June 20, 1961 F. L. HEMINGS 2,988,891

HYDRAULICALLY RESPONSIVE CONTROL SYSTEM

Filed June 17, 1959 4 Sheets-Sheet 1

Fig. 1.

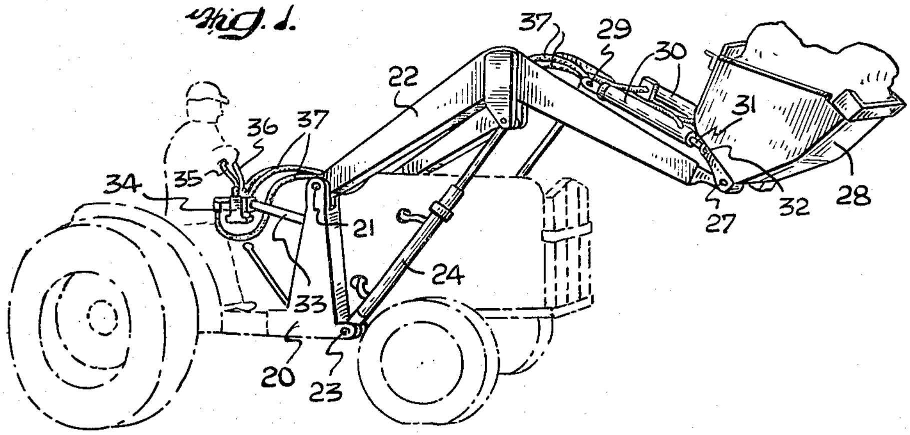
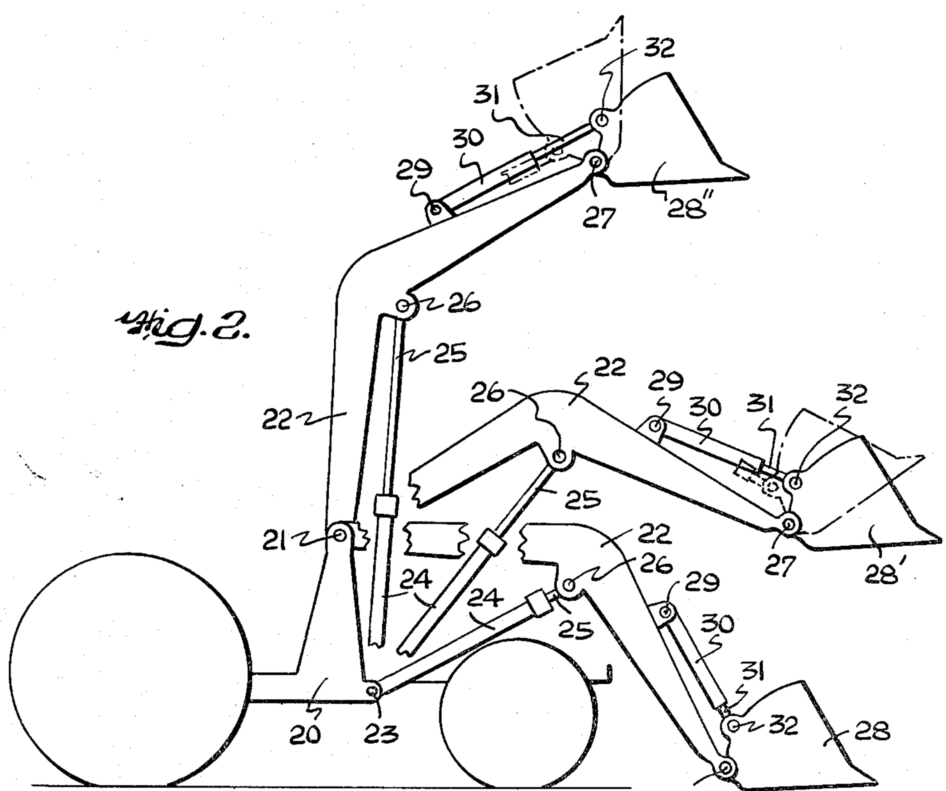


Fig. 2.



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HYDRAULICALLY RESPONSIVE CONTROL SYSTEM

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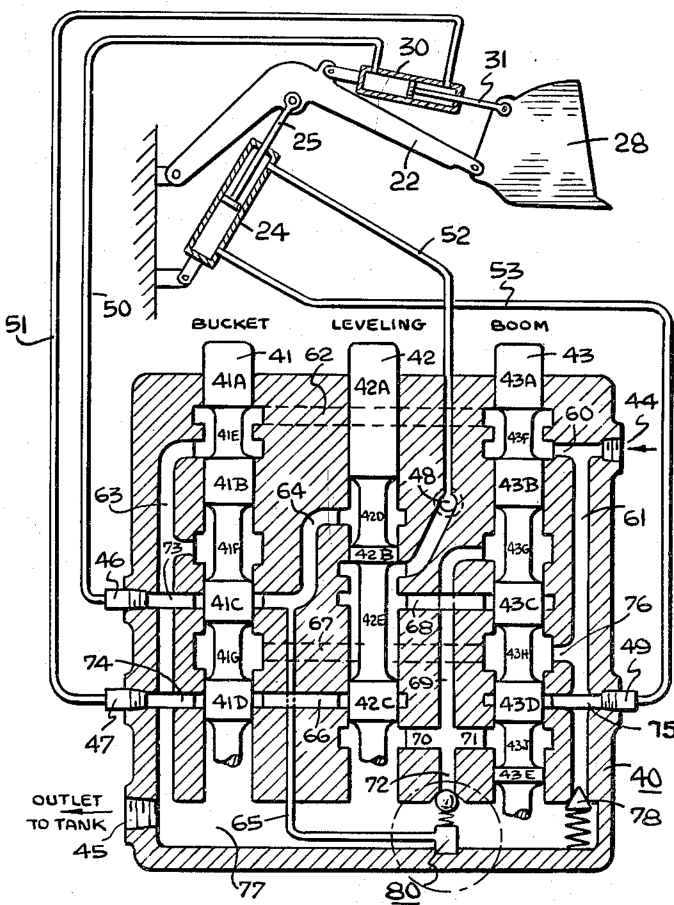

Fig. 3.

Fig. 4.

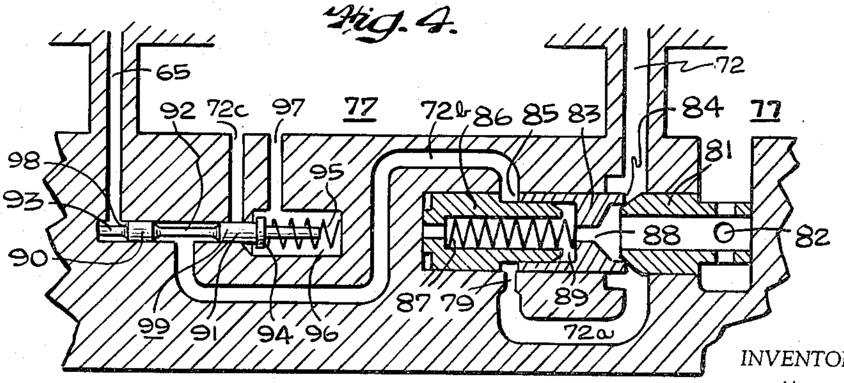

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Fig. 5.

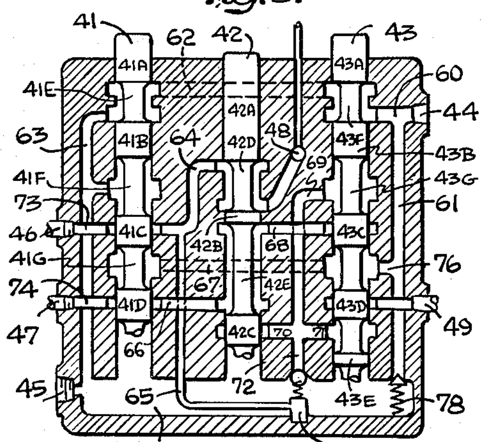

Fig. 6.

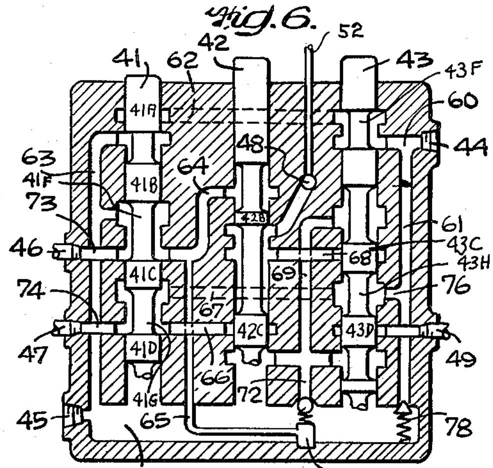

Fig. 7.

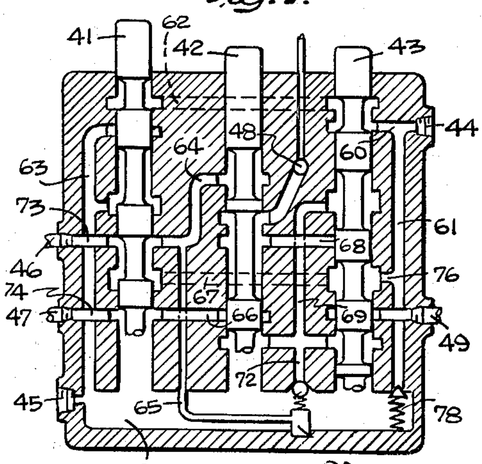

Fig. 8.

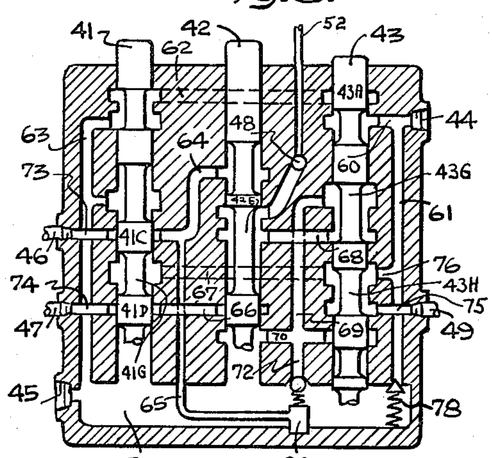

Fig. 9.

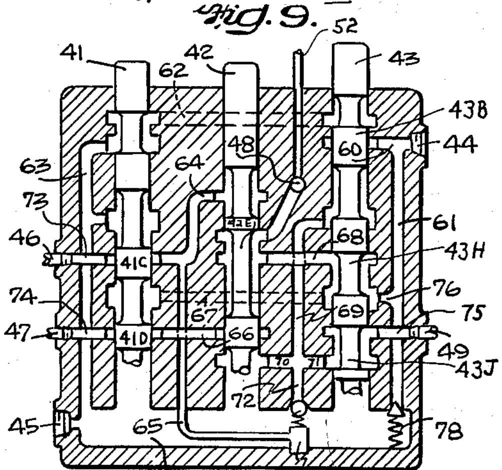

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Fig. 10.

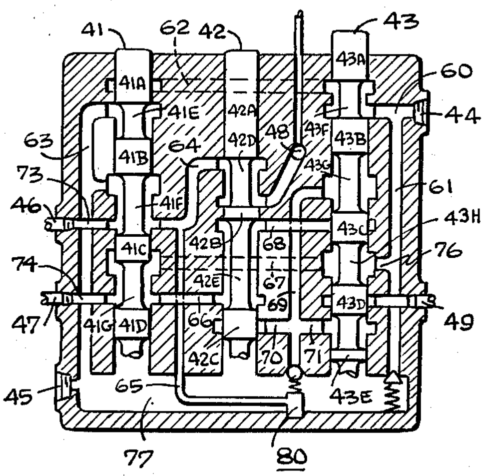


Fig. 11.

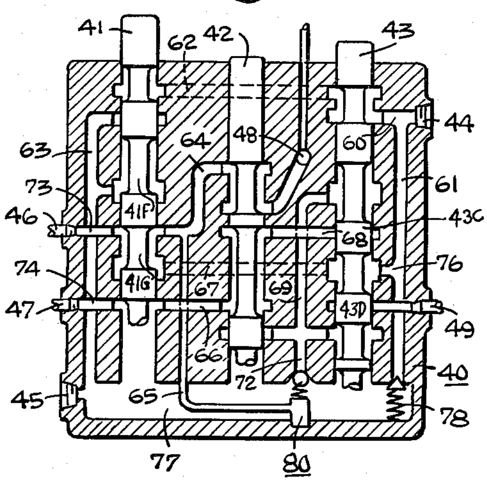


Fig. 12.

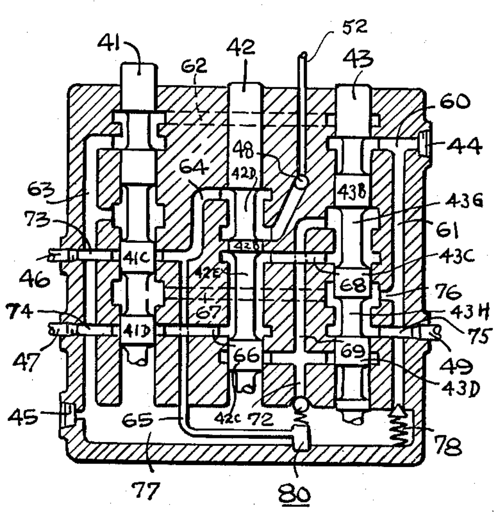
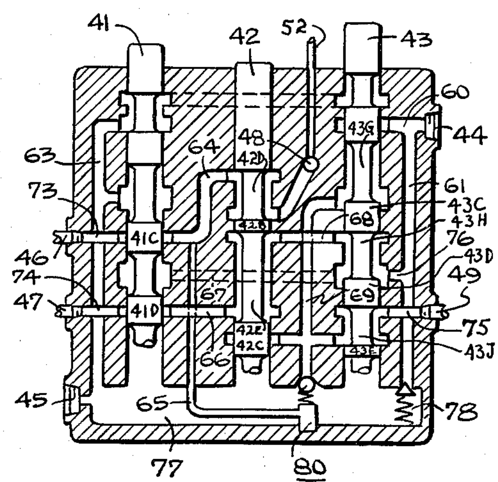


Fig. 13.



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HYDRAULICALLY RESPONSIVE CONTROL SYSTEM

Frank Lester Hemings, Bristol, Pa., assignor to American Industries Company, a corporation of Pennsylvania
Filed June 17, 1959, Ser. No. 821,015
12 Claims. (Cl. 60—97)

This invention relates to a hydraulic control system, and more particularly to a hydraulic control system which provides a leveling function when used in conjunction with certain types of loading apparatus. The loading apparatus may be of the type commonly employed for earth moving, or pallet transportation, or any number of other applications which require lifting and lowering of loads while maintaining such loads in a substantially level state.

For purposes of illustration, one application of my invention will be described in connection with an earth loading machine, which consists essentially of a tractor type vehicle having mounted thereto a boom with a bucket at the boom end. This type of apparatus is most usually employed for the purpose of loading dirt into the bucket at substantially ground level and elevating the bucket by means of the boom in order to dump the dirt into a waiting truck for transportation elsewhere. In the course of raising the filled bucket, a serious problem has been encountered wherein the dirt tends to spill over backwards out of the bucket and onto the operator of the loader device. This condition is serious enough when moving dirt, but becomes intolerable when for example loads of rock are being elevated. In this latter case, a rock dislodged from the bucket may fall upon the loader operator and cause serious injury. Accordingly, it has been found necessary to provide some means for preventing the backspilling of the bucket load. The general method of solution to this vexing problem have been found to lie in the provision of means for causing the bucket to be rotated in a forward direction as it is elevated by operation of the boom. This forward rotation of the bucket as the boom is raised, and also the rearward rotation of the bucket as the boom is lowered, has been generally termed "bucket leveling."

Prior to this invention, known apparatus for achieving bucket leveling had been designed around mechanical systems, such as a pantograph mounted to the bucket. The mechanical pantograph system has been found to suffer from several major defects which make its use undesirable, but for which no satisfactory substitute had been found up until the time of this invention. Some of the undesirable characteristics of the mechanical pantograph systems reside in the fact that such a system requires a substantial amount of power to operate; the pantograph provides a fixed mechanical linkage which cannot be readily changed to accommodate differing situations; and the pantograph has a relatively high incidence of failure resulting in expensive maintenance and a substantial amount of down time. Moreover, the mechanical pantograph system is not adaptable to already existing loader equipment and must be incorporated into a loader when it is built. On the other hand, the present invention does not deal with pantograph systems or any other similar type of mechanical linkage arrangement, but works in conjunction with and utilizes the hydraulic pressure system used to actuate the bucket and boom of substantially all loaders which are presently being made. The present invention therefore has the advantages over the mechanical pantograph system of complete flexibility, substantially lower cost, and the adapability to existing non-bucket-leveling loader equipment by making a relatively simple change in the loader hydraulic system.

Lest a misapprehension as to the universality of appli-

cation of this invention be formed, it is to be specifically noted that "bucket leveling" is only one of many problems to which this invention is specifically applicable. For example, a leveling operation may be mandatory in other applications such as in the case where the bucket of the aforementioned loader device were replaced by a pallet lift, and the pallets to be raised and transported carry articles which must be kept in an upright position. In general, this invention provides a hydraulically actuated control system for causing a plurality of relatively moving members or devices to maintain or assume some predeterminedly decided upon relative positions. Accordingly, it is a primary object of my invention to provide a novel hydraulically responsive control system for causing a plurality of relatively movable devices to be precisely controlled in their movements relative to one another.

It is another object of my invention to provide a novel hydraulically responsive control system which may be incorporated into material loading apparatus of the bucket and boom type which accomplishes the highly desirable function of bucket leveling when the boom and bucket are in motion.

Still another object of my invention is to provide a novel hydraulically responsive control system which is substantially less costly and considerably more flexible than existing mechanical systems designed to accomplish the same end result.

Yet another object of my invention is to provide a novel hydraulically responsive control system for material handling apparatus which may be in large measure incorporated into already existing equipment which is not provided with a leveling function.

Another object of my invention is to provide a novel hydraulically responsive control system which when incorporated into material handling apparatus will optionally provide either a leveling function, or in the alternative, independent simultaneous and non-simultaneous motion of a boom and bucket.

These and other objects of my invention will become apparent from a careful reading of the following specification when read in conjunction with an examination of the appended drawings, wherein:

FIGURE 1 illustrates in perspective a tractor loader having affixed thereto a forwardly extending boom with a bucket mounted at the boom free end;

FIGURE 2 illustrates in side elevation diagrammatic form the extremes and one intermediate position which may be assumed by the boom seen in the illustration of FIGURE 1, and also shows the bucket positions for leveling and non-leveling operation;

FIGURE 3 illustrates, partly in section and partly in diagrammatic elevation, the interconnection of the boom and bucket actuating cylinders with a valve system embodying the invention;

FIGURE 4 is a sectional fragmentary view of a pilot valve system embodied in the invention and shown in diagrammatic form within the phantom circle appearing on FIGURE 3;

FIGURES 5 through 13 illustrate certain of the various combinations of spool positions of the valve system illustrated in FIGURE 3, and which each correspond to a particular functioning of the boom and bucket cylinders, some figures illustrating leveling action and some figures illustrating independent motion of the bucket and boom.

In these several figures like elements are denoted by like reference numerals.

Turning now to an examination of the figures, and firstly, to FIGURE 1 there will be seen a tractor having a frame **20** to which is pivotally fixed as at **21** a boom **22**. Also fixed to the frame **20** by a pivot **23** is a fluid pressure cylinder **24** having a piston rod **25** riding therein, the upper end of the piston rod **25** being fixed to the boom

22 by a pivot 26. Also pivotally mounted, as at 27, to the forward end of the boom 22 is a bucket 28. Pivotally mounted to the forward part of the boom as at 29 are a pair of bucket cylinders 30 having piston rods 31 riding therein. The forward end of each piston rod 31 is pivotally mounted to the bucket 28 as at 32.

Mounted to the tractor frame 20 by a rigid conduit 33 is a hydraulic control valve 34 shown with a pair of top mounted control levers 35 and 36. A plurality of hoses 37 interconnect the control valve 34 with the boom and bucket cylinders 24 and 30. Considering first the case in which the loader illustrated in FIGURE 1 is of the standard type, that is, does not include a bucket leveling system, the operational organization of the component parts would be as follows. Firstly, the cylinders 24 and 30, the plurality of hoses 37, the control valve 34, and the rigid conduit 33 are all part of a closed hydraulic system which includes a pump and a reservoir for the hydraulic fluid which is circulated through the closed system. In fact, there are actually a pair of parallel systems which commonly share the pump, the reservoir, the conduit 33 and the control valve 34. One of these parallel systems includes the boom cylinders 24 and associated hoses 37 interconnecting the boom cylinders with the control valve 34, and the other system includes the bucket cylinders 30 and the hoses 37 interconnecting the latter with the control valve 34. Both the boom cylinders 24 and the bucket cylinders 30 are double-acting devices so that the piston rods associated respectively therewith may be optionally driven either into or out of the cylinders by appropriate manipulation of the control levers 35 and 36.

When for example it is desired to raise the boom 22, the appropriate control lever 35 or 36 is shifted from a neutral position to one of two operating positions, say for example the control lever 35 is shifted rearward. Upon actuation of this control lever 35 the hydraulic pump pumps fluid under pressure through the control valve 34 and into the proper hoses 37 to cause the piston rod 25 to be driven upwardly out of the cylinder 24 and hence raise the boom 22. When the reverse action is desired, that is when it is desired to lower the boom 22, the control lever 35 would be shifted in the opposite direction or forward. Such shifting of the control lever 35 reroutes the fluid under pressure from the pump along a different path through the control valve 34, through the associated hoses 37 and forces the piston rod 25 downwardly into the cylinder 24 and thus lowers the boom 22. A similar action takes place with regard to the bucket 28 when the control lever 36 is actuated.

The control valve 34 is so constructed that actuation of the control lever 35 couples the fluid under pressure only to the boom cylinder 24 but maintains the bucket system in an isolated state. Conversely, actuation of the control lever 36 operates the bucket cylinders 30 but maintains the boom cylinder 24 hydraulic system isolated from the pump. It is of course possible even with this type of system to actuate both the control levers 35 and 36 during the same time interval and hence simultaneously operate both the boom and the bucket. In accordance with the present invention, as will be subsequently described, this standard loader illustrated in FIGURE 1 may be converted for automatic bucket leveling operation by the simple substitution for the control valve 34 of a modified type of control valve which provides for all of the operations that may be accomplished with the control valve 34 and in addition includes certain features which optionally provide the bucket leveling function. The simple substitution of a valve according to the present invention for a control valve of the type designated as 34 in FIGURE 1 is of course conditioned upon the premise that the piston areas of the boom and bucket cylinders 24 and 30 are related to one another by a prescribed ratio. The necessity for this piston area ratio will be most clearly seen by referring to the showing of FIGURE 2, to which reference should now be had.

FIGURE 2 illustrates the boom 22 in completely lowered position, completely elevated position, and one intermediate position. In the completely lowered position it is to be observed that the piston rod 31 which controls the bucket position is in completely retracted condition within the bucket cylinder 30. In the successively elevated boom positions it is further observed that the position of the bucket 28 shown in dashed outline corresponds to the position of the bucket 28 in the case where the boom 22 is in lowered condition, and illustrates no relative motion between the bucket 28 and boom 22 as the boom is elevated. This of course corresponds to a non-automatic bucket leveling condition, the position of the bucket 28 relative to the boom 22 being changeable only by simultaneous, manually actuated, outward stroking of the piston rod 31 from the bucket cylinder 30.

On the other hand, the bucket positions shown in heavy line and designated respectively as 28′ and 28″ show a substantial constancy of the bucket position relative to the ground plane and hence also illustrate a relative change in position between the bucket and the boom as the latter is elevated. This case corresponds to automatic bucket leveling. It should be noted that a constant ratio is illustrated between the stroke length of the bucket cylinder piston rod 31 and the boom cylinder piston rod 25, and as shown is approximately 1 to 3. The stroke length ratio of course corresponds exactly to the inverse of the piston area ratio, and this ratio is necessarily determined by the geometry of the boom and bucket structures. The stroke ratio required is that which maintains the bucket in constant relative orientation to the ground or some other reference plane as the boom rises and lowers without causing bucket override or underride which would result in a deviation of the bucket orientation from that desired. Although some override or underride could be tolerated in the illustrated case, such a condition would be completely unacceptable in other applications, as for example in some cases involving pallet lift operation wherein the lifted material must be maintained in a level state.

FIGURE 3 illustrates a hydraulic valve control system embodying the concept of the present invention. It will be observed that this hydraulic control valve includes three spools 41, 42 and 43, which are respectively the bucket spool, leveling spool, and boom spool, the foregoing designations denoting the function assigned to each of the spools. Also included in the control valve are a plurality of apertures or ports 44 through 49, a plurality of internal passageways 60 through 77, a safety relief valve 78, and a pilot-valve-controlled relief valve 80. The pilot-valve-controlled relief valve 80 is rendered operative only during bucket leveling operations, and its specific function and method of operation will be fully described in connection with the showings of FIGURES 4, 5, 12 and 13. The bucket and boom spools 41 and 43 are adapted for vertical shifting motion in either an upward or a downward direction, whereas the leveling spool 42 is only adapted to be shifted vertically downward. The position of the three spools as illustrated in FIGURE 3 may be termed the "neutral" position for the bucket and boom spools 41 and 43, and may be termed the "non-leveling" position with regard to the leveling spool 42.

With all spools in the positions as illustrated in FIGURE 3, both the boom 22 and bucket 28 are at rest, although not necessarily in any predetermined fixed orientation relative to one another or to any reference plane. With the leveling spool 42 in the position illustrated in FIGURE 3, the bucket spool 41 and boom spool 43 operate essentially independently and in parallel from the pump circuit. That is, actuation of the bucket spool 41 results only in motion of the bucket 28 having no effect whatever upon the boom 22, and actuation of the boom spool **43** results in motion of the boom **22** and has no effect whatever upon the bucket **28**. When therefore the leveling spool **42** is in its illustrated non-leveling condition, the hydraulic control valve illustrated in FIGURE 3 functions exactly as though there were no leveling spool **42** at all and corresponds in function to the control valve **34** illustrated in FIGURE 1. When, however, the leveling spool **42** is shifted downward, the bucket spool **41** and boom spool **43** are converted from two independent parallel systems into a single series connected hydraulic loop, and the motions of the bucket **28** and boom **22** may be locked together to provide synchronized motion therebetween.

The specific operation of the control valve system with regard to particular operations performed when the several spools are actuated, and thereby shifted into various combinations of positions, will be described in some detail in connection with FIGURES 4 through 13 subsequently to be described. However, before turning to these figures for an understanding of specific operational details, it will be profitable to first consider in connection with FIGURE 3 certain aspects of the system which are generic. It will be observed that hydraulic fluid is delivered from the pump to the valve **40** via the inlet port **44**, and that this fluid is delivered into passageways **76** and **67**. The passageway **76** empties into a chamber surrounding the reduced portion **43H** of the boom spool **43** and is blocked from passing out of that chamber by the lands **43C** and **43D** located immediately above and below the reduced portion **43H**.

The passage **67** is shown in dotted outline as extending from the chamber surrounding the reduced portion **41G** of the bucket spool **41** horizontally toward the right behind the leveling spool **42** and behind the boom spool **43**. In order to avoid future confusion it sould be borne firmly in mind that this passage **67** is not connected to the chamber surrounding the reduced portion **43H** of the boom spool **43**, but passes therebehind and is fed from the passage **61** in a similar manner to the feeding of the passage **76**. Each of the passages **67** and **76** is fed from the main supply passage **61** through a check valve, neither of which is shown in the illustration, so that hydraulic fluid from the pump passing down through passage **61** will flow independently into the passages **67** and **76** but backflow from one of these latter two passages to the other cannot occur. Hydraulic fluid passing through the passage **61** and into the passage **67** to the chamber surrounding the reduced portion **41G** of the bucket spool **41** is prevented from passing therebeyond by the lands **41C** and **41D** spaced immediately above and below the chamber.

The passage **61** at its bottom end is closed by a safety relief valve **78** shown diagramatically as a spring loaded cone. When the bucket and boom spools **41** and **43** are in the neutral position as shown, the hydraulic fluid is prevented from passing down through the passage **61** to the bottom chamber **77** and hence out to the return tank through the outlet port **45**. However, the hydraulic fluid from the pump is returned to the tank through outlet port **45** via a bypass route as follows. The fluid travels through passage **60** into the chamber surrounding the reduced portion **43F** of the boom spool **43**, thence out of this chamber and through the passage **62** into the chamber surrounding a reduced portion **41E** of the bucket spool **41**, and out of this chamber and downwardly through the passage **63** to the outlet port **45**. Hence, when neither the boom spool nor the bucket spool is actuated, the hydraulic fluid circulates through the pump and the bypass route just described back to the storage tank. When, however, either the bucket spool **41** or the boom spool **43** are actuated, the bypass route is blocked by one of the spool lands **41A**, **41B**, **43A**, or **43B**.

In such a case either the bucket or the boom is placed in motion, and such motion will continue until the piston actuating piston rod **25** or **31** reaches the limit of its travel, at which time further fluid circulation through the actuated hydraulic circuit is blocked. When such a condition occurs, a back pressure will start to build up against the pump and if this pressure is not relieved a failure is likely to occur in some part of the system, perhaps at the pump itself. In order to avoid such failure the safety relief valve **78** is provided. When the line pressure builds up beyond a certain predetermined level, the safety relief valve **78** opens and the hydraulic fluid under pressure is discharged into the bottom chamber **77** and hence returns to tank through the outlet port **45**. When the line pressure drops, as for example when the bucket and boom spools are returned to their neutral positions thereby unblocking the bypass route, the safety relief valve **78** will again close and remain in such condition until an overpressure situation again develops.

The spools **41**, **42** and **43** are individually, manually operable by any convenient means, as for example by individual hand levers. One convenient arrangement has been found to include the utilization of spring biasing means in conjunction with hand levers to automatically return the bucket and boom spools **41** and **43** to their neutral position when pressure is released from the hand lever by the operator. The leveling spool **42** on the other hand may be cam locked in either of its two possible positions, that is, leveling or non-leveling, and requiring positive actuation to shift this spool from one position to the other. The cam locked arrangement for the leveling spool **42** is obviously desirable since this leaves the operator with two hands free for individual or simultaneous manipulation of the bucket and boom spools **41** and **43**.

Understanding now the general organizational aspects of the control valve system illustrated in FIGURE 3, attention should be directed to the remaining figures, namely, FIGURES 4 through 13. These figures naturally group themselves for examination in a particular order to provide the most lucid understanding of the invention. FIGURES 6, 7, 8 and 9 illustrate spool positions which correspond to normal non-bucket leveling operations. That is, these figures correspond to independent bucket or boom motion wherein the hydraulic systems of the boom and bucket cylinders are essentially operated independently in parallel. The examination of the remaining figures should be in conjunction with FIGURE 3 since FIGURE 3 illustrates the hose line connections from the various ports of the valve system to the bucket and boom cylinders **30** and **24** respectively. In this way, the direction of flow through the control valve may be most readily related to the actuation of the cylinders and the attendant motion of the bucket and boom produced thereby.

It will be observed that FIGURES 6 through 9 show the leveling spool **42** in its non-leveling state. When in this position, the passage **64** which communicates between the bucket spool **41** and the leveling spool **42** is isolated by the leveling spool land 42B from the port **48** which connects via the hose line **52** to the boom cylinder **24**. Similarly, the passage **66** which communicates between the bucket spool **41** and the leveling spool **42** is isolated by the land **42C** of the latter from communication with the passage **68** extending between the leveling spool **42** and the boom spool **43**. Thus, the bucket and boom spools **41** and **43** are effectively isolated from each other to provide the independent action previously referred to.

FIGURE 6 illustrates the actuation of the bucket spool **41** by depressing the latter to cause the bucket to be raised while the boom is maintained in a stationary or motionless state. With the conditions as illustrated, the land **41A** of the bucket spool **41** blocks the bypass route from the pump to the tank by closing the flow path between the passages **62** and **63**. The fluid is therefore pumped downward through the passage **61** and across to the bucket spool **41** via the passage **67**, around the reduced portion 41G of the bucket spool and out through the passage 74 and port 47, upward through the hose line 51 to the bucket cylinder 30. The hydraulic pressure in the hose line 51 is applied to the piston within the bucket cylinder 30 causing it to move to the left and hence raise the bucket 28 by retracting the piston rod 31 into the cylinder 30. As the piston moves to the left within the cylinder 30, the hydraulic fluid in the left-hand chamber of the cylinder is forced outward and downward through the hose line 50, in through the port 46 and passage 73 to the chamber surrounding the reduced portion 41F of the bucket spool 41. From this chamber the fluid passes upward and outward into the passage 63 and downward and out of the port 45 to the tank or reservoir.

The boom 22, however, remains motionless, because although fluid pressure is delivered into the chamber surrounding the reduced portion 43H of the boom spool 43 from the passages 61 and 76, the pressurized fluid is blocked from the port 49 by the boom spool land 43D and is likewise prevented from passing through the port 48 by reason of the land 43C of the boom spool 43. The aforedescribed bucket motion continues until the operator releases the bucket spool 41 for a return to its neutral position, or until the bucket reaches the limit of its motion by virtue of the fact that the piston rod has been completely retracted within the cylinder 30 and the piston therein is bottomed. In such as case, the safety relief valve 78 will operate to prevent an overpressure condition developing in the hydraulic system in the manner already previously described. When the operator releases the bucket spool 41 for a return to its neutral position, the conditions shown in FIGURE 3 are restored, and it is seen therein that the ports 46 and 47 which communicate with the bucket cylinder 30 are blocked off by the lands 41C and 41D of the bucket spool 41 thereby preventing further fluid flow through the hose lines 50 and 51 resulting in a stopped condition for the bucket 28.

FIGURE 7 is very similar to FIGURE 6, the only difference being that the bucket spool 41 is shown in an elevated position rather than the depressed position illustrated in FIGURE 6. This causes the hydraulic fluid being pumped through passage 67 to pass around the reduced portion 41G of the bucket spool 41 and upward and outward through the passage 73 and the port 46 to the hose line 50. As may be seen from the showing of FIGURE 3 this applies pressure to the piston of the bucket cylinder 30 and causes it to move from left to right, thus lowering the bucket 28 and forcing the hydraulic fluid out of the cylinder 30 downward through the hose line 51, into the port 47 and through the passage 74 to the chamber 77 and thence through the outlet port 45 to the return tank. The position of the boom spool 43 as in the showing of FIGURE 6, blocks the flow of hydraulic fluid with regard to the ports 48 and 49, and hence the boom 22 remains motionless.

FIGURES 8 and 9 correspond in function to FIGURES 6 and 7 but with regard to the boom 22, that is, FIGURE 8 which shows the boom spool 43 depressed results in elevation of the boom 22 whereas FIGURE 9 shows the boom spool 43 in an elevated position which corresponds to lowering of the boom 22. Considering first FIGURE 8, it will be observed that the actuation of the boom spool 43 by depressing the latter causes the land 43A of the boom spool 43 to block off the bypass route for the pressurized fluid from the pump, and therefore causes the pressurized fluid to travel downward through the passage 61 and into the passages 76 and 67. The fluid flow through passage 67 is blocked from both of the ports 46 and 47 by the lands 41C and 41D of the bucket spool 41 which are located immediately above and below the reduced portion 41G of the bucket spool.

The flow path of the fluid from the pump is therefore restricted to the course beginning with the passage 76 into the chamber surrounding the reduced portion 43H of the boom spool 43, thence outwardly through passage 75 and port 49 and upwardly through hose 53 to the bottom chamber of the boom cylinder 24. As the piston of the boom cylinder 24 is pushed upwardly by the fluid pressure applied to its undersurface, the hydraulic liquid in the upper chamber of the cylinder 24 is forced outwardly and downwardly through the hose line 52 to the port 48, from which it travels into the chamber surrounding reduced portion 42E of the leveling spool 42 and thence outwardly to the right through the passage 68 into the chamber surrounding the reduced portion 43G of the boom spool 43. From this chamber of the boom spool the pressurized fluid flows outwardly and downwardly through the passage 69 and thence toward the left through passage 70 to the bottom chamber 77, and thence outwardly through the outlet port 45 to the tank. As in the case of the bucket motions described in connection with FIGURES 6 and 7, the boom motion will continue until the boom spool 43 is returned to neutral by the operator thereby re-establishing the bypass, or until piston bottoming occurs and an overpressure arises resulting in operation of the safety relief valve 78.

FIGURE 9 which illustrates the lowering of the boom 22 essentially merely reverses the flow of pressurized fluid from the pump through the hose line 52 and 53, and this occurs in the following way. The pressurized fluid from the pump passes into passage 76 and the chamber surrounding the reduced portion 43H of the boom spool 43. From this chamber the fluid flows upward and outward to the left through passage 68 into the chamber surrounding the reduced portion 42E of the leveling spool 42, thence upwardly and out through the port 48 and up to the boom cylinder 24 through the hose line 52. The downward motion of the piston in the boom cylinder 24 causes the hydraulic fluid to be forced out of the lower chamber, downward through the hose line 53 and into the port 49, progressing therefrom through the passage 75 into the chamber surrounding the reduced portion 43J of the boom spool 43 and thence outward through the passages 71 and 70 to the bottom chamber 77, and from there to the return tank through the outlet port 45. The bucket 28 remains motionless, as in the case of FIGURE 8, since the fluid flow through the passage 67 is blocked by lands 41C and 41D of the bucket spool 41, and hence cannot flow outward through either of the ports 46 or 47 to the bucket cylinder.

Having described now the so-called normal operations which involve no bucket leveling and which correspond essentially to the parallel operation of the bucket spool 41 and boom spool 43 with regard to the pump supply, attention will now be directed to the bucket leveling operations. In this regard reference should first be made to FIGURES 5 and 4 for a preliminary understanding of the essential changes worked in the system by actuation of the leveling spool 42. Consider now FIGURE 5.

FIGURE 5 illustrates a condition of the control valve system wherein the leveling spool 42 is shown in its depressed or leveling position. Since the bucket spool 41 and boom spool 43 are in their neutral position no motion of either the bucket or the boom takes place, the position of the leveling spool 42 merely rearranging the fluid flow paths with regard to the ports 46, 47, 48 and 49 through the bucket and boom spools 41 and 43 respectively. The leveling spool 42 in the condition shown converts the formerly described independent parallel hydraulic systems associated with the bucket spool 41 and boom spool 43 into a composite series hydraulic loop, and couples the motions of the bucket 28 and boom 22 together. It will be recalled from the description of FIGURE 3 that the land 42B of the leveling spool 42 effectively isolated the bucket port 46 from the boom port 48 while at the same time providing for the interconnection of the boom port 48 with the boom port 49 via the chambers surrounding the reduced portion 42E of the leveling spool 42 and the boom spool 43 itself, thus resulting in the essentially parallel operation of the bucket spool 41 and boom spool 43.

Reference to FIGURE 5 shows that this condition no longer holds, and that the downward shifting of the leveling spool 42 into bucket leveling position causes the land 42B of the leveling spool to now isolate the boom port 48 from the boom spool 43 by blocking off the port 48 from the passage 68. The lowered position of the land 42B as seen in FIGURE 5 now interconnects the boom port 48 with the bucket port 46 via the route which may be traced around the reduced portion 42D of the leveling spool 42 and thence to the left through the passage 64, around the land 41C of the bucket spool 41 and out through the passage 73 to the bucket port 46. Additionally, in FIGURE 3, the land 42C of the leveling spool 42 is seen to block the passage 66 extending between the bucket spool 41 and leveling spool 42 from communicating with the chamber surrounding the reduced portion 42E of the leveling spool.

In FIGURE 5 it will be observed that the lowering of the land 42C of the leveling spool 42 now provides for direct communication between the passage 66 and the channel surrounding the reduced portion 42E of the leveling spool 42. There is thus established a continuous hydraulic circuit between the bucket port 47 and the boom spool 43 which progresses from the bucket port along the following path. From the bucket port 47, the path follows through passage 74 and around the land 41D of the bucket spool 41, continuing to the right through passage 66 and upward through the chamber surrounding the reduced portion 42E of the leveling spool and over to the boom spool via the passage 68.

As will be subsequently seen in connection with the description of FIGURES 12 and 13, the passage 68 will be connected to the chamber above the land 43C of the boom spool when the latter is depressed, and will be connected to the chamber immediately below the land 43C of the boom spool when the latter is raised. The result of this raising or lowering of the boom spool 43 will be merely to change the direction of fluid pressure flow in the system, and in one case will cause the hydraulic fluid to flow outward through the boom port 49, and in the other case will cause the pressurized fluid to flow outward through the bucket port 47. In either case, the path which the fluid under pressure must traverse in order to return to the tank through the outlet 45 is downward through the passage 72 into the bottom chamber 77 through the relief valve 80. The flow through the relief valve 80 is caused by the blocking of the passage 70 by the lowering of the land 42C of the leveling spool 42. Hence, with the land 42C of the leveling spool 42 blocking the passage 70 to the lower chamber 77, the pilot valve controlled relief valve 80 is brought into operation.

The pilot valve controlled relief valve 80 is required since it has been found in practice that a higher than normal back pressure must be maintained in the system when the boom cylinder 24 and bucket cylinder 30 are serially connected in order that cavitation should not occur at some point in the system and thereby destroy the synchronous motion of the bucket and boom. The desired back pressure in the hydraulic system is achieved by the use of a properly designed pilot valve controlled relief valve 80 which relieves the system pressure by allowing the hydraulic fluid to return to tank by opening at a predetermined fluid pressure level, this pressure level being of course lower than that required to actuate the safety relief valve 78. The pilot valve controlled relief valve 80, shown symbolically in FIGURE 3 and FIGURES 5 through 13, is illustrated in diagrammatic form in the showing of FIGURE 4, to which reference should not be made.

The descending passages 65 and 72 seen in FIGURE 4 are also seen on the other figures, wherein it is observed that the passage 65 descends from a junction with the passage 64 interconnecting the bucket spool 41 and leveling spool 42, whereas the passage 72 is seen to be the lower terminus of the passage 69 descending from the boom spool 43. The relief valve proper consists essentially of a stationary member 81 having a freely projecting conical end, a spring loaded movable member 83 having seating engagement with the conical end of member 81, and a stationary cylindrical guide 86 for the valve seat 83. The downwardly extending passage 72 conducts the pressurized fluid in the system around the movable seat 83 and stationary cone 81, and continues via the passage 72*a* through a reduced portion 79, around the stationary guide 86 and the other end of the movable seat 83. This same pressurized fluid continues via the passage 72*b* to a chamber surrounding the reduced portion 92 between the lands 90 and 91 of the pilot valve 99. The pressurized fluid in the system also is conducted downward through the passage 65 into the chamber surrounding the reduced portion 93 of the pilot valve 99 and applies pressure against the face 98 of the land 90.

Under conditions of normal system pressure, the pressure in the passages 72, 72*a* and 72*b* is the same, and the land 91 of the pilot valve prevents fluid flow from the passage 72*b* to the passage 72*c* and hence to the chamber 77. The pressure in the passage 72*b*, and hence in the chamber surrounding the reduced portion 92 of the pilot valve 99, produces equal and opposite forces on the facing surfaces of the lands 90 and 91 of the pilot valve and hence exerts a net zero force having no tendency whatever to shift the pilot valve in opposition to the leftward directed force due to the spring 95. Also, the net force developed on the movable seat 83 due to the hydraulic pressure exerted on opposing faces 84 and 85 thereof is also substantially zero, and hence the spring 87 which biases the movable seat 83 toward the right maintains a seal between the movable seat 83 and the stationary cone 81. In order to open the relief valve a pressure differential must be established on the faces 84 and 85 of the movable seat 83, so that a net force is developed tending to shift the movable seat 83 toward the left by overcoming the bias of the spring 87. The development of this net force is accomplished by establishing a pressure differential between the fluid in the passages 72 and 72*a* with respect to the fluid pressure in the passage 72*b*, the latter being made lower than the former.

In order to lower the pressure in the passage 72*b*, the pilot valve 99 must be shifted to the right by overcoming the leftward directed biasing force established by the spring 95 so that the land 91 no longer blocks communication between the passages 72*b* and 72*c*. When the land 91 has been so shifted to the right, the relatively high pressure hydraulic fluid in the passage 72*b* will vent into the chamber 77. The lowering of the pressure in the passage 72*b* is not wholly transmitted back to the passages 72*a* and 72 by virtue of the reduced cross-section portion 79 between the passages 72*a* and 72*b*. The effect of this reduced cross-sectional portion 79 is to establish a net pressure differential between the passages 72*a* and 72*b*, the pressure in the passage 72*b* being lower than that in 72*a*.

Assuming for the moment that the pilot valve 99 has opened so that the land 91 has been right-shifted and the low pressure condition established in the passage 72*b* relative to that in the passages 72*a* and 72, the relief valve will be caused to open in the following manner. The relatively higher pressure in passages 72 and 72*a* as compared to that in 72*b* causes a left-directed force to be exerted on the movable seat 83 via the face 84 thereof which is of greater magnitude than the right-directed force exerted on the movable seat 83 via the face 85. When this net left-directed force exceeds the right-directed force applied to the movable seat 83 by the spring 87, the seat 83 will move to the left and unseat from its sealing engagement with the stationary cone 81. Thus, the pressurized fluid in the passage 72 is conducted into the chamber 88, to the right through the stationary cone **81**, and out through the apertures **82** to the chamber **77**, from which it returns to the tank via the outlet port **45**.

As the pressure in the passage **72** drops due to the venting to tank, the pressure in the system drops, the net unbalanced force on the faces **84** and **85** of the movable seat **83** progressively reduces, and the spring **87** shifts the movable seat **83** again toward the right toward closure position with the stationary cone **81**. If the movable seat **83** moves too far toward closure position the pressure in the system will begin to build up again and hence prevent the seat from completely shutting off the venting action through the apertures **82** of the stationary cone **81**. This relief valve system is hence self-equalizing and establishes a system pressure higher than normal at a predeterminedly decided value.

The foregoing discussion assumed that the pilot valve **99** had been opened by shifting of the land **91** thereof toward the right to connect the passages **72*b*** and **72*c***. The opening of the pilot valve is determined by several considerations in the following way.

It will be observed that the spring **95** which bears against the land **94** of the pilot valve, urges the latter toward the left. The only force in opposition to this spring **95** is that force developed on the face **98** of the land **90** by the fluid pressure existing in the passage **65**. Under normal pressure conditions, the rightward directed force developed on the face **98** of the land **90** in the pilot valve due to the pressure in passage **65** is insufficient to overcome the leftward directed bias of the spring **95**, and the pilot valve remains in the closed position as illustrated. When, however, the pressure in the system builds up due to the fact that no venting to tank can occur because the movable seat **83** is in sealing engagement with the stationary cone **81**, the force developed on the face **98** of the land **90** gradually increases. When the pressure in the system builds up to the predeterminedly decided upon level the force exerted on the face **98** of the land **90** in the pilot valve overcomes the spring bias of the spring **95** and shifts the pilot valve toward the right thus shifting the land **91** to the right and opening communication between the passages **72*b*** and **72*c***.

The opening of the passage **72*b*** to the chamber **77** of course vents the relatively high pressure fluid therein to tank, resulting in a pressure drop in the passage **72*b***. This pressure drop establishes the net pressure differential between the passage **72*b*** and the passages **72*a*** and **72** lying on the other side of the reduced cross-sectional passage portion **79** and causes the relief valve to operate in the manner previously described. As pressure in the system drops, the right-directed force exerted on the face **98** of the land **90** in the pilot valve is diminished and the spring **95** tends to urge the pilot valve again toward the left to block off communication between the passages **72*b*** and **72*c***. However, as previously mentioned, the spring constants and forces developed in the pilot valve and relief valve systems are so chosen that the system is vented to tank by the proper amount of clearance between the movable seat **83** and stationary cone **81** to maintain the desired system pressure. Understanding now the general organization of the hydraulic system as portrayed in the showing of FIGURE 5, and the function and operation of the pilot valve controlled relief valve **80**, attention should now be directed toward the showings of FIGURES 12 and 13.

FIGURE 12 differs from FIGURE 5 only in that the boom spool **43** is illustrated in its depressed position. This depressed position of the boom spool **43** results in upward motion of the boom **22** and forward rotational motion of the bucket **28**, these motions being related in such fashion as to achieve the desired bucket leveling. The flow path of the fluid under pressure from the pump which enters through the inlet **44** may be traced as follows. Firstly, the pumped fluid flows downward through the passage **61** and into the passages **76** and **67**, the fluid in the latter of course proceeds nowhere by virtue of the blocking by the lands **41C** and **41D** of the bucket spool **41**. The fluid, however, passing into the passages **76** flows downward around the reduced portion **43H** of the boom spool **43** and out through the passage **75** and port **49** into the hose line **53** which connects to the bottom chamber of the boom cylinder **24**. As pressurized fluid is pumped into the bottom chamber of the boom cylinder **24**, the piston therein is forced upward, hence causing the boom **22** to rise and the hydraulic fluid in the upper chamber of the boom cylinder **24** to be forced outward and down through the hose line **52** to the port **48**.

Entering the port **48**, the fluid flow progresses into the chamber surrounding the reduced portion **42D** of the leveling spool and upward and out through the passage **64**. From the passage **64**, the fluid flows around the land **41C** of the bucket spool **41** and outward through the passage **73** and port **46** into the hose line **50** which connects to the left-hand chamber of the bucket cylinder **30**. The flow into the left-hand chamber of the bucket cylinder **30** forces the piston therein to move toward the right and rotate the bucket **28** in a clockwise or leveling direction, also causing the hydraulic fluid in the right-hand chamber of the bucket cylinder **30** to be forced outward and downward through the hose line **51** into the port **47**. From the port **47** the hydraulic fluid progresses through passage **74**, around the land **41D** of the bucket spool **41**, through passage **66** and into the chamber surrounding the reduced portion **42E** of the leveling spool, out of this chamber toward the right through passage **68** and into the chamber surrounding the reduced portion **43G** of the boom spool.

From the chamber surrounding the reduced portion **43G** of the boom spool the fluid flows outward through passage **69** and downward into passage **72** to the pilot valve controlled relief valve **80**. Noting, as previously described that the passage **65** which connects to the pilot valve is tapped into the passage **64**, it should be clear from the foregoing description of the pilot valve controlled relief valve system that the passage **65** provides a pressure sampling function to actuate the pilot valve **99** and hence control the operation of the main relief valve. As previously described, when the pressure in the system builds up to the previously decided upon level, the relief valve **80** will operate in the now well-known manner and vent the pressurized fluid in the passage **72** into the chamber **77** and hence back to the return tank through the outlet port **45**.

FIGURE 13 illustrates the reversed operation of the boom and bucket motions from that provided by the valve arrangement illustrated in FIGURE 12. That is, with the boom spool **43** in its raised position, as shown, the boom **22** will be caused to lower and the bucket **28** will rotate in a counterclockwise direction. This is accomplished merely by reversing the direction of fluid flow through the hydraulic system. This flow reversal is clearly seen in FIGURE 13 wherein it is observed that the pressurized fluid flowing in through the passage **76** is directed upward into the chamber surrounding the reduced portion **43H** of the boom spool and thence outward to the left to the passage **68**, and eventually out through the bucket port **47**, whereas in the showing of FIGURE 12 the flow was downward through the chamber surrounding the reduced portion **43H** of the boom spool and outward toward the right through the passage **75** and boom port **49**. Also, in FIGURE 13, it will be found from tracing the fluid flow path that the hydraulic fluid returns from the bucket cylinder **30** into the port **46** and thence progresses outward through the boom port **48**, returning from the boom cylinder through the boom port **49** and down to the relief valve **80** through the chamber surrounding the reduced portion **43J** of the boom spool.

From the foregoing description of FIGURES 12 and 13, it should now be clear that simultaneous boom and bucket motion is obtained when the leveling spool **42** is in its depressed position and when the boom spool **43** is actuated in either direction, the bucket spool **41** remaining in its neutral position. FIGURES 10 and 11 illustrate the operation obtained when the leveling spool **42** is in its depressed position and when the bucket spool **41** is actuated, the boom spool **43** remaining in its neutral position. The resultant operation is exactly the same as that obtained in the showings of FIGURES 6 and 7, FIGURE 10 corresponding to the operation as carried out in FIGURE 6, and FIGURE 11 corresponding to that of FIGURE 7. These two figures, FIGURE 10 and FIGURE 11, provide bucket motion alone without any boom motion whatever, even though the leveling spool **42** is in its depressed or bucket leveling position. That this is so can readily be established by tracing the fluid flow path, and this will now be done for the showing of FIGURE 10, FIGURE 11 being identical except for a flow reversal in the system resulting in opposite bucket motion. Consider now FIGURE 10.

With the valve conditions as shown in FIGURE 10, the hydraulic fluid under pressure from the pump passes down through the passage **61** and across through the passage **67** into the chamber surrounding the reduced portion **41G** of the bucket spool **41**, from this chamber progressing outwardly through the passage **74** and port **47** upward through the hose line **51** to cause the bucket piston rod **31** to be retracted into the bucket cylinder **30** and hence raise bucket **28**. The hydraulic fluid in the rear chamber of the bucket cylinder **30** passes outward therefrom, down the hose line **50**, into the port **46** and passage **73** to the chamber surrounding the reduced portion **41F** of the bucket spool **41**. From this chamber, the fluid passes outwardly and downwardly through the passage **63** to the chamber **77** and eventually to the tank via the outlet port **45**.

The fluid which is pumped into the chamber surrounding the reduced portion **41G** of the bucket spool **41** cannot pass outward therefrom to the passage **66** and upward and over to the boom spool **43** via the passage **68** because this latter passage is blocked by the land **43C** of the boom spool **43**. Similarly, although it would appear that the hydraulic fluid entering the chamber surrounding the reduced portion **41F** of the bucket spool **41** would pass outward therefrom and over to the right toward the boom port **48**, this is not the case because the return path from the boom cylinder through the port **49** is blocked by the land **43D** of the boom spool **43**. Hence no hydraulic circulation through the boom cylinder **24** occurs and the boom **22** remains stationary. The arrangements shown in FIGURES 10 and 11 provide additional flexibility wherein a controlled amount of bucket override or underride may be accomplished simultaneously with bucket leveling operation by merely actuating both the boom spool **43** and the bucket spool **41** and returning the bucket spool **41** to its neutral position when the desired override or underride has been achieved.

Having now described my invention in connection with one particularly illustrated embodiment thereof, it will be appreciated that innumerable modifications and variations may be made from time to time by those persons normally skilled in the art without departing from the essential spirit or scope of the invention, and accordingly, it is therefore intended to claim the same broadly as well as specifically as indicated by the appended claims.

What is claimed as new and useful is:

1. A hydraulic control system comprising first and second hydraulically responsive means, control means for selectively actuating said first and second hydraulically responsive means, and third means coupling said control means to said first and second hydraulically responsive means, said control means including first, second and third controls, said first control when operated actuating said first hydraulically responsive means independently of said second hydraulically responsive means, said second control when operated actuating said second hydraulically responsive means independently of said first hydraulically responsive means, and said third control when operated pre-conditioning said first and second controls so that operation of a particular one of said first and second controls actuates simultaneously said first and second hydraulically responsive means.

2. The hydraulic control system according to claim 1 including fourth means intercoupling said first and second controls, said fourth means being rendered operable when said third control is operated and being rendered inoperable when said third control is not operated, said fourth means when operable being effective to raise the system hydraulic pressure above normal operating pressure when said second control is operated.

3. The hydraulic control system according to claim 1 wherein said control means comprises a control valve, and said third means coupling said control means to said first and second hydraulically responsive means comprise a plurality of conduits for conducting pressurized fluid between said valve and hydraulically responsive means, said valve including an inlet port and an outlet port, said inlet port including means for coupling to a source of pressurized fluid, and said outlet port providing means for delivering hydraulic fluid out of said control valve.

4. The hydraulic control system according to claim 3 wherein said first, second, and third controls comprise first, second and third valve spools respectively, said control valve including a fluid conduit extending between said inlet and outlet ports, said first and second valve spools when either is operated being effective to block said fluid conduit between said inlet and outlet ports and when non-operated allowing free communication between said ports.

5. The hydraulic control system according to claim 3 wherein said first, second, and third controls comprise first, second and third valve spools respectively, said control valve further including a plurality of internal fluid conducting passages interconnecting said first, second, and third spools, connecting said spools with said inlet and outlet ports, and connecting said spools with said plurality of conduits extending between said control valve and said first and second hydraulically responsive means, said inlet port being blocked from communication with said plurality of conduits when said first and second spools are both in their non-operated position and being provided with free communication to selected ones of said plurality of conduits through selected ones of said valve internal passages when said first and second spools are selectively operated.

6. The hydraulic control system according to claim 5 wherein said inlet port is placed in communication with a first one of said plurality of conduits and said outlet port is placed in communication with a second one of said conduits when said first spool is operated in a first way, whereby hydraulic fluid in said first and second conduits may be caused to flow in a first direction and wherein said inlet port is placed in communication with said second conduit and said outlet port is placed in communication with said first conduit when said first spool is operated in a second way, whereby hydraulic fluid in said first and second conduits may be caused to flow in a second direction opposite to said first direction.

7. The hydraulic control system according to claim 5 wherein said inlet port is placed in communication with a third one of said plurality of conduits and said outlet port is placed in communication with a fourth one of said conduits when said second spool is operated in a first way, whereby hydraulic fluid in said third and fourth conduits may be caused to flow in a first direction, and wherein said inlet port is placed in communication with said fourth conduit and said outlet port is placed in communication with said third conduit when said second spool is operated in a second way, whereby hydraulic fluid in said third and fourth conduits may be caused to flow in a second direction opposite to said first direction.

8. The hydraulic control system according to claim 6 wherein said inlet port is placed in communication with a third one of said plurality of conduits and said outlet port is placed in communication with a fourth one of said conduits when said second spool is operated in a first way, whereby hydraulic fluid in said third and fourth conduits may be caused to flow in a first direction, and wherein said inlet port is placed in communication with said fourth conduit and said outlet port is placed in communication with said third conduit when said second spool is operated in a second way, whereby hydraulic fluid in said third and fourth conduits may be caused to flow in a second direction opposite to said first direction, the hydraulic fluid flow through said first and second conduits being isolated from the hydraulic fluid flow through said third and fourth conduits by said third spool when said third spool is in non-operated condition.

9. The hydraulic control system according to claim 8 wherein said third spool when in non-operated condition isolates the fluid flow through said first and second conduits from the fluid flow through said third and fourth conduits by blocking particular ones of said plurality of valve internal passages to thereby isolate said first conduit from said third conduit and isolate said second conduit from said second spool.

10. The hydraulic control system according to claim 8 wherein said third spool when operated isolates said third conduit from said second spool by blocking a particular one of said valve internal passages, connects said third conduit to said first conduit by unblocking a different one of said valve internal passages, and connects said second conduit to said second spool by unblocking another one of said valve internal passages, whereby said first, second, third and fourth conduits are connected in a series hydraulic loop through said first and second hydraulically responsive means and said control valve when said second spool is operated in either of the aforesaid first and second ways, the hydraulic fluid flow through the series hydraulic loop being in a first direction when said second spool is operated in the first way and being in the opposite direction when said second spool is operated in the second way.

11. The hydraulic control system according to claim 10 further including means for controllably increasing the system hydraulic pressure above normal operating pressure when said second and third spools are operated, said further means comprising a pilot-valve-controlled relief valve, said pilot valve sampling the system pressure and controllably opening and closing said relief valve to maintain the desired system pressure, said relief valve when open providing venting of the system pressurized fluid to the said outlet port, said further means being rendered inoperative when said second spool is not operated and being rendered inoperable when said third spool is not operated.

12. A hydraulically operated displacement control system comprising, first and second members displaceable relative to each other and to a third member, a first hydraulically responsive means coupled to said first member and operative when actuated for displacing said first member relative to said second member, second hydraulically responsive means coupled to said second member and operative when actuated for displacing said second member relative to the third member, control means for selectively actuating said first and second hydraulically responsive means, and third means coupling said control means to said first and second hydraulically responsive means, said control means including first, second and third controls, said first control when operated actuating said first hydraulically responsive means independently of said second hydraulically responsive means, said second control when operated actuating said second hydraulically responsive means independently of said first hydraulically responsive means, and said third control when operated pre-conditioning said first and second controls so that operation of a particular one of said first and second controls actuates simultaneously said first and second hydraulically responsive means.

References Cited in the file of this patent

UNITED STATES PATENTS

2,112,466	Maloon	Mar. 29, 1938
2,445,781	Hrdlicka	July 27, 1948
2,475,298	Sloane	July 5, 1949
2,586,932	Gardiner et al.	Feb. 26, 1952
2,811,265	Wagner	Oct. 29, 1957
2,876,921	Salna	Mar. 10, 1959