders causing pre-engagement. At the end of the B power stroke, RPB is actuated interconnecting ports P and 2 placing pilot oil pressure therethrough moving DCVB to the left and PCVB to the right, thereby applying low pressure oil to begin retraction of the B bank of cylinders, and simultaneously moves PCVA to the left supplying high pressure oil therethrough and through DCVA to the A bank of cylinders beginning the A power stroke.

This is the beginning point of the cycle above described with all elements positioned as shown in Figure 2. The cycle repeats at a rate determined by the setting of pump 50 and valve 68. The duration of the retraction and pause portions of each cycle is determined by the setting of valve 54'. The cycle continues automatically supplying low velocity, high torque power to any kind of driving ring which in turn is connected to an appropriate load.

As an example of the practical application of the system of the present invention, the following data will be given describing the use of the apparatus of Figure 2 in conjunction with the high torque low speed rotation of plows used to agitate the upper part of an upwardly moving mass of oil shale treated in an upflow oil shale retort. The diameter of the retort at this point was approximately 17 feet, the plows extended to a depth of about 5 feet, and the driving ring diameter was approximately 22 feet. The unit consisted of 3 banks (A, B, and C) of power cylinders each consisting of 4 power cylinders connected in parallel as shown in Figure 2. These hydraulic cylinders had a 26-inch long stroke, were 12 inches in diameter, and were supplied as described with high pressure hydraulic fluid at a pressure between 500 and 3,000 p. s. i. g. The low pressure hydraulic fluid was supplied by means of a separate pump as described above at a pressure of 150 p. s. i. g. Under these conditions plow rotation at 3.0 revolutions per hour was maintained in the rising bed of shale with an applied torque of about 20 million foot pounds. The power stroke of each bank of cylinders continued for about 28.6 seconds, the return stroke was accomplished in about 7 seconds. The waiting period was approximately 5.3 seconds, and the pre-engagement period was about 2 seconds. The operation of this unit was continuous with no discernible hesitation or interruption in the application of the tangential driving force to the driving ring so that complete elimination of fatigue stresses was obtained.

In the design of a suitable driving ring and hydraulic power cylinders as shown in Figures 1 and 2, the following relationships apply.

The minimum number of dogs around the driving ring periphery occurs in the case where each cylinder applies power to each dog once during each complete revolution of the ring. This number d is determined from:

$$d = (an + 1)b$$

wherein a is the number of sets or banks of power cylinders (e. g. 2 in Figure 1, and 3 in Figure 2), b is the number of power cylinders in each bank (e. g. 3 in Figure 1, and 4 in Figure 2), and n is any whole number (e. g. 1.0 for minimum value of d). The smaller the selected value of n , the longer must be the required stroke of the power cylinders for a given diameter of driving ring.

The minimum length of power cylinder travel or stroke in inches is determined by:

$$L = \frac{\pi DC}{da}$$

wherein a and d have been defined above, D is the diameter of the driving ring in inches, and C is the number of cylinder banks which are in their power stroke

at any one time (e. g., 1 in Figure 1, and 2 in Figure 2). A power cylinder is selected with up to 25% longer stroke to allow for the travel involved in pre-engagement with the driving ring.

The process and apparatus of this invention have been described in connection with hydraulic power cylinders, hydraulic operators for actuating the control valves, and hydraulic fluid lines appropriately linking the valves and cylinders with a source of fluid pressure. The present invention also contemplates the electrical equivalents of all or part of the essential hydraulic elements described. The longitudinal application of force tangentially to the driving ring can be obtained from solenoids instead of hydraulic cylinders. Similarly the control valves can be replaced by appropriate remotely actuated electrical switches. These are actuated by solenoids (as in a relay) which in turn are actuated by mechanically actuated electrical switches equivalent to the rotary and plunger pilot valves. The hydraulic control conduits shown as broken lines in the drawings are of course replaced by electrical connections. The low pressure and high pressure fluid streams are replaced by electrical current flow at low and higher voltage respectively.

One skilled in the art can readily fabricate the electrical modification of this invention from the foregoing description and the listed substitutions.

In both the electrical and hydraulic modifications, the low velocity high torque rotary motion is generated and maintained continuously by applying a continuous longitudinally acting force tangentially at a plurality of points around the periphery of a driving ring or wheel. The means for applying such force are either the hydraulic cylinders or the electrical solenoids, each of which apply the force intermittently in sequence to maintain continuous rotary motion.

A particular embodiment of the present invention has been hereinabove described in considerable detail by way of illustration. It should be understood that various other modifications and adaptations thereof may be made by those skilled in this particular art without departing from the spirit and scope of this invention as set forth in the appended claims.

I claim:

1. An apparatus for providing a continuous low velocity rotary motion at high torque values to a rotary load which comprises a driving ring connected to said rotary load, a plurality of dogs disposed around the periphery of said ring, a plurality of intermittently acting force applying means of limited longitudinal movement disposed in at least two separately actuated sets around the periphery of said ring and connected to apply a force through reciprocable push rods against said dogs substantially tangentially to said ring, a power source having a low force level output and a high force level output connected to said force means, a first signal means disposed adjacent at least one of the force means in each of said sets and connected to signal the arrival of the push rods thereof at a point short of the end of its force stroke and actuate the force means in another set of force means by means of said power source to pre-engage the push rods thereof with said dogs at said low force level, a second signal means disposed adjacent at least one of the force means in each of said sets and connected to signal the arrival of the push rods thereof at the end of the force stroke and actuate a pre-engaged set of force means by means of said power source at said high force level to begin the force stroke thereof and simultaneously actuate the set of force means at the end of its force stroke to retract the push rods thereof, each of said second signal means also being connected to signal the arrival of the push rods at the end of the retraction stroke, whereby a continuous low velocity rotary movement of said driving ring is automatically maintained.

2. An apparatus according to claim 1 wherein said power source is a source of hydraulic power, said signal

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means are mechanically actuated pilot valves, and said force applying means are hydraulic cylinders.

3. An apparatus according to claim 1 wherein said plurality of force applying means comprises two sets of at least one each, and said sets are connected to act in alternation with each other.

4. An apparatus according to claim 1 wherein said plurality of force applying means comprises three sets of at least one each, and said sets are connected to act in a sequence in which two of said sets always are acting simultaneously.

5. An apparatus for providing a continuous low velocity rotary motion at high torque values to a rotary load which comprises a driving ring connected to said load, a plurality of hydraulic cylinders provided with pistons and push rods disposed around the periphery of said ring, said plurality including at least two separately acting sets of at least one cylinder each, said ring being provided with means for receiving the end of said push rods to apply a tangential force thereto, a hydraulic fluid reservoir, a low pressure and a high pressure pump connected to said reservoir, a four-way direction reversing valve connected to at least one of said cylinders in each set to supply fluid to and vent fluid from each end of said cylinder, a pressure control valve connected between said direction reversing valve and said low and high pressure pumps and connected to control the supply of high and low pressure fluid therethrough to said sets of cylinders, said direction reversing and pressure control valves being provided with hydraulic operators to actuate said valves, said operators being in turn actuated by hydraulic fluid flow from and connected to said reservoir through first and second pilot valves disposed so as to be actuated by push rod motion of at least one cylinder in each set thereof, said first pilot valve being actuated near the end of the power stroke of the corresponding set of power cylinders and connected to actuate the directional control valve in another set of power cylinders to cause pre-engagement thereof at low force levels with said ring, said second pilot valve being actuated at the end of the power stroke and connected to actuate the directional control valve of the same set of power cylinders to begin the retraction stroke thereof and actuate simultaneously the pressure control valve of another set of pre-engaged cylinders to begin the power stroke thereof, whereby the sets of power cylinders apply a rotating force to said driving ring continuously.

6. An apparatus according to claim 5 wherein said driving ring is provided with a number of dogs around its periphery which is at least equal to d in the equation:

$$d = (an + 1)b$$

wherein a is the number of sets of power cylinders, b is the number of power cylinders in each set, and n is any whole number, and wherein the length of the power stroke in inches of each power cylinder is at least equal to L in the following equation:

$$L = \frac{\pi DC}{da}$$

7. An apparatus according to claim 5 in which said high pressure pump is a constant volume variable pressure pump whereby a constant rotary velocity of said driving ring is maintained.

8. An apparatus according to claim 5 wherein said low pressure pump is a constant pressure variable volume pump.

9. An apparatus according to claim 5 wherein each set of power cylinders consists of a plurality of hydraulic cylinders connected in parallel, each cylinder having a block valve in the hydraulic fluid connection at each of its ends, and wherein each of said sets is connected to said reservoir, and to said low and said high pressure pumps through a four-way directional control valve and a pressure control valve.

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10. An apparatus according to claim 9 wherein power cylinders are arranged in three sets of four cylinders each around the driving ring, each of said three sets of power cylinders being controlled to operate 120° out of phase with the other two sets so that at all times two sets are in the power stroke while the other set is being retracted from and pre-engaged with said driving ring.

11. An apparatus according to claim 5 wherein said each set of power cylinders includes a master cylinder and at least one slave cylinder forming a master unit and at least one slave unit, said units each including a power cylinder in each set, wherein each cylinder in each unit is provided with a four-way direction reversing valve connected thereto, wherein each unit is provided with a pressure control valve connected in each of said units, said pressure control valves being connected to and operated simultaneously by hydraulic operators connected in parallel, said direction reversing valves connected to the power cylinders in a given set being connected to and operated simultaneously by hydraulic operators connected in parallel, said first and second pilot valves being actuated by movements of the pistons of the hydraulic cylinders only in said master unit.

12. An apparatus according to claim 11 wherein said power cylinders are arranged in two sets of three cylinders each including a master unit and two slave units of two power cylinders each, the power cylinders in each set being controlled to operate 180° out of phase with each other so that at all times one set of power cylinders is in the power stroke while the other set is being retracted from and pre-engaged with said driving ring.

13. An apparatus for providing a continuous low velocity rotary motion at high torque values to a rotary load which comprises a driving wheel provided with peripheral dogs and connected to said load, a plurality of separately supported hydraulic cylinders disposed around said periphery so that the cylinder piston rods can engage said dogs substantially tangentially, said plurality of hydraulic cylinders being made up of a master unit of at least two cylinders and at least one slave unit of at least two cylinders, a hydraulic fluid reservoir, a low pressure and a high pressure pump connected in fluid-receiving relation to said reservoir, a four-way direction reversing valve connected to each of said cylinders and to said reservoir, a four-way pressure control valve connected to all of the direction reversing valves in each of the master and slave units and also to both the low and high pressure pumps, hydraulic operators connected to each of said direction reversing and pressure control valves, means connecting the hydraulic operators of all corresponding direction reversing and pressure control valves in each unit together for simultaneous actuation, said operators being connected in pilot hydraulic fluid-receiving relation to said reservoir through first and second pilot valves disposed so as to be actuated by movements of each power cylinder in said master unit, each of said first pilot valves being actuated near the end of the power stroke of its associated power cylinder and connected to actuate the direction reversing valve of another power cylinder in said master unit to cause pre-engagement thereof and of corresponding cylinders in said slave units with said driving wheel, each of said second pilot valves being actuated at the end of the power stroke of its associated power cylinder and connected to actuate simultaneously the direction reversing valve connected to that power cylinder and actuate the pressure control valves to start retraction of that cylinder and corresponding slave cylinders and the power stroke of the other power cylinder and its corresponding slave cylinders whereby a continuous automatically maintained sequence of tangential forces is continuously applied to said driving wheel to maintain rotation thereof.

14. An apparatus according to claim 13 wherein each master and slave unit includes two hydraulic cylinders

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operated 180° out of phase with each other, corresponding cylinders in each of the master and slave units, operating in phase.

15. An apparatus for providing a continuous low velocity rotary motion at high torque values to a rotary load which comprises a driving wheel provided with peripheral dogs and connected to said load, a plurality of separately supported hydraulic cylinders disposed around said periphery so that the cylinder piston rods can engage said dogs substantially tangentially, said plurality of sets of hydraulic cylinders, each set including a plurality of cylinders connected in parallel, each cylinder having a block valve in each of the fluid connections thereto, a hydraulic fluid reservoir, a low pressure and a high pressure pump connected in fluid-receiving relation to said reservoir, a four-way direction reversing valve connected to each of said sets of cylinders and to said reservoir, a pressure control valve connected to each of said pumps and also to each of said reversing valves, hydraulic operators connected to each of said direction reversing and pressure control valves, means connecting the hydraulic operators in pilot hydraulic fluid-receiving relation to said reservoir through first and second pilot valves disposed so as to be actuated by movements of one hydraulic cylinder in each of said plurality of sets, each of said first pilot valves being actuated near the end of the power stroke of its associated power cylinder in one

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set and connected to actuate the direction reversing valve connected to another set of cylinders to cause them to pre-engage at low force level with said driving wheel, each of said second pilot valves being actuated at the end of the power stroke of its associated power cylinder in one set and connected to actuate simultaneously the direction reversing valve connected in that set to begin retraction thereof and actuate the pressure control switch in another set to begin the power stroke thereof whereby a continuous automatically maintained sequence of tangential forces is continuously applied to said driving wheel to maintain rotation thereof.

16. An apparatus according to claim 15 wherein three sets of hydraulic cylinders are employed, two of which are in the power stroke at all times and each of which operates 120° out of phase with the other two sets at all times.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 2,874,544

February 24, 1959

Robert L. Switzer

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 13, after the equation in lines 57 to 59, claim 6, insert the following:

wherein d and a are defined above, D is the diameter of the driving ring in inches, and C is the number of sets of power cylinders which are in their power stroke at any given time.

Signed and sealed this 7th day of July 1959.

(SEAL)
Attest:

KARL H. AXLINE

Attesting Officer

ROBERT C. WATSON
Commissioner of Patents